The Possible Global Role of Nature-Based Solutions in Reducing People's Vulnerability to Climate Change

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Abstract

While climate mitigation is essential for maintaining global mean temperature within 1.5 °C above pre-industrial levels, climate adaptation is necessary both now and in the coming decades. Ecosystems provide a wide array of services, including those that can reduce the negative impacts of climate change. Actions that solve problems using ecosystem services, called Nature-based Solutions (NbS), include ecosystem conservation, restoration, or improved land management. We computed the vulnerability of the global human population to eight climate change impacts – coastal flooding, food insecurity, heat waves, landslides, river flooding, vector-borne diseases, water stress, and wildfires – and identified areas where ecosystem conservation, restoration, or improved land management could potentially reduce people's vulnerability to climate impacts. Our results indicate that 7.5 billion people are projected to be vulnerable to at least one climate impact by 2030, and NbS can reduce the vulnerability of up to 5.1 billion. We estimate that ecosystem conservation could potentially reduce climate vulnerability of over two billion people;

ecosystem restoration could do so for almost sixty million people; and sustainable land management practices for about four billion people. While we do not quantify the effect of NbS on reducing climate impacts, i.e., we did not conduct a quantitative evaluation of the role of nature for climate adaptation, This study is a key first step in identifying areas where nature could possibly help people adapt to climate change, where such effects could be further explored, and where synergies with biodiversity conservation, climate mitigation, and other benefits to people could be found.

Main

Whereas climate mitigation is critical to keep global mean temperature within a physical limit of 1.5 °C above the pre-industrial levels, climate adaptation is needed to cope with existing climate change and the impacts of a climate overshoot (i.e., the period when the global temperature temporarily exceeds the target limit before going down to safer levels[1,2]). In the past 20 years, at least 3.4 billion people have been directly affected by climate-related disasters, such as floods, droughts, and wildfires[3]. Countries with the lowest levels of human development have suffered the worst impact due to limited resources to respond to climate change and to warn and educate the population about risks[4]. Engineering measures such as sea walls, levees, and other infrastructure are often pursued for climate adaptation by many governments and companies across the world[5,6]. In many instances, those engineering solutions could be replaced or implemented in combination with less-traditional approaches, such as Nature-based Solutions (NbS).

NbS are actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits[7]. NbS can effectively increase climate resilience by minimizing the impacts of multiple types of climate-related disasters[8-10]. For example, protecting wetlands can reduce risk of flooding[11,12]. Grazing management and the conservation of African savannas can protect communities against the effects of droughts[13,14]. The protection and restoration of mangroves help reduce coastal erosion and inundation[15,16]. The protection and restoration of montane rainforests can reduce the chance of mudslides and landslides[17]. NbS can also be cost-effective and lead to other social and environmental benefits[18,19]. Many of the NbS that are effective in reducing the impacts of climate change also provide climate mitigation and ecological and social outcomes, including avoided CO_2 emissions, increased CO_2 sequestration, improved economic benefits related to food security and livelihood diversification, and enhanced species diversity and habitat quality[9].

Despite the importance of NbS for climate adaptation, the global role of NbS in reducing the impacts of climate change on people remains uncertain. Previous studies have provided only partial insights on such potential, as they focused on understanding the importance of nature in reducing one or two specific climate impacts[20,21], on certain areas such as cities[22,23], on specific geographic regions or countries[24-26], and in providing specific contributions to people under climate change scenarios[27]. Likewise, whereas global maps of vulnerability of people to climate impacts exist[28], there are no global maps to date that assess people's vulnerability to multiple climate change impacts at sub-national level, despite the need to understand climate vulnerability to guide actions where most needed.

Here we address these gaps by quantifying, globally, the total number of people whose vulnerability to climate-related impacts is likely to increase and the number of people that could possibly benefit from NbS. Within the scope of this work, NbS included ecosystem conservation (i.e., actions that aim to protect the structure, context, and functioning of existing ecosystems), ecosystem restoration (i.e., actions that aim to restore the structure, content, and functioning of the degraded ecosystem), or the improved management of fire-prone ecosystems or agricultural lands. We calculated the vulnerability of people to eight climate impacts – coastal flooding, food insecurity, heat waves, landslides, river flooding, vector-borne diseases, water stress, and wildfires – using global existing datasets to assess climate exposure, sensitivity, and adaptive capacity of people. To assess the possible role of nature in reducing the impacts of climate change, we overlapped areas where people are projected to be vulnerable to specific climate impacts with areas where natural or modified ecosystems known to help people adapt to those impacts could be conserved, restored, or sustainably managed (i.e., our NbS). This is what we consider the "possible " role of nature on climate adaptation in the context of this work.

The possible role of nature in addressing climate vulnerability

Our results show that 98% of the world's population, or 7.5 billion people, are projected to be vulnerable to at least one climate impact by 2030, and that NbS could possibly reduce the vulnerability of 67% of those people. Whereas those numbers do not necessarily represent those that will be directly affected by climate change, the total number of people that will experience impacts by 2030 is likely on the order of billions, as historical data have shown that 3.4 billion people were directly impacted by climate change in the past two decades[3]. The distribution of people projected to be vulnerable to at least one of the climate impacts addressed in this study (coastal flooding, food insecurity, heat waves, landslides, river flooding, vector borne diseases, water stress, and wildfires) shows clear regional patterns. The people that are most vulnerable are projected to reside primarily in Sub-Saharan Africa, the Middle East, Latin America, and Southeast Asia, especially in Bangladesh and Myanmar. Based on our definition of climate vulnerability, vulnerable people are those located in areas that will experience a projected increase in exposure to climate impacts, and that have less capacity to adapt to those changes, including for example, low education, reduced economic opportunities, and longer travel times to major cities. Figure 1 depicts the global mean change in vulnerability for all climate impacts considered, and global maps of the change in climate vulnerability can be seen in Extended Data Figures 1-8.

About 98% of the world's population is projected to be vulnerable to at least one climate change impact. People that are projected to be vulnerable to more than one impact likely have an increased chance of being directly harmed (e.g., suffer injury or die, lose their homes, and need medical assistance) or of experiencing cumulative stress, depleted financial resources and reduced resilience owing to compounded effects of multiple hazards[29].

Because climate impacts are so pervasive globally, so are climate vulnerabilities. As a result, there is substantial possibility to reduce people's vulnerability to climate change across the globe by conserving, restoring, or sustainably managing ecosystems . More than two billion people (29% of the world's population in 2020) are projected to be vulnerable to at least one climate impact and could benefit from ecosystem conservation, almost sixty million people (1% of the global population) could potentially benefit from ecosystem restoration, and about four billion people (51% of the global population) could benefit from sustainable land management practices, implemented in agricultural lands or in ecosystems that are prone to fires (See Figure 2 for a graphical representation of the number of people who are vulnerable and number of people amenable to NbS).

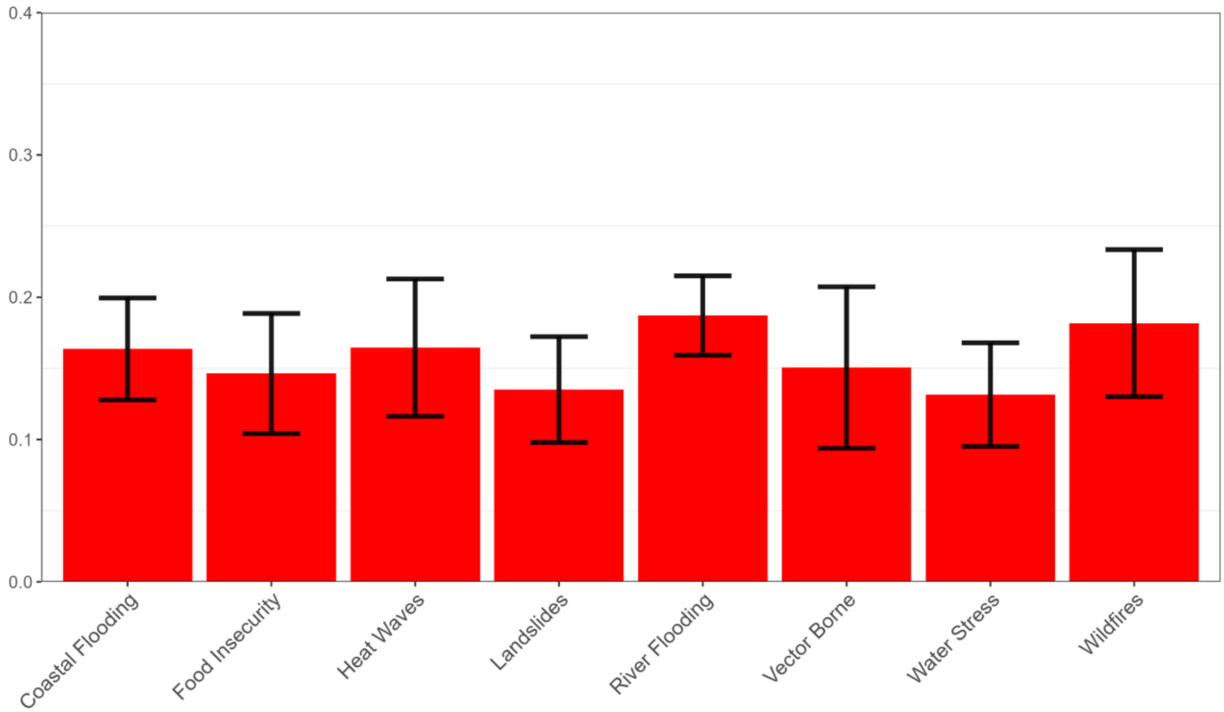

Figure 1. The mean change in global vulnerability of people between the baseline and RCP 4.5 2030 projections across the eight impacts. Error bars represent one standard deviation above and below the mean. The vulnerability index ranges from 0 to 1.

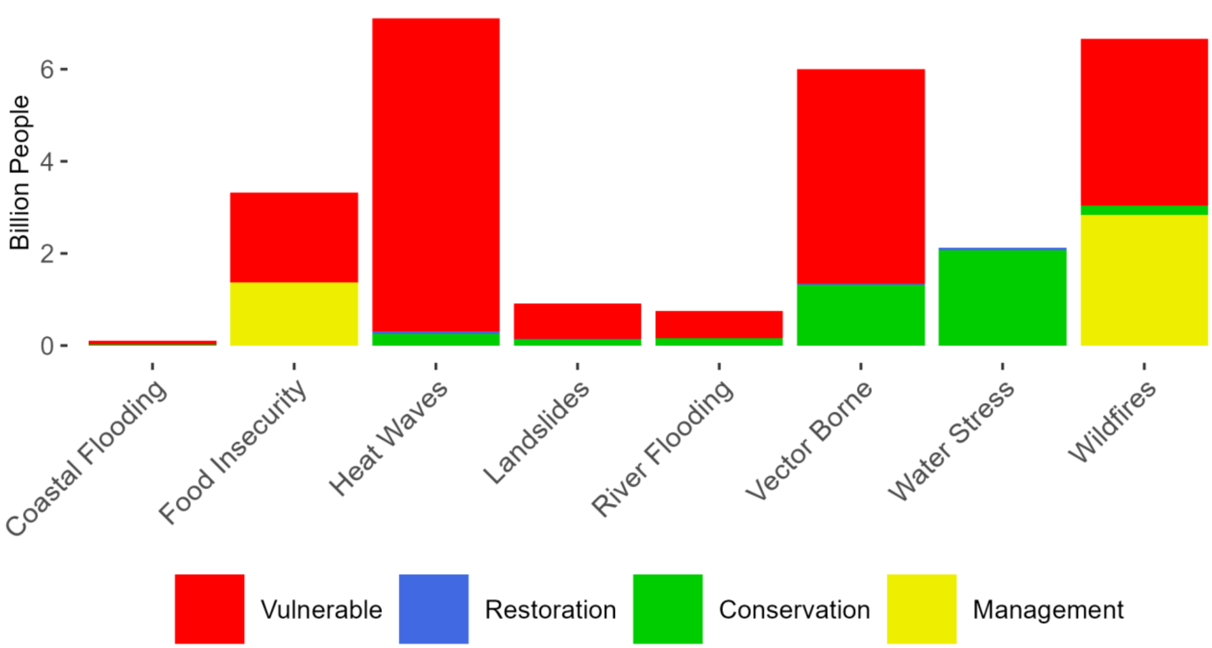

Figure 2. The number of people projected to be vulnerable to each climate impact that could possibly have their vulnerability reduced by Nature-based Solutions (NbS). Each full bar denotes the number of people that

are projected to be vulnerable to a climate impact. The green portion of each bar represents the number of people that would potentially benefit from ecosystem conservation, the blue portion represents ecosystem restoration, the yellow captures fire and agriculture management, and the red portion represents the number of people that remain vulnerable as NbS considered could not be implemented.

Key areas for NbS to reduce climate vulnerability

Although much of the world's population is projected to be vulnerable to at least three climate impacts, most of the areas where ecosystem conservation or restoration could take place can only possibly address one or two climate impacts, respectively (Figure 3). Therefore, it would be necessary to protect and restore a diverse suite of ecosystems located in high risk areas to minimize climate change impacts on a large number of people. A substantial proportion of the NbS potential for climate adaptation is related to the conservation of forests, from the Amazon to the rainforests of central Africa and the large temperate and coniferous forests of the Northern Hemisphere. The prospect of ecosystem restoration for climate adaptation is highest in the African Sahel, the Middle East, and Central Asia. Sustainable agricultural and wildfire management practices appear most consistently throughout the African continent, the southwestern United States, the Middle East, and Central Asia. Ecosystem conservation could be important in areas where people are projected to be vulnerable to a single climate impact, whereas ecosystem restoration could be significant in areas where the population is projected to be vulnerable to two climate impacts. The complete results for the human population size in areas where there are overlaps between vulnerable people and NbS can be found in Extended Data Table 1.

Even though ecosystem conservation could help reduce the impacts of climate change in many parts of the globe, only about 17% of existing ecosystems that could possibly provide adaptation services to people are inside currently protected areas. This overall percentage is similar to the percentage of key areas for biodiversity conservation that are inside protected areas. Those results are, however, not surprising given that only 16% of the global land cover is under some level of protection[30].

Our conservation map serves as a guide to where land could be effectively protected to possibly reduce people's vulnerability to climate change. However, follow-up studies that model the provision of climate adaptation services by ecosystem conservation are needed to define where conservation needs to take place with greater certainty. In addition, the level and type of protection of those areas (e.g., protected areas with sustainable use, national park, strict nature reserve) need to be carefully defined in collaboration with Indigenous Peoples and local communities and based on their needs and interests. Furthermore, considering the needs and interests of these groups generally leads to better conservation outcomes[31,32]. Indigenous Peoples' lands are known to be well managed[33], to host high diversity of species[34], and to conserve intact forest landscapes[35].

About 33% of the areas where people are projected to be vulnerable to climate change and where ecosystems could be restored to possibly help reduce those risks coincide with priority restoration areas for biodiversity conservation and climate mitigation, as identified by Strassburg et al[36]. Our restoration map also provides a first step to define where ecosystem restoration is possibly needed to reduce the vulnerability of people to climate change impacts. As is the case of ecosystem conservation, restoration areas need to be further defined with more certainty by using modeling exercises that assess the magnitude of the adaptation services provided by ecosystem restoration and identified in collaboration with and based on the needs and interests of local communities for better outcomes[37].

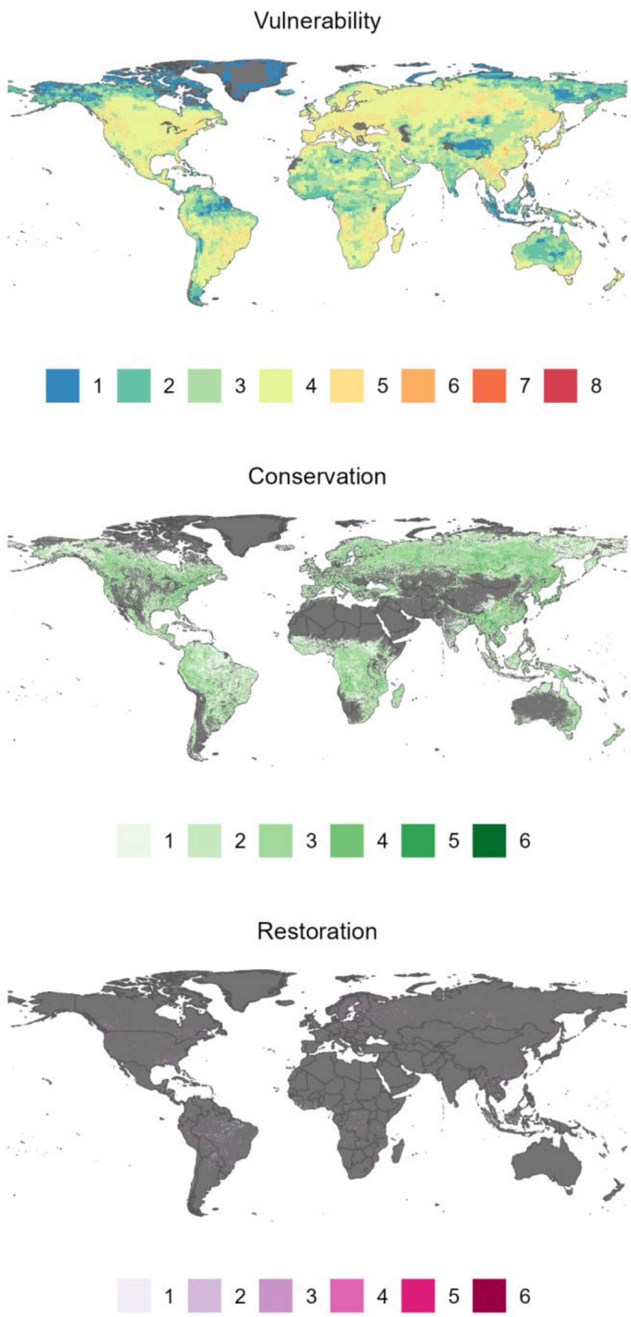

Figure 3. Maps of vulnerability of people to climate change, by the total number of climate impacts, showing areas where people are projected to be vulnerable to a given number of climate impacts (from 1 in blue to 7 in red); of ecosystem conservation by the total number of climate impacts, showing where ecosystem conservation could possibly reduce the vulnerability of people to a given number of climate impacts (from 1 in light green to 6 in dark green), and of ecosystem restoration by the total number of climate impacts showing areas where ecosystem restoration could possibly reduce the vulnerability of people to a given number of climate impacts (from 1 to 6 in light pink to in dark pink).

Study Strengths and Limitations

A strength of this study is that we were able to consider a large and diverse suite of climate-related impacts from flooding and droughts to heat waves and wildfires at a global level with a spatial resolution that has not been available in previous studies (one kilometer). The climate change vulnerability index constructed in this study was built with a wide array of high-quality sensitivity and adaptive capacity constituent layers as well, something is often missing from other studies. This strength also applies to the NbS input layers; the global land cover and land use databases that we relied on (GLAD and Copernicus), Global Mangrove Watch, Global Distribution of Coral Reefs, Global Coral Reef Bleaching Database, and individual studies have all only come into existence and have been made available to the public, or were updated with new and better data, in the past few years.

This study also has limitations. The first is that we were only able to consider future changes in terms of the climate impacts themselves and not changes in sensitivity or adaptive capacity. Second, while we selected a vulnerability cutoff point that is consistent with the literature to designate the areas of top priority (ten percent), that cutoff point of 10% is an arbitrary one with no mechanical basis. However, selecting such a point and designing an empirical foundation for doing so is beyond the scope of this study, so relying on the value found commonly throughout the literature is the next best option. Finally, we did not evaluate the magnitude of benefit that ecosystems can provide in reducing climate impacts nor the feasibility and buy-in of local communities to implement NbS where possibilities to reduce climate vulnerability exist; we only identified where climate impact vulnerability and ecosystems that are important in reducing that vulnerability exist in the same place.

We urge further research to model the association and magnitude of NbS in coastal risk reduction, erosion protection, flood mitigation, water provision, urban cooling and wildfire risk reduction, and other adaptation benefits under climate change, using the maps presented here as basis as they can be used to identify priority areas for such quantitative evaluations. Additional studies could also examine how NbS can contribute to increasing the adaptive capacity of people through nature-based, income-generating activities (e.g., payment for ecosystem services such as carbon credits) that can reduce people's vulnerability by improving their financial situation, and where NbS have the buy-in from local communities and could in fact be implemented. Finally, studies to quantify the costs (capital, recurrent and opportunity) of implementing NbS, as well as the costs of inaction, would allow for the return-on-investment or cost-benefit analyses that are often required in project development for government agencies.

Policy implications of the findings

Almost the entire land surface and human population on the planet are likely at some level of risk for increasing vulnerability to at least one climate-related impact. That includes more deadly heat waves and vector-borne disease incidence, more frequent and intense floods and landslides, more restricted water availability and lower suitability to produce subsistence crops. Although advances have been made in early warning systems, disaster preparedness, and climate adaptation responses in the past few decades[28], it is evident that the increasingly systemic and complex nature of the compounding effects of multiple global change drivers (poverty, population growth, unmanaged urbanization, biodiversity loss) calls for stronger and urgent action.

At the international level, our maps of people's vulnerability to climate change could help identify overall priority areas for action, and the possible role of NbS in reducing vulnerability could help raise awareness about the importance of nature conservation, restoration, and management. In addition to climate change adaptation, the other benefits provided by ecosystems (e.g., biodiversity conservation, climate mitigation, revenue from NbS, and payment for ecosystem services) make NbS very appealing. Policy makers at all levels should therefore consider nature as one ally that can help address the impacts of climate change on people by intentionally supporting the implementation of those types of solutions. When they are inclusive of local knowledge and the needs and interests of Indigenous Peoples and local communities, those solutions can also contribute to environmental and climate justice. However, trade-offs in those types of solutions exist and must be considered as they may lead to resistance in adoption. Trade-offs include the upfront costs of ecosystem restoration versus the provision of adaptation and economic benefits in the long term, and the restriction in access and use of areas that need to be under strict protection.

The fact that only a small percentage of natural ecosystems that could possibly contribute to reducing people's vulnerability to climate change are currently protected is a reflection of the small land area identified as being currently protected or under other effective area-based conservation measures. The commitment of governments to expand the amount of land under protection as part of the Global Biodiversity Framework should open more opportunities for NbS, but land is in high demand in many regions. For these global conservation goals to best serve people, ecosystem conservation must be prioritized where it is most important for biodiversity conservation as well as climate adaptation and mitigation. As such, the implementation of NbS in those areas could continue to provide or improve the provision of multiple societal benefits simultaneously. This would lead to a more strategic use of the limited space to implement NbS, including conservation agriculture in smallholder farms, as studies have highlighted the challenges of restoring and conserving nature with the growing need to increase food production, wood use and the expansion of urban areas[38], especially under climate change.

Finding synergies with other frameworks that promote NbS holds potential to also concurrently finance climate adaptation, climate mitigation, and biodiversity conservation. These win-wins can lead to a more effective use of limited financial resources that are available to address those global challenges. For example, it is estimated that there is a global financial gap of 194–366 billion USD per year for climate adaptation[39], of 79-154 billion USD per year for safeguarding 30 % of terrestrial (and marine) protected areas[40], and of over 7 trillion USD per year for climate mitigation[41]. Selecting areas for the conservation, restoration, and management of ecosystems that can deliver multiple benefits where most needed could be a significant strategy to close those gaps.

Conclusion

We present the first attempt to assess the global role of nature in reducing people's climate vulnerability and to identify regions for ecosystem conservation, restoration and land management that are possibly important in reducing this vulnerability. This is foundational for identifying key areas for further examination, where more in-depth modeling could be performed to quantify the association between the implementation of NbS and reduced climate vulnerability of people. Our findings show that much of the world's human population is projected to be vulnerable to at least one climate impact by 2030, a looming challenge that society needs to confront. By mapping the vulnerability of people to a set of eight climate impacts, we are providing information to decision makers regarding where climate adaptation interventions, such as NbS, could be most critical.

The resulting conservation and restoration maps, as well as the maps where land could be sustainably managed to help address the vulnerability of people to climate-related food insecurity and wildfires, provide guidance on where NbS should be explored further to quantify the magnitude of adaptation benefits. They are also important to help identify where possible synergies with biodiversity conservation, climate mitigation, and other benefits to people could be found. The global maps presented here are a beginning, not the ultimate output that countries need to implement NbS that can align these multiple goals, but they provide both a useful starting point for where to focus energies for research and a broader context for international cooperation. Further studies are called for in light of our findings. Especially valuable would be studies that go beyond the possibility of NbS to reduce vulnerability, especially those that employ a statistical modeling approach that can quantify the relationship between NbS and reduced climate change vulnerability.

Methods

Climate Vulnerability Index

To assess the climate vulnerability of people to each climate impact used in this study, we use the concepts of climate vulnerability as a function of exposure, sensitivity, and adaptive capacity, as proposed by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Reports[42]. In our study, we only considered adverse exposure, i.e., when the system is going to be adversely impacted by climate change. Even though there are other recent studies that assess climate vulnerability, some using the same datasets as ours (e.g., Notre Dame Global Adaptation Initiative), we opted to build on the study by Jones et al.[20], the first of its kind to assess the potential importance of nature to reduce climate impacts, and to focus on climate impacts that can be addressed by NbS. Existing assessments of climate change adaptive capacity, such as the Notre Dame Global Adaptation Initiative mentioned above, could be included in further studies as a sensitivity analysis or robustness check.

Exposure

The climate change impact exposures are described in each section below. See Table 1 for more information.

Sensitivity

The sensitivity value assigned for all climate impacts was the population of the exposed area, as estimated by the 2020 LandScan global population database[43].

Adaptive Capacity

As several indicators can be used to calculate the adaptive capacity of people to climate change, we selected the same indicators used to calculate adaptive capacity as in Jones[20](i.e., governance, health, education and access to market), and opted to replace income with economic productivity and to include age as an additional indicator (see justifications below). Access to market/travel time was the only component that varied across climate impacts as it is not relevant to all of them. For example, the amount of travel time to major cities is an important element of people's adaptive capacity for some impacts, such as wildfires and flooding, but not important for other types of impacts, such as heatwaves. The indicators and respective variables included in the adaptive capacity component for each climate impact assessed in this study are described below and in Table 2. All adaptive capacity indicators listed below were converted to a scalar (0 to 1) and averaged to calculate the overall people's adaptive capacity to a given climate impact.

Age: The capacity of people to adapt to climate change is influenced by age, with both the youngest and oldest people generally less able to adapt to a changing climate[44]. Furthermore, they are more impacted by health issues associated with climate change[45], and have less ability to work, limiting financial resources for adaptation responses. Likewise, children aged one to fourteen have less capacity to adapt to climate change due to their dependence on other family members and limitations on paid work. We therefore considered that adults or individuals of working age can more easily adapt to climate change than other age groups. In our study, age was represented by the percentage of a country's population that is of adult or working age (age 15 to 64), with higher percentages yielding higher adaptive capacity. The demographic data for age distribution were obtained from the World Bank's Population Database[46] (World Bank, 2022), accessed at the following website: https://data.worldbank.org/indicator/SP.POP.1564.TO.ZS

Governance: Countries with good governance can help populations to adapt to climate change due to the greater likelihood of policy incentives, regulatory frameworks and adherence of laws directly or indirectly related to ameliorating climate change. We used the World Bank's national-level World Governance Indicators (WGI) data to capture governmental efficacy[47]. All six of the WGI dimensions were included: Control of Corruption, Government Effectiveness, Political Stability and Absence of Violence/Terrorism, Regulatory Quality, Rule of Law, and Voice and Accountability. The WGI can be accessed at http://info.worldbank.org/governance/wgi/

Human Development Index: Socioeconomic characteristics are key determinants of the ability of an area to adapt to climate change[48, 49]. To capture the core socioeconomic characteristics of an area, we chose the Human Development Index (HDI) as set forth by the United Nations Development Program. The HDI is a composite index constructed from three sub-indices: health, education, and economy. The health index consists of the years of life expectancy at birth, the education index consists of expected years of schooling and mean actual years of schooling, and that location's Gross National Product (in purchasing-power adjusted per capita dollars) serves as the economic index value. These data are constructed and made available by the MOSAIKS program. More information and the data for this source are available at https://www.mosaiks.org/hdi

Access to markets/Travel time: The quality of an area's infrastructure, ability to reach emergency and social services in a reasonable time, and physical access to the markets for goods and services are crucial elements of adaptive capacity to climate change[50]. We selected travel time to major cities[51] as one of the variables to assess adaptive capacity. Due to the statistical distribution of the travel time dataset (many of the data points were either extremely small or large), the dataset was log-transformed and inverted (as longer travel times are less advantageous for adaptive capacity) before preparing it for inclusion in the adaptive capacity layer. Data at 1km spatial resolution was accessed at https://figshare.com/articles/dataset/Travel_time_to_cities_and_ports_in_the_year_2015/7638134/3

Flood protection: Flood management researchers have created an evaluation scheme and database of global flood protection, known as FLOPROS (FLOod PROtection Standards)[52]. The FLOPROS database combines physical, design (policy), and modeled flood protection capacity into a single flood protection conservation index. This indicator was only used to calculate adaptive capacity for river flooding and coastal flooding. The FLOPROS data is available at https://nhess.copernicus.org/articles/16/1049/2016/

Climate Vulnerability Index

All inputs, including exposure, sensitivity, and adaptive capacity variables, were rescaled to the same spatial resolution of one kilometer and the same geographic coordinate system, with WGS 1984 datum. We opted to give every component of the climate vulnerability index the same weight to avoid subjectivity, so all variables related to exposure, sensitivity, and adaptive capacity for each climate impact were normalized (0 to 1). To compute vulnerability, we employed a standard climate change vulnerability index (CCVI) that has been used widely in the literature[53,54]. The standard CCVI formula that we used takes the following form:

$$VU = E + S + (1 - AC)$$

Where the outcome variable, VU, is Climate change Vulnerability, E is Exposure, S is Sensitivity, and AC is Adaptive Capacity. AC is calculated as 1 minus the scaled combined sum of all individual adaptive capacity indicators.

After calculating the total climate vulnerability index, we created a layer that represents the cells that contain anyone who is projected to be vulnerable, which is what we used in the presentation of the results of the paper.

Nature-Based Solutions

Nature-based Solutions (NbS) are actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits[7]. In our study, benefits refer to those provided by natural and modified ecosystems to help people adapt to the impacts of climate change. Even though the concepts of ecosystem conservation, ecosystem restoration and ecosystem management can overlap (i.e., ecosystem management often includes actions that are implemented to restore and/or protect ecosystems restoration and conservation), in our study, we treated each of them as distinct set of actions (see next sections for definitions used in this study).

For each climate impact, we computed areas with projected increases in vulnerability and that are also suitable for the implementation of NbS (see below) to assess the possible role of nature in reducing vulnerability of people to climate change. For most of the climate impacts considered in this study, NbS refer to two types of interventions: ecosystem conservation and ecosystem restoration. However, for wildfires and food security, sustainable management of ecosystems was also used or replaced conservation or restoration, respectively. Those cases are explained in the section below. The type of interventions in specific types of ecosystems (i.e., NbS layer or layers) that could potentially address each climate impact can be seen in Table 1, and the full suite of NbS layers, their descriptions, and sources of datasets are in Table 3.

Ecosystem Conservation

In this study, we considered ecosystem conservation the actions that aim to protect the structure, context and functioning of existing ecosystems. Ecosystem conservation was considered in areas where ecosystems known to minimize specific climate impacts currently exist (i.e., natural vegetative land covers) such as forests that can minimize the impacts of landslides, wetlands that can minimize the impacts of coastal flooding, and grasslands that can minimize the impacts of river flooding. Our conservation layers identify areas where people are going to be vulnerable to a given climate impact and that are also suitable for conservation of ecosystems that can minimize this specific impact. We computed areas that were important to help people adapt to a given climate impact by selecting cells where both people are projected to be vulnerable at any level *and* where natural ecosystems currently exist to quantify the possible role of nature in helping vulnerable people adapt to this specific climate impact. We also selected cells that were both in the top 10% of projected vulnerability *and* flagged as areas where ecosystems currently exist to quantify the potential of nature in helping the *most* vulnerable people adapt to a given climate impact. The results for the top 10% of vulnerability are presented in the extended data only.

To identify and quantify current ecosystem extent and distribution, we used data from the Global Land Analysis and Discovery (GLAD) 2019 global land cover database[55]. Other datasets on land cover used for specific climate impacts are included in the following sections. The natural land cover categories (strata) in the GLAD dataset that were used in our conservation layer include two dynamic states of land covers: i) Static: Unchanged natural land cover categories between GLAD study periods, which includes dense short vegetation, open tree cover, dense tree cover, salt pan, wetland sparse vegetation, wetland dense short vegetation, wetland open tree cover, wetland dense tree cover; and ii) Gain: Cells that were not identified as a specific natural land cover type at the beginning of the GLAD study period but became a specific natural land cover type at the end of that period, which includes forest tree cover gain and wetland tree cover gain.

Which of these land cover categories was used in an outcome and how it was analyzed are described in the subsection for each climate impact below. The GLAD Land Cover and Land Use 2019 data are available at https://glad.umd.edu/dataset/global-land-cover-land-use-v1

Ecosystem Restoration

In this study, we consider ecosystem restoration the actions that aim to restore the structure, content, and functioning of the degraded ecosystem, not necessarily to its previous state but to the fullest possible extent. Ecosystem restoration was considered in areas where natural ecosystems known to minimize specific climate impacts (i.e., natural vegetative land covers, such as forests that are important to minimize the impacts of landslides and wetlands that are important to minimize the impacts of coastal flooding) no longer exist, i.e., have been lost between years 2014 and 2019. Our restoration layer identifies areas where people are projected to be vulnerable to a given climate impact *and* that could also be suitable for ecosystem restoration.

To quantify and identify those natural land covers, we used data from the Global Land Analysis and Discovery (GLAD) 2019 global land cover database[55]. The natural vegetation land cover categories (strata) in the GLAD dataset that were used in our restoration layers include one dynamic state of land covers, namely forest tree cover loss not attributable to fire and wetland tree cover loss not attributable to fire, the only ones available that represent ecosystem loss. Which of these land cover categories was used to assess the role of nature in minimizing vulnerability for each impact and how it was analyzed are described in the subsection for each climate impact below.

We computed areas that were important to help people adapt to a given climate impact by selecting cells where both people are projected to be vulnerable at any level *and* where natural ecosystems could be restored to quantify the possible role of nature in helping vulnerable people adapt to this specific climate impact.

For a given climate impact, raster cells that were designated as part of our ecosystem conservation layer were removed from areas that also fall under our ecosystem restoration layer in order to prevent the redundancy of flagging a cell as suitable for both conservation and restoration, which were considered functionally mutually exclusive for the purpose of this work.

Wildfire and Agriculture Management

For wildfire impacts and food insecurity, we identify areas where people are projected to be vulnerable to each one of those climate impacts and where wildfire management or agriculture management could be implemented. Wildfire management refers to actions that aim at removing vegetation to reduce flammable vegetation, such as by thinning tree canopies to prevent fires from leaping across treetops, and by removing dead wood and debris. As those actions are critical to reduce the risk and the spread of wildfires, we included wildfire management as a type of NbS to minimize the impacts of wildfires.

Agriculture management includes a variety of practices to improve crop production or to reduce crop losses. Among those, some specific practices under conservation agriculture or Nature-based agriculture management, such as the implementation of agroforestry and soil and water conservation practices, are used to conserve the natural properties of the system. As those actions can reduce the vulnerability of farmers to climate impacts, we included such a type of management as our NbS in agricultural lands to reduce the impacts of climate change on subsistence crop production. Even though those types of agricultural practices can help reduce the vulnerability of people to other types of impacts (e.g., water stress), we opted to consider agriculture management in addressing the impacts of climate change on agriculture only (i.e., agricultural subsistence systems.)

Climate Impacts

River Flooding

Exposure

The exposure variable for river flooding represents change in extent and inundation (in meters of depth) of a 100-year river flood event. These selections are consistent with existing studies on climate-induced river flooding risk[57-59]. To estimate the change in exposure to riverine flooding risk in the future, we calculated the increase in flood risk between a baseline year of 1980 and projected future scenarios in the year 2030. The future river flood hazard level was calculated via the average of five scenarios based on different climate models (NorESM1, GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, and MIROC-ESM-CHEM) for the two representative radiative forcing pathways; RCP (Radiative Concentration Pathways) 4.5 (intermediate scenario) and 8.5 (highest emissions). We used riverine flooding data from the World Resources Institute (WRI) Aqueduct Flood Hazards Maps[60]. These data can be accessed online at https://www.wri.org/data/aqueduct-floods-hazard-maps

Nature-Based Solutions

Several ecosystem types can contribute to flood-risk mitigation. Ecosystems that can reduce river flooding risk, in terms of both extent and inundation depth, include forests, floodplains, wetlands, and grasslands or prairies[61]. Healthy forests and grasslands promote infiltration, reducing runoff under some conditions, and wetlands and floodplains can store and convey floodwaters, potentially reducing flood levels in other parts of a river basin. The

Conservation layer for river flooding consists of a combination of the forest, wetland, and grassland layers of the GLAD dataset that exist in areas where people are projected to be vulnerable to river flooding. The Restoration layer for river flooding was computed using the forest and wetland tree cover loss data from GLAD in areas where people are projected to be vulnerable to river flooding.

Coastal Flooding

Exposure

To evaluate exposure to coastal flooding risk, we selected data layers from the World Resources Institute's Aqueduct Flood Hazards Maps[60]. The WRI coastal flooding dataset was constructed with observed and modeled sea levels, including past and future projected sea level rise, as well as storm surges and land subsidence. As with the river flooding hazard level, these coastal flood risk layers were measured in extent and meters of inundation for a 100-year flooding event constructed from a composite of five climate models; NorESM1-M, GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM for the two representative radiative forcing pathways; RCP (Radiative Concentration Pathways) 4.5 (moderate scenario) and 8.5 (business as usual scenario). These data can be accessed online at https://www.wri.org/data/aqueduct-floods-hazard-maps

Nature-Based Solutions

Trees, wetlands, and coral reefs act as physical barriers to oceanic events at the shoreline and can substantially reduce the intensity and severity of coastal surge or flooding events[62,63]. The data for forests and wetlands were taken from the GLAD land cover and land use database (described above under Data and data analysis). Specifically, we selected the GLAD strata layers of forest (open tree cover, dense tree cover, tree cover gain), and wetland (salt pan, sparse vegetation, dense short vegetation, open tree cover, dense tree cover, and tree cover gain). We also used data from the Global Mangrove Watch dataset[64], which contains data layers for both existing mangrove ecosystems and mangrove ecosystem loss. Two additional databases supplied coral reef layers for this study. The first contains data on the current distribution of coral reefs across the world; the Global Distribution of Coral Reefs dataset[65], a product of the Millenium Coral Reef Mapping Project and a consortium between the United Nations Environment Program's World Conservation Monitoring Centre and several nongovernmental organizations. A second coral reef dataset was included to assess coral reef degradation and loss, known as the Global Coral Bleaching 1980-2020 Database[66]. The ecosystem conservation layer for coastal flooding consists of the forest, wetland, and coral reef that exist in areas where people are projected to be vulnerable to coastal flooding. The ecosystem restoration layer for coastal flooding was computed using cells denoted as forest, wetland, or reef loss in areas where people are projected to be vulnerable to coastal flooding.

Heat Waves

Exposure

The exposure data for the heat waves layer was derived from Mora et al.[67]. This dataset was produced by combining global historical records and modeled future atmospheric and surface conditions to calculate the number of days per year that exceed a minimum combined temperature and humidity threshold that is known as fatal to human life. The authors of that study calculated the change in exposure to heat waves between the historical observations from the year 1980 and the modeled predictions from CMIP5 (Combined Modeled Intercomparison Project 5) for the year 2030 in both the RCP 4.5 and RCP 8.5 scenarios.

Nature-Based Solutions

Plants provide cooling during abnormal and extreme heat events via evapotranspiration and the provision of shade[68], lowering the human morbidity and mortality induced by these events. Urban trees and forests are especially well-suited to mitigate the urban heat island effect and extreme heat events, standing as the forefront of NbS to climatically induced heat impacts[69]. Among other terrestrial vegetative ecosystems, wetlands have also been found to exert a cooling effect on land surface temperatures during heat events[70]. The ecosystem conservation layer for heat waves consists of a combination of existing forests, including both urban and naturally occurring forests, and wetlands from the CORINE Land Cover database, a remote-sensing database gathered, verified, and made public by the Copernicus and Land Monitoring Service of the European Union[71]. The CORINE database is a 100-meter resolution global land cover and land use dataset that more precisely captures vegetation in urban environments and is therefore more suitable for use in the conservation layer for heat waves compared to the GLAD dataset, as the urban heat island effect plays a major role in how injurious extreme heat events are on a population. The ecosystem restoration layer for heat waves consists of the forest and wetland tree cover loss from GLAD. in areas where people are projected to be vulnerable to heat waves.

Water Stress

Exposure

We selected the Aqueduct Water Stress Projections Data constructed by the Aqueduct research team at the World Resources Institute[72], to evaluate the global exposure to water stress. The Aqueduct Water Stress Projections Data take the form of a water stress index, which was calculated using future available water supplies, water withdrawals (including irrigation, domestic, and industrial water withdrawals), and seasonal variability in atmospheric and hydrological conditions. The baseline year was set to 1980 and future projections from the year 2030 were selected in the RCP 4.5 and RCP 8.5 scenarios as modeled in CMIP5 (Coupled Model Intercomparison Project 5). More information regarding the Aqueduct Water Stress Projections Data, and the download links for the dataset, are available at https://www.wri.org/data/aqueduct-water-stress-projections-data

Nature-Based Solutions

Forests appear frequently in the literature regarding their potential to reduce water stress, as do other terrestrial vegetative ecosystems, such as wetlands and grasslands[73]. Wetlands, including floodplains, can store water, increase infiltration, and contribute to groundwater recharge, which can help mitigate water stress[74]. The ecosystem conservation layer for water stress consists of a combination of existing forest, wetland, and grassland layers from GLAD in areas where people are projected to be vulnerable to water stress. The ecosystem restoration layer for water stress was computed by combining forest and wetland tree cover loss as per GLAD in areas where people are projected to be vulnerable to water stress.

Wildfires

Exposure

We designated wildfire exposure as the change in the maximum annual value of the Fire Weather Index (FWI) as reported in Quilcaille et al.[75], which was calculated by combining air and surface temperatures, wind velocity, humidity, and precipitation. This modeled FWI dataset was constructed from the sixth Coupled Model Intercomparison Project for the period from 1850 to 2100. As with the other climate impacts, we extracted FWI data for two emissions and climate change scenarios; SSP 4.5 and SSP 8.5 with a baseline period of 1850-2014 (historical values) and a future year set to 2030 as produced by the CMIP6 (Coupled Model Intercomparison Project 6) program. For more information on which climate and atmospheric models were included in CMIP6 for the purposes of modeling wildfire risk, see Quilcalle et al.[75].

Nature-Based Solutions

Determining what ecosystems and types of interventions can minimize wildfire risk and intensity poses a unique and challenging task compared to doing so for other climate impacts, as some ecosystems themselves are at risk for wildfire ignition and spread. In those types of fire-adapted ecosystems, specific management interventions, such as reducing flammable vegetation, thinning tree canopies to prevent fires from leaping across treetops, and removing dead wood and debris, are often implemented to reduce wildfire risk. The definition of NbS for reducing wildfires is thus different from that for the other impacts in this study. For this type of climate impact, we do not have an ecosystem restoration layer, but an ecosystem management layer. We selected ecosystems based on their level of adaptation to wildfires as per Arrogante-Funes et al.[76], flagging ecosystems with higher fire adaptation capacity as materially distinct from those with low fire adaptation capacity. We delineated ecosystems with a “low” wildfire adaptation level (those ecologically not adapted to fire, and for which fire can lead to an irreparable loss of their structure and composition[77], and must be protected in order to minimize the risk of wildfire ignition and spread. The ecosystem conservation layer for wildfire therefore consists of existing ecosystems of low wildfire adaptation level in areas where people are vulnerable to wildfires. Ecosystems that were identified as having “very high,” “high,” and “moderate” levels of wildfire adaptation (those ecologically adapted to fire, i.e., fire-adapted ecosystems) were combined and designated for ecosystem management.

Vector-Borne Disease

Exposure

We considered two infectious diseases transmitted by mosquitoes in our exposure to the vector-borne disease layer: dengue fever and malaria. We extracted and then averaged values of the change in the length of the transmission season for those two infectious diseases between baseline and future time period. The life cycle and disease transmission mechanics of mosquitoes are extremely sensitive to environmental conditions, such as the availability of standing water and high water temperatures[78]. The observed and modeled data for the length of the transmission season were derived from Colón-González et al.[79], which established a baseline time period of 1951 to 2005 and future projected time period of 2006 to 2099 within the context of the RCP 4.5 and 8.5 emissions scenario and the SSP 2 projections.

Nature-Based Solutions

The identification and selection of NbS for mosquito-based vector-borne diseases is complicated, as the ecosystems that serve as mosquito breeding and habitat may also help control mosquito breeding and habitat when healthy and in balance. Adult mosquitos persist, thrive, and breed in natural and semi-natural ecosystems with dense vegetation. However, healthy ecosystems can also keep the vector populations naturally low through various mechanisms such as providing habitat to aquatic, terrestrial, and aerial predators. Deforestation has been consistently associated with larger populations of vector mosquito species and with increased exposure of human populations to malaria[80-82]. Healthy forests[83] and wetlands[84] can reduce the spread of mosquito-borne diseases due to the presence of mosquito controlling organisms. Human populations in areas with more wetland ecosystems exhibit lower dengue fever incidence, possibly via the heat mitigation provided by wetlands that in turn reduces vector reproductive capacity[85]. Grasslands lack the dense foliage and shaded intermittent water bodies that mosquitos require for breeding and habitat and are therefore also counted among the natural areas that counteract mosquito transmission activities[86].

The land cover types for conservation for vector-borne diseases were forests, wetlands, and grasslands from the GLAD dataset. The ecosystem conservation layer for vector-borne disease consists of a combination of existing forest, wetland, and grassland layers from GLAD in areas where people are projected to be vulnerable to malaria and dengue. The cells flagged for restoration in regard to vector-borne disease were those that were identified as forest and wetland tree cover loss by GLAD. The ecosystem restoration layer for vector-borne diseases was computed by combining forest tree cover loss and total wetland loss in areas where people are projected to be vulnerable to malaria and/or dengue. Although we acknowledge that ecosystem restoration may initially lead to a higher exposure of people to those diseases, as such areas are not yet in ecological balance, we assume that those areas will help control mosquito populations and reduce the contacts of mosquitoes and people in the long-term through the same mechanisms as previously described.

Landslides

Exposure

As a changing climate system increases precipitation volumes in many areas throughout the world, precipitation-induced landslides have the potential to rise in both frequency and destructiveness. We selected as our measure of landslide impact the modeled change in landslide risk, measured as the relative magnitude change of number of persons at risk of landslides caused by extreme precipitation events, between a baseline period of 1971-2000 and a future period of 2031-2060 in the SSP 4.5 scenario at a one-kilometer resolution[87]. This dataset did not contain projections for SSP 8.5.

Nature-Based Solutions

Landslides, even those initiated by rainfall and other precipitative events, are physically distinct from other climate-related impacts; in a landslide, a massive amount of physical material moves at a very high rate, accelerating and gaining more mass as it descends downhill. To prevent and reduce landslide risk and severity, any natural solution must increase water infiltration, reducing the flow of water and binding the soil together. Trees accomplish this with their deep roots, and forests dominate the literature on NbS to landslides, with forests consistently being found to offer some protection against landslide events[88]. The ecosystem conservation layer for landslides consists of existing forest layer from GLAD in areas where people are projected to be vulnerable to landslides. The ecosystem restoration layer for landslides consists of the layer on forest loss from GLAD in areas where people are projected to be vulnerable to landslides.

Subsistence Food Insecurity

Exposure

Subsistence agriculture is yet another key area of study and consideration of policymakers in the arena of climate change impacts. Diminishing capacity to grow food for subsistence purposes compromises food security and constitutes a major threat to livelihoods and health around the world. A warming planet and changing climate system can have severe implications for agricultural productivity, which in turn has severe implications in the availability of food items[89]. Because food insecurity is a pivotal dimension of climate impacts and because it is difficult to directly quantify the availability of and access to food items themselves, we selected agricultural productivity of crops commonly used for subsistence to assess how future climate conditions could potentially affect food security. To do so, we derived agricultural land suitability and attainable yield data for six global staple food crops (barley, cassava, sweet potato, wheat, white potato, and yam) available at the Agro-Ecological Zones (GAEZ) dataset developed and published by the Food and Agriculture Organization of the United Nations[90] for two periods; baseline (1971 to 2000) and future (2011 to 2040) covering two emissions and climate change scenarios; RCP 4.5 and RCP 8.5 at a 10-kilometer resolution. The GAEZ program generates modeled agricultural data based on historic productivity, soil and land suitability, and agro-climatological data. Projections are available at https://gaez.fao.org/

Nature-Based Solutions

The possibility of NbS to minimize the projected vulnerability of people to food insecurity as it pertains to subsistence agriculture differs substantially from the processes in other climate impacts; farmland and pasture cannot be fully replaced by natural ecosystems while maintaining the purpose of those lands, i.e., the production of crops and animal products. Instead of identifying ecosystems that share the same cell as areas where people are projected to be vulnerable to food insecurity, and that can minimize that impact, we chose to delineate NbS as Nature-based conservation agriculture practices (e.g., crop diversification, crop rotation, cover crops, and non-tillage) and agroforestry that could be implemented in agricultural lands to reduce food insecurity in areas where the suitability of subsistence crops is expected to decrease. Conservation agriculture practices and agroforestry implemented in agricultural lands can reduce food insecurity by reducing the direct impact of extreme rainfall and temperature on crops[91]. Therefore, for this type of climate impact, we do not have an ecosystem restoration or restoration layer, but an agricultural management layer to assess the importance of nature to possibly reduce food insecurity of subsistence farmers.

Smallholder farmers, in addition to being more vulnerable to climate impacts[92] and to representing the majority of farms in developing countries, are likely more amenable to the implementation of nature-based practices than large industrial farms. This is due to the many ecosystem services they can provide[93], additional income provided from some of those practices[94], and the overall low implementation and labor costs. Therefore, we opted to focus our analysis on smallholder farms only as they are more likely to adopt conservation agriculture practices and agroforestry than larger farms. The global farm size scheme and data used in this study were taken from Lesiv et al.[95], the authors of which employed crowdsourcing techniques to gather geographic data points on farm size across the globe, aggregating the data to ascertain farm sizes and then sorting farms into five size categories ranging from very small (less than 0.64 hectares) to very large (more than 100 hectares). The agriculture management layer for food insecurity consists of areas that are vulnerable to potential food insecurity and that comprise farms of small (0.64 to 2.56 hectares) and very small (less than 0.64 hectares) sizes.

Layer Analysis

Vulnerable area and vulnerable people

We calculated the total area and number of people that are projected to be vulnerable to a given climate impact. The total number of 1-km^2 pixels projected to be vulnerable to each climate impact was summed, as well as the number of pixels referent to the top decile of vulnerability. Please note that the top decile results are only included in the Extended Data. The same process was done for the ecosystem conservation, restoration, and management layers. These layers were then overlapped to extract the total number of people living in those cells as per the LandScan global population dataset.

Ecosystem conservation layer and Protected Areas

To assess how much ecosystem conservation that can possibly help people adapt to the impacts of climate change (i.e., our ecosystem conservation layer) is currently protected, we overlaid pixels that are currently listed as protected areas on cells that we flagged for ecosystem conservation. To do so, we used a vector shapefile of protected areas from the World Database of Protected Areas (WDPA). The WDPA is constructed with data from the United Nations Environment Program World Conservation Monitoring Centre and made available at https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA.

Ecosystem restoration and priority areas for restoration

We also performed an analogous evaluation comparing the areas we identified as potentially having vulnerability ameliorated by restoration efforts with areas that have been designated as high priority areas for restoration in a previous study. To perform this analysis, we accessed data from Strassburg et al.[36], in which a multidimensional scheme, incorporating biodiversity, climate change mitigation, and implementation costs, was developed for the spatial location of the areas of top priority for ecosystem restoration interventions. Our restoration layers were then overlain on the top 20% (high priority) of restoration priority cells identified by Strassburg et al.[36] and the percentage of overlap was calculated.

Total combined impacts

We created layers that convey the total combined number of climate impacts that people in any given cell will potentially experience. Likewise, we created layers to convey the total combined number of climate change impacts that could possibly be reduced by ecosystem conservation and by ecosystem restoration. Then, the grand total area and number of vulnerable persons in those areas were tabulated. The management layers for food security and for wildfire are not presented in the results.

Differences between results using RCP 4.5 and RCP 8.5

Our results were highly consistent for both Representative Concentration Pathways (RCP 4.5 and RCP 8.5). This is true for virtually all our results, from the climate change vulnerability indices to the maps of all combined impacts. Despite some differences in results between the pathways do exist, most prominently regarding the vulnerability index value of food insecurity, there is overall little difference between the pathways, with estimates nearly identical in many cases. The lack of disparity is likely because the emissions and attendant global warming and climate change projections simply do not differ from each other in the year 2030; only later in the twenty-first century, and most markedly by the end of the century, when the pathways begin to diverge significantly[96]. Due to those similarities in results between RCP 4.5 and RCP 8.5, we opted to only present the results for RCP 4.5 in the main body of the paper.

Climate Impact	Measure	Original Resolution	Baseline Year(s)	Future Year(s)	Scenarios	Source	Nature-based Solutions
River Flooding	Flooding extent and meters of inundation	1 km	1980	2030	RCP 4.5, RCP 8.5	WRI Aqueduct	Conservation and restoration of forests, wetlands, grasslands
Coastal Flooding	Flooding extent and meters of inundation	1 km	1980	2030	RCP 4.5, RCP 8.5	WRI Aqueduct	Conservation and restoration of forests, wetlands, mangrove forests and swamps, coral reefs
Water Stress	Water stress index	Water basin	1980	2030	RCP 4.5, RCP 8.5	WRI Aqueduct	Conservation and restoration of forests, wetlands, grasslands
Heat Waves	Number of deadly heat wave days	1.5 degrees	1980	2030	RCP 4.5, RCP 8.5	Mora et al. 2017	Conservation and restoration of forests, urban tree cover, wetlands
Wildfires	Fire Weather Index	2.5 degrees	1850-2014	2030	SSP 245, SSP 585	Quilcaille et al. 2023	Management and conservation of ecosystems adapted to wildfires
Vector Borne Disease	Length of transmission season of dengue and malaria	0.5 degrees	1951-2005	2006-2099	RCP 4.5 SSP 2, RCP 8.5 SSP 2	Colón-González et al. 2021	Conservation and restoration of forests, wetlands, grasslands
Landslides	Change in magnitude of landslide risk	0.25 degrees	1971-2000	2031-2060	SSP 4.5	Wang et al. 2023	Conservation and restoration of forests
Subsistence Food Insecurity	Crop suitability class	10 km	1971-2000	2011-2040	RCP 4.5, RCP 8.5	FAO GAEZ (Fischer et al. 2021)	Nature-based agricultural management in smallholder farms

Table 1. Descriptions of the datasets used to assess vulnerability and NbS identified to address each of the climate impacts.

Table 2. The individual datasets that comprise the adaptive capacity layer. Datasets that were incorporated into the adaptive capacity layer for specific climate impacts are described in the text. (* flood protection was only used to calculate adaptive capacity for river flooding and coastal flooding, along with the other indicators)

Indicator	Description	Resolution	Time Period	Source
Age	Percent of population age 15 to 64	Country	2020	World Bank
Development	Human Development Index	Municipality	2020	MOSAIKS
Governance	Combination of six indicators	Country	1996-2022	World Governance Indicators
Travel Time	Meters to nearest road	1 kilometer	2015	Nelson et al., 2019
Flood protection*	Flood protection capacity index	Country	2016	WRI's FLOod PROtection Standards

Table 3. Layers and sources used to assess the potential role of NbS in potentially reducing climate impacts.

Ecosystem Conservation

Layer	**Description**	**Source**
Forests	Deciduous, coniferous, and mixed forests	Global Land Cover and Use Database, Copernicus
Wetlands	Swamps, estuaries, and other wetlands	Global Land Cover and Use Database, Copernicus
Grasslands	Temperate prairies and grasslands	Global Land Cover and Use Database
Mangroves	Mangrove forests and swamps	Global Mangrove Watch Version 3.0 Dataset
Coral Reefs	Existing coral reef ecosystems	Global Distribution of Coral Reefs

Ecosystem Restoration

Layer	**Description**	**Source**
Forest cover loss	Forest tree loss	Global Land Cover and Use Database
Wetland loss	Wetland tree loss	Global Land Cover and Use Database
Mangrove loss	Loss of mangrove forests and swamps during study period (1996-2020)	Global Mangrove Watch Version 3.0 Dataset
Coral reef loss	Coral reefs that underwent any degree of bleaching	Global Coral-Bleaching Database, 1980–2020

Wildfire and Agricultural Management

Layer	Description	Source
Agricultural management	Farms deemed small (0.64 to 2.56 hectares) and very small (<0.64 hectares)	Lesiv et al. 2019
Ecological vulnerability to wildfires	Ecosystem adaptation to wildfire value	Arrogante-Funes et al. 2022

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Data Availability

Data on climate vulnerability of people to climate impacts, and data on areas that could be conserved, restored and managed to potentially reduce the impacts of climate change can be found at: https://osf.io/3rpfd/

Author Contributions

DAB contributed conception or design of work; acquisition, analysis, or interpretation of data; drafting and revision of work; CID contributed conception or design of work; acquisition, analysis, or interpretation of data; drafting and revision of work; RM contributed conception or design of work; drafting and revision of work; CB contributed conception or design of work; drafting and revision of work; CM contributed conception or design of work; drafting and revision of work; RCK contributed conception or design of work; drafting and revision of work; LD contributed conception or design of work; drafting and revision of work; GF contributed conception or design of work; drafting and revision of work; NBG contributed conception or design of work; drafting and revision of work; DH contributed conception or design of work; drafting and revision of work; HJ contributed conception or design of work; drafting and revision of work; MM contributed conception or design of work; drafting and revision of work; RAN contributed conception or design of work; drafting and revision of work; JJO contributed conception or design of work; drafting and revision of work; SP contributed conception or design of work; drafting and revision of work; PRR contributed conception or design of work; drafting and revision of work; AZ contributed conception or design of work; drafting and revision of work.

Competing Interests

The authors declare no competing interests.

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