INFORM Climate Change: Projecting Effects of Climate Change on the INFORM Risk Index
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Abstract

The INFORM Risk Index is a global indicator-based disaster risk assessment tool which supports humanitarian crisis management decisions. In this article, we present an extension of the index using projections of exposure to climate change hazards to provide better insights for policymakers on the threats imposed by climate change and the extent the amplified risks can be compensated by reduced vulnerability and increased adaptive capacity measures. We consider the RCP 8.5 high greenhouse gas concentration scenario and the SSP3 population projection for the mid-21st century. The largest mid-century changes in climate hazard and exposure are observed in much of Europe, northern and southern Africa, South America, and western and southwestern Asia. To compensate for the increase of climate-related hazards, the countries and regions will need to invest in reducing vulnerability and increasing coping capacity. This knowledge can benefit humanitarian aid management planning and in forming effective disaster risk reduction and climate change adaptation strategies and plans.

Key words: Disaster risk reduction, climate change adaptation, indicator-based assessments, INFORM Risk Index
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Introduction

Background

As anthropogenic greenhouse gas (GHG) concentrations continue to accumulate, extreme weather and climate related risks are becoming increasingly amplified. According to the Emergency Events Database (EM-DAT) (CRED, 2020), 6,681 weather and climate related disasters affecting 3.9 billion people occurred between 2000 and 2019, which is an increase from 3,656 events and 3.2 billion affected in the prior 20 years. Recorded economic losses from disasters amount to 2.97 trillion USD globally between 2000 and 2019, primarily a result of storms and floods.

According to the Intergovernmental Panel on Climate Change (IPCC) special report on the impacts of global warming of 1.5 °C (IPCC, 2018), a mix of mitigation and adaptation options aligned with economic and sustainable development are necessary to accelerate the transition consistent with limiting warming to the 1.5°C Paris Agreement target. Lack of knowledge on the integration and coherence of Climate Change Adaptation (CCA) and mitigation, Disaster Risk Reduction (DRR) and sustainable development is stated as one the major knowledge gaps required to strengthen and implement the global response to limiting warming to 1.5°C (de Coninck et al., 2018).

Sustainable Development Goal (SDG) 13 is dedicated to combatting climate change and its impacts, calling for the widest possible international cooperation to accelerate the efforts on climate change mitigation and adaptation policies and practices (UN, 2015). Synergies between CCA and DRR can aid progress in SDGs poverty reduction, economic growth, social inclusion and environmental protection (UN, 2015). In October 2020, the United Nations Framework Convention on Climate Change (UNFCCC) and United Nations Office for Disaster Risk Reduction (UNDRR) signed a Memorandum of Understanding to enhance and promote CCA and DRR collaboration in National Adaptation Plans and National Strategies for Disaster Risk Reduction (UNFCCC, 2020).

Several major studies and reports have addressed the importance of CCA and DRR integration (EC, 2020; EEA, 2020, 2017; IFRC, 2013; Ilan, 2017; OECD, 2020; Poljansek et al., 2021, 2017; UNDRR, 2019; Wijenayake, 2019). The Sendai Framework on DRR (SFDRR) calls for more dedicated action to address climate change and variability as one of the underlying disaster risk drivers (UNISDR, 2015a). Global Assessment Report 2019 (UNDRR, 2019) emphasizes the full integration of sustainable development plans and DRR and CCA strategies to achieve the Sendai targets. It also updates progress made in implementing DRR, climate change and sustainable development targets and priorities. The Organisation for Economic Co-operation and Development (OECD)’s report on Common Ground between the Paris Agreement and the Sendai Framework (OECD, 2020) highlights the benefits of increased coherence between CCA and DRR through comprehensive and coordinated action across public administrations.

Developing common evidence-based tools for risk-informed decision-making and monitoring, reporting and evaluation (MRE) purposes can help unify DRR and CCA strategies and sustainable development plans (UNISDR, 2015a; Wijenayake, 2019). These include common monitoring, evaluation and learning processes, risk and vulnerability assessments, and indicators for target measuring (Wijenayake, 2019). For example, the International Institute for Environment and Development (IIED) developed the Tracking Adaptation and Measuring
Development (TAMD) tool to track adaptation and measure its impact on development by means of vulnerability and development indicators (IIED, 2014; Kabesiime et al., 2015). In addition, the UN High Level Committee on Programmes Senior Managers Group on Disaster Risk Reduction for Resilience (HLCP/SMG) developed a benchmark indicator-based tool to support and align with SGD progress monitoring by countries, the post-2015 framework for DRR and any future CCA goals and targets (UNISDR, 2015b). This is based on the Sendai framework call for development of coherent global and regional follow-up and indicators in coordination with relevant mechanisms for disaster risk management, sustainable development and climate change (UNISDR, 2015a). The Sendai Framework Monitor provides a set of standards and 38 indicators for countries to track progress towards the targets of the Framework. This can provide valuable information in monitoring disaster risk-related indicators of the SDGs and in measuring CCA progress. In contrast, the Paris agreement does not include any established common agreed indicators to monitor progress (OECD, 2020).

Disaster risk assessment and MRE approaches include quantitative, indicator-based assessments and qualitative, community participatory measures (Birkmann et al., 2020; EEA, 2020, 2015; Poljansek et al., 2017; UNDRR, 2019). Indicator-based assessments are widely used both for analysing risks and assessing progress made by combining hazard, exposure and vulnerability (Bakkensen et al., 2017; Birkmann et al., 2013; EC, 2018; EEA, 2015; ESPON, 2011; Poljanšek et al., 2019a; RESIN, 2018; UNDRR, 2019). The Global Climate Risk Index (Eckstein et al., 2021), the World Risk Index (Welle and Birkmann, 2015), the Notre Dame Global Adaptation Initiative (ND-GAIN) Country Index (University of Notre Dame, 2018), the EU Global Climate Change Alliance plus Flagship Initiative (GCCA+) Index (Miola et al., 2015), and the INFORM Risk Index (De Groeve et al., 2015) are examples of indicator-based disaster risk assessments at the global scale.

Research Gaps

The available global climate risk indices are largely based on an analysis of historical data. By making the implicit assumption that drivers of risk will remain constant, the indices do not account for future socioeconomic development and climate-related impacts. The need for an improved understanding of the dynamics of climate related risk components (hazard, exposure and vulnerability) has been stressed in several reports and research articles (e.g. Birkmann et al., 2015; Debortoli et al., 2019; Dilling et al., 2015; Ford et al., 2018; IPCC, 2014a; Jurgilevich et al., 2017; Rohat, 2018; Rohat et al., 2019).

There are a few studies at the global scale that account for the dynamics of exposure to climate-related hazards using available projections. For example, ND-GAIN Country Index measures a country’s current vulnerability to climate disruptions in combination with its readiness to improve resilience (University of Notre Dame, 2018). ND-GAIN partitions vulnerability into exposure, sensitivity and adaptive capacity considering six life-supporting sectors. The exposure dimension includes projected impacts of climate-related hazards such as extreme sea level rise. However, there is no indication of how sensitivity and adaptive capacity (which are the main components of vulnerability in IPCC fifth assessment report) will evolve in the future due to climate change nor how much effort is needed to counteract changes in climate hazard and exposure. A similar approach has been followed in several local, national and regional risk and vulnerability studies (Debortoli et al., 2019; ESPON, 2011; KC et al., 2015; Mysiak et al., 2018; RESIN, 2018).
Recent studies have employed Shared Socioeconomic Pathways (SSP) scenarios to project the drivers of vulnerability and coping capacity (Birkmann et al., 2020; Rohat, 2018; Yang and Cui, 2019). Vulnerability scenarios under SSPs partially cover tangible (e.g. demographics, poverty, access to infrastructure) and intangible (e.g. governance, risk awareness) aspects of vulnerability.

**Scope of Study**

In this study, we present a new approach for understanding the impact of climate change in the disaster risk and associated vulnerability. Our analysis includes two main stages: i) exploring ways to include climate change hazard and exposure projections into multi-hazard DRR measures using the INFORM Risk Index; and ii) estimating the change in vulnerability and coping capacity required to compensate for the projected change in hazard and exposure. For the hazards, we use projections of river floods, coastal floods and droughts, which are applied to population projections to assess exposure. The study includes considerations from major international organizations addressing how the extended tool can benefit their decision-making and operational processes. The INFORM initiative and the data and methodology used to extend the INFORM Risk Index are described in Sections 2 and 3, respectively. In Section 4 we present the results and in Section 5 we discuss use cases. Section 6 provides conclusions and reflections on policy implications.

**INFORM Initiative**

INFORM is a multi-stakeholder forum that develops shared, quantitative analysis relevant to humanitarian crises and disasters. It includes organizations from across the multilateral system, including the humanitarian and development sector, donors, and technical partners.

INFORM partners believe that the availability of shared analysis of crises and disasters can lead to better coordination of actors and better outcomes for at-risk and crisis-affected people. INFORM creates a space and process for shared analysis that can support joint strategy development, planning and action to prevent, prepare for, respond to and recover from crises. This can bring together development, humanitarian and other actors to manage risk and respond better when crises do occur.

INFORM is developing a suite of quantitative, analytical products to support decision-making on humanitarian crises and disasters, mostly at a country-level resolution (Error! Reference source not found.). These tools aid in decision-making at different stages of the disaster management cycle, specifically prevention, preparedness and response.

The purpose of INFORM products is to make information about crises and disasters more accessible for decision-makers. INFORM products are intended to aggregate and present existing information in a way that can create a common evidence base and be easily incorporated into decision-making systems. INFORM methodologies are flexible and open and can therefore be adapted to the needs of different organizations.
INFORM Risk Index is an open, composite index that identifies: “countries at risk from humanitarian emergencies that could overwhelm current national response capacity, and therefore lead to a need for international assistance”. It was developed in response to recommendations by numerous organizations (e.g. the World Bank, 2013 and OCHA, 2014) to improve the common evidence basis for risk analysis. Although the index quantifies the risk of humanitarian emergencies, it is equally relevant for development and DRR actors, and for high income countries.

INFORM Risk Index facilitates access to a wealth of information about risk and considers two facets: hazards and human exposure to them; and societal vulnerability to those hazards and their capacity to cope with them. The index is defined by combining approximately 50 different indicators that measure these dimensions and their underlying categories, components and indicators (Error! Reference source not found.). Each of the indicators is normalized for each country to a value that varies from 0 and 10, essentially creating a risk profile that is comparable across countries, then combined into an overall index that also varies from 0 to 10. All levels of the index, including the source data, are open.
INFORM Risk Index can be used to help develop priorities for risk management, preparedness and building resilience; to support decisions about resource allocation; and to monitor risk trends over time. A shared understanding of risk can lead to programmes and investments that are more commensurate with the risks people face. The index, in the current framework, considers six “natural” hazards: earthquakes, tsunamis, floods, tropical cyclones, droughts and epidemics. The coverage of weather and climate related hazards, namely flood, tropical cyclone wind, storm surge and drought, is based on Global Risk Assessment (UNISDR, 2015c), FAO Agricultural Stress Index (ASI) (Rojas, 2018) and Emergency Events Database (EM-DAT) (CRED, 2019) data for different hazard intensities.

Besides hazard and exposure, vulnerability and lack of coping capacity are the two other dimensions of the INFORM Risk Index, and are key factors in the analysis of risk. Vulnerability is the susceptibility of communities to potential hazards, while (lack of) coping or adaptative capacity measures the (lack of) resources that can alleviate the impact of those hazards. Functionally, vulnerability and coping capacity are inversely related (IPCC, 2014a). The vulnerability dimension encompasses socioeconomic vulnerability and vulnerable groups. The socioeconomic category is composed of development and deprivation, inequality and aid dependency, and the vulnerable groups category includes uprooted people, refugees and displaced populations, and other vulnerable groups under health, age and food security conditions (Cutter et al., 2003; Fekete, 2009; Poljanšek et al., 2019b). IPCC defines adaptive capacity as ‘the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences’ (IPCC, 2014b). Lack of coping capacity indicators therefore relate to infrastructure and institutional measures, including disaster-risk reduction efforts and risk management. The institutional
category evaluates government efficacy in carrying out DRR activities. The infrastructure category combines communication, physical infrastructures, and access to health systems (Marin-Ferrer et al., 2017).

Climate change projections in INFORM Risk Index

The future climate change hazards river flood, coastal flood and drought in INFORM Risk Index have been computed using the projections based on a historical period and a future mid-21st projection under the RCP 8.5 GHG concentration scenario (see Marzi et al., 2021 for more details). To quantify the population exposure, the hazards for the historical and future periods are applied to the Global Human Settlement Layer (GHSL, Pesaresi et al., 2016) and SSP3 scenario. The influence of climate change on the tropical cyclone wind risk has not been considered at this stage due to lack of data.

The selection of RCP 8.5 provides a challenging yet plausible scenario context to test the robustness of human and natural systems and climate change adaptation measures. While the RCP 8.5 GHG concentrations are considered high, they are similar to other RCP scenario concentrations for the early and mid-21st century (Kebede et al., 2018). Future research will consider the application of other GHG scenarios and time periods to better estimate the full range of uncertainty.

The SSP3 (regional rivalry) population projection envisages a higher tendency towards regional fragmentation; relatively low-income growth and low investments in human capital; relatively high fertility and population growth rates in currently high fertility countries and low fertility rates and low (or negative) population growth in currently low fertility countries; relatively low migration; and slow urbanization (Jones and O’Neill, 2016; NCAR, 2019; Fitch Solutions, 2016; Fricko et al., 2017). According to IPCC 2018 special report, the world’s poorest populations are expected to be disproportionately impacted at higher risk thresholds such as RCP 8.5, particularly in cases of significant inequality in Africa and southern Asia such as with SSP3 (Hoegh-Guldberg et al., 2018). World population is projected to increase from 7.3 billion in 2015 to 9.8 billion in 2050 (+34%) (Error! Reference source not found.). At the continental scale over the same period, population in Asia is projected to increase from 4.3 to 5.6 billion (+28%); in Africa from 1.2 to 2.3 billion (+96%); in North America from 0.57 to 0.66 billion (+16.7%); in South America from 0.42 to 0.54 billion (+28%); in Europe from 0.75 to 0.69 billion (-8.1%) under SSP3; and in Oceania from 0.38 to 0.48 billion (+25%).

Figure 3. a) Population in 2015 (GHSL) and b) changes in population in 2050 under SSP3 scenario (adapted from Marzi et al., 2021).

<table>
<thead>
<tr>
<th>a) Population in 2015 (GHSL 2015) – millions</th>
<th>b) Percentage of change from 2015 to 2050 (SSP3)</th>
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<td>&lt; 10</td>
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In addition to the climate change projections, the population projections are applied to non-climate natural hazards except for epidemics. Although we recognize that epidemics may be affected by climate and demographic changes (Watts et al., 2019), their current lack of predictability at a climate time-scale do not allow us to take them into account. The human hazards (non-climate) which include conflict intensity or future conflict probability (HIIK, 2019), and the projected risk of conflict within the next four years (JRC, 2017) are assumed to be constant. According to Mach et al. (2019), there is general consensus that although climate variability can affect organized armed conflict within countries, the mechanisms of climate–conflict linkages contain significant uncertainties and there is currently not enough understanding to project its future impact. Low socioeconomic development and low capabilities of the state (vulnerability and lack of coping capacity) are considered substantially more influential.

The evolution of country’s vulnerability and capacity is influenced by a variety of factors, internal and external (e.g. poverty, illiteracy and lack of skills, weak institutions, limited infrastructure, lack of technology and information, low levels of primary education and health care, poor access to resources, low management capabilities and armed conflicts), including climate change (UNFCCC, 2007). For the mid-century projections, it is assumed that each country’s vulnerability and coping capacity is preserved at the current level and that reducing vulnerability and increasing capacity are the only mechanisms to counteract of climate change hazards and manage the risk.

River floods

Global flood models (GFMs) have developed rapidly over the last decade as a result of increased computational power and global data availability, with increasing contributions from remotely sensed products. GFMs are based on a cascade of meteorological-hydrological-hydraulic models. They are particularly suitable for estimating potential inundation under different flood probabilities, hence, the project potential future flood hazard. A non-exhaustive list of non-commercial GFMs belonging to this category includes CaMa-UT from the University of Tokyo (Yamazaki et al., 2011), CIMA-UNEP developed for the UNISDR Global Assessment Report 2015 (GAR) (Rudari et al., 2015), the ECMWF model (Pappenberger et al., 2012), GLOFRIS by Deltares (Winsemius et al., 2013), and the European Commission - Joint Research Centre (JRC) model (Dottori et al., 2016). Among them, the JRC model benefits from continuous research efforts and operational improvements of the Copernicus Emergency Management Service (EMS) – Global Flood Awareness System (GloFAS, Alfieri et al., 2020b, 2013), which contribute to its high skill (Bernhofen et al., 2018).

For INFORM Risk Index, we use inundation level at 1km resolution for six flood return periods (10, 20, 50, 100, 200 and 500 years). The frequency and magnitude of present and future flood events are taken from seven hydrological simulations run with the Lisflood model (van der Knijff et al., 2010), spanning at least 130 years starting in 1971 up to 2120 at a daily resolution. Atmospheric forcing from seven RCP 8.5 CMIP5 Atmosphere Ocean Global Climate model (AOGCM) projections is downscaled using EC-EARTH3-HR at resolution of 0.35° (~40 km at the equator) (Alfieri et al., 2017). Future discharge peaks are selected through a peak-over-threshold routine, and their magnitude is assessed by inversion of the respective extreme value distribution fitted on the annual maxima of their baseline climate (1976-2005). Future flood events are then identified as the peak flows exceeding the flood
protection levels for the period 2036 to 2065 (Scussolini et al., 2016). Estimates of population affected from the seven scenarios are aggregated at country level and averaged over 30-year time slices for the present-day and future (mid-21st century). The expected annual exposed population is estimated as the integral of the curve of the potentially exposed population for flood probability (Alfieri et al., 2020a).

**Storm Surge**

Extreme sea levels (ESLs) result from a combination of factors including mean sea level, tides, wind-waves, storm surges, and vertical land movement. A non-exhaustive list of flood models that have been applied in a context of estimating global coastal flooding hazard includes GLOFRIS (Ward et al., 2013) and Aqueduct global flood analyser (Ward et al., 2020), DIVA (Brown et al., 2016; Vafeidis et al., 2008), Global Tide and Surge Reanalysis (GTSR) (Muis et al., 2016), and LISFLOOD-FP (Dottori et al., 2016; Vousdoukas et al., 2020).

For INFORM Risk Index, we use probabilistic coastal flood simulations produced by the LISFLOOD-FP model for seven different return periods (5, 10, 20, 50, 100, 200, 500, and 1000 year events) (Vousdoukas et al., 2020, 2018a, 2018b). The period 1980 to 2014 is considered as baseline and 2036 to 2065 as the future projection. Six RCP 8.5 CMIP5 ESLs projections are used for the atmospheric forcing contribution to extreme wind and atmospheric pressure drive waves for the dynamic ocean simulations to determine ESLs (Mentaschi et al., 2017; Vousdoukas et al., 2017). Mean sea level, and consequently sea level rise, are mainly driven by thermal expansion, followed by contributions from ice mass-loss from glaciers and ice sheets in Greenland and Antarctica (Mentaschi et al., 2017). Maximum tide levels are obtained from a 10-year time series database from the TOPEX/POSEIDON Global Inverse Solution (Egbert and Erofeeva, 2002; Vousdoukas et al., 2016). The effects of sea level rise on global tidal elevations are assessed through a set of simulations using the global DFLOW FM setup (Vousdoukas et al., 2018b). Consistent with river floods, the expected annual exposed population is the integral of the potentially exposed population to storm surge inundation at each flood probability (Alfieri et al., 2020a).

**Droughts**

Drought is one of the major weather-related natural hazards worldwide, causing severe economic losses, environmental damage and human suffering. Measuring drought impacts is more complex than for other natural hazard impacts that cause immediate and structural damages such as floods and storms (UNDRR, 2019). A wide variety of drought indices are used to characterize the severity and frequency and typically depend on one or more components of the hydrological cycle such as precipitation, soil moisture, snowpack, reservoir levels, river flow, and groundwater levels and can also depend on water demands (EC, 2017; Svoboda and Fuchs, 2016). The standardized precipitation index and the standardized precipitation evapotranspiration index (SPEI) are widely used to assess the meteorological droughts (Beguería et al., 2014; Spinoni et al., 2019; Vicente-Serrano et al., 2010). Drought indices such as European Drought Observatory (EDO)’s Soil Moisture Anomaly (SMA), the Drought Severity Index (DSI), or the Palmer Drought Severity Index (PDSI) characterize plant water stress based on soil water content (EC, 2019, 2017). Hydrological droughts are mainly assessed through indicators that measure water deficit in rivers and reservoirs such as EDO’s Low Flow Index (LFI) (EC, 2017; Svoboda and Fuchs, 2016).

For INFORM Risk Index, we compute SPEI using temperature and precipitation from 21 the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (NCCS,
NEX-GDDP is comprised of daily precipitation and minimum and maximum temperature statistically downscaled CMIP5 AOGCM simulations for RCP 8.5 to 0.25° grid. SPEI is a multi-scalar drought index based on climatic data that measures drought severity according to its intensity and duration (Beguería et al., 2014; Vicente-Serrano et al., 2010). For the scope of our analysis, we consider 12-month SPEI which captures medium term water deficits and hydrological droughts likely to affect agriculture, river discharge and groundwater recharge (Farinosi et al., 2020; Liu and Chen, 2021; Naumann et al., 2018). We consider a drought occurrence when SPEI less than −1.5, which is defined as the threshold for severe drought (Smirnov et al., 2016; Törnros and Menzel, 2014; UK Centre for Ecology and Hydrology, 2020). Exposure is based on the population exposed to severe or greater drought. The exposure analysis is based on historical period 1976 to 2005 and the future period 2036 to 2065.

Results and Discussion

Multi-Hazard Climate Change Exposure

At global scale by the mid-century, 1.8 billion people (+249%) annually are projected to be exposed under SSP3 to at least one of the following hazards: river flood, coastal flood, or drought (Figure 4). The region with the highest multi-hazard exposure is found in Asia, with 958 million people (+206%), and the largest percent change in population exposed occurs in Africa (+430%) and Oceania (+285%). Amplified droughts tend to dominate the response in the changes primarily due to changes in evaporative demand from warmer surface temperatures. EM-DAT historical observations reveal that more than one billion people were affected by droughts in the period 1995-2015 which was more than a quarter of all people affected by all types of weather-related disasters worldwide. According to IPCC 2018 report, climate change is expected to increase the risk of droughts in many vulnerable regions of the world, particularly in those with concurrent population growth, vulnerable populations, and challenges with food security. The impacts include widespread agricultural failures, loss of livestock, water shortages and outbreaks of epidemic diseases malnutrition, and displacement. Detailed information on the exposed population to the climate-related amplified hazards can be found in Marzi et al. 2021.
Figure 4. Combined climate-related hazard projections: a) absolute exposed population in historical baseline (2015 population), b) percent change (%) between the historical baseline data and the projections (2036-2065) under SSP3 population projections (adapted from Marzi et al., 2021).

Extended INFORM Risk Index (mid-21st century)

The INFORM Risk Index modified Natural Hazard-Exposure and Risk indices according to the mid-21st century RCP8.5 and SSP3 scenarios are considered (Figure 5). In INFORM, exposed population is considered in terms of both total exposed population and exposed population relative to the total. We use risk classifications composed of a five threshold hierarchical scale to systematically identify risk in a consistent manner (Marin-Ferrer et al. 2017). Risk classes allow for the identification of the root causes of risk and therefore provide a greater ability to monitor, control and even manage risk.

In our analysis of historical climate trends, the largest exposure to natural hazards occurs primarily in Asia and the Americas where total populations are currently greatest. The largest overall risk, however, occurs in Africa, Western and Southern Asia and Central America where vulnerabilities tend to be highest. The largest mid-century changes in exposure to natural hazard occur primarily in much of Europe, northern and southern Africa, South America, and western and southwestern Asia. The largest changes in overall risk are projected in parts of west and southern Africa, South America, Central Asia and Eastern Europe.

Despite considerable changes in hazard and exposure levels, countries with currently high coping capacity levels with considerable amplified projected climate change hazards are able to counteract the adverse impacts of increased amplified natural hazard and exposure (e.g. Spain and the United States). In contrast, countries with low coping capacity (high vulnerability) levels with large amplified climate change hazards show increased risk levels similar to the increment in amplified hazards (e.g. Namibia, Peru and Romania). Among top 20 highly exposed countries to natural hazards, Myanmar, Vietnam, Japan, Philippines, Indonesia, Bangladesh, China, Ecuador and Pakistan have the highest exposure to floods, while Iran, Iraq, Turkey, Afghanistan, Chile, Mexico and Uzbekistan are projected to be highly prone to droughts. Afghanistan and Iraq are as the vulnerable countries due to underperformances in both natural hazard and exposure and disaster risk indices.
Exposure Dynamics

The projected changes in exposure due to climate change is generally greater than that associated to population changes (Marzi et al., 2021). Nevertheless, similar patterns can be detected between changes in exposure and SSP3 population. Africa, South America, Western and Central Asia are projected to experience the highest increase in both population growth and population exposed to natural hazards (Error! Reference source not found. and Figure 5). Exposed population is dependent on the assumed socioeconomic pathways. For instance, exposure to climate-related hazards under SSP5 are higher than SSP3 in Europe and North America and lower in Asia (Marzi et al., 2021). Population migration and displacement are a fundamental component of population exposure dynamics and vulnerability to the impacts of different crises and should be considered to fully understand how future crises might affect our societies. Not only do population movements shape the distribution of population (and therefore the exposure to different hazards), they also affect the extent to which people can access resources and opportunities (and therefore their coping capacity and resilience). Understanding the evolution of future hazards and risk patterns, in conjunction with future population movements, can help better plan for more inclusive and effective disaster risk reduction and emergency preparedness, response and recovery work.
Vulnerability and Coping Capacity Changes

The change in vulnerability and lack of coping capacity due to climate and population changes to maintain the current level of risk provides an indication of the change in resilience required to overcome the effects of climate and population change. While vulnerabilities associated with climate and population change, such as forced migration and food security are often linked, they are considered fixed at the current baseline values in this study. The reduction levels are normalized by baseline risk values to provide better insight regarding the risk and resilience interconnections. Countries with similar changes in natural hazard generally have widely varying levels of humanitarian impact. For instance, countries with low human development levels represent only 11% of the world population exposed to natural hazards between 1980 and 2000 but 53% of the total deaths in this period. High human development countries represent 15% of the exposed population but less than 2% of the deaths (UNDP, 2004). Since we alter only the exposure to natural hazards, the varying levels of disaster risk and resilience are not considered. We instead consider the current risk levels as a proxy to differentiate between high and low human development countries.

The results reveal that countries and regions will need to invest in reducing vulnerability and increasing coping capacity to compensate for the increase in climate-related hazards. At a regional scale, countries in Africa, South America, Western and Central Asia and Eastern Europe tend to show the high reduction classes to maintain the current risk (Figure 6). Most of these countries are identified with initial Low to High risk classes, but not very low nor very high. Countries with Very Low current risk (mainly industrialized countries) are more resilient to climate change hazards and are therefore able to maintain a lower risk level. Similarly, in countries with Very High current risk levels (mainly non-industrialized countries), an increase in climate change hazard does not result in a risk class change and subsequent Vulnerability (lack of coping capacity) reduction since the risk is already at its highest level. Therefore, a low vulnerability (lack of coping capacity) reduction in response to risk increase translates into different prevention, preparedness, and response measures depending on a country’s socioeconomic structure and adaptive capacity, i.e. industrialised vs non-industrialized countries.
In order to explore the distinct contribution of vulnerability and coping capacity, we estimate the change in each dimension due to the change in climate exposure with risk is fixed at current levels (Figure 7). As many SDG and Sendai Framework indicators are included (or will be included) in the INFORM Risk for assessing the vulnerability and lack of coping capacity dimension (Poljanšek et al., 2019b), we will be able to provide operational recommendations on where to allocate DRR and adaptation resources. The SDG and Sendai targets provide the frameworks necessary to monitor a country’s progress towards reducing vulnerability and increasing capacity to the required level according to our results.

In investigating the distinct contribution of vulnerability and coping capacity, three different patterns can be identified among the countries that require a high reduction in combined vulnerability and lack of coping capacity.

1) Countries like Turkmenistan with Medium vulnerability and High lack of coping capacity. As INFORM Risk coping capacity dimension shows, Turkmenistan’s low performance is mainly characterised by very low institutional capacity due to high corruption perception and weak government effectiveness. Based on Andrijevic et al. (2020) projections of the WGI government effectiveness and control of corruption components for 2050, Turkmenistan’s performance under SSP3 scenario would remain relatively low. According to the United Nations Economic Commission for Europe (UNECE) review (UNECE, 2012), Turkmenistan is actively implementing development projects that consider coping capacity improvements into development plans, mostly driven by UNDP. In June 2018, Turkmenistan hosted the conference “Partnership for Development Financing at the Heart of the Great Silk Road” to discuss the issue of financing in relation to progress towards the SDG goals. Turkmenistan is working towards strengthening financial stability of the system and creation of...
favourable investment environment for development of non-hydrocarbon sectors of the economy (Service, 2019).

2) Countries like Jordan, with High vulnerability and Medium lack of coping capacity, Jordan’s high vulnerability is largely driven by the high number of uprooted people according to INFORM Risk. Regional instability and the Syrian refugee crisis have resulted in multiple socioeconomic impacts in Jordan (UNCT, 2017). The poverty rate of Syrian refugees is very high, and there is evidence that poverty among refugees increased by several percentage points between 2013 and 2015 (EC, 2021).

3) Countries like Senegal with High vulnerability and High lack of coping capacity. Senegal’s underperformance with High vulnerability and High lack of coping capacity is driven by underdevelopment and deprivation and low accessibility to health systems. Senegal is classified by the World Bank as a low-income country with the poverty rate at 35.4% in 2016, which is lower than the average for low-income countries worldwide. Poverty is linked to both macroeconomic volatility (commodity price spikes, the global financial crisis and epidemics) and idiosyncratic shocks (illnesses, deaths of family members, loss of assets and/or employment). A considerable share of the population is vulnerable to food insecurity and malnutrition, with over 15% of rural households and over 8% of urban. In addition, environmental and socioeconomic changes have intensified migration and displacement in Senegal. The main governance indicators reveal that the government effectiveness has also progressively declined (World Bank, 2018).

Despite the difference in concepts, synergy among vulnerability and coping capacity is essential as sustainable development cannot be reached unless risk is reduced. INFORM’s approach is recognized as supporting both the monitoring and reporting frameworks of SFDRR and sustainable development agenda (Poljanšek et al., 2019b).
Figure 7. Vulnerability and Lack of Coping Capacity Changes in mid 21st century required to maintain the current levels of risk.

Absolute Reduction in Vulnerability to Keep the Current Risk

Absolute Reduction in Lack of Coping Capacity to Keep the Current Risk
Use Cases

Policy implications and uses of the INFORM Climate Change tool have been identified by its partners, namely the United Kingdom’s Foreign, Commonwealth & Development Office (FCDO), the United Nations Development Cooperation Office (UNDCO), the International Organization for Migration (IOM), and the International Federation of Red Cross and Red Crescent Societies (IFRC).

INFORM data feed into the FCDO’s global risk monitoring and early warning systems which guides FCDO’s humanitarian work. The FCDO early warning system provides a centralized, independently assesses humanitarian need, flags overlooked risks, and informs senior decisionmakers about new crises or ongoing emergencies that may require intervention on a monthly and on-demand basis. In the context of a changing climate, many factors that underpin the INFORM Risk Index values will also change (both natural hazards and likely exposed populations). By capturing the projected effects of climate change, the extended INFORM Risk Index enables the FCDO and its partners to assess future likely humanitarian need and invest in appropriate preparedness measures in risk-prone countries.

The UNDCO recognises the benefit of the INFORM Risk tool in its work such as supporting the UN’s activities for sustainable development, which inform policy, program and operations on the ground. The UNDCO highlights several thematic areas in which climate informed risk data could strengthen the annual United Nations Common Country Analysis (UN-CCA) and Sustainable Development Cooperation Framework (SDCF). CCA is a strategic planning and implementation instrument which prioritizes development activities at country level and is ultimately translated into an agreement with the government through the SDCF. All CCAs include a section summarizing the country’s climate and environmental challenges. This typically covers SDG progress, obligations under international environmental law and climate agreements, implementation challenges, capacity gaps and opportunities. With climate informed risk data, this analysis could additionally include a forward-looking analysis with predictions or scenarios on future climatic conditions and their environmental, development, humanitarian or peace implications. Climate informed risk data could also guide CCA to further address discrimination by identifying inequalities in terms of the climate impact on marginalized groups such as people on the move and including risks to youth and future generations not accounted for in typical short-term policymaking. Furthermore, the economic transformation analysis in CCA can benefit from INFORM Risk climate change data which support economic policymaking that is more resilient to the adverse impacts of climate change. Since climate does not exist in a vacuum but interacts with multidimensional risks, exacerbating socio-economic vulnerabilities climate-informed risk data can breakdown the siloes around related disciplines, such as CCA and DRR, for a more comprehensive analysis of present and emerging risks. The UNDCO also identifies disaggregating climate-informed risk data at sub-national level and by gender as a possible development of the INFORM instrument.

The International Organization for Migration’s (IOM’s) approach in managing and preventing migration and forced displacement is implemented through DRR, CCA and environmental sustainability measures. IOM uses INFORM Risk data as a key indicator for its global preparedness efforts, including to identify gaps in available capacities for response and priorities for capacity building. Moreover, risk profiles based on available assessments of different hazards support the development or update country-specific contingency plans and
preparedness measures in IOM Country Offices. INFORM Climate Change offers an additional layer of information, which can contribute to develop a stronger analytical capacity that can link the IOM’s current data collection capacities to operational preparedness and offer Member States the possibility to ensure the needs of individual mobile populations are anticipated and met at all stages of their journey.

Understanding the potential impacts of climate and population change is important for the IFRC. Information about future risks is essential for the prevention and alleviation of human suffering in order to address underlying risk drivers, take anticipatory action and respond to crises in a timely manner. The IFRC uses INFORM’s climate change impacts data to inform DRR and CCA interventions, ensuring these efforts are based on sound science and facilitating the engagement of communities in the process. In the near term, this information is also useful for IFRC’s annual programming, knowing what kind of assistance is likely to be needed, when and where, during the course of a year and in support of forecast-based action. Early results from the INFORM Climate Change tool have been included in the IFRC’s World Disaster Report (WDR) (IFRC, 2020) “Come Heat or High Water”.
Conclusion

Extreme weather and climate related events cause fatalities, injuries and displacement. Indicator-based assessment of risks and needs are used for humanitarian and development aid operations. These assessments are often based on historical observations or present-day hazard conditions. We have presented ways to extend the INFORM Risk Index to include future projections of climate change-altered hazards (floods and droughts) and exposed population. To do so, we have used projections based on high-emissions (RCP8.5) and high socioeconomic global change (SSP3) scenarios for the mid-21st century. The projected risk is used to estimate changes in coping capacity and vulnerability required to compensate for the change in risk. This assessment exercise has been conducted in collaboration with major international organizations to stimulate reflection on how the extended index can be used to inform decision-making and operational choices.

The results of the hazard-exposure projections suggest that 1.8 billion people annually will be exposed to climate-related amplified hazards under SSP3 scenario by 2050 at the global scale. According to this analysis, the largest population exposed is found in Asia and the largest percent changes in population exposed occurs in Africa. The results also make explicit the trade-offs between evolving hazards and the investments in capacity and resilience building needed to compensate for the amplified hazards. The largest changes in overall risk are projected in parts of west and southern Africa, South America, Central Asia and Eastern Europe. For countries initially classified as very low risk (for a major part developed nations), the increase in exposure to climate hazards may be countered by already high levels of coping capacity. In some cases, the dramatic increase in the exposure to natural hazards can only be compensated by sizeable reduction of vulnerability. In contrast, for countries already characterised by very high levels of risk, the increase in exposure to natural hazards requires substantial efforts to enhance coping capacities.

By adding climate and demographic projections, the extended INFORM Risk Index offers snapshots of current and future conditions resulting from the "committed" climate change under different emission scenarios. This knowledge can not only serve planning for humanitarian aid management, but also in drafting effective DRR and CCA strategies and plans (Hallegatte et al., 2020). The emphasis on required increase in coping capacity can inform decision making processes on adaptation options at local and national level (OECD, 2020). International partners (e.g. FCDO, IOM and IFRC) have recognized the benefits of such a tool in terms of horizon scanning and global humanitarian risk monitoring (IFRC, 2020). International partners (e.g. FCDO, IOM and IFRC) have recognized the benefits of such tool in terms of horizon scanning and global humanitarian risk monitoring (IFRC, 2020). Capturing the projections of climate, exposure and vulnerability in INFORM is key to invest in appropriate preparedness measures, according to FCDO. For UNDCO, climate change enhanced risk indices are able to explore long-term drivers of social inequalities. IOM's global preparedness effort benefits from INFORM's integration of climate and demographic projections as it provides an additional layer of information on the needs of individual mobile populations.

Future research may focus on extending the INFORM Risk Index using available projections of various drivers of vulnerability and coping capacity such as social characteristics, migration, governance, urbanization, infrastructure, and health status under the SSPs.
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