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Commentary

Reflecting Disaster Risk in Development Indicators

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Abstract: Disasters triggered by hazards, such as floods, earthquakes, droughts, and cyclones, pose significant impediments to sustainable development efforts in the most vulnerable and exposed countries. Mainstreaming disaster risk is hence seen as an important global agenda as reflected in the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030. Yet, conventional development indicators remain largely negligent of the potential setbacks that may be posed by disaster risk. This article discusses the need to reflect disaster risk in development indicators and proposes a concept disaster risk-adjusted human development index (RHDI) as an example. Globally available national-level datasets of disaster risk to public and private assets (including health, educational facilities, and private housing) is combined with an estimate of expenditure on health, education, and capital formation to construct an RHDI. The RHDI is then analyzed across various regions and HDI groups, and contrasted with other HDI variants including inequality-adjusted HDI (IHDI) and the gender-specific female HDI (FHDI) to identify groups of countries where transformational disaster risk reduction (DRR) approaches may be necessary.

Keywords: human development; disaster risk reduction; transformational DRR

1. Introduction

Disasters triggered by hazards, such as floods, earthquakes, droughts, and cyclones, pose significant impediments to sustainable development efforts in the most vulnerable and exposed countries. The annual average cost of disasters globally (the cost of direct damage to buildings and infrastructure due to riverine floods, earthquakes, tsunamis, and cyclones [1]) is estimated at approximately US\$314 billion [1], with the world's most costly disasters in relative terms taking place in small and vulnerable low-income economies. Hurricane Maria, which devastated parts of the Caribbean region in September 2017, for example, cost Dominica US\$931 million in damages and US\$382 million in combined losses, together accounting for more than 200% of the country's gross domestic product (GDP) [2]. In Puerto Rico, the same hurricane caused US\$20 billion in damages and US\$10 billion in losses combined, which is equivalent to approximately 30% of the territory's GDP [3]. In these countries and territories, the development process and outcomes have direct bearing on disaster risk and vice versa. When household savings are used to rebuild destroyed houses, or when government budgets are diverted for public infrastructure rehabilitation, these constitute important opportunity costs for productive resources that could have been used to improve a country's human development. As countries, regions, and communities strive to achieve the Sustainable Development Goals (SDGs), taking proper account of disaster risk is becoming increasingly important, particularly for the most vulnerable countries whose finance options are limited.

In the field of disaster risk management, practitioners and academicians alike have long urged that consideration for disaster risk be integrated in development analysis and planning. Understanding risk

is the first priority of the Sendai Framework for Disaster Risk Reduction 2015–2030, where global efforts are ongoing to collect, assess, and monitor disaster risk information globally [4]. With an anticipated rise of disaster risk, and especially in the context climate change, a number of multi-lateral institutions have also begun promoting various climate and disaster screening and monitoring procedures with as many as twelve UN agencies having included disaster risk reduction (DRR) into their monitoring frameworks [5,6]. Recent years have also seen initiatives to make disaster risks explicit to private investors [7].

Better tracking of disaster risk and development allows us to gauge whether a country's development is disaster-risk sensitive; that is, a country achieves a development path that either does not generate additional disaster risk or reduces risk. A combined measure of disaster risk and development may be used to monitor this trend. Commonly used development indicators, such as human development indicators, and multi-dimensional poverty and inequality measures adjusted for catastrophic disaster risk, may be used for this purpose. However, this potential is yet to be explored. Using the human development index (HDI) as an example, we demonstrate how such an indicator (hereafter termed risk-adjusted human development index (RHDI)) may be constructed with another readily available global dataset, allowing one to jointly measure the evolution of disaster risk and development. In this commentary, we ask how incorporating disaster risk measured relative to a country's capacity to cope affects its human development measured across the three dimensions of health, education, and standard of living. As spatially explicit disaster risk information is increasingly becoming globally available [1,8], there is an opportunity to design combined measures of disaster and development.

2. Disaster Risk and Human Development

The empirical evidence of disaster and development indicate that three dimensions of human development are incorporated in the HDI (i.e., education, health, and income as proxy for standard of living), and are in turn affected by disaster risk and damages.

First, in the educational sector, school facilities, when safely constructed, for example, provide much-needed physical protection during emergencies [9], and when poorly constructed, may lead to major casualties as seen in recent years during the Kashmir (Pakistan), Wenchuan (China), and Haiti earthquakes of 2005, 2008, and 2010, respectively [10]. Disaster damages are known to affect educational attainment and other aspects of educational system operation. The occurrence of disasters may lead to temporary effects, such as school closures and student absenteeism [11], or long-term effects, such as lower educational attainment [12] and a higher school dropout rate, both in general, or affecting a specific gender more pronouncedly [13].

General level of education is also an important determinant for one's survival and longer-term wellbeing following disaster events [14,15]. Education affects wellbeing outcomes through channels, such as its impact on access to information and resources, as well as social capital and earning potential [16]. In addition, education is a primary means through which one obtains essential cognitive skills and scientific knowledge to inform one's interpretation of surrounding environments, including risk perceptions and disaster preparedness knowledge [17–19]. Over recent decades, various educational curriculums on natural hazards and preparedness have been widely adopted around the world, with more than 60% of countries reporting having such subjects in their national curriculum [20,21].

Second, a better state of public health is also a factor that can reduce vulnerability to disaster risk. Access to health facilities and the availability of health experts are important factors affecting immediate disaster survival and longer-term recovery outcomes [22]. Health systems may be disrupted by disasters through, for example, the physical destruction of facilities, or the disruption of critical infrastructure services and medical supply chains. Lacking access to adequate and secure public health provisions, such as clean water and sanitation, immediate impacts of disasters pose significant risks to the health of the population [23]. Displacement of population and disruption of services, such as

potable water and waste treatment facilities, could lead to outbreaks of infectious diseases. Commonly observed health impacts of disasters include enteric diseases, respiratory illnesses, mental health issues, and vector borne diseases such as malaria [24–26]. Higher levels of vaccination, the safe disposal of dead bodies, better nutrition, and good hygiene practices can reduce the risk of such follow-on impacts.

One of the most notable recent examples illustrating the importance of critical infrastructure access to survivors' health during emergency is Hurricane Maria, which hit Puerto Rico in September 2017. Kishore et al. [27], for example, estimated that on average households suffered critical infrastructure disruption of "84 days without electricity, 68 days without water, and 41 days without cellular telephone coverage after the hurricane and until 31 December 2017 (pp. 165–166)." A total of 14.4%, 9.5%, and 8.6% of the population also reported the lack of access to medication, respiratory equipment in need of electricity, and closer medical facilities, respectively. After series of investigations suggesting the bleak possibility of a large increase in death counts triggered by factors, such as the lack of access to these medical services and generally due to the deteriorating living conditions in the aftermath of Hurricane Maria [28,29], official death counts were revised from the original figure of 64 to 2975 almost one year following the hurricane [30].

Third, the destruction of physical assets and livelihood means, as well as consumption made unwillingly during the preparedness response, recovery, and reconstruction phases, all contribute to loss in income (and hence in standard of living) for the affected population. Income has been found to affect risk through a variety of channels, such as the location and building materials of residences, adoption of preparedness activities, and adherence to early warnings [31–34]. In turn, disasters affect income both directly, through the destruction of assets, and indirectly, through differential coping behaviors and access to informal and formal safety-net mechanisms [35–37]. Factors, such as the availability of savings, access to credit and external assistance, initial levels of asset endowment, and other prevailing socioeconomic conditions, also affect the extent of disaster impacts. In general, studies suggest that poorer households and firms are not only more exposed to natural hazard risks, but their economic wellbeing is disproportionately affected in both the short- and long-term [33,34,37]. At the same time, the rapid buildup of population and wealth within hazard-prone areas has also contributed to the recent growth in economic losses due to disasters globally, especially for hazards such as coastal and urban floods [38].

Finally, it is important to note that relationships between disasters and the three dimensions of health, education, and income as a proxy for standard of living are highly interwoven in that loss of income due to disasters, for example, may contribute to students' absenteeism and drop-out, while higher health burden, such as trauma and mental health issues brought about by disasters, may negatively affect ones' earning potential. Reflecting all these complex and potentially non-linear dynamics of disaster risk and development linkages (such as a shock to critical infrastructure may have disproportionately large cascading socioeconomic impact) [39] is certainly beyond the scope of our present analysis, in this study, we will instead use the measurement of risk to capital asset as a proxy and propose a method to adjust a development indicator using the human development index as an example.

3. Materials and Methods

3.1. Calculating the Risk-Adjusted Human Development Index

In this study, we adjust the HDI based on the notion of direct disaster risk, that is, risk measured in terms of direct economic losses, defined as the monetary value of the total or partial destruction of physical assets in the affected area [40].

First published in 1990, the HDI is a multidimensional indicator of human development capturing progress on health, education, and standard of living, proposed as an alternative to gross national product (GNP) as the measure of a country's well-being. The HDI and its variants have been adopted by various national and regional governments to facilitate policy decisions and allocation of resources [41].

Sehnbruch et al. [42] identify the strengths of HDI as (i) a solid theoretical foundation, (ii) availability of national and internationally comparable data, and (iii) political will and institutional structure of proponent organizations. At the same time, the HDI has been criticized on grounds such as: missing dimensions, data quality, aggregation, and other technical limitations [43–46]. To date, HDI has been adjusted for a number of other missing dimensions, such as inequality and gender [47,48], and these have been reported annually since the 2010 HDI report.

In its latest form, the three dimensions $j = \{\text{education, health, income}\}$ of HDI are calculated based on pre-determined minimum and maximum values, which serve as common goalposts (Since 2010, the HDI has taken the form of a geometric mean across (i) life expectancy at birth, (ii) mean and expected years of schooling, and (iii) gross national income (GNI) per capita. For life expectancy, the minimum and maximum value take 20 to 85 years respectively. For expected and mean years of schooling, values range between zero to 18 and 15 years respectively. Finally, for gross national income, values in 2011 PPP\$ (purchasing power parity) between 100 and 75,000 are used [49]). Each dimension's index I is hence calculated as:

$$I_j = \frac{(\text{actual value}_j - \text{minimum value}_j)}{(\text{maximum value}_j - \text{minimum value}_j)} \quad (1)$$

where HDI is a geometric mean of the above indices expressed as:

$$\text{HDI} = (I_{\text{education}} \times I_{\text{health}} \times I_{\text{income}})^{\frac{1}{3}} \quad (2)$$

We use direct risk relative to public expenditure on health, education, and gross fixed capital formation to penalize the original HDI in a similar fashion to the adjustment made for the inequality adjusted HDI (IHDI) [49]. Direct risk relative to these public and private expenses reflects the relative sizes of lost investment due to physical destruction caused by disasters, and may be interpreted as an opportunity cost, that is, replacement costs of these assets could have been used for the betterment of human development in these three aspects (The achievement of development outcomes today may to some extent reflect the impact of past disasters. However, in this article, we are interested in incorporating the potential impact of catastrophic disasters that could happen, as measured by probabilistic risk information).

We adjust each country's HDI to incorporate proportional risk using adjustment coefficients R_j in the following manner:

$$\text{RHDI} = (1 - R_{\text{health}})(1 - R_{\text{education}})(1 - R_{\text{income}}) \times \text{HDI} \quad (3)$$

R_{health} : Annual average losses (AAL) to health facilities relative to public expenditure on health.

$R_{\text{education}}$: AAL of educational facilities relative to public expenditure on education.

R_{income} : AAL of other capital stock relative to gross capital formation.

(While risk estimates per building categories of health and education are only available for earthquake and cyclone wind hazards, all other hazards are included as other capital stock categories in the present study. AAL of other capital stock include agricultural asset losses due to drought).

While the original HDI measures the human development outcome on a per capita basis, the risk-adjustment coefficient is calculated at the aggregate level by comparing the country's risk to its capacity to cope collectively measured by various public expenditures. As such, this formulation recognizes the importance of public services provision in enabling development outcomes on a per capita basis, while acknowledging that such public services provision may be affected by disaster related shocks and additional expenses borne to recover from disasters. Also, while there is a possibility that destruction of assets opens up opportunities for the build back to be better [50–52], there is currently limited empirical studies on such possibilities [53], hence we did not include this into our RHDI construction.

3.2. Data

For this study, public expenditures, socioeconomic development, and disaster risk data were collected through a number of global datasets. For rapid onset hazards, we used global estimates on multi-hazard risk to public and private assets in 196 countries and territories available from the Global Assessment Report (GAR) [1]. The GAR dataset contains probabilistic risk estimates for earthquakes, cyclone winds, storm surges, tsunamis, floods, and volcanic eruptions with detailed breakdowns of risks to education, health, and other facilities provided for earthquakes and cyclone winds. We supplement this dataset with additional estimates of drought risk taken from the United Nations Environment Programme [54] (Global Risk Data Platform, 2013 [54] estimated drought risk in terms of annual average GDP exposure for 2007 expressed in 2000 US\$. For the present study, these drought risk estimates were adjusted to the 2014 GDP exposure expressed as 2014 US\$ assuming a real growth rate of GDP from 2007–2014 and GDP deflators from 2000–2014 [55]). Data regarding public expenditure on education, health, and gross capital formation, together with various HDI variants, were taken from the United Nations Development Programme (UNDP) database [40]. Needed adjustments to prices were made using the GDP deflators available from the World Development Indicators [55], and total net official development assistance (ODA) flows were taken from the Organisation for Economic Co-operation and Development (OECD) development finance data [56]. Due to missing data across these three dimensions and different hazards, final estimates were available for 131 countries (All data are expressed in 2014 values. In the case where data for 2014 were unavailable, we have substituted figures based on the year of last entry).

4. Results

The 131 countries analyzed face varying degrees of disaster risk due to floods, cyclones (wind and storm surges), earthquakes, tsunamis, and droughts. Combined global annual average losses are estimated at US\$243 billion, with rapid onset events contributing to the vast majority of the estimated asset losses (>99%). According to the original HDI categories, low HDI countries on average face a disaster risk worth US\$105 million, while medium HDI countries are on average looking at US\$1.2 billion, high HDI countries US\$902 million, and high and very high HDI countries are facing US\$4.4 billion. In terms of regional variability, small island states on average face US\$120 million, Europe US\$1 billion million, North and South Americas US\$4.2 billion, Asia US\$5.1 billion, Middle East and Northern Africa US\$820 million, and Sub-Saharan Africa US\$100 million.

The economic value of disaster damage is only a small fraction of the size of the national economy in most countries (Figure 1). Small islands, such as Vanuatu and St. Vincent and the Grenadines, face the highest relative risk for cyclone wind and storm surges, while Honduras faces the highest relative earthquake risk in relative terms. Drought risk is generally lower than risk for other hazards, with Sub-Saharan countries, such as Malawi, Ghana, and Ethiopia, facing the highest relative risk. Due to the high economic value of exposed assets, countries such as Japan and the United States face risk of over US\$61.5 billion and US\$52.5 billion annually in all hazards combined, but these only account for approximately 1.3% and 0.3% of the country's annual GDP. In our sample of 131 countries, 31 countries had a total AAL of more than 1% of GDP, while only 19 countries had total AAL of more than 2% of GDP.

The smaller relative value of risk nevertheless implies a significant cost of forgone public and private investment for the world's most vulnerable countries. Assuming indicative costs to address poverty reduction, health, and educational attainment based on Manuel and Hoy [57], for example, annual average loss of US\$105.3 million for low HDI countries is equivalent to extending social transfer, educational, and health services to more than half a million people annually, while US\$904.2 million for medium HDI countries is equivalent to serving 3.7 million people annually in these countries. It is also important to note that while direct risk may be small, follow-on consequences of disasters may be sizable if countries lack resilience in these sectors to maintain or swiftly recover their public services provision, as seen in recent disasters such as Hurricane Maria of 2017 in Puerto Rico [27–29].

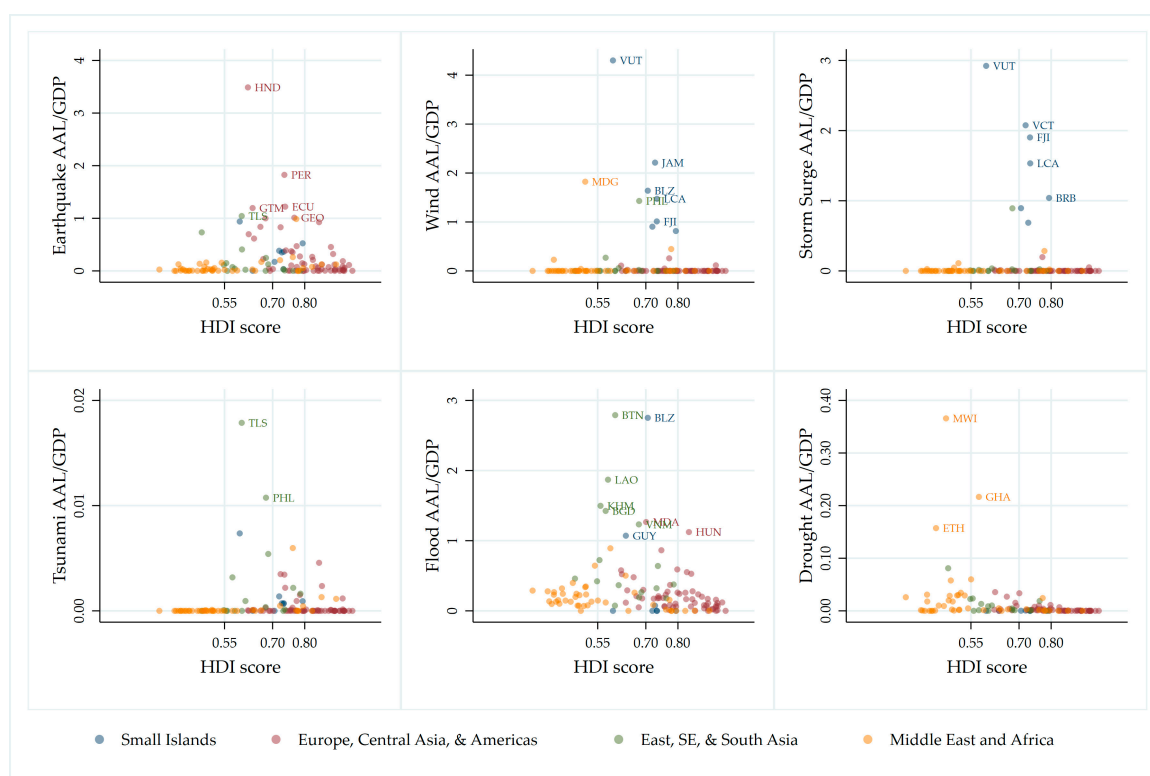


Figure 1. Percentage of annual average losses (AAL) relative to GDP for earthquakes, cyclone winds, storm surges, tsunamis, floods, and droughts. The boxplots in the panels provide the same statistics with the y-axes showing the percentage of AAL/GDP and the x-axes showing the original HDI scores (<0.55 = Low HDI, >0.55 & <0.7 = Medium HDI, >0.7 & <0.8 = High HDI and >0.8 = Very High HDI). HND (Honduras), VUT (Vanuatu), VCT (Saint Vincent and the Grenadines), JPN (Japan), BTN (Bhutan), BLZ (Belize), LAO (Lao People’s Democratic Republic), MWI (Malawi), GHA (Ghana), ETH (Ethiopia).

Reflecting these opportunity costs of disasters in the three dimensions of education, health, and income, a number of countries—particularly small and highly exposed countries—have significantly lower RHDI estimates. Figure 2 shows the estimated risk adjustment coefficients across different regions. Within region variabilities are high for small island countries where there are a number of countries with high-risk adjustment coefficients (e.g., Vanuatu with $R_{education}$ of 0.43, and Belize with R_{other} of 0.26). Madagascar is also a notable outlier in the Middle East and African region with $R_{education}$ of 0.34 (Not shown in Figure 2). Risk adjustment coefficients for health are small for most countries due to limited exposure of health assets globally (Another probable cause is underestimation of risk in the health sector. While the past records of disasters available from the Desinventar database [58] show the ratio between the number of damaged health facilities to educational facilities is on average 18.5%, the ratio of AAL of health to education facilities used in this study is on average 0.5%. While public expenditures of health and education per GDP on average are 4.2% and 4.7% respectively, the low health AAL estimates largely explained the low R_{health} estimated in this analysis), whereas risks to educational and other facilities are higher, particularly for low and medium HDI countries in small islands, Asia and Europe, Central Asia, and the North and South Americas. Globally, risk adjustments to the health dimension range below 0.003, adjustments to the educational dimension range below 0.1, and those to the standard of living dimension range below 0.90. The supplementary material shows the estimated HDI and RHDI for all countries.

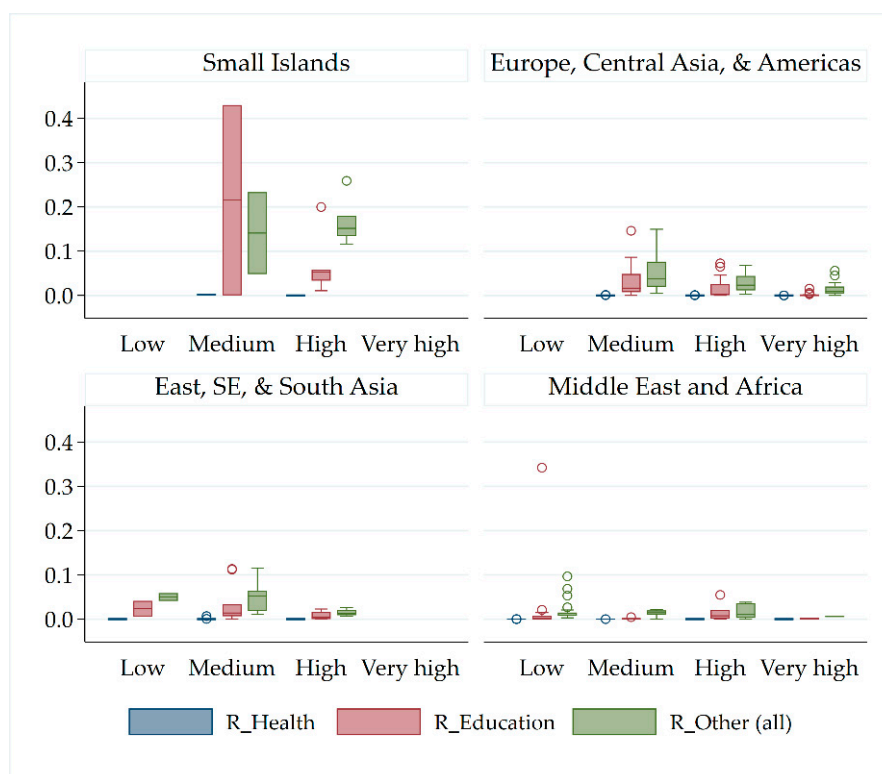


Figure 2. Risk adjustment coefficients across the three dimensions of health, education, and other in various regions. The y-axes show the magnitude of risk adjustment coefficients and the x-axes show the original categories of low, medium, high, and very high HDI countries.

Figure 3 shows the comparisons of the original HDI, RHDI, female HDI (FHD), and IHDI for the top six countries overall in terms of RHDI adjustments made. Many of these countries face a combined challenge of disaster risk and inequity: RHDI and IHDI were 27% and 32% lower than the original HDI for Honduras, 38% and 27% lower for Madagascar, and 30% and 22% lower for Belize. Given that inequity is often an important underlying driver of disaster risk [59,60], these are the countries in which challenges for DRR implementation will be high and where different types of policy interventions (or what the DRR community increasingly refers to as the “transformational approach”) that not only addresses physical exposure and vulnerability, but also fundamental social vulnerabilities, including marginalization of the poor, uneven power dynamics, and other institutional and structural factors [61–64].

As shown in Figure 4, countries that have high risk adjustments in general, receive relatively smaller external assistance in the form of total per capita aid flow, thus illustrating the need to integrate future disaster risk considerations in such global resource allocation. Honduras, for example, receives US\$21 per capita in aid, while Madagascar, The Philippines, and Belize receive US\$7.5, US\$5.9, and US\$19 per capita, respectively. Fiji and Vanuatu are notable exceptions, in that they respectively receive US\$69 and US\$324 per person in total aid, which is much higher than the mean of 93 other countries (US\$34 per person) for which data on total aid flow in 2014 was available.

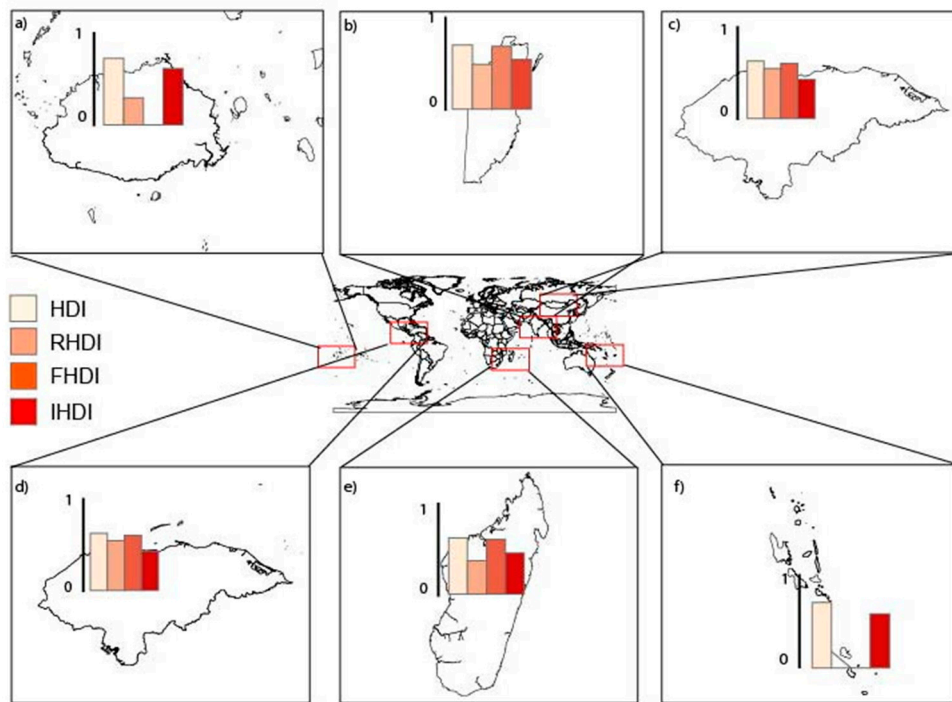


Figure 3. HDI, RHDJ, FHDI, and IHDI for selected countries: (a) Fiji, (b) Belize, (c) Philippines, (d) Honduras, (e) Madagascar, and (f) Vanuatu. The countries listed above rank as the top six in terms of the magnitude of RHDJ adjustments made. Bars range from a maximum of 0.734 for HDI in Fiji and a minimum of 0.26 RHDJ in Vanuatu. FHDI values are missing for Fiji and Vanuatu.

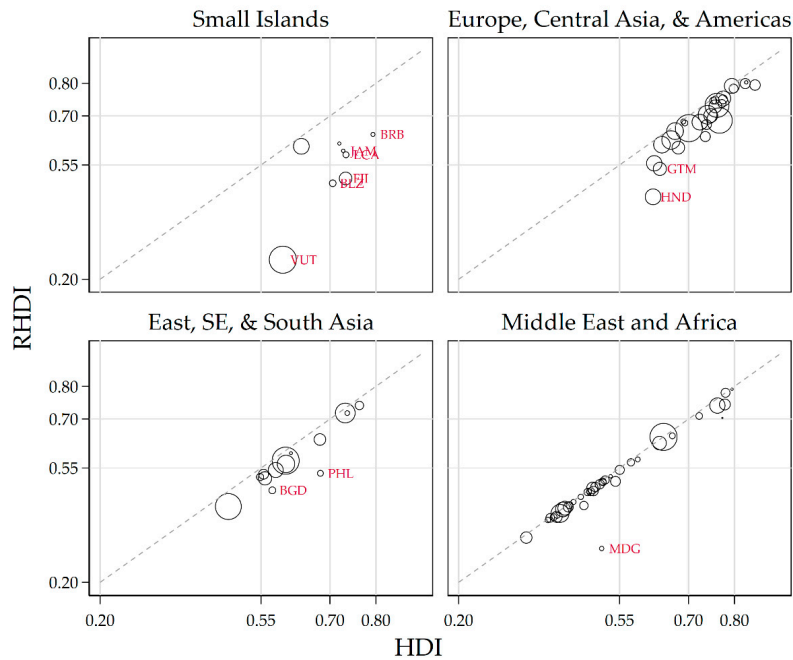


Figure 4. Relationships between RHDJ and original HDI. Circles are weighted by total per capita aid flow in countries. Countries with more than 15% change in HDI scores are labelled accordingly: LCA (Saint Lucia), FJI (Fiji), BLZ (Belize), VUT (Vanuatu), HND (Honduras), PHL (Philippines), MDG (Madagascar).

5. Discussions and Conclusions

5.1. Insights Gained through Disaster Risk Adjustment of HDI

Unless addressed adequately, disaster risk is expected to rise due to socioeconomic growth and climate change in coming decades [65,66]. While various fields including disaster risk, climate change adaptation, and development aim for better integration of disaster risk in development planning, commonly used development indicators do not reflect the potential risk posed by disasters. Many disaster risk indicators exist globally, but these have generally been analyzed separately from commonly used development indicators. This study proposed a novel concept of RHDI and applied it to 131 countries globally, offering the first overarching view on this topic.

RHDI estimates demonstrated considerable variabilities in risk across different HDI groups and geographic regions, with smaller islands and highly exposed countries in Asia Pacific and Central America showing the highest risk relative to public expenditure and gross investment. Medium HDI countries were found to show the most variability in relative disaster risk to health education and other facilities, whereas low HDI countries were found to face on average lower relative risk than other HDI groups (except for a few outliers such as Madagascar). The existing low risk penalization for low HDI countries is due to their lower exposure to rapid onset events and limited accumulation of assets in general. Compared to other HDI variants, such as IHDI and FHDI, the study has also identified a group of countries where inequality may add further challenges to the implementation of disaster risk management policies.

5.2. Limitations and Prospects for Further Research

While this study offered a cursory look on this topic, further research is certainly needed to improve on the concept of disaster risk integration in development indicators in general and in HDI in particular.

First, recent advances in the development of spatially explicit indicators of development and disaster risk (for example: http://www.worldpop.org.uk/about_our_work/acknowledgements/ [8] (Pesaresi, 2015)) offers much potential for measuring and tracking progress at much finer resolutions. As illustrated in this study, most disasters are small relative to the sizes of national economies and geographical territories, and national level analyses alone often overlook important spatial heterogeneity in vulnerability and resilience that exist within a country. Subnational indicators of human development are increasingly becoming available [67–69]. These provide a basis from which to construct spatially explicit RHDI. Disaggregated indicators may be used to track better progress and allow for better geographical targeting of scarce resources. Identifying commonalities of disaster and development challenges across various subnational regions also help facilitate “inter-local-learning” among communities and actors [70,71].

Second, the inclusion of indirect risk is also an important area for analysis. Indirect risk is typically defined as “a decline in economic value added, as a consequence of direct economic loss and/or human and environmental impacts” [40], and is known to be sizable relative to direct risk [72,73]. The extent of indirect risk at the household and community levels is determined by factors such as the availability of formal and informal coping mechanisms [35,74] and factors such as critical infrastructure vulnerability and inter-industry linkages at economic sectoral levels [75]. The extent of indirect risk hence depends on the overall economic, institutional, and political landscape of countries and subnational regions. It is important to note that to account for indirect risk, linear risk adjustment equations proposed in this study will have to be majorly revised (the linearity assumption adopted in this study may be especially problematic for the health sector risk which is currently estimated to be very low on average). Without compromising the key strength of HDI as a simple composite indicator, one could also aim to find useful means of reflecting indirect disaster risk into development.

Third, it is important to analyze past trends, as well as potential future trajectories of RHDI. Although many low HDI countries presently face low relative risk due to limited asset buildup and

urbanization, this will likely change due to expected population growth, urbanization, and other socioeconomic development in the future. The total urban population in the Sub-Saharan region for example, is projected to increase at approximately 3.45% annually (as opposed to the world average of 1.48%) between 2015 and 2050 [76]. While many of these countries currently lack proper implementation of regulations, such as building codes and land-use restrictions, as well as investments in urban infrastructure, such as drainage and slope stabilization [20], taking disaster risk into account when planning for urban space will be crucial in preventing future risk creation.

Fourth, analysis of high impact low probability events—rather than annual average losses used in this study—also deserves attention, due at least to two reasons. First, given the limited abilities of communities and society to withstand shocks through preparedness and coping measures, catastrophic disasters may cause non-linear and sometimes irreversible consequences than smaller events. Second, part of the population in some countries may be more risk averse than others, therefore experiencing higher disutility from extreme risks. The present research did not take these aspects into account and will certainly be an important avenue to explore in further research.

Fifth, uncertainty analysis of underlying disaster risk data deserves attention. Multi-hazard risk data used for this analysis combines risk estimates from multiple hazard models, calibrated for different periods of historical hazard occurrences globally [77]. The probabilistic cyclone risk model, for example, is based on the IBTrACS database where the global record of past cyclone tracks are available from 1945 [78] and the global flood model uses discharge dataset of more than 7500 stations from various datasets (for example, the data archive from the Global Runoff Data Centre (GRDC) available up to 200 years) [79]. Given the large variation in availability of data across hazards and regions (with notable likely data limitations in small islands), the sensitivity of the RDHI estimates needs further exploration. In addition to uncertainty in individual hazard probability estimation, potential correlations across multi-hazard distributions deserves attention.

Finally, continued data collection will definitely be helpful as a considerable number of countries were excluded from the present analysis because of missing data. Apart from the 131 countries analyzed in the present study, original HDI values are available for 56 additional countries and territories (13 small islands; five countries in East, Southeast, and South Asia; 10 in Europe and Central Asia; three in North and South America; 14 in the Middle East and North Africa (MENA) region; and 11 in Sub-Saharan Africa). These countries and territories were excluded mostly because public expenditure (mostly on education) and capital investment data were missing. The further inclusion of these data will enable more complete global analyses. Proactive disaster risk reduction is known to be more cost-effective than an ex-post disaster response and also brings a number of known co-benefits [80]. As considerable public and private investments are needed to achieve the Sustainable Development Goals over the coming decades, safeguarding development from potential harm due to disasters deserves attention. Conventional development indicators until today have often neglected the potential risk posed by disasters, but the integration of such a dimension can be performed with readily available global datasets as demonstrated in this study. The proposed approach could be used in a number of ways to inform policy on disasters and development. Symbolically, it offers a common language and conceptual space in which development and disaster risk communities can jointly track the progress towards risk sensitive development. It can be used to gauge whether public and private investments made are performed in a risk-sensitive manner, where a build-up of assets do not lead to an increased risk to development in the future. When analyzed at the global level, we could further assess whether global financing for development and disaster risk reduction is allocated in line with relative needs of countries; when analyzed at sub-national levels, it can highlight sub-regions and communities that should be prioritized for ex-ante disaster preparedness policy interventions. The risk adjustment concept may also be expanded on by using other development indicators, such as poverty and distributional measures, for greater conversion between the research and policy of disasters and development.

Supplementary Materials: The supplementary material is available online at <http://www.mdpi.com/2071-1050/11/4/996/s1>.

Author Contributions: J.M. and A.N. conceptualized the paper and developed the methodology; A.N. did the data analysis with support of J.M. J.M. and A.N. worked on visualization; J.M. wrote, reviewed, and edited the final draft with support from A.N.

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Conflicts of Interest: The authors declare no conflict of interest.

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