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People in Harm's Way

Flood Exposure and Poverty in 189 Countries

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Abstract

Flooding is among the most prevalent natural hazards affecting people around the world. This study provides a global estimate of the number of people who face the risk of intense fluvial, pluvial, or coastal flooding. The findings suggest that 1.47 billion people, or 19 percent of the world population, are directly exposed to substantial risks during 1-in-100 year flood events. The majority of flood exposed people, about 1.36 billion, are located in South and East Asia; China (329 million) and India (225 million) account for over a third of global exposure. Of the 1.47 billion people who are exposed to flood risk, 89 percent live in low- and middle-income countries. Of the 132 million people who are estimated to live in both extreme poverty (under $1.9 per day) and in high flood risk areas, 55 percent are in Sub-Saharan Africa. About 587 million people face high flood risk, while living on less than $5.5 per day. These findings are based on high-resolution flood hazard and population maps that enable global coverage, as well as poverty estimates from the World Bank's Global Monitoring Database of harmonized household surveys.

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People in Harm's Way:
Flood Exposure and Poverty in 189 Countries

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1. Introduction

Natural disasters are estimated to cause an average of over $300 billion in direct asset losses every year; this estimate increases to $520 billion when considering the well-being (or consumption) losses experienced by people (Hallegatte et al. 2017). While each country faces its individual set of natural hazards – including cyclones, earthquakes, or wildfires – floods are one of the most common and severe hazards to disrupt people's livelihoods around the world. Especially in lower income countries where infrastructure systems – including drainage and flood protection – tend to be less developed, floods often cause unmitigated damage and suffering. Recent events, ranging from Bangladesh and Nigeria to the United States and Vietnam, illustrate that the threat is a global reality. Not only rare and major floods, but also smaller and frequent events can revert years of progress in poverty reduction and development. In the coming years, land subsidence, rapid coastal urbanization, and climate change are bound to result in increasing exposure of people and their livelihoods.

In this study we estimate the number of people who are directly exposed to the risk of intense flooding in 189 countries. We do so by using high-resolution flood and population data that enable a global yet detailed analysis of flood risks. We find that 2.2 billion people, or 29 percent of the world population live in areas that would experience some level of inundation during a 1-in-100 year flood event. About 1.47 billion people, or 19 percent of the world population, are directly exposed to inundation depths of over 0.15 meter, which would pose significant risk to lives, especially of vulnerable population groups. While the largest number of exposed people live in East and South Asia (1.36 billion people), subnational poverty estimates highlight another regional hotspot of risk: At least 71 million people in Sub-Saharan Africa are estimated to live in both extreme poverty (using a $1.9 a day definition) and significant flood risk – thus making them particularly vulnerable to prolonged adverse impacts on livelihoods and well-being.

The remainder of this study is structured as follows. Section 2 offers an overview of the existing evidence base, especially on flood risk and poverty. Section 3 summarizes the flood risk, population, and poverty data used in the analysis. Section 4 details the analytical methodology and computational process. Section 5 presents and discusses the results.[1]

2. Existing evidence

Prior to the availability of high-resolution global flood hazard maps, studies relied on historical disaster catalogues to produce rough global exposure estimates. Peduzzi et al. (2009) use a global inventory of recorded flood events from EM-DAT to estimate an exposure indicator at the country level. Yet, the lacking data on the spatial distribution and coincidence of flood risk and population, this approach does not allow a robust estimation of exposure headcounts. Jongman et al. (2012) provide the first global flood exposure analysis that utilizes spatial hazard and population data, albeit at relatively coarse resolution by current standards (10 x 10 kilometers for population data, and 1 x 1 kilometers for flood data). The authors estimate that in 2010, 805 million people worldwide were exposed to fluvial flooding with a 1-in-100 year return period; 271 million people to coastal flooding with the same return period. By accounting for overlap between coastal and fluvial flood risk zones, they further estimate that the global flood exposed population was 992 million in 2010, and project this number to reach 1.3 billion by 2050.

In this study, we show that this projection has already been exceeded in 2020, with 1.47 billion living in high-risk flood zones. Several factors can explain this increase in estimated exposure headcount: On the

[1] Disclaimer: The boundaries, colors, denominations, and other information shown on the maps in this study do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

one hand, since 2010 urbanization and development in high-risk coastal zones has been occurring at rapid rates in many parts of the world. These trends are putting an increasing number of people in harm's way. Human activities, such as ground water extraction, are exacerbating risks as land subsidence is increasing the extent and intensity of flooding. On the other hand, the increase in the estimated flood exposure headcount is methodological; the use of more accurate and higher resolution data, as well as the inclusion of pluvial flooding mean that this study captures flood risks more comprehensively than past studies.

In addition, the Global Assessment Report (UNDRR 2017) offers estimates of risks from five major natural hazards (including flood risks), though it focuses on monetary quantifications of disaster risks. Besides such global assessments, the recent availability of high-resolution flood and population maps has enabled countless local and national risk assessments, for instance in Tanzania, the United Kingdom, the United States, and Vietnam (Chakraborty et al. 2014; Erman et al. 2019; Fielding 2012; Braese et al. 2020).

Flood risks and poverty.

Many analyses have explored the link between natural hazards – flood risks in particular – and poverty; a detailed review of this literature is offered by Hallegatte et al (2020). Studies at the country level illustrate the complex factors at play. For instance, Rentschler et al. (2020) show that people in coastal provinces in Vietnam are by far the most exposed to flood risks. In particular, the low-lying and densely populated Red River and Mekong Deltas display a concentration of people, economic activities, and assets. Coastal provinces also consistently have the lowest poverty rates in the countries. For instance, in Ho Chi Minh City, the country's economic powerhouse, extreme poverty is nearly eradicated – and yet more people than anywhere else in the country live in flood hazard zones. In other words, high-income provinces and districts tend to be more exposed to flood risks. However, a different study finds that in Ho Chi Minh City, the poor are disproportionally exposed to flooding (Narloch and Bangalore 2018). How do these results fit together?

Indeed, at the local level the relationship between poverty and flood exposure can be inversed. Flood hazards tend to be highly localized, with some neighborhoods being at risk from frequent inundation, while other nearby neighborhoods may benefit from higher elevation or better drainage systems. Hallegatte et al. (2017) review the literature and conclude that land and housing markets often push poorer people to settle in these riskier areas, especially where land is scarce. Indeed, a meta-analysis of the literature suggests that a 1 percentage point increase in the yearly probability of flooding is associated with a 0.6 percent decrease in housing prices (Daniel, Florax, and Rietveld 2009). In Ho Chi Minh City, for instance, qualitative surveys suggest flood-prone areas can be much cheaper than non-flood-prone areas for the same quality of accommodation (World Bank and Australian AID 2014). Using a household survey in Dar es Salaam, Tanzania, Erman et al. (2019) find that flood-prone dwellings are valued at 30 percent less on average than safe ones.

Reduced housing prices, then, make it possible for poor people to access housing opportunities that could be out of reach in the absence of risk (Husby et al. 2015). In developing countries with informal markets, land scarcity can be particularly acute and land markets function poorly (Durand-Lasserve, Selod, and Durand-Lasserve 2013). In these places, it may not be the prices that push poor people into risky places but simply the availability of land with appropriate access to jobs and services. Informal settlements are often located in hazard-prone locations such as on hillsides, close to riverbanks, or near open drains and sewers—Pune (India), Dhaka, Caracas, Rio de Janeiro, and Mumbai have many such settlements (Lall and Deichmann 2012; Lall, Lundberg, and Shalizi 2008).

Evidence from Mumbai, India, illustrates why inadequate infrastructure in low-income neighborhoods exacerbates flood risks (Patankar 2015). The city is prone to recurrent floods during the monsoon season, with significant impacts on poor people. The authorities have identified 40 chronic flood spots and 200 localized flood spots, where waterlogging stems from inadequate drainage and poor land-use planning. Many low-income slum dwellers report floodwaters entering their homes several times during the monsoon season. High-income neighborhoods on the other hand, tend to be equipped with effective drainage systems that can mitigate frequent small floods, but still be at risk from rare and major events that can affect low- and high-income areas alike.

Climate change is expected to aggravate risks.

There is some evidence that climate change will result in increased flood hazards. Hirabayashi et al. (2013) present regionally disaggregated flood risk estimates for the year 2100, based on the outputs of 11 climate models. By modeling changes in river discharge and inundation areas, they show that a high-concentration climate change scenario could lead to a large increase in flood frequencies in Southeast Asia, India, East and Central Africa, and large parts of Latin America.

Yet, existing models are ill-suited to provide reliable long-term projections of climate change at the local level. The IPCC's Fifth Assessment report shows that forecasts for average temperature and rainfall changes by mid-century vary significantly depending on which model and which assumptions are considered. However, it is not only the change in the mean that matters – already regions around the world are experiencing changes in the variability of climatic events; in the form of increased frequency of formally rare and extreme events, such as droughts and intense floods. In the meanwhile, the continued urbanization of high-risk areas will mean that more and more people will be exposed to flood risks.

Indeed, large coastal cities are likely to be risk hotspots. Hallegatte et al. (2013) estimate the flood risks in the world's 136 largest coastal cities. They show that population and asset growth, climate change and subsidence are all likely to contribute to a drastic increase in global average flood losses – from $6 billion per year in 2005 to over $60 billion in 2050, assuming proactive adaptation actions in all cities.

Kulp and Strauss (2019) conduct a global assessment of the potential impact of sea level rise on the world's coastal population. The global scale of their study and the use of high-resolution flood and population data makes it the closest comparable analysis of flood risk. Their assessment suggests that today between 190 million and 630 million people (depending on the emissions scenario considered) live in areas that could be inundated by sea level rise by the year 2100. They also estimate that one billion people live on land that is less than 10 meters above current high tide lines.

This present study complements the one by Kulp and Strauss (2019) in several ways: First, it considers not only the one billion people living near current high tide zones and coastal flood risk zones – but expands the analysis to the world's population of 7.7 billion, including those living inland. This study does so by considering fluvial and pluvial flooding, in addition to coastal flooding. Second, rather than focusing on future risk, this study considers the risk levels that already persist today. And third, rather than focusing on the slow-onset hazard of sea level rise, this study estimates people's exposure to intense flood disasters – for instance those caused by intense rainfall.

3. Data

Several data sets are used in this study to calculate global population exposure to flood risk. The methods for combining the data sets into a single flood risk map per country are described in the methodology section.

3.1. Flooding hazard data

Floods can be caused by a variety of factors. The most common types are considered in this analysis:

Fluvial flooding occurs when intense precipitation or snow melt causes rivers to overflow. **Pluvial flooding** occurs when rainwater builds up beyond the absorptive capacity of soil. Country-level pluvial and fluvial flood maps, developed by Fathom Ltd, are used in this analysis (Smith et al. 2015). The data sets provide information on flood extents and flood depth at an approximate spatial resolution of 90 meters and are available for all countries. The maps are based on a global hydrological and topographic model. The model simulates flood events with return periods of 5, 20, 50, 100, 250, and 500 years. This study considers flooding with a 100-year return period. A 1-in-100-year event, for example, is expected to occur once every 100 years on average (i.e. it has a probability of 1% of occurring in any given year). As with all global flood maps, the effects of artificial flood protection structures like dikes are not incorporated.

Two editions of the Fathom global flood maps are available; 2016 and 2019. Wherever available, the newer version has been used. The 2019 version differs from the 2016 version in the resolution of the digital elevation model that has been used to simulate event scenarios. The 2019 edition uses the newest DEM MERIT elevation model that corrects for multiple errors, including tree and building height adjustments.

Coastal flooding is caused by storm surges and high tides in coastal areas. A commonly used global coastal flood risk map is used in this study: the Global Tide and Surge Reanalysis (GTSR) data set by Muis et al. 2016. As it uses a digital terrain model that does not account for common errors such as stripe noise and tree heights (unlike for instance DTM MERIT), this map is expected to provide a lower bound or conservative estimate of global coastal flood risk. In particular, resulting from coarse resolution in modeling elevation, bathymetry and meteorological forcing, the data set underestimates extreme sea levels. In addition, the largest tropical cyclone-induced surges are not all included in the available observations after which storm surges were modeled due to the limited period of the available records (Muis et al. 2016). However, no global coastal flood maps are readily available at this point to address these shortcomings (specifically, no flood maps that offer different return periods based on modeled storm surges).

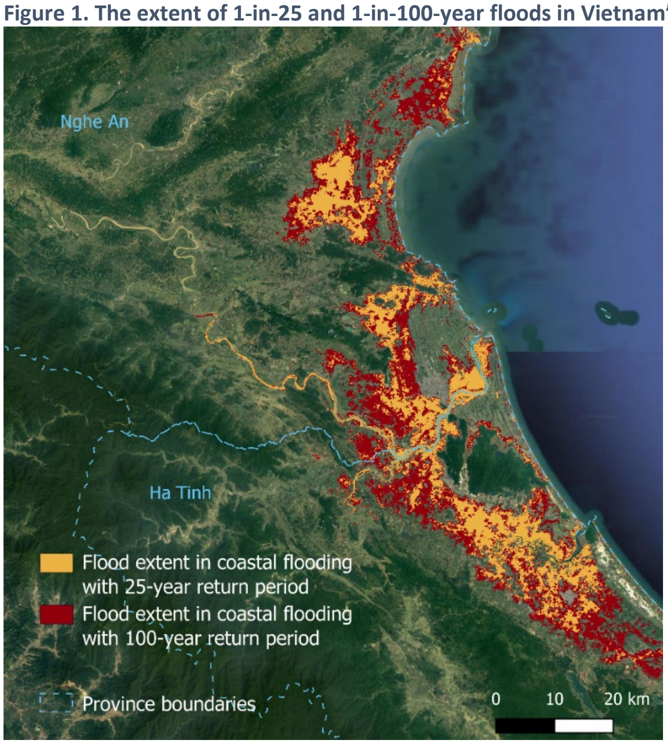
Interpreting return periods: classifying the probability and intensity of natural shocks: Natural hazard data typically distinguish *return periods* to describe the spatial distribution and intensity of natural shocks. A return period describes how much time is expected to pass before a natural shock of the same intensity occurs again. Using historical data and based on the statistical frequency of a shock of a certain intensity, it describes the probability of such an event.

Figure 1 illustrates the extent of floods with two return periods: one with a 25-year return period (or a 1-in-25-year flood) and one with a 100-year return period (or a 1-in-100-year flood). The 1-in-25-year flood has a 1/25 or 0.04 annual probability of occurring. In other words, each year there is a 4 percent chance of such an event occurring, regardless of when the last such event took place. The probabilistic nature of return periods means that there is a 63.9 percent probability that a flood of at least this intensity will occur once within a 25-year period. But this also leaves the possibility for this event to not occur at all, or to occur several times. In comparison, a 1-in-100-year flood is a more extreme event with a lower probability but higher intensity — that is, it affects a wider area and has a greater depth.

As time passes, more climatic data become available, which will update the empirical probabilities associated with certain natural shocks. As the impacts of climate change increase, intense shocks will probably become more frequent. This means that there is significant uncertainty around the probability of natural shocks, and historical data only offer limited guidance on the future. So, when taking long-term investment and planning decisions, selecting options that offer robust performance under a variety of scenarios is crucial (Hallegatte et al. 2019).

This study considers a 1-in-100 year return flood intensity to reflect a relatively rare and intense disaster. However, the concept of return periods is easily misunderstood and the probability underestimated. A 1-in-100 year flood has, on average, a 1% probability of occurrence in any given year. But this translates to or 10% probability in a decade, or 50% in a lifetime (68 years). These are significant probabilities that lie well within reasonable planning horizons of governments. For comparison, the Dutch flood protection system protects against events up to 1-in-10,000 years. In addition, it should be noted that these probabilities apply independently to a given river basin or microclimate. For the purpose of this study, we consider hundreds of thousands of such locations. This means that, globally, hundreds of 1-in-100 year flood events happen every year.

Figure 1. The extent of 1-in-25 and 1-in-100-year floods in Vietnam's North Central Coast Region



Source: Braese et al. 2020.

3.2. Population density

This study estimates the location of people using the Global Human Settlement Layer (GHSL), produced by the EC JRC. It offers global coverage and is available for the years 1975, 1990, 2000, 2015, and 2020. While GHSL provides several layers (including those specifying built-up areas, population, and settlements), this study uses the population density map (GHSL-POP 2020). In a raster format, this data set provides the number of inhabitants per cell, with a resolution of 3 arc seconds (approximately 90 by 90 meters), thus specifying the distribution of population. This information is based on administrative or census-based population data, which is then disaggregated to grid cells based on distribution and density of built-up area, which in turn is derived from satellite imagery. For details of the methodology, see Freire et al. (2016).

It should be noted that the choice of population density map is important for the purpose of this study. Smith et al. (2019) provide a sensitivity analysis for flood exposure assessments using different population density maps, including GHSL-POP 2015 (3-arc second, ~90 m resolution). They show that high-resolution population density maps perform best in capturing local exposure distribution, in particular the High-Resolution Settlement Layer (HRSL) with 1 arc second, or ~30 m resolution, produced jointly by Facebook, Columbia University and the World Bank (2018). While HRSL is only available for a limited number of countries, GHSL-POP is shown to perform better than alternatives with global coverage, such as LandScan data (30-arc second, ~900 m resolution; Bright et al. 2016).

3.3. Administrative boundaries

The definition of national administrative boundaries follows the standard World Bank global administrative map. However, national boundaries are further disaggregated into subnational units for all countries where World Bank household surveys are available with subnational representativeness. These subnational units are typically provinces or states (i.e. admin1) but can also include custom groupings of subnational regions determined by the sampling strategy of household surveys. Overall, this study covers 189 countries, which are disaggregated into 2,260 subnational units.

3.4. Poverty estimates

For each of the 2,260 subnational units, the World Bank's Global Monitoring Database offers several poverty estimates, which are all derived from the latest available Living Standards Measurement Survey (LSMS) for the respective country. For the purpose of this study, the standard World Bank definitions of poverty are used to determine the number of poor people in a given subnational administrative unit. Specifically, poverty is defined by the daily expenditure thresholds of $1.90, $3.20, and $5.50.

4. Methodology

4.1. Concept of analysis

To estimate the number of people who are exposed to intense flood risk, this study follows four main steps:

1. **Generate a combined flood hazard map:** For each country and each subnational administrative unit, a single flood hazard layer is created by combining different flood types. The resulting flood map has a 90-meters resolution, with each pixel showing estimated inundation depths in meters. For pixels where different flood types overlap the higher inundation depth estimate is used (e.g. coastal areas near rivers are exposed to both coastal and fluvial flooding). The flood hazard map is then resampled to ensure that pixels perfectly overlay the GHSL population density map.
2. **Define flood risk categories:** While the flood hazard map offers inundation depths along a continuous scale, the values are aggregated into the following risk categories:

Flood risk classification		Inundation depth
Low risk	No risk	0 meters
	Low risk	0 – 0.15 meters
High risk	Moderate risk	0.15 – 0.5 meters
	High risk	0.5 – 1.5 meters
	Very high risk	Over 1.5 meters

These flood risk categories are defined in line with an approximation of the risk to the lives of affected people. Up to 0.15 meter inundation depth, no significant risk to life is expected. Up to 0.5 meter, some risk to life must be expected, especially for vulnerable groups such as children and the disabled. Up to 1.5 meters, a significant share of the affected population could face risk to life, especially if flood waters have a current. Above 1.5 meters, most affected people could face substantial risk to life without rescue measures.

Through this process, each 90 by 90 meter cell of a country will be assigned one of the five risk categories (e.g. a pixel that has an estimated inundation depth of 5 cm is classified as low risk, while a pixel with depth 4.3 meters is classified as very high risk). This is repeated for the world's landmass of 510 million square kilometers, which implies the processing of 63 billion pixels.

3. **Assign flood risk categories to population headcounts at the pixel level and aggregate to the administrative unit:** As the flood hazard and population density maps are converted into the same spatial resolution, each population map cell can be assigned a unique flood risk classification – these cells can then be aggregated to the administrative unit level (e.g. province or district level). This allows the calculation of population headcounts for each flood risk category and for each (sub-)national administrative unit. A detailed description of how this process is implemented in practice is provided in Section 4.2.

   This process yields an estimate of the number and share of people exposed to no-, low, moderate, high, and very high flood risk during an intense flood event. These estimates are available globally with a resolution of 90 meters, but they are also aggregated to administrative units, including for each country and subnational unit. These estimates are also aggregated to yield regional and global estimates.

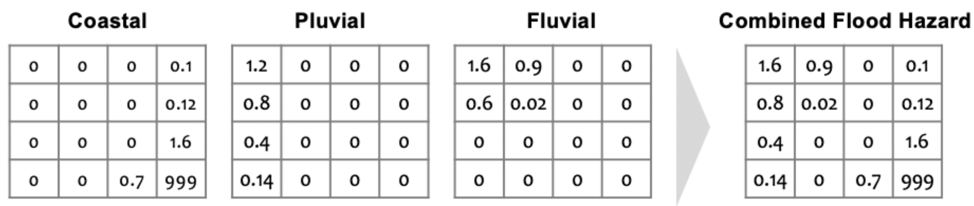
4. **Compute the number of poor people exposed to flood risk:** While poverty estimates are not available at the pixel level, the World Bank's GMD database provides them at the subnational level for most countries. These poverty shares are multiplied with the population headcount that is estimated to be exposed to flooding, in order to obtain an estimate of the number of poor people in each administrative unit exposed to flood risk. Similarly, exposure headcount estimates are multiplied with subnational GDP per capita figures to obtain estimates of flood exposed GDP in monetary terms.

4.2. Stepwise computational process

The following steps are repeated for each subnational region where data are available.

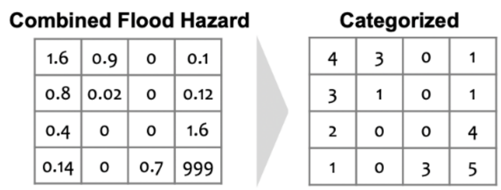
Merge coastal, pluvial, fluvial flood hazard maps

- Crop fluvial and pluvial flood rasters to subnational boundary
- Crop then virtually warp the coastal flood raster, using a nearest neighbors resampling method, to perfectly match the resolution and extent of the fluvial and pluvial rasters
- Merge fluvial, pluvial, and coastal rasters using a maximum value method



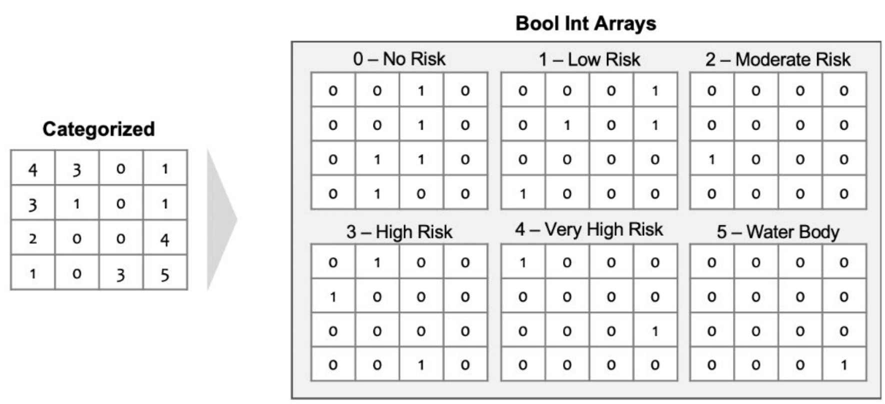
Categorize the flood raster

- Using pre-defined flood categories and a category for water bodies, categorize each pixel value



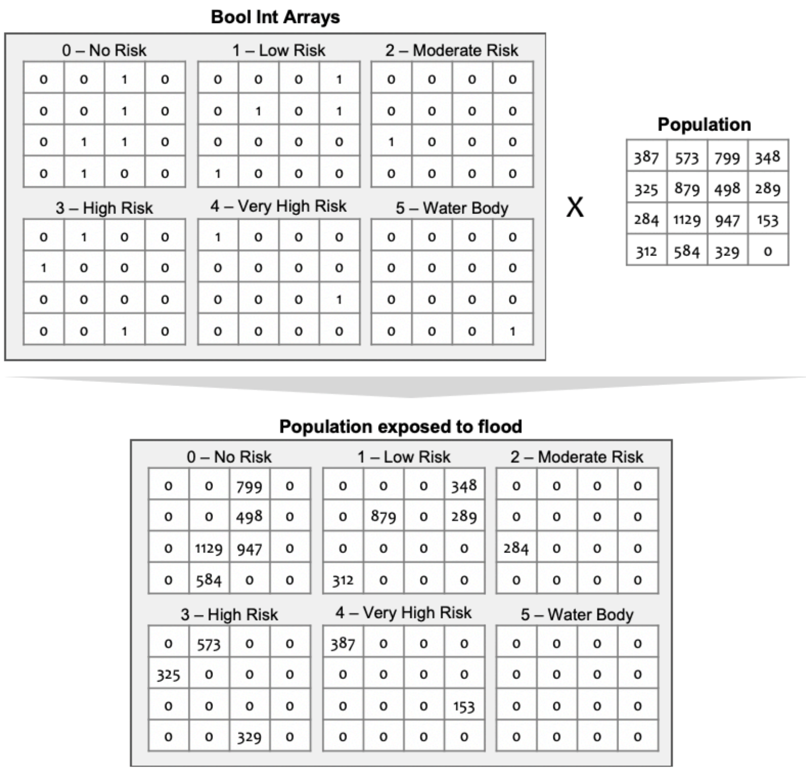
Convert to Boolean integer raster

- Convert the country map/raster into six different rasters, one for each flood bin
- Convert each raster for each flood bin to a Boolean (true / false) integer array, where 1 represents the presence of flood risk level in the specific pixel, and 0 represents no presence of flood risk for that pixel



Multiply each flood array by the population array:

- Crop and virtually warp the population raster to perfectly match the flood raster
- For each flood risk array, multiply the array by the population
- Each flood array pixel is multiplied by the corresponding population array pixel
- The 1/0 structure allows the resulting array to capture population data for the specific flood risk level



Calculate sums

- For each flood risk array, calculate the total number of people exposed and add the results to the World Bank global administrative map shapefile

5. Results

For each of the countries analyzed, the results are available as raster files with a 90m spatial resolution and as shapefiles with data aggregated to the admin 1 (sub-national), admin 0 (national), regional, and global levels. In this section, we present visualizations of key findings as maps, using a variety of spatial scales, as well as graphs to highlight pertinent insights.

5.1. Global and regional flood exposure

Our estimates show that globally 2.2 billion people are exposed to some level of flood risk; 1.47 billion people, or 19 percent of the world population, are exposed to a significant level of flood risk (i.e. facing inundation depths of over 0.15 meter in the event of a 1-in-100 year flood, or *moderate* risk or higher in Figure 2). In other words, considering a global population of 7.7 billion (World Bank, 2019), approximately one in five people in the world are exposed to substantial flood risk.

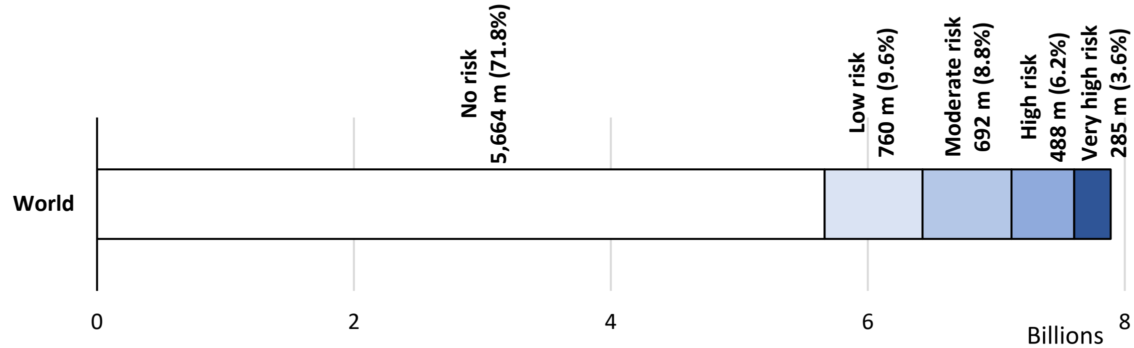


Figure 2. ***Global population headcounts exposed to different levels of flood risk***

By regionally disaggregating global exposure headcounts, it becomes apparent that flood risks are particularly prevalent in certain regions. At 595.3 million people, the East Asia and Pacific (EAP) region has the highest number of people exposed to significant flood risk – corresponding to about 25% of EAP's total population. In all other regions, flood exposed people account for a smaller share of the overall population. In the South Asia region (SAR), 370 million people are exposed to significant flood risk – i.e. about 19.5 percent of the SAR population. In Sub-Saharan Africa (SSA), Europe and Central Asia (ECA), Middle East and North Africa (MENA), Latin America and the Caribbean (LAC), and the United States and Canada (USA & CAN), between 16.3 to 8 percent of the respective regional populations are exposed to high flood risk. Figure 4 provides a full breakdown of regional exposure estimates in absolute and relative terms. In several cases, regional exposure numbers are driven by single countries – like is the case for China in EAP, India in SAR, or Egypt in MENA. Section 5.2. presents the most exposed countries.

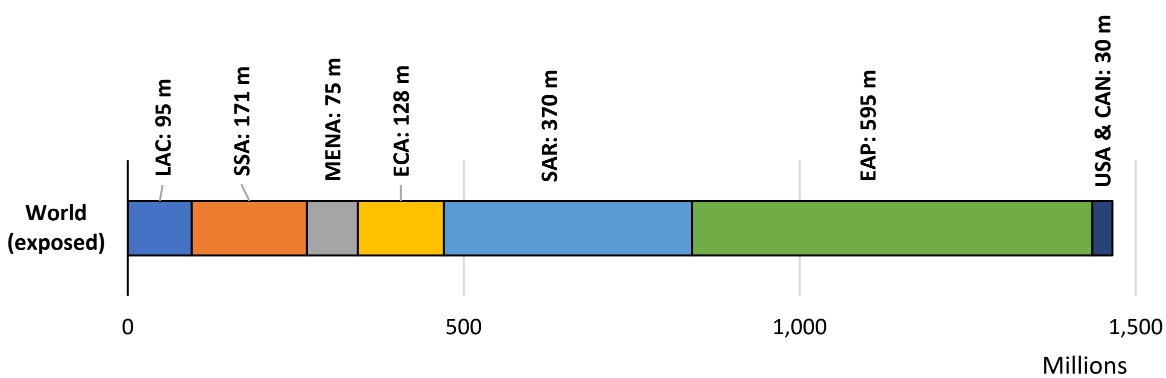


Figure 3. Regional disaggregation the global headcount estimates of people exposed to significant flood risk

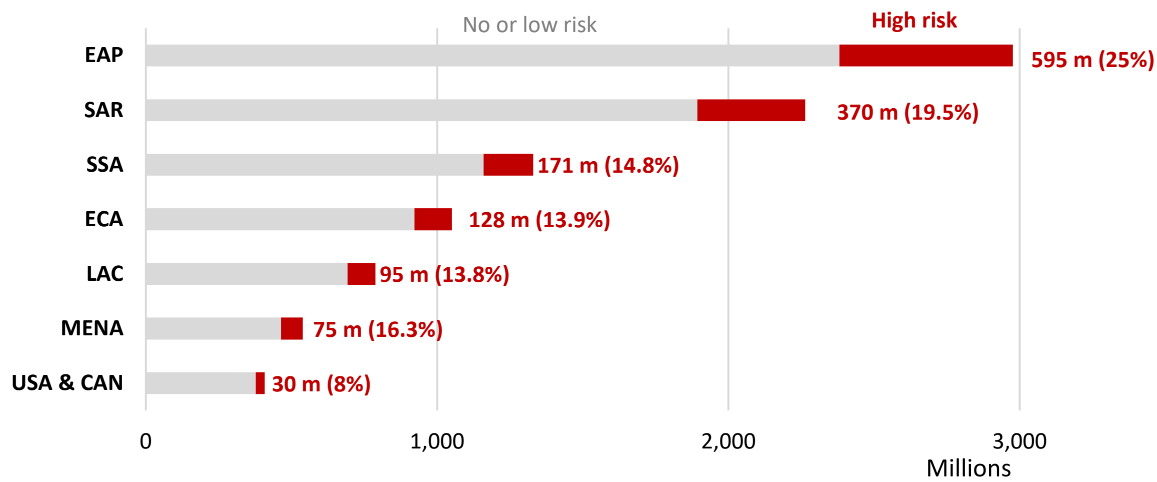


Figure 4. Number of people exposed to significant flood risk by region (and as share of total regional population)

5.2. Countries with the largest flood exposed populations

Absolute exposure headcounts by country. Several countries stand out with particularly large populations directly exposed to high flood risk. In particular, the two most populous countries, China and India, also have the highest absolute population exposure to flood risk. Approximately one-third of all people exposed to flood risk globally reside in India or China. These two countries are home to approximately as many flood exposed people as in the next 18 highest exposure countries combined. Figures 5 and 6 present total headcount estimates at the country level.

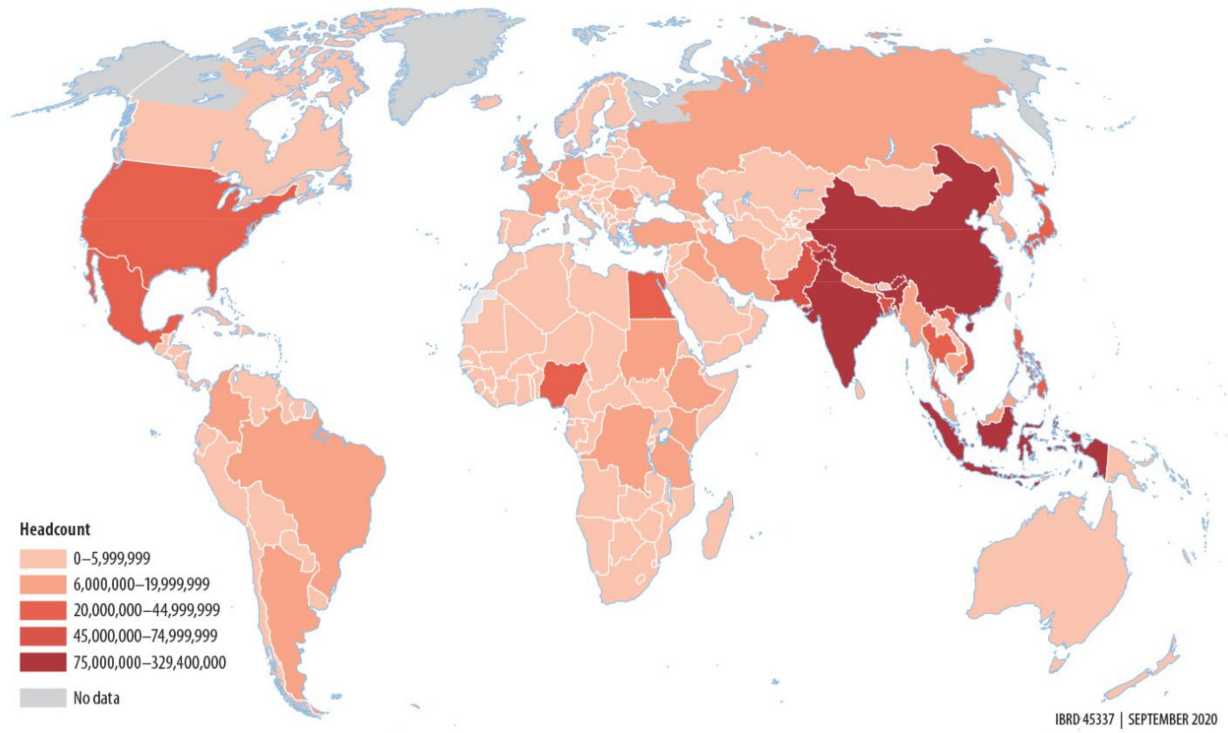


Figure 5. Absolute population exposure to 15cm or more flood inundation risk at the country level (millions)

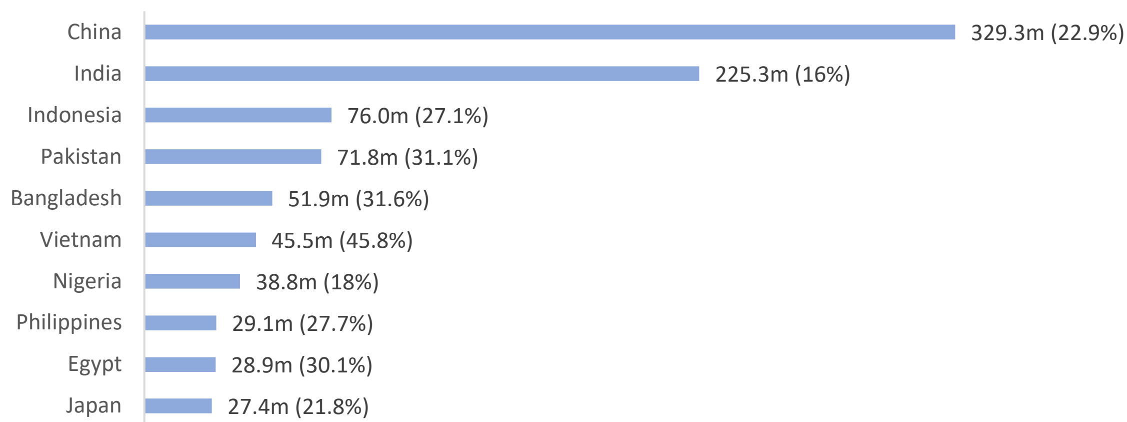


Figure 6. Top 10 countries: Number of people exposed to significant flood risk (and as share of total national population)

Relative exposure headcounts by country. Considering relative exposure yields additional insights. The Netherlands has the world's highest relative exposure to flood risk, with 58.1% of the population being exposed to inundation depth of over 15cm in the event of a 1-in-100 year flood – that is, before taking into account flood protection systems. While the Netherlands has some of the most comprehensive flood protection systems in the world, with protection against up to 1-in-10,000 year events, the same is not true for other countries; in particular, low- and middle-income countries. Vietnam for instance, also has an extensive sea dike system in place, yet in only protects against coastal flooding with return periods of up to 1-in-30 years (Rentschler et al. 2020).

Figure 7 presents relative exposure estimates for all countries, while figure 8 highlights the top 10. These estimates confirm that in these countries a third or more of the population lives in high-risk flood zones, such as coastal areas or low-lying river plains (such as the Mekong, Brahmaputra, or Irrawaddy rivers). Unlike in the absolute exposure ranking, China (22.9 percent of population exposed) and India (16 percent) do not appear in the top 10 (nor top 20) of this relative exposure ranking. Bangladesh and Vietnam are the only two countries that appear in both absolute and relative exposure rankings.

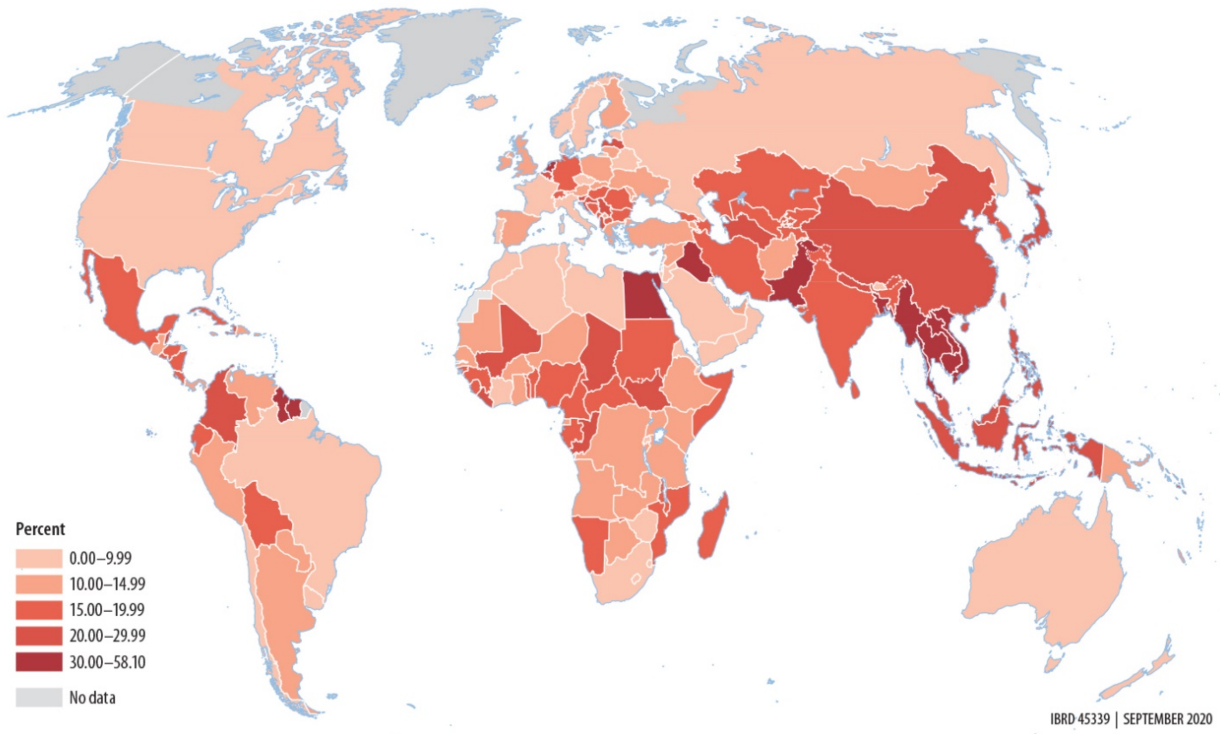


Figure 7. Relative population exposure to 15cm or more flood inundation risk at the country level (percentage)

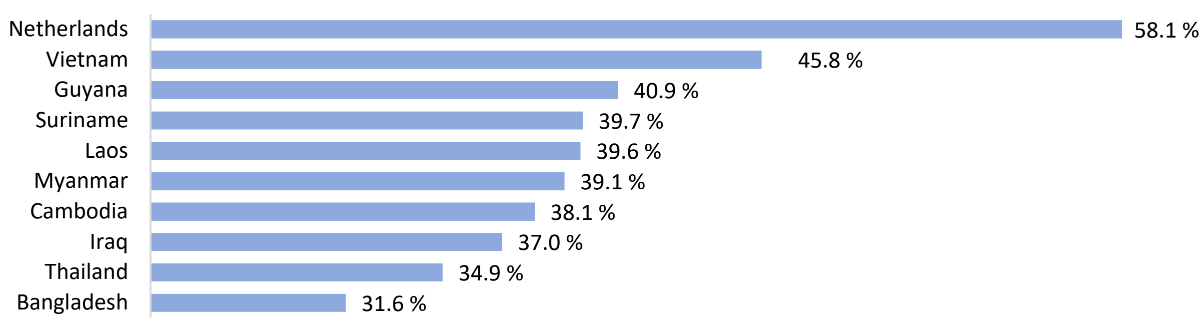


Figure 8. Top 10 countries: Share of total national population that is exposed to significant flood risk

5.3. Flood exposure at the subnational level

Country-level estimates provided in the previous section can highlight countries in which flood risks are particularly prevalent. However, in most cases flood risks are not uniformly distributed across a country but concentrated in high-risk areas such as the coast or river basins. In this section we present flood exposure estimated disaggregated to subnational regions, the number of which can vary across countries. World Bank household surveys are sampled to be statistically representative at different subnational levels – in this study we adopt these statistically representative subnational units which enable us to compare flood exposure estimates with socio-economic characteristics, such as income levels and poverty (Section 3.4).

The disaggregation of exposure estimates highlights several subnational regions with high risks (Figure 9). Punjab, Pakistan, with a population of 120 million people, frequently experiences heavy flooding and ranks highest in terms of the absolute population headcount exposed to significant flood risk; approximately 48 million people are exposed, which is 38% of the total population. Several of the populous regions in China and India are also among the world's subnational regions with the highest number of people exposed to flood risk. In China for instance, high population exposure tends to be close to the coast and around the Yellow River valley. However, the sub-national region with the highest population exposure in China is Guangdong in the southeast, on the South China Sea, where 43 million people are exposed across Hong Kong SAR, China; Macao SAR, China; Shenzhen; and the rest of the region. In India, the three sub-regions with the highest population exposure to flood risk (Uttar Pradesh, Bihar, and West Bengal) are all situated in the Ganges basin. Maharashta, which spreads across the central and western regions of India, experiences heavy monsoon seasons and ranks fourth in India in terms of absolute population exposure.

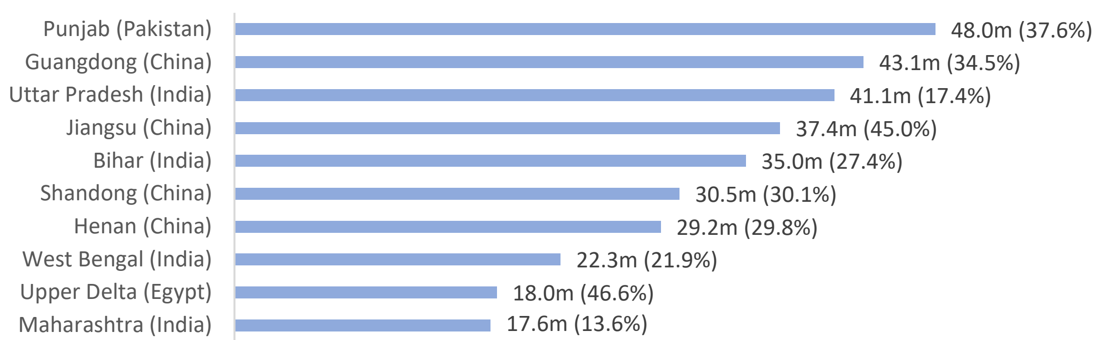


Figure 9. Top 10 countries: Number of people exposed to significant flood risk (and as share of total regional population)

Considering the absolute population exposure figures above biases attention towards large and populous regions. Notably, Uttar Pradesh, Maharashtra, and Bihar are the three most populous sub-national regions in the world. Instead, considering relative population exposure, i.e. the share of the overall population that is exposed to flood risks, can help identify regions in which flood risks are prevalent across large parts of the population. Figures 10 and 11 present relative flood exposure estimates, which demonstrate that in various regions the vast majority of the population is facing significant flood risks.

The sub-national region with the highest relative exposure to flood inundation risk is the Pool region in the Republic of Congo. The region, home to Pool Malebo, has a population of approximately 360,000 people, 91% of whom are exposed to significant flood risk. In all of the top 10 subnational regions in terms of relative population exposure, over two-thirds of the population are estimated to face significant flood risks. Strikingly, regions with high flood exposure can be found in all regions, and in low- and high-income regions alike. Figure 10 especially highlights high-risk regions in coastal regions and large river basins – such as the Mississippi, Nile, Ganges, Brahmaputra, or Mekong basins.

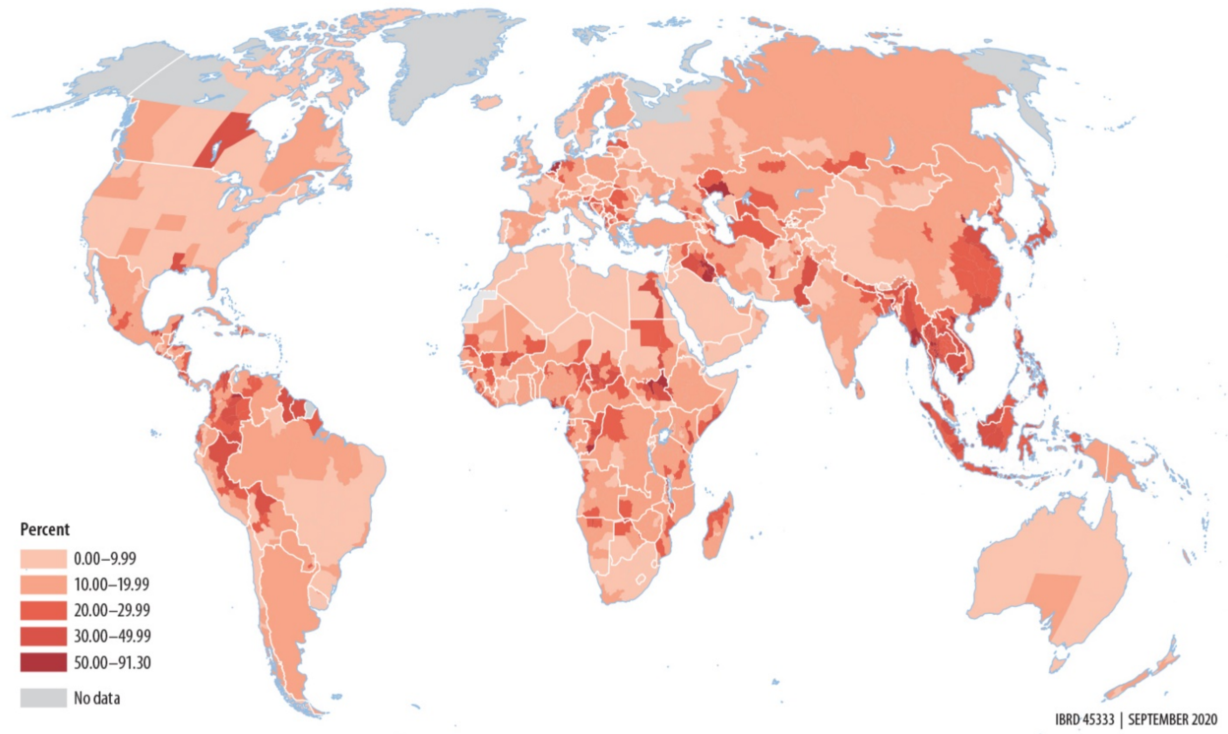


Figure 10. Share of total subnational population that is exposed to significant flood risk (percent)

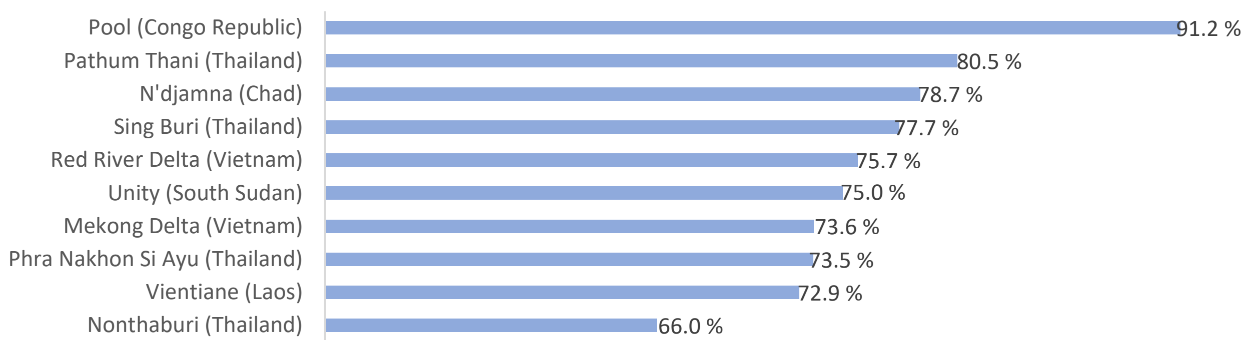


Figure 11. Top 10 countries: Share of total subnational population that is exposed to significant flood risk

5.4. Income levels, poverty, and flood exposure

The flood exposure of economic production value.

By taking into account per capita income levels, it is possible to obtain estimates of the value of economic activity that is exposed to flood risks around the world. Specifically, we multiply flood exposure headcounts with subnational estimates of daily income per capita (in $PPP terms, as obtained from the World Bank household survey database, Section 3.4). This yields the estimate that $5.3 trillion of economic activity is directly located in areas with significant flood risks (note that this refers to exposed economic activity, not annually lost activity).

Figure 12 demonstrates that the use of income levels or GDP for assessing flood risks mostly highlights risks in high-income countries. Of the $5.3 trillion of economic activity in flood risk areas, 77 percent is in upper middle- and high-income countries (UMC, HIC). Low-income countries (LIC) account for 48 percent of the world's flood exposed population, but only 22.6 percent of exposed economic activity. In contrast, high-income countries account for 11 percent of people exposed, but for 53 percent of at-risk economic output. Among countries with the largest economic value at risk, the United States leads the ranking with $1.9 billion in economic output exposed, followed by Japan with $1.3 billion; no low-income country is among the top 10 countries in terms of economic value at risk (Figure 13). Figure 14 confirms this picture at the global scale, as the highest economic exposure is highlighted in North America, Europe and East Asia, while Sub-Saharan Africa is classified as "low exposure" in monetary terms.

In interpreting these results, it is important to note that the flood risk exposure does not account for existing flood protection measures. Such protection measures tend to be better developed in high-income countries, meaning that the fraction of exposed economic activity that actually gets lost during a flood is likely to be higher in low-income countries.

Figure 12. Flood exposed economic activity, disaggregated by countries' income groups. Computed as exposure headcount per country multiplied by GDP per capita. (LIC: low-income countries; LMIC/UMIC: lower/upper middle-income countries; HIC: high income countries, based on World Bank income classifications)

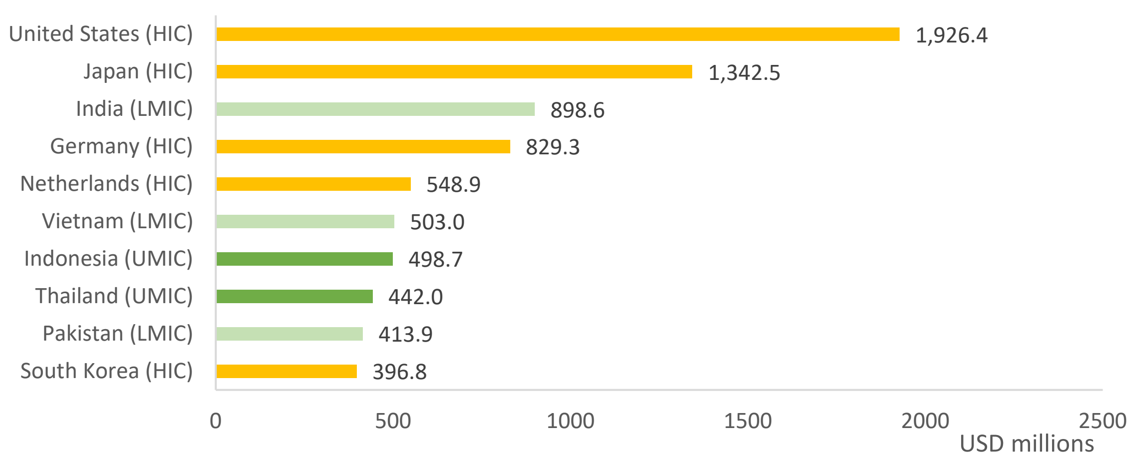


Figure 13. Top 10 countries: Economic value at risk, computed as exposure headcount multiplied by subnational income per capita. Note: no subnational income data are available for several countries, including China.

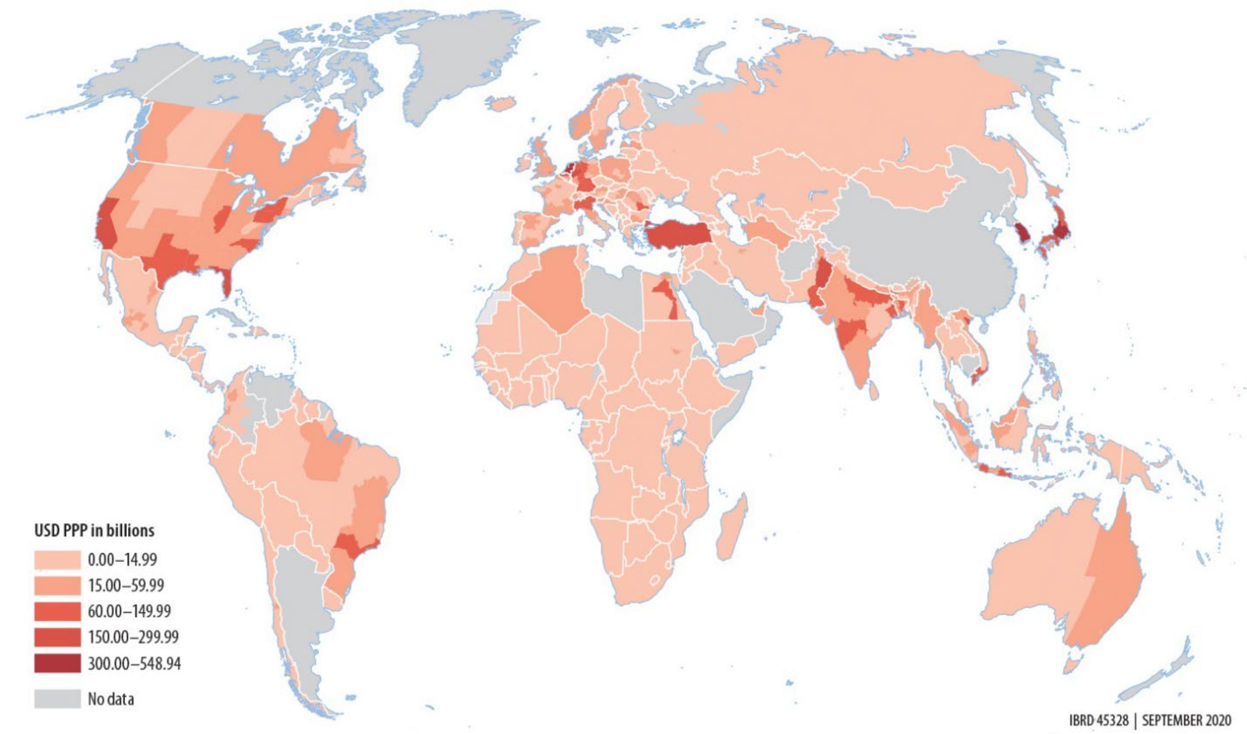


Figure 14. Economic value at risk, computed as exposure headcount multiplied by subnational income per capita. Note: no subnational income data are available for several countries, including China.

Exposure headcounts by income groups.

To address the bias that high-income areas have higher flood exposure in monetary terms, we consider flood exposure headcount disaggregated by national income classifications. The results, presented in Figure 15, show that 710 million people (or 48 percent) of the world's flood exposed population live in lower- or lower middle-income countries. About 159 million (11 percent) of flood exposed people live in high-income countries. Considering that the flood exposed population in high-income countries is more likely to benefit from flood protection systems, social post-disaster assistance, and other risk management support, these figures highlight that monetary exposure estimates (including GDP) offer a distorted account of the distribution of global flood risks.

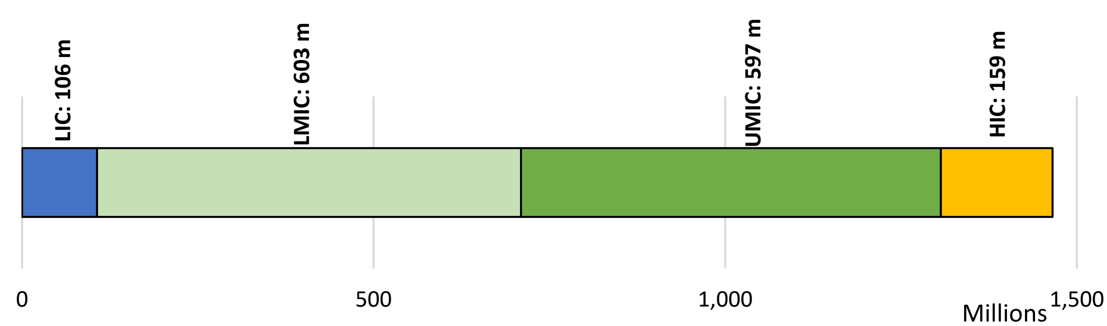


Figure 15. Number of people exposed to significant flood risk, disaggregated by national income level classification

Poverty and flood exposure.

By combining flood exposure estimates with survey-based sub-national data on poverty, we further estimate flood exposure among the world's poor. Our estimates show that 132 million people living in extreme poverty (living on less than $1.90 per day) are directly exposed to flood risk; of these, 72.5 million (or 55 percent) are in Sub-Saharan Africa (figure 16). Approximately two out of ten people exposed to flood risk globally are living in extreme poverty.

When poverty is defined using less extreme (i.e. higher) thresholds, the number of flood-exposed poor people increases significantly. Around 343 million are estimated to live in high-risk flood zones while living on less than $3.20 a day. The number increases to 587 million when considering incomes below $5.50 a day. Increasing the poverty threshold from $1.90 to $5.50 doubles the number of poor people exposed to floods in Sub-Saharan Africa from 73 million to 147 million. However, in South Asia the number of the poor and flood-exposed increases seven-fold from 41 million to 289 million; in East Asia the increase is nine-fold from 9 million to 80 million. but increases the poor people exposed in SAR by a factor of 6.55 to 286.8 million people. In other words, four out of every ten people exposed to flood risk globally are living on less than $5.50 a day.

	Poverty threshold (consumption per day)		
	$1.90	**$3.20**	**$5.50**
Number of poor (millions)	741.8	1,812.0	2,986.6
Number of poor with flood exposure (millions)	132.0	343.4	586.8
Share of global population that is poor	9.4%	23%	37.8%
Share of population that is poor and flood exposed	1.7%	4.4%	7.4%

Table 1. Absolute and relative flood exposure headcounts at different poverty thresholds

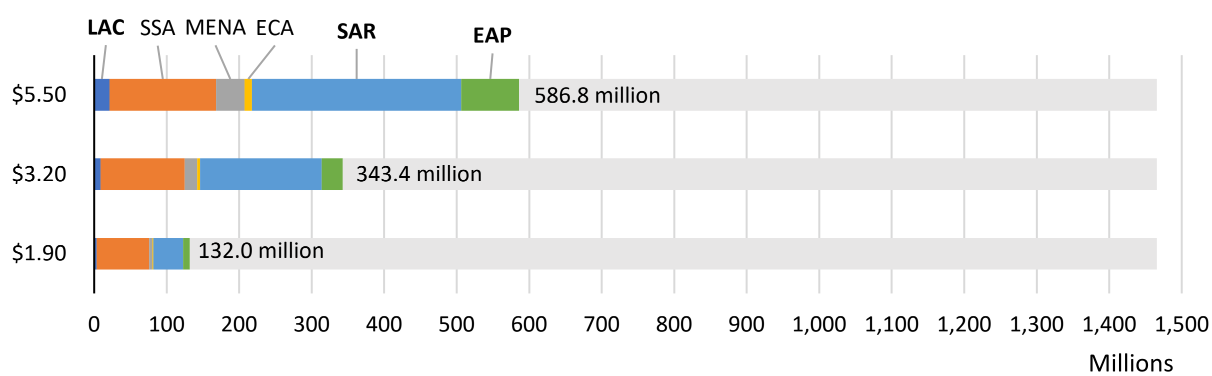


Figure 16. The number of poor people with high flood exposure, using different poverty thresholds and disaggregated by regions

Country-level poverty exposure. Of the 132 million people living in extreme poverty and high flood exposure, almost half are located in just three countries. With over 35 million, India has the highest number of extremely poor people exposed to flood risk of any country in the world; corresponding to 2.5

percent of India's overall population. The top 10 countries in terms of number of poor people exposed at $1.90 (figure 17) account for 65 percent of all poor people exposed to flood risk globally. Seven out of the top ten countries are located in Sub-Saharan Africa. In the 10 countries with the highest share of the population being poor and flood-exposed, about 10 to 20 percent of the population is estimated to be exposed – all of which are in Sub-Saharan Africa (figure 18).

Figure 19 further highlights that extreme poverty and flood risk coincide most acutely in Sub-Saharan Africa; though when considering high poverty thresholds, pockets of vulnerability also become apparent in regions of the Middle East, South and East Asia, as well as Latin America.

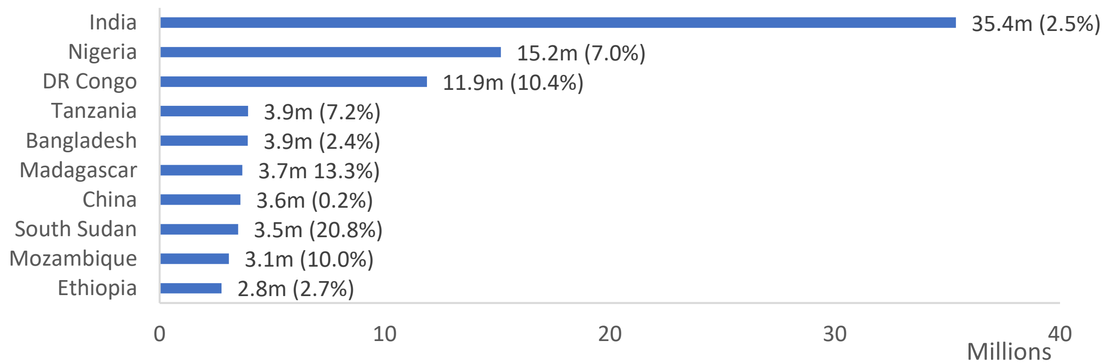


Figure 17. Top 10 countries - number of poor people exposed to significant flood risk at $1.90/day (and as percentage of the total population)

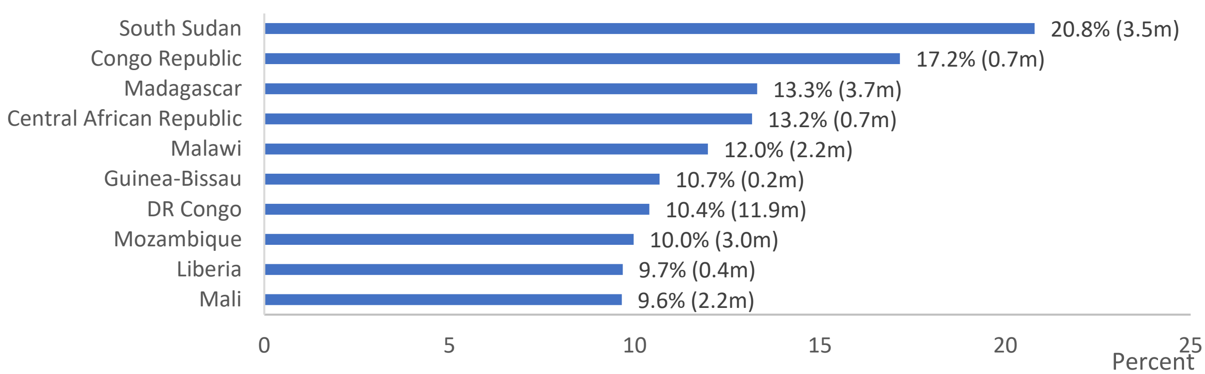


Figure 18. Top 10 countries – proportion of poor people exposed to significant flood risk at $1.90/day (percentage)

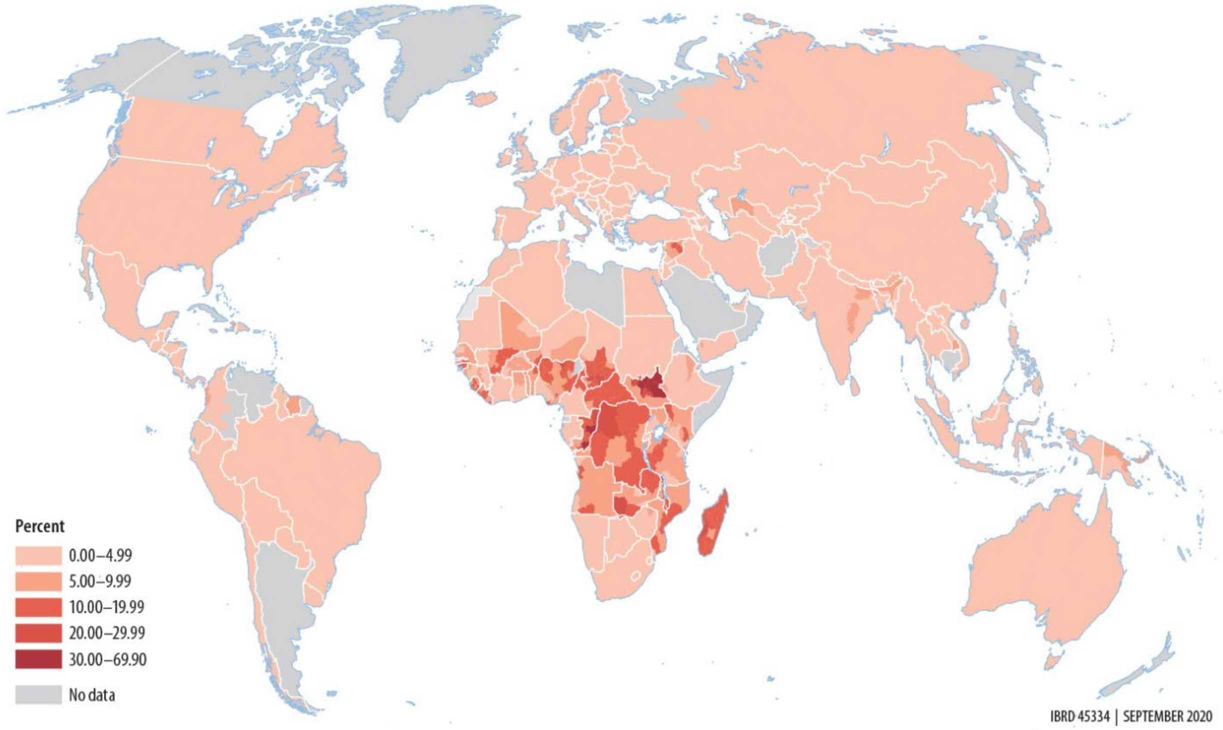


Figure 19. Share of total population that is exposed to significant flood risk and living in poverty at $1.90/day

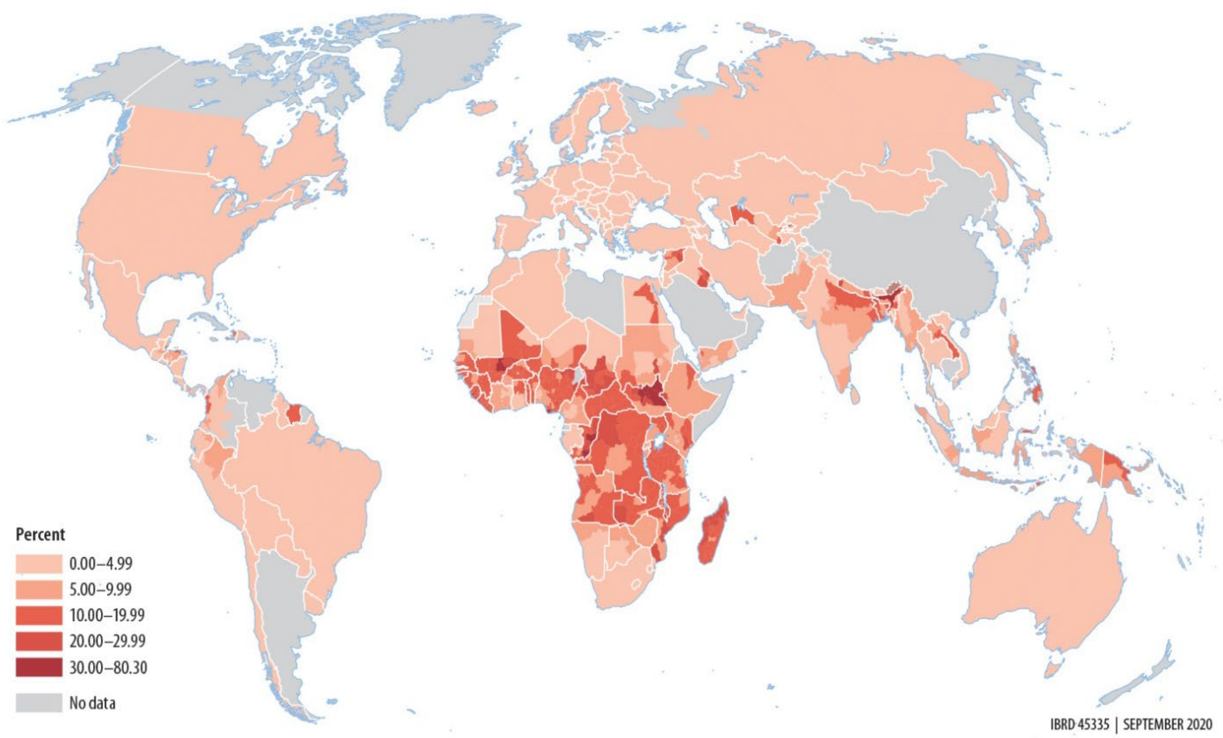


Figure 20. Share of total population that is exposed to significant flood risk and living in poverty at $3.20/day

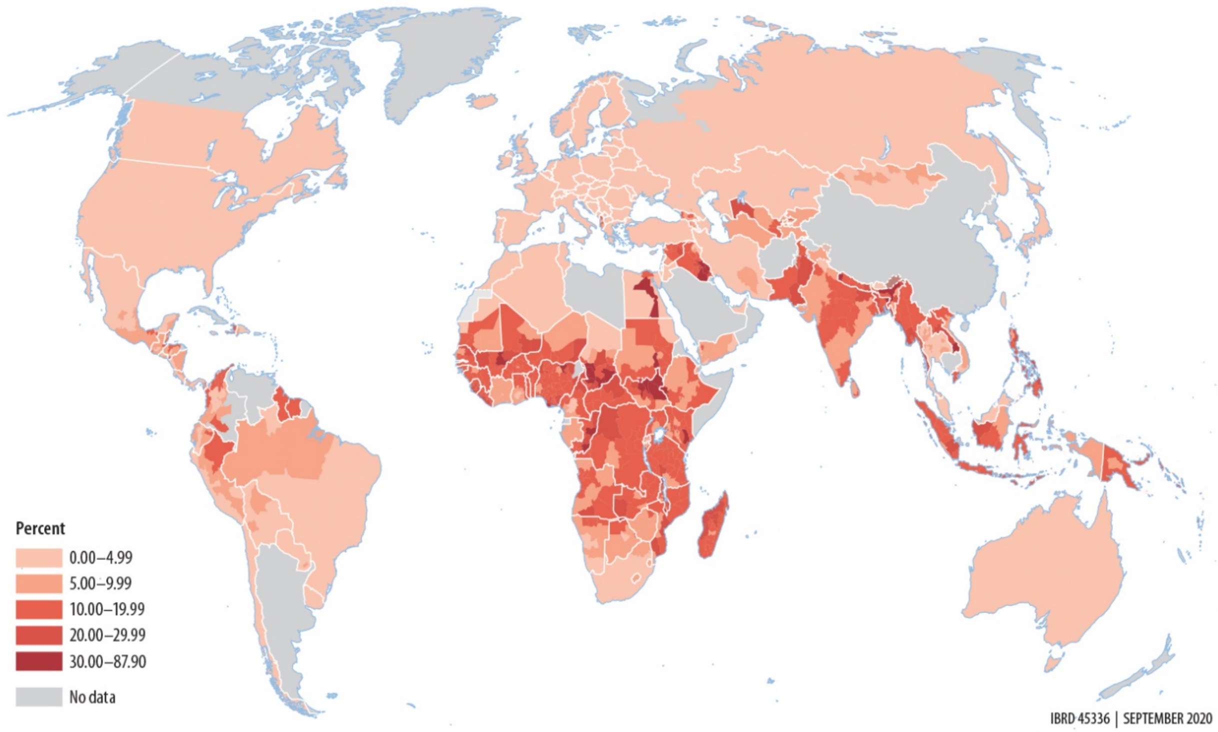


Figure 21. Share of total population that is exposed to significant flood risk and living in poverty at $5.50/day

Relationship between population exposure and other variables. The relationship between poverty and flood risk exposure is driven by multiple partly opposing forces. As section 2 has outlined, country-level evidence has demonstrated that areas with higher flood risks (such as coastal zones) can offer economic opportunities, thus resulting in lower poverty rates; yet at the local level (e.g. within coastal towns), low-income households can be driven into low-cost and high-risk neighborhoods. This means that – depending on the resolution of analysis and country-specific geographic and economic characteristics – the relationship between poverty and flood exposure could be either positive or negative. The global-level data used in this study only offer a limited view on this question. Figure 22 illustrates the relationship between average income levels and flood exposure rates for the 2,260 sub-national regions for which data are available. The figure suggests that regions with high flood-exposure tend to have lower income levels on average, only dedicated country-level analysis can assess this question conclusively – for instance based on household survey data.

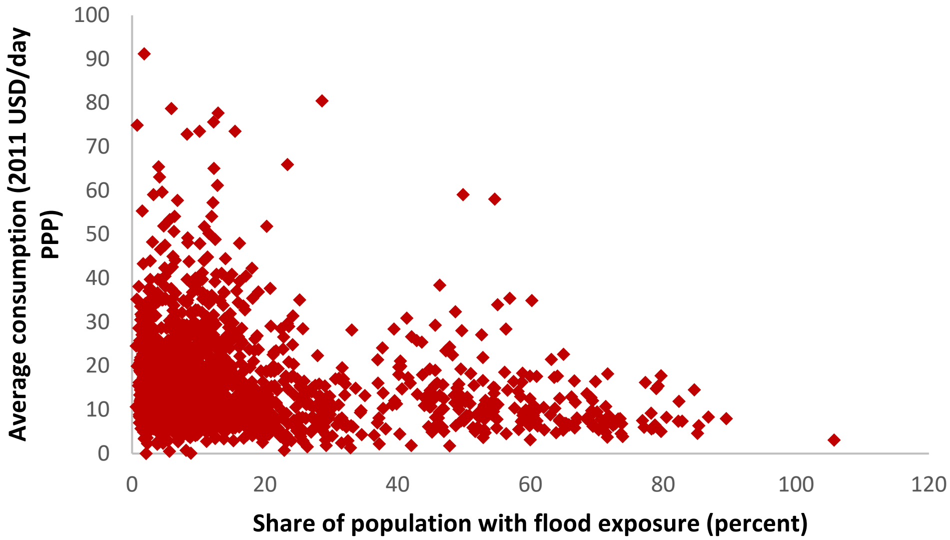


Figure 22. Scatterplot of share of population exposed by income (2011 PPP USD/day)

5.5. From global aggregates towards local flood risk assessments

The results in previous subsections that are presented at the subnational, national, regional and global scales are aggregates of flood exposure maps that were generated as part of this study for all countries. These exposure maps with higher spatial resolutions have been retained and can be used to derive more granular insights at the local level.[2]

For illustration, Figure 23 shows the population flood exposure estimates for Vietnam in an aggregate form at the national and subnational scales, as well as in its high-resolution raster format for example areas. The raster displays the number of people exposed to flood risk of each 90m x 90m pixel. The map shows a high concentration of flood-exposed populations in Hanoi, as well as urbanized areas along the Red River.

The granularity offered by these pre-processed population exposure maps could be valuable for various applications; e.g. for the development of disaster mitigation plans prior to a flood event, or to estimate the number of affected people during flood events in order to prepare the scale-up of shock-responsive social protection systems. However, several limitations of these maps should be noted: First, poverty estimates are not available with the same resolution and are not incorporated in these maps. Second, while the maps can help to identify the scale of overall vulnerability and the location of pockets of vulnerability, they cannot replace detailed needs assessments for the targeting of post-disaster support or the evaluation of damages after specific events.

[2] These maps will be made available publicly, and will be available upon request in the meanwhile.

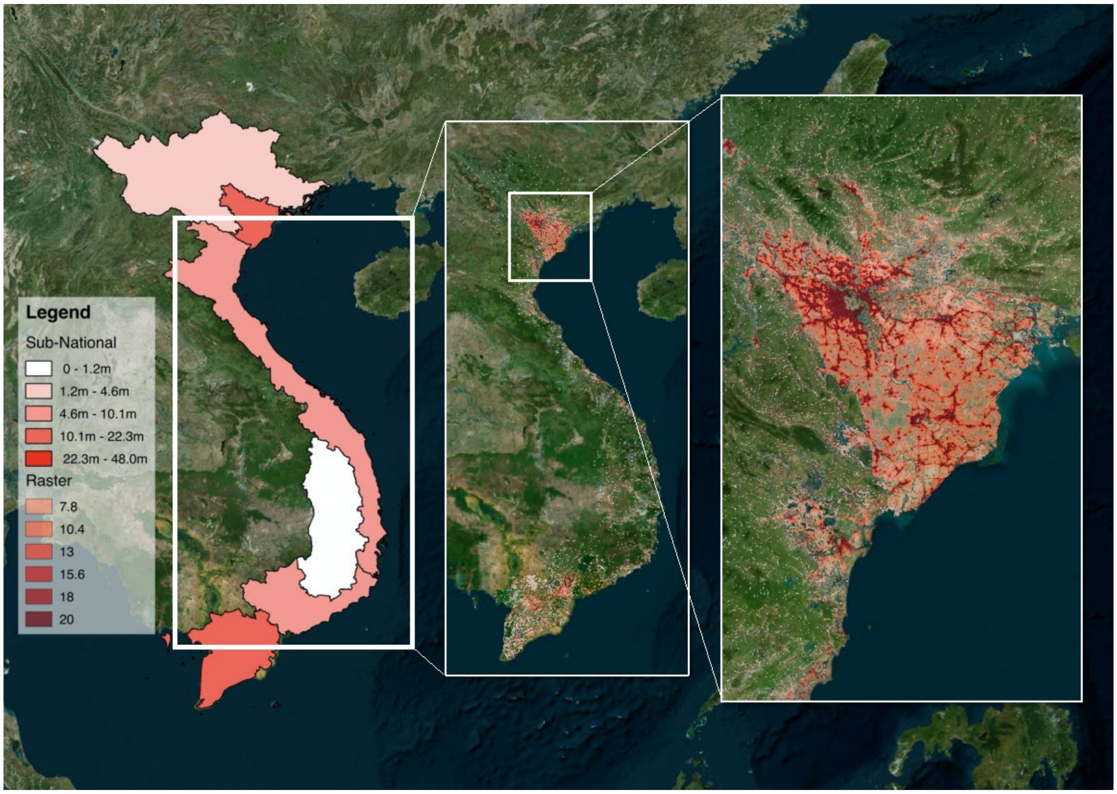


Figure 23. Estimates of population flood exposure in Vietnam, aggregated to sub-national administrative units (left), and in rasterized format (right). Disclaimer: The boundaries, colors, denominations, and other information shown on this map do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

6. Conclusion

In this study we estimate the number of people who are directly exposed to the risk of intense flooding in 189 countries. The study offers several key messages:

- **The exposure of people to flood risk is substantial:** We find that 2.2 billion people, or 29 percent of the world population live in areas that would experience some level of inundation during a 1-in-100 year flood event. About 1.46 billion people, or 19 percent of the world population, are directly exposed to inundation depths of over 0.15 meter, which would pose significant risk to lives, especially of vulnerable population groups.
- **While flood risks are global, East and South Asia stand out.** Flood risks are a near universal threat, affecting people in all countries covered in this study – albeit at different scales. The largest number of flood exposed people live in East and South Asia (1.36 billion people). In several subnational areas of East and South Asia, more than two-thirds of the population is exposed to significant flood risks.
- **When considering poverty among the flood exposed population, risks are largest in Sub-Saharan Africa.** At least 71 million people in Sub-Saharan Africa are estimated to live in both extreme poverty (using a $1.9 a day definition) and significant flood risk – thus making them particularly vulnerable to prolonged adverse impacts on livelihoods and well-being. Globally,

between 132 million and 587 million poor people are exposed to flood risks (depending on which poverty definition is used). About 1.2 billion flood-exposed people live in lower- and upper-middle-income countries.

Taking into account the income levels of flood exposed populations is particularly important, as income is a relatively reliable proxy for people's ability to mitigate, withstand, cope with, and recover from floods. For instance, while a large share of the Dutch population lives in flood risk areas, large-scale investments in flood protection infrastructure have enabled them to mitigate risks. Similarly, flood exposed populations in Canada or Japan are more likely to have access to rapid government support systems in post-disaster situations compared to people in Malawi or Bangladesh. Thus, action to strengthen disaster prevention and recovery capacity is most urgently needed in the hotspots where poverty and flood exposure coincide.

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