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Global human exposure to urban riverine floods and storms

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Abstract

The world's urban population is soaring, with an increasing number of people exposed to urban natural hazards such as riverine floods and storm surges. The global quantification of their extent is, however, still blurred. The ongoing surge in high-resolution data allows novel opportunities for quantification of hazards and exposure. Here, we provide a global spatial synthesis of urban populations' exposure to riverine floods and storm surges in 1990 and 2015. Our results reveal that, owing to rapid economic development globally in a large proportion of exposed areas, most of the exposure has shifted from low-income to middle-income countries. Asia dominates as a continent. The total growth of human exposure continues, suggesting that disaster risk reduction policies and implementation call for enduring effort.

KEYWORDS

data infrastructure, GHSL, riverine floods, Sendai framework, storm surges, urban

1 | INTRODUCTION

The world is urbanizing at an unprecedented pace as human settlements are becoming ever larger and more condensed, and today, over 90% of the world's population lives closer than 10 km from a freshwater body (Kummu et al., 2011). From 1975 to 2015, the world's urban population almost tripled to 3.98 billion (UN, 2020). This development has substantially enlarged the population under high flood and storm risk as both formal and informal built-up areas have grown globally, including flood- and storm-prone areas (Han et al., 2020). Because of the high density of the affected population, urban riverine floods and storm surges, and their overall impacts have become particularly costly and difficult to manage (Jha et al., 2011). The recent IPCC report concludes how the increasing flood events will have high or very high negative impacts globally, pointing out the severe development especially in Asia, Australasia, North America, and small islands. Their highly heterogenic geographical prevalence and diverse consequences (Allan et al., 2020) make them particularly tricky hazards.

Urban growth is fastest in developing countries (UN, 2018), raising concerns for an increase in urban water security problems in the economically less affluent parts of the world (Lundqvist et al., 2005; Varis et al., 2006). Simultaneously, many urban areas are politically important hubs that drive economic and technical development (Brunn et al., 2008) and provide unprecedented opportunities for increased livelihood standards and wealth for a big share of the world's population (UN Habitat, 2016). Urban areas also hosts to over a billion people who live in slums and other marginalized urban conditions (UN, 2018; UN Habitat, 2016). The observed increased floods are known to intensify inequalities: outcomes such as increased occurrence of diarrheal diseases and decreased food security have resulted in increased inequity and societal marginalization in, for example, Africa and Central and South America (IPCC, 2022).

Over the course of the last decade, there has been a surge in scholarly literature and assessment methodologies on large-scale natural hazards and related risks, as well as a leap in policy-driven data infrastructure. Ward, Blauhut, et al. (2020) present a comprehensive review of the various assessment approaches for natural hazard risks. They used the United Nations Sendai Framework (United Nations Office for Disaster Risk Reduction [UNDRR], 2015) as the point of departure and concluded that, while the efforts to understand and assess these risks are rapidly growing, they remain insufficient. Ward, Blauhut, et al. (2020) maintain that the lack of high-quality data has been a key limitation for broader analyses and understanding of the situation on the ground, impeding the possibility to inform policies to adopt measures that mitigate the creation of new risks, reduce existing ones, and build up resilience.

Although an array of global-scale analyses is available on exposure and vulnerability to natural hazards such as floods and storms (Adikari & Yoshitani, 2009; Bouwer, 2011; de Moel et al., 2015; Güneralp et al., 2015; Schröter et al., 2021; Smith et al., 2019; Ward, Blauhut, et al., 2020; Ward et al., 2013), overall trends and figures that would help in obtaining a global understanding are not easily available. In fact, despite the gigantic socioeconomic and environmental impacts of urbanization globally, and the close links to vulnerability and exposure to water-related risks, a macro-view of the situation is currently blurred. Such basic information would be extremely useful as the United Nation's Sendai Framework's priority is that disaster management ought to be based on an understanding of disaster risk in all its dimensions: vulnerability, capacity, exposure of persons and assets, hazard characteristics, and the environment (UNDRR, 2015). Aligned with this priority, one of the Framework's seven targets is to reduce the number of people affected globally by 2030 (UNDRR, 2015). Therefore, we echo the concern of many recent studies (as summarized by Sun et al., 2020) on the lack of quantitative, comparative, and cross-sectorial analyses and thus the macro-scale understanding of the world's urbanization development and related disaster risk challenges.

The existing studies do not yet cover certain key policy-driven data infrastructure and spatial-earth observation data portals such as the European Union Science Hub (JRC, 2022), which include promising policy-driven, high-resolution global data that we wanted to investigate, and understand how they could contribute towards data availability. Interestingly, the number and coverage of such open access data portals have recently increased in an unprecedented manner, and a review on their usability on global-scale water security analyses and integrated science-based policy frameworks would be highly useful and timely (cf., Di Baldassarre et al., 2018).

The EU Science Hub (JRC, 2022) includes the Global Human Settlement Layer data product (GHSL). It is an earth-observation-based data set, which provides a collection of geospatial data sets including spatial distribution of human urban population, as well as built-up areas, hazard exposure, and several other layers with global coverage at subnational high spatial resolution (Florczyk et al., 2020). Its layers have been designed to support the implementation of the EU regional urban policy, which, in turn, aims to support monitoring of the implementation of the Sendai Framework and the other three key post-2015 international policy frameworks that are relevant for disaster management of built-up areas: Sustainable Development Goals, Climate Change Agreements, and the Global Urban Agenda (GHSL, 2016). These all make it highly attractive for the assessment of global flood and storm surge hazard and exposure.

In our analysis, we aim to provide a global view of urban populations' exposure to floods and storm surges by using the GHSL data set. We include the spatial distribution and temporal evolution of the key flood hazard types: riverine floods and tropical storm surges. We also relate exposure to the World Bank's country-specific income categories (high, upper-middle, lower-middle, low) as a proxy for vulnerability. While aiming for a global overview of urban population exposure to specific natural hazards, our objective includes the exploration of the potential of GHSL as a methodological approach that allows analyses across hydrological and administrative scales (UNDRR, 2019).

Using data from 13,136 urban areas (with population ≥50,000 in 2015) (GHSL, 2019) for 1990 and 2015, we provide the first global-scale estimate of urban population exposure to both riverine floods and storm surge hazards with the account of exposed population by the World Bank's income categories. This study expands the work of Ehrlich et al. (2018), who analyzed global exposure to five natural hazards, including the two that we consider, but did not assess exposure by income category, relevance to policy frameworks, or provide spatial summary statistics on exposure, which we do in our study. Such information is crucial for the implementation of global disaster reduction policies such as the Sendai Framework (UNDRR, 2015) as they require data obtained through robust methodology and their comprehensive analysis.

Our study fills two critical knowledge gaps. First, we provide a global-scale and long-term synthesis on human flood and storm surge exposure in urban areas and discuss how this situation is embodied into the post-2015 UN policy agenda, particularly the Sendai Framework. Second, we contribute to the overall understanding of riverine flood and storm surge hazards that have been reported to be hindered by the lack of standardized and comprehensive data collection and integrated analytical frameworks (Di Baldassarre et al., 2018; UNDRR, 2019; Walsh et al., 2016). Both of these have high potential to contribute to more fact-based policy-making.

2 | METHODS

To study the geographical and temporal characteristics of the global population and its exposure to two hazards, riverine floods and storm surges, we use the GHSL data (EC/JRC, 2018; Florczyk et al., 2019), complemented by World Bank data (WDI, 1990). The GHSL documentation uses the term "tropical storm surges," but we use a shorter term "storm surges" for practical reasons in our text. With probabilistic modeling of satellite imaginary, population census data, and the use of several dozens of other global administrative, socioeconomic, and ecological data sets, it allows going beyond the typical administrative-boundary-based approach in the analysis of urban areas (EC/JRC, 2018; Ehrlich et al., 2018; Florczyk et al., 2019; Liu et al., 2020). The GHSL uses probabilistic geospatial modeling to globally define urban areas from population census data (CIESIN/SEDAC, 2018) and Landsat satellite image-based multi-band data of the land cover (resolution 38 m; Markham & Helder, 2012). Landsat is widely used in urban land cover classification studies due to its high potential to produce accurate land cover classification, and additional data for urban microclimate and hydrology studies (Zhu et al., 2012).

The GHSL data set includes data both in raster (several resolutions are available, depending on the data set) and vector formats. For the sake of computational efficiency, we use the point feature data and consider all 13,136 urban areas with the 2015 population over 50,000, taking each urban concentration as a point feature. Thus, each data point represents one urban concentration or city.

Our analysis is based on the GHSL data for the years 1975, 1990, 2000, and 2015. As the GHSL data include income only in 1990 and 2015, the income-related results are illustrated only for these years. We draw the 1990 country-level income categories (low, lower middle, upper middle, and high income) from World Development Indicators (WDI, 1990). For 1975, compatible data were not available. These income levels, indicated by Gross Domestic Product (GDP) per capita, are frequently used indicators for economic performance, which is normally used in vulnerability studies (Nicholls, 2004; Varis et al., 2012, 2019). The spatial analyses and illustrations were produced with ArcGIS Pro 2.5.2, and statistical analysis was performed using R Studio using *dplyr* (Wickham & François, 2019), *ggplot2* (Wickham, 2016), and *sf* (Pebesma, 2018) packages).

3 | RESULTS

The world's urban population grew from 1.54 billion in 1975 to 3.98 billion by 2015 (UN, 2020). The GHSL (2019) data set (considering urban agglomerations of over 50,000 inhabitants instead of the entire urban population) shows a more moderate change: 1.78 billion in 1975 and 3.54 billion in 2015, yielding a population growth of 1.75 billion (2.0-fold) rather than UN's 2.44 billion (2.6-fold). These substantial discrepancies are due to a difference in the definitions of "urban area." While the UN adopts the typically administrative region-based definitions of the countries, the GHSL follows the EU Regional and Urban Policy, which defines urbanized areas or cities as those where at least 50% of the population lives in high-density clusters (Dijkstra & Poelman, 2014).

The world's massive urbanization has meant rapid growth in the *number* of people exposed to natural hazards with regard to floods and tropical storm surges. However, the *proportion* of the world's urban population exposed to these two hazards has remained very much unchanged over the same 40-year period (Table 1), apart from low-income economies of 2015. Their relative exposure to tropical storm surges halved within the study period (Table 1), from 8% to 4%. In terms of the population headcount, this means from 128 million in 1990 to 12 million in 2015.

Asia turned out to be an evident hotspot for both floods and storm surges. In 2015, globally, 75% of the urban population exposed to riverine floods and 80% of that exposed to tropical storm surges, were living in Asia (Figures 1–3). Of the other riverine-flood-exposed people, 12% were in Africa, 7% were in Europe, 4% were in Latin America, and 2% were in North America. In the case of tropical storm surges, 10% were in Northern America, 8% were in Latin America, and 2% were elsewhere. Asia is characterized by big rivers, vast archipelagos, and a very large urban population, and thus it is a significant hotspot for both flood and storm surge hazard exposure (Figures 1 and 2).

In 1990, low-income countries accounted for 70% of all riverine-flood-exposed urban people (Figure 4). The drop after that has been dramatic: in 2015, only 4% were in low-income countries, while 87% were in middle-income countries. For tropical storm surges, the low-income exposure dropped from 50% to 3% in the same period, and the share of the middle-income population grew accordingly. The high-income exposure was much larger in tropical storm surges (32% in 2015) than in riverine floods (9%), and the trend was temporally constant.

From the lists of the 20 globally largest urban agglomerations affected by riverine floods and tropical storm surges in 1990 and 2015 (Figures 1 and 2), we make several novel observations. In 1990, in terms of both phenomena, there was an exposure of approximately 100 million people within the listed cities. Interestingly, flood exposure has grown twice as fast compared to tropical storm surges and threatened 173 million people in 2015. These 20 largest agglomerations are concentrated on the world's most populated latitudinal area between 10°N and 40°N (cf., Kummu & Varis, 2011), that is, on both sides of the Tropic of Cancer (23°26′N). None of the top-20 agglomerations, except Jakarta for storm surges, is in the southern hemisphere. In tropical areas, intense runoff is known to cause flooding more often than in many other regions (Jahandideh-Tehrani et al., 2019).

In each top-20 city, exposure in terms of headcount has been growing. The fastest growth occurred typically in cities that were in low-income countries in 1990. Most of these, however, had moved to the middle-income category by 2015. Regarding floods, in 1990, 12 cities were in low-income countries, while in 2015, there was none. In 1990, three were in high-income countries; in 2015, there were two. The middle-income-country cities became dominant (upper-middle going from two to nine, and lower-middle from one to nine). Regarding storm surges, high-income cities remained at seven; low-income cities dropped from ten to none, and middle-income cities rose from three to thirteen. Six Asian cities are in all four lists: Guangzhou, Shanghai, Seoul, Osaka, Shantou, and Chittagong.

4 | DISCUSSION

4.1 | Exposure patterns to riverine floods and storm surges

The most striking finding is the very rapid and massive change of a remarkable part of both riverine flood

TABLE 1 Urban population (in millions) exposed to riverine floods and storm surges, by income category and by continent.

		Exposed to riverine floods				Exposed to tropical storm surges			
IC	**Continent**	**1975**	**1990**	**2000**	**2015**	**1975**	**1990**	**2000**	**2015**
H in	Asia	14.1	16.7	17.5	18.0	56.8	66.3	69.6	72.0
2015	Europe	23.3	24.8	25.8	27.2	0.0	0.0	0.0	0.0
	Latin America, Carib.	0.3	0.4	0.5	0.6	1.8	2.0	2.0	1.9
	Northern America	9.2	10.8	12.1	13.3	23.2	28.1	31.4	33.4
	Oceania	0.3	0.3	0.4	0.5	1.7	2.0	2.3	2.9
	Total exposed urban population	47.1	53.0	56.3	59.6	83.5	98.4	105.3	110.2
	Total urban population	415.7	482.4	521.6	582.0	415.7	482.4	521.6	582.0
	% Exposed per total population	11	11	11	10	20	20	20	19
UM in	Africa	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4
2015	Asia	110.8	153.5	179.8	216.7	30.5	46.8	58.3	76.6
	Europe	17.1	18.5	18.1	17.7	0.7	0.8	0.7	0.6
	Latin America, Carib.	14.2	18.8	21.6	25.0	8.9	13.2	15.9	19.6
	Oceania	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.2
	Total exposed urban population	142.1	190.9	219.6	259.6	40.5	61.2	75.4	97.4
	Total urban population	609.3	853.6	993.9	1171.6	609.3	853.6	993.9	1171.6
	% Exposed	23	22	22	22	7	7	8	8
LM in	Africa	22.8	34.5	43.2	60.3	0.0	0.0	0.0	0.0
2015	Asia	117.9	177.6	217.4	267.9	56.5	84.7	101.8	121.4
	Europe	2.5	2.7	2.6	2.5	0.0	0.0	0.0	0.0
	Latin America, Carib.	0.3	0.4	0.4	0.6	0.1	0.2	0.3	0.4
	Oceania	0.0	0.1	0.1	0.1	0.3	0.4	0.5	0.7
	Total exposed urban population	143.5	215.2	263.8	331.4	56.9	85.3	102.6	122.5
	Total urban population	676.5	1000.5	1217.6	1514.7	676.5	1000.5	1217.6	1514.7
	% Exposed	21	22	22	22	8	9	8	8
L in	Africa	6.8	10.0	13.1	19.8	1.9	2.4	3.1	4.2
2015	Asia	2.1	2.4	3.0	4.0	1.8	2.3	2.5	2.7
	Latin America, Carib.	0.0	0.0	0.0	0.1	2.6	2.3	3.1	4.5
	Total exposed urban population	8.9	12.5	16.2	24.0	6.4	7.0	8.8	11.4
	Total urban	82.5	125.6	170.7	266.2	82.5	125.6	170.7	266.2
	% Exposed population	11	10	9	9	8	6	5	4
Total	Africa	29.7	44.6	56.5	80.3	2.2	2.7	3.5	4.6
	Asia	244.9	350.1	417.7	506.6	145.6	200.0	232.2	272.7
	Europe	42.9	46.0	46.5	47.4	0.7	0.8	0.7	0.6
	Latin America, Carib.	14.7	19.7	22.5	26.3	13.4	17.7	21.3	26.5
	Northern America	9.2	10.8	12.1	13.3	23.2	28.1	31.4	33.4

TABLE 1 (Continued)

IC	Continent	Exposed to riverine floods 1975	1990	2000	2015	Exposed to tropical storm surges 1975	1990	2000	2015
	Oceania	0.3	0.4	0.5	0.6	2.1	2.6	3.0	3.8
	Total exposed urban population	341.7	471.7	555.9	674.5	187.2	251.8	292.1	341.5
	Total urban population	1784.0	2462.1	2903.8	3534.6	1784.0	2462.1	2903.8	3534.6
	% Exposed	19.2	19.2	19.1	19.1	10.5	10.2	10.1	9.7

Note: Income category (IC, according to country status in 2015): H, high; L, low; LM, lower-middle; UM, upper-middle;.
Source: GHSL (2019).

exposure and tropical storm surge-exposed population from low-income to middle-income categories. Jongman et al. (2015) reported a similar shift when analyzing riverine flood vulnerability development for the period 1980–2010. The authors noted that for a big part of the flood-exposed population, vulnerability decreased due to a shift from lower to higher income class, which typically meant that people were living in places with better infrastructure. They, however, did not quantify this shift, and only analyzed riverine flood-related vulnerability.

Asia is a hotspot of large populations exposed to storm surges, as tropical cyclones occur between tropics, which is also an important zone for crop production (Chikodzi et al., 2021). In terms of vulnerability, Africa stands out as having less capacity and resilience (Birkmann et al., 2022; Varis et al., 2019) to tackle stressors such as floods and storm surges, which can then cause disproportionally high death rates and abrupt food crises to local communities.

4.2 | Reflections related to the Sendai framework

The change of population exposed to the analyzed natural hazards is quite remarkable by itself. However, the Sendai Framework´s classification on developed and developing countries (UNDRR, 2015) without further granularity may not capture much of the dynamics of global developments within the past decades regarding urban riverine flood and storm surge exposure. Most remarkably, it does not appear to fully appreciate what had already happened by the time of the adoption of the Framework, 2015: in 1990, 70% of urban flood exposure was in low-income countries (Figure 4a), but in 2015, this was only 4% (Figure 4c). In 2015, the low-income country exposure had already decreased from 389 million to mere 24. In 2015, already 40% of the total urban riverine flood exposure was in Asian lower-middle income cities, and another 32% in Asian upper-middle income cities (Table 1). To understand the contexts much better and make more effective recommendations, local aspects should be considered more specifically.

Many of the countries—particularly outside Africa—that were still in the low-income category in 1990 are rapidly closing the gap—or moving ahead—of many “developed” or high-income countries with inadequate investment and protection strategies to floods and storms (Aerts et al., 2014; Jongman et al., 2015). In many rapidly developing countries and urban centers, there has been considerable progress regarding disaster risk reduction strategies (Briceño, 2015; Chan et al., 2018; Jongman et al., 2015). The main credit can be given to national and local authorities, policy-making and implementation, and funding of risk reduction strategies. This is the case in cities in countries such as China, Japan, The Philippines, and Indonesia, all of them in different stages of development. At the same time, there are cities, such as Baghdad, that have been considered as upper-middle income cities from 1990 and to date, but that have required of substantial external financial and technical assistance for decades for protection strategies. This reinforces our previous arguments that local conditions as well as highly dynamic and varying development trajectories should be considered for any policy.

4.3 | GHSL and other spatial data products

In this study, we provide a methodology for assessment that is scalable from global down to regional and local levels.

GHSL is one among numerous available, relevant spatial data products for flood and other hazard risk analyses. The most prominent among the other products are the following ones. The Sendai Protocol organization (United Nations Office for Disaster Risk Reduction, UNDRR) supports two of those, namely, DesInventar (UNDRR, 2022a) and PreventionWeb (UNDRR, 2022b). Databases such as EM-DAT (UCLouvain, 2022), The World Bank/Columbia University (Dilley et al., 2005), Integrated Research on Disaster Risk (IRDR, 2022), the Dartmouth Flood Observatory (Brakenridge & Kettner, 2022), NatCatService (MunichRe, 2022), Aqueduct Floods (Hofste et al., 2019; Ward et al., 2013; Ward, Winsemius, et al., 2020), and CATDAT (Daniell, 2022) are also highly relevant, and would deserve research as to their applicability to water security studies. Using such databases systematically for policy development, monitoring activities, and

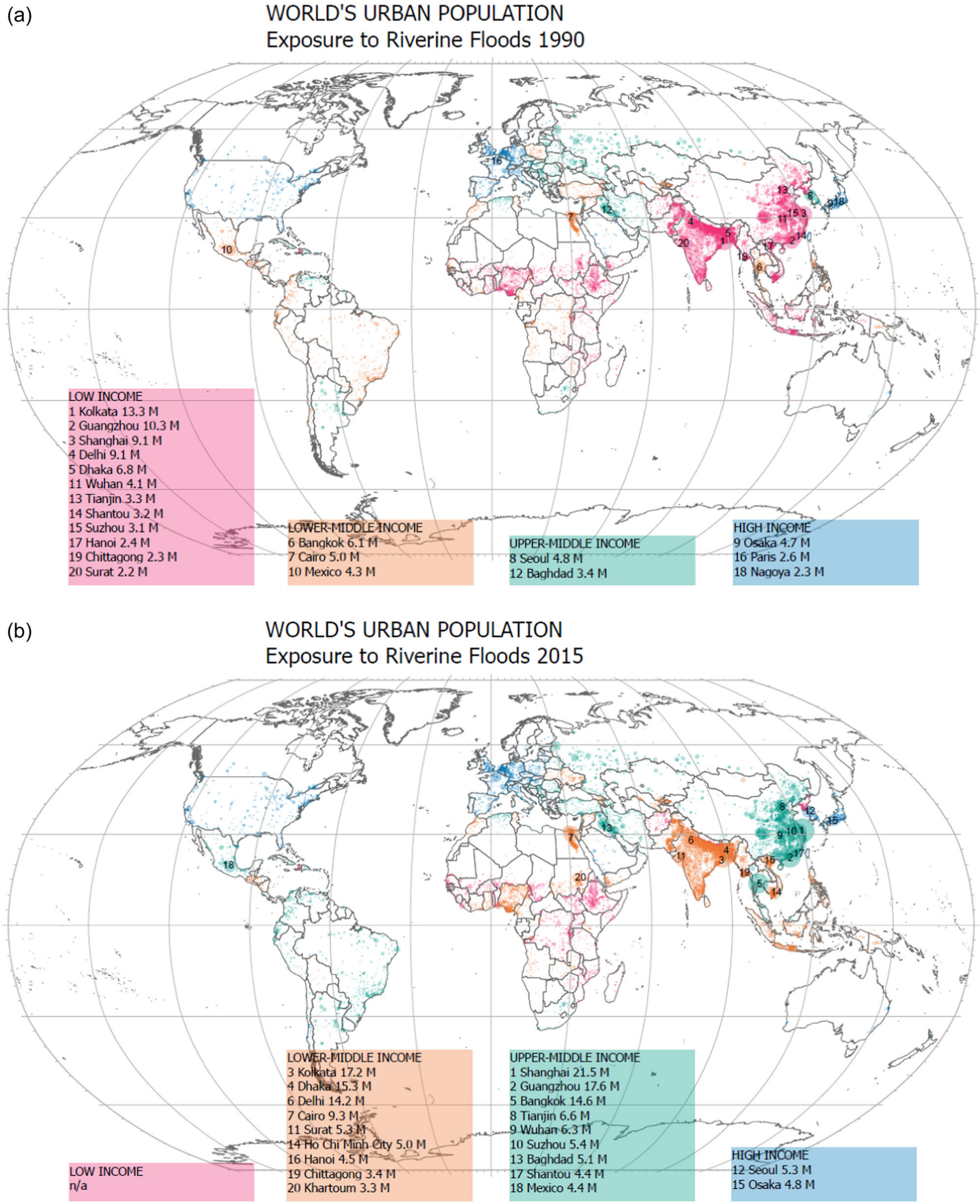

FIGURE 1 Exposure to riverine floods in urban areas with population >50,000 in 1990 (a) and 2015 (b). The 20 most affected (in terms of population affected) cities are numbered, and the numbering indicates the order of magnitude based on people affected. City's circle area is proportional to population and as they are transparent, higher saturation in color means a larger population in the area. Only those urban areas that are exposed to riverine floods are included in the maps (1990, 3930 and 2015, 3958 areas). *Source*: GHSL (2019), WDI (1990).

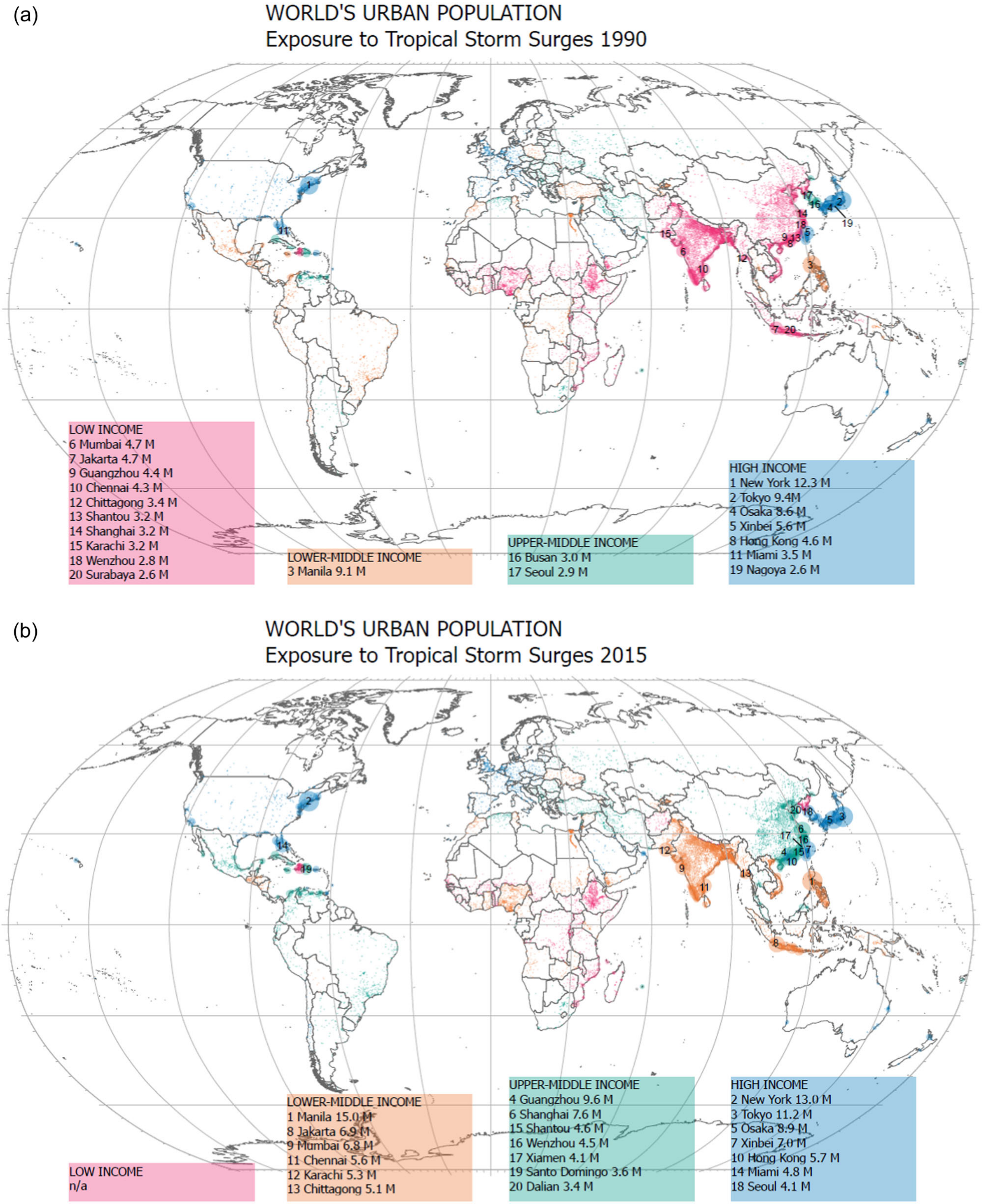

FIGURE 2 Exposure to storm surges in urban areas with population >50,000 in 1990 (a) and 2015 (b). The 20 most affected cities are numbered, and the numbering indicates the order of magnitude based on people affected. City's circle area is proportional to population and as they are transparent, higher saturation in color means a larger population in the area. Only those urban areas that are exposed to tropical storm surges are included in the maps (1990, 889 and 2015, 898 areas). *Source*: GHSL (2019); WDI (1990).

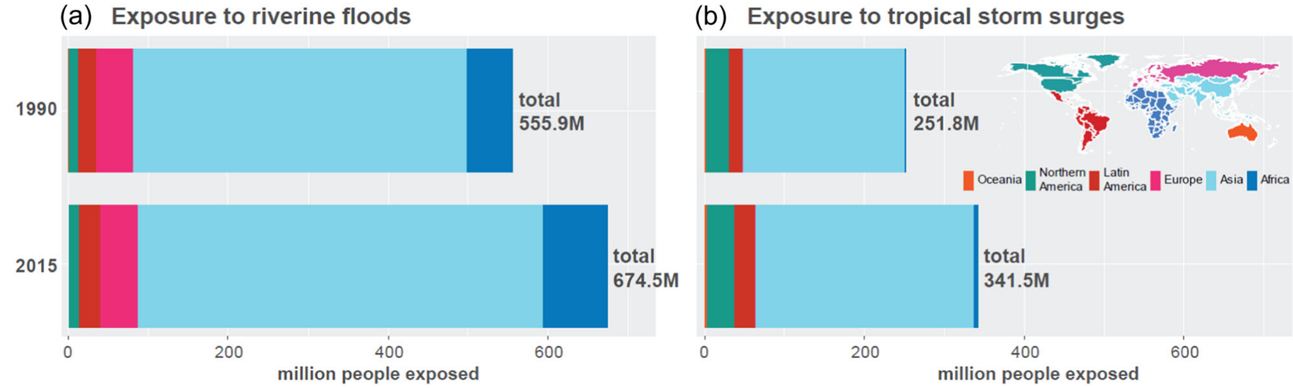

FIGURE 3 Exposure of urban populations (built-up areas with over 50,000 people) to riverine floods (a) and storm surges (b) in 1990 and 2015, by continent. Exposed population in millions. *Source*: GHSL (2019).

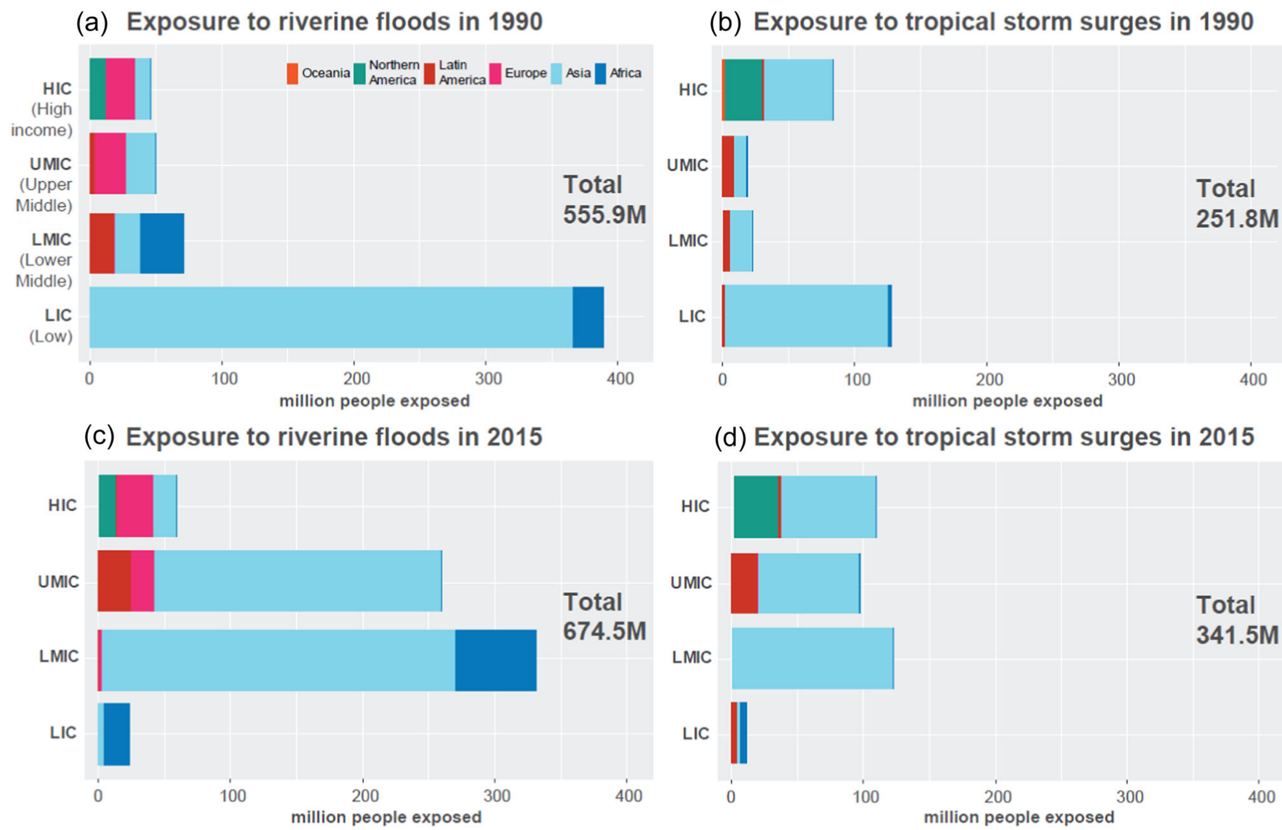

FIGURE 4 Exposure of urban populations (built-up areas with over 50,000 people) to riverine floods and storm surges in 1990 and 2015. Classified by income category and exposed population in millions. *Source*: GHSL (2019).

flood risk investigations would be a rigorous way toward an integrative research framework for studying and interlinking natural hazards and vulnerabilities, as suggested by Di Baldassarre et al. (2018).

A more systematic collection and usability of reporting data from national agencies—scantily available on the annual basis in DesInventar (UNDRR, 2022a)—would benefit in a big way from more systematic linking of disaster reduction policies with the available geospatial information than what has been done at present.

We found the GHSL highly relevant, easy to use, and smartly organized, and we can fully recommend its use in further water security-related studies that are urban area focused. However, the GHSL would largely benefit from the inclusion of more variables, structured systematically across the trajectory of hazards–exposure–vulnerability, to better support policy-relevant analyses. Variables such as flood return periods, topographic and land use data, other hazards, asset damages, casualties, and so forth are not included in GHSL, but in databases, data such as EM-DAT (UCLouvain, 2022), and the documentation of these databases would benefit from better cross-referencing. Analyzing them together should be a standard geospatial undertaking. We highly recommend moving systematically toward that direction, particularly for policy development and monitoring of disaster risks within the Sendai Framework and other post-2015 policy approaches. In general terms, the Sendai Protocol's very broad definition of hazards, so that it is as inclusive as possible, would be among the most useful aspects to consider when developing more comprehensive data products.

Ground proofing of the GHSL data set (as well as other above-mentioned data sets) would be one research priority for future work. For instance, given the Sendai Framework's poverty-related focus, it would be important to know whether peri-urban areas and slums are adequately represented in the GHSL data. If they are not properly identified, then the exposed population, particularly in low-income clusters, may be highly inaccurate.

5 | CONCLUSIONS

Natural hazards are unavoidable, but the extent of their impacts depends on development choices that can result in increasing vulnerabilities and higher exposure of populations to risk, or the opposite. In this study, we address the exposure of two such hazards, riverine floods and tropical storm surges, in a global study considering all urban areas in the world that exceed 50,000 inhabitants. We also scrutinize the opportunities provided by the surge of relevant data products and data infrastructure that enhances the possibilities to inform policies and reduce and tackle disaster risks. Our focus is on the Global Human Settlement Layer data product provided by the European Union Science Hub (JRC, 2022).

Within our study period (1975–2015), the bulk of global riverine flood and storm surge exposure (in terms of population headcount) remained in the Asian continent. With nearly 60% of the world's population, the continent continues to account for 75% of the exposure to riverine floods, and 80% to tropical storm surges. Partly due to widespread social and economic progress in that continent, a dramatic shift was observed for exposure from low-income to middle-income regions. Whereas in 1990, 70% of the world's urban exposed populations were in low-income countries, this share had dropped dramatically to mere 4% by 2015. That was the year of the onset of the Sendai Framework in 2015. Tropical storm surge exposure showed a similar shift, albeit not as dramatic: from 50% to 3%. Vast socioeconomic development accounted for this shift as countries have become richer. In most cases, this has resulted in more effective disaster risk reduction policies, strategies, and actions, including strengthening community preparedness, establishing early warning systems, introducing international standards, and improved monitoring.

In terms of global policy frameworks, such as the Sendai Framework, we conclude that there is time to further elaborate and specify the use of terms such as "developing countries," where many vibrant economies but also the poorest ones are put together, without consideration of major societal aspects including economic and institutional capacities, status of governance, planning and management of urban areas, an appropriate balance of structural and nonstructural measures, and more. All these aspects ought to be incorporated into disaster risk reduction policy-making and implementation for these to be more effective at the local levels.

The availability of published and quality-checked high-resolution data is expanding rapidly, and we see many benefits for making enhanced use of that enormous resource in both scholarly and policy-related work. The benefits include more accurate estimates of population sizes, location of human settlements, and extent of urban areas, which are examples of factors that are fundamental to delineating disaster risk reduction policies in the presence of natural hazards. Finally, more links from policy frameworks such as the Sendai Framework should be done to drivers such as socioeconomic development, development in built environment, and land use including changes in permeability, population dynamics, and peri-urban areas and slums. This will contribute towards building better preparedness and response strategies.

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