Mapping Global Population Exposure to Rainstorms

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1 Background

With global warming, the global hydrological cycle and the spatiotemporal pattern of extreme precipitation have changed greatly in recent years (IPCC 2013; Kong 2020). Evidence from both observations and climate model simulations suggests that the frequency and intensity of extreme precipitation showed an increasing trend and will further increase in the future with climate change. For example, Westra et al. (2013) examined data from 8326 high-quality land-based observing stations globally and found that about two-thirds of the stations showed a significant increase in extreme precipitation. Using the same dataset but for a longer time period, Sun et al. (2021) found that a larger percentage of stations showed statistically significant increasing trends. Climate projections from the Coupled Model Intercomparison Project Phase 5 show continued intensification of daily precipitation extremes from 1951 to 2099 (Donat et al. 2016). Given that extreme precipitation and its induced disasters (e.g., floods and landslides) are one of the most serious consequences of climate change and pose a great threat to life and property, it has aroused widespread attention. Understanding exposure is necessary for disaster risk reduction (IPCC 2012). Likewise, with the social and economic developments and the acceleration of

urbanization, the population exposed to natural hazards is increasing and demographic changes, such as an increase in the elderly population, will also amplify exposure of vulnerable people (Qin et al. 2015; Liang et al. 2017). Different levels of global warming (e.g., 1.5 °C and 2 °C) would cause different population exposure to extreme precipitation, and an 0.5 °C less warming would reduce exposures remarkably (Zhang et al. 2018; Shi et al. 2021). From the baseline period to the end of the twenty-first century, under Representative Concentration Pathway (RCP) 4.5-shared socioeconomic pathway (SSP) 2 scenario, population exposure to rainstorms shows an increasing trend in most regions of the world, and the areas with high exposure are mainly distributed in Asia (Liao et al. 2019). By the end of the twenty-first century, although China's estimated population will drop, the population exposure to extreme precipitation will increase significantly under the RCP4.5-SSP2 scenario and the increase in the RCP8.5-SSP3 scenario is even larger (Chen and Sun 2020). While there exist many studies on population exposure to extreme precipitation, the resolution of climate models used in most studies is relatively coarse and there are few studies on RCP2.6 scenarios.

In this section, the population exposure to rainstorms of the world was calculated based on daily precipitation data (RCP2.6, RCP4.5 and RCP8.5) from the Institute of Atmospheric Physics, Chinese Academy of Sciences and population data (SSP1, SSP2, and SSP3) from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. The data cover three time periods and three scenario combinations, namely, the baseline (1986–2005), 2030s (2016–2035), and 2050s (2046–2065) and the RCP2.6-SSP1 scenario, RCP4.5-SSP2 scenario, and RCP8.5-SSP3 scenario, respectively. Based on these, the global population exposure to rainstorms was assessed and mapped at the grid level.

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2 Method

In this section, rainstorm was defined by daily precipitation exceeding the 95th percentile value for each grid. The method improved by Bonsal et al. (2001) was used when calculating the 95th percentile, in which daily precipitation data for each year were first ranked in ascending order $X_1, X_2, \dots, X_N$, and the probability P_{ro} that a random value is less than or equal to the rank of that value X_m was estimated by Eq. (1).

$$P_{ro} = (m - 0.31) / (N + 0.38) \quad (1)$$

where m is the rank and N is the number of samples. For example, if there are 120 values, the 95th percentile value is linearly interpolated between the 115th-ranked value (corresponding to $P_{ro} = 95.27\%$) and the 114th-ranked value ($P_{ro} = 94.44\%$).

Figure 1 shows the technical flowchart for mapping the population exposure to rainstorms. We first calculated the threshold of each model for each year, then calculated the average threshold values of the 20 years in each period, which represents the threshold of each model for each period. Multi-model ensembles (MMEs) are widely used in research especially for global-scale climate change studies because it is generally found to have a better performance than single models. So, in this study, the average of the individual rainstorm thresholds of the 21 models (RCP2.6 has only 13 models) was calculated and used as the rainstorm threshold for each grid. Based on the threshold value, we calculated the annual rainfall from rainstorms (R95pTOT) by accumulating daily precipitation exceeding the threshold in a certain year for each model, then used the

20-year averages of the rainfall in each period to represent the rainstorm intensity, and rainfall from rainstorms was the average of the 21 models (RCP2.6 has only 13 models).

In this study, population exposure to rainstorms is defined as the population in rainstorm-prone areas. The exposure can be computed by multiplying the rainstorm intensity and population for each grid. Then by zonal statistics, we derived national population exposures to rainstorms. We obtained the change of exposures by subtracting exposures in the baseline period from exposures in the future scenarios and then calculated exposures' change of the MME by the same method as for exposures. We used standard deviation to represent the uncertainty between models.

3 Results

By zonal statistics of the population exposure to rainstorms, we obtained the national population exposures to rainstorms of each country/region and present the data of the top 10 countries/regions in Fig. 2. Figure 2 shows that most of these countries are in Asia. The exposures of India and China are more than 2.5×10^{11} person · mm, which is 2 to 18 times of the other eight countries.

The spatial distribution patterns of the population exposure to rainstorms are similar for each scenario and time period combination. The areas with high exposure are mainly distributed in East Asia (e.g., southeastern China, South Korea, and Japan), South Asia (e.g., India and Bangladesh), and Southeast Asia (e.g., the Philippines and Indonesia), and scattered in Africa (e.g., Uganda, Nigeria, and Ethiopia). The spatial patterns in Asia and Africa have changed the most.

Fig. 1 Technical flowchart for mapping global population exposure to rainstorms

Fig. 2 Population exposure to rainstorms of the top 10 countries/regions (in descending order by total exposure). The error bar represents the one standard deviation across the combination of 21 (13 for Representative Concentration Pathway (RCP) 2.6) general circulation models (GCMs) and 3 shared socioeconomic pathways (SSPs)

4 Maps

Global population exposure to rainstorm (Baseline)

Global population exposure to rainstorm (2030s, RCP2.6-SSP1)

Global population exposure to rainstorm (2030s, RCP4.5-SSP2)

Global population exposure to rainstorm (2030s, RCP8.5-SSP3)

Global population exposure to rainstorm (2050s, RCP2.6-SSP1)

Global population exposure to rainstorm (2050s, RCP4.5-SSP2)

Global population exposure to rainstorm (2050s, RCP8.5-SSP3)

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