

Global risk of flood-induced population displacements

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Introduction

Assessments of climate extremes on human security are one of the urgent issues in the world (IPCC 2014, SDGs Goal13). Especially, extreme weather events such as floods often cause population displacements that force people to change their residences temporarily or permanently (Black et al. 2011; Lu et al. 2016; Mora et al. 2018). However, complex and multiple social and environmental factors drive population displacements (Black et al. 2011), and it is difficult to estimate high potential areas of displacements at a global scale. Here we showed vulnerable areas of flood-induced displacements in the world by combining observed flood-induced displacements with modelled flood exposed population. We also examine effects of economic levels and flood exposures on flood-induced displacements.

Methods

We used an output of a global hydrological model (Cama-Flood, Yamazaki et al. 2011) to estimate the potential flooded areas and exposed population in each country in the world (Tanoue et al. 2020). We made a bivariate map that is based on flood exposed population divided and flood-induced displacements during 2008-2013. In addition to that, we used a generalized linear model to examine effects of flood exposed population and economic conditions on flood-induced displacements as following.

Flood-induced displacements $\sim \beta_0 + \beta_1 * \text{Economic Level} + \beta_2 * \text{Flood exposed population}$
 β_i is coefficient of explanatory variables.

For “Economic Level”, we used the classification during 2008 -2013 that are provided by World Bank (<https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>). They classified countries and regions into High, Upper middle, Lower middle and Low economic levels that based on their GNI (Gross National Income). “Flood scale” is based on the anomaly of flood areas in each country during 1960-2013.

Results and Discussion

Flood-induced displacements had been high in African, South/South-eastern Asian, Oceania and South American countries while it had been low in European countries during 2008-2013, Particularly, Africa might be highly vulnerable to floods because they have high flood-induced displacement even at low- to mid-level flood exposure (Figure 1). Results of a generalized linear

model analysis showed that economic conditions substantial impact flood-induced displacements (Table 1). Especially, high economic level countries may reduce impacts of floods on population displacements while low- middle economic level countries have high flood-induced displacements. For example, Netherlands has very small number of flood-induced displacements during 2008-2013 even there were potentially exposed people every year (around 280,000-6,440,000 people). Moreover, the relationship between income levels and displacement is nonlinear, and this nonlinearity indicates large gaps in flood-induced displacement between high- and low-income countries. We suggest that low-income countries, particularly in Africa, face a high risk of flood-induced displacement at even low or medium flood exposures (Kakinuma et al.2020).

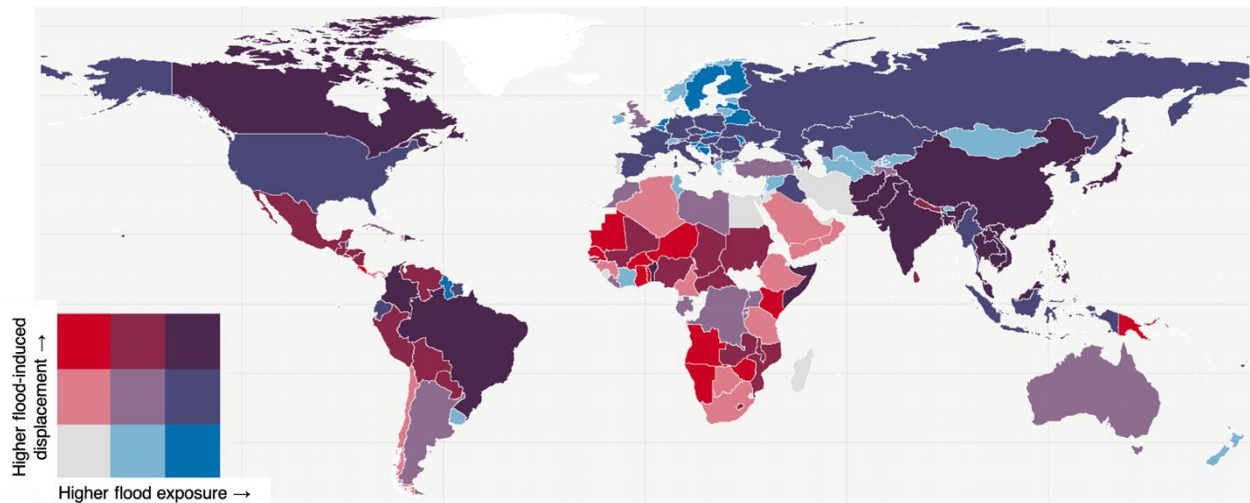


Figure 1 Flood exposures and flood-induced population displacement in the world. The figure is from Kakinuma *et al.* (2020). We used average of flood-induced displacement and flood-exposures to total population in each country during 2008-2013. The relation between flood-induced displacements and flood exposures determined colors that based on 1/3 quantile of each variable. White colored areas have no available data.

Table 1. Parameter estimates for the GLM. Data from Kakinuma et al. (2020)

	Estimates	95% Credible Interval	p
Economic Condition (GNI per capita)	-0.25	[-0.39, -0.080]	< 0.01
Flood exposure	0.064	[-0.089, 0.22]	0.41

Unstable social conditions, such as conflicts and rapid urban growth, may interact with extreme weather events and cause synergistic impacts on displacements. For example, our results showed that Colombia has extremely large occurrence of displacements, especially around 3 million people are displaced by floods in 2010 (IDMC 2017). Most of the flood-induced displacement population in 2010 experienced conflict-induced displacements (Shultz et al. 2014). Such

secondary displacements were also reported in Eastern African countries, conflicts often force people to settle in environmental vulnerable places (Tafere 2018). Poverty and rapid urbanization also caused secondary displacements especially previous studies reported it in African countries (e.g., Douglas et al. 2009, Dube 2018). People often move from rural to urban because of poverty or unstable social condition, and some of them force to live in unsafe zones around a city (Douglas et al. 2009). In addition to that, infrastructures and drainage managements often can't be update in accordance with massive urbanization (Agbola et al. 2012). For instance, Nigeria where had extremely high occurrence of the displacement, flood hit metropolitan areas in 2011 and a lack of effective drainage managements would amplify impacts of the flood (Agbola et al. 2012). Zimbabwe was observed that there is a feedback between poverty and flood, poor people usually live in flood-exposed areas and get more severe economic damages by floods (Dube et al. 2018). Poor people often are trapped in these environmental vulnerable zones even after flood attacked because of their economic conditions make them difficult to move to another areas (Black et al. 2013). Poverty, unstable social conditions and rapid population may relate with flood-induced displacements, and this may be one of the most reasons that many African countries had extremely high occurrence of displacements.

Extremes weather events are projected to be increased and it will have significant impact on population displacements that compromise human security (IPCC 2014). Assessment of potential flood-induced displacements with global perspectives are critical to develop adaptation measures to future climate changes. We showed occurrence of flood-induced displacements in the world. In addition to that, we showed that low economic conditions may intensify occurrence of displacement and most of extremely high occurrence countries are found in Africa. Many of high occurrence of displacement countries, such as Southeast Asia, Peninsular India, eastern Africa, are projected to increase of flood intensities and magnitude (Hirabayashi et al. 2013). Development of adaptation measures such as drainage management, planned relocations are urgent issues especially in these regions. This study focused only on the economic conditions and flood scales to explain flood-induced displacements. Population displacement are complex phenomena (Black et al. 2011), and multiple factors such as the social memories of floods, political conditions, and agricultural productions need to be considered to clarify patterns and mechanism of displacements in future studies. In addition to that, human migration and displacements occurred and interrelated across multiple scales, so that is important to conduct research through from local to global scales. Although our research includes several limitations, our study made a first step to examine the potential environmental-induced population displacements in the world.

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