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Estimation of the effects of climate change on flood-triggered economic losses in Japan

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ABSTRACT

This study evaluates the effects of climate change on economic losses due to flood-related damage in Japan. Three selected GCM climate data were downscaled using an analytical method that uses observed precipitation data as the reference resolution. The downscaled climate data were used to estimate extreme rainfall for different return periods. The extreme rainfall estimates were then entered into a two-dimensional (2D) non-uniform flow model to estimate flood inundation information. A technique based on the land use type of the flood area was employed to estimate economic losses due to flood damages. The results of the rainfall analysis show that at present (in 2000), the Nankai region, and the area from Wakayama Prefecture to Kagoshima Prefecture and the mountains of the Japan Alps receive very high extreme rainfall. By 2050, in addition to these areas, the rainfall in the Tokai and Koshinetsu regions will be 1.2 to 1.3 times greater than at present. The overall variations show that the potential economic loss is greater for the SRES-B1, A2 and A1B scenarios for all return periods. These results clearly show that flood-related economic losses in Japan will increase significantly in the future as a result of climate change. It indicates that Japan needs to increase the capital investment to implement flood control and mitigation measures in the future. As this study presents comprehensive results in very fine resolution (1 km × 1 km), the outcome of this study is more important for regional scale decision making processes will be useful to the public, economists, and policy and decision makers in planning and designing flood control measures.

1. Introduction

In recent years, the effects of climate change on natural disasters have attracted significant attention among researchers and the public [8]. Cyclones, typhoons, floods, landslides and other slope hazards are major natural disasters. Growing attention to the threats posed by the effects of climate change on natural disasters has led to increasing contact and interaction between the fields of climate change adaptation and disaster risk reduction [34]. In addition, authorities, decision makers and policy makers have responded to the public's needs for vulnerability reduction and resilience improvement to adapt to climate-change-induced disasters [33,31]. Several studies related to natural disasters and climate change have highlighted the ways in which climate change alters disaster risks and the contributions that disaster risk reduction can make to climate change adaptation [4,29,20,5].

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The literature highlights several major studies on the effects of climate change on natural disasters in Japan [15,27,6]. Flood is one of the major types of natural disasters that occur in Japan [3,17,26]. Therefore, it is very important to evaluate how future climate change may alter the probability of flood disasters. Due to its steep geography and humid climate, Japan is particularly prone to flood hazards [17]. Several local heavy storms have been recorded in Japan in recent years (Niigata and Fukushima: 12–13 July 2004; Fukui: 17–18 July 2004; Miyazaki: 4–7 September 2005; Chugoku and Kyushu: 19–26 July 2009; Amami: 18–21 October 2010; Niigata and Fukushima: 27–30 July 2011; Kyushu: 11–14 July 2012). All of these heavy rainfalls created local floods and damage, leading to significant economic losses. Literature shows that Japan has been coping with the issues related to flood control for a long time ([25,35,37,17]). The frequency of floods and the damage caused by flooding has increased since 2004 [17]. In 2008, the Japanese government organized a committee of experts to implement local flood control policies [24]. However, torrential rains associated with climate change create floods that exceed current design criteria, and current flood control measures are not adequate to address such floods [27]. The damage caused by these floods calls attention to the necessity of updated flood control measures that take the potential effects of future climate change into account.

Global climate models (GCMs) are the basic source of projections of future trends in various climate variables. These models can simulate climate projections at the global or continental scale quite reliably but are not accurate enough at the regional scale [30,10]. This inaccuracy is because the spatial resolution of GCM grids is too coarse to resolve many important sub-grid scale processes (most notably those pertaining to the hydrological cycle) and because GCM output is often unreliable at the individual grid and sub-grid box scales [7]. The general procedures for assessing the effects of climate change is to first project future climate change with GCM simulations, then downscale climate projections from the global to the regional scale, and then generate projections using numerical models and climate change simulations [1].

Taking these facts into account, this study mainly aims to develop tools and mechanisms to estimate the flood related economic loss in Japan taking the impacts of climate change into consideration. Three GCM data sources (MIROC3.2, CGCM2.3.2 and PCM) were used in this study to evaluate the effects of future climate change on flood disasters in Japan. As the spatial resolutions of the selected GCMs are very coarse (280 km × 280 km), an analytical downscaling method was used to downscale the data to a fine resolution of 1 km × 1 km. The downscaled climate change data were used to estimate extreme rainfall data, and these data were used to estimate flood inundation using a 2D non-uniform flow model. An approach which uses land use type of the inundation area was used to estimate the economic loss due to flooding and to predict future damage. The relationships developed in this study and the estimated economic loss due to floods will be useful to predict the future damage and in developing sustainable flood mitigation and adaptation procedures in Japan.

2. Methodology and data

The methodology for predicting future economic losses due to flood damage triggered by climate change involves downscaling the collected GCM precipitation data to a fine resolution that is compatible with regional-scale evaluations. We also used a numerical approach to simulate flood inundation and estimate the associated flood depth, inundation period and inundation area for use in estimating flood damage.

2.1. Regional climate downscaling

Three sets of GCM data were used for the assessment: MIROC3.2, co-developed by the Center for Climate System Research (CCSR), the National Institute for Environmental Studies (NIES) and the Frontier Research Center for Global Change (FRCGC); CGCM2.3.2, developed by the Japanese Meteorological Research Institute; and PCM, developed by the National Centre for Atmospheric Research in Japan ([13]). These models were developed by the Meteorological Research Institute and other domestic research organizations, and they offer the advantage that additional detailed information about the whole of Japan is provided. All of these models have a horizontal resolution of 280 km × 280 km, which creates 18 grid cells covering all of Japan. To evaluate the effects of different climate scenarios on flood damage, we used three SRES scenarios (Special Report on Emissions Scenarios: A1B, A2 and B1) [9].

Mesh Climate Value 2000, produced by the Japan Meteorological Agency [11], was used as the main reference data set for the analytical downscaling process. The resolution of Mesh Climate Value 2000 is 1 km × 1 km. These data are produced using precipitation observation data from AMeDAS (the Automated Meteorological Data Acquisition System). As the mean monthly precipitation data are used for the analysis, mean monthly precipitation data from GCM models are downscaled to fine resolution using the following equation.

$$P_i = Bd_i \times Gf_j \tag{1}$$

where P = monthly precipitation after downscaling (mm), Bd = fine resolution factor, Gf = monthly precipitation obtained from GCM model data (mm), and i, j = elements of 1- and 280 km resolution data sets.

The fine resolution factor (Bd) is the main governing factor in developing the downscaled precipitation value for a given location. The fine resolution factor (Bd) is defined as the ratio between the Mesh Climate Value (observed data) and the present precipitation data of the GCM model considered at a resolution of 1 km × 1 km, as shown below.

$$Bd_i = \frac{\text{Mesh climate Model precipitation value}_i\ (1\text{ km} \times 1\text{ km resolution})}{\text{GCM model present precipitation value}_i\ (1\text{ km} \times 1\text{ km resolution})} \tag{2}$$

To minimize the resolution of the present climate data of the given GCM model data to 1 km × 1 km resolution, we used the inverse distance weighing method. Bd represents regional characteristics of rainfall that depend on the geographic features of the area. This method permits the generation of smooth- and fine-resolution spatial distributions of