Adaptation effect for flood in whole Japan using GCMs with scenarios

So Kazama, Masayoshi Akima, and Yasuaki Hijioka
School of Engineering, Tohoku University, Japan
National Institute of Environmental Studies

Abstract

In the case of current flood protection level, future flood damage costs are much different for each GCM with scenario which has double value on the estimation. Roughly the damage cost will be 2 to 3 times in around 2100 comparing with current situation. In the case of adapted flood protection level by increase of 20 years return period for peak discharge, some of all damage costs by all GCMs will be negative to current damage and the average future damage cost with the adaptation is similar to current damage cost that the shift of damage cost in the future is similar to the investment of 20 years return period protection.

Keywords: Climate change, Landuse change, impact, damage cost

Introduction

Recently Japan had severe flood damages with casualties every year. The damages occurred in Yamagata, 2013 and 2014, 4 people casualties in Ibaraki and Miyagi in 2015, and more than 10 death people in Iwate in 2016. These damage areas never have such extreme rainfall events for long time. Therefore almost mass media doubt them by climate change with global warming. These water disasters had been already noticed by researchers in the world and international organizations (IPCC, 2012, 2014, ADB, 2013).

Currently many organizations in Japan are studying on impact and adaptation by climate change using some methods. Tezuka et al.(2013) evaluated the flood damage cost in the future using 3 GCMs with SRES scenarios. Although nowadays similar researches have been made by many Japanese researchers (Yoshikawa wt al., 2010, Mouri et al, 2012.), little discussion pays attention on flood damage cost in whole Japan and adaptation assessment.

This study shows the future projection of flood damage cost in the future and discuss the uncertainty for the projections using 4 GCMs and RCP scenarios. The method advanced discussion on adaptation effect using change of protection level of flood. These results was shown in distributed data as type of a map in Japan and was used for comparison with each region in view of nation. Also these study could indicate vulnerable and risk areas and make us consider investment of flood adaptation and the policy in each area.

Data used

Elevation and landuse data are used for flood calculation with extreme rainfall data with each return period, which are distributed data by interpolation on GIS. The all data resolution is 1km X 1km as grid cell type. The flood damage cost is also calculated as the same resolution, which is common scale to discuss it in the whole national area and to compare with other national data. Many researchers in Japan are using this scale for study on climate change impact. Extreme rainfall data is also made with 1km X 1km resolution interpolated by the extreme data at observing points by Japan Meteorological Agency, which is estimated from the past 30 to 50 years data to obtain the return period. For calibration of damage cost, we used water disaster statistics by Ministry of Land, Infrastructure, Transportation and Tourism (MLIT).

Input data should consider the return period of discharge to provide probabilistic rainfall (with return period) producing the same probabilistic discharge (with same return period) in whole Japan. For this purpose, the catchment area is used to obtain distribution of probabilistic rainfall, which is called as rainfall contributing to probabilistic flood discharge (RCPD). To estimate the RCPD, we focus on runoff coefficient, which is a ratio of discharge to rainfall according to catchment area. The relationship between the catchment area and extreme runoff coefficient (ERC), which is calculated by extreme rainfall and flood discharge at the same period (daily), is obtained from 109 catchment areas in Japan. The relationship is expressed as the following logarithm function,

$$RF_m(A)=86.4D_m/R_mA\ .$$

Where RF: ERC, D:flood discharge(m3/s), A: catchment area(km2), R: daily extreme rainfall(mm/d), and m:return period. Here 86.4 is a unit adjust parameter. Then, observed data provides relationship between ERC and catchment area for each return period by regression analysis. For example, we obtain the following function with 100 years return period.

$$RF_{100}(A)=3.536(A+80.512)^{-0.287}$$

We can see that ERC function is decreasing as exponentially. The phenomena that the rainfall area is expanding as the highest rainfall decreasing, is well-known as DAD(Duration-Area-Depth) analysis. To provide RCPD at an arbitrary point, we uses point runoff ratio (PRR), which is ratio of probabilistic discharge to the same probabilistic rainfall at an arbitrary point. This means PRR is distributed runoff ratio for the upstream direction to satisfy extreme runoff ratio at an arbitrary point in the upstream. To produce the probabilistic flood discharge at each grid cell, the following equation is obtained.

$$RC_m(A_n) = \sum_{n=1}^{n-1} \left\{ \frac{R_m(A_{n-i})}{R_m(A_n)} \left(RF_m(A_n) - RC_m(A_{n-i}) \right) \right\} + RF_m(A_n)$$

$$RF_m(A_1)=RC_m(A_1)=1.0, \quad n=2,3,4\dots.$$

Where $R_m(A_i)$:rainfall(mm/d) with return period m at catchment area A_i, n:grid cell number from the highest upstream point, $RC_m(A_n)$: PRR. The highest point, catchment area is 1km2, has 1.0 for RCC because there is no inflow. Finally distributed RCPD is obtained from the multiplying PRR with distributed extreme rainfall with certain return period interpolated extreme rainfall obtained at observed points. The probabilistic discharge map is validated by Tezuka et al.(2013) and shows good tendency with not a little variance. This dataset is better method to estimate probabilistic flood discharge than other past methods. However, we should notice that this study has uncertainty on this estimation similar to GCM projections.

For future projection, we prepared 3 scenarios of RCP 2.6, 4.5 and 8.5 for 4 GCMs, which are MIROC5, MRI-CGCM3.0, GFDL-CM3, and HadGEM2-ES from CIMP5 dataset. The near future and far future projection are set for 2050 and 2100 averaged data duration 2031-2050 and 2081-2100. These are carried out by S-8 project by Ministry of Environment, Japan (S-8, 2014).

Methodology

The rainfall data is input into flood and inundation simulation using 2D unsteady flow model depending on elevation data, which neglect hydraulic structures such as dike, levee, pumping station, and so forth. Instead of this supposition, the difference between damage costs with difference return period floods is used considering the flood damage with countermeasures. Japan has constructed many flood protections for long time. Although the protection level is difference depending on regions, which cover from 5 years to 150 years return period, we used the average 50 years return period in all areas of Japan. Roughness of the model is given as landuse according to hydraulic formula book (JSCE, 1999).

Damage cost is calculated using the flood control economy investigation manual (2005), which is estimating damage cost depending on water depth and inundation duration for each landuse. For simulation restriction, the calculation period is 7 days and the maximum duration of inundation is 7 days in this study. Only general assets is considered for simulation without infrastructure and civil works damages.

For future projection of each scenarios and GCMs, we make a table of rainfall intensity and damage cost input by the simulations except simulation for all conditions as simple method for time reduction. Flood damage cost on future rainfall by a GCM and a RCP, is calculated interpolating some combination datasets for rainfalls and damage costs by pre-simulation.

Adaptation effect is evaluated by change of flood protection level with different return period. Fundamental flood protection level is 50 years return period as average in whole Japan and the adapted flood protection level is 70 years return period. Therefore this adaption increases the level with 20 years return period higher in whole Japan.

These evaluation is carried out for each scenarios and GCMs using simple method in the near and far future.

Results and discussion

The damage cost estimation using flood and inundation in current climate condition. The current annual expected flood damage cost is estimated from the multiplying damage cost for each return period with interval probability from 50 years return period as flood protection level. The expected annul flood damage cost is 714 billion JPY (is nearly equaled to 7 billion USD). This estimation is verified with actual flood damages obtained in 7 1st class river basins in Japan from MLIT assessment reports and actual flood damage record as shown in Figure 1. We can see that this estimation is much less than MLIT assessment report and more than actual flood records. The reasons are that the MLIT assessment report calculates the damage cost in the case of flooding concentration in urban areas with high assets and that the actual flood often generates in rural areas with low assets. Therefore this study estimation is higher than actual flood and lower than potential flood. Tezuka (2014) discussed more detailed cases for this estimation and concluded that this estimation can be used for relative evaluation in spatial and temporal projections.

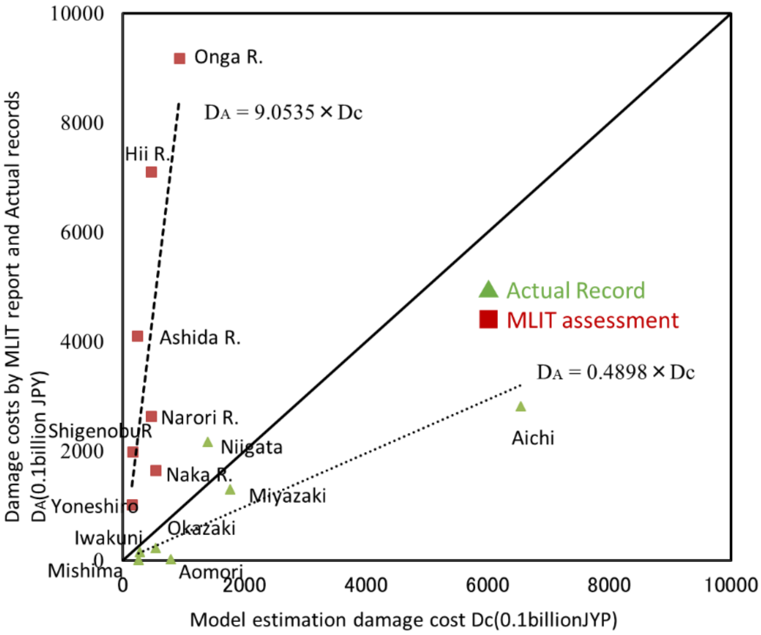

Figure 1 Flood damage cost estimation with different methods

Simple evaluation methodology constructed by the above algorism and applied on 4 GCMs and 3 scenarios as shown in Figure 2. Annual expected damage cost in Japan is almost 180 billion JPY in current stage and future damage costs will increase to about 200 to 500 billion JPY in 2050 and to about 200 to 600 billion JPY in 2100. We can see that the estimation costs have a big variance of each GCM with scenarios. However, the ensemble tendency shows an increasing trend.

The difference between current damage and future damage shows in Figure 3 to understand easier the increase rate. All projects except MRI model with RCP4.5 in 2100 have increase trend. These shows that Japan will have more sever situation on water disasters in the future. Japan may pay more cost to 200 and 300 billion JPY (1USD=100JPY) in 2050 and 2100, respectively. This cost is almost double to current flood damage costs. These results can show a map type in all Japan and make us understand easily where flood produces more severe and can help making a nationwide adaptation policy depending on each area.

The model simulation can calculate damage costs with different flood protection level. Figure 3 also shows the difference between current flood protection level and future flood protection level rising up to 20 years return period higher. The gray color marks show change of damage cost in the future after the adaption. We can see the decreased damage cost, which means flood protection level with 20 years return period higher is useful for future flood. This may be one of the target tackling with future flood disasters. However, it takes too long time to rise up the flood protection level from urban city to rural area in whole Japan and need huge amount investments. It would not be easy to adapt like this according to climate change. This calculation does not consider other water-disasters like slope failure and storm surge, which also occurs at the same time as flooding. Water disasters would show more severe adaptation and investment. We need more discussion on adaptation options such as infrastructures and soft wares hereafter.

Summary

We estimated flood damage cost more accurately introducing rainfall contributing to probabilistic flood discharge (RCPD), extreme runoff coefficient (ERC), and point runoff ratio (PRR) with flood and inundation simulation model and the flood control economy investigation manual. This flood damage estimation was carried out on 4 GCMs and 3 RCP scenarios and showed different future damage costs in the near and far future, which was almost double damage cost comparing with current flood damage. To reduce the future flood damage, flood protection ability increased until 20 years return period higher is necessary. We need more evaluation and discussion on specified options for adaption using these results.

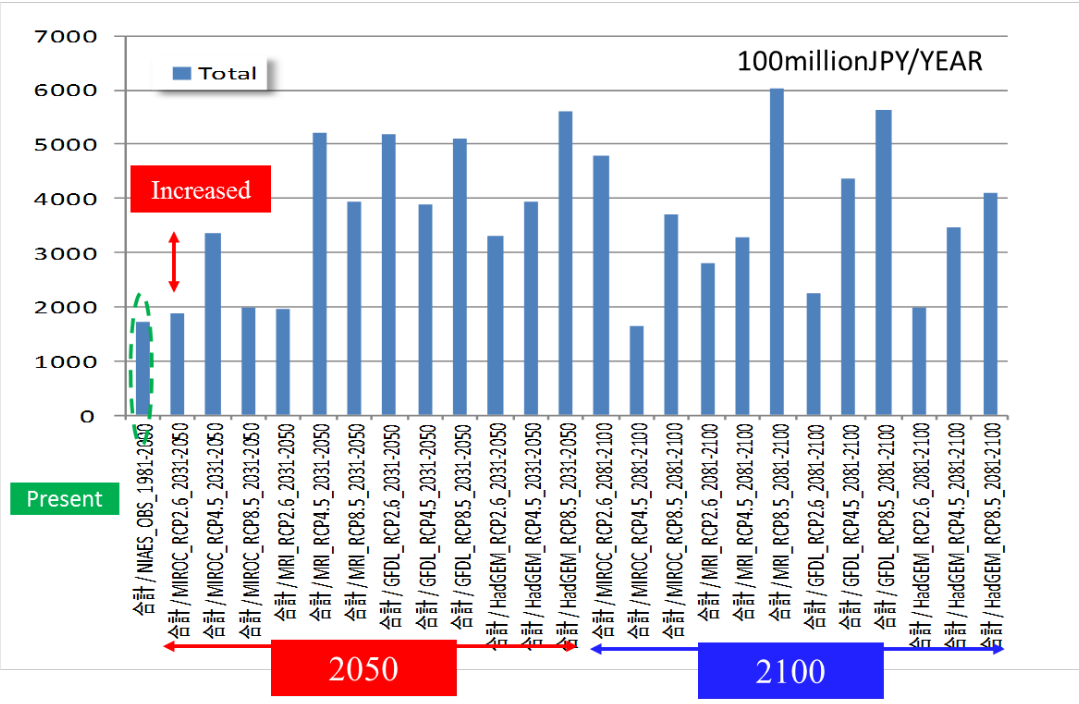

Figure 2 Flood damage cost in Japan in the future

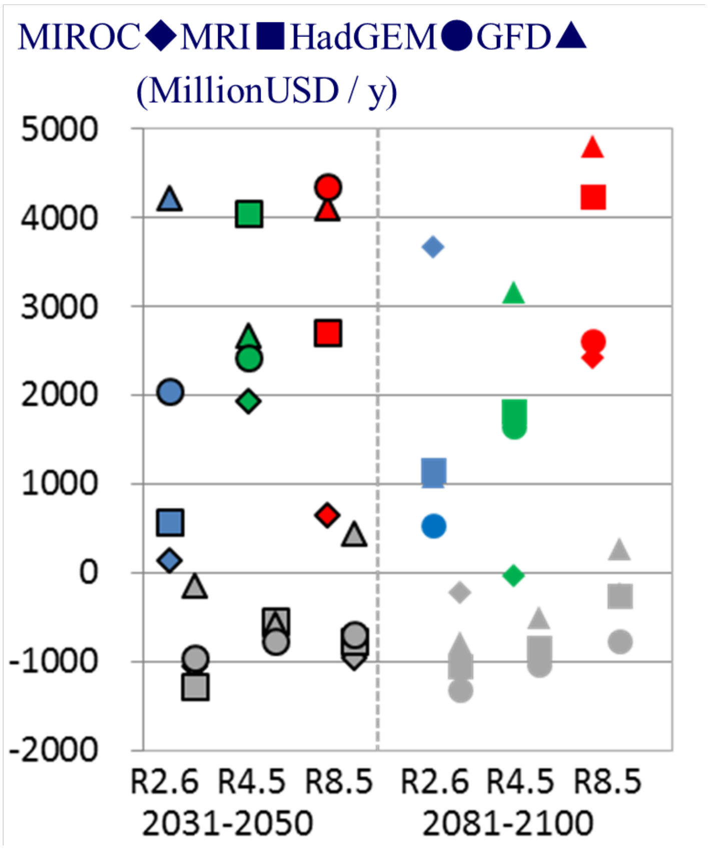

Figure 3 Difference between current and future damage costs in Japan in the future

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