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Countermeasures against floods that exceed design levels based on topographical and historical analyses of the September 2015 Kinu River flooding

Rei Itsukushima

Institute of Decision Science for Sustainable Society, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

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ABSTRACT

Study region: The Kinu River basin receiving serious damage in September 2015 because of the heavy rainfall disaster that hit the districts of Kanto and Tohoku in Japan.
Study focus: This paper provides future flood risk management for floods that exceed design levels (FEDL) based on past flood control systems and land use considering the natural topography in the area that was inundated by flood water from the Kinu River.
New hydrological insights for the region: The results of the literature research reveal flood management methods for preventing inundation of the city of Mitsukaido, such as drainage using a discontinuous embankment and a low-lying backswamp. In addition, the areas inundated by this flood were mainly those around a high-altitude natural levee, and residential land in the backland lowland area was developed after the Meiji period (1868–1912). Furthermore, a field survey revealed that many of these flood management systems are not functioning completely because of artificial modification. Identifying locations of potential flooding in areas of low population density is necessary as a countermeasure against FEDL. It is also important to recognize microtopography such as natural levees or backswamps, to induce land use based on the different flood risks of these topographies, and to utilize historical flood control systems as countermeasures against FEDL.

1. Introduction

The world is experiencing major problems due to destructive flood damage and other natural disasters (Wilby and Keenan, 2012; Sanyal and Lu, 2004; Chang and Franczyk, 2008; Kundzewicz et al., 2010). Recently, large-scale floods have occurred in Central Europe (Vogel, 2002), the UK (Arduino et al., 2005), the southern United States (Travis, 2005), and Southeast Asia (Alam and Rabbani, 2007). The potentially changing global climate could exacerbate the risk of flooding (van Aalst, 2006; Milly et al., 2002). The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) pointed out that localized torrential rain is becoming more intense and frequent in mid-latitude areas (IPCC, 2013). Therefore, the preparation of countermeasures against floods that exceed design levels (FEDL) is an urgent issue in Japan and the monsoon region of Asia.

Urban areas have traditionally relied on river canalization as a flood control method to mitigate flood hazards, but this approach has been criticized for degrading riverine ecosystems and increasing long-term flood risk (Pedroli et al., 2002; Rohde et al., 2006). Alternative flood management concepts have emerged, which emphasize integrated watershed management and structural and nonstructural measures (Schneidergruber et al., 2004). Recently, the concept of ecosystem-based disaster risk reduction (Eco-DRR)

E-mail address: itsukushima@civil.kyushu-u.ac.jp.

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has emerged (Renaud, 2013), in which disaster prevention measures themselves are required to strengthen ecosystem function (Iwasa and Nishida, 2017). Examples of such countermeasures include conserving wetlands and floodplains (Wharton and Gilvear, 2007; Birol et al., 2009; Hey and Philippi, 1995; Gopakumar, 2011), using paddy fields (Natuhara, 2013; Yu et al., 2006; Yoon, 2009), reducing flood risk by land utilization guide (Correia et al., 1995; Wheater and Evans, 2009; Parrott et al., 2009; Pattison and Lane, 2012), multiple flood defenses using natural topography or artificial embankments (Saito and Fukuoka, 2013; Gouldby et al., 2008; Klijn et al., 2015; Nillesen and Kok, 2015; Van Veelen et al., 2015), and reducing vulnerability in inland areas. It is also important to apply traditional knowledge and facilities for flood control. In Japan, localized flood control methods such as flood control forests (Okuma, 1997; Nagao, 2004; Watanabe and Hirakawa, 2010) and circle levees (Hori and Tanabe, 2012; Nakajima et al., 2005; Hori et al., 2008; Shimazu, 2013) were developed in ancient times. Such localized technology is now deemed effective for reducing vulnerability.

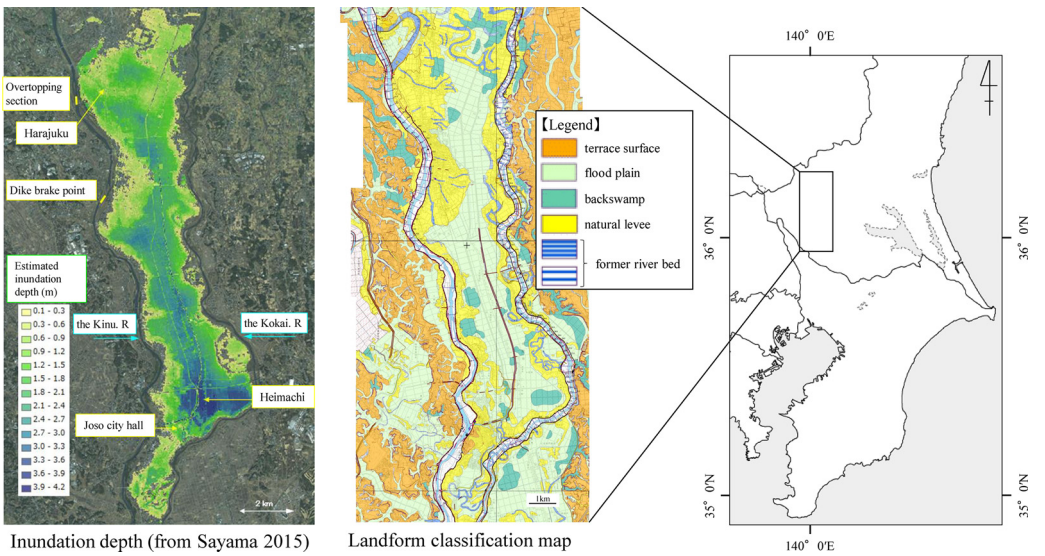
The present research is aimed at the flooding that occurred in September 2015 when the Kinu River burst its banks, causing enormous damage to the city of Joso in Ibaraki Prefecture in Japan. This event occurred because of heavy rainfall: 511 mm per basin area fell during three days (roughly 1/110 of the annual exceedance probability) (Sayama and Takara, 2016a). Comprehensive flood management policy throughout the watershed basin was shown to be effective against large-scale floods. A Japanese River Council report in 2000 pointed out the importance of various countermeasures against large-scale floods in rivers and watersheds to minimize flood damage, recognizing the delineation of correspondence with flood control facilities. Land-use management, strengthening of partnerships between rivers and sewerage systems, and hazard map development were described as important issues (Japanese River Council, 2000). Furthermore, measures that have been proposed for adapting to climate change include (i) conserving natural levees or consecutive embankments that are intended to stop floods from spreading, (ii) flood management considering land use, and (iii) providing guidance to local residents regarding urban functions in areas of low flood risk (Japanese Council for Social Infrastructure, 2015). A river has both a natural history and a social history: the former directs the latter, and the latter reflects the former. In addition, social history takes at least several thousand years and is the result of continuous experiments that continue today (Koide, 1974). Therefore, countermeasures against FEDL should be designed to accept not only changes in the force of the disaster but also potential future social changes based on historical land use and development. Furthermore, issues such as rapid population reduction, overcrowding in urban areas, depopulation in rural areas, and reduction in public investment are currently aggravating the situation in Japan. In dealing with countermeasures against FEDL, it is necessary to take these social issues into consideration.

The purpose of this paper is to propose countermeasures against FEDL. The aim is to reduce the flood risk and control the flood water based on past flood control systems and land use. The target is the flooding of the Kinu River in the heavy rainfall disaster of September 2015 in the districts of Kanto and Tohoku (hereinafter, the disaster is referred to as KT2015).

2. Methodology

2.1. Geographical characteristics of the study area

This study is focused on the area surrounded by the Kinu River and the Kokai River that was inundated by KT2015 (see Fig. 1). To the west of the Kinu River is the alluvium-based floodplain of the Kinu and Kokai rivers. Known as “Akuto,” this floodplain is roughly 12 m sea level and is used for paddy fields; the community extends above the natural levee. The urban district of the city of



Inundation depth (from Sayama 2015) Landform classification map

Fig. 1. Geomorphic characteristics of the inundated area.
Modified from Nakamura et al. (2017)