ARTICLE IN PRESS

International Journal of Disaster Risk Reduction xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Establishment of flood damage function models: A case study in the Bago River Basin, Myanmar

Shelly Win[a,*], Win Win Zin[a], Akiyuki Kawasaki[b], Zin Mar Lar Tin San[a]

[a] Department of Civil Engineering, Yangon Technological University, Yangon, Myanmar
[b] Department of Civil Engineering, The University of Tokyo, Tokyo, Japan

ARTICLE INFO

Keywords:
Flood damage function model
Questionnaire survey
House damage
In-house damage
Income loss
Agricultural damage

ABSTRACT

This paper derives flood damage function models based on the relationships between flood inundation parameters and damage-aggravating factors for two land use categories: residential and agricultural. This case study considers the Bago River Basin in Myanmar, which is frequently damaged by flooding. A survey was conducted to determine the economic damage to affected populations and properties during a large flood in 2011. House damage, in-house damage, and income loss function models were established for residential areas, along with an agricultural damage function model. Flood water height, floor height from the ground, occurrence of landslide erosion and types of building materials could aggravate house damage, whereas in-house damage is exacerbated by flood water height above plinth level and types of house's plinth level. Income loss scales with flood duration, job category and household level. Flood water height, flood duration and the growth stage of paddies worsen agricultural damage. Knowing the relationship between flooding and its damaging factors, these models can be easily applied to a flood loss estimation model in further research.

1. Introduction

1.1. Background

The new millennium has brought a string of devastating disasters, including the Indian Ocean tsunami, Hurricane Katrina in the USA, Cyclone Nargis in Myanmar, the Tōhoku tsunami in Japan, and Cyclone Komen in Bangladesh and Myanmar. These disasters have resulted in staggering human suffering and socioeconomic setbacks. They have demonstrated the need for increased international cooperation in disaster preparedness, data collection and sharing, and public awareness [1]. According to a recent IAP report [1], Even though there is a lack of scientific and technological tools or experience, it cannot be explained why so many hazards transform into disasters. Without sharing the information, data, and scientific understanding of natural disasters, there is a problem to incorporate with social and political decision-making.

Disaster risk assessment is a critical tool for evaluating the effectiveness of prevailing and alternative coping mechanisms within different risk scenarios. The total disaster risk can be decreased by applying countermeasures to each of three risk components: hazard, exposure, and vulnerability [2]. In order to perform reliable quantitative risk assessments, we must first understand how various damage-inducing factors contribute to changes in these three risk components. This is an important step toward improving our understanding of the complex interactions between societies and floods [3,4]. Therefore, loss estimation and evaluation of disaster consequences are indispensable parts of flood risk assessment, and the results provide decision-makers with essential tools for planning better risk-reduction strategies [5–9]. Unfortunately, the disaster itself can make complete data collection from a devastated region difficult. Thus, the relationship between the cost of a disaster and its influencing factors is sometimes estimated through the use of stage-damage functions.

1.2. Flood damage assessment

There are two basic methods for conducting flood damage estimations. One approach is to perform a thorough questionnaire survey of the affected population and properties to estimate the incurred loss. Post-flood damage surveys have long been believed to be the most reliable way to predict flood damage [10]. Although such surveys can be of enormous value for estimating the risk of future damage, funding and time are often insufficient to study an entire area affected by a major flood.

The other method is to use stage-damage functions. Stage-damage functions define the relation between flood parameters and possible

* Corresponding author.
E-mail address: shellywin.zigmo@gmail.com (S. Win).

https://doi.org/10.1016/j.ijdrr.2018.01.030
Received 12 June 2017; Received in revised form 21 November 2017; Accepted 29 January 2018

damage, which are derived based on the historical information about flood damage, questionnaire survey, laboratory experiences, and so on [11–13]. Using such stage-damage functions, the economic damage to different property categories is estimated and the summation of these category results reflects the total flood damage. They are usually obtained by averaging the ratio of the damages to a group of properties that were inundated to the same depth [14]. Traditionally, these stage-damage functions have been used to estimate the damage caused by a flood or to do a cost-benefit analysis of a project designed to reduce future flood damage.

1.2.1. Types of flood damages and parameters

There are two main types of flood damage: tangible and intangible. Any damage that can be readily measured in monetary value is tangible damage, while damage that cannot be directly measured in monetary terms is considered intangible [15,16]. Tangible damage can be further divided into two subtypes: direct and indirect damage. Direct damage is caused to items (e.g. buildings or inventory items) by contact with, or submersion in, water. In contrast, indirect damage is caused by the interruption of physical or economic networks, such as traffic flow disruption and individual income loss, as well as economic loss due to business downtime [15,17].

The amount of damage resulting from a flood depends on variable flood parameters, such as depth, duration, the year of flooding, and the use of a flood warning system [15,18–20]. According to D. Dutta [12], any of these factors may significantly influence flood damage; however, most previous flood damage assessment studies have chosen water depth as the most suitable flood damage variable. In this study, we mainly focused on the flood characteristics such as flood height and flood duration.

1.3. Flood damage estimation model of previous studies

In the USA, US Federal Emergency Management Agency and National Institute of Building Sciences developed HAZUS, which is the most advanced methodology for spatial multi-hazard risk assessment and is publicly available. HAZUS can be used for estimating the potential loss caused due to earthquake, flood, and hurricane hazards and was developed using a very extensive module dealing with an inventory and classification of element at risk. The major features of HAZUS-MH (Multi-Hazard) include a complete flood or earthquake model, capability to test both deterministic and probabilistic scenarios, fully integrated set of functions for the three models, functions of a geographic information system (GIS), capability to receive user-supplied input for all the three models, real-time analysis, and state-of-the-art software [21]. However, as it was primarily developed for the USA, the elements of risk classification cannot be directly used in other countries, particularly in developing countries where building types and population densities will not be the same as that in the USA. Furthermore, HAZUS requires an extensive data input in terms of information about elements at risk and hazards, which are often observed to be not available in developing countries like Myanmar [22].

D. Dutta [12] developed an integrated mathematical model for flood inundation and loss estimation by applying their investigation to a Japanese river basin. Few categories of stage-damage functions were considered while developing a flood loss estimation model. The limitation of such a system was that more detailed and local stage-damage functions along with indirect flood losses were caused due to business interruption. Further, various other factors were required to increase the accuracy of loss estimation. G. Zhai [14] used a mathematical model that explored the determinants of flood damage to develop a conceptual “doughnut structure” model for damage to houses and their contents that were damaged by flooding of the Tokai River in Japan. However, this also cannot be easily applied to locations with different housing and content characteristics like the Bago River Basin.

The assessment of the agricultural and residence damages that were observed in the Pampanga river basin in Philippines was conducted by B. B. Shrestha [23]. Stage-damage functions for agriculture were developed using minimum and maximum damage functions that were obtained from [24]. Stage-damage functions of houses were calculated using the damage rates that were obtained from Japan [25] because data from field investigations were insignificant to create damage functions. Thus, using this research, we understand that the regional baseline data is important and that creating stage-damage functions on a local scale is necessary if no such baseline exists. However, we may adopt an assumption methodology using generalized data developed by [25]. In order to compensate for the difficulties of assessing damage in monetary terms and the lack of necessary information and field surveys for prior flood events, T. M. Aung [26] generated a stage-damage relation for the Bago River Basin in Myanmar by assuming the possible damage factors for various properties including paddy fields and households.

1.4. Problem statement for Myanmar

According to the World Risk Report [27], Myanmar was ranked 42nd in the world (with a score of 9.15) on the World Risk Index and was ranked sixth in the world with regard to the highest lack of coping capabilities because of its high disaster risk exposure and vulnerability and its insufficient coping capabilities that were exposed in the aftermath of the Nargis Cylone in 2008. Since Cyclone Nargis hit Myanmar in 2008, each subsequent disaster has prompted a flurry of disaster risk assessments, calls for disaster risk reduction and resilience, and efforts to improve the country's disaster response systems [28–32]. According to the most recent investigation [33], Myanmar had a score of 8.9% on the World Risk Index and is still ranked 42nd in the world. However, Myanmar is still at high risk because it is ranked 15th in the world with regard to the highest lack of coping capacities [33]. Rapid urbanization and the effects of climate change have made Myanmar's need to reduce the risk of floods more urgent than ever [34]. These twin challenges will worsen flood disasters unless they are checked by preparedness.

Academic papers on flood disasters in Myanmar are sparse, with only limited studies related to soil loss modeling and morphometric analysis [35], climate change scenario analysis [34,36], river flood inundation modeling [37], the current disaster response system and management [38], and a social network approach to the military's role in disaster management and response [39]. Moreover, the Government of the Union of Myanmar [32] strongly recommended a house-to-house assessment in order to systematize its understanding of common failures and identify needed improvements in construction methods. No scientific publications have focused on flooding in Myanmar and its causes and effects.

1.4.1. Flood history of the Bago River Basin

Myanmar has numerous flood plains where monsoon flooding is an annual concern. The Bago River Basin is often particularly hard-hit, with frequent loss of life and damage to households, property, and physical facilities [37,38]. The Bago River originates from the middle mountainous region of Bago Yoma, and a large portion of the river itself is within Bago Township. A small portion of the river (the outlet) is in the Yangon Region, where the Bago River joins the Yangon river and, from there, enters the Gulf of Mottama. The entire river basin lies between two other river systems: the Sittaung River to the east and the Ayeyarwaddy River to the west. The Bago River is used for hydropower generation, irrigation, fishing, and navigation, so finding a solution to this flood problem is particularly important.

In 1878, which was the era of the British Government, the Bago–Sittaung Canal that linked Sittaung and Bago Rivers was constructed to navigate from upper east Myanmar to Yangon River estuary. Further, a levee system was constructed on the east bank of the Bago River from Bago City to Tarwa Sluicegate of the Bago–Sittaung Canal in 1883. The Zaung Tu hydroelectric dam and a diversion weir for