FLOOD HAZARDS ASSESSMENT AND RESIDENTIAL FLOOD DAMAGE MAPPING IN HITOYOSHI PREFECTURE, JAPAN

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ABSTRACT

Natural disasters are one of the things that have risks and hazards to the population. This study aims to simulate the flood hazard and calculate its impact on the Hitoyoshi area, Japan residential areas. Hitoyoshi was chosen as the case study because the area experienced a catastrophic flood in 2020 that destroyed the city. The calculation of the impact of this study is also based on mapping the area based on land function, damage to buildings, and building materials, especially in areas affected by floods in the city of Hitoyoshi, Kumamoto. The results of this study indicate how much risk will be caused by flooding, especially in the Hitoyoshi area, with simulations carried out in ArcGIS software. In addition, the simulated hazard map is overlaid with buildings to determine the impact caused by the Hitoyoshi Area. This research aims to provide input for the Japanese institution in increasing the risk of natural disasters against floods, especially in the Hitoyoshi area, in dealing with future disasters. Simulations carried out in areas that have been affected by flooding by making a hazard map and validating it to prove the accuracy of the data are expected to be used and applied in several other countries besides Japan.

Keywords: *flood, disaster, urban planning, housing damage mapping, hazard map*

INTRODUCTION

Disaster risk reduction results from a systematic analysis of various related factors that cause a disaster to reduce exposure to and damage to life and property(Pistrika & Tsakiris, 2007). Disaster risk reduction is also intended to prepare for future disasters. This climate change is considered in a plan for disaster risk reduction.

In recent decades there have been several increases in the intensity of flooding in countries, including Japan, due to climate change(ICIMOD, 2006). Disaster risk assessment and adaptation to climate change are two interrelated issues that are rarely applied(Cabrera & Lee, 2019). Disaster risk is defined as the potential loss caused by disasters in various aspects, and one of them is the loss to the community (Uddin et al., 2013). Factors contributing to disaster risk management in an area are vulnerability to hazards and response capacity.

A flood is a natural disaster related to water, which has recently been a global concern. Flood disaster is one of the natural disasters with a frequency that is quite worrying worldwide (Adachi, 2009). The hazard of flooding has many significant effects, especially for humans, such as damage to many buildings, causing many people to lose their homes, and inundating several public facilities and essential infrastructure (Fan & Huang, 2020). It also causes traffic and communication disruptions. As a result, people's living standards in disaster-stricken areas are changed and affected.

In Japan, natural disasters take account for over 70% of all-natural disasters , include typhoons, floods, and landslides (Huang, 2014). These natural disasters happen due to Japan's geographical condition, consisting of steep river slopes and many rivers. Even in the last ten years, there has been an increase in rainfall, causing flooding and damage in several residential areas in Japan (Katiyar et al., 2020). This climate change is related to the increase in rainfall levels in Japan. The study said that heavy rainfall in 2017 and 2018 was reported and is likely to increase by about 1.5 and 3.3 every 50 years due to global warming.

In July 2020, one of the major cities in Kumamoto prefecture, namely Hitoyoshi City, experienced a flood that caused significant damage to Hitoyoshi City's residential area (Parmenter, 2012).

Figure 1. Damage of 2020 Hitoyoshi Flood in Kumamoto Prefecture, Japan
Source: Author Field Survey, 2

THEORY / RESEARCH METHODS

Research Significance

This paper investigates flood hazard assessment and damage mapping, especially in residential areas in the Hitoyoshi area is currently not widely available. The Hitoyoshi area is one of the areas located in an area that is quite prone to flooding, so this study is needed to provide more detailed information related to disaster risk and mapping of the impact of floods in the 2020 Hitoyoshi flood. The method used in this study is a related analysis of Binary Linear Regression to see the relationship between related driving factors to find an effective and more accurate flood model and mapping using machine learning. This study is expected to help the government and decision-makers to provide warnings to residents living in areas prone to flooding in the future. At the same time, improve and improve planning for development.

Research Method

This research was conducted using a software simulation method from some data and based on a field survey conducted by the researcher during the research process. In addition, the research data was also validated to maximize and see how accurate the simulation data was with data in the field to be applied in other locations in planning for flood-safe areas by learning from case studies in Japan.

The following is a figure of the research process with a case study of flooding in the Hitoyoshi area of Japan shown in Figure 2.

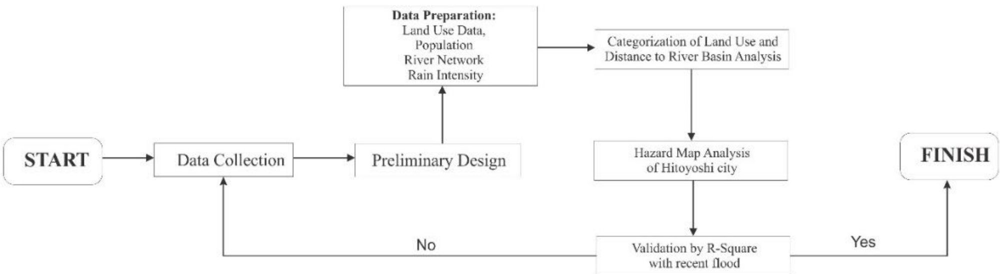

Figure 2. Research Flow Model
Source: Author, 2022

Study Case

Hitoyoshi City s is located in the mountainous region of Kumamoto Prefecture, in the southern part of Japan (Hitoyoshi City Government, 2020). Hitoyoshi was chosen as the case study's location in early 2020, which destroyed downtown Hitoyoshi due to a major flood. Regarding Hitoyoshi's based data, the population of Hitoyoshi town reached 31,588 at the end of October 2020, with a total city area of 210.5 km^2. Figure 3 shows the location of Hitoyoshi, which is located in Kumamoto Prefecture, Japan (Das et al., 2020). This study selected the Kuma River, one of Japan's rapid rivers. Hitoyoshi City consists of 2 regions: the northern part with an area of 26.7 km^2 and the southern part with 183.7 km^2. The northern part of Hitoyoshi was hit by heavy flooding, which resulted in several casualties and damage to residential areas and supporting areas such as infrastructure, agricultural land, and recreational facilities (Liu et al., 2020). This research was conducted because it can be used to develop disaster mitigation for small cities in making spatial data, especially in terms of emergency response and allocation in calculating the impact in Hitoyoshi city (FDMA, 2015).

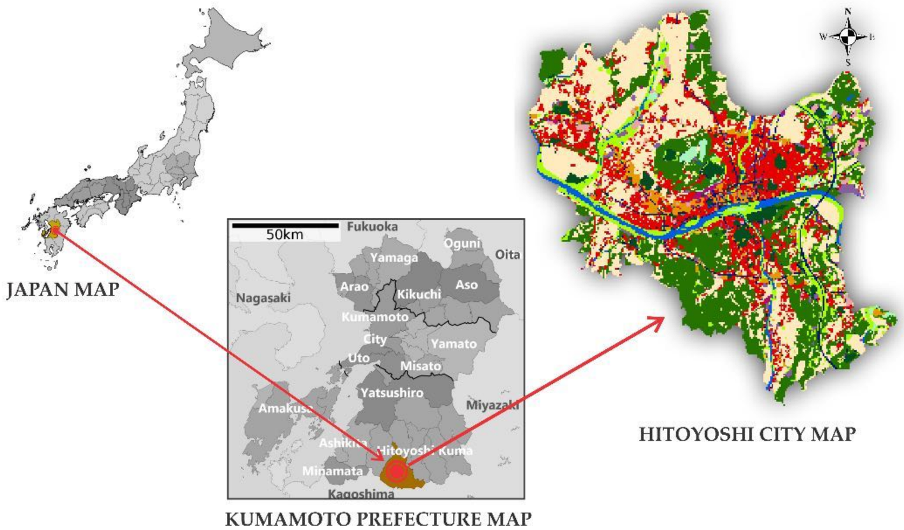

Figure 3. Location of Hitoyoshi City, Kumamoto Prefecture, Japam
Source: Author, 2022

Flood History in Hitoyoshi

This study aims to provide an overview of disaster risk assessment using a flood inundation map in the Hitoyoshi area. Inundation or flood can be defined as an area of an overflow of a body of water that is normally dry but becomes inundated by overflowing rivers (Tripathi et al., 2022). The information obtained from this study provides an overview of each location's vulnerability to create a better environment.

Mapping the hazard areas in the Hitoyoshi area and mapping the impact of the flood is necessary because this is not the first time Hitoyoshi has experienced flooding in history (Prefecture et al., 2021). Several historical records have explained that Hitoyoshi often experienced floods, as shown in Table 1.

Table 1. Flood History in Hitoyoshi, Kumamoto

Year Record	Flood Situation
July 1965	The flood submerged two-thirds of the town of Hitoyoshi and destroyed the Hagiwara Dam in the town of Yatsushiro.
July 1982	The flood caused 5000 houses to be affected by the flood and 47 to be swept away due to the flood
Aug. 2004	The typhoon brought heavy rains, which caused the Kuma River to overflow and forced residents to evacuate to safer places.
Sept. 2005	119 houses were submerged by the overflowing river and displaced 750 families.
July 2006	80 houses were submerged and over 900 families needed to be evacuated due to the overflowing Kuma River.
June 2008	33 houses were inundated, and 1000 families were affected in Hitoyoshi, Yatsushiro, and Ashikita areas.
June 2011	Due to heavy rain, the river overflowed beyond the limit and forced residents to evacuate themselves.

Source: http://www.qsr.mlit.go.jp/yatusiro/river/kouzui/index.html, accessed on 3 January 2022

Data Availability

In planning the 2D model, some related data are needed to make the HEC RAS model. Several data needed to create this model are a digital elevation model (DEM), Slope, Land Use, River Distance, Rainfall, and flood-prone area. Because some of the data points were taken from different sources, there are several possibilities for the accuracy of the flood model created.

Table 2. Research Data Infromation and Sources

No	Type of Data	Source
1.	Digital Elevation Model (DEM)	Geospatial Information Authority of Japan
2	Slope	Geospatial Information Authority of Japan
3	Land Use and Built-up Area	Hitoyoshi City Basic Survey 2017
4	River Distance	Hitoyoshi City Basic Survey 2017
5	Rainfall	Japan Meteorological Agency
6	Flood-prone area	Japan National Land Numerical https://nlftp.mlit.go.jp/ksj/index.html

Source: Author, 2022

The data used in this study consists of several data, including DEM, Slope, Land use, River Distance, Rainfall, and flood-prone area. Details of the data are shown in table 2. Land use data of the Hitoyoshi area (Figure 3) were obtained from the

Hitoyoshi City Basic Survey. Land-use data is divided into important points: crops, land, forests, water, residential areas, industry, and commercial. In this research, the type of land use metadata is vector based, that data then converted into the raster data with size of 30 m x 30 m by ArcGis polygons to raster.

The value of n in this manning is set for retrieval in the HEC-RAS hydraulic reference in various land use types within the study area, namely Hitoyoshi. Geometric data editing at HEC RAS determines the area affected by the flooded area.

RESULTS AND DISCUSSION

Elevation and Slope Data Tools

For the hazards assessment, this study uses ArcGIS software to map areas of interest (land-use areas, roads, river areas, and flood-prone areas) were used to create the inundation maps for each river basin. Several driving factors are used to be considered in this study (Shakti et al., 2020)

In this research, a digital elevation model (DEM) is used to create and define the terrain model in the RAS Mapper. Moreover, the slope data is used to determine which areas have a potential flood risk. River distance is used to determine areas with a risk of flooding, followed by rainfall data to produce runoff. Several related factors are used and then overlaid with land functions to find out about the impact caused by the flood model and how much potential for disaster and flood impact mapping(Hussain et al., 2021).

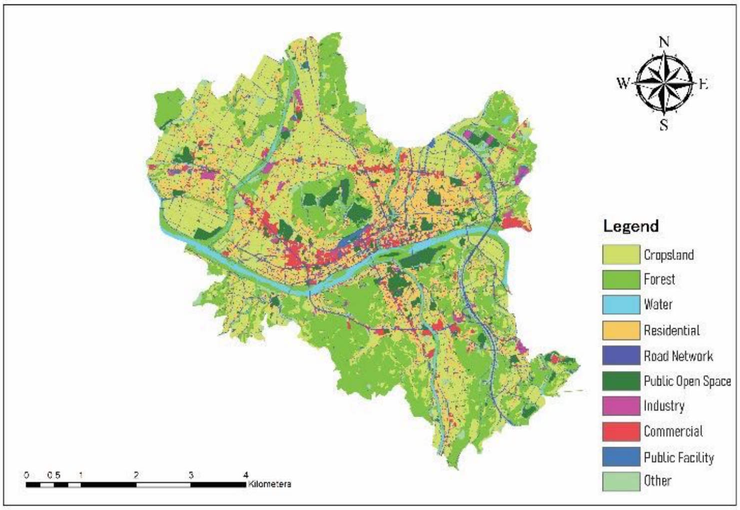

Figure 4. Digital Elevation Model (DEM) of Hitoyoshi, City, Kumamoto Prefecture
Source: Author, 2022

Computational data on elevation were used in the simulation to show the results of the simulation of the extent of the flood level against the flood boundary of the river(Glas et al., 2016). In addition, this elevation data is useful for determining the impact of this flood if it is overlaid with building function data to determine the amount of damage from the flood shown in Figure 4.

Land Use Classification

Based on data obtained from the Hitoyoshi's institution for 2017, then a comparison of the latest data obtained from Google Earth satellite data, this study tries to classify land use into ten types consisting of cropland, forest, water area, residential, road network, public open space, industry, commercial, public facility, and other shown in Figure 5. This classification facilitates the land use category in determining areas with a high risk of flooding and in making maps of the impacts caused by the Hitoyoshi flood disaster. The data on the land use classification in the Hitoyoshi area.

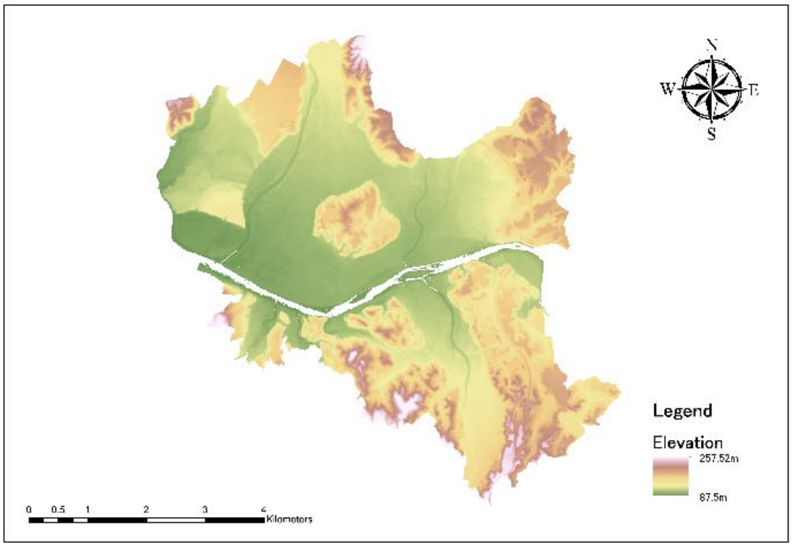

Figure 5. Land Use Classification of Hitoysohi, Kumamoto
Source: Author, 2022

River Distance Tools

The purpose of using the buffer area of the Kuma River and the river channel is one of the driving factors in the watershed problem. Because the distance of this river affects the simulation of rainfall sub-catchment, this study is divided into two types of river distances in the mapping, namely the distance between the main river basin and the distance between the river channels in Hitoyoshi city, as shown in Figures 6 and 7. Figure 6 explains that Hitoyoshi has a large river, namely the Kuma River, the main river that divides the city of Hitoyoshi, which is the source of the 2020 floods. Figure 7 is the main river branch, which is also a source of overflow when a flood occurs. So that the river branch becomes one of the indicators of making a hazard map in this study.

River flow from urban planning is one of the important driving factors(Mallick et al., 2021), especially in seeing how risky an area, especially an area inhabited by residents, is against natural disasters such as Hitoyoshi City, which is at risk of flooding. The distance to the river is one of the considerations in carrying out this simulation because the closer an occupied settlement is to the main river or tributary, the greater the risk of damage caused by floods that often occur in Hitoyoshi City when summer arrives.

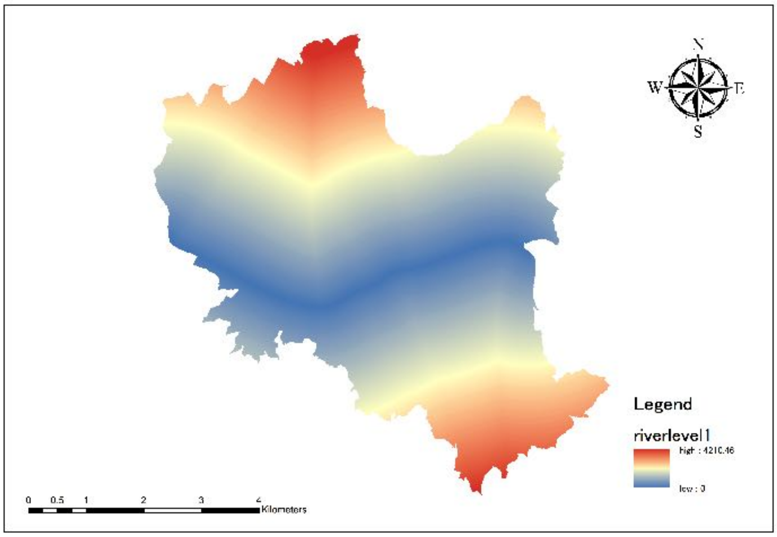

Figure 6. Main River area in Hitoyoshi, Kumamoto
Source: Author, 2022

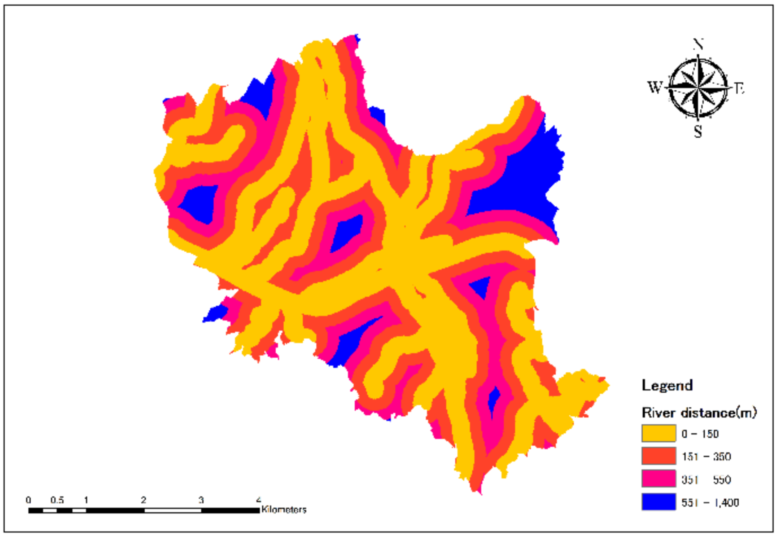

Figure 7. River Distance area in Hitoyoshi, Kumamoto
Source: Author, 2022

Flood Hazard Mapping

Flood hazard is defined as the severity of an area against flooding which is indicated by the inundation area, inundation depth, and inundation duration (Tripathi et al., 2022). Other factors that are directly related to the flood hazard are social and economic related factors, especially areas related to land functions consisting of residential areas, commercial areas, industrial areas, areas that are public in nature, and other supporting areas(Abdulharis et al., 2022). Several criteria used in this study that affect the flood hazard area in Hitoyoshi consist of flood-prone areas as well as water areas and areas directly affected by the flood.

Based on the simulation results of the study shown in Figure 8, it shows that the area in red color indicates that the area has a relatively high level of danger in the Hitoyoshi area which is influenced by elevation, slope, rainfall, flood-prone, areas and several other driving factors. The red area is an area that has the potential to inundate when rainfall is high in the Hitoyoshi area.

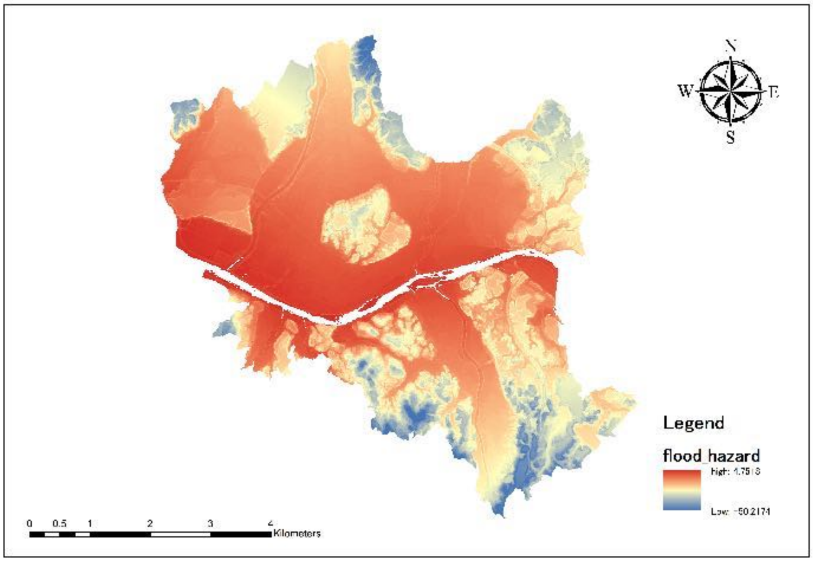

Figure 8. Hazard Map of Hitoyoshi city, Kumamoto Prefecture
Source: Author, 2022

Based on the mapping result carried out from the land use map and the simulated hazard map with several driving factors, it can be concluded that the residential area and land owned by the residents of the Hitoyoshi area are areas with conditions that are directly exposed to flooding.

A disaster can be called a natural disaster if it can pose a risk to humans. The percentage of population settlements in the Hitoyoshi area directly affected by the flood shown in Table 3, reached 15%, and losses to land owned by residents reached 29% of the total land use. Based on this simulation, it proves that there are still many residents of Hitoyoshi city who live close to the Kuma River, directly facing the disaster's source.

Table 3. Table of Damage area of Land Use

Class Area	Number of Point	Land-use Area（m2）	Percentage
Cropsland	95060	9505436.049	**29%**
Green Area	100997	10099100.83	30%
Water Area	11612	1161131.111	4%
Residential	49188	4918508.188	**15%**
Road Network	24529	2452754.48	7%
Public Open Space	16410	1640902.646	5%
Industry	4102	410175.6645	1%
Commercial	11504	1150331.752	3%
Public Facility	2868	286782.9854	1%
Other	15142	1514110.169	5%
Total	331412	33139233.87	100%

Source: Author, 2022

Damage Mapping Area

There are about 4310 points of buildings around the Kuma River in this study, shown in Table 4. And based on the simulation results of the floods carried out in this study, they were divided into six types of damage caused by floods. The results show that the most damage reached 1414 building points that were completely damaged due to flooding. Several other buildings were half-destroyed, going 1065 building points, and large-scale half-damaged, reaching 1191 building points shown in Figure 8.

Table 4. Table of Damage area of Land Use

No.	Building Damage Information	Number of Building	Percentage
1	Completely destroyed	1414	32.81%
2	Half destroyed	1065	24.71%
3	Large-scale half-destroyed	1191	27.63%
4	Semi-half destroyed	180	4.18%
5	partially damaged	309	7.17%
6	undecided	5	0.12%
7	other	146	3.39%
	Total	4310	100%

Source: Author, 2022

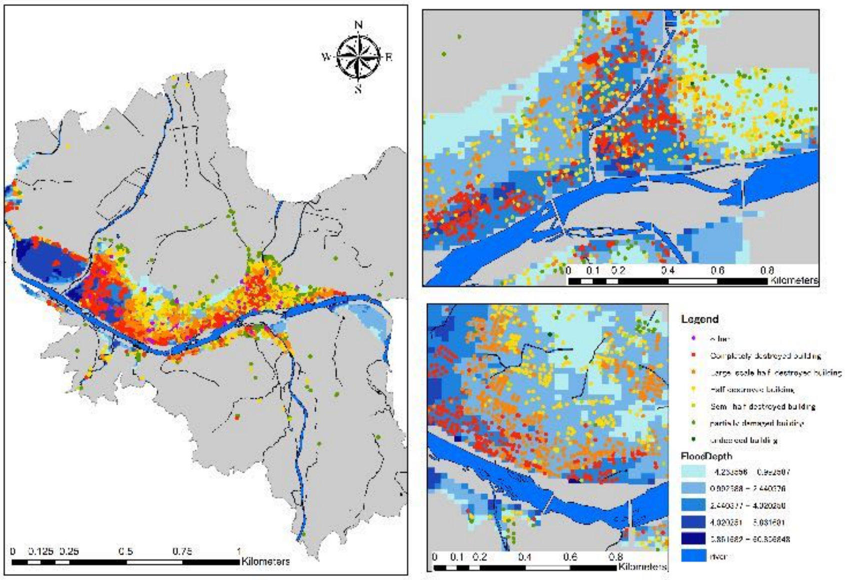

Figure 9. Damage Mapping of Hitoyoshi city, Kumamoto Prefecture
Source: Author, 2022

When viewed from the number of buildings affected by the Hitoyoshi flood, most people living in the area along the Kuma River are highly impacted by flooding risk in the future. The red color shown on the map is the area that was really badly damaged by the Hitoyoshi flood in the flood area shown in Figure 9. Many buildings and land use are concentrated along the river, and this situation needs to be one of the concerns in the development of disaster risk reduction for the Hitoyoshi area in the future.

Building Material Damage Mapping Area

Table 5. Table of Damage area based on Building Materials in Hitoyoshi

Materials and Construction	Number
Other (non-wooden)	1
Concrete	86
Wooden Structure	3469
Lightweight steel frame prefabrication	5
Reinforced concrete	125
Steel structure 3 mm or less	37
Steel structure over 3-4 mm	153
Steel structure over 4 mm	416
Steel rebar concrete	17

Source: Author, 2022

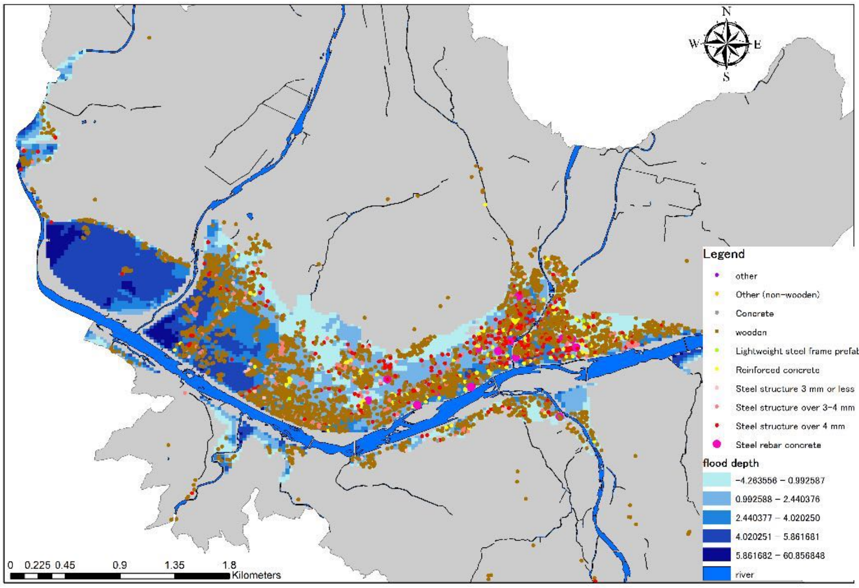

Figure 10. Damage Mapping by Building Material Selection of Hitoyoshi city, Kumamoto Prefecture
Source: Author, 2022

Based on the overlay of the Hitoyoshi city hazard map and the buildings in the Hitoyoshi area, Kumamoto proved as many as 3469 points, where most residents live on wooden construction materials shown in Table 5. Then several other points that also suffered much damage due to flooding were buildings made of steel construction and concrete.

The map in Figure 10 shows that most buildings made of wooden construction (brown colour) are in flood-affected areas and inundated areas. The simulation and mapping process shows that Hitoyoshi is still a disaster-risk area because many buildings are made of wood, and severe building damage has caused residents to move from residential areas to new areas.

Data Validation Process

The data to be validated in this research is taken regarding the comparison between the results of the simulation of the hazard map in the following study (shown in Figures 8 and 9) with the rapid response affected map issued by the Japanese government to see the level of accuracy of the data using SPSS statistics software. Based on the validation results using SPSS software (for Statistical Analytic Tool calculations), the R-square method is used to show a level of significance and accuracy. The value of x is usually written as $0<x<1$, it can be used to indicate that the results have a good significance and have a good level of accuracy because it can be close to the real condition in the field.

Variables to be compared are described before in Figure 8 and Figure 9. These figures are generated based on Digital Elevation Model (DEM), slope, land use and built-up area, river distance, rainfall, and flood-prone area. The regression analysis has resulted in a hazard map and a government rapid affected area map (source: NIED Japan). This study used Binary L (Logistic Regression), with the results from simulations in making hazard maps as the independent variable and affected area maps issued by the Japanese government for the city of Hitoyoshi as the dependent variable. Therefore, Negelkerke R-squared is used to validate the model. The R-square number significance is close to the value of one (R-square = 0.704), indicating that the accuracy and validation results are considered good and can be accounted shown in Table 6. Moreover, the Pearson correlation test also shows that there is a significant relationship between the hazard simulation and the government map, shown by the significant test values less than the significant level $\alpha = 0.05$.

Table 6. SPSS Data Validation with R-Square

No	Variables	Hazard Simulation	Government Map
1	Hazard – Pearson Correlation	1	.660**
	Pearson Significance		.000
	N	6400	6400
2	Government Map – Pearson Correlation	.660**	1
	Pearson Significance	.000	
	N	6400	6400
Nagelkerke R-square			**0.704**

Source: Author, 2022

CONCLUSIONS

1. The result showed that to make Hitoyoshi a disaster-prone city, it was constructed from the perspectives of "not easily destroyed" and "high resilience". The results show that the land use damaged area, the construction damage rate, and the percentage of wooden have the consideration for better future disaster risk reduction.
2. The result showed that almost 29% of cropland and 15% of the residential area are damaged by the Hitoyoshi flood and in the high-hazard area.
3. The evaluation showed that almost 32.81% of buildings are completely destroyed by the Hitoyoshi flood, and it means that Hitoyoshi city still needs to make high resilience for cities, especially to reduce the number of hazards in that area. There are 3469 points of wooden structure building damaged by flood. Needs some other consideration, especially for building material in a high-risk area like Hitoyoshi.

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