Quick Exposure Assessment of Flood Inundation: A Case Study of Hitoyoshi City in Kumamoto Prefecture, Japan

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Abstract

In recent years, heavy rain and associated flooding have triggered considerable damage to agricultural land, houses, and human life in many cities in Japan. A quick exposure assessment of such catastrophic events can be a useful reference for the warning, response, mitigation, and evaluation of flooding events. Hence, we developed a tool that can quickly estimate the status of the land use profile, buildings, and road networks within a city throughout a flooding event. As a case study, we applied this new tool to the Hitoyoshi City of Kumamoto Prefecture, Japan, for the first week of the area's flood event in July 2020. The results show that the total percentage of flooded urban, agricultural, and forest areas were estimated as 36.80 %, 20.90 %, and 0.55 %, respectively, and approximately 5,355 buildings were inundated in northern Hitoyoshi City during this event. Moreover, an estimated 24 % of the buildings in this city were inundated by more than 2.0 m of flood water corresponding to the danger condition (Stage 4). The detailed status of the land-use profile, buildings, and road networks were summarized based on the spatial variation of flood inundation depth within the city. This type of estimated information may assist in future emergency response coordination efforts and ensure informed allocation of resources. We believe that the proposed tool can be applied to any city in Japan for a quick exposure assessment of flood inundation.

Key words: Flood inundation, Exposure assessment, ArcGIS, Buildings, Road networks

1. Introduction

Flooding caused by extreme rain is one of the costliest water-related disasters. Several model experiments and a review of historical data have revealed that such disasters will increase in the future (Hirabayashi *et al.*, 2013). In recent years, extreme rain events and associated floods have been frequently experienced in Japan. Examples include catastrophic flooding in the Kanto region in 2015 (P.C. *et al.*, 2016), Northern Kyushu in 2017 (P.C. *et al.*, 2018), Western Japan in 2018 (P.C. *et al.*, 2020a), Eastern Japan in 2019 (P.C. *et al.*, 2020b), and recent flood events of July 2020 in Kyushu. All these events caused a substantial loss of life and damage to agricultural land and several houses.

Several approaches have been undertaken to provide enhanced information about floods in near real-time. For example, remotely sensed satellite data were used to extract the extent of flood inundation during disaster events (Clement *et al.*, 2018). Such satellite-based data may miss the peak flood inundation extent due to a narrow swath and longer repeat cycles of the observation. Furthermore, persistent cloud cover over the flooding area is a major obstacle to optical sensors for satellite observation. In some cases, flood inundation profiles were used from the hydrological simulation, but the incorporation of flood scenarios such as embankment failure and the backwater effect in the early stages of the simulation is a challenge because the time and location of such failures is unknown (P.C. *et al.* 2020a). To compensate for these shortcomings, Idehara and Hirano (2020) and P.C. *et al.* (2020b) have recently developed a quick mapping method to estimate flood inundation for a flood-affected area that is based on high-resolution digital elevation model (DEM) data and SNS information, which is a key reference for emergency response and the further impact assessment of socio-economic magnitude.

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The collection and processing of data from disaster areas in near real-time and their aggregation is always desirable to enhance disaster management. Therefore, utilizing the flood inundation mapping product and socio-economic information (e.g., land use data, building datasets, road networks, and population datasets), an exposure assessment of flood inundation for any area can be disseminated that provides insight on various types of socio-economic factors within the flood-affected region. Such information is commonly provided at the municipal or national level for mitigation and emergency response measures and can be used as a reference for future unpredictable flood events. When such an exposure assessment of flood inundation is released quickly for any flooded region in near real-time, it would be a key reference for implementing quick strategies and special actions to collect damage information, emergency response, evacuation, smooth recovery of living environments, and resource allocation by local or national governments. Some private companies may also have an interest in using the outcomes of assessment to understand the value of assets at risk and to price their policies accordingly.

Research on the estimation of flood inundation profiles of any flooded area has continued in Japan, and some important information on the subject has been issued to the public. For example, the National Research Institute for Earth Science and Disaster Resilience (NIED) in Tsukuba, Japan, has issued several types of flood-related information, which are available on the NIED's crisis response website (http://crs.bosai.go.jp/). An important type of information is quick mapping of flood inundation for a flood-affected area. These mapping products are based on high-resolution DEM data and SNS information and can be issued rapidly (Idehara and Hirano, 2020; P.C. *et al.*, 2020b) in any region of the country. With the assistance of a quick flood inundation mapping product, in this study, we developed a tool for the quick exposure assessment of flood inundation in a city of Japan. As a case study, we conducted our research on a city that was severely affected by flooding.

In the first week of July 2020, torrential rainfall caused heavy flooding in the Kyushu region. Flood inundation caused remarkable losses in different cities of Kumamoto and in the Fukuoka Prefecture in Japan. Among them, Hitoyoshi City in Kumamoto Prefecture (**Fig. 1**) was severely flooded, especially the northern part. The central part of the city is extremely close to the Kuma River, which was flooded by the heavy rain event of July 2020. According to the Fire and Disaster Management Agency (FDMA, 2020), 20 people were killed, and approximately 4,681 houses were damaged in Hitoyoshi City. In this study, we have further applied the developed exposure assessment tool to flood inundation in Hitoyoshi City.

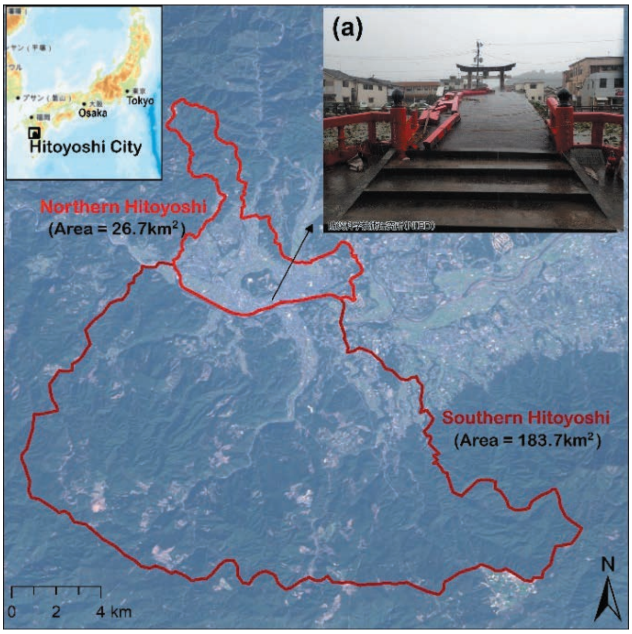

Fig. 1 Boundary profile of Hitoyoshi City. (a) Flood-damaged Misogi bridge in northern Hitoyoshi City.

2. Flood Inundation in Hitoyoshi City

Hitoyoshi City is located in the mountainous region of Kumamoto Prefecture in Japan (**Fig. 1**). According to the city hall of Hitoyoshi (https://www.city.hitoyoshi.lg.jp/), the estimated population of the city was approximately 31,588 at the end of October 2020, and the total area of the city is 210.5 km^2. The Kuma River, which is considered one of the three most rapid rivers of Japan, passes through the city. In this study, the northern part of the Kuma River is hereafter referred to as the northern part of Hitoyoshi City, which covers more urban and agricultural lands, whereas the southern part is hereafter referred to as the southern part of Hitoyoshi City, which is mostly covered by forest. The total areas of the northern and southern Hitoyoshi City are approximately 26.7 km^2 and 183.7 km^2, respectively (based on boundary polygons of Hitoyoshi City in **Fig. 1**). The northern part of Hitoyoshi City was severely flooded, resulting in a considerable loss of life, infrastructure, agricultural lands, and recreation facilities.

First, we developed a flood inundation profile within the northern part of Hitoyoshi City, as shown in **Fig. 2**. The detailed methodology used to generate these mapping products and their applications can be found in Idehara and Hirano (2020) and P.C. *et al.* (2020b). DEM data are available at the Geographical Survey Institute (GSI), which are also freely available for application purposes. These data are available at a 5 m or 10 m spatial resolution.

The maximum flood inundation depth reached approximately 10 m, especially in the western part. We validated the estimated flood inundation depth using our

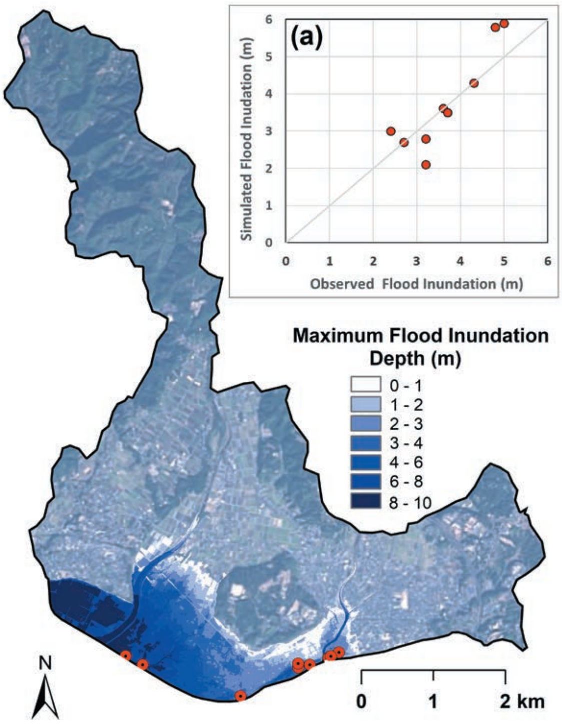

Fig. 2 Flood inundation profile of northern Hitoyoshi City. (a) Comparison of observed and simulated flood inundation depth at different points (red circles) of the flood inundation zone.

field survey. **Fig. 2a** shows a scatterplot of the estimated flood inundation depth against the observed flood inundation at nine points in the flood-affected region (red circle points in **Fig. 2**). We found that the observed and estimated data matched closely. This flood inundation profile acts as the key reference for the exposure assessment in this study. Uncertainties in the mapping product based on DEM data and SNS information will be discussed later.

3. Tools for Exposure Assessment

The development of the flood inundation profile map was the first step in this study. The next step was the collection of social data for the city. In this study, we collected land use, DEM, building, and road network data. The details of the sources and information of such datasets are presented in **Table 1**. Land use data were downloaded from the Japan Aerospace Exploration Agency (JAXA) website, which is freely available for research purposes. The default land use data has a 30 m spatial resolution that covers Japan. DEM data are also freely available at GSI for application purposes. These data are available at a 5 m or 10 m spatial resolution. Buildings and road network data are not publicly available at this stage but are instead housed at the NIED. Building and road data were collected in a polygon format. NTT Infrastructure Network Corporation and NIED collaboratively operate the data for research and development purposes only, and they are not available for commercial purposes. These datasets were updated in 2018. Some of these datasets were pre-processed as explained in the next section.

3.1 Land Use Status Tool

The estimation of the quick flooded area by separate land use profiles is very useful for land use planners. It helps to analyze losses during flood events and is useful in allocating resources for recovery and reconstruction. In this study, we developed a tool that can calculate the total area of each land use profile that has been flooded in the city. In this case, we allocate the total flooded area of each land use profile within the city, which is the first step to estimate damage area of land use profile. In some cases, flood depth, velocity and seasons are the most important components for estimating direct damage of each land use profile of any area. All those components have not applied in this study. However, we have given slightly more emphasis on flood depth of urban and built-up areas, which are relatively sensitive and the dominant land use as compared to remaining other land use profile in any city in Japan.

The land use data has been prepared by JAXA based on detailed observations from 2006 to 2011 throughout Japan. Various types of land use classifications, such as water, urban and built-up, rice paddy, crops, grassland, broadleaf forest, deciduous needle-leaf forest, evergreen broadleaf forest, evergreen needle-leaf forest, and bare land are found in the land use data. To simply assess the flood inundation status in the agricultural sector, we simplified the JAXA land use data

Table 1 Specification of the data sets used in this study.

Name	Data source	Spatial resolution	Data format/coverage area
Land use data	Japan Aerospace Exploration Agency (JAXA) Website: https://www.eorc.jaxa.jp/	≈ 30 m	GeoTIFF raster, covers all of Japan
DEM data	Geographical Survey Institute (GSI) Website: https://www.gsi.go.jp/	≈ 5 m or 10 m	Raster format, some parts of Japan
Building and road networks data	NTT Infrastructure Network Corporation Website: https://www.nttinf.co.jp/	-	Polygon format, shapefile, entire Japan

into five categorical classifications in the first step. They are water, urban-built, agriculture, forest, and others. Paddies, croplands, and grasslands were merged into the agricultural category. For the forest category, deciduous and evergreen forests were combined. The remaining categories were categorized as others in the re-classified map. This land use classification is considered to be common in many parts of cities in Japan. The profile of the study area is shown in **Fig. 3**. Any change in land use profile after 2011 was not included in the data set.

3.2 Buildings Status Tool

Damage to buildings and loss of human life would be intensified with increasing flood inundation depth. Defining the detailed status of buildings under flooding events helps in understanding the physical condition of buildings as well as the evacuation process for local residences. Hence, it is a useful reference for management strategy, especially for the preparedness and recovery processes. In this case, we applied a condition to define the situation of buildings in the flood inundation zone according to the flood inundation height for disaster management.

The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT, 2020) has categorized that areas with a flood depth of less than 0.5 m can harm the ground floor of buildings; 0.5 m–2.0 m may flood a one-story house or an apartment home, and greater than 2.0 m may pose a high risk of collapsing up to two-story buildings. MLIT (2020) also categorized additional details considering prompt evacuation in the event of a flood or for preventing flood inundation. Kanagawa Prefecture has adopted a categorization scheme that is almost the same as the MLIT design. Other prefectures and cities have designed slightly different categorization schemes targeting the statuses of buildings, people, and infrastructure. However, MLIT provides special attention if the flood inundation water level is higher than 2.0 m. In this study, we proposed a simple classification for the status of buildings, as shown in **Table 2**. Hence, we have five categories starting from 0 to greater than 2.0 m (**Table 2**).

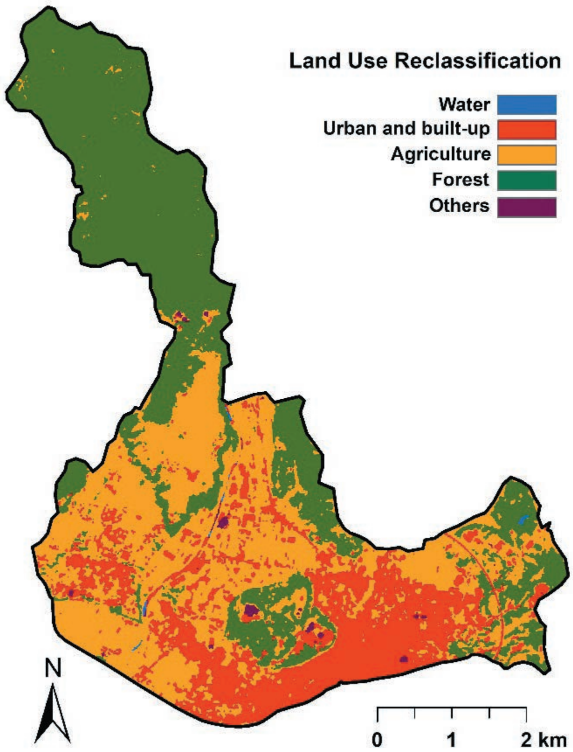

Fig. 3 Land-use classification of northern Hitoyoshi City.

3.3 Roads Status Tool

It is extremely important to understand the status of roads during or just after the flood events. Many rescue vehicles seek to visit the inundation areas, whereas many seek to exit the flooded area. Hence, traffic congestion of vehicles around the flooded zone might be higher. Driving vehicles is very risky after flood water inundation reaches a certain height relative to the roads. Therefore, displaying road status under

Table 2 Classification of building status based on the flood inundation depth profile.

Flood Inundation depth	Given status	Buildings status explanation
0	Stage 0	Building are safe
≤ 0.5 m	Stage 1	Flood water can enter ground floor of building
> 0.5 m - 1.0 m	Stage 2	First floor of the building could be flooded
>1.0 m - 2.0 m	Stage 3	High risk submerged the first floor of building
> 2.0 m	Stage 4	Buildings are in danger

Table 3 Classification of road network status based on the flood inundation depth profile.

Flood inundation depth	Given status	Roads status explanation
0 m	Zone 0	Roads should be in normal condition
Buffer 0 m	Zone 1	Not recommended to enter this zone
≤ 0.5 m	Zone 2	Risk to enter this zone
> 0.5 m	Zone 3	Roads should be closed

the flooding event is a useful reference for the preparedness and recovery processes.

In this tool, we define the overall condition of road networks during the flood event of a city, and this information can be applied in real time throughout the inundated area of any city in Japan. There is no direct method to identify the status of roads during flood inundation for a given area. However, it is generally accepted that if flood-inundated water depth increases by greater than 0.3 m on a road, there may be a problem with driving automobiles (Choo *et al.*, 2020). Moreover, the MLIT (2020) clearly indicates that when the floodwater depth increases over 0.5 m, there will be danger in driving vehicles inroads.

In this study, we designed our classification based on our experience, which is shown in **Table 3**. First, we defined safe roads that are far from the flood inundation zone (approximately 0.5 km distance) as zone 0. A selected distance of 0.5 km was classed the buffer zone from the flood inundation area and was defined as zone 1. A flood inundation depth of less than or equal to 0.5 m is risky for vehicles driving on roads, and hence, it is recommended not to enter these zones. When the inundation water level is more than 0.5 m, the roads become extremely dangerous; therefore, roads should be closed as soon as possible.

3.4 Pre-processing and Arrangement of Data Set

Our study area was fixed to the northern part of Hitoyoshi City. The boundary profile of Hitoyoshi City is an important reference and was traced with a polygon format using a Google Map layout. These polygon data can be extracted or downloaded from an authorized agency.

The default spatial resolution of the raster data sets was used in this study. The polygon shapefile of the northern part of Hitoyoshi City was used to prepare all the required data in the same coverage area. A flood inundation map was developed in the raster GeoTIFF format and masked with the reference of the polygon shapefile of the northern part of Hitoyoshi City.

Buildings and road network data are not publicly available at this stage but are instead housed at the NIED. Considering the privacy of the building data, we first converted the polygonal data into point data within the city using ArcGIS 10.5. These datasets were masked in the same manner as the flood inundation map. **Fig. 4** shows an example of building and road network maps over the northern part of Hitoyoshi City. The map shows that there is a high and low density of buildings in the southern and northern parts of the city, respectively.

3.5 Quick Exposure Assessment

All the required tools were designed in ArcGIS 10.5 or above to perform an exposure assessment. When all the required data were prepared, we linked them as the input

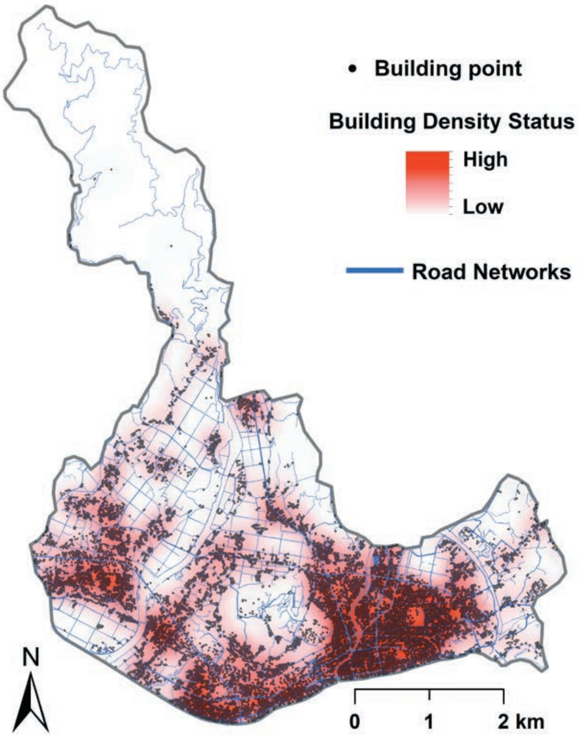

Fig. 4 Status of buildings and road networks in the northern Hitoyoshi City.

to the assessment tool. We prepared different sub-tools for each social data set and combined them with each other for the analysis. Then, we obtained summary results with necessary output data for a given city. There were different integrated components in this analysis, and each has been described individually to detail our adopted assumptions and conditions.

4. Results

Our designed tools can quickly accomplish all the necessary outputs graphically, statistically, or both. In this section, we demonstrate our results for each case so that it is easy to understand the output results. Note that the results are mainly summarized into three parts, namely land use scenarios, building status scenarios, and road network scenarios, within northern Hitoyoshi City for the flood event of July 2020.

4.1 Land Use Scenarios

Flood inundation scenarios for each land use area of Hitoyoshi City are shown in **Fig. 5**. The total area of northern Hitoyoshi City is approximately 26.7 km^2, whereas the total areas of water availability, urban zones, agricultural areas, forests, and others are approximately 0.03, 5.70, 10.17, 10.71, and 0.12 km^2, respectively. By comparison, the flooded areas of these land use categories were 0.01, 2.09, 2.13, 0.06, and 0.01 km^2, respectively. Hence, the total percentage of flooded urban zones, agricultural areas, and forests were estimated at

36.80%, 20.90%, and 0.55%, respectively, within the northern city. Within the flooded zone, the percentage of the flooded land use profile was different. The area of the total flooded land within the city was approximately 4.30 km^2. Among the flooded areas, the percentages of urban, agricultural, forest, and other zones were 48.80%, 49.46%, 1.37%, and 0.20%, respectively. In this study domain, most of the forest area is located in the upper part of northern Hitoyoshi City. Hence, few parts of the forest areas were found in the flood-inundated zone. Notably, land use profiles may be different for each city. This type of information can be obtained with the help of the land use status tool presented in this study.

We further categorized urban zones into two classes. In urban areas, roads and buildings as well as the movement of people and vehicles, are common; hence, there is a need to provide more detailed scenarios. In northern Hitoyoshi City, we found that flood water levels in inundated areas less than or equal to 0.5 m accounted for approximately 0.29 km^2, and areas greater than 0.5 m accounted for approximately 1.81 km^2, which corresponds to approximately 5% and 31.8% within the city; meanwhile, for the flooded zone only (southern part of the city), they were 6.67% and 42%, respectively. Hence, flood inundation greater than 0.5 m was found in many places in the urban zone of the city.

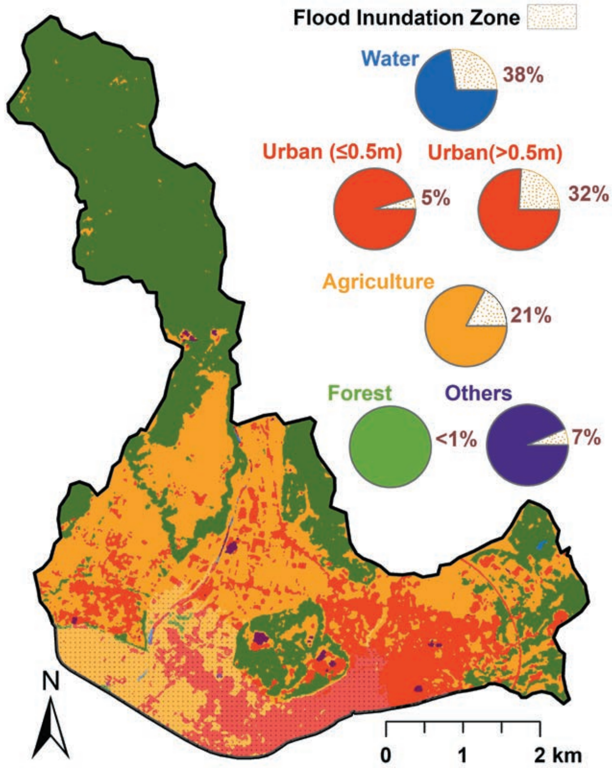

Fig. 5 Flood inundation scenario for the different land use of northern Hitoyoshi City.

4.2 Buildings Status Scenarios

In northern Hitoyoshi City, there are more than 14,000 buildings, and a high density of these buildings was found near the Kuma River (**Fig. 4**). Most of the buildings were also located in flat areas of the city. In general, a higher density of buildings means that there will be a higher population density; hence, detailed information on the status of buildings within the city is extremely important for evacuation and emergence response. The statuses of buildings during the flooding situation were classified and are presented in **Table 2**. Based on this classification, the total number of buildings was classified based on their flood depth. **Fig. 6** shows the defined status of buildings during the flood event in northern Hitoyoshi City. Approximately 5,355 buildings were inundated during this event, whereas 8,960 buildings were not affected by flood inundation (Stage 0). Within the flood inundation zone, 536, 560, 837, and 3,422 buildings belonged to stages 1, 2, 3, and 4, respectively.

When viewing the percentage of affected buildings more specifically within the city and the flood inundation zone, the relative percentage differed, as depicted in **Fig. 7**. The building status at stage 4 was approximately 64% within the flood-inundated zone, whereas for the whole city, the percentage was approximately 24%. Note that the actual number of buildings may be slightly different in reality because of the data observation time and spatial resolution of the dataset used in this study.

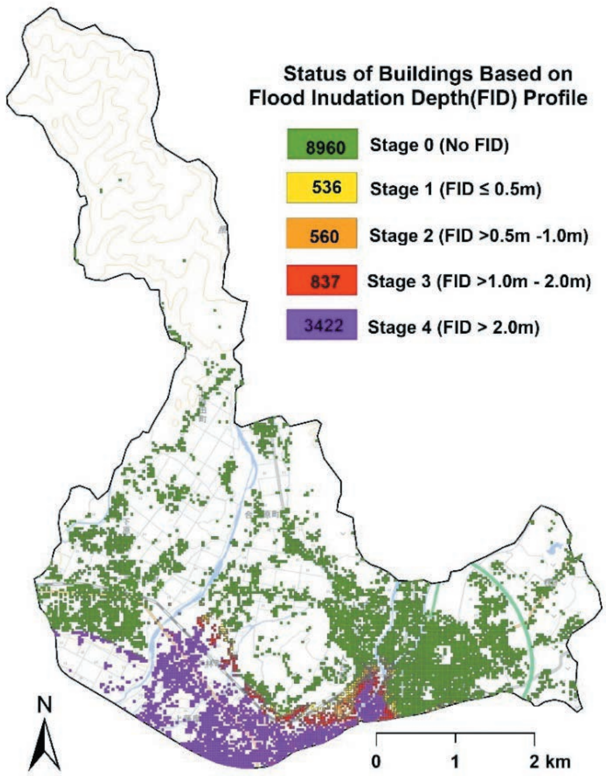

Fig. 6 Building status profile based on flood inundation depth profile in the northern Hitoyoshi City.

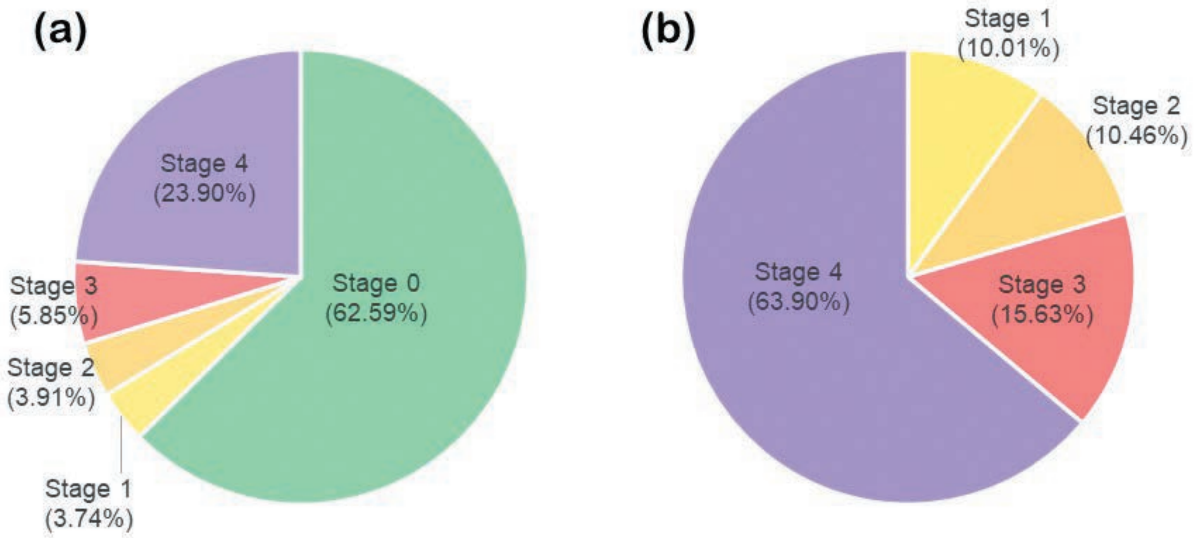

Fig. 7 Relative percentage of building status with in (a) northern Hitoyoshi City, (b) flood inundation zone only.

4.3 Road Network Scenarios

Road networks are highly concentrated near the Kuma River, where the density of buildings is also highly concentrated. In this study, we classified the road zone based on the status of the flood inundation profile (**Table 3**). **Fig. 8** shows the status of road networks based on flood inundation status. Overall, four zones can be observed within the city. Green road networks are designated as normal road networks. Then, a buffer zone (yellow color in **Fig. 8**) was generated, which was approximately 0.5 km from the boundary of the flood inundation zone. This was important for ensuring that vehicles departed from the inundated area and that vehicles returned from zone 1 to zone 0 within a city. Zones 2 and 3 were classed as relative in danger, as indicated by the red and purple colors, respectively. These scenarios were updated with the flood inundation situation in real-time.

The quick display of these road networks within the flooded city may be the most suitable way to warn drivers who are moving toward floods inundated or nearby areas. Such a display of the status of road networks can provide a critically important reference for handling disaster management within a city. However, there may also be smaller road networks within the city that were not included or were missing in this study.

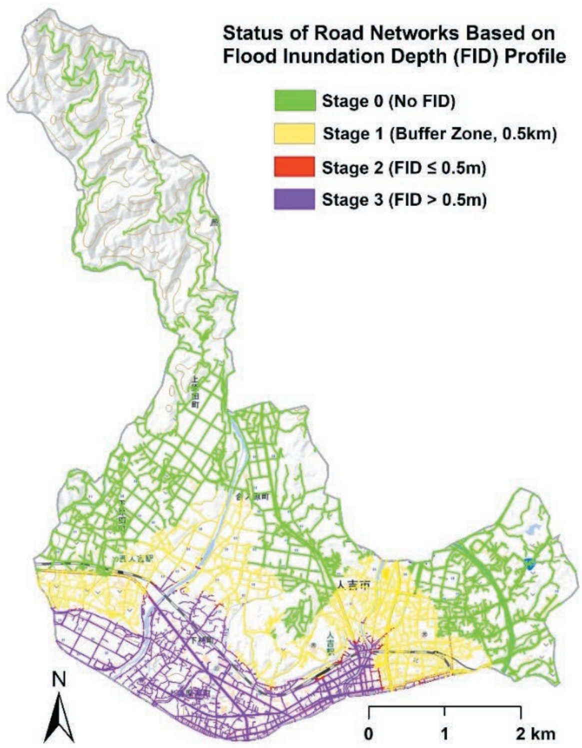

Fig. 8 Status of road networks based on different stages of flood inundation depth.

5. Discussion

A quick exposure assessment of flood inundation was performed within northern Hitoyoshi City as a case study in this research. We outlined the hazard and exposure scenarios based on a simple assumption and presented the overall results. Ultimately, this information is an important reference for presenting flood risk within the city. **Fig. 9** shows the damage to buildings and roads for the given points. The stages of buildings and road networks for this information are stages 4 and 3, respectively. In addition, FDMA (2020) found that a total of 4,681 buildings were damaged in the entire city of Hitoyoshi, based on a detailed survey. In our study, approximately 4,819 buildings were inundated at a

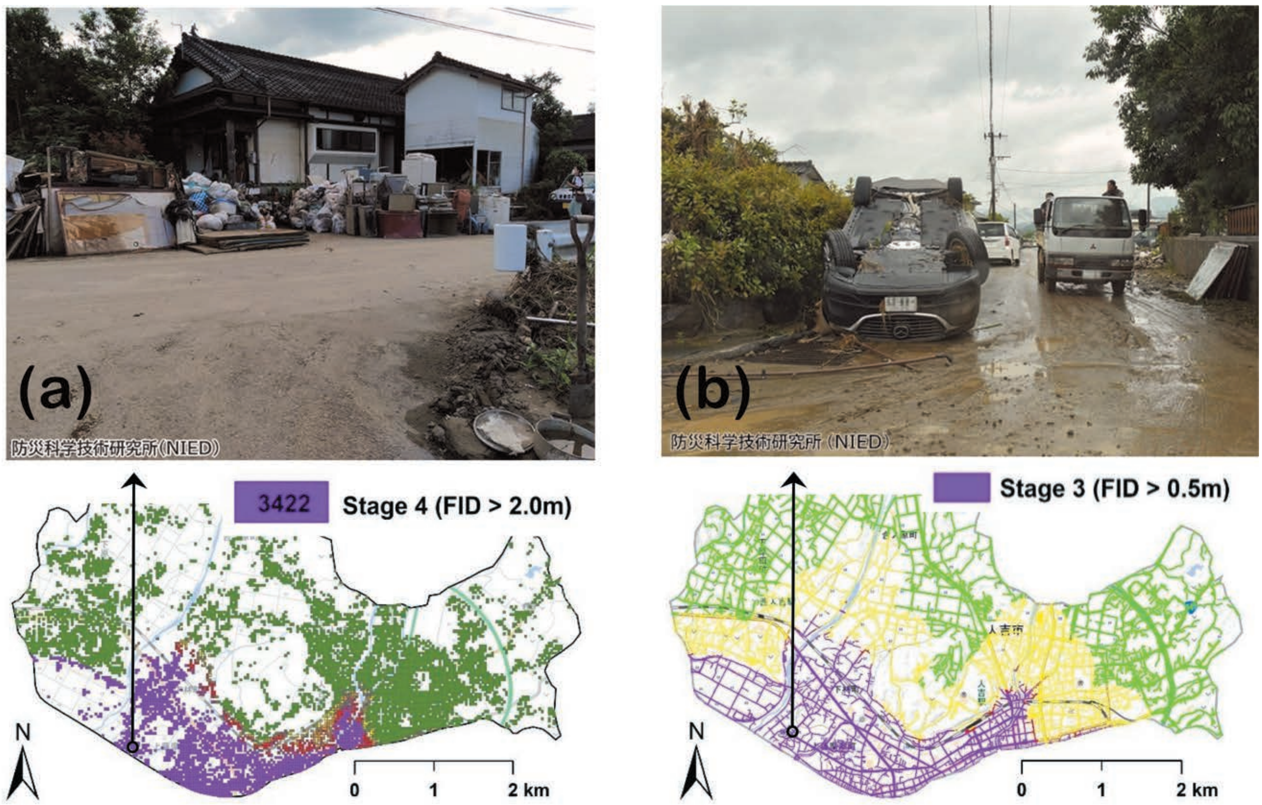

Fig. 9 Damage to (a) buildings and (b) roads and their warning stages for the specific points during the flood inundation in Hitoyoshi City.

>0.5 m flood depth, and 4,259 buildings were inundated at >1.0 m. Notably, several factors could affect the estimation of accurate outputs, which are discussed in the next sub-section. This is a case study, and we plan to apply our quick assessment tool to future flood events for further verification. A detailed understanding of vulnerability scenarios will be the future objective of this study.

All purposed tools were designed in ArcGIS 10.5 or above to perform an exposure assessment. Processing time was quick once all the required reference data were prepared. At this stage, our developed tools are based on simple approaches and include certain elements and provides a robust assessment. Hence, we believe that there is no remarkable issue with the robustness of developed assessment tool. Before concluding this study, there are some important points that should be discussed.

5.1 Flood Inundation Mapping

The assessment was based on flood inundation mapping so that any error in the estimation of possible maximum inundation depth profile would also lead to uncertainties in the dissemination of exposure within the city. In this study, we also checked our mapping product; hence, we believe that the flood inundation profile and assessment results are close to reality. Notably, the mapping product is based on DEM data and SNS information. Occasionally, the SNS information required verification, especially to determine an exact location point. Hence, obtaining reliable information was a challenge in some cases. Recently, the active sharing of flooding situations on several social media has become common; hence, closely reviewing all these social networks may help to obtain real-time SNS information, thereby reducing uncertainties in developing flood inundation maps. In contrast, we used 5 m DEM data to generate a flood inundation mapping product. A high spatial resolution of DEM is always desired to obtain high-quality flood inundation mapping products. However, 5 m DEM may be not available for other areas in Japan; hence, we may have to consider a coarser resolution DEM data to generate mapping products, which could complicate maintaining the quality of the mapping product.

In some cases, flood inundation may occur because of the breaking of embankments in several cities (P.C. *et al.*, 2020a; P. C. *et al.*, 2020b). Collecting and combining this information and generating such mapping products will be a challenging task. Including embankment information of close rivers also needs to be considered when updating the mapping product.

5.2 Social Data

In this study, we used different types of social data in different spatial resolution formats. Notably, observations were performed for a certain period to prepare all the social data. However, information about these data may change over time. Hence, any recent change should be excluded from the collected data set. Recent updated social data should be used so that uncertainties are lower; however, this may not be a simple process. Moreover, we did not cross-check or validate the social datasets in detail in this study. Hitoyoshi City is well organized and is not a new city; hence, we believe that the possibility of drastic changes in social data is rare and that these data will usually reflect reality. Some data sets were freely available for research purposes, whereas some, especially building and road network data, are not publicly available. If these data were made available for any region or any part of the world, the model proposed in this study could be applied for a quick exposure assessment of any event at any time. In addition, our proposed model was designed in ArcGIS 10.5 at our workplace, and we propose to release it publicly after organizing it more precisely.

Population data is also one of the important inputs that can be used for various vulnerabilities such as shelter deficiency, vulnerable populations, and vulnerable shelters (Sritart *et al.*, 2020); such an approach may provide a useful reference for disaster preparation planning and resource allocation. In the future, we will include population data in the model to present a more comprehensive assessment of flood inundation in a city in Japan.

5.3 Flood Risk Assessments

Assessments such as flood hazards, exposure, and vulnerability are the key components for performing overall flood risk assessment in engineering and natural sciences (Foudi *et al.*, 2015, Kvocka *et al.*, 2016). Each of these assessments plays a significant role in disaster management, and they have been considered separately or jointly during a flood disaster event in any area.

Geographic information system (GIS) datasets are available for many parts of the world. Hence, exposure assessments of flood events has been performed worldwide (Foudi *et al.*, 2015; Koks *et al.*, 2015; Kvocka *et al.*, 2016). Notably, there are various other factors such as warning time, preparedness, economic resistance, and healthcare that may influence the exposure assessment, which may or may not be included in the assessment due to difficulties in quantification and valuing. However, detailed evaluation of land-use property damage may also depend on inundation depth, duration, and flood velocity. In this study, only the possible damage area of land use properties was investigated.

In general, flood risk assessments are performed based on the geospatial map of flood hazards, which is normally based on the probability of a flood event (Kvocka *et al.*, 2016; Fan and Huang 2020). However, uncertainties in such hazard mapping products is a serious issue (P.C. *et al.*, 2020c) and will likely increase with climate change (Kwak and Iwami, 2016). Hence, quick mapping of flood inundation for a flood-affected area, such as the method presented herein, can be an alternative option for risk analysis. In this study, detailed damage analysis of land -use status (e.g., agriculture, forest, and urban) was not included in the exposure assessment. Hence, in future studies, the consideration of these issues and more social datasets would allow for a more holistic flood risk assessment.

6. Conclusion

In the first week of July 2020, torrential rain caused catastrophic flooding in several prefectures of southern Japan. Substantial losses of physical property and human lives were recorded during that event, as many cities were inundated. Among them, Hitoyoshi City flooded severely with losses to agriculture, urban areas, and buildings, especially in its northern part. We developed a tool and applied it for a quick exposure assessment of floods in northern Hitoyoshi City, Kumamoto Prefecture, Japan.

The quick exposure assessment of a city during such an event is a challenging task but is necessary as reliable assessment results can provide a key reference for the proper management of flood disasters. Therefore, we have proposed a tool that can estimate simple information based on possible flood water exposure within the city. We used several social datasets to issue this output information. We believe that this assessment can be performed anywhere in Japan. However, regular updates to the tool and further consideration of this quick assessment will be addressed in our future work. We believe that this assessment will be a useful reference for the public, city officers, managers, engineers, and water-related organizations in flood-affected cities. Finally, our proposed tool also produced several output data in a GIS format for land use profiles, buildings, and road networks, which are easy to display. Hence, we also expect that the estimated output images can be published through the crisis response site of the NIED for any upcoming flood-affected cities in Japan. This information may assist emergency response coordination efforts and ensure the informed allocation of resources.

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洪水氾濫の迅速暴露評価：熊本県人吉市の事例研究

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要　旨

近年，大雨とそれに伴う洪水は，日本の多くの都市で農地，家屋，そして人命に重大な被害をもたらしています．このような壊滅的なイベントの迅速な暴露評価は，洪水イベントに対する警告，対応，緩和，および評価に有益な情報を与えると考えられます．そのため，洪水発生時に都市内の土地利用プロファイル，建物，道路網の状態を迅速に推定できるツールを開発しました．事例研究として，2020 年 7 月第 1 週の熊本県の人吉市での洪水イベントに，この新しいツールを適用しました．人吉市北部では，都市建設，農業，森林地域の洪水浸水率はそれぞれ 36.80%，20.90%，0.55% と推定されました．また，このイベントによる市内の浸水建物数は約 5,355 棟と推定されました．さらに，このうちの約 24% が 2 m を超える洪水で浸水し，危険な状態 (ステージ 4) にあると推定されました．市内の洪水氾濫深度に基づいて，土地利用プロファイル，建物，道路網の詳細な状況も推定しました．このようなタイプの推定情報は，緊急時対応の調整作業と情報に基づくリソースの割り当てに役立つと考えられます．開発したツールは，洪水の迅速な影響評価のために日本のどの都市にも適用できると考えられます．

キーワード：洪水氾濫，暴露評価，ArcGIS，建物，道路網