Paper:

Development of a Framework for the Flood Economic Risk Assessment Using Vector GIS Data

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This paper proposes a flood economic risk assessment framework using vector GIS data, expressing individual house and paddyfield, prepared by a municipal Japanese government. Flood inundation is first simulated with a structured grid, then the simulated flood inundation depth, expressed in grid cells, is assigned to vector data house and paddyfield polygons as attributes. Flood-damage ratios of houses and paddyfields are then calculated using relationships of the flood depth, duration, and damage ratio opened by the Japanese Ministry of Land, Infrastructure, Transport, and Tourisms (MLIT). Economic loss involving building and paddyfield damages due to flooding is then calculated by multiplying the damage ratio, evaluation price per area, and the asset area. The advantage of using such vector data is that it yields the area of each house and paddyfield precisely, which also realizes, on average, the precise economic loss estimation. As the results, the spatial distribution of economic loss on an individual house/paddyfield scale is also identified. Since vector data shows area characteristics, the framework proposed here is useful in community-based flood management. A workshop presenting the framework showed that the system potentially induces workshop participants to consider community-based flood hazard management.

Keywords: flood hazard, GIS vector data, economic loss, damage ratio, house and crop field polygon

1. Introduction

Flood disasters increasing over the last 30 years numbered 150 in 1980-1982, growing to 550 in 2004-2006 in the world. By geographical area, Asia and Africa have suffered the most – accounting for 60% of all recent disasters. Natural disasters in Asia and Africa accounted for 95% of all casualties and 83% of all deaths. Economic loss in Asia and Africa, in contrast, accounts only for 55%, meaning asset values in Asia and Africa are, on the average, lower than in other regions. This also means that potential economic risk – economic loss accounting for part of overall flood risk – is not necessarily proportional to the number of hazardous events. Here is where regional vulnerability comes in. Economic loss also should be at least somewhat predictable before natural disasters occur.

Engineers may tend to focus on the details of a hazard – e.g., flood inundation depth and concrete preventive measures – but problems of natural disasters, especially in Asia and Africa, cannot be solved without lessening regional vulnerability. Societal resilience is only realized by enhancing corrective measures before disaster occurrence and improving crisis management implemented after the fact.

Risk is conventionally expressed as risk = hazard ∗ vulnerability (International Risk Governance Council, 2005 [1]). Given this concept, risk becomes zero even the hazard is huge when the vulnerability of the exposed area is zero (e.g. people are not living in the area). Thus, it is very important to know the characteristic of the area to be exposed in order to estimate the vulnerability of the area. Hereat, detailed vector data which even identify the exact shape of the houses/paddyfield becomes of grate help since people can see exactly how the area is like. If each polygon of the vector data has attribute (e.g. the polygon expresses a house and the attribute is the area/height/floor number of the house), then the data becomes further useful. Using such vector data, the paper presents a framework to estimate economic risk due to flooding in Japan.

Similar type of research can be found in, for example, FEMA (2010) [2], van der Sande et al. (2003) [3], Choong-Sung Yi et al. (2010) [4]. These papers deal with the economic assessment framework in the United States, Netherland and Korea and serve as useful references. For example, the economic risk estimation pro-

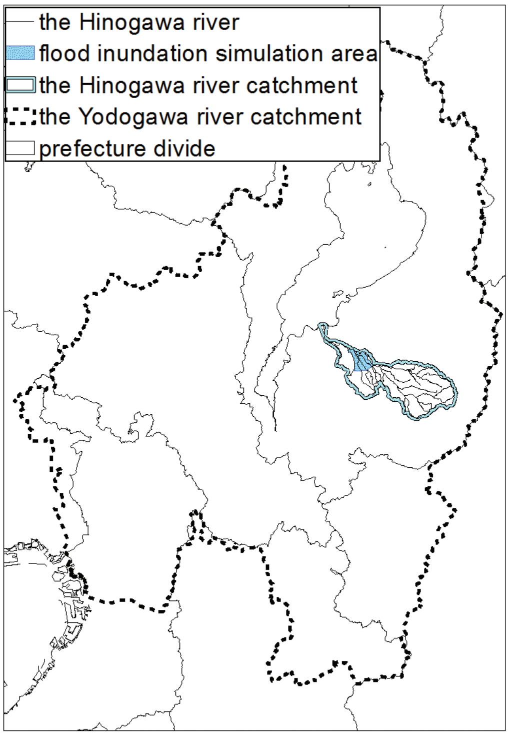

Fig. 1. The Hinoagwa river catchment and the flood inundation simulation area.

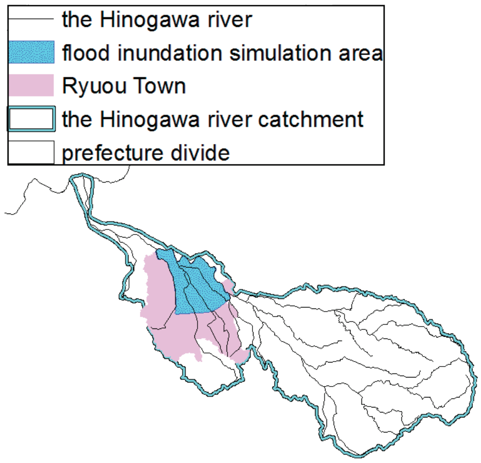

Fig. 2. Enlarged view of the Hinoagwa river catchment and Ryuou Town.

cedure used in van der Sande et al. is based on a damage function expressing the relationship between the water depth and damage factor. Likewise, Choong-Sung Yi et al. deal with a form of the damage function, what they call, "Depth-percent damage". On the other hand, this paper presents an economic assessment framework tailored for Japan based on the statistics of the Japanese Ministry of Land, Infrastructure, Transport and Tourisms (MLIT, 2005) [5] and the vector data being prepared in Japan. The reason is that although the above three methods all based on the flood inundation depth-damage relationship, the damage functions used in the Netherland and Korea are not generally applicable in Japan since the structure, materials of the houses and crop resistances are not necessary the same among the countries. In other words, the house/paddy filed damage against a flood depth is probably not the same. Above all, the framework being proposed here has advantage in that it can yield the spatial distribution of the economic losses of even individual house and paddyfields.

In the paper the economic loss is calculated as follows: First the flood inundation simulation including the inland water inundation is carried out with a rectangle grid also considering the drainage effect (see. e.g. Kobayashi and Takara, 2009 [6], Kobayashi et al., 2009 [7], 2009 [8], 2010 [9]). Then, the simulated grid-cell flood depth is assigned to each house/paddyfield polygon of the vector data as attribute. Afterwards, the damage ratios of the house/paddyfield are calculated using the relationships between the inundation depth, duration and damage ratios quantified based on a survey by MLIT. Finally the economic loss due to the flooding is calculated by multiplying the damage ratio, the area of the house/paddyfield and the evaluation price of the house/paddyfield. In the following, each procedure is explained step by step.

2. The Hinogawa River Catchment and the Ryuou Town

The Yodogawa river catchment, the Hinogawa river catchment, Japan and flood inundation simulation area are shown in **Fig. 1**. The Hinogawa river belongs to the Yodogawa river system and is the first class river. The Hinogawa river starts from the Watamukiyama Mountain in the Suzuka Range (land elevation: 1100 m) and flows through 3 cities (Higashi-Omi City, Omi-Hachiman City, and Yasu City) and 2 towns (Hino Town and Ryuou Town) of Shiga Prefecture. According to the report by Shiga Prefecture, 183 floods are counted for the period of 1815-1998 in the Hinogawa river catchment, thus the flood risk of the Hinogawa river catchment is very high. The Shiga Prefecture allocates one of the maximum budgets for the river improvement project on the river.

The Ryuou Town is located at the middle to downstream region of the Hinoagawa river catchment as shown in **Fig. 2**. The town is surrounded by the Yukinoyma Mountain in the east, the Kagamiyama Mountain in the west, the hilly terrain in the south and the meandering Hinogawa river in the north. From this topography, the town is severely susceptible to floods especially in the flood simulation area in **Fig. 2**. If inundated, the rainwater/dike-break water flows toward the low elevation area of the town (i.e. toward the downstream of the Hinogawa river). The topography of the town is from the elevation as bowl.

There exists a local Non Profit Organization, Hinogawa River Reformation Consortium in the town and the consortium works eagerly for self-help and mutual assistance of the region against flooding. Thus, the town is

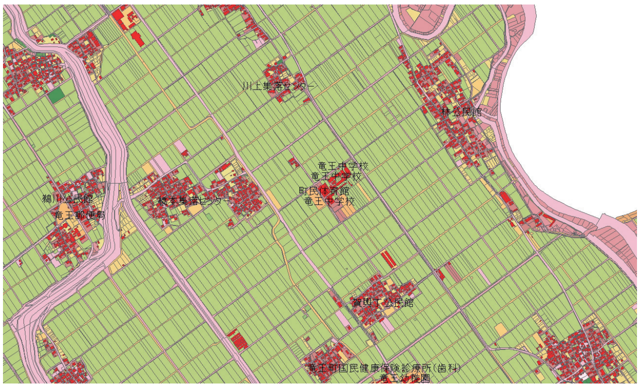

Fig. 3. Vector GIS data prepared by the Ryuou Town, Japan.

selected as the test site since the town has high flood risk; Shiga Prefecture engages eagerly in the river improvement work; and the good support both by the town and the consortium for the development and the evaluation of the economic loss estimation framework is obtained.

3. Vector Data

Figure 3 shows a vector data prepared by Ryuou Town, Shiga Prefecture, Japan. Such vector data is now being prepared little by little in many parts of Japan. The house/building and paddy/crop fields are precisely delineated by polygons in the figure. For example, the red small rectangle polygons in the figure indicate the house/buildings, while the light green rectangle polygons represent the paddy/crop fields. As each polygon can have the attributes such as the position, area, floor levels, we have the possibility to estimate the economic damage more accurately using the data.

4. Integration of Grid Cell Inundation Depth to Vector House/Paddyfield Polygon

Figure 4 shows the flood inundation simulation result carried out with the rectangle-structured grid on the vector data from **Fig. 3**. **Fig. 4** shows the integration results in which the inundation depth information of the grid-cell is assigned to each polygon as attribute. The transfer process is carried out only for the house/paddyfield polygons, thus, for example, the mountain area in the lower left corner of **Fig. 5** has no inundation depth. There are cases that a polygon crosses over several grid-cells with different inundation depths. In that case, the maximum water depth is selected as the representative value. For instance, the minimum inundation depth or the average inundation depth can also be the candidate for the attribute. However the safer side consideration (i.e. taking the maximum inundation depth which yields the highest damage) is considered most reasonable especially for the flood defence planning. By this method, no inundation place in **Fig. 4** can have the water depth in **Fig. 5**. It is natural to consider

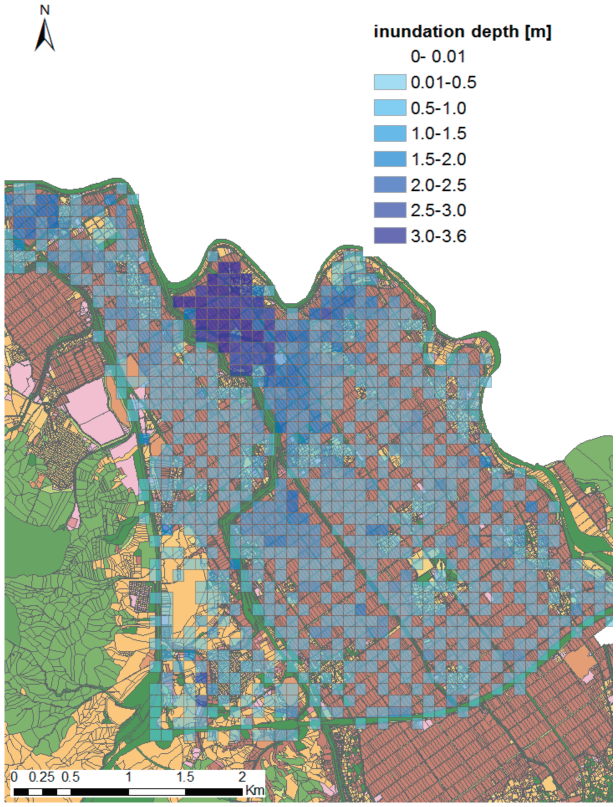

Fig. 4. The flood inundation simulation result with the rectangle-structured grid.

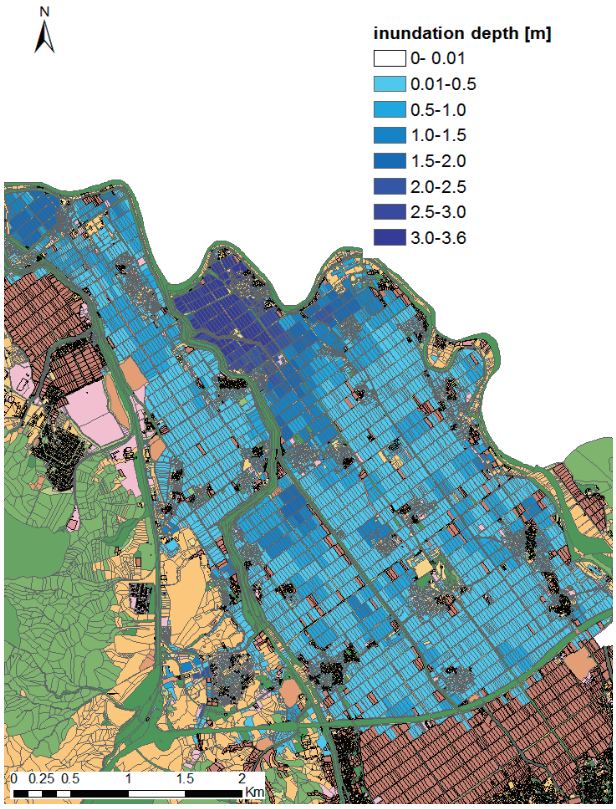

Fig. 5. The integrated inundation depths for building and paddyfield polygons.

Table 1. The relationship between the house damage ratio and the flood inundation depth (MLIT, 2005).

Ground slope [-] \ Water depth [m]	< 0.45	< 0.5	≥ 0.5 < 1.0	≥ 1.0 < 2.0	≥ 2.0 < 3.0	≥ 3.0
<1/1000	3.2 [%]	9.2	11.9	26.6	58.0	83.4
1/1000 – 1/500	4.4	12.6	17.6	34.3	64.7	87.0
≥1/500	5	14.4	20.5	38.2	68.1	88.8

Table 2. The relationship between the rice/crop damage ratio, the flood inundation depth and the inundation duration (MLIT, 2005).

Crop type \ Water depth [m]	< 0.5				≥ 0.5 < 1.0				≥1.0			
Inundation duration [day]	1-2	3-4	5-6	7	1-2	3-4	5-6	7	1-2	3-4	5-6	7
rice (paddy) [%]	21	30	36	50	24	44	50	71	37	54	64	74
crop average [%]	27	42	54	67	35	48	67	74	51	67	81	91

that the water depth is the same in each division (polygon) if no obstacle exists within the division. As the results, the owner of each property (house/crop field etc.) can judge if one's property is inundated and how much the water depth is.

5. Damage Ratio Estimation

The damage ratio presented in this paper expresses the extent (ratio) how much percent of the house/paddyfield is damaged by a flooding. The house and paddyfield damage ratio as the function of inundation depth and duration is opened public by MLIT (2005) in Japan. Some insurance companies have such information as well but they cannot open the information in principle since the professionals can speculate the risks hold by the companies by the business from the statistics. There are statistics opened in other countries but it cannot be used as it is for the cases of Japan. Thus we may be able to rely only on the statistics by MLIT in Japan currently as the general number.

The damage ratio of the house is shown in **Table 1**. The ground slope in **Table 1** indicates the ground slope of each grid-cell or the average slope of the region. The slope classification is designed to consider the hydrodynamic force (i.e. flood velocity) effect implicitly. In other words, the damage ratio of the house is the function of the inundation depth explicitly and implicitly the velocity. The statistics in the table is derived from a survey on actual conditions of water-related disasters conducted by the Ministry of Construction (currently MLIT) during the period of 1993-1996.

The damage ratio of the crop is shown in **Table 2**. A note is that the inundation duration is also considered for the crop damage estimation. **Table 2** indicates a principle that the crops can survive more even after the flooding if the inundation duration is shorter. For instance, when the inundation depth is less than 0.5 m and the inundation duration is 1-2 days, the rice damage is 21%, while when the duration is more than 7 days, then the rice damage becomes 50%. The difference attains 29%. Note that, in the paper, the inundation duration less than 1 day is included in 1-2 day classification.

An example of the house damage ratio calculation is shown in **Fig. 6**. In the region, the average ground slope is more than 1/500. Thus, the lowest row of **Table 1** is used for the estimation of the damage ratio. **Fig. 6** shows that the damage ratio of the houses in the region. The damage ratios reach up to 88.8%, then down to 68.1%, 38.2%, 20.5%, 14.4% respectively. Since the damage ratio of each individual house is clearly indicated, the owners can have a clear perception on the status of their properties after flooding. This is considered more useful compared to estimating the flood inundation depth only since the owner's can think what and how are the risks of their assets in addition to the hazard.

On the other hand, an instance of the crop damage ratio estimation is shown in **Fig. 7**. In this area, the flood inundation duration is calculated by simulation as around 10 hours, thus 1-2 days classification of **Table 2** is used (This estimation is possible only when the flood model can deal with the drainage as well). As shown in **Fig. 7**, the damage ratio ranges at 21%, 24% and 37% respectively. The crop damage is the highest (i.e. 37%) where the land elevation is lowest.

6. Economic Loss Estimation

The economic loss of each house and paddyfield can be calculated by multiplying the damage ratio, the evaluation prices of the assets per area and the area. With this vector data, we can calculate in average the area of each individual house and paddyfield precisely. The evaluation price of house/building per m^2 in each prefecture is obtained also from MLIT (2005). For example, the per-area house price of Shiga Prefecture is 1519 USD/m^2 (given 1 USD approx 100 JPY) as of 2004. As we know the house area, we can estimate the economic loss of a house

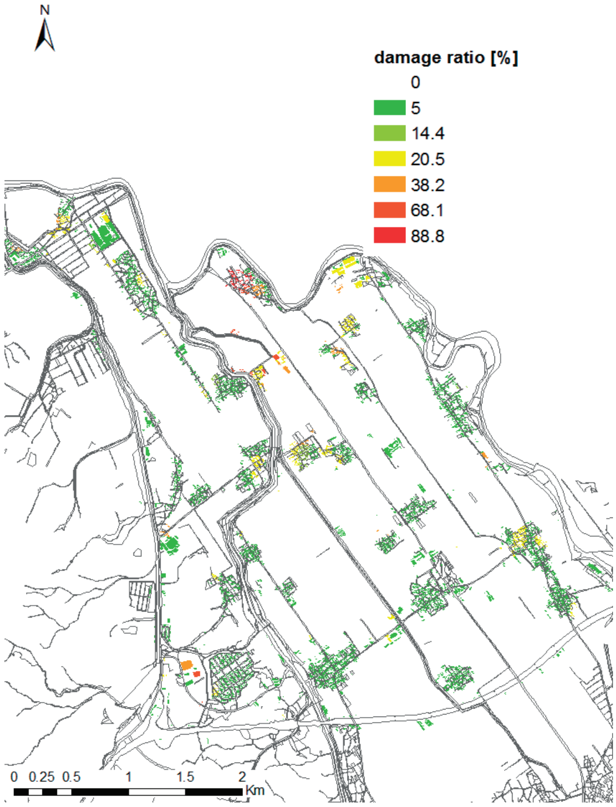

Fig. 6. The house damage ratio calculated.

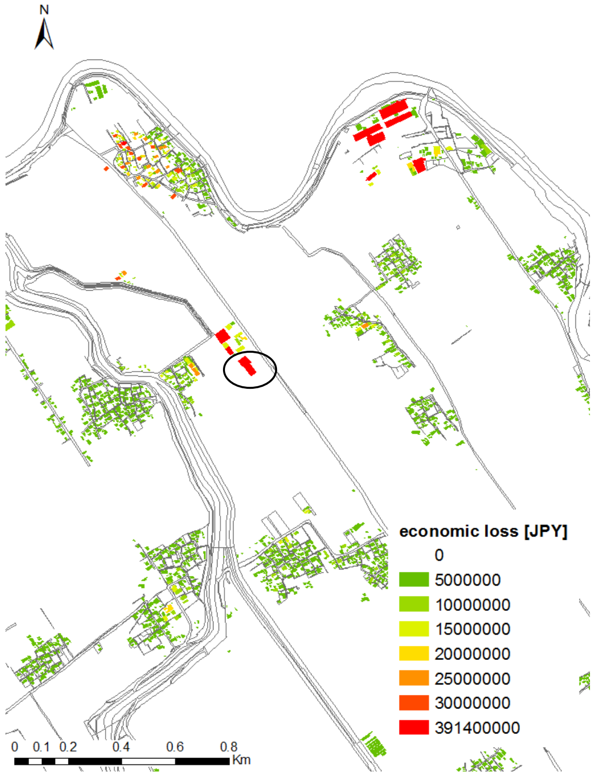

Fig. 8. The building economic loss distribution.

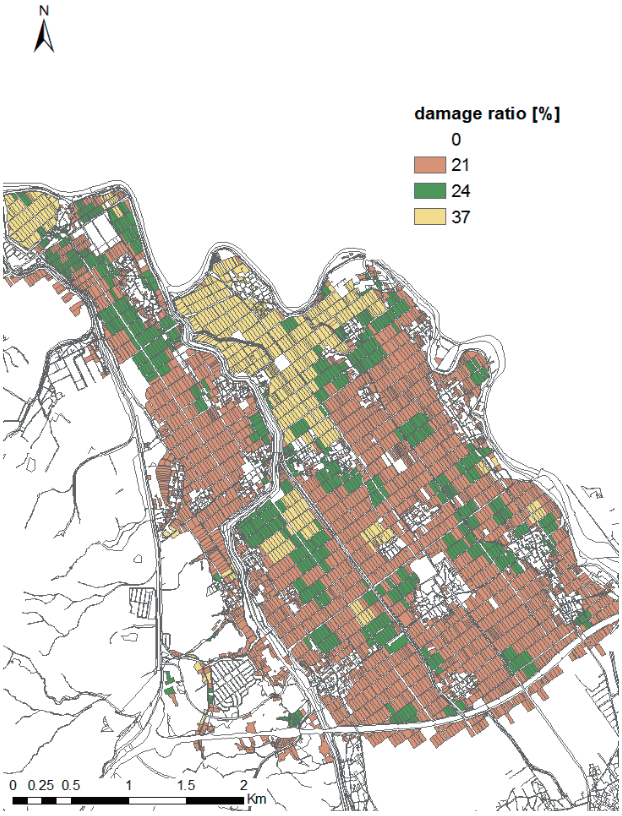

Fig. 7. The crop damage ratio calculated.

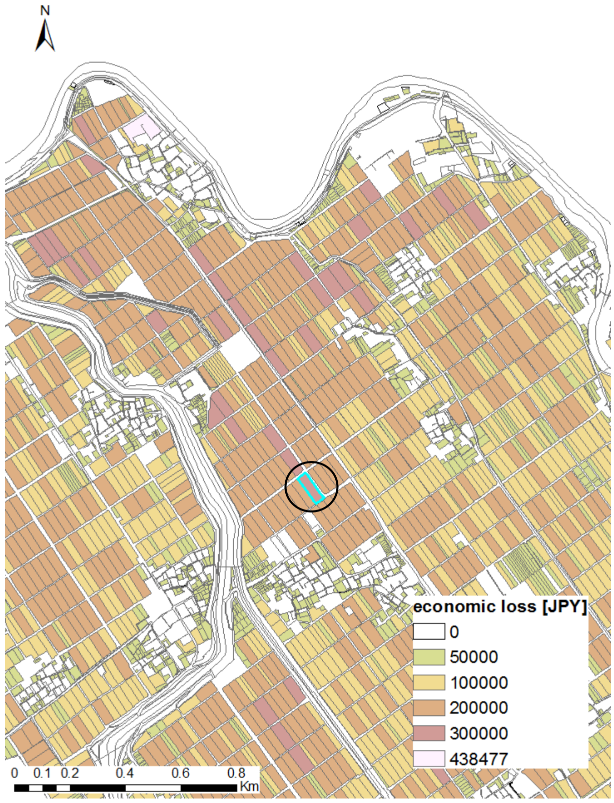

Fig. 9. The paddyfield economic loss distribution.

due to flooding by the equation "economic loss = house area $*$ price per area $*$ damage ratio." **Fig. 8** shows an example of the economic damage distribution of the houses. The area of the building in the circle is 2250 m^2. The price/m^2 is 1519 USD/m^2. The inundation depth is 1.52 m and the damage ratio is 38.2%. As the results, the economic loss for the building becomes $2250 * 1519 * 0.382 = 1306000$ USD.

With regard to the paddyfield, we can estimate the economic loss by the equation "economic loss = paddyfield area $*$ crop yield per area $*$ crop price per kg $*$ damage ratio." Same as the house, the paddyfield area is precisely calculated with the vector data. In Japan, there is an estimate how much crop is on average produced in each prefecture. For the case of Shiga Prefecture, the crop yield is 0.525 kg/m^2 as of 2004 (MLIT, 2005). The crop price per kg, for example, of the rice is 2.89 USD/kg as of 2004 in Shiga Prefecture (MLIT, 2005). Since it is difficult to know the crop type cultivated in each paddyfield, the price of the rice is used in the following as the representative value. The area of the paddyfield in the circle of **Fig. 9** is 4033 m^2. The inundation depth is 1.4 m and the damage ratio is 37%. As the result, the economic loss becomes $4033 * 0.525 * 2.89 * 0.37 = 2264$ USD. In general the economic loss per area of the house becomes higher than that of the paddyfield when this methodology is applied.

7. Advantage and Limitation of the Estimation Framework with Vector Data

All the procedure in the economic risk assessment framework of the paper is based on the transfer of the raster-type flood inundation information to the vector data. By doing this, we try to take the advantage of holding the attributes of the houses/paddyfields in the polygons of the vector data. The advantage includes that the spatial distributions of the economic losses is able to be visualized and the economic loss of each house/paddyfield is one by one indicated. Probably almost no research has been yet carried out that both the flood inundation simulation and economic loss estimation are conducted with the vector data in an integrated manner. Thus, what remains to be done is to clarify the differences between a raster-type flood simulation+vector economic loss estimation and a vector flood simulation+vector economic loss estimation. Nevertheless, the proposed method here is considered that it has a practical advantage and is a good basis for the citizen's involvement in the economic loss estimation due to disasters.

The framework is also considered in general not affected much by the scale location accuracy of the base map and/or of the base aerial/satellite images as it takes the maximum water depth which brings a safer side economic loss prediction. As the damage function has also uncertainty, the resultant estimation is better to be adjusted by comparing it with the reported losses by the public administration when the last data exists. However, there are many places where such past economic loss data is not remained. In that case, the average statistics needs to be used as shown in this paper. Comparison effort for other site is now being taken by the authors.

This economic loss estimation can be carried out by using e.g. the 100 m resolution land use data of Digital National Land Information (MLIT, 2010 [10]). However, the house/paddyfield area becomes 100 m times 100 m when this data set is used. This brings in general the overestimation of the economic loss as the area is larger than the actual area. For example, 10 m resolution land use data which is published for large metropolitan areas (Japan Map Center, 2010 [11]) can be good alternative of the vector data.

In practice, for example, gross floor area data of Housing and Land Survey data by Ministry of Internal Affairs and Communications (MIC, 2010 [12]) is used for the estimation of economic losses (JACIC, 2010 [13]). By using this gross floor area data, it is possible to estimate the house area more accurately. However, this data is offered by a district unit and the information inside the district is filtered out. Thus, it is not possible to look at the damage situation of each individual house/paddyfield. The use of the vector data in this paper has advantage in that aspect. A note is that if the attributes (area, evaluation price, damage function) of the base data are the same apart from the type of the data (e.g. raster/feature/vector), then the estimation result becomes basically the same. However, the vector data can offer visually better impression to the viewer and the spatial analysis is possible.

The flood hazard and economic risk assessment framework are presented to the member of the Hinogawa River Reformation Consortium, the Ryuou Town and the Shiga Prefecture at the Workshop as of 2009/10/20, 14:00-16:10. There were 22 participants and some opinions expressed in the workshop were as follows:

- The damage of the paddy rice is different by the season. It is totally damaged by 1hr inundation before the spike of the paddy rice grows.
- Paddy rice has still resistance against water. Vegetable such as cabbage is very week.
- The paddyfield economic damage based on the estimation may be affordable. The damages of cars/buildings are much harder.
- The inundation depth of Yuge district, Ryuou Town is probably correct but the corrective measure has already been taken. The houses in Yuge district are built on high foundation.
- The house economic damage is probably overestimation. It was less.

These opinions indicate that the flood hazard and the economic risk assessment system successfully became a tool for the participants to consider the flood disaster problems concretely. However, there was opinion also that the estimation is probably in average accurate, thus a good system for the estimation by the public sector, but maybe still not in detail enough for the individuals. Overall, the system is considered useful for the flood defense planning of regional scale at this stage but need more devices for the individuals.

8. Concluding Remarks

This paper presented a framework to estimate the economic damages due to flooding using vector GIS data expressing even individual house and paddyfield. By using such vector data, the assessment framework can yield not only the average economic damages due to flooding but also the spatial distributions along with the house/paddyfield polygons. This enables the local people to perceive what happens to their properties more intuitively.

In the framework, firstly, the procedure to assign the grid cell flood inundation simulation results to the polygons of the vector GIS data is explained. The information assigned in the polygon as attribute is considered more useful for the community-based flood disaster management since citizens can perceive the flood disaster closer and one's own. The Ryuou Town, Shiga Prefecture, Japan has prepared the vector GIS data. This type of data and the methodology hereat are usable not only to the flood disaster but also earthquake and fire disasters.

Then the house/building and crop damage ratios are calculated using the statistics based on the water disaster actual condition survey in Japan. Further study of deciding damage ratio is considered necessary, although such effort has not been carried out so far so much compared to the effort of developing the flood inundation simulation models. The research for the vulnerability assessment in broad sense is required.

The economic loss of each individual house/building and crop field is then calculated in this paper. By doing this, people can in average know the economic loss of their own properties, thus this will be useful for the preparation and insurance consideration of each household.

The methodology introduced hereat is applicable even if there exists no such detailed vector data. If there is an aerial photo of the target region, the area can be roughly delineated by the basic function of GIS. Thus, the rough estimation is possible in many cases of developing countries, although it may not be able to address each household issue as the case here this paper. The damage ratio is also different according to the region or countries, thus the damage ratio estimation work is also required.

The basic definition of the resilient society in the disaster prevention aspects here is to enhance the resistance of the society by establishing the good soft/hard corrective measures before the disaster happens and to enable the prompt disaster recovery after even the disaster happens (Disaster Resilient Society Research Group, 2009 [14]). In other words, the society equipped with the integrated strategy against disaster is considered the resilient society. The paper deals with a framework of the economic loss estimation due to flooding, i.e. the situation after the flood occurs. By carrying out such flood hazard and economic risk predictions, we can consider what may happen when the flood disasters happen. Thus, it becomes possible to prepare well with the situation by referring such predictions. Moreover the more accurately we can predict the economic losses before the flood disasters, the more appropriately we can allocate the budget individually/publicly even when the economy is shrinking. To save human lives is considered the first priority at the flood disasters, but once the lives are saved, the economy matters. Therefore, if the estimation framework as shown in this paper becomes more familiar to the public and is offered with the detailed vector map, it will be a help for the local people. The detailed statistic data and vector maps are being prepared very rapidly especially in the developed countries but the development of the utilization method is probably not as progressed as the preparation. Thus, the more effort for the development as well as requesting the necessary data based on the development is expected in the future. Likewise the authors would like to contribute to them.

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• K. Takara, S. Kim, Y. Tachikawa, and E. Nakakita, "Assessing climate change impact on water resources in the Tone River basin, Japan, using super-high-resolution atmospheric model output," Journal of Disaster Research, Vol.4, No.1, pp. 12-23, 2009.
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Academic Societies & Scientific Organizations:
• International Water Resources Association (IWRA)
• International Association of Hydro-Environment Engineering and Research (IAHR)
• International Association of Hydrological Sciences (IAHS)
• American Society of Civil Engineers (ASCE)
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Selected Publications:

- R. Shaw, A. Sharma, and Y. Takeuchi, "Indigenous Knowledge and Disaster Risk Reduction," NOVA Publisher, USA, p. 490, 2009.
- Y. Takeuchi and R. Shaw, "Risk Communication Strategy for Effective Coastal Zone Management," Communities and Coastal Zone Management, Rajib Shaw and Ramasamy Krishnamurthy (Eds.), Research Publishing Services, Singapore, pp. 155-164, 2010.
- Y. Takeuchi and R. Shaw, "Gender Dimensions in Risk Communication A perspective from a Sediment Disaster in Hiroshima, Japan," Regional Development Dialogue (RDD), United Nations Center for Regional Development, Vol.30, No.1, pp. 63-75, 2009.

Academic Societies & Scientific Organizations:

- The Association of Japanese Geographers
- Japan Society for Natural Disaster Science
- Japan Society of Civil Engineers