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Development of Flood Exposure Map Considering Dynamics of Urban Life

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Synopsis

This paper aims to develop exposure maps by involving the dynamics of urban life. The dynamic exposure map is developed through an overlap of information of people's exposure and flood hazards. The 4th person trip (PT) survey for the Keihanshin Metropolitan Region is used as the data source for human activities on a daily base. The flood hazard map of Kyoto City is used to represent the information of flood hazards.

Two sets of dynamic exposure maps, one for weekend and another for weekday have been generated for the case study in Nakagyo Ward, Kyoto. The analytical results provide useful policy implications to examine time and place dependent conditions for evacuation in urban areas. The paper concludes with in-depth discussions of the findings and a summery of policy implications.

Keywords: population exposure, GIS, urban dynamics, flood hazard, PT survey

1. Introduction

The European Commission's (2000) DG SANCO report defines a risk assessment as comprising hazard identification, hazard characterization, exposure assessment, and risk characterization. The exposure assessment, among the four-step sequence, is defined as the quantitative or semi-quantitative evaluation of the likely exposure of humans and/or the environment to risk sources from one or more media.

The night time population is often used for producing exposure to flood hazards in many researches. Pending-Rowsell et al[2005] used the population within the floodplain as the total exposed population. Barredo et al.[2005] used population density as an input to assess the number of people in danger. Dekay and Mcclelland[1993] estimated the people at risk by multiplying the number of residences with minor or major damaged or destroyed times the average number of persons per residence. Chan and Parker [2006] modeled flood exposure as a measure of the human population, land uses and investment located in flood zones and at risk from flooding.

However, it is noted that people are engaged in different activities at different time and place. The spatial extent of individuals' activities could include the place where they live as residents and the place where they work or travel as non-residents. The spatial- temporal distribution of human activities identifies the extent people are exposed to different types and severities of flood hazards, which significantly affects and constraints people's response to a flood disaster. The activity based dynamic exposure has been mentioned in many researches particularly those related to the analysis on reasons for death by a flood hazard. For example, Ruin et al [2008] analyzed the reason for injury and death by the event in September 2002 in southern France. It was said that "The event started on a Sunday night when there are fewer people on the roads compared with weekdays. When it is realized that more than 200 school buses transporting 4000 children normally operate on weekdays in this region, it suggests that the consequences could have been worse if the floods had occurred during the week. Additionally, the event occurred in September when far fewer tourists are on holiday in the region than in the summer". Pending-Rowsell et al [2005] also pointed out that at any particular time, people potentially at risk may be outdoors on foot, outdoors in vehicle, indoors in a basement or confined by disabilities to the ground floor, etc. The distribution of people amongst these locations (or the probabilities of particular individuals being a particular location) will vary with nature of the area, the time of day and the time of year, etc.

Therefore, it is very necessary to take into account the time-dependent dynamic characteristics of population in estimating total population exposures to a flood hazard. It will help to understand the situations for evacuation, which are denoted by the place, time, population attributes, engaged activities and flood hazard level etc. Since few research efforts have been made on this issue, this paper intends to study such a dynamic characteristics of population exposure to flood hazards in a city. Given the limitation on data and knowledge, this paper is an attempt to combine a set of activity based trip generation data to estimate the human exposure over space and time. The focus of this article is to map the population exposure derived directly from the PT survey rather than the estimated total human exposure.

This article is structured as follows: Section 2 describes the data flow diagram and data source for generating the dynamic flood exposure maps. The application is demonstrated in Section 3. Concluding remarks are presented in Section 4.

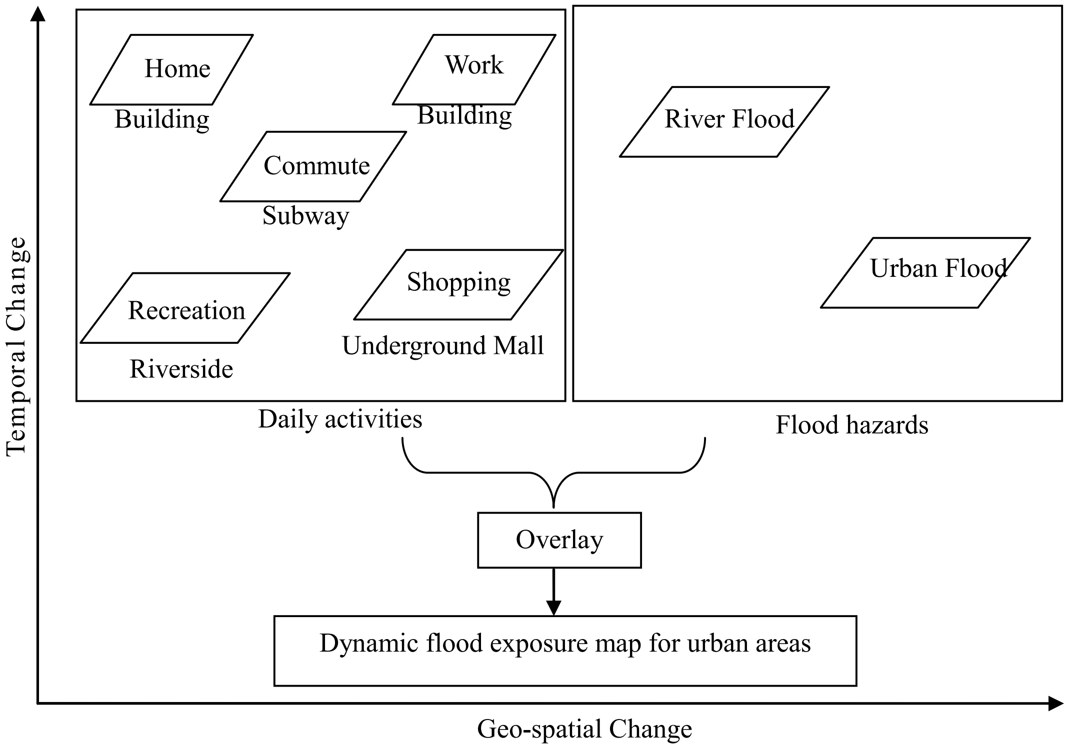


Fig. 1 Flow diagram of dynamic flood exposure map

2. Development of dynamic flood exposure map

2.1 Data flow diagram

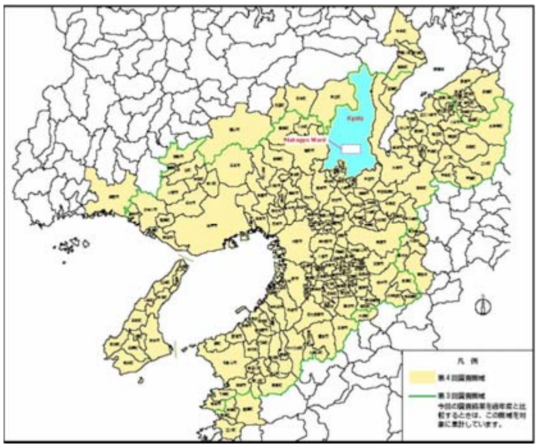
Two types of data are required for the development of dynamic exposure map as shown in Fig.1. On the one hand, distribution of people over space and time on a daily basis should be identified; on the other hand, spatial- temporal patterns of flood hazards should also be explored. The flood hazard may vary greatly with seasonal change. For example, a flood usually happens in summer and typhoon seasons in Kyoto. We assume that the flood hazard is steady within the time of day, and then only spatial pattern of a flood hazard is considered in this research. By overlaying the above two information sets, we can get the visual representation of population attributes, activities, and characteristics of flood hazards at a specific time and place. PT survey provides the data for people's daily activities and the flood hazard map of Nakagyo Ward clearly shows the spatial pattern of a flood hazard in type and severity level.

2.2 Data source

The Person Trip (PT) survey in 2000 for the Keihanshin Metropolitan Region is used as the data source of human activities. PT survey, starting from 1970s, is conducted every ten years for the purpose of the development of comprehensive urban transportation system. The 4th PT survey was carried out in 2000. The Keihanshin Metropolitan Region includes Kyoto Prefecture, Osaka Prefecture, Hyogo Prefecture, Shiga Prefecture, Nara Prefecture, and Wakayama Prefecture as shown in Fig. 2. The PT survey covers all inhabitants, that is, about 19.22 million people who live in the region and are over 5 years old.

The PT data preserve a record of individual person's detailed day trip information in terms of the behavioral agent, time and place of departure, objective of the trip, time and place of arrival, and the means of transportation etc. PT survey data are useful in various ways such as the simulation of expansion of influenza, the bus lane planning etc [TMRTPC]. In the filed of disaster management, the PT survey is found useful for the estimation of victims by earthquake and estimation of those with difficulty in returning home. For example, based on 3rd PT survey, Kajitani Y.(2003) built the people's activity database for the analysis of potential victims by an earthquake disaster in the case area of Nagata Ward, Kobe. But beside this few studies have applied person trip data in the analysis of people's exposure to flood hazards.

A zone is used as the basic spatial unit in the PT survey. The zone has different levels according to spatial scales. There are a total of four levels of spatial zones including big zones, middle zones, small zones and input zones corresponding to a spatial scale from big to small. In the entire Keihanshin Metropolitan Region, there are a total of 19 big zones, 75 middle zones, 250 small zones and 745 input zones. Taking Kyoto as an example, the entire area of Kyoto City corresponds to a big zone, and the central Kyoto City corresponds to a middle zone, the Nakagyo Ward corresponds to a small zone which is further divided into four input zones.



(*Source: Website of the Keihanshin Metropolitan Region Transport Planning Commission, http://www.kkr.mlit.go.jp/plan/pt/index.html)

Fig. 2 The entire areas covered by the 4th PT survey

The PT data contains two separate data sets respectively for weekend and weekday. The data set for weekend record the trip information of 36947 people and the data set for weekday the trips of 429647 people (it is about 2.4% of total population in this region) within the Keihanshin Metropolitan Region.

In the 4th PT survey, the trip information is organized in a master file as shown in Table 1. A person's information includes age, gender, occupation, living place, property, and the number of trips etc. Trip information appears following the person's information and a composite primary key denoted as "Record No" is used to identify a person and the person's trips.

However, as far as exposure is concerned, a data structure focusing on the time period that a person stays at a specific place is required for the calculation, which is not directly shown but can be derived from the original master file. Therefore, the master file is restructured by involving the starting time and ending time of each stay as shown in

Table 1 File structure of the master file

Master File			
Record No	Trip Mount	Trip No	Contents
A	0	0	Person a
B	1		Person b
		1	Trip 1
C	2		Person c
		1	Trip 1
		2	Trip 2

Table 2 Restructured master file

Record No	Place	Starting Time	Ending Time	Master File	
				Person ID	Trip Info
A	Place1	○	○	ID-a	
B	Place 1	○	○	ID-b	
	Place 2	○	○	ID-b	
C	Place 1	○	○	ID-c	
	Place 2	○	○	ID-c	
	Place3	○	○	ID-c	

Table 3 Level of detail for people and trip related information

Elements	Value	Explanation
Age	01	Children(<14 years old)
	02	Adult(15-64 years old)
	03	Senior(>=65 years old)
Gender	1	Male
	2	Female
Trip Objective	1	Go to work
	2	Go to school
	3	Social activities
	4	Business related activities
	5	Go back home

Table 2.

The trip related information is categorized into multiple levels in PT survey data. The objective of a trip, for instance, the primary category is labeled as to work (Code:1), to go to school (Code:2), social activities (Code:3), business related activities (Code:4) and to go back home(Code:5). A breakdown of the information is for social and business related activities. For example, the social activity is further classified as shopping, recreation and others such as picking someone up, to hospital etc. Table 3 shows the level of details on people and trip related information in this research.

3. Case Study

The Nakagyo Ward, located in the central Kyoto City, is taken as the case area. It corresponds to the small zone (No. 3122) which is composed of four input zones as A (No. 31221), B(No. 31222), C (No. 31223) and D (No.31224) in the PT survey as shown in Fig. 3. From the flood hazard map of Nakagyo Ward, the four spatial zones are prone to different types and severity levels of flood hazards.

The spatial zones of A and B are susceptible to the hazard of river flooding by the Kamo River. And there are several underground shopping malls in the B zone. For this reason, the B zone is also under the risk of underground inundation. In the spatial zone of D, a lot of places are located in the areas under inundation risks predicted to occur from 0.5m to 3m. In the spatial zone of C, more than a half of places are covered by previously flooded areas and easily flooded areas, geographically.

The exposed population is a group of people who managed a trip or multiple trips to, or from, or within Nakagyo Ward, Kyoto. The group also involves those residents who live in Nakagyo ward but do not have any trips on the survey day.

3.1 Spatial-temporal Analysis of Population Exposure

The following part introduces how the spatial-temporal analysis of population exposure is carried out for Nakagyo Ward, Kyoto. The temporal analysis is conducted for four periods from 7am to10am, from 11am to 3pm, from 4pm to 8pm, and from 9pm to 6am on next day. The spatial analysis is done for each input zones in Nakagyo Ward, Kyoto. For this reason, we define residents and non-residents according to the zone where people live. For example, a person managed a trip to the A zone. If the person lives in the same zone, he or she will be viewed as a resident; otherwise the person will be viewed as a non-resident. In the collective exposure map, the following population's information including total number of people, residents and non-residents, age (kid, adult and senior), gender (male and female) is counted for every spatial zone. In addition, statistical analysis is also performed for their engaged activities. Mapinfo, a GIS software, has been used for data management and mapping in this research.

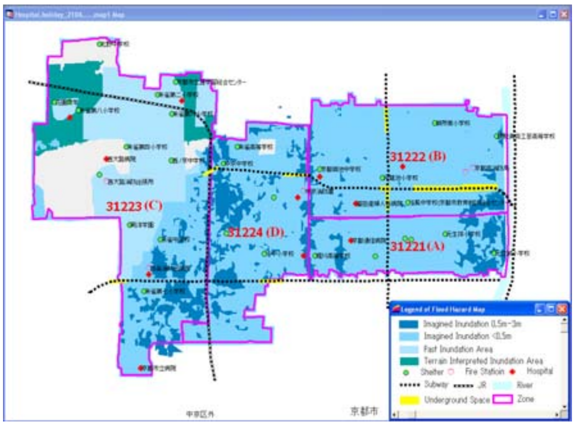


Fig. 3 Input zone based flood hazard Map for Nakagyo Ward in Kyoto City

Fig. 4, Fig.5, Fig.6, and Fig.7 show the dynamic exposure maps for weekend. The overwhelming majority of exposed population is residents in the spatial zones of C and D. However, the pattern is not obvious in the B zone and the reverse situation happens in a zone where the most of the exposed population are non-residents. In addition, there is no obvious increase or decrease of residents over the whole day in the above four zones but for non-residents, there is an obvious increase for the time period from 11am to 3pm and then it stays high till 8pm. After that, there is a sharp decrease of non-residents, which means that people are going back home. This pattern of change is particularly prominent in the zones of A and B. It is found that more than 50 percent of population stay at home for the whole day in the zones of C and D. However, non-residents hold a majority in the A zone, irrespective of time. The reason for the pattern is closely related to the feature of each zone. The zones of A and B are typical business zones but C and D are typical residential zones. In the case of flood disaster, evacuees appear to be not only residents but also non-residents in a mixed group. This distinguishing feature should be well considered in the evacuation planning.

Regarding the activities, common characteristics are such that the majority of people either stay at home or do social activities. Only a few people are found engaged in work related activities. The temporal change of social activities is such that they first increase rapidly from 11am to 3pm and then gradually decrease till 8pm. After 9pm, many people end up their trips by going back home.

In terms of the characteristics of exposure's age, first comes the adults, then the senior and kids. This age structure applies to any zones at any time. As for gender, more females are found in time period from 11am to 3pm than male and they are half-half in other time periods.

Fig.8, Fig.9, Fig.10 and Fig.11 show the dynamic exposure maps for weekday. Compared to PT survey on a weekend, more than 10 times of

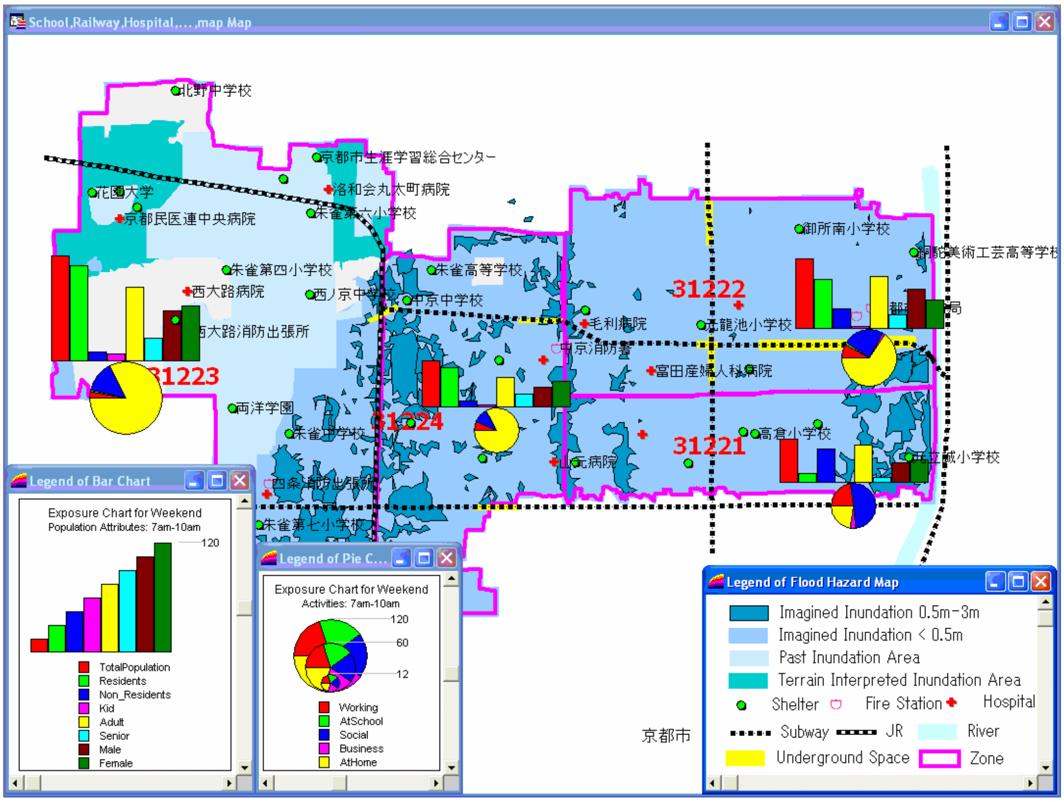


Fig. 4 Dynamic flood exposure map for weekend at the time period of 7am-10am.

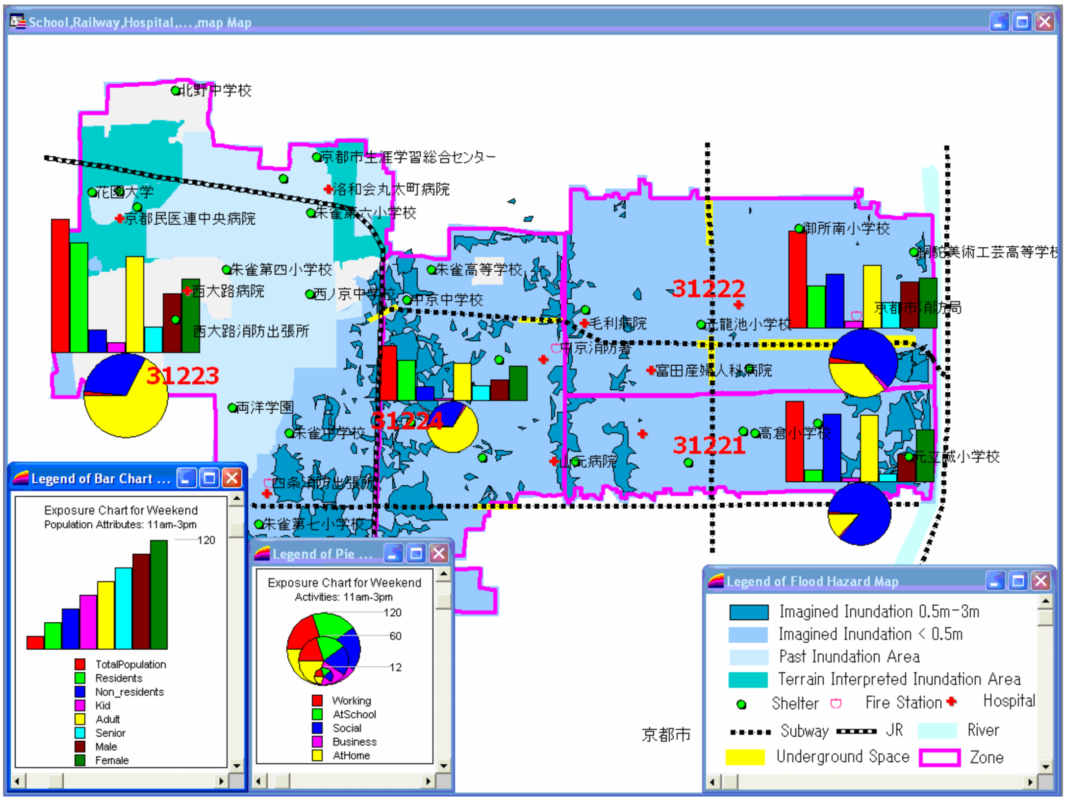


Fig. 5 Dynamic flood exposure map for weekend at the time period of 11am-3pm.

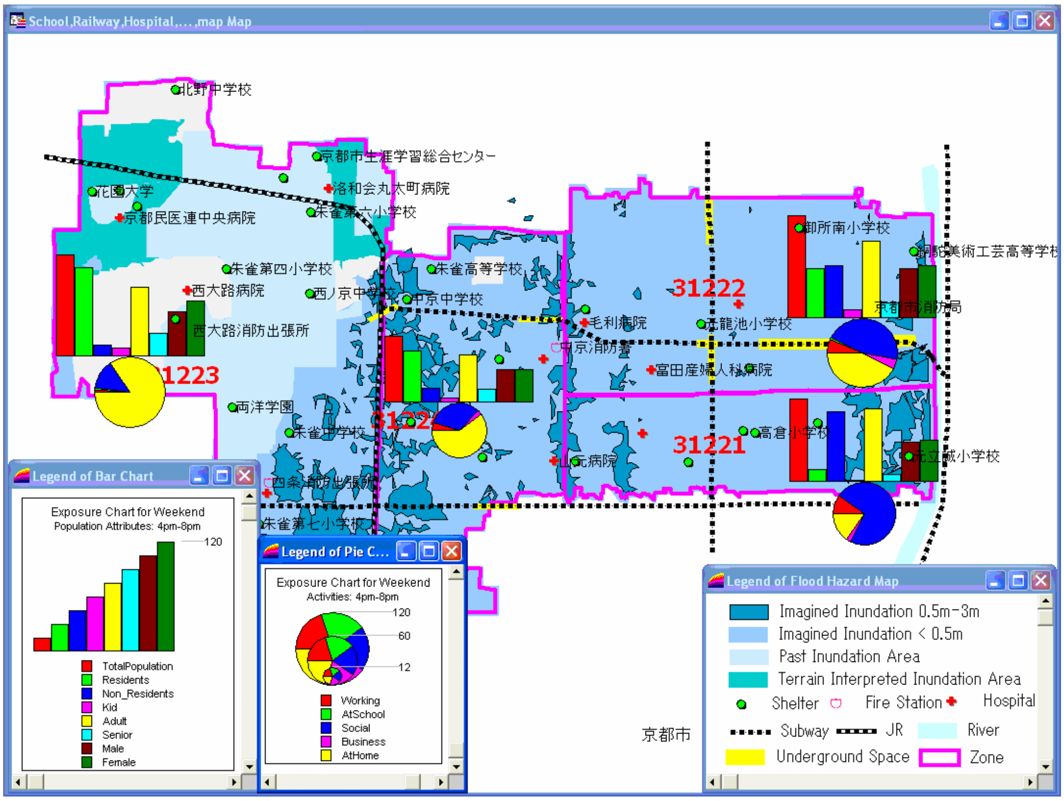


Fig. 6 Dynamic flood exposure map for weekend at the time period of 4pm-8pm.

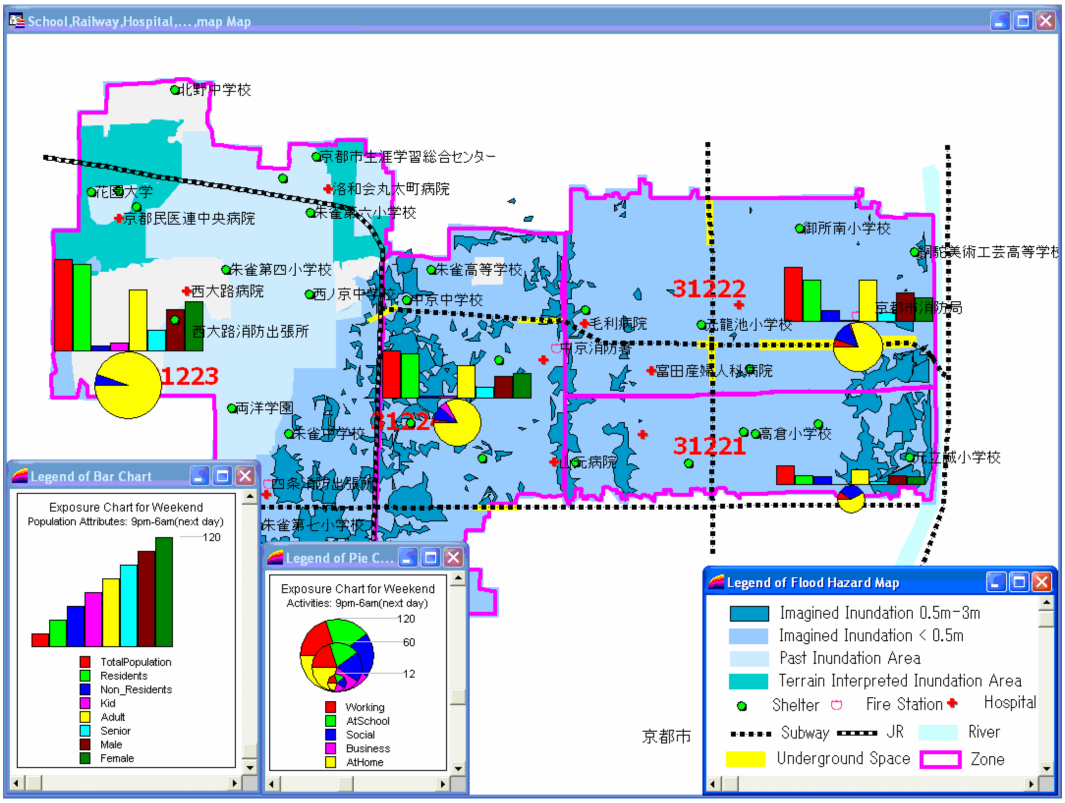


Fig.7 Dynamic flood exposure map for weekend at the time period of 9pm- 6am (Next day).

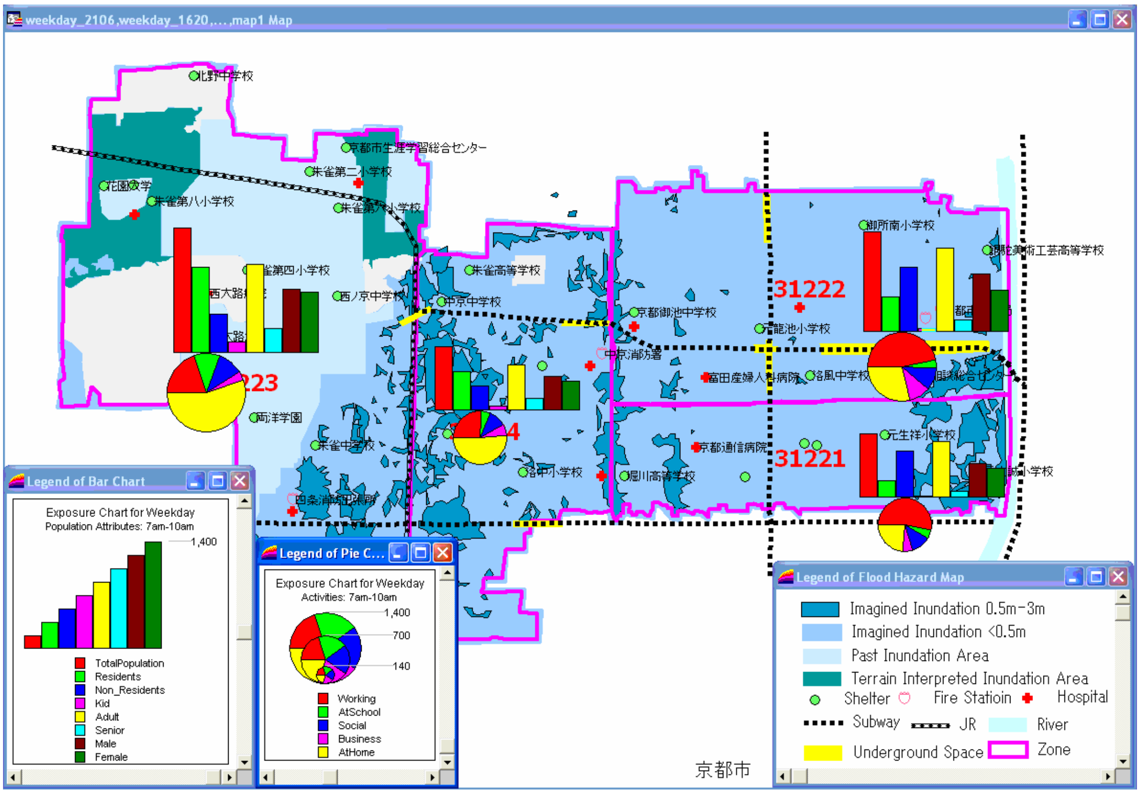


Fig. 8 Dynamic flood exposure map for weekday at the time period of 7am-10am.

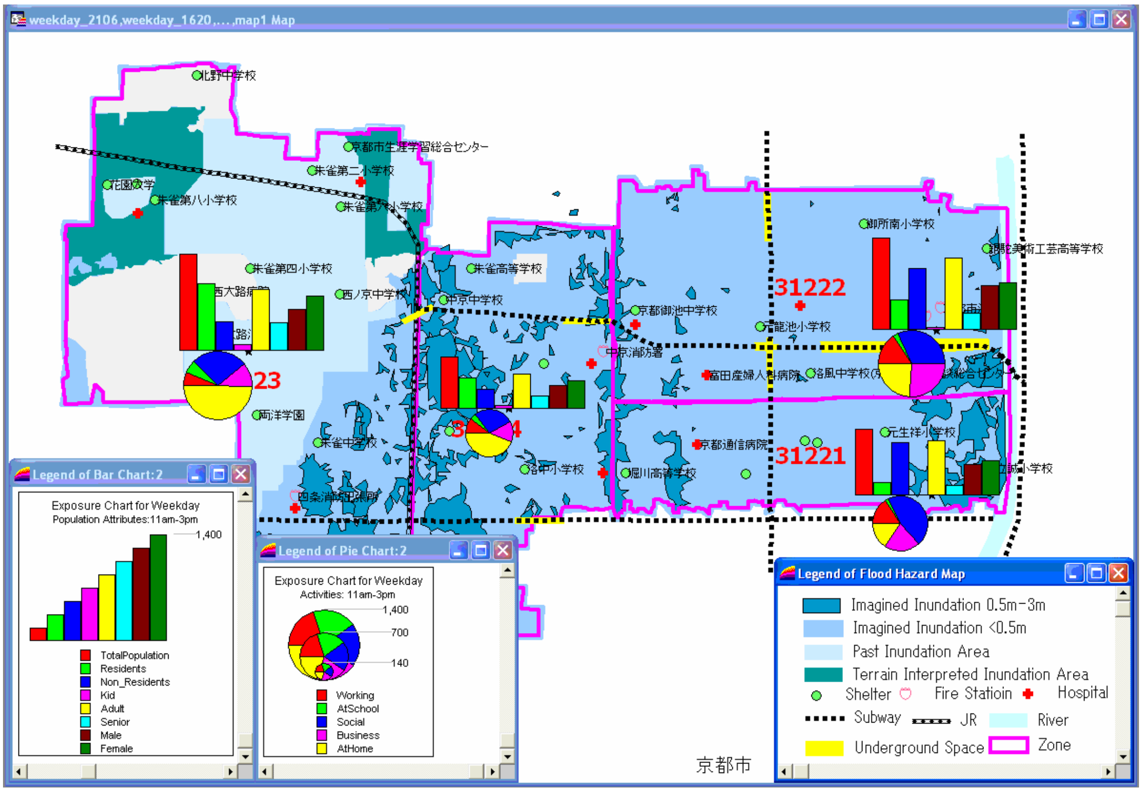


Fig. 9 Dynamic flood exposure map for weekday at the time period of 11am-3pm

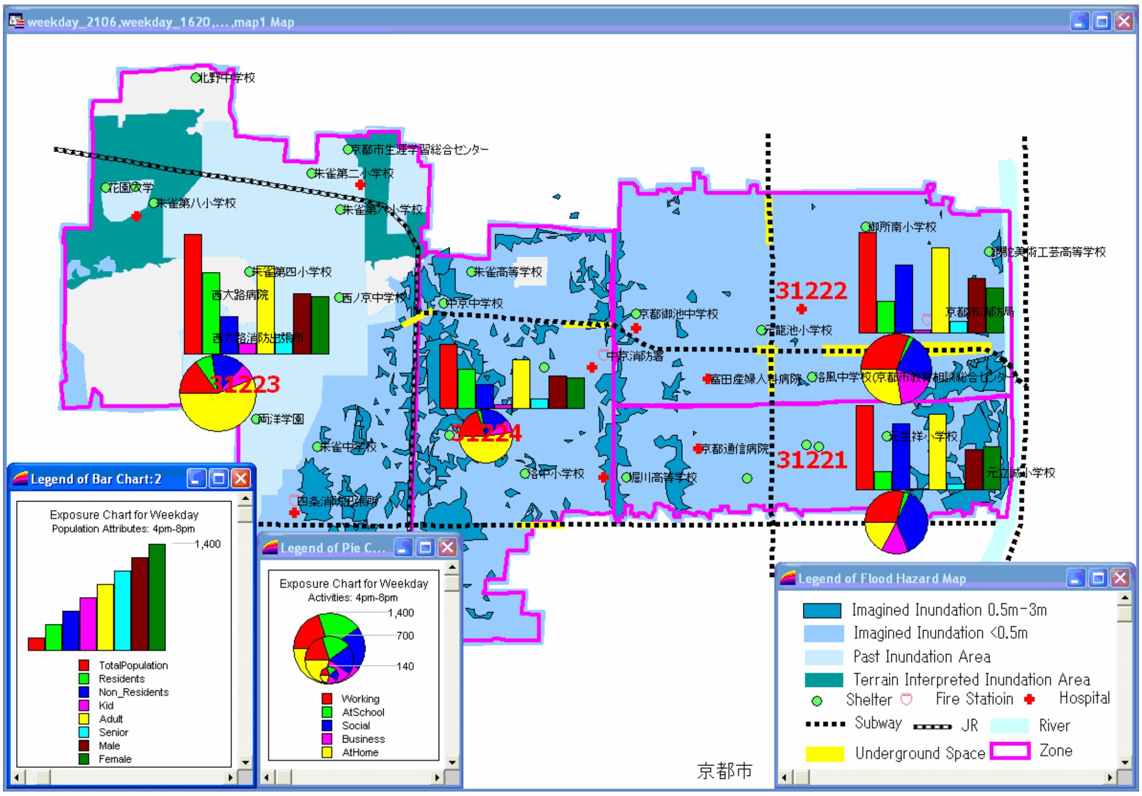


Fig. 10 Dynamic flood exposure map for weekday at the time period of 4pm-8pm

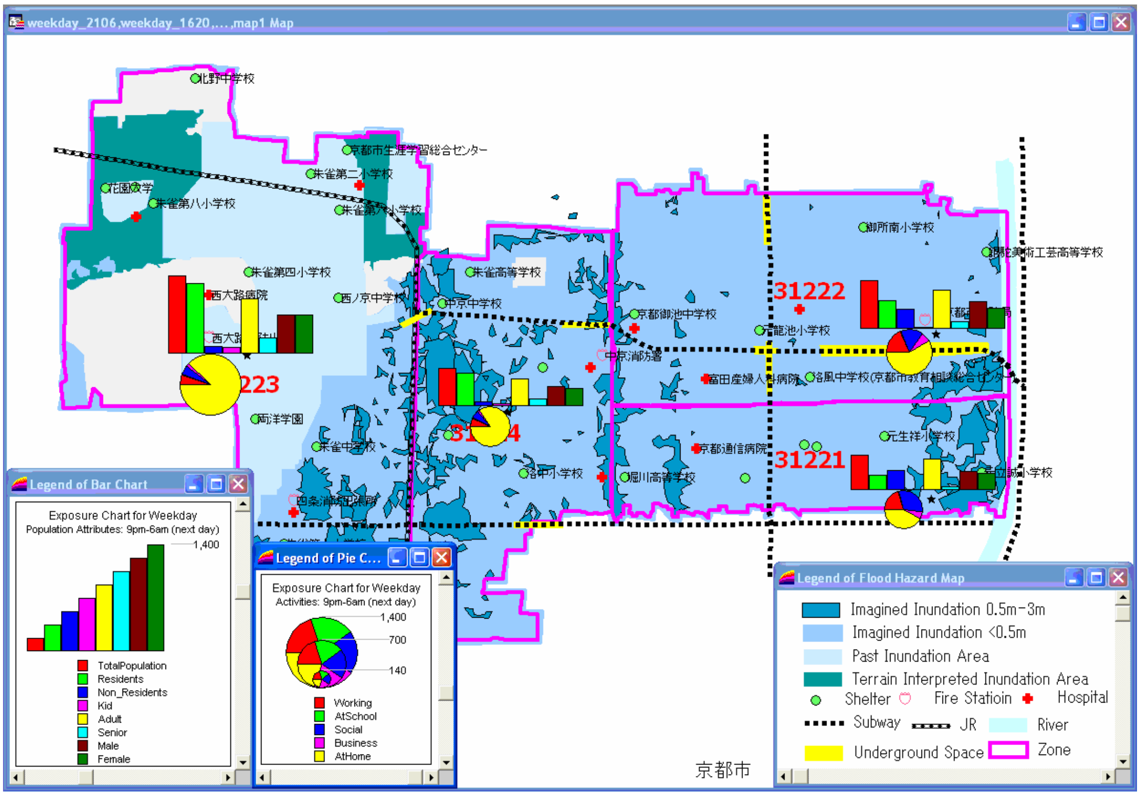


Fig. 11 Dynamic flood exposure map for weekday at the time period of 9pm-6am (next day)

responses in number are found in the data set for weekday. In addition, more exposures appear in rush hours in the morning and evening. A remarkable decrease of exposed population appears at night time from 9pm to 6am on the next day. Among those exposed, more residents are found in the spatial zones of C and D and the reverse situation happens in the spatial zones of both A and B where the most of exposed population are non-residents.

It is also shown that exposed populations have a similar structure of age and gender on weekend and weekday. Regarding the activities, a variety of activities are found in the exposure map for weekday. In the morning, apart of those people who stay at home, a lot of people go to work or school. The trend is clearly shown in the zones of A and B where about 50% people are in the activities of going to work. At noon, social activities and business related activities have a rapid increase in every spatial zone. In the evening, there is a slight decrease of social activities and a slight increase of activities of going back home and working. At night time, the majority of people are found at home even in the business zones of A and B.

4. Discussion and conclusions

The analysis on the dynamic population exposure provides policy implications for local evacuation planning. The discussion revolves around the following aspects: residents and non-residents mixed evacuation, structure of age and gender, time and place concerns.

(1) Residents and non-residents mixed evacuation

From the flood exposure map, the situation of residents and non-residents mixed exposure happens in every spatial zone in Nakagyo Ward, Kyoto. The great majority of exposed individuals are residents in the spatial zones of C and D, while non-residents are the great majority in the spatial zones of A and B. As we know, residents and non-residents may have different level of knowledge on the local environment, which will somehow affect their evacuation behaviors. For this reason, the evacuation planning for Nakagyo Ward should differentiate the two types of zones. For the spatial zones of A and B, evacuation plans should be reinforced for those market places, shopping centers, restaurants as well as transportation stations, etc. The evacuation signs and guidance are essential for these two zones. In addition, as more non-residents show up in the daytime than night time, evacuation plans have to put more efforts on daytime disaster management. For the spatial zones of C and D, self help and mutual aids should be highlighted in the evacuation planning. Disaster education and training will help residents become familiar with the shelter, evacuation route, etc.

Moreover, with information made available related to the spatial-temporal distribution of exposed non-residents, people will find it easier to estimate the timing of evacuation particularly those who are with difficulty getting back home once a flood disaster takes place.

(2) Structure of age and gender

As shown in above exposure maps, among the exposed population, the majority are adults, and then the senior and kids. Gender does not count significantly since male and female are almost always fifty-fifty regardless of zone and time. Therefore, a special consideration goes to those seniors and kids. This is a common problem for those four spatial zones in Nakagyo Ward.

(3) Time concern

The exposure maps show the great difference of exposed population in their characteristics and engaged activities on weekday and weekend. In addition, it shows a typical temporal change in different time periods of the day. Therefore, flood evacuation plans have to consider temporal factors, especially daytime and nighttime differences in order to carry out an effective evacuation and rescue.

(4) Place concern

The activities differ greatly in type for weekend and weekday. Weekend activities focus on at home and social activities but there are diverse activities on weekdays. In terms of the place to stay in, working populations may stay in the office, and students may stay at school. It is necessary to develop evacuation plans for office buildings, shopping malls, public buildings and even some small restaurants. Fortunately, some companies (e.g. St.Claire Inc in USA) have realized the problem and developed an evacuation plan for their office buildings.

It is noted that some schools in the study are of Kyoto are located in the predicted inundation areas. For example, the Rissei elementary school is under the risk of river flooding from the Kamo River and predicted inundation is at the level of 0.5m-3m. For this reason, it is not suitable as a formal shelter site for a flood disaster. This safety problem of in appropriate location of formal shelters has been identified as an emerging cause for death during flood evacuation. The adaptation of shelters to multi-hazards needs to be examined to address such safety concerns.

As for social activities, it is likely for people to do shopping in an underground town or play by a river. Besides these, a lot of people commute in rush hours by train or subway. Evacuation plans face more severe challenges in these confined or semi-confined places. Individuals have to be aware of possible different flood hazards when they stay at different places. It is significantly important for people to respond to a hazard in a way adaptive to the conditions determined by the time, place and characteristic of hazards. The evacuation plans for underground flooding are different from the ones for surface water flooding in available shelters, evacuation routes etc. The evacuation planning for Oike underground space (EPOUI), for instance, should enforce more in disseminating information and guiding people out of the underground space as quickly as possible.

To sum up, this paper has analyzed the dynamic characteristics of people's exposure to a flood hazard in urban areas based on the PT Survey for the Keihanshin Metropolitan Region in 2000. The time- and place- dependent people's exposure maps have been developed for the case area of Nakagyo Ward in Kyoto City, Japan. The series of exposure maps clearly show the spatial-temporal change of population exposure to a flood hazard. All this implies a more need for analyzing and assessing time and space dependent characteristics when developing more realistic and effective flood evacuation plans in urban areas.

Based on the results developed in this paper, a follow-up research on the estimation of total population exposure will be carried out in the future.

References

Barredo, J.I., Lavalle, C., De Roo, A. (2005) European flood risk mapping. European Commission - Joint Research Centre, Ispra, S.P.I.05.151.EN.

Edmund Penning-Rowsell,W, Peter Floyd,David Ramsbottom And Suresh Surendran (2005), Estimating Injury and Loss of Life in Floods:A Deterministic Framework, Natural Hazards 36: pp.43–64

European Commission (2000), First Report on the Harmonisation of Risk Assessment Procedures, DG Health & Consumer Protection. European Commission, Brussels.

Evacuation planning for Oike Underground Inundation (EPOUI), available at: http://www.zestoike.com/plan_doc/plan_doc.pdf

Isabelle Ruin, Jean-Dominique Creutin, Sandrine Anquetin and Ce´line Lutoff (2008), Human exposure to flash floods – Relation between flood parameters and human vulnerability during a storm of September 2002 in Southern France, Journal of Hydrology, 361, pp.199– 213

Kajitani Y. (2003), Study on potential victims of Earthquake Based on Spatial-Temporal Distribution of Human Activities in Urban Areas, Doctoral Dissertation, Kyoto University.

Michael L. DeKay and Gary H. McClelland (1993), Predicting Loss of Life in Cases of Dam Failure and Flash Flood, RiskAnalysk, Vol. 13, No. 2,pp 193-205,

Nakagawa, H., Kawata, Y., Inoue, K. and Tanino, T. (1996): Flooding in Sandwip Island in the 1991 storm surge disasters, Journal of Japan Society for Natural Disaster Science, Vol. 15, No. 2, pp. 151-174.

Ngai Weng Chan and Dennisj. Parker (1996), Response to dynamic flood hazard factors in peninsular Malaysia, The Geographical Journal, Vol. 162, No. 3, pp. 313-325

St.Claire Inc, available at: http://www.stclaire.com/go/evacuation_plans/example_2/html

Tokyo Metropolitan Region Transport Planning Commission (TMRTPC), available at http://www.tokyo-pt.jp/person/pt_gaiyou.html

都市生活の動態性を考慮したエクスポージャマップの開発

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要　旨

本研究では都市生活の動態性を考慮したエクスポージャーマップの開発することを目的とする。エクスポージャーマップは，人々の時空間的活動と洪水ハザードの分布情報を重ね合わせることにより求められる。平成12年の京阪神都市圏パーソントリップ(PT)調査から，都市における人々の活動の時空間分布情報を求めた。また京都市の洪水ハザードマップを活用した。これにより本研究では，京都市中京区を対象区域として平日と週末の2つのエクスポージャマップを作成した。これらのマップを活用した分析結果を用いて，都市における洪水避難計画をより実情に即した形で改善するためのいくつかの有用な政策的知見を導いた。

キーワード: 人口エクスポージャ，GIS，都市の動態性，洪水ハザード，PT調査