

GIS-based distributed technique for assessing economic loss from flood damage: pre-feasibility study for the Anyang Stream Basin in Korea

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Abstract Large national budgets are required for flood damage reduction projects, making it critical to ensure that public money used therein be spent efficiently. Accordingly, reliable assessment of flood damage is a critical issue in analysis of the economic aspects of flood damage reduction projects. To this end, this study aims to provide a GIS (geographical information system)-based technique for distributed flood damage assessment. We consider two aspects of flood damage assessment from an engineering and economic perspective, i.e. flood inundation analysis and multi-dimensional flood damage analysis (MD-FDA). To perform this assessment, we used a GIS-based framework and data processing method to assess damages. The proposed methodology was applied to flood control channel projects for flood disaster prevention in the Anyang Stream Basin in Korea and presents detailed GIS data processing and assessment results. Findings from this study may contribute to the improvement of usability of MD-FDA and may provide research directions for integrating economic and engineering factors. This distributed technique will also assist in the decision-making process when evaluating the economic feasibility of flood damage reduction projects for structural and non-structural measures.

Keywords Flood damage assessment · Economic analysis · GIS · MD-FDA · Flood inundation

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1 Introduction

The real benefits of economic analysis of flood damage reduction projects may be difficult to identify (whether before or after commencement) because such benefits may not be immediately visible or tangible. Estimating potential real damages from flooding is therefore a very important and sensitive part of flood damage reduction; as such forecasts are directly useful to the parties and communities affected. Such analysis must be broad, because flood damage assessment includes both engineering and economic aspects. In an engineering study, floodplain analysis and inundation prediction in the protected lowlands are usually conducted via hydraulic and hydrologic analysis (which are necessary for flood mitigation planning), as well as flood damage assessment. Economic studies quantify flood damage using various statistical data, as well as indices that serve as proxies for economic value in flood affected areas.

While these basic concepts have existed since the 1960s (James and Lee 1971), they have not been implemented due to a lack of statistical data needed for analysis, as well as a lack of the requisite technical infrastructure required for their integration. Many studies in the past have used the ‘depth–damage function’ to assess losses from floods (Kates 1965; Penning-Rowsell and Chatterton 1977; Davis and Skaggs 1992; Cannon et al. 1995; Kiefer and Willett 1996; Merz et al. 2004). The depth–damage function represents damages to a particular asset category (i.e. physical structures, personal property, farmland, crops, and other items) as a function of depth of inundation. Damages are assessed based on a percentage of the total value in a particular asset category, and the percent damage is then multiplied by the total value for monetary damages. The depth–damage function can be used to assess flood damage by applying the flood inundation and assets data gathered in a specific area. However, attaining data for flood inundation analysis and asset surveys requires field surveys and/or manual work, incurring massive time and cost expenditures. In contrast, ‘stage–damage functions’ are a function of aggregated damages to a particular region in accordance with the stages of river station, in a specific geographical area within a floodplain (USACE 2008).

The stage–damage function approach has been actively applied in the USA, UK, and Australia. The U.S. Army Corps of Engineers has developed and is in the process of applying the HEC-FDA (flood damage reduction analysis), which is a flood damage assessment model that takes risk analysis into consideration (USACE 1998; 2008). In the UK, the most comprehensive approach has been the Blue Manual of Penning-Rowsell and Chatterton (1977), which contains stage–damage curves for both residential and commercial property. In this study, they determine the expected annual flood damage via four interrelationships: stage–discharge, probability–discharge, stage–damage and probability–damage (Merz et al. 2004). In Australia, damage to residential, commercial and industrial assets, socioeconomic activities, land and non-structural assets are estimated using the stage–damage function (Bureau of Transport and Regional Economics 2001a, b, 2002). However, to reflect variation of asset values in a range of flood stages, stage–damage functions must be newly devised every time the spatio-temporal variations of land use takes place, resulting in high complexity. Recent progress in information technology in this field, however, has helped to address this problem. In engineering terms, the availability of 1D or 2D hydraulic models and a distributed rainfall-runoff model has enabled more precise floodplain analysis. In economic terms, the internet has enabled the collection of an abundant amount of statistical data. Furthermore, the advance of geographic information system (GIS) technology has enabled precise analysis by converting all data into spatial information.

Many existing studies are available that perform floodplain analysis using GIS techniques. Most of them suggest methodologies of flood inundation analysis in order to evaluate flood risk and develop flood protection policy (Dutta et al. 2000; Du Plessis 2001; Zenger and Wealands 2004; Rodda 2005; Van der Most and Wehrung 2005; Van der Veen and Logtmeijer 2005; Lastra et al. 2008). Furthermore, there are numerous studies that combine GIS-based flood inundation analysis with a flood damage assessment methodology to assess economic loss incurred by flooding. Dutta and Herath (1998), Du Plessis and Viljoen (1998), Venkatachary et al. (2001) and Fattorelli and Frank (2005) in their studies presented GIS-based flood damage assessment methodologies that combine hydraulic and/or hydrologic models and damage assessment models to predict and quantify the economic loss caused by flood damage. In addition, several studies have used remote sensing data in the flood damage assessment (Todhunter and Rundquist 2003; Sanyal and Lu 2004; Stăncălie and Craciunescu 2005). As sustainability of river basin development has increased in importance, particularly in its social and environmental dimensions, a few studies have assessed flood damage or flood risk using multi-criteria approaches (Viljoen et al. 2001; Meyer et al. 2009).

On the basis of this technological progress, many countries have developed flood damage assessment methodologies based on GIS. In Japan, the FDAM (flood damage assessment methodology) was developed by relating assets survey and a flood inundation model to GIS (Dutta and Herath 1998). In the Czech Republic, the FAT (flood analysis toolbox), which is a flood damage assessment model relating assets information, economic data, and hydrological data to GIS was developed (Biza et al. 2001). In South Africa, the FLODSIM (FLOOD Damage SIMulation Model for irrigation areas) and the TEWA (flood damage simulation model for urban areas), which are GIS-based flood damage assessment models, were developed (Du Plessis and Viljoen 1998; Viljoen et al. 2001).

In Korea, flood damage is assessed using multi-dimensional flood damage analysis or MD-FDA, which was developed in 2004 (Choi et al. 2005). It is now the national standard for the economic analysis of flood damage reduction projects. Though the MD-FDA is not linked with GIS software or a flood inundation model, it requires more asset survey items than the previous methodologies and spatial information in inundated areas. It is thus a more effective way to analyze the spatial distribution of inundated areas and assets using GIS to apply the MD-FDA. To this end, a method for deployment of GIS in flood damage assessment within MD-FDA is presented in this study with a preliminary feasibility study applied to the case study of the Anyang Stream Basin. As most flood damage assessments are conducted to perform a preliminary feasibility study or feasibility study prior to a detailed design, the method proposed herein is expected to be practical and useful in flood mitigation planning, as well as in further studies.

2 Flood damage assessment methodology

2.1 Basic principles and framework

In general, flood damages include quantitative and qualitative damages. While quantitative damages are tangible economic losses, including direct and indirect damages, expressed in monetary terms, qualitative damages are social, intangible, and indirect damages, and includes items like “emotional distress” from residential instability, and cannot be quantified. Accordingly, flood damage assessment deals with quantitative, economic, and

qualitative damages. In general, the following conditions are required in a flood damage assessment methodology:

- (1) Accurate and efficient prediction of flood inundation: This defines the spatial scope of flood damage. This element, which is an engineering factor unrelated to economic factor, is required to guarantee reliability of results.
- (2) Accuracy and precision in surveys of land use and assets in the damaged area: This represents the severity of potential damage in the target area and defines whether the assessed damages can describe the characteristics of the area.
- (3) Reasonable information on the susceptibility of assets (or depth–percent damage relationships): This defines the percent of total value of assets damaged for a range of flood inundations with respect to structures, personal properties, and other items. This element is crucial in relating condition 2 with condition 1.
- (4) Generality and convenience of analysis: As flood damage assessment is utilized in the economic analysis of various flood damage reduction projects, the methodology used must be universal and convenient to use.

The first to the third conditions emphasize the accuracy and precision of engineering and economic aspects of flood damage assessment. On the other hand, the fourth condition emphasizes the work efficiency, including generality and convenience, as economic analysis is a premise of flood damage assessment. All four conditions imply the importance of GIS to reflect the spatial distribution of the damaged area. This indicates that use of GIS is itself a necessary and sufficient condition that fulfills the methodological requirements of distributed flood damage assessment. The basic concept of flood damage assessment in this study is based on these conditions. We have realized MD-FDA in practice under real world conditions. The procedures are the same; however, it reflects the reality more closely by making it easy to apply GIS. In particular, this study focused on the prediction of flood inundation and the aggregation of flood damages to be dispersed spatially over damaged areas. Fig. 1 presents the process and framework of the analysis.

2.2 Prediction of flood inundation

A ‘flood inundation area’ can be defined as a protected lowland, which is submerged in water for a period of time, such that all the assets in the area including land, buildings, and personal property therein, as well as public facilities and structures, and crops are damaged. Generally, the major factors of a flood inundation map include the area, depth, and time of inundation, taking into account the topography and disaster prevention facilities in the area. Accurate prediction of flood inundation is very important because it is the key factor for accuracy in flood damage assessment. However, whether or not the depth and period of inundation are included and whether or not the accuracy of the result will differ depend on the purpose and technical constraint of the prediction of flood inundation. For example, if the purpose of flood damage assessment is for a pre-feasibility study, providing accuracy and precision that are higher than necessary is inefficient and difficult because money and time are limited.

Due to the foregoing reasons described, more approximate methods that extend the flood level to the protected lowland have often been used. However, such methods may result in over-estimation of flood damage according to the topographical characteristics of the area. Recently, flood inundation analysis techniques using two-dimensional diffusion wave and the dynamic wave shallow water equations have been actively studied. However, since studies mainly focus on the analysis of the flood waves resulting from levee breaches

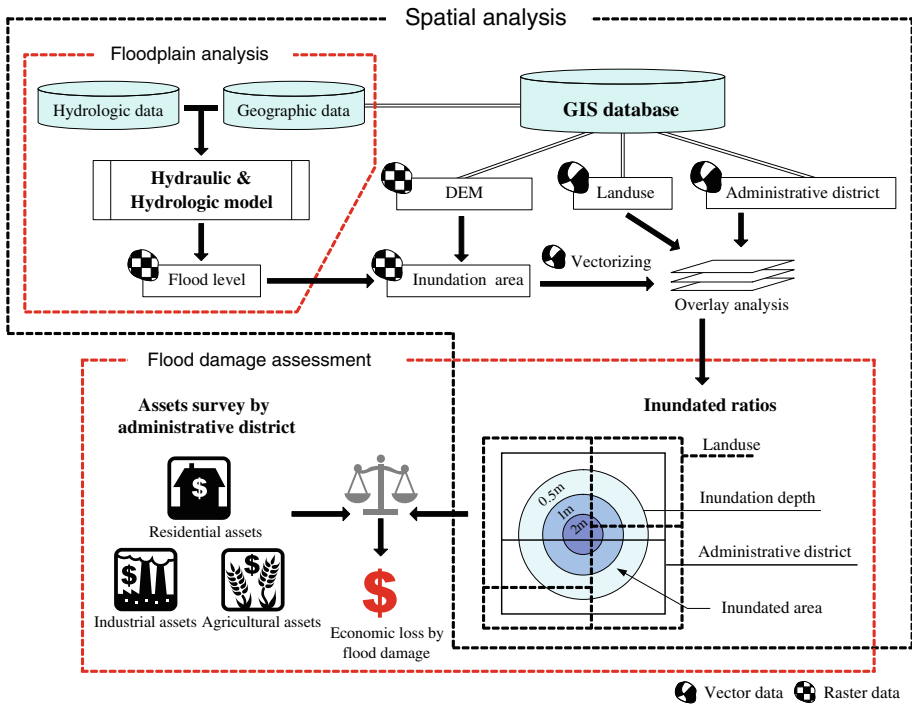


Fig. 1 Framework of flood damage assessment

or overtopping, they are not suitable for predicting flood inundation of protected lowland, which represents the majority of actual flood damage. Furthermore, the degree of difficulty is high for the economic analysis.

In this study, the inundated area was estimated by deducting the volume of internal drainage pumped from the total volume of flood inundation in order to improve the foregoing ‘rough method’. While this method may not be suitable when the purpose of the analysis is flood forecasting, provision of warnings, or securing an evacuation route for the residents, it can be useful in economic analysis, as the purpose of flood mitigation planning is to take all potential damages into account. Furthermore, this has the advantage of efficiency as the existing 1D hydraulic model, which is commonly used in practical application, is utilized in relation to the GIS.

Figure 2 shows the analysis proceedings and data processing for predicting flood inundation using GIS, as proposed in this study. The analysis begins with creating input data, including ground elevation (EL), water surface (WS), and pumping drainage (PD), which are used to perform the grid-based inundation depth calculation. Both the EL grid and the WS grid are created by rasterizing from the digital topographical map via the TIN (triangular irregular network). The PD, which represents the volume of internal drainage by the operating pumping station, is calculated by the pumping capacity multiplied against the duration of the flood level. Using the input data, the inundation depth of each grid cell is calculated recursively by subtracting the EL grid from the WS grid considering the PD. The flood level duration, as shown in Fig. 3, can be determined with the flood hydrograph by estimating the discharge at the water level equivalent to the ground level of the protected lowland and calculating the time for which the discharge continues or increases.

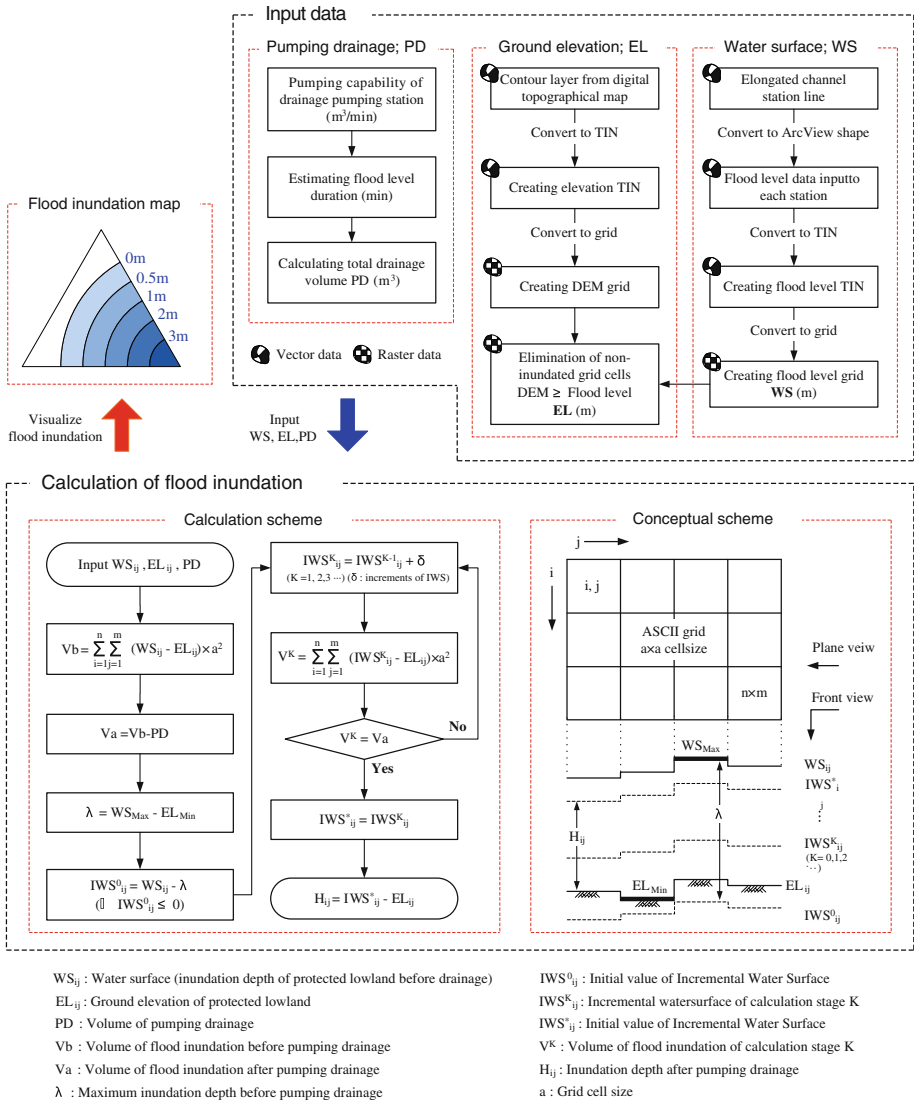


Fig. 2 Flowchart of data processing for predicting flood inundation using GIS

2.3 Estimation of economic loss using MD-FDA

The MD-FDA was developed by the Ministry of Land, Transport, and Maritime Affairs of Korea (MLTM) to estimate flood damages more accurately (Choi et al. 2005). The MD-FDA deals with tangible and intangible damage categories. The tangible damages are categorized by general asset damages, including five categories of general assets estimated using statistical data, as well as damage to public facilities calculated by multiplying general asset damages by a factor ratio. Damages to flood victims, classified as intangible damages, are calculated with unit damage costs. The assessment methods for indirect

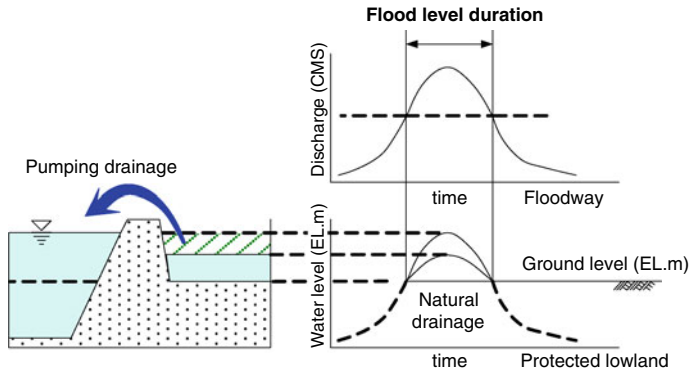


Fig. 3 Concept of determining flood level duration

Table 1 Classification of general assets and the details of the assets survey

Classification		Data needed	Evaluation of assets
Residential assets	Structure	Price per unit m ² of building by type of living quarters Ratio of number of houses by total floor space of building by type of living quarters Number of houses by type of living quarters Average number of layers of multistory buildings	Price per unit m ² × number of houses by total floor space of building × number of the houses × construction industry deflator (when appropriate)
	Contents	Penetration and average price of household contents Number of households	Assessment of contents for a household × number of households × consumer price index
Agricultural assets	Farmland	Areas of rice paddy and dry field Average damage price per unit m ² of buried and lost areas	Areas of farmland × price per unit m ² of lost areas
	Crops	Production cost per unit ha of crops by type (paddy and field crops) Types of field crops Areas of rice paddy and dry field	Areas of farmland × production cost per unit ha × consumer price index
Industrial assets	Fixed assets	Fixed assets and inventories per employee by industrial classification Number of employees	Assessment of fixed assets and inventories per employee × number of employees × consumer price index

damages, including losses to industrial production, traffic disruption, and emergency costs, are not included in this guideline. General assets are classified as residential assets (i.e. structures and the contents thereof), agricultural assets (farmlands and crops), and industrial assets (fixed assets and inventories). Table 1 shows the classification of general assets and the means to survey them in detail.

When ascertaining economic damages, it is important to use amortized values (assessed according to the value at the time) to reflect the value of assets at the time of the flood, because using full replacement costs (i.e. value as new) will overestimate true damages to

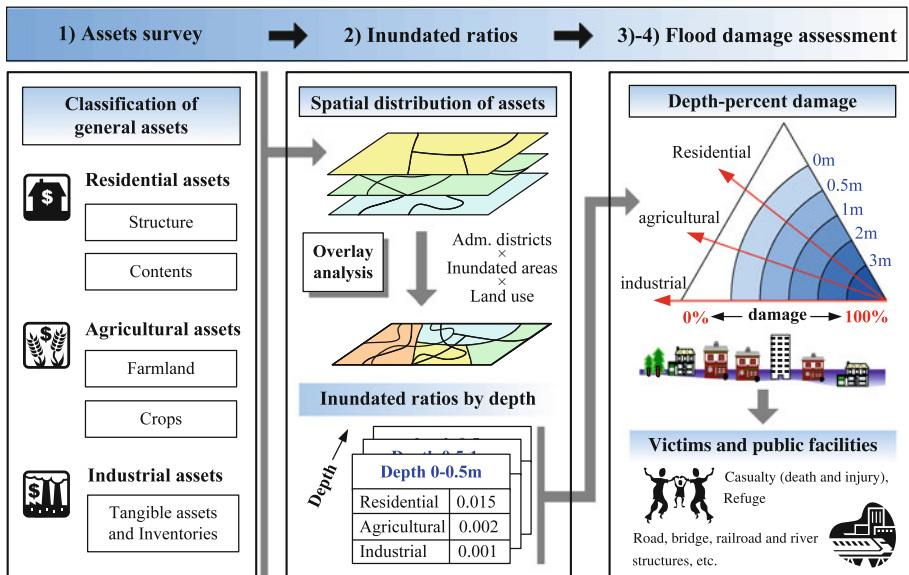


Fig. 4 Schematic process for applying MD-FDA

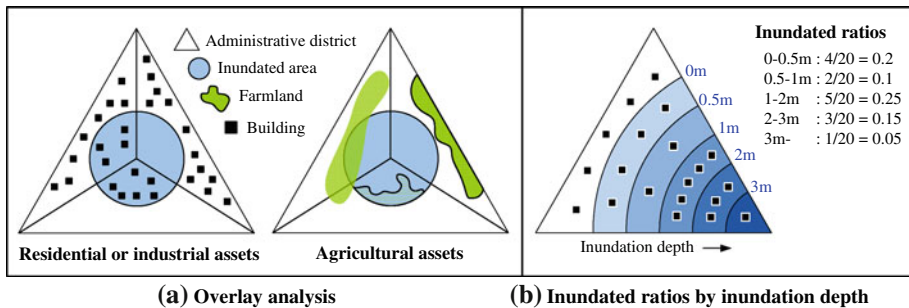


Fig. 5 Computation of inundated ratios

the economy (Messner et al. 2007). In the assets survey for applying MD-FDA, each of the structures and content items for residential assets, and fixed assets and inventories for industrial assets were assessed as net values after amortization.

Figure 4 presents the schematic process of the MD-FDA, which estimates flood damages as follows: (1) assets survey of the administrative district surrounding the inundated area; (2) calculation of inundated ratios for considering the spatial distribution of the general assets; (3) estimation of the general assets damage by multiplying the depth-percent damage by the inundation depth; and (4) calculation of the damage to victims and public facilities. Here, the inundated ratios represent the rates of the damaged general assets within the inundated area to the total general assets in the administrative districts. The inundated ratios are calculated by overlaying spatial information, such as that from the administrative districts of the inundated areas, with the inundation depth, and the land use or building layers of a digital map as shown in Fig. 5. The calculated inundated ratios are multiplied by the total general assets in the districts to estimate only the assets in the

district subject to the damage. At this time, depth–percent damage, which represent the severity of damage according to inundation depth, are applied differently to estimate the severity of the damage of the assets in the inundated area.

Damage to flood victims is categorized into damage to flood casualties and flood refugees. Damage to flood casualties, including death and injury is estimated by multiplying the inundated area by the number of casualties per unit inundated area and per capita damage costs. Here, the number of casualties per unit inundated area, shown in Table 2, is estimated by averaging the historical data from the annual statistical abstracts of the NEMA (National Emergency Management Agency) during the past 30 years (1971 ~ 2001). Furthermore, per capita damage costs were applied at \$389,877 for death and \$4,228 for injury pursuant to the guidelines of the MLTM (2008). The damage to flood refugees is estimated by multiplying the inundated area by the number of refugees per unit inundated area, daily GNI (nominal) per capita in 2007, and the amount of days required for sheltering of refugees. Here, the number of refugees per unit inundated area, as depicted in Table 3, is estimated in the same manner as the number of casualties. The daily GNI per capita was set at \$48, and the number of days of refuge was set at 10 days by averaging NEMA’s historical data.

Public facilities damage was calculated by multiplying the general assets damage by a factor ratio. The factor ratio of public facilities damage to general asset damage is shown in Table 4 (MLTM 2004). If some kinds of public facilities do not exist in the damaged area, the factor ratio should be applied additionally.

Figure 6 presents the procedures and data processing for the flood damage assessment using GIS in this study. As shown in Fig. 6, when damage has been estimated according to flood frequency, the damages due to flood frequency are multiplied by the sectional increment of the excessive probability to calculate the conditional expected values. The annual expected flood damage can be obtained by summing up the conditional expected values, which are the damage values according to each section. The actual survey data required for the MD-FDA can be obtained from the annual statistical abstracts of the district administrations, and the unit prices of the asset categories can be obtained from the values presented by the MLTM (2004).

Table 2 The number of casualties per unit inundated area (person/ha)

City type	Megacity	Small city	Suburb	Rural area	Mountain area
Death	0.004	0.004	0.001	0.002	0.002
Injury	0.002	0.002	0.001	0.001	0.002

Table 3 The number of refugees per unit inundated area (person/ha)

City type	Megacity	Small city	Suburb	Rural area	Mountain area
Casualty	1.85	1.17	0.27	0.37	0.98

Table 4 The factor ratio of the public facilities damage to the general assets damage

Facility item	Road	Bridge	Sewerage	Urban infra	Utility structure	Agricultural facility	Sum
Factor ratio	0.616	0.037	0.004	0.002	0.086	0.949	1.694

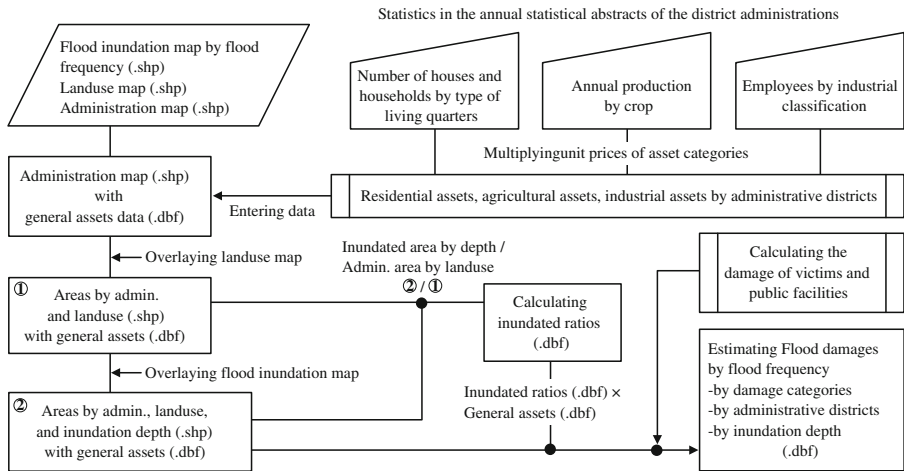


Fig. 6 Flowchart of data processing for the flood damage assessment using GIS

3 Case study: pre-feasibility analysis

3.1 Project overview

The southwestern area of Seoul is on the lower Anyang Stream, where the Mokgam Stream and the Dorim Stream (tributaries of the Anyang Stream) join. It is densely populated and subject to frequent flooding. The MLTM has proposed flood control channel projects for the Mokgam Stream and the Dorim Stream, in the Basin-wide Integrated Flood Control Plans for the Anyang Stream Basin (MLTM 2005), to mitigate flood damage in this area. In this study, a GIS-based flood damage assessment method was applied for the pre-feasibility study of these flood control channel projects.

In the Mokgam Stream flood control channel project, an artificial channel will connect the Mokgam Stream to the adjacent Eunhaeng Stream to drain a portion of the flood water from the Mokgam Stream Basin to the West Sea via the Eunhaeng Stream. On the other hand, the Dorim Stream flood control channel will be constructed in the form of an underground tunnel in order to drain flood discharge into the Han River. Figure 7 shows the geographic scope of these projects. Because the flood control channel of the Mokgam Stream project will be a diversion channel, flooding in the Mokgam Stream Basin affects the flooding level of the Eunhaeng Stream. To solve this problem, the Eunhaeng Stream will be widened for the project. In the Dorim Stream project, analysis revealed that the flood water discharged into the Han River will not have a significant impact thereon.

3.2 Prediction of flood inundation according to flood frequency

The flood inundation area was estimated in accordance with the procedure presented in Fig. 2, and data was processed with ArcView-GIS. For the flood event in the analysis, flood level data presented by the MLTM (2005) of 200, 150, 100, 80, and 50 years' frequency was used, with and without the projects. From the flood level data by flood frequency, the target areas of this study are safe for under 50-year flood frequency events without the project. Thus, we neglect the impact of the under 50-year frequency, because it

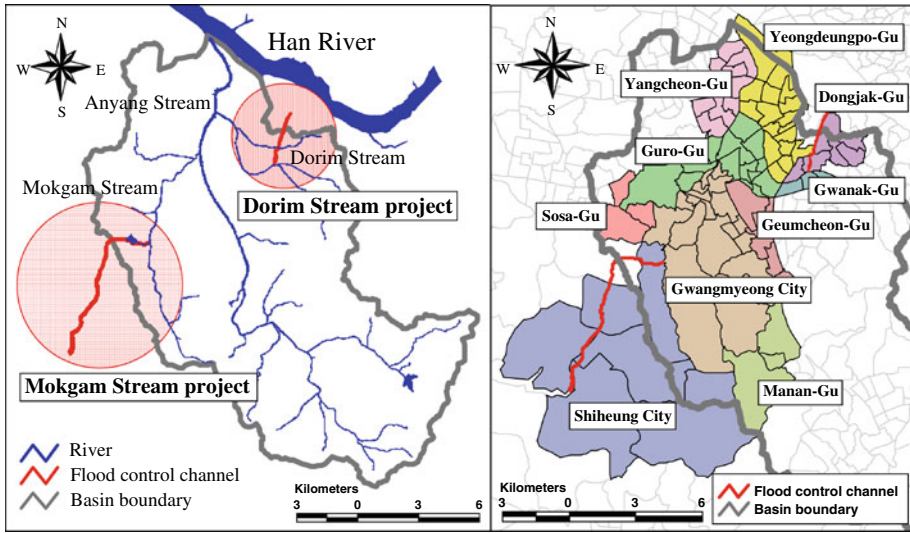


Fig. 7 Overview of the study area. The left side shows flood control channel projects, the right side shows administrative districts

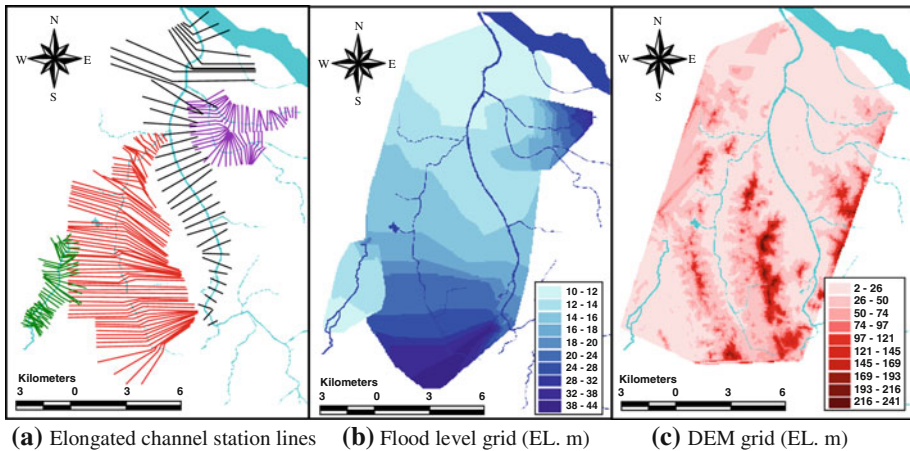


Fig. 8 Creation of flood level grid (WS_{ij}) and DEM grid (EL_{ij}) for estimating inundated area (cell size: $5\text{ m} \times 5\text{ m}$)

could be considered as no damage frequency at all under existing system. Figure 8a shows the channel station lines for entering the flood level data according to frequency. The station lines are elongated from the original river cross-sections in order to extend the flood level to the protected lowland. The flood level data entered in the station lines are used to create TINs, and the TINs created by flood frequency are then converted to flood level grids. Fig. 8b shows a flood-level grid for a frequency of 100 years, which is the design frequency of the Anyang Stream, prior to the flood control channel projects. The DEM (digital elevation model) in Fig. 8c was extracted from a 1/5,000 scale digital topographic map and used to predict the inundated area by comparing the flood level grid.

The internal drainage capacity of the pumping station was taken into account in the flood inundation analysis of the proposed method in Fig. 2 and Fig. 3. The total drainage capacity (m^3) was calculated by multiplying the flood-level duration (min) by the pumping capacity (m^3/min) of the pumping station, and the total inundated volume was deducted there from. In the Anyang Stream Basin, 32 pumping stations are in operation covering an area of 120.9 km^2 with a total pumping capacity of $49,200 \text{ m}^3/\text{min}$. In this study, 29 pumping stations on the downstream area of Mokgam, Dorim, and Anyang Streams were analyzed, as presented in Table 5. Through the procedures described earlier, the prediction of flood inundation is performed on the Mokgam, Dorim, Anyang, and Eunhaeng Stream Basins, for 50, 80, 100, 150, and 200 years of frequencies, with and without the project. Figure 9 presents the inundation areas for a flood frequency of 100 years with and without the project.

Table 5 Details and specifications of drainage pumping stations in the study area (MLTM 2005)

Stream	Station name	Pumping capacity (m^3/min)	Flood level duration (hr)	Total drainage capacity (m^3)
Anyang	Mok2	80	13.5	64,800
	Yangpyeong2	1,089	12.0	784,080
	Yangpyeong1	2,424	12.0	1,745,280
	Sinjeong1	6,380	13.5	5,167,800
	Sinjeong3	294	13.5	238,140
	Sindorim	920	9.5	524,400
	Sinjeong2	1,750	9.5	997,500
	Gaebong2	4,800	8.2	2,361,600
	Cheolsan	2,100	7.2	907,200
	Shinguro	1,075	10.2	657,900
	Gasam2	300	10.2	183,600
	Gasam1	300	10.2	183,600
	Doksan	360	10.2	220,320
	Haan	3,800	7.2	1,641,600
	Shiheung	680	7.2	293,760
	Soha	3,000	6.2	1,116,000
	Yeonhyeon	440	7.2	190,080
Mokgam	Gaebong1	9,440	8.2	4,644,480
	Gwangmyeong3	340	6.0	122,400
	Gwangmyeong2	380	6.0	136,800
	Gwangmyeong1	1,060	6.0	381,600
	Gwangmyeong	736	6.0	264,960
Dorim	Munrae	1,435	4.4	378,840
	Guro1	616	4.4	162,624
	Dorim1	1,290	5.4	417,960
	Guro2	690	4.8	198,720
	Guro3	525	4.8	151,200
	Daerim	336	4.5	90,720
	Dorim3	1,301	4.4	343,464
Total	29 stations	47,941		24,571,428

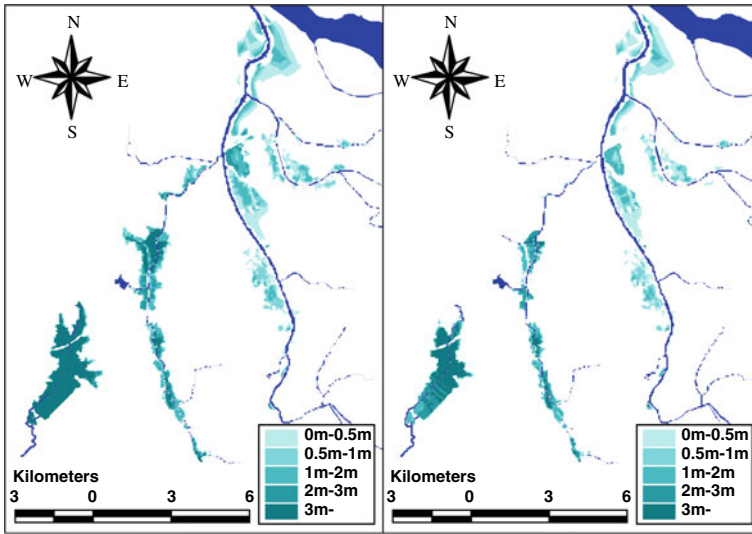


Fig. 9 Impact of project: without project (*left*) and with project (*right*) for a flood frequency of 100 years

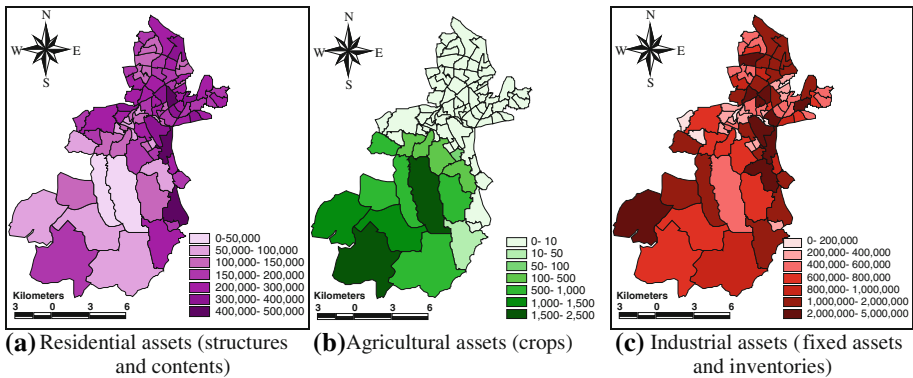


Fig. 10 Administrative district map with assets survey (unit: 1,000 USD)

3.3 Assessment of economic loss by flood damage

Flood damage was estimated in the process set forth in Fig. 6 using ArcView-GIS for data processing. For the GIS data, the flood inundation map according to frequency estimated previously in this study, the land use map for the spatial distribution of assets, and the administrative district map for entering the results of the assets survey by district were utilized. For the assets survey, actual survey data from the annual statistical abstracts of the administrative districts includes the number of houses and households by type of living quarters, employees by industrial classification, and annual production by crop. These were multiplied by the unit prices of the asset categories. Figure 10 presents the administrative district map with the surveyed general assets. As shown in Fig. 10, residential and industrial assets were relatively larger in the Dorim Stream Basin and the downstream area of the Mokgam Stream Basin, while agricultural assets were larger in the middle and

upstream areas of the Mokgam Stream Basin. However, the total amount of agricultural assets was insignificant compared to the residential or industrial assets across the entire region. Although the original calculations for assets survey have been done in Korean currency, this study represents all the monetary value in US Dollar converted from Korean Won ($\sim 1 \text{ USD} = 1,000 \text{ KRW}$ in 2007 year).

Figure 11 shows the process of estimating flood damages in consideration of the spatial distribution of assets classified into administrative district, land use, and inundated areas. In the process, the administrative district map and land use map are primarily overlaid to produce the spatial distribution of assets according to administrative district and land use, and then overlaid with the flood inundation map according to frequency. The inundated ratios were calculated in steps (a) and (b), allowing the flood damage distribution map (c) to be produced by multiplying the inundated ratios by the pre-entered general assets in the administrative district map before overlaying. Since Fig. 11c contains the asset information according to the administrative district, inundation area (by frequency and inundation depth), land use, and various visual information can be reproduced by combining this multi-dimensional spatial information. Figure 12 presents the search results of an inundated area and flood damage distribution after magnifying a certain damaged area in the study. As a result of flood damage assessment process, flood damage to general assets, flood victims, and public facilities are estimated, respectively, as shown in Tables 6 and 7.

The purpose of flood damage assessment is to estimate damages in order to specify the benefits of flood damage reduction projects. Accordingly, flood damages estimated according to frequency need to be expressed in annual expected flood damage, which is the sum of the conditional expected values, to be applied in a cost-benefit analysis. For levee projects, as shown in Fig. 13a, the annual expected flood damage under the design frequency level is identical to the annual expected damage mitigation. Typically, the construction of the levee leads to increased urbanization in the protected lowland, consequently to increase asset values and finally to incur higher damages in case of levee breach. In this case, the frequency–damage curve in Fig. 13a would be shifted to the right for events higher than the original design frequency event.

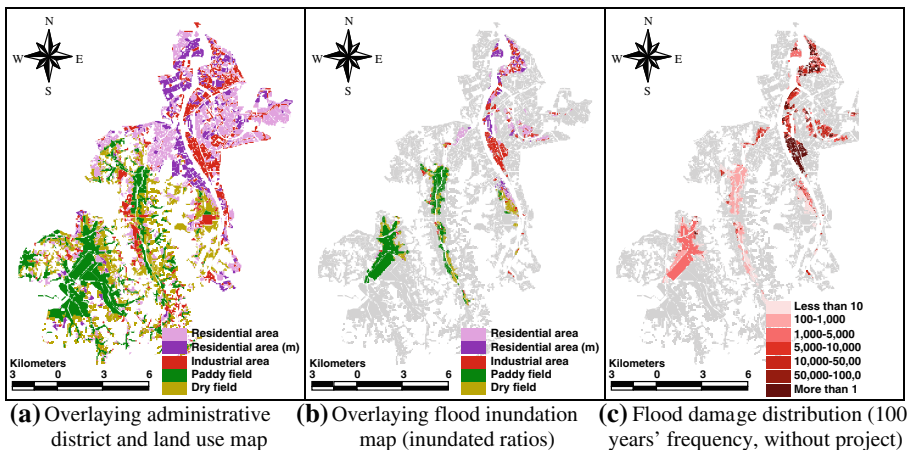


Fig. 11 Flood damage assessment process considering spatial distribution of assets using GIS data

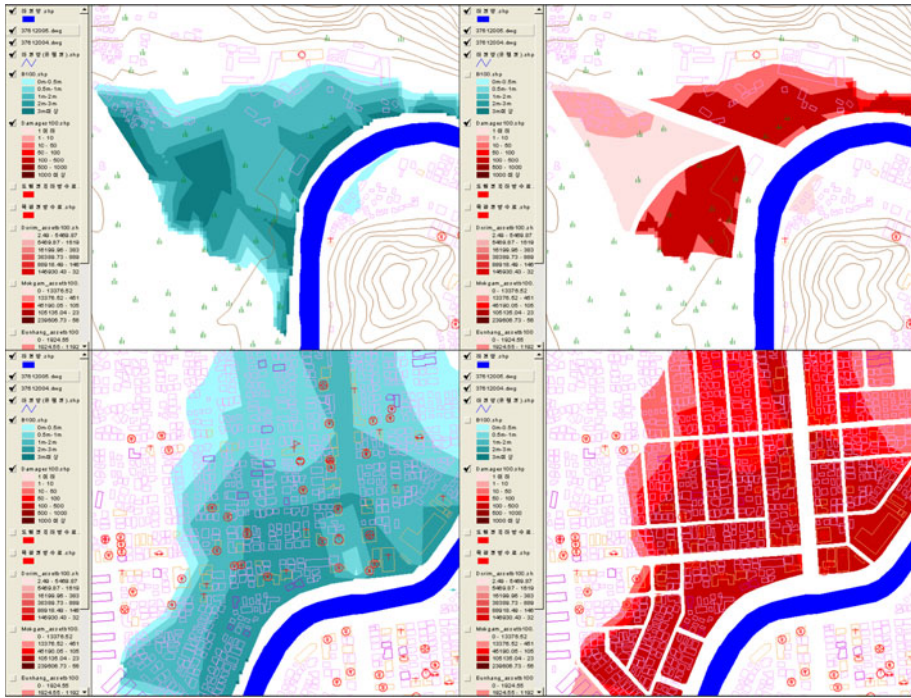


Fig. 12 Sample search of an inundated area (*left*) and flood damage information (*right*) for an urban area (*upper*) and a rural area (*lower*) in the Mokgam Stream Basin, based on 100 years' frequency flood, without the flood control channel

Table 6 Flood damages for the Mokgam Stream with and without flood control channel projects

Return period (years)	General assets (1,000 USD)		Flood victims (1,000 USD)		Public facilities (1,000 USD)		Sum (1,000 USD)	
	Without project	With project	Without project	With project	Without project	With project	Without project	With project
50 year	3,927,434	2,607,685	1,135	792	3,862,642	2,443,829	7,790,076	5,051,513
80 year	5,193,391	3,574,632	1,286	934	5,098,574	3,235,611	10,291,965	6,810,243
100 year	5,733,982	3,546,962	1,413	982	5,589,224	3,249,922	11,323,207	6,796,884
150 year	5,922,955	4,283,249	1,344	1,007	5,445,436	3,854,317	11,368,391	8,137,567
200 year	6,521,622	5,532,536	1,339	1,107	5,939,966	4,918,271	12,461,588	10,450,806

For non-levee projects as shown in Fig. 13b, i.e. for the purpose of mitigating flood discharges, annual expected damage mitigation is calculated by the difference between the annual expected flood damages with and without the project implementation. As the study project is a non-levee project, the annual expected damage mitigation was estimated in Fig. 13b. As a result, the expected amounts of annual expected damage mitigation were 50.6 million USD in the Mogkam Stream flood control channel project and 13.9 million USD in the Dorim Stream flood control channel project. The process and the results of assessment are presented in Tables 8 and 9.

Table 7 Flood damages for the Dorim Stream with and without flood control channel projects

Return period (years)	General assets (1,000 USD)		Flood victims (1,000 USD)		Public facilities (1,000 USD)		Sum (1,000 USD)	
	Without project	With project	Without project	With project	Without project	With project	Without project	With project
50 year	1,180,712	726,200	210	123	879,631	541,019	2,060,343	1,267,219
80 year	1,558,773	999,323	249	172	1,161,286	744,495	2,720,058	1,743,818
100 year	1,784,348	1,159,898	271	200	1,329,339	864,123	3,113,688	2,024,021
150 year	2,017,856	1,501,928	305	235	1,503,302	1,118,936	3,521,160	2,620,864
200 year	2,128,790	1,707,491	318	256	1,585,948	1,272,081	3,714,738	2,979,573

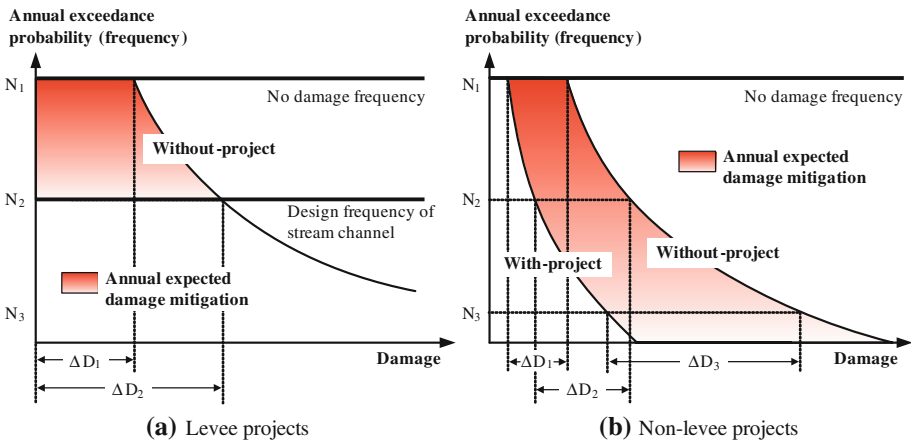


Fig. 13 Flood frequency-damage relationship and annual expected damage mitigation

4 Discussion

4.1 Economic analysis

The purpose of economic analysis in public projects is to evaluate their feasibility in the national economy. Economic feasibility is evaluated by economic evaluation indices like B/C (benefit cost ratio), NPV (net present value), and IRR (internal rate of return), which are calculated by estimating benefits and costs arising there from. B/C is the ratio of the benefits of a project relative to its costs, while NPV is the difference between the benefits and costs. All benefits and costs of both indices should be expressed in discounted present values. In the decision problem under the absence of budget constraint, the best decision is to choose a project with the highest net present value. Where there is a budget constraint, the B/C to the expenditure falling within the constraint should be used. IRR means the discount rate at which the costs of the project lead to the benefits of the project.

In compliance with the pre-feasibility analysis guideline from the Korean Development Institute (KDI 2009), this study assumed that benefits will be generated for 50 years after the projects are completed and that the social discount rate is 5.5% for the first 30 years and 4.5% thereafter. The reference year of the economic analysis is 2007, and the project is

Table 8 Calculation of the annual expected damage mitigation for the Mokgam Stream flood control channel project

Return period (years)	Annual exceedance probability	Damage (1,000 USD)		Incremental damage (1,000 USD)		Incremental probability	Incremental expected damage (1,000 USD/year)		Incremental expected damage mitigation (1,000 USD/year)
		Without project	With project	Without project	With project		Without project	With project	
		50 year	0.0200	7,790,076	5,051,513				
80 year	0.0125	10,291,965	6,810,243	9,041,020	5,930,878	0.0075	67,808	44,482	23,326
100 year	0.0100	11,323,207	6,796,884	10,807,586	6,803,563	0.0025	27,019	17,009	10,010
150 year	0.0067	11,368,391	8,137,567	11,345,799	7,467,225	0.0033	37,819	24,891	12,929
200 year	0.0050	12,461,588	10,450,806	11,914,990	9,294,186	0.0017	19,858	15,490	4,368
						Total	152,504	101,872	50,633

Annual expected damage mitigation = 50,633,000 USD

Table 9 Calculation of the annual expected damage mitigation for the Dorim Stream flood control channel project

Return period (years)	Annual exceedance probability	Damage (1,000 USD)		Incremental damage (1,000 USD)		Incremental probability	Incremental expected damage (1,000 USD/year)		Incremental expected damage mitigation (1,000 USD/year)
		Without project	With project	Without project	With project		Without project	With project	
50 year	0.0200	2,060,343	1,267,219						
80 year	0.0125	2,720,058	1,743,818	2,390,201	1,505,519	0.0075	17,927	11,291	6,635
100 year	0.0100	3,113,688	2,024,021	2,916,873	1,883,920	0.0025	7,292	4,710	2,582
150 year	0.0067	3,521,160	2,620,864	3,317,424	2,322,442	0.0033	11,058	7,741	3,317
200 year	0.0050	3,714,738	2,979,573	3,617,949	2,800,218	0.0017	6,030	4,667	1,363
						Total	42,307	28,410	13,897

Annual expected damage mitigation = 13,897,000 USD

Table 10 Yearly investment plan for Mokgam and Dorim Stream projects (unit: 1,000 USD)

Project	Present value 2007	Design cost			Construction cost				Total investment	OM&R (annually after 2015)
		2009	2010	2011	2012	2013	2014	2015		
Mokgam	323,514	4,276	7,231	32,350	70,396	58,194	110,063	36,737	319,246	8,212
Dorim	123,674	1,872	3,177	20,881	31,354	30,757	20,626	–	108,667	3,560

Table 11 Results of the economic analysis

Project	Present value (1,000 USD)		B/C	NPV (1,000 USD)	IRR (%)
	Benefit	Cost			
Mokgam	1,853,737	323,514	5.73	1530,222	19.61
Dorim	519,887	123,674	4.20	396,213	17.09

assumed to begin in 2009. The benefits of the Mokgam and Dorim Stream projects are annual expected damage mitigation estimated with the MD-FDA. Since the estimation was based on statistical data obtained from the asset survey conducted in 2006, the value was corrected to that of 2007 by applying the GDP (gross domestic product) growth rate (5.04%) from 2006 to 2007. The corrected values are 53.2 million USD for the Mokgam Stream and 14.6 million USD for the Dorim Stream flood control channel projects.

Generally, as the value of assets subject to flood damage increases with economic growth, the benefits of flood damage reduction projects increase correspondingly. To take this economic growth effect into account, the economic growth rate must be applied separately from the discount rate. According to the potential growth rate prediction by Han et al. (2002) for the Korean economy, the economic growth rate was assumed to be 5.2% from 2007 to 2012, which will be declined by 0.1% per year for 10 years from 2013 and will remain at 4.2% after 2022.

The costs considered in the economic analysis were the project costs estimated in the Basin-wide Integrated Flood Control Plans for Anyang Stream Basin (MLTM 2005). Table 10 presents the yearly investment plan allocated in accordance with the construction schedule and yearly funding plan of the government. Meanwhile, the OM&R (operations, maintenance, and replacement) cost is assumed to be 3% of the construction cost. Table 11 presents the B/C, NPV, and IRR as a result of economic analysis with the benefits and costs. The B/C of the Mokgam Stream project is 5.73 and that of the Dorim Stream project is 4.20, both of which are significantly large. This is because these areas have high population density as well as significant concentrations of industrial facilities.

4.2 Comparison between the estimation and past experiences

According to the Annual Report on Disasters from the NEMA, flood damage in the Anyang Stream Basin for the past 25 years (1982 ~ 2006) was 159.6 million USD, which converted to present values, is equal to 6.4 million USD per year. The largest amount of damage occurred in 1987, at a total amount of 39.1 million USD, followed by 38.8 million USD in 2001, and 15.5 million USD in 1990. However, according to Table 3 and 4, the amount of annual expected damage estimated in this study is more than 194.8 million

USD, so there are significant differences between experienced and estimated flood damage. There are two major factors that contribute to this discrepancy.

The first factor is the scope of damage in the inundated area. In flood damage reduction projects where disaster prevention facilities are considered alternatives, all possible potential damages have to be taken into account to accomplish the primary objective, i.e. protecting human life and property. Accordingly, direct comparisons between field surveys of damage caused by a specific disaster and expected damages are not particularly meaningful in estimating the benefits of flood damage reduction projects. Actually, damages were widespread throughout the entire Anyang Stream Basin according to previous investigations. This means that the inundated areas for each flood event do not coincide. In this study, we tried to ensure similarities between actual and model generated inundation areas. This means that actual damaged areas may differ even under the same flood scale due to social and natural uncertainties. Accordingly, the largest possible inundated area is estimated in the planning phase of a flood damage reduction project taking such uncertainties into consideration.

The second factor is the dynamic nature of human behavior. Flood damages can be reduced by risk avoidance actions taken by the disaster prevention authority or individual residents. It is well known that active non-structured measures, including flood forecasts and training against floods, can significantly mitigate flood damages. However, these dynamic behaviors cannot be considered in the methodology for assessing annual expected flood damage, but it cannot be assumed that everything will remain in a static state. In other words, the MD-FDA may be able to estimate potential damage via an assets survey, but it cannot evaluate damage mitigated by avoidance behavior. While such uncertainties cannot be eliminated, the expected flood damage should be estimated on a static condition to take such uncertainties into account.

5 Conclusions

Flood damage assessment models that have been used in Korea are lumped-type, in which only the inundated area is considered, ignoring the spatial distribution of the damaged area. In economic terms, the entire damaged area is analyzed by a single characteristic. On the other hand, the MD-FDA positively makes use of spatial information to predict the inundated area and considers asset distribution. Accordingly, MD-FDA has significantly improved the explanatory power compared to the conventional methodologies, as a distributed-type flood damage assessment model. However, the MD-FDA suffers from complicated processing of data. The application of GIS in this study can improve the convenience of the MD-FDA while maintaining the advantage as a distributed-type flood damage assessment model.

As is well known, in flood damage assessment, the engineering and economic aspects have to be systematically correlated by predicting and taking into account flood inundation using hydraulic and hydrologic analyses and various data and indices that can represent the economic values of the inundated area. However, the conventional flood damage estimation methodologies in Korea, including the MD-FDA, have focused on the economic aspect rather than systematic integration with the engineering aspect. The refinement of the analysis system of MD-FDA in this study is used to propose systematic integration with the engineering aspect, which has been given less weight.

In conclusion, it should be emphasized that flood inundation prediction must take the engineering aspect into account as much as possible, but within an allowable range of

economic efficiency of analysis and work convenience, so that the method can be a comprehensive distributed model. In particular, simpler and more user-friendly software should be developed for MD-FDA to include floodplain analysis models and GIS required for the forecast of flood inundation.

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