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INTEGRATED EVALUATION OF THE MEKONG RIVER FLOOD USING BENEFIT CALCULATION

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SYNOPSIS

Flood benefit is calculated for integrated evaluation of the Mekong River flood and inundation in Cambodia. Floods and inundations are simulated using a dynamic hydraulic wave model in main channels and a non-uniform flow model for flood areas. Agricultural, industrial and fishery benefits are mainly considered. Data are obtained from the field and literature surveys. The estimated benefits are about 41 thousand US Dollars (USD) per square kilometers for rice production and 15 thousand USD per square kilometers for fishery production. Supposing that upstream countries developed a flood control system and could make 50% water level reduction, the damage decrease would be less than all benefits decrease. This means that flood and inundation produce a lot of benefits for agriculture and fishery in the lower Mekong. We propose an appropriate development to make allowances for floods and damages.

INTRODUCTION

JSCE (Japan Society of Civil Engineers) dispatched a mission to investigate a record-breaking 2000 flood in the lower Mekong River. The team made field surveys and collected information (see JSCE (1)). They pointed out the different viewpoints of the flood between urban and rural people in the final report. Urban residents think that the flood leads to a serious situation because of the stagnation of education and physical distribution preventions. On the other hand, rural people think that floods are natural and productive events. In recent years, there has been a change in people view of floods. Especially, some papers have discussed the correlation between flood magnitude and fishery product (see Baran et al. (2)), and fertilization in agricultural land (Kakudo et al. (3)) in the Mekong River Basin.

In order to discuss comprehensively the all problems related to a flood, every item of the evaluation should be compared quantitatively. The aim of the present study is to develop an integrated evaluation of flood and inundation by introducing a cost benefit analysis, which can transfer secondary quantity produced by a flood to price value.

A number of examples have been found of the benefit analysis of flood damage in Japan, and a manual was published for economic researches on flood control (see (4)). JICA (Japan International Cooperation Agency)(5) has also reported cost effect of flood control in Phnom Penh, Cambodia. These reports discussed flood damages and their cost unit but did not mention flood and inundation benefits.

A great deal of effort has been made to estimate the damage to the environment. IPCC (The Inter-governmental Panel on Climate Change)(6) summarized one report, which was written on the environmental impacts of global warming with the cost value of ecology, water, forest and so forth. This report also discusses the differences between developed and developing countries. We evaluate flood

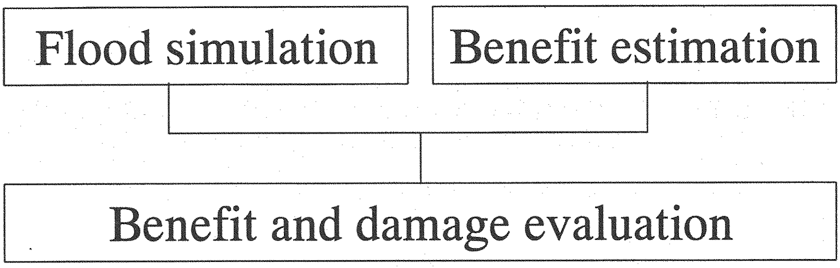

Fig. 1 The research flow chart

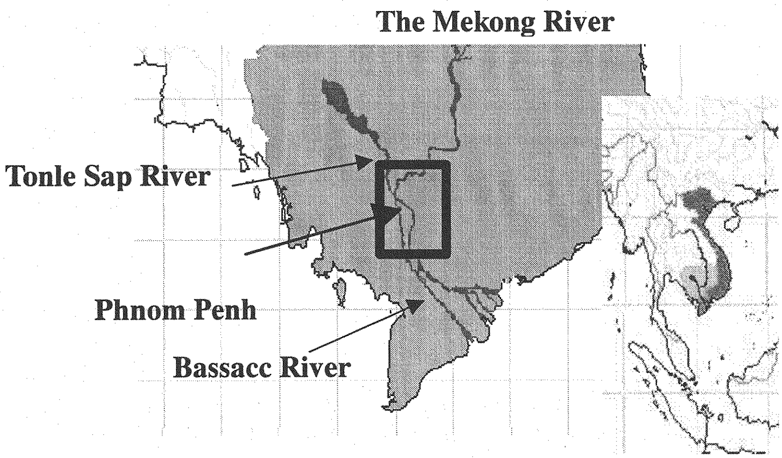

Fig. 2 The study region

benefits using a numerical flood simulation.

The Mekong upstream countries have many plans for dam construction and they stress their effectiveness of flood control by storing water during the rainy season. The downstream countries oppose these plans because of draught problems restricting discharge from upper countries during the dry season (see Nakayama (7)). The downstream countries are paying attention to domestic flood protections. However, flood protection systems such as levees and retarding ponds have never been proposed because flood magnitude and protection costs are too large. Accordingly, it is necessary to show a development plan under symbiosis with flood. Because of this need, we need to determine how much flood produces benefits depending on its magnitude and from what point of view we should consider in the integrated flood protection. We introduce the same quantitative variables for all effects by a flood varying spatially and temporally on its magnitude. This enables us to acquire information for development design for harmonious coexistence of flood and humans.

The present paper examines a numerical simulation of the 2000 flood around Phnom Penh, and demonstrates how this simulation contributes to benefit-damage cost calculation (Fig. 1).

DATA AND FLOOD SIMULATION

The area under study is a rectangular area with 110 km and 140 km around Phnom Penh, the capital city in Cambodia as shown in Fig. 2. We use GTOPO30 as elevation data and IDI (Infrastructure Development Institute, Japan) database as land use data. GTOPO30 is global elevation data archived by the United States of Geological Survey (USGS) and is available via Internet. Meteorological and hydrological data are available in MRC (Mekong River Commission).

Hagiwara et al. (8) have developed flood and inundation models composed of Dynamic wave model in channels, a non-uniform flow model, and surge models were introduced on inundated areas by Inoue et al. (9). We use this model to evaluate floods.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial s}-q=0 \qquad (1)$$

$$\frac{1}{g}\frac{\partial v}{\partial t}+\frac{1}{2g}\frac{\partial v^2}{\partial s}+\frac{\partial H}{\partial s}+\frac{n^2|v|v}{h^{4/3}}=0 \qquad (2)$$

where A is cross sectional area, Q is channel discharge, q is inflow or outflow discharge per unit length, v is velocity, H is water level, s is the direction along the downstream, and h is water depth. Spatial and temporal intervals are respectively 1 km and 1 minute. Water level data at 4 points, at the upstream of the Mekong and Tonle Sap Rivers and at the downstream of the Mekong and Bassacc Rivers, are used as boundary conditions for the numerical simulation. Validation was carried out at Phnom Penh comparing it with the observed and calculated water levels, and revealed a good agreement as shown in Fig. 3. The one dimensional dynamic wave model in this study is expressed substituting the conservation equation (1) into the momentum equation (2) for numerical solution.

The inundation model consists of the conservation equation (3) and the momentum equations (4) and (5) where $M=uh$ and $N=vh$ are the discharge in the unit width in x and y direction respectively.

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \qquad (3)$$

$$\frac{\partial M}{\partial t}=-gh\frac{\partial H}{\partial x}-\frac{gn^2M\sqrt{M^2+N^2}}{h^{7/3}} \qquad (4)$$

$$\frac{\partial N}{\partial t}=-gh\frac{\partial H}{\partial y}-\frac{gn^2N\sqrt{M^2+N^2}}{h^{7/3}}. \qquad (5)$$

Manning's roughness coefficient n is set at 0.05 in all equations. The complete over flow discharge and one for the submerged overflow are calculated by means of the following formula:

$$Q=0.35Bh_1\sqrt{2gh_1} \qquad (6)$$

$$Q=0.91Bh_2\sqrt{2g(h_1-h_2)} \qquad (7)$$

where B is the width of grid intervals, h_1 and h_2 are water stages of the channel and the flood plain from the crest of overflow levee which is supposed to protect from flood invasion under the usual situation. This model has a good agreement of inundation distribution to a remote sensing image (see Hagiwara et al. (8)).

BENEFIT OF FLOOD PER UNIT AREA

Although JICA has obtained damage costs per unit area around Phnom Penh for the flood prevention design (JICA 1999), benefits per unit area has been never informed. Accordingly, we estimate the benefit from the field survey and the literature citing.

Flood and inundation yield much benefit from mainly agricultural and fishery productions and groundwater recharge. In other benefits, there are conservation of rare species, navigation and so forth. Benefits on the environment and nature have been reported in the IPCC report, which said the difficulty for evaluating and grasping all items. This study concentrates on the benefit calculations of agriculture, fishery, and industry by a flood, which are the main economic productions in Cambodia.

A primary production price for one product, even with various qualities, varies with place and time. One article for sale on the same distribution network has different prices in a developing country because bargaining and haggling determine the price. We ignore these price changes and estimate the average price from the field survey in 2002 and available official reports.

The agricultural benefits

Cambodian methods of rice production are divided into two categories: cultivation using irrigated and

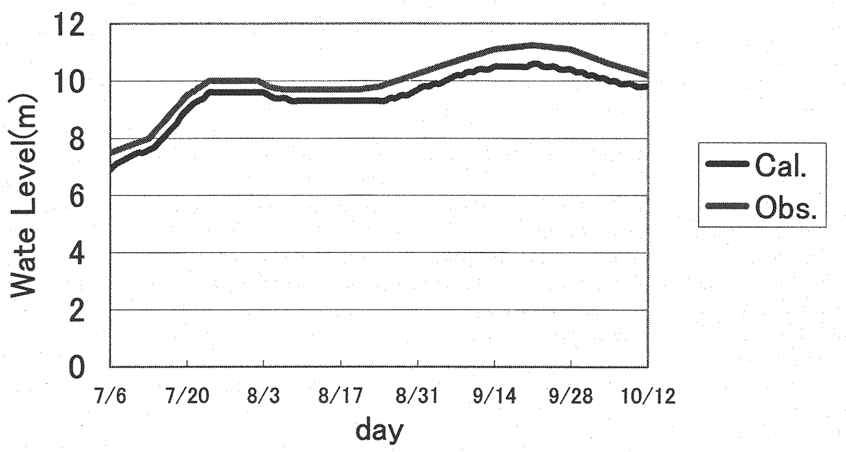

Fig. 3 Calculation results comparing with Observed data at Phnom Penh

flooded water. Natural agricultural system is called "Colmatage", which draws floodwater into an inundation area and plant rice on the edge of flood retreating area. This is a widely used method in the downstream region from Phnom Penh.

Rice prices are not uniform in Cambodia as mentioned above. The purchase price of rice brokers in the outskirts of Phnom Penh is about 300 Riel/kg (about 3,000 Riel is 1 US Dollar) with husks. Supermarkets and local markets sell rice at 1500 and 800 Riel per kg, respectively. We consider the price without the distribution margin processes. Accordingly, we use the consumer price averaging over the survey data for convenience. Here we evaluate 1,200 Riel/kg as the rice price.

Rice yield in Cambodia is 135 ton/km^2 (Kakudo and Goto, (10)) and the ratio of husk to rice is 15% from data in Indonesia and Vietnam (Sekai kokusei Zue, (11)). Therefore, rice yield is 108 ton per km^2 and its price is 41,400USD.

The fishery benefit

The main aquatic products in flood plains in Cambodia are catfish and carp species, which are sold as processed fishes such as fish sauce or ferment fish in the case of small fishes, or are cooked directly in the case of large fishes. We can see a fixed netting method as fishing style at the intakes of colmatage from the river. A casting net method is also popular.

Aquatic product prices also vary spatially and temporally but we use an averaged consumer price. The price is 1USD/kg, which is cited from the official report from the Ministry of agriculture, forestry and fishery (see (12)) and the field survey.

Almost fin in the Mekong tend to migrate seasonally, spawning on flood plains during flood periods and hatched fishes moving to rivers during the flood retention season (Lim et al. (13)). Based on this mode of life, Baran et al. (2) showed a correlation between fish catches and flood peak level from the investigation of fixed netting method called "Dai" in the Tonle Sap river, one of the tributaries of the Mekong River. We suppose that there is a linear relation between them. Baran et al. (2) have also showed the total aquatic products in only paddy fields and in the whole region of flood plain, which are 12,900 ton and 230,000ton 1995, respectively. On the other hand, Kite (14) made the 1995-inundation simulation for the same area, which indicated the area of the inundated paddy field was 1,300km^2 and all inundated area was 15,000km^2 in the Tonle Sap River basin.

The above findings gives us 10ton/km^2 for paddy field and 15ton/km^2 for the whole inundated area as the aquatic products per unit area. The benefits of flood fishery per unit area are 10,000USD/km^2 and 15,000USD/km^2, respectively.

The industrial benefit

GDP from industry in Cambodia is not so large and its ratio to the total GDP amount is about 25%. Industry here includes manufactures, mining, construction, and so forth. These industries need a little water from water supply system but do not need much flooded water. However, beverage companies use ground water, which is recharged during the flood season. Therefore, inundated water yields the industrial benefits. FAO (Food and Agriculture Organization, UN) has reported that yearly alcohol is 0.7kg intake for one person. Accordingly, people in the greater Phnom Penh drink 1,050ton/year alcohol, supposing that the area population is 1.5 million.

Because the cost of water in alcoholic drinks is not known, the industrial water price (500 Riel/m^3) from the water supply is used. Then, the total ground water value for drinking is 170USD. The benefit of flooded water for drinking is much smaller than the other water benefits. There is evidence that industry production is much smaller than agriculture and fishery. Accordingly, we ignored this in our discussion on water benefit.

Flood damage

UN organizations and the Red Cross have reported many different damage costs for the flood.of 2000 Only OCHA (UN, Office of the Coordination of Humanitarian Affairs)(15) in collected reports has evaluated the damage cost of the paddy field, which is 10 million USD for the total paddy field including destroyed areas 1,200km^2 anflooded areas, 1,370km^2. Therefore, damage cost per km^2 is 4,000USD. The unit damage per km^2 is less than that of product because some parts of the fields had been already harvested in this region.

We should focus attention on the fact that this evaluation is not effective for every year. The 2000 flood occurred earlier than usual year, damaging crops before harvesting. The 1996 flood damage, in which the flood peak level is similar to that of the 2000 one, is half as much as the 2000 flood damage. We can show that flood peak time influences the damage cost. Earlier flood arrival causes more damage.

In concluding this section, le 1 shows the benefit and damage per unit area.

BENEFIT ESTIMATION

Calculation condition

To understand the dependency of the change in inundated area to flood benefits, a numerical simulation is carried out. The flood and inundation simulation for the 2000 flood modeled by Hagiwara et al. (8) are used for some scenarios of flood with intervals of 10% water depth reduction. The reduced ratio is defined as the ratio of the difference between base flow and the highest level of the simulation to that of the 2000 one. In the 50% reduction case, flood peak of 16m and flood stage period of 20 days are decreased to 13.8m and 7days, respectively. The benefit estimations of different flood peaks can yield information when the flood magnitude will change according to the upstream development such as reservoirs and water use, and the climate change.

Benefit and damage costs are estimated by multiplying each cost per unit area by inundated area. Land use data shows that study area has 50% paddy field and 36% of the inundated area. We are dealing with two examination areas, which are only paddy fields and all inundated areas including the paddy field. This means that flooded water in the paddy field and water in all the inundated area including paddy field is used for cultivation. Although the inundated area does not include all paddy fields actually, we supposed that floating rice and reclamation would be possible in those areas in the near future as potential production. We found such many reclaimed areas by the field survey and considered two cases for fishery area, which are only paddy filed and all inundated area including channels.

Calculation results

Figure 4 shows the relationship between the water level and the inundated area by the numerical simulation. We select the largest flooded area during three months of flood season. If 50% flood reduction of water stage will be possible, the inundated area would be 6,700km^2 although the 2000 flood have had 8,500km^2. This reveals that the decreasing area of inundation is not so large as compared with the decrease of water level because this region is quite low and plain. Even a small flood can spread out on the Mekong delta widely.

Figure 5 depicts the relationship between rice production and damage to the water level using the results of Fig. 4. The reason for the 10 % damage cost to the product is that some harvesting had been

Table 1 Benefits per area by flood

	Benefits (USD/km²)	Damage (USD/ km²)
Paddy Field	41,400	4,000
Fishery (Inundated area)	15,000	
Fishery (Paddy field)	10,000	
Industry	170 USD	

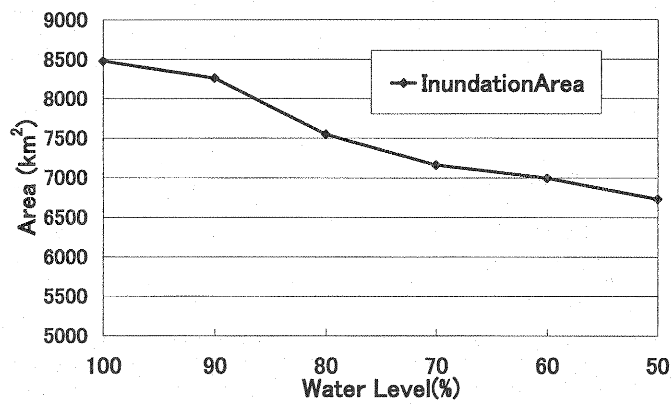

Fig. 4 Relationship between water level and inundated area

carried out before the flood and some areas had floating and deeper rice as explained. Benefits are greater than damage for flood and inundation on paddy field. Rice production is the main industry in Cambodia and benefits are considerable.

Figure 6 illustrates the relationship between the water level and the fishery product on paddy and inundated areas. Fishery benefits are also large and this amount is half as much as total production, about 100,000,000 to 225,000,000 USD in all fishery production in Cambodia estimated by Gum (16). Only paddy field production of fishery is 60% as much as flooded plain production of that.

DISCUSSION

A summary of the above-mentioned results reveals that fishery and agricultural products are more than ten times as large as damage cost. Flood benefit is much superior to its damage. The total damage of the 2000 flood in Cambodia is 80,000,000USD, which includes road broken, obstructed physical distribution, and so forth. This damage cost is similar to only the fishery benefit on paddy fields. Actually, this benefit cannot be expected because all fishes are not available. However we could ascertain that inundation in the Mekong provides a lot of benefits if we consider the other living aquatic resources. Many kinds of fish are known as migratory fishes. This means that inundation area reduction in the downstream region affects the upstream aquatic resources. Recently, a giant catfish released in Tonle Sap Lake was caught in Thailand. Spawning area in the downstream is important for the upstream countries.

Rice benefit is twice as much as fishery benefit in paddy fields. This also shows that the production is much larger than the damage. It should be noted that the benefit in all areas is greater than damage cost even if some rice fields were damaged owing to the earlier flood. The inundated water is used for cultivation after flood by colmatage. If locals plant floating rice just before the flood and high yielding rice after the flood, flood damage will be less. In addition, information distribution of flood and market is effective for the farming management. These days, the international price of rice is decreasing but it is expected to increase again due to a lack of food. If that happens, rice production can be more advantageous.

Water storage in the upstream countries can make reduction of flood level but can not reduce a large inundated area. The upstream countries can enjoy the advantages of water but they can not prevent the flood in the downstream region. The down stream countries do not have the benefit of water storage in

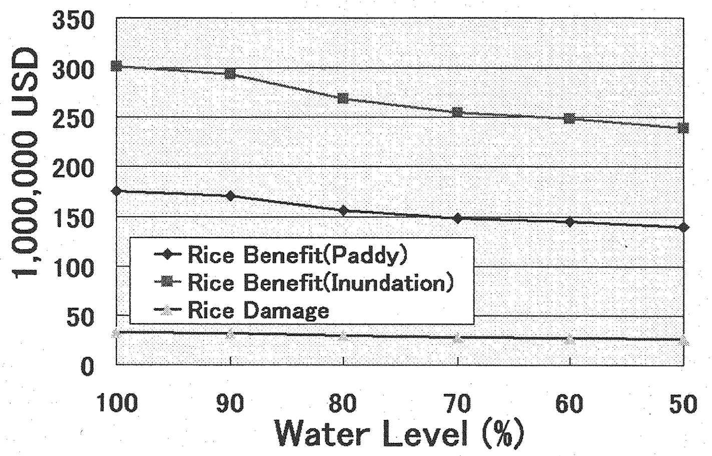

Fig. 5 Relationship of rice benefits and damage to water level

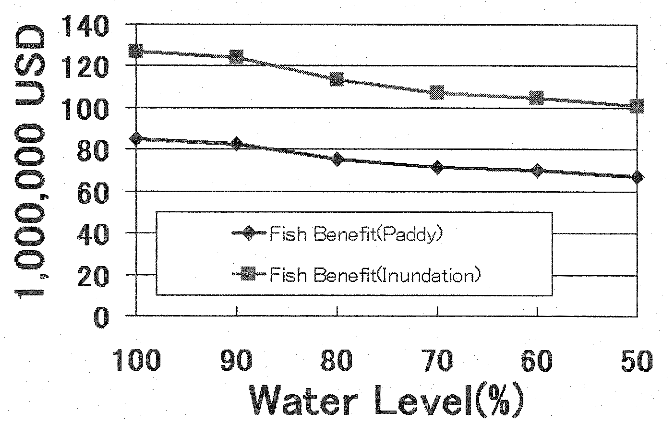

Fig. 6 Relationship of fishery benefits to water level

the upstream. Also, the downstream countries are worried about sedimentation problems such as coastal erosion.

Based on the above results, we were able to tell that maintenance of the status quo yields more benefit than flood prevention in Cambodia. Flood inundation in Cambodia spreads quite widely then, development with harmonious coexistence of flood and humans is hoped because the flood prevention cost is too large. In Vietnam, a surrounding dike called dike system is introduced and water is stored in the dikes during flood season and use it during dry season. In addition, dredging soil in a channel next to a dike is used for filling the dike (Kazama et al. (17)). This is one example for good utilization of flood.

The present study is a fundamental benefit calculation based on a linear approximation. We should consider more kinds of benefits such as rare species and ground water use. For example, not only ecologist but also tourists are attracted by Irrawaddy dolphin. Rare species benefit is 10USD per one person and the total benefit would be huge if we counted all people all over the world who are interested in (IPCC, (6)). Groundwater also provides a lot of benefit for not only drinking water but also irrigation in the dry season.

We should also consider the future benefits due to environmental change depending on time. This benefit evaluation could be changed if the net production in Cambodia were to become higher. For example, the current estate asset value is little or nothing now but will increase if, for example, a paddy field will be changed to factories when industrial composition will be changed. Also environmental values such as rare vegetation and wild life are increasing. These changes will reveal more different and complex results. We plan to study in the near future the integrated evaluation of flood and inundation in consideration of asset values and environmental influences.

CONCLUSIONS

This study evaluates flood and inundation benefits in the greater Phnom Penh and shows that benefits in rice production and fishery products are greater than flood damage and that the estimated fishery benefit in only paddy fields is similar to the total 2000 flood damage. We would like to propose some flood damage prevention policies from these results. They are as follows;

1) Prompt distribution of flood information for local people,
2) Encouragement of river transportation,
3) Encouragement of floating and deep rice cultivation before flood, and
4) Colmatage agriculture conservation.

The integrated analysis examined here has been a great advantage in making such recommendations.

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