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THE PREDICTION OF FLASH FLOOD CAUSED BY DAM FAILURE A CASE STUDY AT THE THE THA DAN DAM, THAILAND

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ABSTRACT: The Tha Dan Dam, Nayok Province, was selected as a case study to predict flood disaster caused by dam failure and overflow through spillway. It is a roller-compacted concrete dam with 114 meters above the mean sea level of ridge height and 224 million m^3 of volume capacity. The objectives of this study were to predict the characteristics of flood wave and to estimate damaged areas using an integration of mathematical model, remote sensing, and geographic information system. Information on the highest water inflow in 10,000 years of return period and cracks on the dam, trapezoid shape, were utilized to simulate dam failure at various degrees of severity. In case of dam failure of high severity, Ban Tha Dan, locating 200 meters from the dam, will be completely inundated with the highest flooding level of 43.8 m above the mean sea level. The flood discharge will be 221,506 m^3/s with the velocity of 19.7 m/s, and flooding will exist in the villages of Ban Tha Dan within 2 hours. The wave front will arrive the city in Amphoe Muang, 27.8 km from the dam site, within 1.3 hours and the highest water level will reach 9 m above the mean sea level within 5 hours. The flood level in Amphoe Muang can reach 3.5 m and remains in the city for 39 hours. The discharge of flood wave will be 8,837 m^3/s with the velocity of approximately 4 m/s. Total areas received an impact from the flood disaster are about 391.8 km^2. In case of overflow from the spillway, Ban Tha Dan will not be flooded whereas Amphoe Muang could not avoid this impact. The wave front will arrive the city in Amphoe Muang within 3 hours and the water level can reach 6.4 m above the mean sea level within 28 hours, and flooding can exist for 41 hours. Results from this study can be applied to land use planing. Relevant organizations in public sectors can also prepare strategic plans to protect and reduce the impacts on life and the assets of government and local people in the downstream area.

1. INTRODUCTION

1.1 Statements of Problems

Dam is a ubiquitously disputed subject ranging from its benefits, the effects of dam construction towards the ecology system, the collapse of local communities, and epidemic diseases. In addition, the failure of large dam that might immediately occur could lead into a tremendous loss of lives and assets.

From history, there were dams worldwide that have been collapsed. One example was the Teton Dam in the United States, 305-feet in height, which was collapsed in June 1976. Fourteen people were killed and 25,000 people became homeless. An estimated loss in that incident was from 400 to 1,000 million U.S. dollars, approximately 10 times greater than its construction cost.

The failure of dams is frequently caused by factors such as internal piping or leakage. However, one substantial factor is the overtopping in the rainy season. The Machur II dam in India was collapsed due to flooding in 1979. There were 1,500 people killed in that incident. In Thailand, statistical loss caused by dam failure was found in 1990 as a result of Era and Lola typhoons, which reinforced a heavy rainstorm over the Mun Bon Dam. Water level in the dam was rapidly raised up to 220 m above the mean sea level. The volume of water in the reservoir reached 131 million m^3, thus, caused a big hole over the middle of the dam ridge. Water flowed from the dam with the speed greater than 20 million m^3/s, or approximately 1,728 million m^3/day. If this flood disaster could not be controlled, it could have eroded the dam ridge and led to dam failure and rapid flood in downstream area.

From the disastrous flood over the Mun Bon Dam, people started to realize and examine dam conditions in Thailand. Nonetheless, such tragic incident is likely to happen again, especially in the area where large dam is located. Natural calamity or carelessness in dam construction can be a causal factor as well. Therefore, it is important to predict the flood caused by dam failure. This task can be accomplished by developing a model of dam collapse and considering the volume of water discharge, water level, velocity, and time taken for runoff from dam to downstream area. A map demonstrating the flooded area and estimating the loss from such incident can then be produced. This information can be useful to planning, disaster announcement measures, and evacuation of people living in downstream area.

1.2 Objectives

1. To predict the characteristics of flood wave; e.g., the amount of water flow, water level, water discharge, speed, and time taken for runoff from dam to downstream area.
2. To apply mathematical model together with remote sensing and geographic information system to predict the flood from dam failure and overflow through spillway.
3. To develop a map of the downstream area if flooded as a result from a collapse of the The Tha Dan Dam or overflow through spillway.

1.3 Scope and Study Area

The study was focused on the flood caused by the dam failure or overflow through spillway. The simulation dam failure is in specific breach geometry. In this case, trapezoid was applied to predict the amount of water discharge, water level, velocity, and time taken for runoff from dam to downstream.

Many variables involve in the prediction of dam failure. Researchers have developed a concept to apply an appropriate mathematical model that can simulate the flood resulted from dam collapse. The model was integrated with remote sensing which can provide the updated data and geographic information system for data analysis. With technology advancement, the prediction of dam failure and estimation on loss can be more correct and accurate. The simulation of this study focused on flood caused by overflow through spillway and the failure of the The Tha Dan Dam, a roller compacted concrete (RCC) dam, with 114 meters above the mean sea level of ridge height and 224 million m^3 of volume capacity.

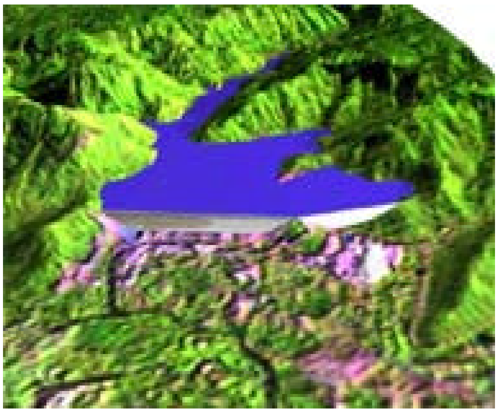

Figure1: Simulation of The Tha Dan Dam

2. METHODOLOGY

2.1 Materials

The materials and data used in this study to predict the flood disaster caused by dam failure and the overflow from spillway are as follows:

2.1.1 Topographic maps: 1:250,000 and 1:50,000 scales.

2.1.2 Satellite data: Landsat-5 Thematic Mapper (TM) both digital data and hard copy were provided by the Geo-Informatics and Space Technology Development Agency (Public Organization). Data was acquired on April 11, 1998 and December 26, 1999.

2.1.3 Cross section of watershed: Cross section and profile of the watershed were collected from the Royal Irrigation Department.

2.1.4 Hydrological data: Hydrological data of Nakhon Nayok watershed was provided by the Royal Irrigation Department.

2.1.5 General information of the The Tha Dan Dam: The data include the capacity of water retention and dam structure.

2.1.6 Processing instruments: GIS database were created using Intergraph (Model TD420) with 520 MB of memory workstation. In addition, MGE (Modula GIS Environment) and Oracle 7 operating on Window NT were additional programs for data processing and analysis. Mathematical model was run on a microcomputer with 32 bit and 64 MB of memory using MIKE 11 to operate and analyze data.

2.2 Methodology

Steps to predict flood disaster caused by dam failure and overflow through spillway can be described as follows:

2.2.1 Investigation on general characteristics of dam location and downstream area

This step focused on an investigation of geographic characteristics and land cover in downstream area through interpreting data from satellite imagery. Landsat-5 TM data was selected having the least signal error and cloud cover. Georeferencing was done based on topographic map. Data interpretation techniques included both visual interpretation and automated image processing.

2.2.2 Study of flood wave

The prediction of flash flood caused by overflow through spillway and dam failure of the Tha Dan Dam is simulated.

Study of flood wave caused by dam failure

Dam failure generally occurs when dam retains high water volume and there is high water inflow in the upstream area, as well as the deficiency of the dam itself. This study was focused on dam failure caused by overtopping when water volume in the dam reached peak capacity. In addition, the pattern of dam failure was simulated on a specific crack like trapezoid. Factors to be considered in predicting the water discharge from the crack, water level, velocity, time taken for runoff, and flooding time in downstream area are:

- Volume of water inflow during dam failure: The highest volume of water inflow to the Tha Dan Dam was determined by the highest water discharge occurred in 10,000 years of return period.
- Pattern of dam failure: Historically, parabola or trapezoid pattern are mostly observed in dam failure. In this study, trapezoid pattern was selected. It was simulated that the water volume in the dam reached peak capacity at 114 meters or more above the mean sea level. When the water level was higher, it overtopped dam ridges and water discharge could erode dam materials leading to cracks on the dam and a sudden dam failure. There were three types of cracks; large, medium, and small. Large crack is extremely violent; the width of crack is about 3 times of dam height or about 300 meter wide. Medium crack is somewhat violent and the size of crack is around 180 x 60 meter whereas the size of small crack is 90 x 30 meter.
- The water discharge from the dam was estimated using a hydrograph. General characteristics and dimensions of the Tha Dan Dam were considered.
- Cross-section in downstream area and flood plain.
- Manning Coeffic ients is a representative parameter to indicate characteristics of each watercourse such as bed roughness and cross-section. The composition of Manning Coefficients is derived from the hydraulic radius of each cross section, type of vegetation, and land cover along the outer edge of stream and flood plain. To get Manning Coefficients of mainstream, the characteristics of mainstream were observed and then compared to the standard value of Manning Coefficients produced by Chow (1959) and French (1985). This was then applied to forecast the condition of water discharge due to dam failure and water drainage through spillway. Manipulation of Manning Coefficients in different periods was also performed.

Because the information of water outflow into the flood plain was not available, Manning Coefficients of flood plain area was based on an estimation from 1:50,000 topographic map and its land cover.

Study of flood wave caused by overflow through spillway

When water volume in the dam is higher than its full capacity, water drainage through spillway normally takes place. This could lead to flood disaster in downstream area. However, it provides less impact than dam failure. The simulation concentrated on an estimation of constant water discharge from the spillway, water level, velocity, time taken for runoff, as well as the flooding time in downstream area.

2.2.3 GIS Manipulation

GIS database of the study area consisted of both spatial (i.e., geographical coordination of each materials) and attribute data. Steps in GIS manipulation were as follows:

- Preparation of project structure: This included coordinating system, map parameters, and design of database structure. Two parts of database were categories and features. Category consisted of many features, which included geographic data or specific map. Feature known as element of graphic
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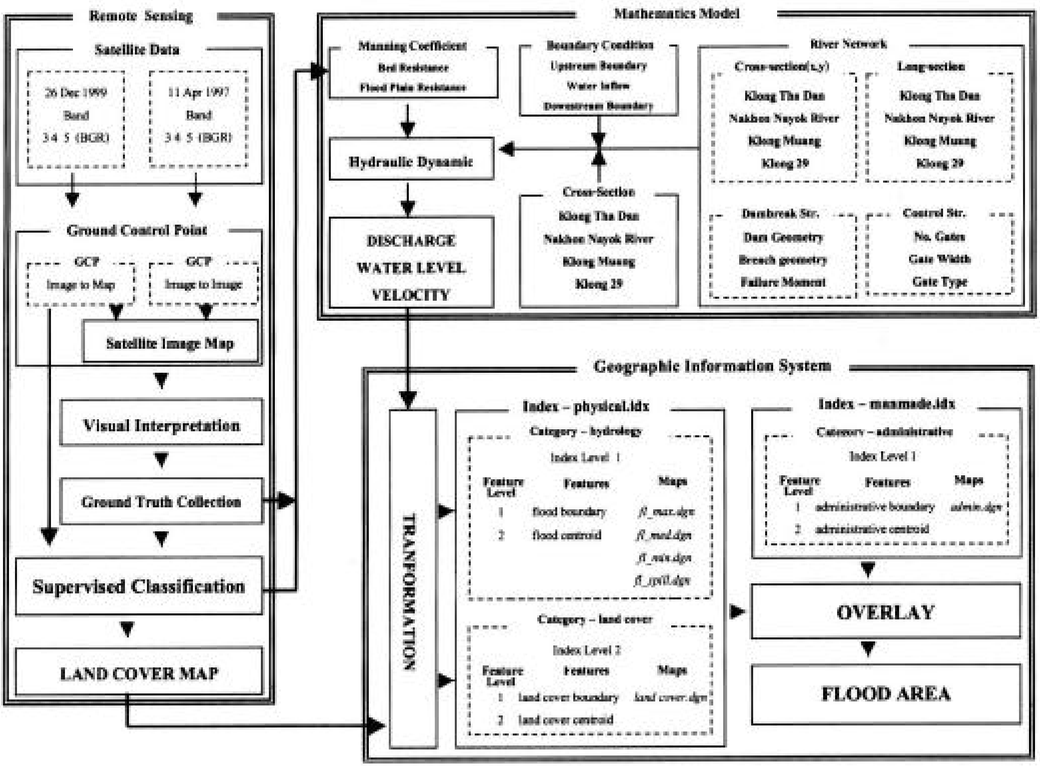
- presented on map, was linked to table of attribute data to provide information about the characteristics of spatial data.
- Data preparation: Data can be achieved in various forms; therefore, data preparation was required so that such data could be manipulated for GIS database. Land cover map interpreted from satellite data was a raster file and, thus, converted into a vector file.
- Digitizing: Administrative boundaries, 10-20 meters of contour lines, transportation network, watershed network, and the boundaries of flooded areas derived from mathematics model in different severity of impact were all digitized. These data were in vector files and data correction is recommended for more accuracy and completion. The overlays of vector files were checked as well.
- Linking attribute data to graphic data was performed as well as the calculation of areas and polygons recorded in database for overlay and further analysis.
- Overlay and data analysis: Information derived from the simulation of water discharge caused by both dam failure and water drainage from spillway, administrative boundaries, and land cover information were overlaid. The impact area from flood disaster caused by the failure of the Tha Dan Dam was then estimated.
- Three-dimension modeling was accomplished using TIN (triangular irregular networks) and GRID models. Digital elevation model (DEM) was also generated, and satellite imagery and information of study area were draped on it to produce digital terrain model (DTM). The DTM indicated the direction of water discharge, gradient, slope length, and flooded areas caused by dam failure and overflow trough spillway.

2.2.4 Mapping of flooded area in different timings

GIS database was used to map flooding in the study area to demonstrate the direction of water discharge and the location of damaged areas as well as its boundary. This map was produced in different timings.



Figures 2: An integrated framework for flood prediction.

3. RESULTS

An integration of mathematical model, remote sensing, and geographical information system was conducted to predict flood disaster caused by dam failure and overflow through spillway at The Tha Dan Dam. Four main steps included (1) investigation of general characteristics of dam, its location, and watercourse in downstream area; (2) developing of a mathematical model of dam failure; (3) estimation of damaged areas using GIS; and (4) mapping of flooding in various degrees of severity.

3.1 Characteristics of land cover in downstream area

Through the interpretation of satellite imagery, agricultural area, e.g., paddy, horticulture, aquaculture, and etc., was the major land cover, 2,255 km^2 or 85 % of the study area. Forest occupied 337 km^2 or 13 % whereas 38 km^2 or 1.4 % were water and 10 km^2 or 0.4 % of dwelling and built up area.

3.2 Study of flood wave

Manning Coefficients of major watercourse derived from model calibration were 0.03-0.05. In flood plain, however, Manning Coefficients derived from the estimation of topography and land use were 0.05-0.15. The Tha Dan Dam failure and the movement of flood wave were modeled. If dam failure promptly occurs, the degrees of severity of impact can be divided into 3 levels: high severity, moderate severity, and low severity. In case of high severity, Ban Tha Dan, located 200 meters from the dam, will be completely inundated, and the discharge of flood wave can be about 221,506 m^3/s with the speed of 19.7 m/s. The flood level can reach 43.8 m above the mean sea level after 12 minutes of dam failure. Flooding will exist in Ban Tha Dan within 2 hours. For Amphoe Muang, 27.8 km from the dam, wave front will arrive the city within 1.3 hours and the highest water level will reach 9 m above the mean sea level within 5.4 hours. Therefore, the flood level in Amphoe Muang will reach 3.5 m and flood will remain in the city for 39 hours. The discharge of flood wave is about 8,837 m^3/s with the speed at 3.9 m/s.

To study the movement of overflow from the spillway in downstream area, the highest water volume of return period in 10,000 years was taken into consideration. Flood wave in the downstream area does not move to Ban Tha Dan so the village will not be flooded like in case of dam failure. However, Amphoe Muang still receives the adverse impact of this incident. The wave front from water drainage will arrive the city within 3 hours and the water level will reach 6.4 m above the mean sea level within 28 hours. The highest flood level in Amphoe Muang can reach 0.9 m and the flood will exist for 41 hours.

3.3 Damaged areas from dam failure and overflow through spillway

The flooded area caused by dam failure in various degrees of severity and water drainage through spillway was calculated. Details were as follows:

3.3.1 Dam failure in case of high severity: The flooded area is about 392 km^2 or 14.8 % of study area. This represents 316 km^2 of agricultural area, and 3 km^2 of dwelling and built up area.

3.3.2 Dam failure in case of moderate severity: The flooded area is about 332 km^2 or 12.6 % of study area. This represents 316 km^2 of agricultural area and 2.7 km^2 of dwelling and built up area.

3.3.3 Dam failure in case of low severity: The flooded area is about 140 km^2 or 5.3 % of study area. This represents 127 km^2 of agricultural area and 2.1 km^2 of dwelling and built up area.

3.3.4 Dam failure in case of water drainage through spillway: The flooded area is about 43 km^2 or 1.6 % of study area. This represents 34 km^2 of agricultural area and 1.7 km^2 of dwelling and built up area.

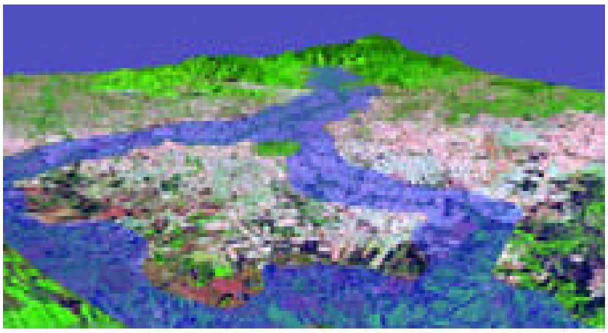


Figure 3: Terrain model of flood area at high severity of dam failure.

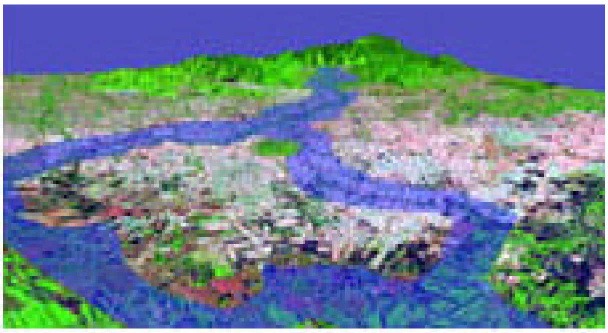


Figure 4: Terrain model of flood area at moderate severity of dam failure.

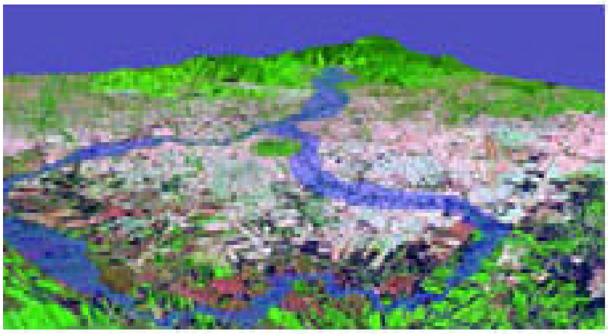


Figure 5: Terrain model of flood area at low severity of dam failure.

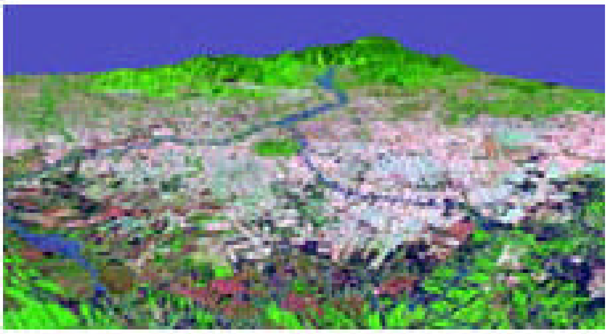


Figure 6: Terrain model of flood area in case of water drainage through spillway.

4. CONCLUSIONS

Remote sensing and geographic information system were applied with mathematical model to ensure more accurate prediction on flood caused by dam failure. The results derived from this study can be applied to land use planning. Relevant organizations in public sectors can then prepare strategic plans to protect and reduce the impact on life and the assets of government and local people in the downstream area.

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