Assessment of the Inundation Area and Volume of Tonle Sap Lake using remote sensing and GIS

Hyosok CHAE[1※]

원격탐사와 GIS를 이용한 Tonle Sap호의 홍수량 평가

채효석[1※]

ABSTRACT

The ability of remote sensing and GIS technique, which used to provide valuable informations in the time and space domain, has been known to be very useful in providing permanent records by mapping and monitoring flooded area. In 2000, floods were at the worst stage of devastation in Tonle Sap Lake, Mekong River Basin, for the second time in records during July and October. In this study, Landsat ETM+ and RADARSAT imagery were used to obtain the basic information on computation of the inundation area and volume using ISODATA classifier and segmentation technique. However, the extracted inundatton area showed only a small fraction than the actually inundated area because of clouds in the imagery and complex ground conditions. To overcome these limitations, the cost-distance method of GIS was used to estimate the inundated area at the peak level by integrating the inundated area from satellite imagery in corporation with digital elevation model (DEM). The estimated inundation area was simply converted with the inundation volume using GIS. The inundation volume was compared with the volume based on hydraulic modeling with MIKE 11, which is the most poppular among the dynamic river modeling system. The method is suitable for estimating inundation volume even when Landsat ETM+ has many clouds in the imagery.

KEYWORDS : Tonle Sap Lake, Cost-distance Method, Inundation Volume, Remote Sensing, GIS

요 약

원격탐사와 GIS 기법는 시공간 측면에서 매우 귀중한 정보를 제공할 수 있으며, 홍수와 같은 재해 발생시 홍수발생 지역에 대한 매핑, 모니터링 및 재해지역 관리 등에 있어 매우 유용한 정보를 제공할 수 있다. 지난 2000년 메콩강 유역의 Tonle Sap호에서 발생한 홍수에 의해 많은 피해가 발생하였으며, 특히 7월과 10월 사이에 두 차례의 홍수 피크가 기록되었다. 본 연구에서는 홍수피해

2005년 7월 21일 접수 Recieved on July 21, 2005 / 2005년 8월 22일 심사완료 Accepted on August 22, 2005

1 한국수자원공사 수자원연구원 물정보화연구소 HydroGIS Team, Hydroinformatics Research Center(HRC) Korea Institute of Water and Environment, KOWACO

※ 연락저자 E-mail : chaehs@kowaco.or.kr

에 대한 정량적인 분석을 위해 ISODATA와 세크멘테이션 기법을 이용하여 Landsat ETM+와 RADARSAT 영상을 분석하였다. 그러나, 영상으로부터 분석된 범람면적이 구름과 복잡한 지표피복물 등으로 인해 실제 홍수피해 상황을 정확히 반영하지 못했다. 따라서, 이러한 문제점을 해결하고자 GIS 기능 중 비용-거리 (cost-distance) 기법을 이용하여 홍수범람 면적을 분석하였으며, 분석결과는 수치표고자료(DEM)와 중첩하여 홍수량을 계산하였다. 계산된 홍수량은 수리모형인 MIKE 11의 모델링 결과와 비교하였다. 계산결과, 영상 내에 많은 구름이 존재하는 Landsat ETM+ 영상의 경우와 복잡한 지표피복이나 시스템 변수 등의 영향으로 홍수피해 지역을 정확히 분류하기 어려운 RADARSAT 영상에서도 좋은 결과를 얻을 수 있었다.

주요어 : Tonle Sap호, 비용-거리기법, 홍수범람량, 원격탐사, GIS

1. INTRODUCTION

Flooding is an unfailing annual event in the major river basins all over the world, causing great havoc and extensive damage to agricultural crops and property, in addition to loss of life. The United Nations report proved the results of disasters statistics collected world wide for the 30 year period (1963~1992) and reveals that floods killed more people than any other type of disaster (22% all of deaths) and caused the worst damage (32% of the total bill) (Nguyen and Bui, 2001). Mekong river basin is perhaps one of the most disaster-prone basins in the world and water-related disaster including floods occuring every year. There are four countries (Laos PDR, Thailand, Vietnam, and Cambodia) in lower Mekong river basin. Among them, Cambodia is the most severely affected by the devastating floods that have broken all the past records. In 2000, the water levels at the gauging station of Chhatomouk in Basac River, located near the Phnom Pehn City, the Capital of Cambodia, has reached several centimeters higher than the past highest record level (Dutta and Takeuchi, 2000).

In general, ground surveys aerial photograph is one of the traditional methods for flood mapping in a regional scale, but when the flood is widespread, such methods are time consuming and very expensive. Also, the aerial photograph can be impossible to delineate the accurate inundated area due to weather conditions. Therefore, to overcome these problems, the best way is to analyze remotely sensed data which is acquired by satellite. The ability of remote sensing to provide basic informations in space, time and frequency domain has been proved to be very useful in providing permanent records by mapping, monitoring and managing flood dynamics. In many cases, synthetic aperture radar (SAR) including RADARSAT or ERS-1 is used to analyze flood situations and Landsat ETM+ and NOAA/AVHRR having lower spatial resolution are used in regional scale such as Mekong river basin. Because of the clouds in Landsat ETM+ imagery or decreasing the return signal in SAR imagery, it is very difficult to detect the accurate flood situation by remotely sensed data during flooding.

To overcome these limitations, the cost-distance method of GIS was used to extract the inundated area at the peak level in Kampoung Luong. The extracted inundation area was converted with the inundation volume by integrating DEM using GIS and it was compared with the result of hydraulic modeling using MIKE

11 which is the most widely used dynamic river modeling system. This method is suitable for estimating inundation volume even when Landsat ETM+ has many clouds in the imagery. Also, it is possible to overcome the disadvantage of RADARSAT imagery with the difficult classification of the acquired signal since the influence of complex ground conditions and system variables.

2. METHOD

In this study, the inundation area and the inundation volume were estimated using Landsat ETM+ and RADARSAT imagery acquired in 2000 for Tonle Sap Lake, Mekong River Basin by integrating DEM and GIS. The results based on remote sensing data were compared with that of hydraulic modeling using MIKE 11. The main steps of the overall methodology are presented in Figure 1. Also, the sensitivity analysis was carried out find the adequate spatial resolution to map the inundation area.

3. DATA PROCESSING

3.1. STUDY AREA

The study area is the floodplain of Tonle Sap Lake in the Mekong River basin, Cambodia. The most popular land use of this area is the paddy field and the shrub. The Mekong River is the longest river in Southeast Asia and its length is about 4,800km. The Mekong River Basin is defined by the land area surrounding all the streams and rivers that flow into the Mekong River. This includes parts of China, Myanmar and Viet Nam, nearly one third of Thailand and most of Cambodia and Lao PDR. With a total area of 795,000km^2, the Mekong River Basin is nearly the size of France and Germany together.

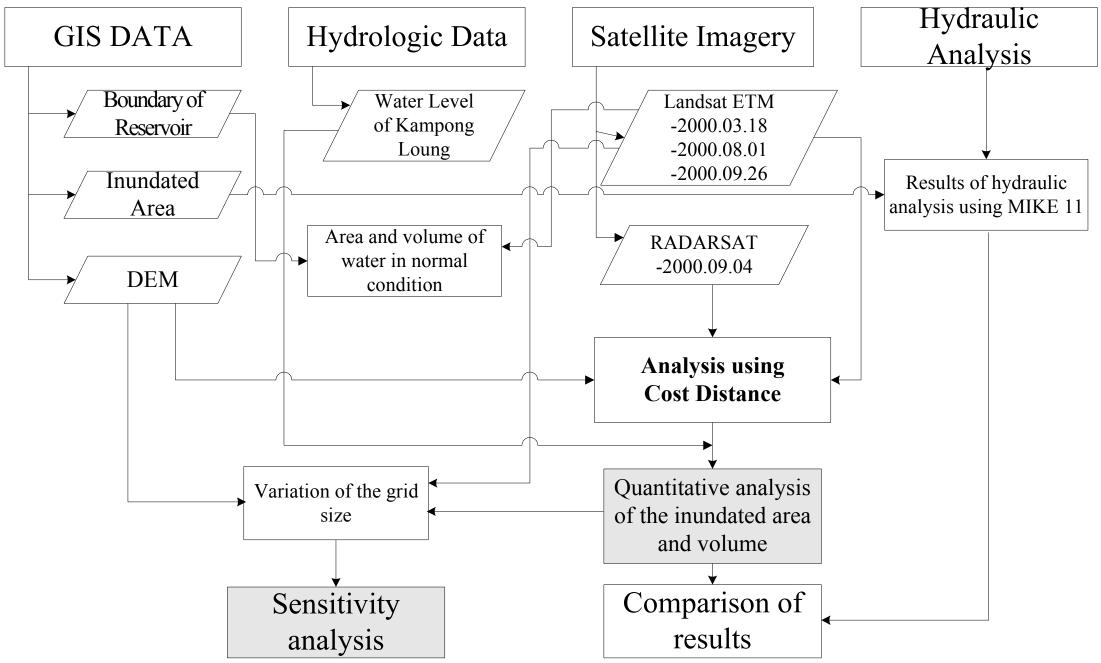

FIGURE 1. The main steps of the overall methodology used in this study

From its headwaters thousands of meters high on the Tibetan Plateau, it flows through six distinct geographical regions, each with characteristic features of elevation, topography and land cover.

Tonle Sap Lake on the Cambodian floodplain is the largest body of fresh water in Southeast Asia and forms on the key feature of the lowlands. During the flood season, water flows from the Mekong mainstream northwest to contribute most of the water that fills Tonle Sap Lake. The depth of Tonle Sap Lake increases from a dry season maximum of 3.6m to more than 10m, and the area of open water increases from approximately 2,500～3,000km^2, to up to 13,000km^2. As water levels fall in the Mekong River in October and November, flows into Tonle Sap Lake reverse and much of the water flows out and down the Tonal Sap River. Through the dry season, water from Tonle Sap Lake continues to supplement the flow of the Mekong, providing some 16 percent of the dry season flow.

3.2. DATA

Spatial data used in this study consist of satellite imagery and DEM. The satellite imagery employed is Landsat ETM+ and RADARSAT imagery (Table 1). The SAR mounted onboard RADARSAT is a C-band system (5.6cm wavelength) with a nominal incidence angle of 39.6 at mid-width, which transmits and receives horizontally polarized microwave electromagnetic energy. In addition to satellite imagery, DEM was used to estimate the flood volume in study area. DEM used was provided by Mekong River Committee (MRC) and the grid size is 100m grid. It was developed from contour data compiled by Société Grenobloise d'Etudes et d'Applications Hydrauliques (SOGREAH) and the contour data were originally derived from a 1960s hypsometric contour map at the scale of 1:100,000. Therefore, contour data was necessary to upgrade for reflecting present topographic condition. In the process of upgrading the DEM, MRC used SOGREAHs contour map and Philippine surveys results. The polyline was then converted to point using ArcView and the interpolation process was performed using IDW interpolation method with 100m×100m as the output grid (MRC, 2003).

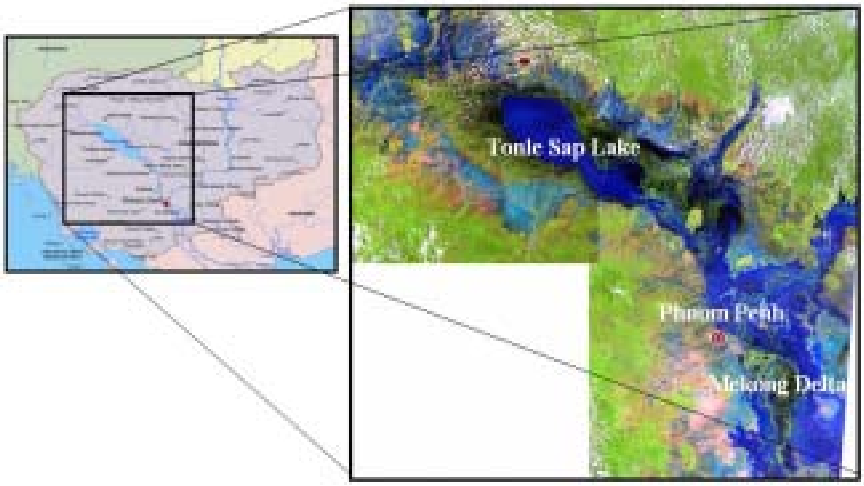

FIGURE 2. Location of the study area.

TABLE 1. Detailed of remotely sensed data collected for this study.

Satellite	Sensor/Image Model	Acquisition Date	Resolution
Landsat	ETM+	Mar 18, 2000	30m
Landsat	ETM+	Aug 01, 2000	30m
Landsat	ETM+	Sep 26, 2000	30m
RADARSAT	S4(Ascending)	Sep 04, 2000	25m

3.3. DATA PROCESSING

To estimate the accurate inundation volume, it is necessary to delineate correctly the inundation area using Landsat ETM+ and RADARSAT imagery. In case of Landsat ETM+, the inundation area can be easily extracted by the classification stage in image processing. However, because of clouds in the imagery acquired in monsoon season, it is very difficult to detect the accurate inundation area by the classification process. In this study, ISODATA classifier was firstly applied to extract the inundation area in Landsat ETM+ acquired on Aug 1, 2000 and Sep 26, 2000. Landsat ETM+ acquired on Mar 18, 2000 shows the water surface of the normal conditions and the water surface was extracted by the OR operator using the digital map of Cambodia GIS (JICA, 1999). In this case, the classification rule was as follows:

1) if Landsat ETM+ is water and Cambodian GIS is water, the pixel represents water
2) if Landsat ETM+ is water and Cambodian GIS is not water, the pixel represents non-water
3) if Landsat ETM+ is not water and Cambodian GIS is water, the pixel represents water

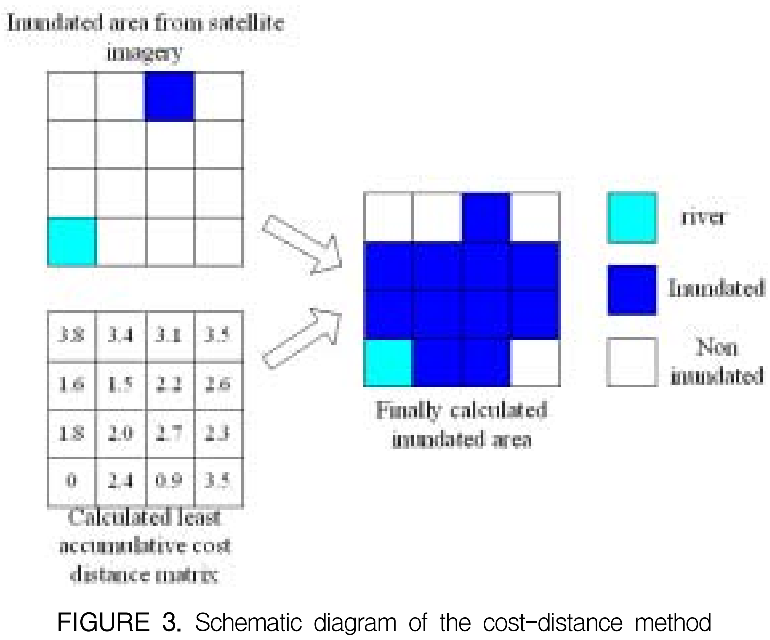

FIGURE 3. Schematic diagram of the cost-distance method

4) if Landsat ETM+ is not water and Cambodian GIS is not water, the pixel represents non-water

The fundamental characteristic recorded on a radar image is the backscattering coefficient, which may vary from surface to surface. The strength of the recorded on the image is influenced by various parameters, including the surface roughness and soil dielectric properties. Horizontal smooth surfaces, such as water bodies, reflect nearly all incident radiation away from the sensors and the weak return signal is recorded by dark tonality on radar image. Especially, this specular reflection can be decreased by bad weather conditions and/or the presence of vegetation on the ground, roughening the surface and making the detection of inundated areas more difficult (Brivio, 2002; Laugier et al., 1997).

To overcome these limitations, the cost-distance method of GIS was used to extract the accurate inundated area at the peak level in Kampong Loung (ESRI, 2000). The basic assumption to apply this method is that water has to flow out from the main river channel up to reach at least the areas recognized as inundated in the satellite imagery. Also, it is that there is no variation of the water level when the imagery is acquired by the satellite. In general, the cost-distance between the two adjacent cells A and B (cost-distA_B) is calculated by the following equation:

$$cost\_distA\_B = \frac{(costA + costB)distA\_B}{2}(VF)(HF) \quad (1)$$

where, costA and costB are values associated with each cell A and B, distA_B is the distance between two cells, and VF and HF are vertical and horizontal factors accounting for topography and surface typology, respectively. The vertical factor VF is based on the slope map and the values are assigned using SLOPE command in ArcView Spatial Analyst. The horizontal factor HF is linked to the surface characteristics, for example, roughness, land use and vegetation cover, etc. So, it is very complex in the real world and it is set equal to one everywhere in this study.

4. RESULTS AND DISCUSSION

4.1. INUNDATION AREA AND VOLUME

Firstly, the inundation area was estimated by ISODATA classifier and segmentation method for Landsat ETM+ and RADARSAT imagery, respectively (Figure 4). When the flooding occurs, the water flows continuously in high place to low place. However, it showed that there are many misclassified area and the characteristic of the flooding situations wasnt reflected. Its reason is considered to be the clouds and vegetations in Landsat ETM+ and RADARSAT imagery. So, if this results are used to estimate the inundation volume, it seems to be the smaller than the actual inundation volume.

Figure 5 show the map of inundated area derived from the classification rule and thee cost-distance method of the multi-temporal imagery. As shown in Figure 5, the whole vicinity of Tonle Sap Lake was inundated by the flooding of the river in Aug 1, Sep 4, and Sep 26, 2000. In 2000, floods started from mid-July, about a month earlier that usual in the Mekong River basin. The Mekong River overflowed breaching its banks on Jul 18, 2000 and started to recede slowly on Jul 22, 2000. The second wave of the floods started from end of August.

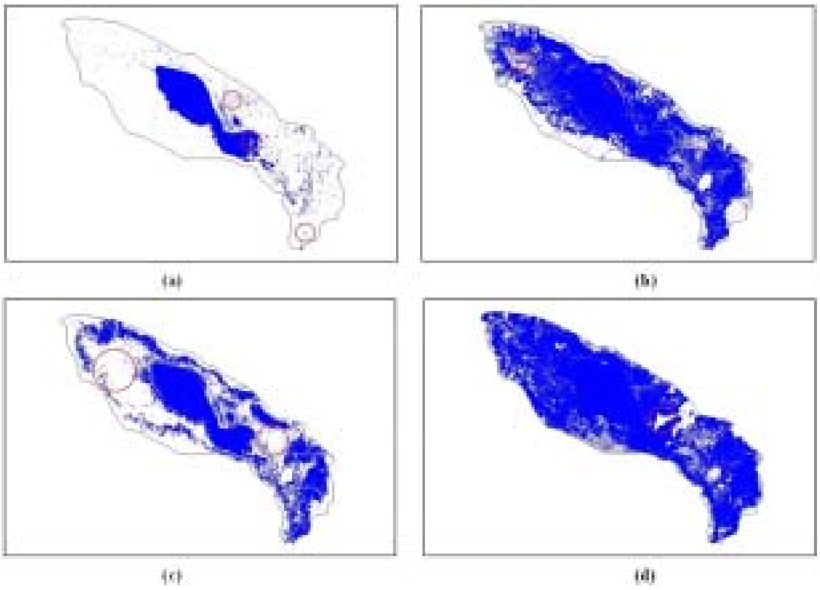

FIGURE 4. Image of the maximum extent of inundated area estimated by ISODATA classifier and segmentation method. (a) Mar 18, (b) Aug 1, (c) Sep 4, and (d) Sep 26

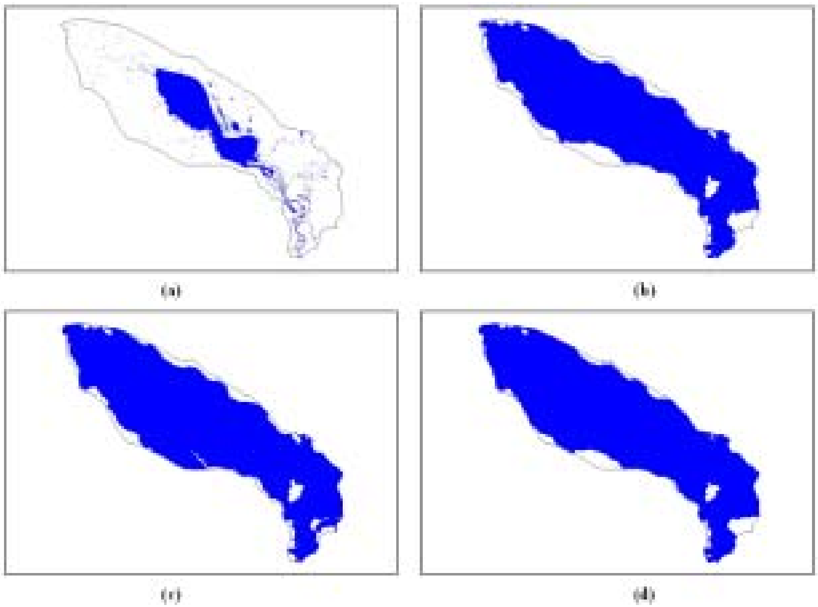

FIGURE 5. Image of the maximum extent of inundated area estimated by the classification rule and cost-distance method. (a) Mar 18, (b) Aug 1, (c) Sep 4, and (d) Sep 26

As all lakes, rivers, and low-lying areas were already filled with water due to the previous flood wave, the second flood waves inundated vast areas beyond the usual flood affected areas. The flood was expected to continue till end of October, 2000. It showed that the situation of the flooding in 2000 was very well represented by the cost-distance method. Especially, the characteristic of the flooding was reflected in classified map and the inundation area was patches spread around Tonle Sap Lake.

Table 2 represents the result of various methods to estimate the inundation area, including MRC-TSLV (MRC, 2003a). The inundation area of MRC-TSLV represents the potential inundated area derived from DEM. It doesnt take into the water surface slope consequently generated by the running flood water. As shown the table, the result of the cost-distance method is very similar with that of TSLV project by MRC (MRC, 2003b), excluding Mar 18, 2000. On Mar 18, 2000, the water level of Tonle Sap Lake fell gradually and the inundated area was on the decrease. However, the result of ISODATA classifier and segmentation method is smaller than the others due to the influence of clouds and vegetations.

The inundation volume was calculated by the above estimated inundation area using GIS and it was compared with that of the other researches. In this study, the result of the hydraulic modeling using MIKE 11 was thought as the true value. Table 3 shows the comparison of the inundation volume in various researches (MRC,

TABLE 2. Results of the inundation area estimated by various methods (ISO. and Seg. mean ISODATA and segmentation method, respectively)

Items \ Date		Mar 18, 2000	Aug 1, 2000	Sep 4, 2000	Sep 26, 2000
WL(Heiten MSL, m)		2.40	7.98	9.23	10.33
Inundation Area(ha)	MRC-TSLV	397,795	1,218,930	1,402,841	1,564,958
	ISO. & Seg.	301,588	1,001,135	774,791	1,441,443
	Cost-distance	300,481	1,200,632	1,418,188	1,564,361

TABLE 3. Results of the inundation volume using cost-distance method and other researches (Obs. WL means Observation of Water Level)

Items \ Date		Mar 18, 2000	Aug 1, 2000	Sep 4, 2000	Sep 26, 2000
WL(Hetien MSL, m)		2.40	7.98	9.23	10.33
Inundation Volume (MCM)	MRC-TSLV	3,983.3	47,518.9	63,291.7	79,472.8
	MRC H-V	5,200.0	48,110.0	59,050.0	71,200.0
	Obs. WL	4,138.0	47,556.0	63,993.0	80.261.0
	MIKE 11	6,694.2	41,125.6	62,214.1	79,982.4
	Cost-distance	3,264.4	47,291.6	63,706.6	79,922.1

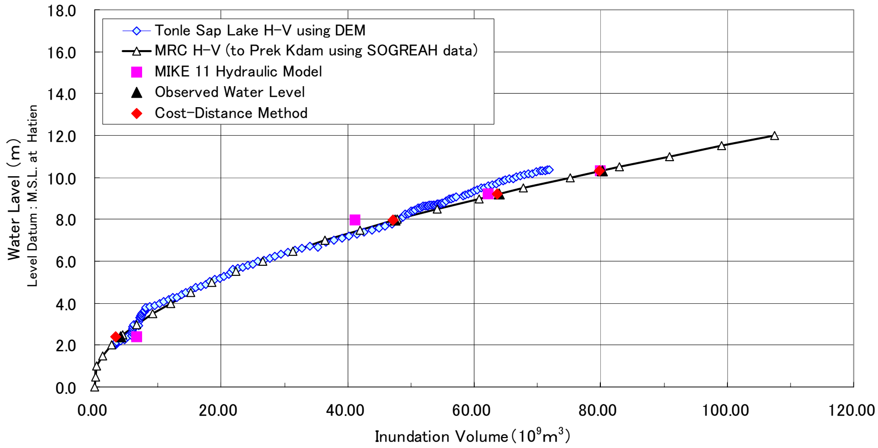

FIGURE 6. The comparison of results according to various researches

2003b). The inundation volume of MRC-TSLV represents the potential inundation volume derived from DEM such as the inundated area. Also, the result of the MIKE 11 is the results of WUP-JICA in 2004. As shown in Table 3, the result of the cost-distance method is very consistent with that of the hydraulic modeling using MIKE 11, excluding the result of Mar 18, 2000.

On Aug 1, the inundation volume was overestimated about 6,000 MCM than that of MIKE 11. It is considered that the result of MIKE 11 was reflected in the variation of the water level of Tonle Sap Lake in calculation process. However, the inundated area derived from the cost-distance affected by the trace of the flooding and then the derived inundation area was overestimated than the real inundation area. On Sep 4 and Sep 26, the results of the cost-distance were very well consistent with that of MIKE 11 because of the rising of the water level under the influence of the second flooding.

4.2. SENSITIVITY ANALYSIS

The sensitivity analysis was conducted to investigate the applicability of the satellite imagery of the lower resolution such as MODIS and NOAA/AVHRR. The grid size of the satellite imagery and DEM for the sensitivity analysis was 250m, 500m, and 1,000m. As a result, it showed that the amount of the inundated area and volume decreased according to increasing of the grid size of the satellite imagery and DEM, excluding Mar 18, 2000. In the case of the grid size 250m, the inundated area was reduced to 0.5% than the result of the grid size 100m. Also, for the grid size 500m and 1,000m, it was reduced to 1.1% and 2.2%, respectively. That is, it showed that the inundated area decreased in inversely proportion to the increasing of the grid size. Also, the result of the sensitivity analysis for the inundation volume was similar with that of the inundation area, but the variation is small than that of the inundation area. In the case of grid size 250m, 500m, and 1,000m, it was reduced to 0.1%, 0.23%, and 0.63%, respectively. As a result, it showed that the applicability of MODIS and NOAA/AVHRR for the assessment of the inundation area and

TABLE 4. The results of the sensitivity analysis varying with the grid size

Grid Size	Date	Mar 18, 2000	Aug 1, 2000	Sep 4, 2000	Sep 26, 2000
100m	Area(ha)	300,481	1,165,849	1,399,242	1,523,189
	Volume(MCM)	3,246.4	47,197.9	63,719.5	79,799.2
250m	Area(ha)	2,998.6	1,159,162	1,394,207	1,514,439
	Volume(MCM)	3,169.2	47,149.6	63,662.9	79,736.4
500m	Area(ha)	3,004.3	1,152,011	1,386,238	1,505,562
	Volume(MCM)	3,091.4	47.065.9	63,581.2	79,631.1
1,000m	Area(ha)	2,998.0	1,143,896	1,368,815	1,485,584
	Volume(MCM)	2,978.9	46,876.0	63,341.3	79,340.0

volume is very good in regional scale such as Tonle Sap Lake.

5. CONCLUSIONS

Satellite imagery including Landsat ETM+ and RADARSAT imagery is widely used to obtain the basic information, such as the flood damage, inundation areas, and flood situation, in near real time. However, it is impossible to extract the accurate inundation area using only satellite imagery because of clouds in the imagery and complex ground. To overcome these limitations, the cost-distance method of GIS was used to estimate the inundated area at the peak level by integrating the inundated area from satellite imagery with digital elevation model. The estimated inundation area was converted with the inundation volume using GIS. The inundation volume was compared with the result of hydraulic modeling using MIKE 11, which is the most popular among the dynamic river modeling system. This method is suitable for estimating inundation volume even when Landsat ETM+ has many clouds in the imagery. Also, it is possible to overcome the disadvantage of the use of RADARSAT imagery with the difficult classification of the acquired signal since the influence of complex ground and system variables.

REFERENCES

Brivio, P. A., R. Colombo, M. Maggi and R. Tomasoni. 2002. Integration of remote sensing data and GIS for accurate mapping of flooded areas. Int. J. Remote Sensing 23(3):429-441.

Dutta, D. and K. Tekeuchi. 2000. A Report on the Devastating Floods in Cambodia, Report, International Center for Disaster-Mitigation and Engineering (INCEDE), Institute of Industrial Science, University of Tokyo,

Environmental System Research Institute (ESRI), 2000. Introduction to Working with ArcView Spatial Analyst, ESRI Press.

JICA, 1999, Cambodiain GIS.

Laugier, O., K. Fellah, N. Tholey, C. Meyer and P. De Fraipont. 1997. High temporal detection and monitoring of flood zone dynamic using ERS data around catastrophic natural events:the 1993 and 1994 Camargue flood events, Proc. Third ERS Symposium on Space at the Service of our Environment 1:559-564.

Mekong River Commission (MRC). 2003a. Consolidation of hydro-meteorological data and multi-functional hydrologic roles of Tonle Sap Lake and its vicinities.

Mekong River Commision (MRC). 2003b. Flood area and volume analysis by RADARSAT images.

Nguyen T. L. and D. T. Bui. 2001. Flood monitoring of Mekong River delta, Vietnam using ERS SAR data, Proc. ACRS 2001-22nd Asian Conference on Remote Sensing 1:454-459.