Proceedings of 13th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2023 Month: April Volume: 13

Flood Hazard Mapping of West Rapti and Assessing Impact on Agricultural Production in Dang District using HEC-RAS 2D

Saurab Tamang [a], Pawan Bhattarai [b]

[a,b] *Department of Civil Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] kakutamang@gmail.com, [b] nepal.pawan@gmail.com

Abstract

This study aims at simulating flood inundation extent, developing flood hazard map, and evaluating impacts on Agriculture of Dang District. Maximum discharge data of Jalkundi Hydrological Station acquired from Department of Hydrology and Meteorology (DHM) from year 1991-2015 was used for the analysis. 2D models of the floods are simulated using HEC-RAS version 6.2 (Hydrological Engineering Centre – River Analysis System). Validation of the study has been done by comparing the results obtained from HEC-RAS simulation with the Inundation extent map from Rastrapati Chure Conservation Program. Model Validity from satellite images was found to be 68.80%. Hence, HEC-RAS 2D has been proven to be effective in simulating the flooding events with desired accuracy. Flood hazard maps 2 years, 5 years, 20 years, 50years and 100 years return periods been prepared with respect to inundation depth obtained from the model. About 9.51% of cultivable land is inundated by 100 year flood causing loss of food crops and cash crops endangering food security. Estimated loss in agricultural production by 24435.33 Metric ton impacts livelihood of the affected communities as it is dependent mostly on agriculture. This information can be useful for urban planner, land use planning process, and others government authorities to make a effective mitigation and prevention action plan.

Keywords

2D simulation, flood inundation, flood hazard mapping, HEC-RAS

1. Introduction

Flood is a phenomenon which mostly affects low lying areas around the river course. Floods are one of the noteworthy catastrophic events that generously sway the monetary and public activities of individuals in numerous regions and countries [1]. Due to the geographical landscape of Nepal, which mainly consists of young mountainous region, and concentrated rainfall floods are common. Due to lack of preparedness and proper forecasting system Nepal is Vulnerable to disaster such as flooding [2].

The study area, which is located in Terai region, is subject to flooding. A large portion of the Nepalese territory is inundated every year by flooding from the Rapti River[3].The West Rapti River of Nepal is considered as one of the most flood-prone rivers. The major causes of flooding in this basin are natural causes like high rainfall, soil erosion, flat topography, debris flow and sedimentation, river coarse shifting, deforestation, poor planning, massive increase of settlement along the highway, lack of participatory approach in disaster management, lack of long term flood management plan covering whole flood prone areas and socio-political causes like lack of public sensitivity and awareness, attitude of people and culture of abandonment [4]. This basin usually suffers from flash floods as the catchment responds to high intensity and short duration precipitation. Recent extreme flood events were reported in 1984,1989,1998, 2007, 2013 and 2017. Most of the area nearby the river is composed of agricultural land which exposes them to flood. It poses a high risk to food security, which directly impacts on residents' livelihoods.

Flood Hazard Assessment is the estimation of overall adverse effects of flooding. It depends on many parameters such as depth of flooding, duration of flooding, flood wave velocity and rate of rise of water level. One or more parameters can be considered in the hazard assessment [5].Today with introduction of new technologies such as geographic information system (GIS), Global Positioning System (GPS), digital terrain, numerical hydraulic models, and remote sensing demarcating floodplains has become much easier with accurate and dependable results. Accurate flood plain maps, generated under wide range of flow conditions are useful for efficient flood management practices. HEC-RAS software has been widely used in flood analysis. RAS Mapper makes HEC-RAS capable of generating geometric data from underlying terrain and performs 2- D hydraulic simulation of flooding events. The main focus of this study is to prepare flood hazard map of West Rapti River and assess potential impacts of inundation on agriculture production.

2. Materials and methods

2.1 Study area

West Rapti River originates from mid mountainous region of Nepal and Extends up to India where it meets Ghagara (Karnali) but under the study is the section of West Rapti extending from Bagasoti Hydrological Station to Jalkundi Hydrological Station. Major tributaries of this river include Lundri Khola, Jhimrkuh River, Madi River, Arun River, and Dhunduwa River. There are mainly four Hydrologcal Staions named Nayagaon, Cherneta, Bagasoti and Jalkundi which have catchment area of 1980 km2, 644 km2, 3380 km2 and 5100 km2 respectively as shown in Figure 1.

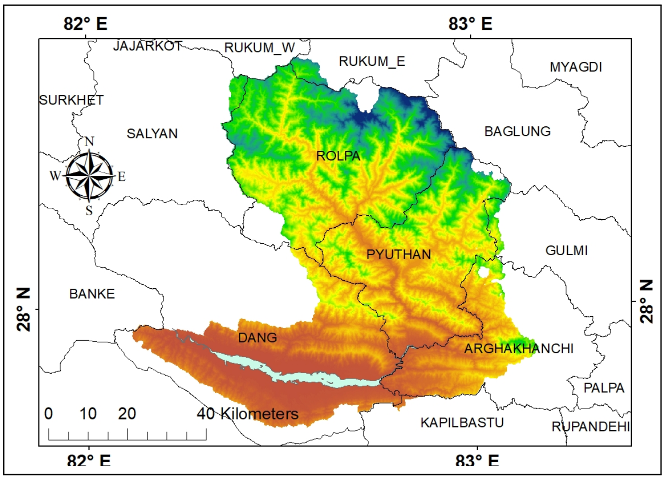

Figure 1: Study area

2.2 Data

In order to develop the mathematical flood model, various kinds of data, recent and past several years have been collected and compiled. These data also form the basis for further analysis and interpretation of the model results leading to accurate assessment of hydrological condition of study area. The collected data have been summarized in the Table 1 along with its source.

Table 1: Data and its source

SN	Data type	Data Source	Remarks
1	Maximum Instantaneous Discharge	DHM	Jalkundi Station Year:1991-2015
2	DEM	USGS	30 m resolution
3	Chure Land use	Rastrapati Chure Conservation Program	2015
4	Inundation extent map	Rastrapati Chure Conservation Program	Span of 25 year
5	Agricultural Data	MoALD	2019/20

2.3 Methodology

Different data set over the study area were acquired from different sources and hydrological and hydraulic modeling were carried out using HEC-RAS software and flood hazard map and its impact were assessment which is briefly summarized in Figure 2.

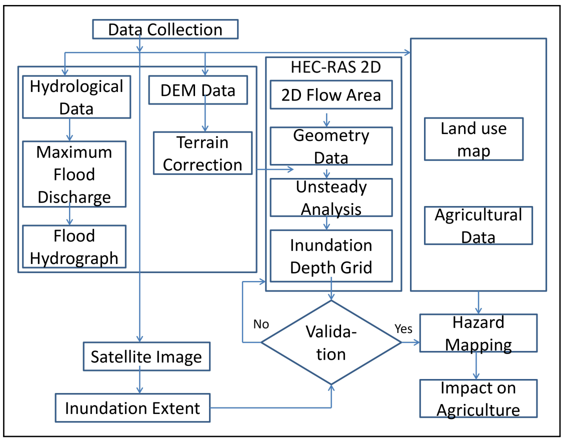

Figure 2: Research Framework flow chart

2.3.1 Hydrologic Analysis

For 2D hydraulic modeling in HEC-RAS, we need flood hydrograph and corrected terrain. Maximum instantaneous discharge data of Hydrological Station were obtained from Department of Hydrology and Meteorology. Gumbel Distribution, Log-Pearson Type III Distribution and Log Normal Distribution, some of the most often utilized frequency distribution functions, were used for predicting extreme flood values for 2 year, 5 year, 20, 50 year and 100 year return periods [6].

Using Easy Fit 5.6 Professional, we found that Lognormal holds better in probability test of goodness of fit. The synthetic unit hydrograph of Snyder (1938) is based on five characteristics of a standard unit hydrograph and various catchment characteristics like area, flow path, centroidal flow path. These informations were extracted from a DEM through GIS applications. Snyder's Synthetic Unit hydrograph has been adopted for generating flood hydrograph for this study.

Table 2: Discharge for different return period using different method

Method	Return period (years)					
	2	5	10	20	50	100
Log normal	2779	4092	5010	5921	7146	8100
Log Pearson III	2706	4051	5082	6180	7773	9107
Gumbel	2841	4209	5114	5982	7106	7948

Table 3: Fitting of Gauged methods

SN	Distribution	Kolmog-orov Smirnov		Anderson Darling		Chi-Squared	
		S	R	S	R	S	R
1	Gumbel Max	0.134	2	0.779	2	4.212	2
2	Lognormal	0.113	1	0.519	1	1.267	1

S = Statistic and R = Rank

2.3.2 Hydraulic Modelling

HEC-RAS version 6.2 has been used in this study for preparing the 2D model. With the help of RAS Mapper DEM is imported, spatial reference projection system of the data frame is given and terrain data set is created. 2D flow area polygon is created around the river where 2D flow area defines the boundary in which computational mesh will be created. In this study, mesh size of 50mx50m has been used in the model. Manning's coefficient of the underlying terrain was assigned based on land cover data. Normal depth boundary condition is applied for the downstream where as flow hydrograph is given as the upstream boundary condition.

Diffusion wave equation has been used for the study. Computational time step was adjusted by the model based on

Courant condition criteria. For Diffusion wave equation Courant Number (C) as high as 5.0 still gets stable and accurate results [7]. Since, flood inundation mapping involves Gradually Varied Flow (GVF) larger time step is permitted. Therefore Maximum and minimum Courant Number used were 5 and 1 respectively. Simulations were run for different return periods using Snyder's Unit Hydrograph for respective return period. The simulation time window is equal to the base time of unsteady flow hydrograph. Flooding mapping option was also checked, which gives inundation extent in post processor.

2.3.3 Flood Hazard Mapping

Presence of flooding in any area is itself a hazard whereas the severity of which can be categorized according to the depth of flooding. Hazard with respect to velocity of flooding can be neglected as the velocity of flooding in floodplains is too small (0.5-1.5 m/s) to cause any significant damage. Many studies have suggested flood depth to a primary indicator of flood hazard. Flood depth is considered as the most important indicator of the intensity of flood hazard [8].

In this study the flood depth is classified into three hazard levels high, medium and low. Depth of inundation less than 1 m is considered to be of low hazard. This depth is insufficient to enter residential buildings in most of the scenario and cause appreciable damage to life and property whereas streets and commercial centers are widely flooded and affected due to this depth. Depth beyond 1m, can cause severe damages to life and properties especially in the areas with settlement, low height roads and cultivation. High, moderate and low hazard depth are given rankings 3, 2 and 1 respectively. Hazard maps of the study area as shown in Figure 3 are prepared accordingly by overlapping terrain layer with depth grid for various return period.

2.3.4 Assessing Impacts on Agriculture

For assessing impact on agricultural production, the amount of agricultural land flooded by the rivers in Dang district is estimated. The agricultural production data is taken form MoALD. Agricultural production affected by flood is quantified by estimating the district wise decrement in agricultural output in Metric ton.

3. Results and Discussion

Inundation extent for different years return period flood event was simulated by HEC-RAS 2D over West Rapti river. From the present study it has been found that 2% to 2.46% of catchment area is flooded from 2 year to 100 year return period flood (see Table 4).

Table 4: Return Period wise flood extent and % of catchment area flooded.

S.N	Return Period (Year)	Catchment Area (km^2)	Flooding extent(km^2)	% flooded
1	2	5106.12	102.14	2.00
2	5	5106.12	110.79	2.17
3	20	5106.12	118.16	2.31
4	50	5106.12	123.23	2.41
4	100	5106.12	125.65	2.46

3.1 Validation of Flooding Extent

Validation of the study has been done by comparing the results obtained from HEC- RAS simulation with the inundation extent map prepared by Rastrapati Chure Conservation Program. The inundation extent map used for validation was generated from the satellite images collected from Google Earth over the span of 25 years i.e. from 1991-2015. At first flooding extent has been generated for the simulated 2 year flood. Total flooding extent from the simulated model was found to be 110.79 km2 whereas it was found to be 87.75 km2 from Inundation extent map from Rastrapati Chure Conservation Program. Intersection of simulated flood extent map and Inundation extent map was calculated. Intersected area was found to be 68.80% of Inundation extent map from Rastrapati Chure Conservation Program. Therefore, model validity from satellite images was found to be 68.80%. Hence, HEC-RAS 2D has been proven to be satisfactory in simulating flood events in plain terrain. Table 5.

Table 5: Flooding Extent and Intersection area.

Sn.	Satellite Flooding Extent (km^2)	Simulation Flooding Extent (km^2)	Intersection with simulation (km^2)	Intersec-tion %
1	87.75	110.79	60.37	68.80

3.2 Flood Hazard

Hazard aspect of flood has been identified based on the inundation depth obtained from HEC-RAS hydraulic modeling. Inundation depth is computed by overlaying water surface elevation with underlying terrain. Since it is obtained from modelling it incorporates all the hydrological and hydraulic components of the study area. The raster file of the inundated area of different return period were exported from the HEC-RAS and imported to ArcGIS which were then reclassified into three hazard classes on the basis of inundation depth. Flood depth less than 1 m has been classified as low hazard, 1 to 3 m has been classified as medium hazard and greater than 3 m has been classified as high hazard. The reclassified raster was then converted into vector and its respective area was calculated in ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information System). Hazard map of different return period has been shown in Figure 3.

3.3 Impacts on Agriculture

Impact on Agriculture has been assessed based on reduction in agricultural production due to inundation of the cultivable land. Impact has been analyzed considering partial and complete destruction of crops caused by flooding of cultivable land.

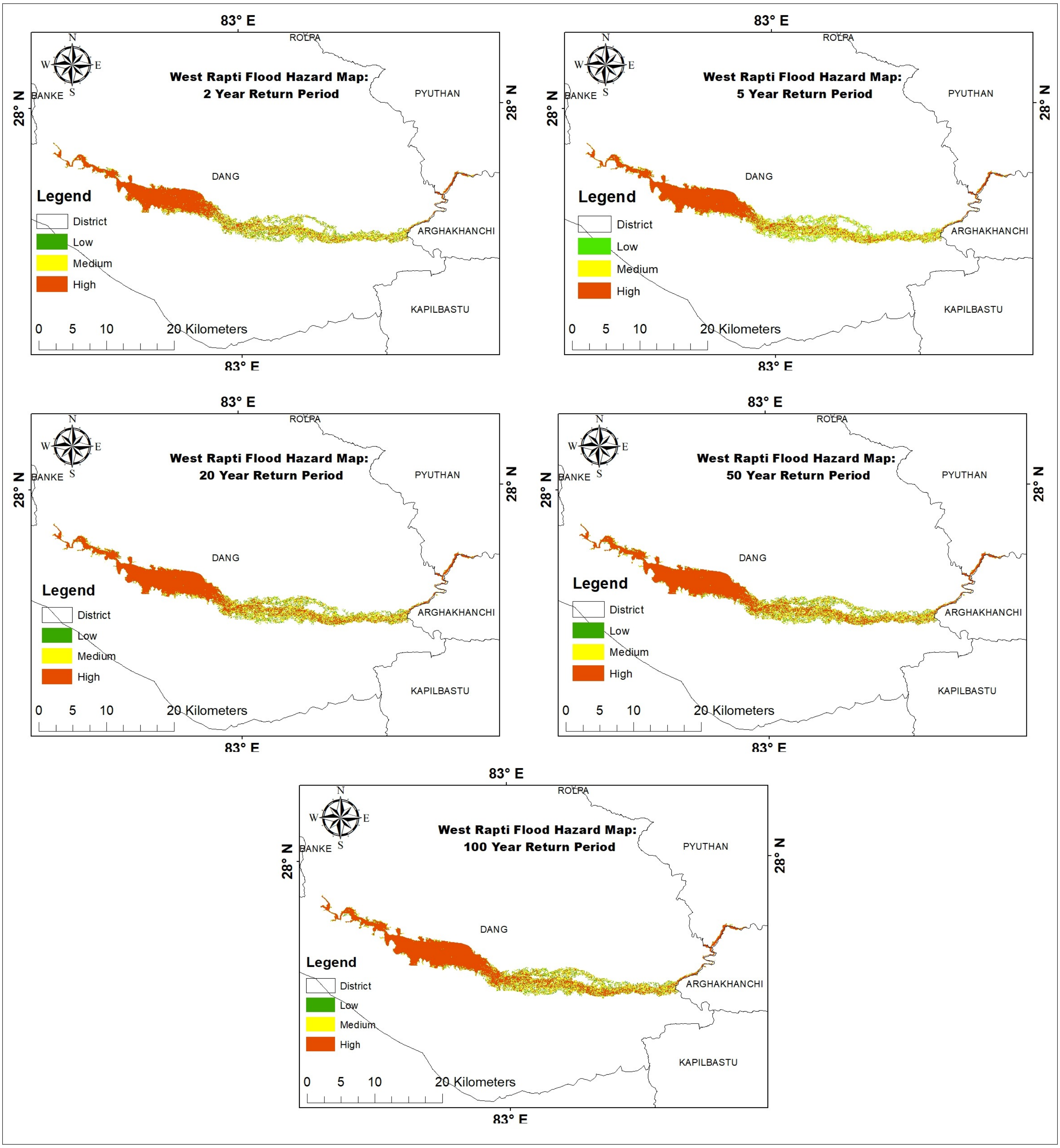

Figure 3: Flood hazard map for different return period data.

Table 6: Reduction in yield as per severity of flooding in (Mt) with different return period

Sn.	Flood Return Period (year)	Total Cultivable Land (Ha)	Affected Cultivable Land (Ha)	% affected	Yield in Mt./Ha	Reduction in yield as per severity of flooding (Mt)	
						50%	100%
1	2 years	73643	5569	7.56	3.49	9717.77	19435.54
2	5 years	73643	6075	8.25	3.49	10601.27	21202.54
3	20 years	73643	6542	8.88	3.49	11415.13	22830.26
4	50 years	73643	6837	9.28	3.49	11929.79	23859.58
5	100 years	73643	7002	9.51	3.49	12217.66	24435.33

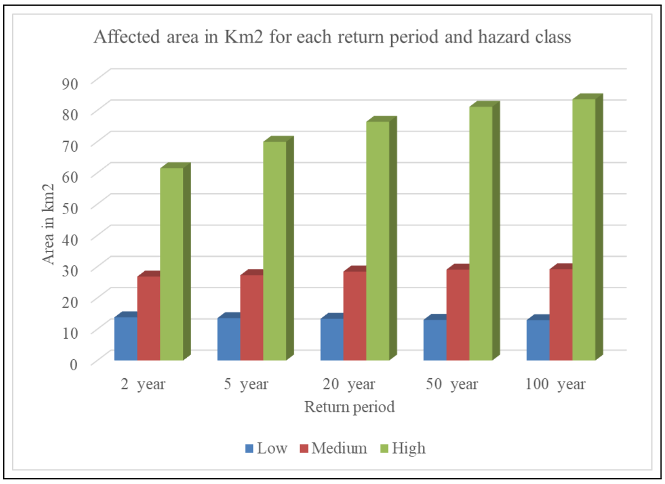

Figure 4: Flooded area in each hazard class for different return period

4. Conclusions

West Rapti River has potential of inundating large area. From the Figure 4, it was observed that there is significant increase in high hazard area with the increase in return period, whereas the medium hazard area increases very slightly. However, low hazard area remains almost same. 100 year return period inundate 125.65 km2 of land which accounts for 2.46% of catchment area.

Large areas of cultivable land are affected in the study area imposing threats on food security. Flood disaster causes impact on livelihood of the affected communities. Estimated loss in agricultural production due to 100 year flood inundation is 12217.66 Metric ton when 50% of crops get destroyed and 24435.33 Metric ton when there is 100% destruction, which directly impacts livelihood of the affected communities as it is dependent mostly on agriculture.

2D hydraulic modeling capability of HEC-RAS facilitates flood modeling in plain terrain. Hazard mapping with the help of GIS tool is an effective way of visualizing the data. The visualization and quantification of flood data facilitates the decision makers to better understand the problem and take necessary counter measures accordingly.

Acknowledgments

Authors are thankful to the Department of Hydrology and Meteorology for providing the necessary data with the required support and cooperation.

Authors also acknowledge the invaluable assistance of friends whose constant support, encouragement, and valuable feedback throughout the research work were of immense help in shaping the ideas and improving the quality of this research.

References

[1] Renalt Capes. *The Use of Earth Observing Satellites for Hazard Support: Assessments & Scenarios*. National Oceanic & Atmospheric Administration, 2003.

[2] MOHA. Nepal disaster report 2017 the road to sendai ministry of home affairs, 2017.

[3] Nokh, Bahadur Bashyal, Rajan Shakya, Advisory Board, Narayan, Prasad Bhattarai, Khom, Raj Dahal, Lal, Chand Pradhan, and Hitoshi Kato. Members mr. samanta man sthapit chief-rehabilitation section section officer-administration section ministry of water resources department of water induced disaster prevention july 2007 series xiv annual, 2006.

[4] Dilip Gautam and Anup Phaiju. Community based approach to flood early warning in west rapti river basin of nepal. *Journal of Integrated Disaster Risk Management*, 3:155–169, 06 2013.

[5] Dibit Aryal, Lei Wang, Tirtha Adhikari, Jing Zhou, Xiuping Li, Maheswor Shrestha, Yuanwei Wang, and Deliang Chen. A model-based flood hazard mapping on the southern slope of himalaya. *Water*, 12:540, 02 2020.

[6] K. Subramanya. *Engineering Hydrology*. Tata McGraw-Hill, 2008.

[7] Gary W.Brunner. Hec-ras river analysis system. hydraulic reference manual,, 2 2016.

[8] M. M. Islam and Kimiteru Sado. Development priority map for flood countermeasures by remote sensing data with geographic information system. *Journal of Hydrologic Engineering*, 7:346–355, 09 2002.