

Analysis of the flood extent extraction model and the natural flood influencing factors: A GIS-based and remote sensing analysis

D U Lawal¹, A N Matori, K W Yusuf, A M Hashim and A L Balogun
Civil Engineering Department, Universiti Teknologi PETRONAS

Email: bblawaldano@gmail.com

Abstract. Serious floods have hit the State of Perlis in 2005, 2010, as well as 2011. Perlis is situated in the northern part of Peninsula Malaysia. The floods caused great damage to properties and human lives. There are various methods used in an attempt to provide the most reliable ways to reduce the flood risk and damage to the optimum level by identifying the flood vulnerable zones. The purpose of this paper is to develop a flood extent extraction model based on Minimum Distance Algorithm and to overlay with the natural flood influencing factors considered herein in order to examine the effect of each factor in flood generation. GIS spatial database was created from a geological map, SPOT satellite image, and the topographical map. An attribute database was equally created from field investigations and historical flood areas reports of the study area. The results show a great correlation between the flood extent extraction model and the flood factors.

1. Introduction

Many nations experience fatalities, injuries, damage to properties, monetary as well as interpersonal disruption caused by natural hazards. Natural catastrophes such as earthquakes, tornados, floods, volcanic outbreaks, and landslides have constantly make-up an issue in most developing and developed nations. It killed millions and destroyed billions of dollars yearly. The rapid increased of the world's population has escalated equally the number and rigorousness of the natural catastrophes. Flood tragedy possesses a very special place in natural hazards. It has been documented in Malaysia since 1973, the nation's flood catastrophe; floodwater control turns to be a rising matter of debate among authorities, researchers as well as non-public sectors [1]. More than thirty-five years, the flood's magnitude and frequency were tremendously accelerated particularly triggered by human actions; for example land clearing for urbanization or farming activities, building of structure such as freeways, roads and bridges which repeatedly alters the flood behavior [1,2].

Report from The Department of Irrigation and Drainage Malaysia equally disclosed that, around twenty nine thousand kilometers of the entire land area and over 4.82 million individuals (22%) are affected by flood every year along with damages approximated to cost about RM915 million [3]. Hence, the main objective of this paper is to develop a flood extent extraction model based on Minimum Distance Algorithm and to overlay with the natural flood influencing factors considered herein in order to examine the effect of each factor in flood generation. Geographic Information System (GIS) and Remote Sensing tools are utilized in this study.

2. GIS and remote sensing tools in flood management

GIS has grown to be appealing and excellent software adopted in the control of flood threats along with risk zones evaluation based on a certain geographical regions [4]. For that reason, its powerful

¹ To whom any correspondence should be addressed.



features made it feasible to create a flood risk map by delineating the actual flood inclined zones. Such type of map can certainly help the responsible regulators to instantly appraise the likely effects of the flood tragedy and carryout a proper control actions to deal with the predicted flood devastating impact. GIS offers a wide range of applications in pinpointing areas stricken by floods or foretelling areas which are more likely to be inundated by severe flooding [4]. Furthermore, GIS is certainly a program that could facilitate the planning bodies as well as the floodplain administrators in identifying and delineating flood vulnerable zones within a given neighborhood. Moreover, it aids geographical data storage into a database, which can be queried and also presented graphically for analysis. Flood inclined regions could be detected and targeted for alleviation strategies or rigorous floodplain control practices via the overlay or intersection techniques of different geographical layers. [5] carried out a research applying GIS for flood risk mapping in Segamat, Johor Bahru in the Western Malaysia. Data employed were primarily produced by the Directorate of National Mapping Malaysia (JUPEM), for example the topographical map series L7030 at scale 1:50 000 with 20 meters contour intervals.

[6] employed amplitude change detection technique using multi-pass Synthetic Aperture Radar (SAR) data in identifying flooded areas. However, both the aforesaid methods only permits flooded areas to be detected after being flooded during the time when the second satellite pass and not during the time of the first one [7]. [7] further elaborated that coherence resulting from multi-pass interferometry data could be used alternatively, as an indication of changes in the electro-magnetic spreading behavior of the surface, thus likely showing each and every area afflicted with the flood incident anytime among the two passes. Two waves are considered to be in coherence if their crests and troughs meet at the same place and at the same moment in time. Therefore, GIS and remote sensing tools were used in developing the flood extent extraction model, creating the thematic layers of the flood factors and overlaying them with the flood extent extraction model to see the effect of each factor in flood generation.

3. Study area

The state of Perlis is surrounded by Thailand in the north, Kedah in the south, whilst its western coastline is bordered by the Straits of Malacca. The weather, which is normally warm and wet, is actually controlled by the yearly fluctuations in position of the Inter Tropical Convergence Zone since it follows the obvious movement of the sun north and south of the equator. This results in two distinct rainy periods, and a prolonged drought period. It experiences a Monsoon Tropical climate and "Winter Winds" (East Coast Wind from Teluk Siam).

4. Study methodology

4.1. Scanning

A setback experienced when performing this study was that some of spatial data used in the study were only available in the form of hardcopy or printed maps. These maps in hardcopy needed to be scanned and digitized in a GIS environment.

4.2. Digitization

Digitization was carried out in order to allow details of the scanned maps to be saved into the GIS database. All scanned maps were saved in jpg format. All plotting were completed using ArcGIS software which allowed the user access to both data formats. However, before plotting could be done, each of the scanned maps needed to be registered in the local coordinate system using ArcGIS software. Coordinate registration was achieved by reference to the coordinates of the satellite image.

4.3. Satellite image processing

The satellite images used in this study are SPOT (*Système Pour l'Observation de la Terre*) and RADAR satellite images. The SPOT image is a 3-band multi-spectral image, dated 2005, covering the entire state of Perlis was procured from the Malaysia Centre of Remote Sensing (MACRES). The SPOT satellite image was chosen for this study since the resolution capability of SPOT's panchromatic (black and white) sensor was 10 meters, while its multi-spectral sensor can have a resolution up to 20 meters. Here the multi-spectral image of Perlis with a resolution of 20 meters was

chosen. The results suggested that a raster based GIS can facilitate the necessary digital analysis and manipulations, including data integration, geo-corrections and handling classification.

The second satellite image used in this research is the RADARSAT image. This is because the presence of cloud covers seems as the only most essential obstacle in recording the progress of floods in horrible weather conditions [8,9,10]. The microwave radiation has the strength of penetrating a clouded sky and giving an insight into the composition of rainfall itself. At the moment the most common technique to inundation management is by using Synthetic Aperture Radar (SAR) images [11,12,13]. Canadian satellite utilizes the SAR sensor, which is an onboard Earth Resource Satellite (ERS) and RADAR satellite. The SAR permits a 24hrs data collection, which is independent of weather conditions as well as lightening. It has thorough viewing angles permitting a wide range of topographical scenarios, applications and overall requirements of the land coverage to be covered and it also possesses the capability to obviously distinguish between the ground and water bodies. SAR have the ability of providing images through the day and night time in spite of any predicament like haze, snowfall, gentle rainfall, smoke or clouds. Therefore, RADARSAT during-flood image of the study area was used in developing the flood extent extraction model based on a Minimum Distance Algorithm embedded in ENVI 4.8 software.

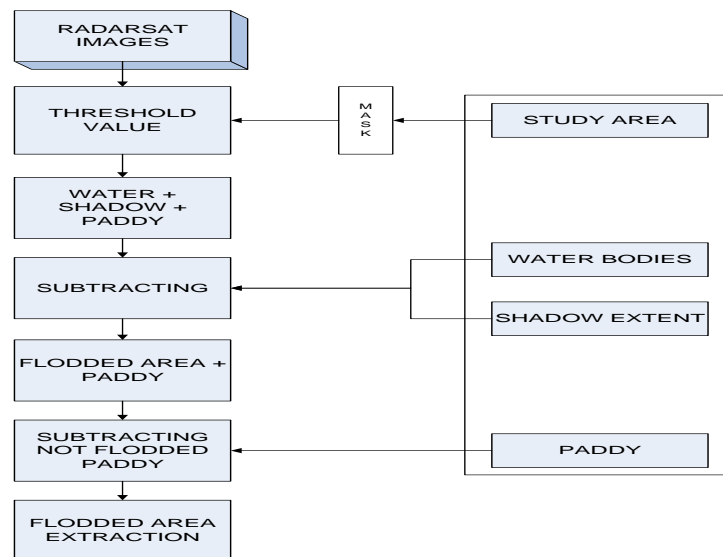


Figure 1. Flowchart for flooded area extraction from RADARSAT during-flood image.

4.4. Building the Database

The satellite images that had been processed through the classification process now had to be processed using ArcGIS software to create the land use and flood extent maps. In ArcGIS various data formats were available. Some of the data needed in this study were only available in the form of printed or hardcopy maps. These maps first had to be scanned with a digital scanner and saved into the GIS system together with all spatial and attribute data. After scanning of all maps, registration to the local coordinates system had to be carried out before spatial analysis was done.

4.5. Overlaying the Flood Extent Extraction Model with the Flood factors Thematic Maps

The developed flood extent extraction model was overlaid with the natural flood influencing factors considered herein with the aid of GIS software. The rationale is to investigate the effect of each factor in flood generation based on the flood extent model produced from the RADARSAT during-flood image of the study area.

5. Results and conclusion

5.1. Flood extent extraction model

The Flood Extent Extraction Model was developed from the RADARSAT during-flood image of November, 2010 of Perlis, Malaysia. Since December 2005 and April 2006, Perlis and Kedah were faced with their worst floods in 30 years with more than 16,000 people relocated to 113 evacuation centers in both states. Two-thirds of Perlis and most of the northern Kedah had been flooded by non-stop rain over a three-day period. The floods have destroyed an estimated 25,000ha of paddy fields in Muda Agricultural Development Authority areas in Kedah and Perlis and non-Mada areas. Losses were likely to be over RM81 million. In November 2010, Perlis and Kedah were faced with floods in which it was stated that the number of evacuees in both Perlis and Kedah has escalated since the 1st November rainfall flooded Perlis, Kedah, Terengganu and Kelantan. In Kedah only, the number have summed up to more than 28,000 evacuees while in Perlis the number of evacuees have hit a total number of 13,723.

Similarly in April and September 2011, flood has again stroked the state of Perlis. During the April's flood, number of flood evacuees at relief centers all over Perlis state has augmented to 4,761 persons up till 6pm Friday. A spokesman from the Perlis flood operations room said it reflected an increase of 531 people, compared with 4,230 registered in the morning. He further explained that most of the people taking lodging at 30 relocation centers were from Kangar (3,474) while the rest were from Padang Besar and Arau. Several roads in this town remained flooded, he added.

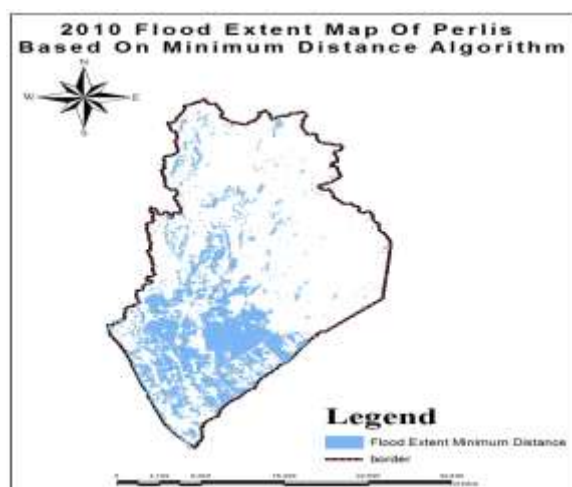


Figure 2: Flood Extent Extraction Model of Perlis Produced from RADARSAT During-Flood Image Based on Minimum Distance Algorithm. (Source:MACRES, 2012).

The flood extent extraction model developed was integrated with the thematic maps of the flood influencing factors using GIS to produce the model result showing the impact of each factor in flood generation through the overlay process. Figure 8, 9, and 10 below illustrates the result of the overlay:

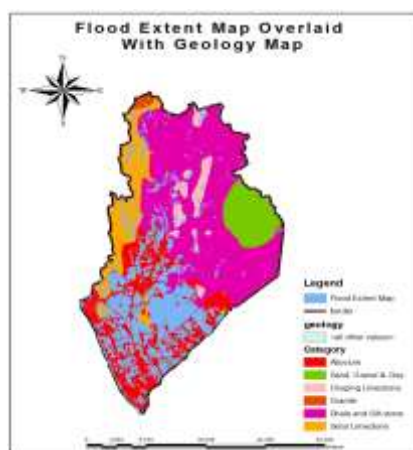


Figure 8: Overlaid of the Geology Map with Flood Extent Extraction.

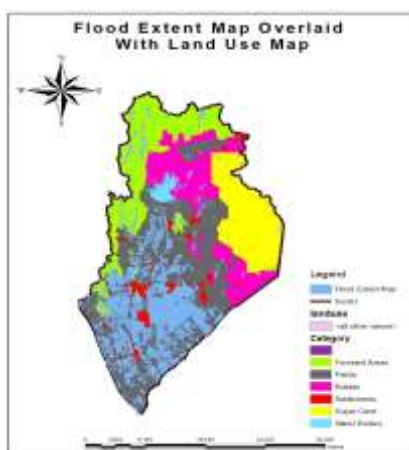


Figure 9: Overlaid of the Land use Map with Flood Extent Extraction Model.

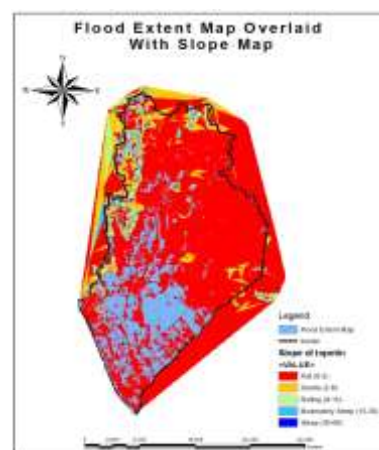


Figure 10: Overlaid of the Slope gradient Map with Flood Extent.

As illustrated in the above Figure 8, the major flooded geological portion falls in the major alluvium areas represented in red color. This is followed by the Setul limestone formation represented in orange color. Similarly in Figure 9, the major flooded areas falls in those areas that constitute the major paddy field land uses represented in dark-grey color, which is followed by the forested areas represented in lemon green color. Lastly Figure 10 depicted the major flooded areas to fall within the areas of flat slope gradient (0-2%) and gentle slope (2-8%) represented in red and orange colors respectively.

The rationale behind these results of the comparisons is to demonstrate the influence of each and every factor in flood generation. For instance when talking about geology; flooding coming from rivers and seas take place across natural landforms that have a characteristic of geomorphology and geologic make-up. These related geological deposits can present an important clue in pinpointing exactly where flood has occurred previously and accentuate some other methods of forecasting exactly where flood is likely to occur in the future. Moreover, on a catchment's level, the ability of the ground to absorb water is proportional to the underlying geology. For example, clay-rich rocks and other quaternary deposits are impermeable. Hence, these kinds of geological landscapes can probably be susceptible to high-speed run-off, increasing the likelihood of severe flooding downstream in the course of excessive rainfall incidents.

On the other hand, paddy fields land use covers a significant portion of Perlis particularly in the southern as well as central Perlis. This very portion constitutes a clay soil which has fewer pore spaces, being impermeable, and in turn worsens the flood runoff responses. Lastly is the slope gradient. Slope controls the rate of infiltration of groundwater into the subsurface. When the slope of an area is flat or gentle, the surface runoff is slow allowing more time for raindrops to infiltrate into the ground and as a result, the area will be highly susceptible to flooding. Similarly, when the slope of an area is steep, it facilitates rapid surface runoff allowing little time for rainfall to percolate into the ground thereby making the area to be less susceptible to flood [14].

Conclusively, GIS and remote sensing tools proved profound potentials in combating flood catastrophe. Alluvium, paddy fields, and flat/gentle slope gradients of geology, land use, and slope gradients respectively are one of the major natural flood influencing factors needs to be well investigated in order to aid in coming up with the flood susceptibility map of an area. The flood susceptibility map will help the civil authorities for a quick assessment of potential impact of the flood hazard and commencement of suitable measures to reduce the impact. It will similarly help the planners and decision makers in taking a positive and in time steps during pre-disaster situations. More so it will equally help them during post-disaster situations to evaluate damages and losses caused as a result flood.

References

- [1] M. Ekhwan Toriman et al. 2009. Integration of 1-d Hydrodynamic Model and GIS Approach in Flood Management Study in Malaysia. *Research Journal of Earth Sciences* 1(1): 22-27
- [2] Rabie, A.H., A.G. Aminuddin, Z. Nor Azizi, S.A. Mohd Sanusi and A.H. Zorkeflee, 2007. Modeling floodplain inundation by integrating of hydrological with hydraulic model. Case study: Muda River, Kedah. 2nd International Conference on Managing Rivers in the 21st Century: Towards PWTC sustainable River Basins, Kuching.
- [3] Abd Jalil Hassan, 2002. Penggunaan Teknologi Terkini Ke Arah Pengurusan Banjir yang Bersepadu. Conference on Pengurus Kanan JPS, 2002, Terengganu.
- [4] Dano Umar Lawal, 2011. Geographic Information System and Remote Sensing Applications in Flood Hazards Management: A Review. *Research Journal of Applied Sciences, Engineering and Technology* 3(9): 933-947
- [5] Safie, M., A. Buang and D. Dzurlkanian, 2006. GIS Analysis for Flood Hazard Mapping: Case Study; Segamat, Johor, West Malaysia.
- [6] Nico, G., M. Pappalepore, G. Pasquariello, A. Refice and S. Samarelli, 2000: Comparison of SAR amplitude vs. coherence flood detection methods a GIS application. *Int. J. Remote Sensing*, 21(8): 1619-1631.
- [7] Nirupama and S.P. Simonovic, 2002. The Role of Remote Sensing in Disaster Management. ICLR Research Paper Series- No. 21.
- [8] Rango, A. and V.V. Solomonson, 1977. The utility of short wavelength (<1 mm) remote sensing techniques for the monitoring and assessment of hydrological parameters. *Proceeding of 11th International Symposium on Remote Sensing of Environment*, Ann Arbor, MI, 25-29 April, pp: 55-64.
- [9] Lowry, R.T., E.J. Langham and N. Murdy, 1981. A preliminary analysis of SAR mapping of Manitoba flood, May 1979. *Proceeding Satellite Hydrology, Fifth Anniversary*.
- [10] Melack, J.M., L.L. Hess and S. Sippel, 1994. Remote sensing of lakes and floodplains in the Amazon Basin. *Remote Sens. Rev.*, 10: 127-142.
- [14] K. A. N. Adiat et al., 2012. Integration of Geographic Information System and 2D Imaging to Investigate the Effects of Subsurface Conditions on Flood Occurrence. *Journal of Modern Applied Science* Vol. 6, No. 3.
- [15] Calder, I.R. (1993): The Balquhider catchment water balance and process experiment results in the context - What do they reveal? *J. Hydrol.*, 145 (3-4): 467-477
- [16] M. Ekhwan Toriman et al 2006. An analysis of rainfall interception on the selected experimental plot of Pangkor Hill Reserved Forest. *J. Wildlife and National Park*, 4: 169-178.
- [17] Ragab, R. and J.D. Cooper 1993. Variability of unsaturated zone water transport parameters: implications for hydrological modelling. 1. In situ measurements, *Journal of Hydrology*, 148, 109-131.
- [18] Sadlers, R. and S. Tabuchi, 2000. Decision Support System for Flood Risk Analysis for the River Thames, United Kingdom. *J. Amer. Soc. PE&RS*, 66(10).