Flood Prediction Using Geographical Information System (GIS) Application at Sungai Sembrong

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***Abstract*—The occurrence of flood disaster in Malaysia has received much attention due to its negative impact towards society, environment and economy. In hydrological field, researchers are interested in flood prediction analysis and it is no longer a stranger in this area. The latest flood incident that hit Sg. Sembrong, Batu Pahat, Johor, Malaysia in 2007 is considered as the worst flood occurrence in Johor. This study focused on the effectiveness of using Geographical Information System (GIS) to predict flood at Sg. Sembrong. The combination of hydrological model and water balance model that takes into consideration the minimum, maximum and average temperature data for January 2007 is used to illustrate the predicted flood area for future reference. The results from the analysis showed that flood does not occur at the minimum and average rainfall, 17.2mm and 2mm respectively. However, with the maximum rainfall of 203mm, it is expected that 9983ha of land will be affected with 2m water level rise. In can be concluded that GIS is a suitable tool for the provision of preliminary information of flood, and it can be a powerful tool in aiding flood analysis, problem solving and provides rational, accurate and efficient decision making.**

***Index Terms*—Flood Prediction; GIS; Hydrological Model; Water Balance Model.**

I. INTRODUCTION

Flooding is a natural disaster that results in major damages to the physical structure of the human civilization and geography of the earth. The effects of flooding can also cause death and loss of life property and value to the individual, the community and ultimately the state. A study done by the World Meteorological Organization (WMO) shows that flooding is the third largest natural disaster that has claimed many lives and property damage [1]. Relating to this, the government has taken various flooding management actions to manage this issue.

Disseminating information of the comparison between the high and low land with flood depth to the local community is essential for early preparation for managing flood. However, this information seems to be lacking. Early exposure on information related to the types of flooding, flood situation should be disseminated to the local community as they can take appropriate preventive actions [2]. A research conducted by WMO reported that several countries suggested that disseminating reminders related to the dangers of flooding could reduce the potential loss between 6% and 40% [1].

It is necessary to adopt a more systematic approach in the planning process for quicker and more accurate decisions. Geographic Information System (GIS) is an updated and effective method to regulate the plan of flood control management and analysis in a selected catchment area [3]. GIS is one of the systems that is used for storing, retrieving, and analyzing a large amount of data as well as providing output visualization. This system helps to make some analysis operation become easier. It is also a tool that can be used in many types of application, where it can be functioned to show the earth layer more clearly compared to ordinary map [3]. The purpose of this study is to design and develop the flood raster database in *Sg. Sembrong* using ArcGIS software and to determine the flood area using hydrological models and water balance model.

II. LITERATURE REVIEW

Flood is defined as a large volume of overflow water that comes from a channel where it can no longer hold its capacity. In Malaysia, flood disasters phenomenon regularly hit almost every year. It often occurs due to the inability of the existing drainage system to accommodate the runoff flow rate and volume of exceeding water, such as outlet drains and rivers [4]. This condition occurs through a variety of ways and situations resulting from natural reactions or effects of excessive unplanned development. In this paper, the concept of this flooding occurrence refers to a process that begins when there is a rainfall water due to heavy rain or prolonged or both, to the surface of the earth. There is an excessive quantity of rainfall water which could not be absorbed by plants or artificial surface such as a roof or pavement.

The rainfall water will fall to the ground and it goes through the process of evaporation, infiltration or stored as depressions storage. After taking into account all of the loss, the quantity of rain water is still flowing excessively. This excess flow of water will flow into the drainage system near a river and the sea, assisted by water flow direction and the law of gravity from the earth [2]. Many floods cause damage to property and life threatening residents. In most areas, the constructed drainage allows the rainfall runoff and the waste water to avoid floods. Unplanned development can also cause flooding. However, recently repeatedly floods recurrence has caught authorities' attention. Ineffectiveness in irrigation and drainage systems are the main cause contributing to the flooding problem in this country [3].

According to [6], approximately 12.5 percent of Johor land is covered with flood at a time. This number is critical when dealing with human life and property damage. There are instances where some floods unpredictably occurred off-season. In this case, Johor is considered as a high-risk state

to receive a flood. This assertion is supported by major floods that hit Batu Pahat District in the late 2006 and early 2007 [7].

A. Geographical Information System (GIS)

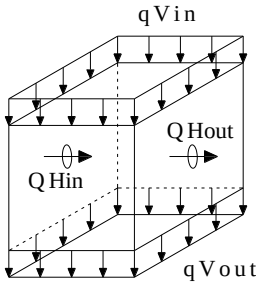
GIS has started to get attention in many organizations in both public and private sector. Several organizations in Malaysia have implemented information systems development using GIS [8]. GIS is a set of computer software and hardware in consolidating common database operations such as query and static analysis of visualization mapping and geographic analysis. This capability gives the other GIS information system and is useful in providing information, forecasts or plans in a matter [8].

GIS is an information statistical system based on the map. These systems can be classified as a set of procedures used to produce a specific result and the procedure was defined as a series of steps that are followed on a regular basis and in accordance with specific rules to obtain a result. A system can be called information system when there is a set of components that are made up of data, people, procedures, hardware, software and information. All components are required to perform a set of functions organized [9].

Besides that, GIS is an information system that is conducted using a combination of information operations planning, observation, collection, storage and analysis of data to produce information that can be used in a decision-making process. Generally, GIS is a tool that provides the ability in handling spatial data. From the point of function, a GIS is defined as a computer-aided system to collect, store, modify or transform the space and display data from the real world [8].

B. Water Balance Model

The water balance model is used for flood analysis. Input parameters of the model consist of five variables; basin area (m^2), rainfall (mm/s), flow upstream drainage (m^3/s), flow downstream drainage (m^3/s) and surface soil permeability rate (mm/s), as illustrated in Figure 1.



$$Q_{Hin} + (q_{Vin} - q_{Vout})Area - Q_{Hout} = \frac{dS}{dt}$$

Figure 1: Water Balance Model

where Q_{Hin} is the drainage upstream flow rate (m^3/s), Q_{Hout} is the drainage downstream flow rate (m^3/s), q_{Vin} is the quantity of rainfall (mm/s), q_{Vout} is the surface diffusion rate (mm/s) and Area is the surface area (m^2).

C. Flood Scenario in Johor

Johor Darul Ta'zim is a state located in the southern part of Peninsular Malaysia and it is the last projected from the mainland of the Asian continent. The state has two beaches, namely the West Coast and East Coast. The East Coast is exposed to the Northeast Monsoon winds during the monsoon season. This monsoon wind blows from November to February and usually brings heavy and prolonged rainfall. This situation can cause water overflowing from its banks and flows to the low lands along the river valley, especially in the valley of the *Sungai Johor* and *Sungai Muar*. Floods in 1969, 1971 and 1979 are the worst floods that ever recorded [5]. A study conducted in 2003 on the "National Register of River basins" (2003) found that the flooding area in Malaysia consumes 29,800 km² (9% of land area) and involves population amounted to 4.82 million people [6]. Table 1 shows that flood area in Johor state occupies up to 12.5 percent from the total land.

Table 1
The Total Floods in Malaysia [7]

State	Area km²	Total Population (Year 2000)	Flood Area (km²)	Flood Involved Population (2002)
Perlis	795	198,335	26.74	12,736
Kedah	9,425	1,572,107	209.44	117,368
Pulau Pinang	1,030	1,225,501	206.83	342,524
Perak	21,005	2,030,382	662.84	275,374
Selangor	7,955	3,947,527	1,788.70	669,217
Kuala Lumpur	243	1,297,526	13.18	157,302
Negeri Sembilan	6,643	830,080	129.48	40,887
Melaka	1,651	602,867	80.85	27,811
Johor	**18,986**	**2,565,701**	**2,366.71**	**290,570**
Pahang	35,965	1,231,176	6,271.62	615,128
Terengganu	12,955	879,691	2,222.87	425,396
Kelantan	14,920	1,289,199	1,640.38	714,287

Some floods occurred unpredictably namely during off seasonal; hence, Johor is considered as a high-risk state to receive flood. This assertion is supported by the major floods that have hit the Batu Pahat District in late 2006 and early 2007 [8].

III. METHODOLOGY

This methodology guides the implementation of the study in order to achieve the research objectives. The planning activities include phase identification and data entry, the implementation phase includes the design, development, operation and analysis of data, and finally the result fulfils the objectives of this research. This chapter describes the methods and means used to analyse the database of flood. Figure 2 shows the methodology of the study to produce a flood area.

The summarization of the work flow for this study is best described in Figure 3. The hydrological data such as catchment area and digital elevation model (DEM) that is the spatial data were identified before the hydrology model process can be started. The stream flow direction, targeted location area and the stream flow were determined at this stage. The results obtained from this stage are then used in the water balance model. This is the last stage before the affected area of flood can be produced as presented in Figure 4. The area of the selected catchment, input and output of the flow rate, rainfall as well as types of soil data are needed during the water balance model stage.

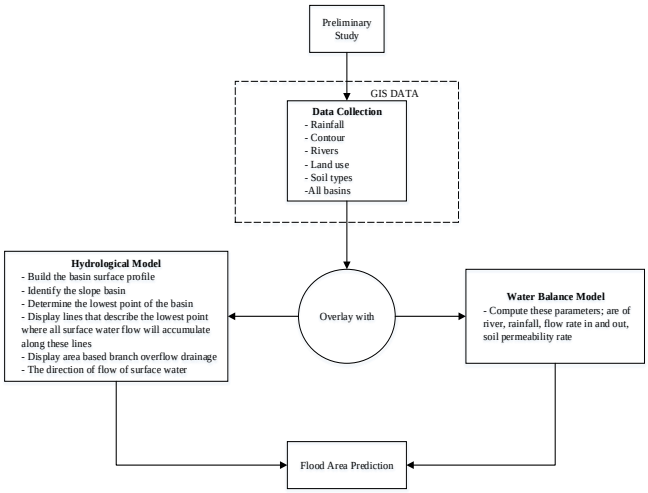


Figure 2: Methodology of Study and Step Sequence

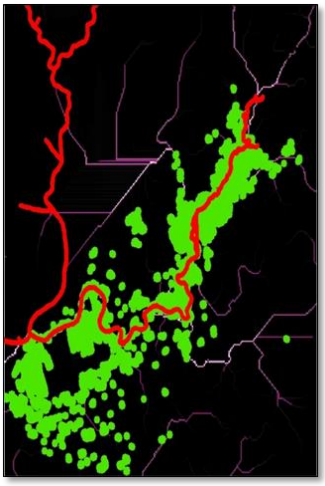


Figure 4: Affected flood area for 203mm of rainfall

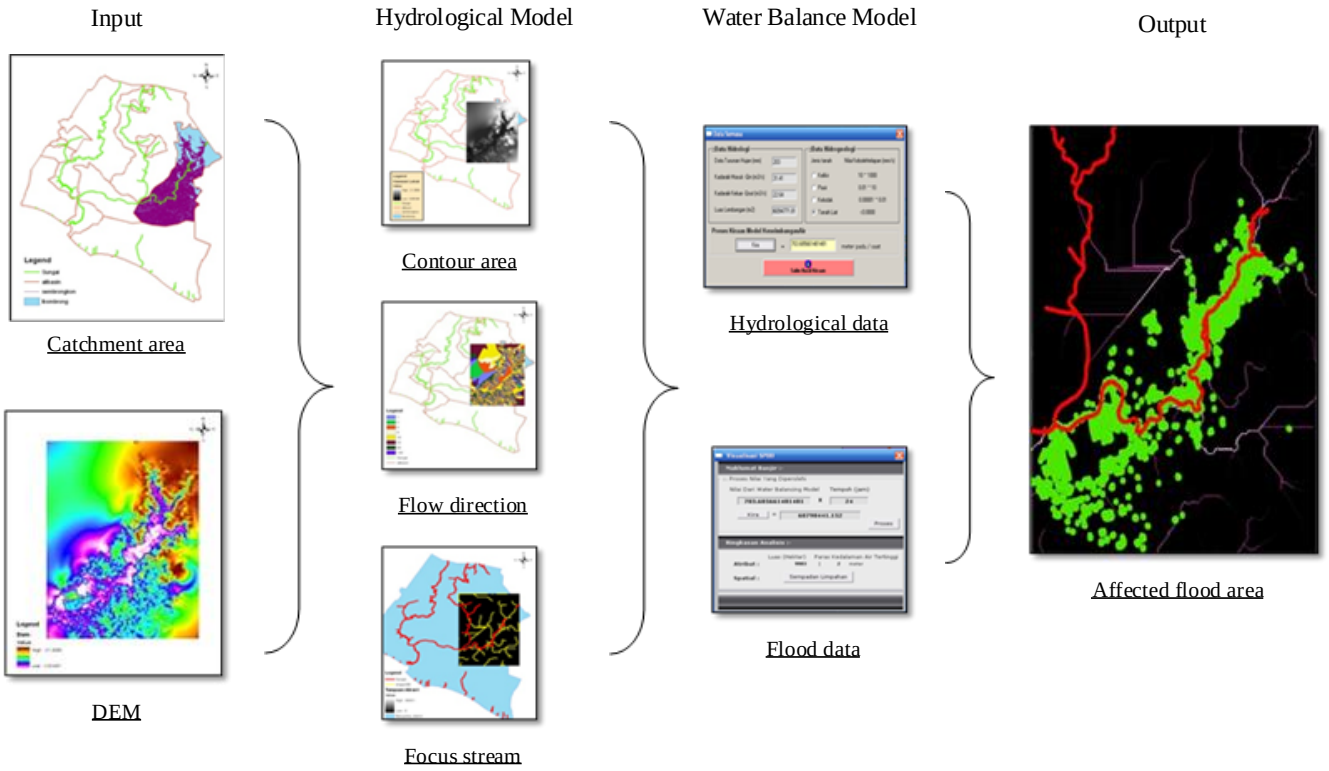


Figure 3: Work flow for analyzed the affected flood area

IV. Results and Discussion

From the hydrological models, the contour was converted into DEM that describes the basin surface profile. The sequence of the steps for the hydrological model are illustrated as in Figure 5(a) to (f).

After completing all of the above processes, only the new box water balance models can be activated by using the hydrological model. This activation is necessary due to the importance of the concentration flow data needed in the box water balance model.

All variables in the water balance model programmed in the water balance model box are included in the current data box. Hydrological data for this study is the data used in 2007, when at the beginning of January 2007, the district has experienced an extraordinary flood phenomenon known as 'pensive flood', where the water level rises slowly to recede [10]. The water balance model has been translated into Bahasa and was programmed by Mohamad Abdul Rahman. Table 2 lists the monthly rainfall data released by the Department of Irrigation and Saliran (DID) Batu Pahat. Due to the limitation in recording the data, only the maximum monthly rainfall in the month of January 2007 are given.

A manual calculation was done to double check all variables in the water balance model programmed in the water balance model box. The hydrological data entered into this box water balance model of the rainfall data is 203 mm, the flow rate (Q_{in}) is 31.41 m^3 / s, the rate of outflow (Q_{out}) is 22.64 m^3 / s and the area of Sg Sembrong is 296094771.81 m^2. For the hydrogeological data, the type of soil is clay since Batu Pahat district is mostly clayey.

The flood of the period and the volume of flood water were obtained based on the water balance model formula.

To process the data, the values were obtained from the water balance model and the next value was put in the box of flood information. From the summary of the analysis, it showed the flood overflow area in hectare (ha) and the highest level of water depth units in meters together with the boundaries of overflow.

After the minimum rainfall data, maximum and average rainfall data entered into the box water balance model, the results of the flood of information and the boundary of overflow is shown in Table 3.

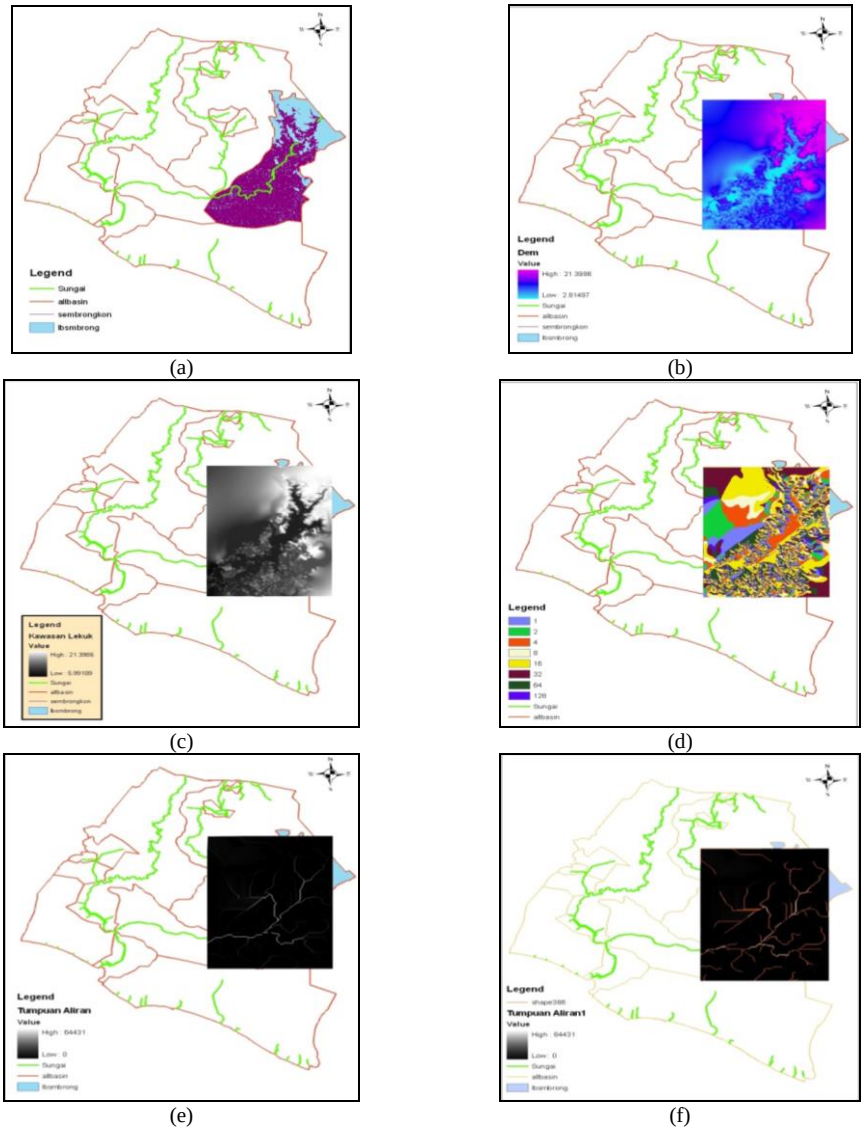


Figure 5: Sequence of GIS Analysis; (a) Basin Contour Line, (b) Contours to DEM, (c) Formation of Indentations Area, (d) Formation of Flow Direction, (e) Flow Accumulation, (f) Flow Accumulation Line

Table 2
Monthly Rainfall Data in January 2007

Day	Reading Time	Rainfall (mm)	Day	Reading Time	Rainfall (mm)
1	8.00 am	0	17	8.00 am	0
2	8.00 am	0	18	8.00 am	0
3	8.00 am	0	19	8.00 am	2.5
4	8.00 am	0	20	8.00 am	0
5	8.00 am	35	21	8.00 am	0
6	8.00 am	0	22	8.00 am	0
7	8.00 am	0	23	8.00 am	0
8	8.00 am	0	24	8.00 am	0
9	8.00 am	0	25	8.00 am	0
10	8.00 am	25	26	8.00 am	0
11	8.00 am	6.5	27	8.00 am	23
12	8.00 am	203	28	8.00 am	0
13	8.00 am	195	29	8.00 am	0
14	8.00 am	25	30	8.00 am	0
15	8.00 am	11	31	8.00 am	0
16	8.00 am	2	Total		534

Table 3
Summary of the Difference Rainfall Data

Rainfall (mm)	Flood Basin Area (hectare)	Highest Water Level (m)
2 (min)	Does not have a flood	-
20 (max)	9983	2
17.2 (average)	Does not have a flood	-

From the minimum rainfall data, the maximum and average rainfall data for January 2007 were inserted in the water balance model. It shows the difference that only the maximum rainfall data shows flooding in a Sg. Sembrong basin with an area of 9983 ha and the highest water level is 2m. The minimum rainfall data and average rainfall data shows the same analysis results, in which Sg. Sembrong basin does not have a flood.

V. CONCLUSION

Overall, the main objective of this study, which is to determine the flood area at Sg. Sembrong has been achieved with the application of Geographical Information System (GIS) and it gives an acceptable result. Apart from that, the combination between the hydrological models and water balance model is suitable in determining the flood area at Sg. Sembrong. The authors would like to emphasize that the GIS is the suitable and excellent tool that help in combining information from various sources. It is really a helpful tool for decision making procedure.

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