Flood Zoning Simulation by HEC-RAS Model (Case Study: Johor River-Kota Tinggi Region)

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ABSTRACT

Flooding of rivers has caused many human and financial losses. Hence, studies and research on the nature of the river is inevitable. However, the behavior of rivers has many complexities and in this respect, computer models are efficient tools in order to study and simulate the behavior of rivers with the least possible cost. In this paper, a one-dimensional model HEC-RAS was used to simulate the flood zoning in the Kota Tinggi district in Johor state. Implementation processes of the zoning on catchment for return periods of 2, 25, 50 and 100 years were applied with different roughness coefficients. In order to improve the results of flood zoning from the obtained results, it is better to include the items for changing hydraulic platform as a different scenario’s problem. The sensitivity of HEC-RAS model to the roughness coefficient, the coefficient of narrowing and opening, and energy slope were examined and observed. The most sensitive on water surface profile is created by the changes in the roughness coefficient. The volume and upstream surface runoff area and stream or flood conditions and physical characteristics of the area (surface morphology, etc.) can be named as the most significant factors that can affect the severity and recurrence of floods in every region.

KEYWORD

Flood Zoning, HEC-RAS, Kota Tinggi, Water Surface Profile

INTRODUCTION

Floods have always been natural disasters, which are associated with human and financial losses and have influenced human’s life (Abghari, Mohseni Saravi et al. 2007). The risks have also increased due to climate changes and human interference to the river systems in recent times (Bronstert 2003). Human has been fighting with flood in different ways for a long time, but the fact must be accepted that flood is not fully controlled, but its losses can be reduced by floodplain management. Behavior survey of river events by its simulator models which accurately predict the flow of the river, and its result leads to produce flood zoning maps which are among the useful tools in the management of floodplain (Birkland, Burby et al. 2003). Without the use of such tools, engineering judgment is often performed more conservative and with higher fees. So, the flood zoning maps are one of the basic and important information in construction project's research around the world, and it should be placed on the agenda of related organizations before any investment or implementation of development projects.

Several hydraulic models have been developed to simulate flood zoning such as MIKE, HEC-RAS, INFOWORK, ISIS, and etc. (Shahiri Parsa, Vuatalevu et al. 2013). HEC-RAS model can be cited as one of these river flow simulator software. Johnson et al. (1999) were used HEC-RAS model to predict and define desirable lands within 10 km of the river View Ming Garry Yule in America. Tate and Maidment (1999) conducted a study to integrate HEC-RAS and Arcview software in order to study privacy bed of Valler Creek River in Austin, America. Safari (2001) zoned flood risk in Neka River in the Mazandaran Province by using HEC-RAS model and concluded that this model has high efficiency in planning and determining floodplain management optimal model. (Jalali-Rad 2002) Simulated flood risk in urban areas of Darabad, Tehran by using HEC-RAS model with mapping of the cross sections and showed the ability of the model to process the water surface in different elevation. Haji Qolizadeh (2002) checked the effects of human interventions on the behavior of a Kan River by using HEC-RAS model. While conducting the model, he examined the effect of bridge and its usage to change the water surface and flooding elevation. Knebl, Yang et al. (2005) did a framework for flood modeling by integrating several accessions by using HEC-RAS model on San Antonio River over 10,000 square kilometers. Furthermore, it shows that HEC-RAS can simulate...
floodplain inform of a polygon which is comparable to satellite imagery as well. Meire, De Doncker et al. (2010) compared HEC-RAS model with one-dimensional model based on the equations of Sent and Nantes that results a perfect agreement to measure and simulate by the two models. Remo, Carlson et al. (2012) simulated a part of the Mississippi River by using HEC-RAS model.

This paper attempts to determine river privacy and producing flood zoning maps by using HEC-RAS model to check flooding risks along the Johor river and by considering different return periods.

MATERIALS AND METHODS

Case Study:
Johor River Basin is located on the southeast of Peninsular Malaysia. The River emanates from Gunung Belumut at with an altitude of 1010 meters to Bukit Gemuruh at with an altitude of 109 meters on the north basin. The river flows towards the Southeast and into the straits of Johor. The main population and the administrative center are located at Kota Tinggi city, which is 42 km North East of Johor state in Malaysia (Figure 1). Kuala Sedili town is located 37 km North East of Kota Tinggi city and is considered as the second largest fishing port on the east coast of Peninsular Malaysia. Average annual rainfall is 2500 millimeters (mm), and the average annual discharge is 37.7 cubic meters per second (m³/s) at the Rantau Panjang station. The catchment area of Johor River at Kota Tinggi is 1620 square kilometers. The main branches of the river are Sayong, Linggiu, Semanggar, Tiram and Lebam.

Kota Tinggi is a flooding area, and its flood history shows great floods causes destruction and many human and financial losses. Floods on December 19, 2006 and January 11, 2007 can be observed as the largest floods (Figure 2) that almost all of Kota Tinggi town went under water by these two floods.

Governing Rules:
HEC-RAS is a one-dimensional model which can simulate flow conditions on steady and unsteady states. In steady state, HEC-RAS model calculates water surface elevation (WSE) and velocity in cross sections by solving the energy continuity equations and flow resistance (like manning coefficient). In this software, the simulation is based on standard step by step numerical methods to calculate the WSE between the two periods. The method is based on the energy relationship that starts the calculations from one end of the range (supercritical flow at upstream to subcritical flow downstream) and continues the calculation from this section to the next. The size of motion equation is also used in the place of narrowing and the place of changing in the flow regime (converting critical flow to supercritical flow and vice versa).

Water surface profiles of a cross section to another are calculated by solving the energy equation through the standard procedure. Energy equation (1) is as follows:

\[ Y_2 + Z_2 + \alpha_2 \left( \frac{V_2^2}{2g} \right) = Y_1 + Z_1 + \alpha_1 \left( \frac{V_1^2}{2g} \right) + h_d(I) \]
Where \( Y_1 \) and \( Y_2 \) are water depths at the cross section; \( Z_1 \) and \( Z_2 \) are the floor heights of the main channel; \( V_1 \) and \( V_2 \) are the average velocities; \( \alpha_1 \) and \( \alpha_2 \) are coefficients of mass momentum speed; \( g \) is acceleration of gravity and \( h_e \) is loss of energy level.

Input Data:
The required data for HEC-RAS model includes topography data, Manning's roughness coefficients (n) and the flow data that includes flow rate, boundary conditions, etc.

1. **Topography Data:**
   Topography data was considered as the form of a set of cross sections, which in this study is shown according to the following figure in the form of seven cross sections with equal distance that is one thousand meters.

   ![Fig.3. A view of the simulation of water surface in Johor River in the interval Kota Tinggi (return period 2, 25, 50 and 100 years)](image)

   The following terms are considered to determine the modeling of the river cross section by HEC-RAS:
   - The cross section prepares the distances where significant changes have occurred in the area of section, roughness coefficient and slope of the river.
   - The cross sections are chosen perpendicular to the flow. (In this study, local complications along the cross sections which is not representative of the vertical topography of its range have been removed.)
   - The scopes of cross sections are extended to the highest hot water.

2. **Manning Roughness Coefficient (n):**
   The friction parameters have been considered as the form of Manning's roughness coefficient (n). Determining bed roughness coefficient and sides of different ranges of the river has been carried out by using the river geometry, bed vegetation and sides, and the amount of the bed material in the form of two types of the roughness coefficients which are \( n = 0.035 \) and \( n = 0.2 \).

3. **Flow Data and Boundary Conditions:**
   The boundary conditions are consistent with the nature of the river that requires to predict the flow characteristics along the range of the river. Boundary conditions represent the input and output states from the upstream range under study. It is obvious that if the number of measurement stations in the range under study is more, the accuracy of the results will be higher. Introducing the water level to the software can be used when the flow data is not available. In regard to the rivers and considering the fact that flow conditions are constantly changing (converting subcritical flow to supercritical flow and vice versa), it is necessary to define the boundary conditions at the downstream and upstream. Normal slope of corresponding river and the normal depth can introduce a very good approximation as the boundary conditions. The paper also presents the same amount used in the upstream and downstream boundary conditions. For example, the boundary conditions are the WSE at downstream to simulate the subcritical on steady state.

   ![Tab.1. The first scenarios (the return period, Discharge , Manning coefficient)](image)

<table>
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<tr>
<th>ARI</th>
<th>100yr</th>
<th>50yr</th>
<th>25yr</th>
<th>2yr</th>
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<td>Q(m3/s)</td>
<td>942</td>
<td>853</td>
<td>756</td>
<td>360</td>
</tr>
<tr>
<td>n</td>
<td>0.035</td>
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</table>

   ![Tab.2. The second scenarios (the return period, Discharge , Manning coefficient)](image)

<table>
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<tr>
<th>ARI</th>
<th>100yr</th>
<th>50yr</th>
<th>25yr</th>
<th>2yr</th>
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<tr>
<td>n</td>
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**RESULTS**

According to the survey conducted in this research, topographic maps and metropolitan area with data layers flood zones, flood zoning maps for return periods of 2, 25, 50 and 100 years were obtained. Furthermore, changes in the depth, velocity and flow area, Froude number and shear stress etc. were calculated for different return periods; the output of the 100-year return period design is shown in the table (3) and (4).
Fig. 4. Three-dimensional view of the river scheme with regard to roughness coefficient \( n = 0.02 \)

Fig. 5. A view of a cross section

Fig. 6. 2 years water surface profile

The results show the difference in expanding the flood retention zone is primarily branched from the route topographical features. Every width of the stream bed is increased; Width of the floodplain is also increased, and water is spread over a larger surface. In contrary to the narrow valley, the width of the floodplain is also decreased and parallel to it while the floodplain depth is increased. Actually, the steep topography along the sidelines of the main river is the reason of the little difference on the level of flood retention on many parts.
Tab.3. Scenario #1: Profile ARI= 100 (year), Q total=942(m3/s)

<table>
<thead>
<tr>
<th>River Sta</th>
<th>Min Ch El (m)</th>
<th>W.S. Elev (m)</th>
<th>Crit W.S. Elev (m)</th>
<th>E.G. Elevation (m)</th>
<th>E.G. Slope</th>
<th>VelChnl (m/s)</th>
<th>Flow Area (m2)</th>
<th>Top Width (m)</th>
<th>Froude # Chl</th>
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<tr>
<td>7.00*</td>
<td>3.42</td>
<td>12.42</td>
<td>5.71</td>
<td>12.45</td>
<td>0.000055</td>
<td>0.77</td>
<td>1291</td>
<td>230</td>
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Tab.4. Scenario #2: Profile ARI= 100 (year), Q total=942(m3/s)

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<th>River Sta</th>
<th>Min Ch El (m)</th>
<th>W.S. Elev (m)</th>
<th>Crit W.S. Elev (m)</th>
<th>E.G. Elevation (m)</th>
<th>E.G. Slope</th>
<th>VelChnl (m/s)</th>
<th>Flow Area (m2)</th>
<th>Top Width (m)</th>
<th>Vel Head (m)</th>
<th>Frcntn Loss (m2)</th>
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**CONCLUSION AND RECOMMENDATION**

The sensitivity of HEC-RAS model to the roughness coefficient, the coefficient of narrowing and opening, and energy slope were examined and observed. The most sensitive on water surface profile is created by the changes in the roughness coefficient.

The volume and upstream surface runoff area and stream or flood conditions and physical characteristics of the area (surface morphology, etc.) can be named as the most significant factors that can affect the severity and recurrence of floods in every region. Modeling can appear as a regional warning system to reduce the risk and this tool can be used for flood simulation studies, flooding in towns, city and regional levels.

The following table shows the accurately determined parameters of the bed limit. In addition to the item accuracy calculated water level; the changing of the hydraulic bed is also an important parameter that should be considered in studies.

It is suggested that:

1. Zoning of flood generated by the HEC-RAS software can be easily created for other different floods and transferred to ArcView program and placed on the Triangulated Irregular Network (TIN) of the ground and determined the flood zone, and also distinguished the places which are in need of structural measures along the river. Flood zone area and damages can be calculated and the results are important especially for insurance companies.

2. Studies have shown that the main cause of increased damage caused by the flood is not short return period or high flow rate, but also increasing the usage of the flood plain lands or bund lands adjacent to the river are major factors to make the flood happen. The codification of a comprehensive program is aimed at improving the control and appropriate exploitation by applying appropriate management measures with all the factors involved in producing the regional flood seems necessary.
The accuracy of the calculated water level (hydraulic flow)

1. Possibility of accurately modeling surface
2. The rate of accuracy in determining the natural conditions
3. Manning coefficient estimate
4. The rate of accuracy of river Software
5. Boundary conditions
6. Flood calculations (hydrology)

The hydraulic bed changing

1. High speed flow and erodible
2. Falling sides
3. Slip and break bulk
4. Deep and high valleys
5. Morphological changes
6. Legal issues and ownership

3- Areas are classified into three groups as high risk, medium risk and low risk to assess the damage from the flood by using the maximum water depth and velocity in different regions, which can be extracted from the HEC-RAS hydraulic model and calling this data in ArcView and preparation of the three-dimensional images for the areas under water. Having information about residential, agricultural and etc. the vulnerability was checked and damage was estimated caused by the floods on the range under study. The Mitigation Plan solutions are proposed by using modern program and the project economic issues are examined by using HEC-FDA model.

REFERENCES


