Impact of Climate Change on Flood Inundation Levels in Chereh Dam Failure Scenarios

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Abstract. This study evaluates the climate change impact to the depth of inundation due to dam breaks during a heavy rainfall through Hydrological Engineering Centre–River Analysis System (HEC-RAS). Increasing of intensity rainfall is an evidence of climate change exists and it explicitly informs that possibility of higher inflow rates will be also getting bigger. This fact become main concern in connection with raising probability of dam breaks with higher magnitude of flooding. This current study determines the flood inundation depth due to Chereh Dam failure by including the Climate Change Factor (CCF). The result of analysis point out that the depth and level of flood due dam break creates a significant impact and risk to the Kuantan City such as inundated of transportation networks and also various public facilities.

1. Introduction

The climate change brings disastrous impact to physical structure and social system in the different way. Take an example flood; this natural disaster gives a many effects such as distraction in the transportation and communication networks, disruption of property and inundation of agricultural area and many more. Present extremes events in connection with weather occurred more frequently as compared in the past, currently more region have heavy rainfall with more intense than before [1; 2; 3]. This fact verifies that climate change exists. The changing of climate pattern will give significant impact on total amount of hydrograph used in the dam design. And it also will trigger the possibility of dam failure with more severe damage and higher risk. The dam break investigation is the output of multi-subjects analyzes: precipitation analysis; rainfall runoff model; dam breaching investigation; the routing of flood wave due to dam break then followed by flood inundation mapping.

The current study applies the HEC-RAS model to simulate the Chereh Dam break flood inundation on some design scenarios: 50 years and 100 years ARI with consider on Climate Change Factor. Chereh Dam which is located in Pahang State of Malaysia, about 40km north-west of Kuantan City (Figure 1) has some features: an earth fill embankment dam of 48m high; 54km² of water surface area and 250x10⁶ m³ of maximum reservoir volume and its equipped with a 50m width un-gated chute spillway. The objective of this present study is simulating flood inundation map due to dam failure with some particular scenarios; this map will be very useful for city or state government to arrange policy, rule and strategy in connection with city planning and also Emergency Response Plan (ERP).
Figure 1. Location of study: Chereh Dam, Kuantan, Pahang State, Malaysia

2. HEC RAS Model

HEC-RAS is open source software prepared and developed by U.S Army Corps of Engineers for river analysis. Currently, this software has ability and capability to carry out one–two dimensional (1D-2D) analysis for steady and unsteady flow conditions, sediment movement model and also several cases in correlation with water quality model. Dam break analysis can be made using the flood routing approach proposed by Saint-Venant equations under unsteady flow state. The new version of HEC-RAS (5.0.x) solved 2D Saint Venant and diffusive wave equations [4].

\[
\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0
\]  

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) = -n^2 \rho g \frac{p^2 + q^2}{h^2} - gh \frac{\partial \zeta}{\partial x} + pf + \frac{\partial}{\partial \rho} \left( \rho \tau_{xx} \right) + \frac{\partial}{\partial \rho y} \left( \rho \tau_{xy} \right)
\]

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial y} \left( \frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left( \frac{pq}{h} \right) = -n^2 \rho g \frac{p^2 + q^2}{h^2} - gh \frac{\partial \zeta}{\partial y} + qf + \frac{\partial}{\partial \rho} \left( \rho \tau_{yx} \right) + \frac{\partial}{\partial \rho x} \left( \rho \tau_{yy} \right)
\]

Where:
- \( h \) = the flow depth (m),
- \( p, q \) = the x and y flow direction (m²s⁻¹),
- \( \zeta \) = the water surface elevation (m),
- \( g \) = the acceleration of gravity (ms²),
- \( n \) = the manning value (sm⁻¹/³),
- \( \rho \) = the density of water (kgm⁻³),
- \( \tau_{xx}, \tau_{yy}, \tau_{xy} \) = the effective of shear stress,
- \( f \) = the Coriolis value (s⁻¹).
3. Result and Discussion

3.1. Hydrological Model

One of essential data as an input of HEC-RAS model is flow hydrograph or lateral flow hydrograph. In here, flow hydrograph data was generated from calibrated and confirmed HEC-HMS model (Hydrological Engineering Center–Hydrological Modeling System). The result of calibration and confirmation of HEC-HMS model can be found in the previous publication [5]. The other results using HEC-HMS confirmed model are displayed in Figures 2 and 3.

![Figure 2. Observed and simulated flow hydrographs on January 2001](image)

![Figure 3. Observed and simulated flow hydrographs on January 2012](image)

Figures 2 and 3 demonstrate the comparison between observed and simulated flow hydrograph on January 2001 and January 2012 as the result of HEC-HMS model during confirmation exercises. The modeled and the observed data confirm a good agreement each other with the values of Nash–Sutcliffe efficiency coefficient ($NSE$) and the coefficient of determination, $R^2$ are 0.906 and 0.953 for January 2001 and $NSE = 0.749$; $R^2 = 0.872$ for January 2012. The result of model reaches the performance acceptable level when the value of $NSE$ in between 0.0 and 1.0 (0.0 < $NSE$ < 1.0) and $R^2$ value must be above of 0.5 ($R^2 > 0.5$) [6; 7]. Therefore, it can be concluded that HEC-HMS model can replicate flow hydrograph well.
Table 1 below informs the maximum flood hydrograph that have been recorded in stream flow station of SF 3930012 Sg Lembing PCC Mill for 14 years (2000–2013). Unfortunately, some data during the extreme events can’t be caught due to limitation of device capability. Based on those measured data, the maximum flood hydrograph occurred on December 11, 2004 with the magnitude of 2413 m$^3$/s.

| No | Date      | Flow (m$^3$/s) | Additional note                                      |
|----|-----------|---------------|-----------------------------------------------------|
| 1  | 03 Jan 2000 | 319.50        | No data recorded on November 7 to December 14, 2000  |
| 2  | 22 Dec 2001 | 1742.40       |                                                     |
| 3  | 14 Dec 2002 | 628.00        |                                                     |
| 4  | 09 Dec 2003 | 1107.70       |                                                     |
| 5  | 11 Dec 2004 | 2413.00       |                                                     |
| 6  | 22 Nov 2005 | 812.10        |                                                     |
| 7  | 11 Feb 2006 | 1223.90       |                                                     |
| 8  | 20 Jan 2007 | 551.20        | No data recorded on November and December, 2007      |
| 9  | 31 Dec 2008 | 505.00        | No data recorded on December 1-13, 2008              |
| 10 | 02 Jan 2009 | 1290.20       |                                                     |
| 11 | 06 Dec 2010 | 255.40        | No data recorded on February and March, 2010         |
| 12 | 11 Mar 2011 | 531.90        |                                                     |
| 13 | 12 Jan 2012 | 876.10        | No data recorded on November and December, 2012      |
| 14 | 03 Dec 2013 | 838.10        | No data recorded on January to February, 2013 and 16-31 December, 2013 |

3.2. Design Storm

In this study, 24-hours design storm was used to simulate flood hydrograph under 50 years (Q$^{50}$) and 100 years ARI (Q$^{100}$), in addition the Intensity Duration Frequency (IDF) constant of Sg Lembing PCC Mill (SF 3930012) was selected. The empirical of IDF curve is written in Eq. 4, the calculation result of rainfall intensity for 50 years and 100 years ARI with storm duration of 24 hours are tabulated in Table 2.

\[ i = \frac{\lambda T^\kappa}{(d + \theta)^\theta} \]  

Where,
\[ i \] = average rainfall intensity (mm/hr),  
\[ T \] = average recurrence interval (ARI) = 50 years and 100 years  
\[ d \] = storm duration = 24 hours  
\[ \lambda = 45.999; \kappa = 0.210; \theta = 0.074; \eta = 0.590 \]

Table 2. Calculated rainfall intensity and rainfall depth at SF 3930012

| ARI (years) | 24-hours Rainfall intensity (mm/hr) | Rainfall depth (mm) |
|-------------|-------------------------------------|---------------------|
| 50          | 16.011                              | 384.264             |
| 100         | 18.520                              | 444.474             |
National Hydraulic Research Institute of Malaysia (NAHRIM) has published a technical guide on future design rainstorm with Climate Change Factor (CCF) [8]. This guideline divided Peninsular Malaysia into 5 regions and Pahang State is in the region 1 for Northern Pahang, while another Pahang area is in the region 2. CCF constant of Rumah Pam Pahang Tua (3533102) was selected in order to calculate storm flood hydrograph with the value of CCF is 1.41 for 50 years and 1.46 for 100 years ARI. The generated flood hydrograph for 50 years ($Q_{50}$) and 100 years ($Q_{100}$) ARI in the junction of Lembing River and Kuantan River where stream flow station of SF 3930012 located are shown in Figures 4 and 5. Figure 4 tells about 50 years ARI flood hydrograph, the maximum magnitudes are 1362.4m$^3$/s and 2741.5m$^3$/s when CCF included in computation. Based on the data written in Table 1 that the measured maximum flood at SF 3930012 was above of $Q_{50}$ magnitude occurred on 22 December 2001 with 1742.40m$^3$/s and 2413.00m$^3$/s on 11 December 2004. While, Figure 5 gives information on the maximum flood of 100 years ARI without and with CCF which is equal to 1.46.

![Figure 4](image1.png)

**Figure 4.** Simulated flood hydrograph in the junction of Lembing River and Kuantan River for 50 years ARI without and with concern on CCF = 1.41

![Figure 5](image2.png)

**Figure 5.** Simulated flood hydrograph in the junction of Lembing River and Kuantan River for 100 years ARI without and with concern on CCF = 1.46
3.3. Hydraulics Model
The result of generated flood inundation due to Chereh Dam failure in some design scenarios, illustrate in some following figures. Scenarios used in this present study were dam break occurred during heavy rainfall of 50 years and 100 years ARI and it was also consider on climate change impact.

![Flood Inundation Map](image)

**Figure 6.** Flood inundation map due to Chereh Dam break with design rainfall of 50 years ARI; (a) without [8] and (b) with consider on CCF
Figures 6 and 7 depict the flood inundation due to dam break without and with concern on climate change impact. The most differences can be seen clearly from both scenarios are the area and the depth of inundation. Some places are far away from flood inundation in a scenario without considered on CCF, but it becomes inundated area when a scenario by considering on CCF was carried out.
4. Conclusions
Climate change impacts have been considered in generating of flood inundation map due to Chereh Dam break scenarios. The result shows that there are differences in term of the depth and the area of inundation in the downstream part of Chereh Dam under situation with and without Climate Change Factor (CCF) especially in the area along Belat River as shown in Figures 6 and 7 (red box mark). This location is dense urban area; there are some colleges in here, such as: Kolej Universiti Islam Pahang Sultan Ahmad Shah, Kolej Kemahiran Tinggi Mara Kuantan, Kolej Poly-Tech Mara Kuantan, residency and commercial area. Main road of Tanah Putih that connected Kuantan City to Kuala Lumpur also located in here. As mentioned before that the main goal of this present study is to reproduce flood inundation map in the purpose of arranging policy and strategy in correlation with dam break properly by the city or state government. Integrated and deep analysis on flood impact and risk for all design scenarios should be done to select an appropriate framework for Emergency Response Plan (ERP).

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