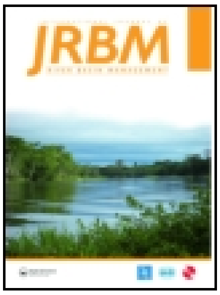

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Sungai Pahang digital flood mapping: 2007 flood

Aminuddin Ab. Ghani [a], Chun Kiat Chang [b], Cheng Siang Leow [b] & Nor Azazi Zakaria [b]

[a] River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia

[b] REDAC, Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia

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Research paper

Sungai Pahang digital flood mapping: 2007 flood

AMINUDDIN AB. GHANI, *Professor and Deputy Director, River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia. Email: redac02@eng.usm.my (Author correspondence)*

CHUN KIAT CHANG, *Science Officer, REDAC, Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia.*

CHENG SIANG LEOW, *Research Officer, REDAC, Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia.*

NOR AZAZI ZAKARIA, *Professor and Director, REDAC, Universiti Sains Malaysia, Engineering Campus, Seri Ampangan, 14300 Nibong Tebal, Penang, Malaysia.*

ABSTRACT
In this study, visits to areas in the subcatchments of Sungai Pahang, including Mentakab, Temerloh, Maran and Pekan, were made throughout the year 2009 to obtain information regarding inundation areas, flood depth, flow discharge and water levels relevant to the 2007 flood. Interviews with local people were also made to ascertain the true picture of the 2007 flood. Analyses of rainfall data, water level, flow discharge and river cross-sectional changes were carried out from data gathering. The development of a digital elevation model (DEM) was made from a combination of digital topographical maps and satellite images which were purchased from Jabatan Ukur dan Pemetaan Malaysia. This visually enhanced DEM was then used for the development of the actual extent of the 2007 flood in the study area. Several options of flood mitigation works are proposed to reduce the impact of a similar flood in the future based on the developed DEM.

Keywords: Flooding; alluvial river; flood mitigation; GIS; Sungai Pahang

1 Introduction

Malaysia is fortunate in that historically it has not experienced natural disasters in the form of earthquakes, volcanoes and typhoons. The most common natural disaster frequently encountered in Malaysia is flooding. Two major types of floods occur in Malaysia, namely monsoon floods and flash floods. The Department of Irrigation and Drainage (DID) in Malaysia has estimated that about 29,000 km^2, or 9%, of the total land area and more than 4.82 million people (i.e. 22% of the population) are affected by flooding annually. The damage caused by flooding is estimated to be about US$310 million (Chan 2005).

While monsoon floods are governed by heavy and long-duration rainfalls, more localized flooding, which occurs especially in newly developed town areas, has been reported more frequently in recent years. In October 2003, major flooding affected a large area in the northwestern part of Peninsular Malaysia, including the states of Kedah, Penang and Northern Perak. The December 2007 flood, on the other hand, occurred in the state of Pahang, after more than 30 years (DID 1974) since the last flood of a similar magnitude in 1971. Flash floods have occurred more frequently in the country since the 1980s, with this type of floods often having a drastic impact.

Several major floods have been experienced in Malaysia in the last few decades. Flood occurrences seem to be getting more frequent in recent years, especially in some cities such as Kuala Lumpur, Penang and Kuching, where rapid urbanization is taking place. The business of flood control and mitigation seems to be closely associated with the development of Malaysia. After the occurrence of several dramatic flooding events in the country, causing substantial losses of lives and property since the 1960s, the government has taken several positive steps to develop flood mitigation projects in its national plans. These have been facilitated by the establishment of the Natural

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Disaster Relief Committee in 1972 and the Permanent Flood Control Commission on 21 December 1971 specifically to study short-term measures to prevent the occurrence of floods and long-term measures for flood mitigation. Both structural and non-structural flood mitigation measures have been developed by the DID to be implemented for 17 major river basins and 27 towns nationwide including the Sungai Pahang basin. The objective of river basin studies is to draw up appropriate flood maps and also feasible projects for the respective basin areas so that their development is properly managed and that water resource management, including flood control measures, is effective and well controlled. These studies recommend the optional flood control planning and design criteria for the respective basins. Generally, socio-economic considerations for the basin dominate the design criteria (Chia 2004).

In recent years, DID has become more conscious of the need to carry out flood mitigation projects on a river basin basis rather than on a piecemeal basis. This kind of approach will involve a shift from traditional thinking in terms of controlling flooding through expensive engineering structures to the more comprehensive approach of viewing the solution in terms of managing flooding by incorporating structural as well as non-structural measures. In this paper, results are presented to formulate the study objectives, that is, digitally map the 2007 flood inundation areas along Sungai Pahang by gathering hydraulic and hydrological data. In this study, a digital map of the 2007 flood inundation areas in the Sungai Pahang basin was developed by gathering available hydraulic and hydrological data.

2 Study area

The Sungai Pahang basin (Figure 1) is located in the eastern part of Peninsular Malaysia and drains an area of 29,300 km^2, of which 27,000 km^2 lies within Pahang (about 75% of the State) and 2300 km^2 is located in Negeri Sembilan. Sungai Pahang is the longest river in Peninsular Malaysia of about 435 km. Sungai Pahang originates at Kuala Tembeling as a result of the confluence of two equally large and long rivers: Sungai Jelai and Sungai Tembeling. Other main tributaries of Sungai Pahang are Sungai Semantan, Sungai Teriang, Sungai Bera and Sungai Lepar.

Sungai Pahang begins to flow in a south east and south direction, passing along several major towns such as Kuala Lipis, at the mouth of the river bearing the same name on Sungai Jelai; Jerantut, the gateway to Taman Negara Sungai Tembeling; Temerloh, midway on the river at its confluence with Sungai Semantan; and finally turning eastward at Mengkarak in the central south of the catchment and flowing through the royal town of Bandar Diraja Pekan near the coast before discharging into the South China Sea.

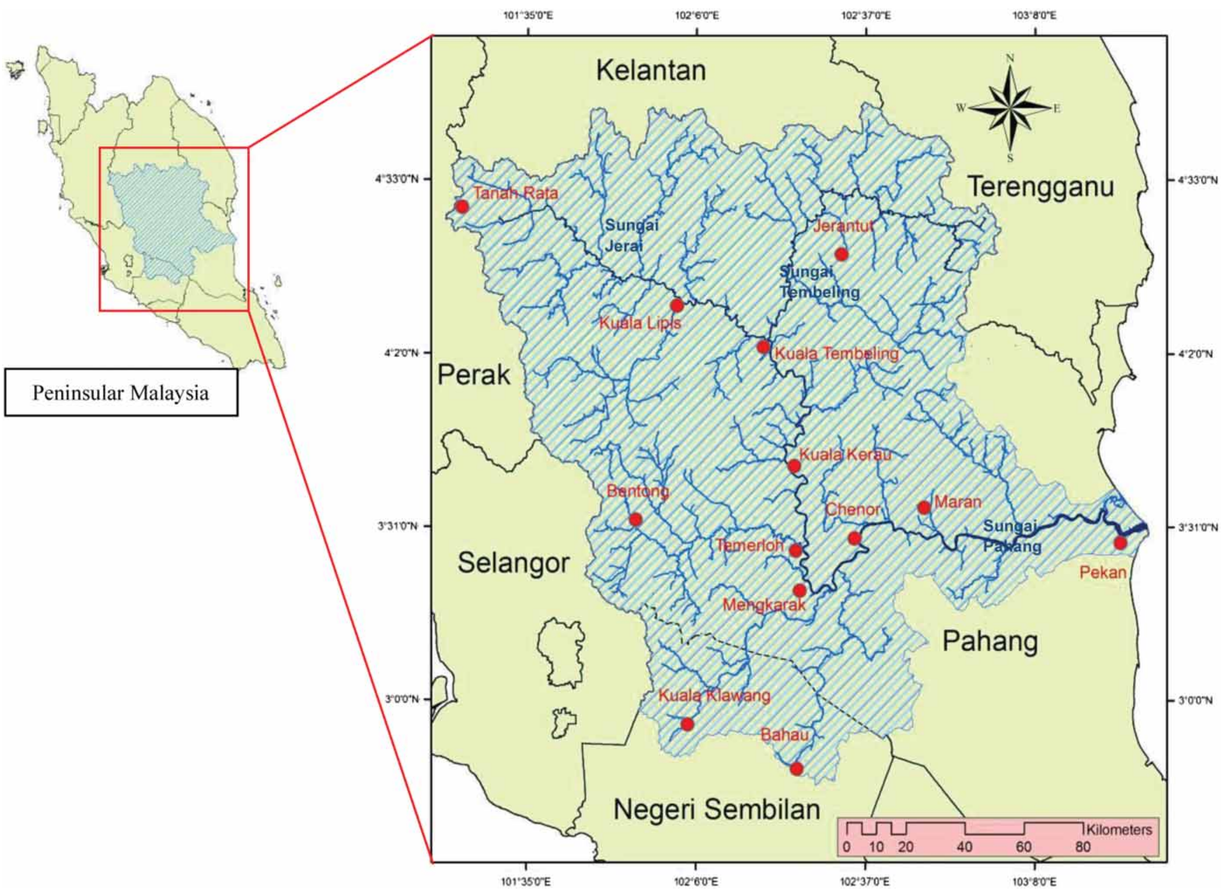

Figure 1 Sungai Pahang basin delineation

Table 1 Details of the Sungai Pahang basin

Location	Central part of Peninsular Malaysia, sandwiched by the Titiwangsa Range in the west and the Timur Range in the east, both of which expand in the north-northeastern direction.
Area	29,300 km^2
Length	435 km
River bed slope	Sungai Pahang: 0.016% (1/6200)
	Sungai Jerai: 0.034% (1/2900)
	Sungai Tembeling: 0.024% (1/4100)
Population	1,190,000 (2010)
Geographical regions	Tributaries: Tembeling, Jelai, Lipis, Tekman, Kerau, Semantan, Triang, Bera, Jengka, Jempul, Luit, Mentiga, Lepar and Serting
	Main lakes: Lake Bera and Lake Chini
Land use	Virgin jungle, rubber, paddy, oil palm, other agricultural crops and urban
Ecosystems	Lowland tropical rainforests:
	Lowland Dipterocarp forest: usually dense, with many thousands of species of trees as well as shrubs, herbs and woody climbers
	Hill Dipterocarp forest: similar to lowland Dipterocarp forest
	Upper Dipterocarp forest: characterized by *Shorea platyclados*
	Lower and upper montane forest: *Fagaceae* and *Lauraceae*, *Preris ovalifolia*, *Rhododendron spp.* and *Vaccinium spp.*
	Peat swamp forests and mangrove forests: along the coast
	Forest plantation: *Pinus caribaea*, *Araucaria spp.*, *Acacia mangium*, *Gmelina arborea* and *Paraserianthes falcataria*
Climate	Daily minimum and maximum temperatures are around 23°C and 32°C (except in the highland area)
	Annual rainfall varies from approximately 1700–2800 mm within the basin (mean annual rainfall obtained from 10-year rainfall data of 1999–2008 is 2136 mm)

Source: Summarized from JICA (2011).

The Sungai Pahang basin has an annual rainfall of about 2136 mm, a large proportion of which is brought by the North-East Monsoon between mid-October and mid-January. Due to the gentle terrain, the flow velocity drops and the river channel of the Sungai Pahang proper is wider and shallower than that of Sungai Jelai and Sungai Tembeling. The mean flow of Sungai Pahang measured at Station 3527410 (Lubok Paku), which is the most downstream stage station in the Sungai Pahang basin, is 689 m^3/s based on the latest 10-year (1999–2008) data (Japan International Cooperation Agency (JICA) 2011). Details of the Sungai Pahang basin are given in Table 1.

2.1 *Historical flood conditions*

Several major floods have occurred in the last few decades in the Sungai Pahang basin, causing extensive damage and inconvenience to the local community. According to historical records, the flood of 1926 that affected most parts of Peninsular Malaysia is supposedly the worst in living memory. However, official records are insufficient to describe the condition of that flood in detail. In January 1971, a catastrophic flood again swept across many parts of the country and it is considered as the second largest flood on record. Pahang was severely affected, suffering great economic losses to properties and crops, with the inundated area of about 3000 km^2, 150,000 evacuees and loss of 24 lives. This led experts to conclude that the estimated flood damage was around US$38 million including the intangible damages. The scale of the 1971 flood is over the 100-year annual recurrence interval (ARI) based on hydrological probability analysis using the mean 8-day rainfall records (DID 1974).

The December 2007 flood can be considered as the third largest flood in the Sungai Pahang basin in terms of basin mean 8-day rainfall. The water level exceeded the danger level at the Lubok Paku, Temerloh and Pekan stations. According to field survey, the inundation depth ranged from 1.0 to 2.0 m in Pekan Town Center and from 0.5 to 2.0 in the major towns in Temerloh and Maran districts. The long-duration flood forced people to stay at designated evacuation centres in Rompin, Maran, Kuantan, Pekan, Raub, Bera, Jerantut, Bentong, Temerloh and Kuala Lipis districts for as long as 22 days. A total of eight casualties were also recorded in the state of Pahang, with one casualty at Rompin, two at Pekan, three at Temerloh and two in Maran district, respectively. The flood damage was estimated at US$ 86 million by DID (JICA 2011). A flood map, which was delineated by DID using satellite images, is shown in Figure 2.

3 Study approach and model development

Two common approaches used for reducing the impact of flood problems have been increasingly adopted in Malaysia, namely structural and non-structural measures. Structural measures include river widening, deepening and straightening, with the aim being to reduce the magnitude of the inundation, but at the same time this approach often transfers the flooding problem further downstream. For non-structural measures, tools such as

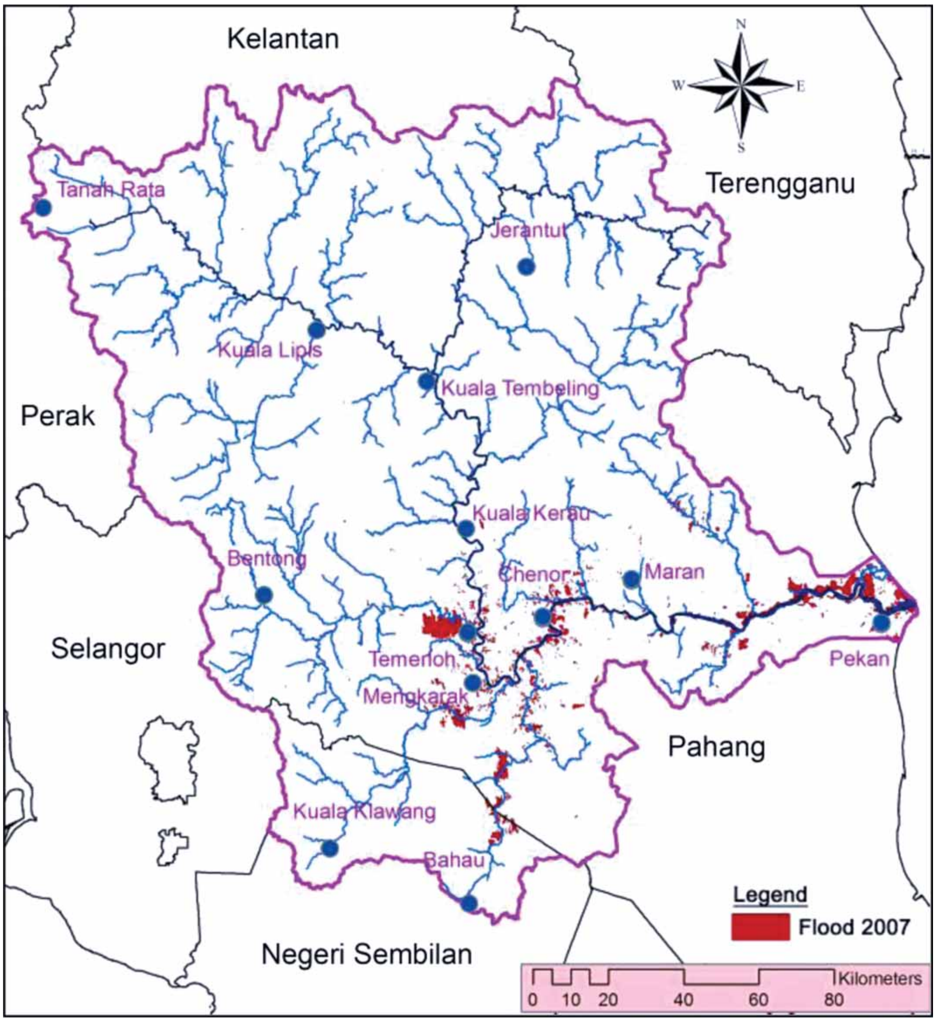

Figure 2 Sungai Pahang flood map for December 2007 (after DID 2007)

computer models can be used to quantify the effects of human interference on the river system. Such tools are already available and widely used in many countries worldwide, but the application of sophisticated models is still relatively new in Malaysia (Chang *et al*. 2008, Leow *et al*. 2009, Ab. Ghani *et al*. 2010, Liew *et al*. 2012). One reason for the limited use of such models in Malaysia is that the tools often do not properly model the more extreme flood events, where the river flows are often supercritical. In Malaysia, it is regarded as increasingly important to carry out a thorough analysis of flood events with the help of the available river models to understand the flood behaviour before undertaking any structural measures. Therefore, before implementing any amendments within a river basin, river engineers must evaluate the potential extent and impact of flood events and advise the implementing agencies as to what steps should be undertaken to provide further preventive measures to avoid the anticipated flood problems that might occur (Ab. Ghani *et al*. 2009).

3.1 *Flood information gathering*

The types of data used in this study for building the model of the 2007 flood event are as follows: a digital topographical map, satellite images, land-use data, soil data, hydraulic and hydrological data (flow discharge hydrographs and water level and tidal data), flood inundation area data and field observations. Interviews with local people and on-site ground survey and validation (Figure 3) were also used to ascertain the true picture of the 2007 flood.

3.2 *Inundation area mapping*

The mapping first involved the creation of a terrain model. The NASA Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) (90 m $\times$ 90 m) was used to profile the terrain. SPOT-5 satellite images that were obtained were then overlaid and georeferenced to better describe the geographical features of the study area. Figure 4 presents the flowchart describing the procedures executed to produce the corrected DEM. As the SRTM DEM comes with approximately 10-m absolute error (Rodriguez *et al*. 2006), it was not quite sufficient for flood mapping. To improve the DEM, more than 150 exact field elevation points were collected using differential global positioning system (DGPS) with a vertical accuracy of less than 0.3 m in a field survey exercise in May 2010. The points were used to

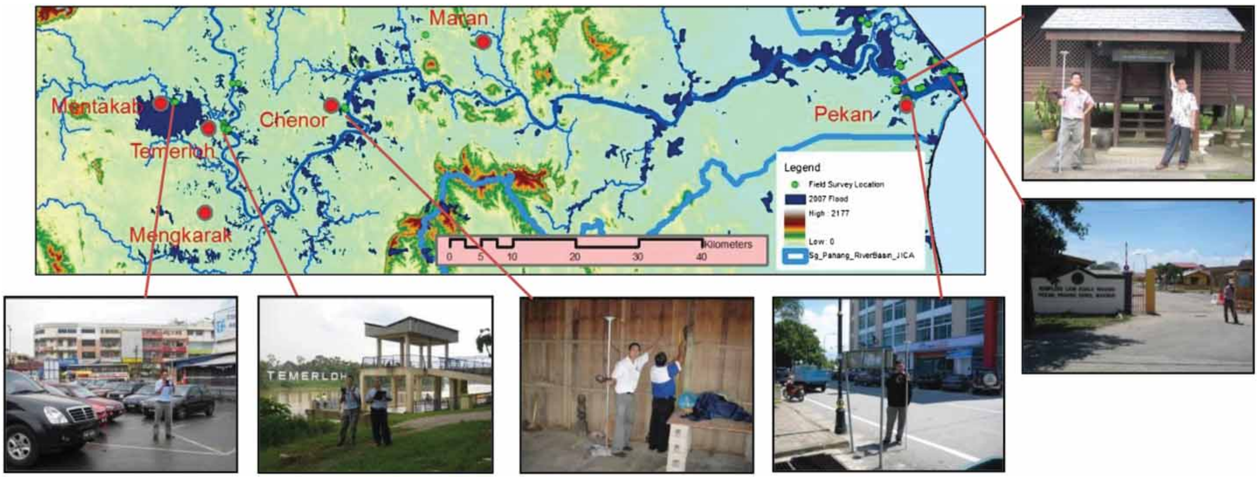

Figure 3 On-site ground survey and validation using professional data mapper for GPS data collection and mapping (Ab. Ghani *et al*. 2011)

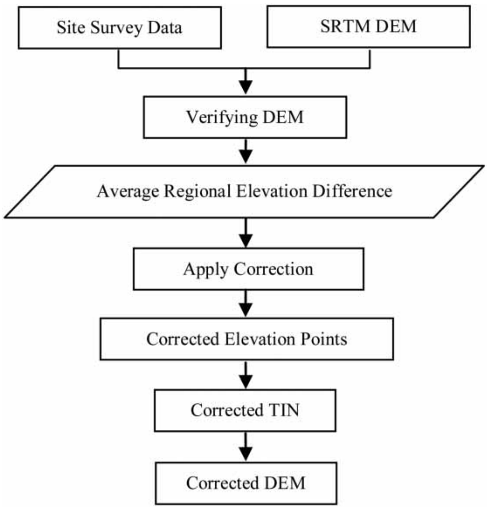

Figure 4 DEM development

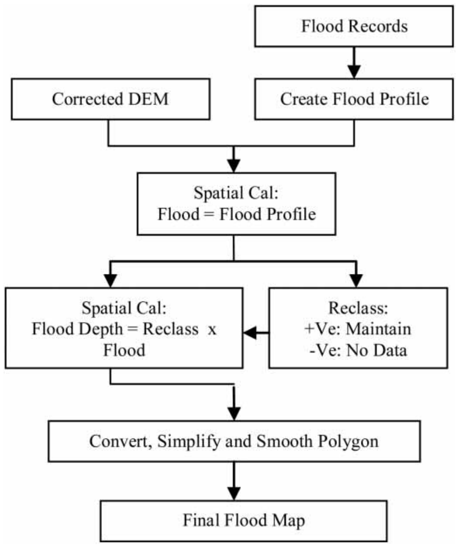

Figure 5 Flood map development

compare the DEM elevations of the same locations. The discrepancies were averaged out and applied as corrections to the DEM. This enhanced DEM was then used for flood mapping.

In order to describe the flood, maximum water levels at four gauge stations (namely, Temerloh, Mengkarak, Chenor and Triang) during the 2007 flood were used. A linear interpolation method was used to profile the water level gradient along the river. The result was converted into a triangulated irregular network (TIN) and subsequently a raster file. By overlaying the flood profile raster on the DEM, areas where flooding occurred (flood raster > DEM) can be identified. These areas are then reclassified and generalized to form the flood inundation map for the study area. The records of flood elevation obtained can then be profiled into the DEM to study the actual extent of the flood. The geographic information systems (GIS) workflow used to produce this flood inundation map is described in Figure 5, while Figure 6 shows the obtained DEM with the SPOT-5 satellite images overlaid.

3.3 *Hydraulic and hydrological data analysis*

The analysis of hydraulic and hydrological data will benefit and provide data for future hydraulic modelling works. Accurate information about the flow rates of rivers is important for a variety of hydrological applications such as water and sediment bed material load estimation, water resource planning, operation and development, and hydraulic and hydrological modelling (Guven and Aytek 2009). However, collecting discharge data on a continuous basis is costly, especially during large flood events. An alternative approach is to convert records of water stages into discharges using a stage–discharge relationship. In this study, a mathematical model for the estimation of stage–discharge relationships based on gene expression programming (GEP) techniques was used. GEP is a new evolutionary artificial intelligence technique developed by Ferreira (2001). This technique is an extension of genetic programming, developed by Koza (1992).

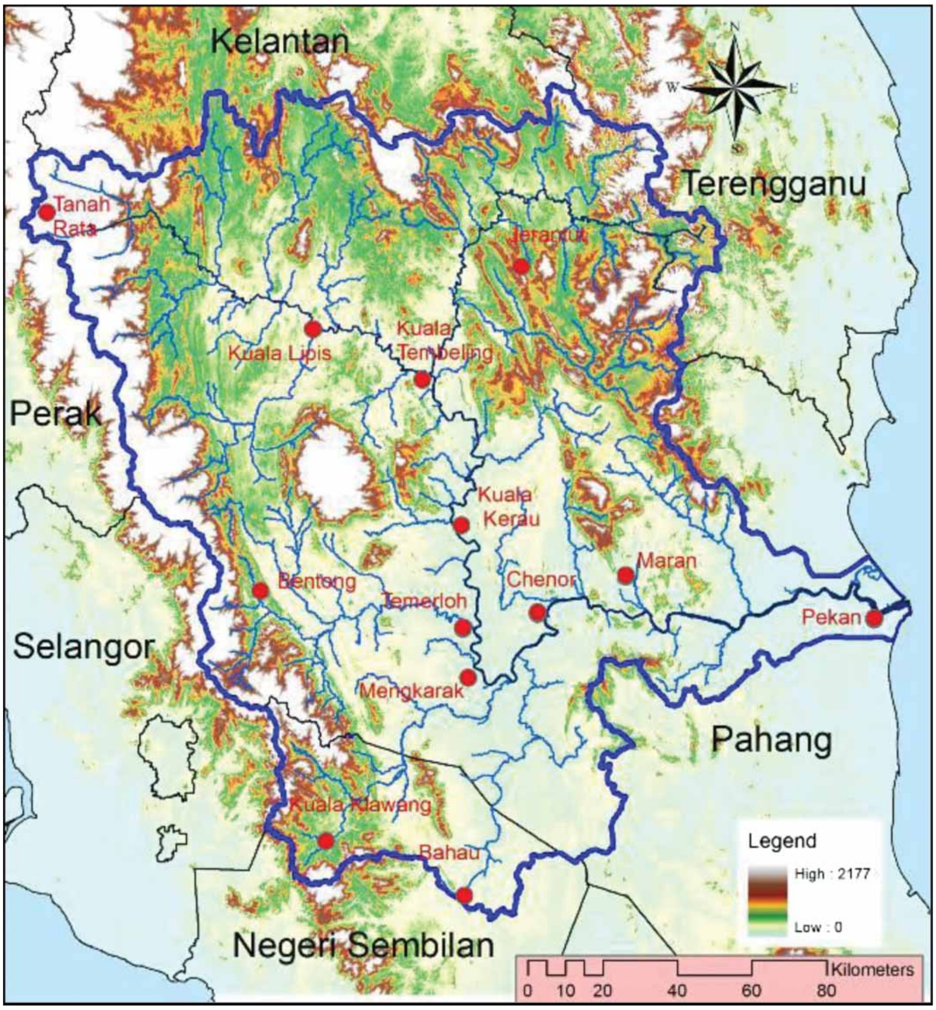

Figure 6 DEM development (Ab. Ghani *et al*. 2011)

The daily discharge data collected at Station 3424411 (Temerloh) for the year 2007 were chosen for the training of the proposed GEP models, and the 2004 daily discharge data were chosen for the testing. The 2007 daily discharge data were chosen for training because the worst recent flood occurred in that year and the range of discharges also gave a wider spectrum. Training with a wider data spectrum can ensure a robust model to predict discharges over a wider range and better estimation of maximum flooding in extreme events (Azamathulla *et al*. 2011). The discharge (Q) was modelled in terms of the stage (S) using a GEP approach. Initially, the 'training set' was selected from the entire data set and the rest of the data were used as the 'testing set'. Once the training set is selected, one could say that the learning environment of the system is defined. Detailed modelling, which includes five major steps to prepare the GEP for use, is described in Azamathulla *et al*. (2011). The explicit formulation of the GEP for discharge as a function of stage was obtained in a simplified form as follows:

$$Q = 9.84S^2 - 64.391S - 4033.296.$$

Figure 7 shows the expression tree for the above formulation.

4 Results and discussion

4.1 *Digital flood map*

A comparison was made between the simulated flood map and the DID flood map (delineated using satellite images) in order to verify the performance of the SRTM data set for flood inundation mapping. To achieve this, an indicator proposed by Horritt (2006) was used. Equation 2 gives the mathematical expression of the indicator:

$$F = \frac{A - B}{A + B + C},$$

where F is the goodness of fit, A is the wet area correctly predicted by simulation, B is the wet area wrongly predicted as dry (under prediction) and C is the dry area wrongly predicted as wet (over-prediction). An F value close to 1 indicates that the model flood extent prediction is close to the observed flood inundation area.

An assessment using the indicator given by Eq. 2 was made for flooding in the region between Mentakab and Chenor. Table 2 summarizes the calculations and results. The areas

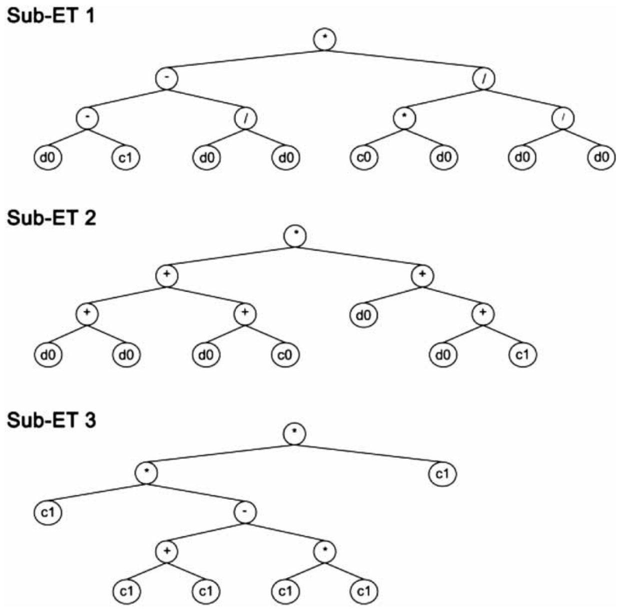

Figure 7 Expression tree for the GEP formulation for the Temerloh Station, where $d0 = S$

required were derived using GIS. The results were also mapped on the same sheet for comparison (Figure 8).

It can be observed that the result for flood map verification is not encouraging. With $F = -0.312$, it can be said that the produced flood maps are not in good agreement with the actual

Table 2 Verification of flood inundation map

Parameters	Area (km^2)
Total test area	1411.06
Predicted flood	104.79
Actual flood	149.42
A	41.55
B	107.86
C	63.24
F	-0.312

flood condition. This poor result can be attributed to the following:

- Accuracy of the DEM. While an effort has been made to apply the correction, it is perhaps not sufficient. On top of that, the correction applied also contains uncertainties. The current elevation correction is very crude, that is, there is no consideration for vegetation/building removal prior to correction. This will affect the DEM.
- Lack of water level station, especially for the tributaries. As shown in Figure 8, a large flood area was missed by the model, as it is beyond the most upstream gauge (Temerloh). The linear extrapolation method used in this study is clearly not sufficient to profile floods coming into the Pahang River from the tributaries.

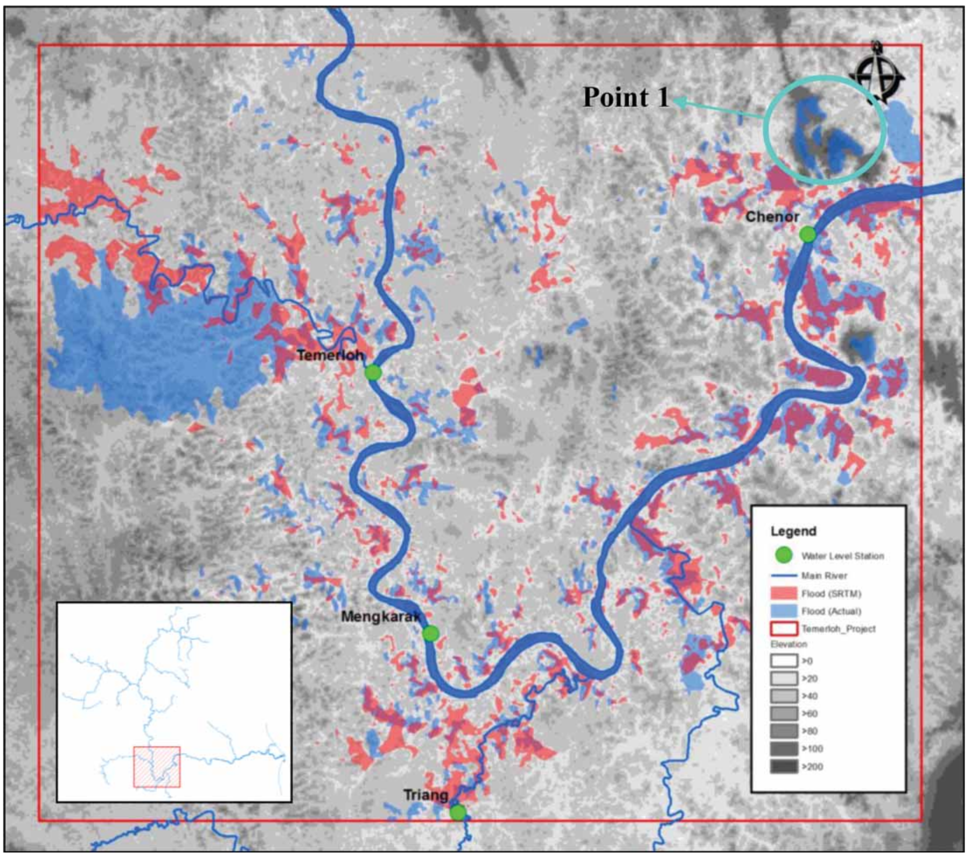

Figure 8 Comparison of flood inundation area of the model with actual conditions (Ab. Ghani *et al*. 2011)

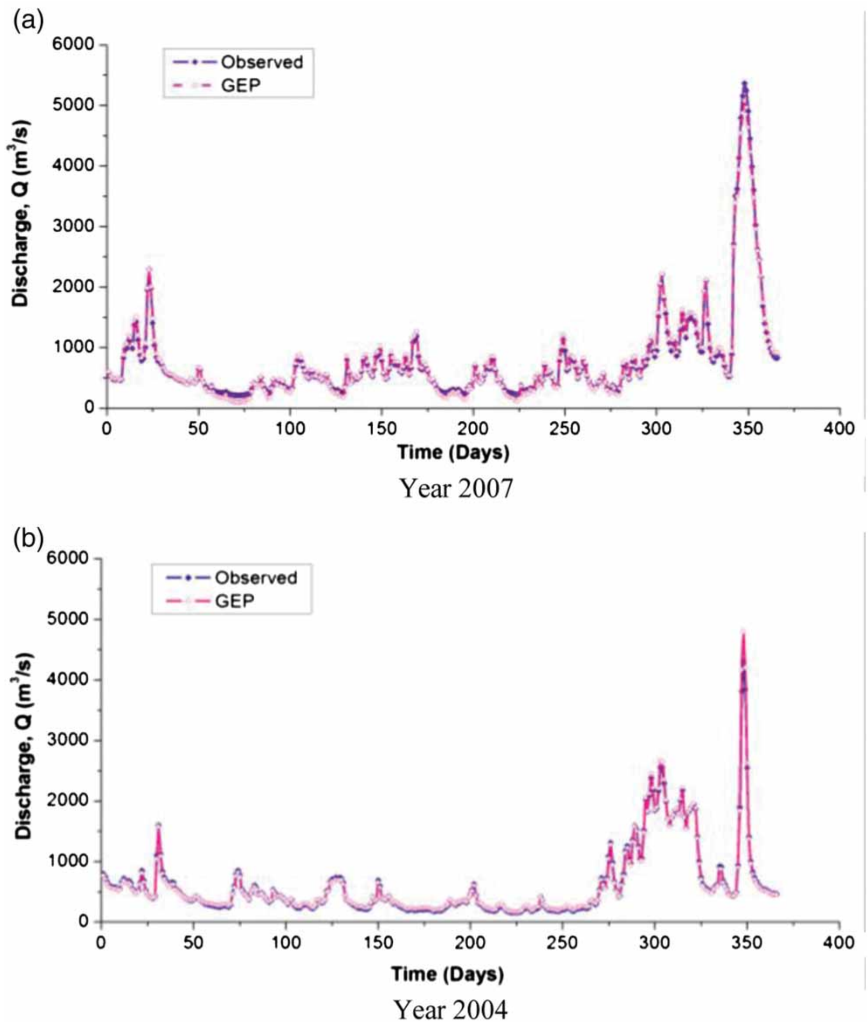

Figure 9 Scatter plots in the GEP-based training period for the Temerloh Station (Azamathulla *et al*. 2011): (a) year 2007 and (b) year 2004

- Uncertainties in flood delineation from satellite. While this is the most convenient way to derive a flood map for a large area, there are uncertainties involved in this process. For example, floods in tropical climates typically occur during the monsoon with a heavy cloud cover, which requires cloud removal that induces uncertainty in the map. One example would be Point 1 (Figure 8) where flooding is indicated on the ground with an elevation that is much higher than that in the observed flood stage.

In response to these weaknesses, the authors are currently improving the methodology with the following enhancements:

- Further site survey to collect more DGPS points. With a larger sample that covers a wider area, the reliability of the correction to be applied can be increased.
- Development of a mechanism to remove building/vegetation height from the DEM to create a digital terrain model which will better represent the terrain of the study. Instead of applying regional corrections, corrections will be determined based on land-use type, where each land use would have a certain average height of vegetation or building to be removed.

4.2 *Hydraulic and hydrological data analysis*

Different input sets of daily stage–discharge records were developed to calibrate the GEP models. The GEP estimates were then compared with the observed data via scatter plots for the training (Figure 9(a)) and the testing (Figure 9(b)) sets. As shown in the figures, it is evident that the proposed GEP model determined the nonlinear relationship between the input and the output variables impressively well, with an R^2 of 0.993 and an root mean square error (RMSE) of 62.34 m^3/s. The comparison of the GEP predictions with the observed data for the test stage demonstrated a high generalization capacity with $R^2 = 0.945$ and RMSE $= 78.98$ m^3/s for the 2004 data. Therefore, the modelling demonstrated the acceptable performance of the GEP models for estimating discharge in both the training and testing stages.

4.3 *Proposed structural and non-structural works*

It was observed that flooding in this river basin is extensive starting from Temerloh. It can be argued that the excess flow from headwaters could not be contained within the river channel starting from this point. As water overspills the river banks, flooding

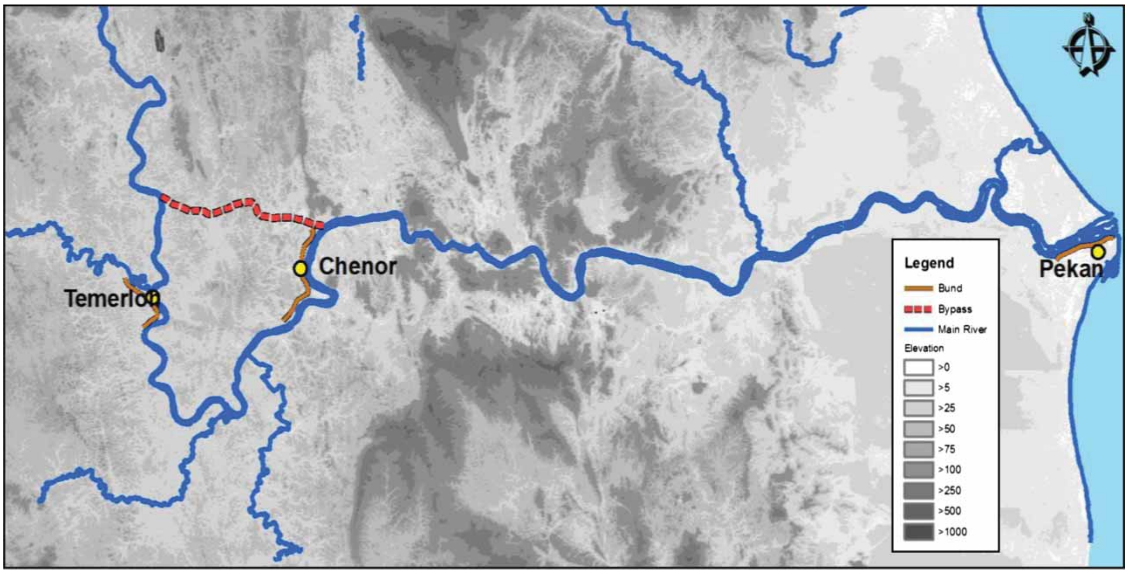

Figure 10 Proposed flood mitigation alternatives for Sungai Pahang (Ab. Ghani *et al*. 2011)

occurs in a very extensive manner, submerging a large area of land, including riverside towns.

These observations have led to the proposed construction of a flood bypass channel and a stretch of river bund along the channel (Figure 10). First a flood bypass channel was proposed to provide an alternative route for flood water before it enters Temerloh. The channel will directly convey the flood water further downstream, limiting flood damage in Mentakab and Temerloh. As the flow is redirected, it is estimated that the flood level would drop. However, critical areas such as Temerloh and Chenor townships would require bund constructions along their river banks. Details of the proposed bund such as height, length and distance from the main channel would require further study.

In the next phase of the study, a hydrodynamic model would be used to gauge the performance of these flood mitigation alternatives. First, the DEM will be modified to include the bypass channel and river bunds. Hydrodynamic model simulation based on the 2007 flood would be used as the hydrological input. The reduction in flood depth and extent would be used to gauge the performance of the proposed alternatives. The hydrological and hydraulic regime and response of the entire river system will also be investigated to ensure the sustainability of the proposed alternatives.

5 Conclusions

A thorough analysis of flood events with the help of the available river models to understand the flood behaviour before undertaking any structural measures is a better option before implementing highly expensive flood mitigation projects. DEM development for a major river basin such as Sungai Pahang is deemed very important before any river modelling is applied. As such, this study developed the required DEM for Sungai Pahang utilizing the 2007 flood data and reconnaissance data from field survey, although some further improvement is required. It is hoped that the final DEM will help improve the river modelling results for better planning and flood mitigation options.

GEP was also used as an alternative tool for modelling the stage–discharge relationship for the Sungai Pahang basin in this study. The RMSE and R^2 values were calculated to measure the deviation from and approximation of the observed flows obtained from the Temerloh station. The overall results produced R^2 values very close to 1, suggesting very little discrepancy between the observed and the predicted discharges. Besides this, the RMSE remained at a very low level, also confirming GEP as an effective tool to be used for forecasting and estimating daily discharge data in flood events.

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