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Development of an Intelligent Decision Support System for Flood Mitigation in the Pahang River

Faisal Nadeem Saher[1*], Nasly Binti Mohamed Ali[1], Wan Mohd Faizal Bin Wan Ishak[2], and Mohd Abdul Nassir Bin Bidin[3]

[1] Faculty of Civil Engineering & Earth Resources, University Malaysia Pahang
[2] Centre for Earth Resources Research & Management, University Malaysia Pahang
[3] Flood Management Divisions, Department of Irrigation and Drainage Malaysia

Abstract

This is an established truth that with the growing world, the flood hazards cannot be avoided but the technology is a solution to minimize this process. A sustainable development depends on plans, which are designed on the strong basis of comprehensive datasets. Managing river is an acute and more attentive area where it faces heavy water feeds due to rains. Malaysia is going on fast development including infrastructural developments and change of land uses from forest cover to other non-green land uses. Adopting innovative products for flood mitigation are required as an integral part of local design transformation. Keeping this fact in view, the vulnerability which may cause due to floods in Pahang River seems to be a threat for the sustainable development of the area. The general objective of this study was to propose a visual aided decision support platform providing an ease but acceptable level of strategy. Presented prototype includes modelling and GIS based visual aids. A study of Pahang River in Malaysia conducted, to explain the applications of the prototype. To achieve this goal a geodatabase, consisting of different hydro-informatics data layers, has been developed. Further work on modified models for better forecasting under real time data input and design of innovative self-protecting flood mitigation at industrial and house hold level is identified as future research area. Under this research studies, the required datasets were generated using remote sensing and GIS system integrated with field GPS surveys. The methodology adopted to achieve the desired goals and to combat the complexity of the hydro-geodatabase of Pahang River drawn from the idea to integrate the engineering tools with the geo-informatics techniques

Keywords: *Flood mitigation; decision support system; GIS; river management*

1. Introduction

The river management is a critical and more focused area where the Malaysian rivers receive heavy water feeds due to rains and high-sloped catchments. The Pahang River is an example of such a situation, and it receives a runoff due to 220 mm average monthly rainfall. Malaysia is on a fast track of development in infrastructure and focusing on a transformation process of the economy. Keeping this fact in view, floods in the Pahang River may become a cause for disaster, and it seems to be a threat for the sustainable development in this area.

The Pahang River is the main channel to drain off water from the inundated area of the Pahang Basin to the South China Sea during the rainy season,

* Corresponding author: saher.gis@gmail.com

which is caused by the northeast monsoon. Most of the inundations of lower areas of the Pahang River Basin were caused by overflowing of the Pahang River. In order to safeguard the sustainability of water resources, the Pahang River Basin requires a sustainable system of water database and full participation of all levels of stakeholders to articulate the key issues of flood hazard.

The development of the country is an ongoing process interconnecting to economic parameters. Water resources of any country are considered a hub to uplift and to gear up the growth of the economy. Hence, the Pahang River is not only a source of water but also a source to ensure the economic development of the country in a sustainable manner. Therefore, it is of utmost importance that all stakeholders contribute as a joint venture with the government towards an effective and sustainable management of river basins in Malaysia.

2. Research Objectives

Following are the objectives of the research study:

1. Integration of datasets

– Integration of datasets (maps, topographic sheets, satellite imagery, hydrological data, and land use) for the Pahang River Basin

– To integrate the findings of the research study to develop source data for Decision Support System for the Pahang River Basin

2. Framework Development of Intelligent Decision Support System (IDSS)

– Development of hydro-database in the environment of GIS

– To investigate data-driven modelling and computational intelligence tools for water management/planning in the Pahang River

3. Development of a visual aided DSS prototype to mitigate the flood hazards as a data access system for flood management of the Pahang River Basin

3. Decision Support System

A decision support system (DSS) helps the users to resolve the complex problems interactively for reliable decision development (Turban et al., 2007). However, the complexity of the problems can be simplified to come up with an understandable action plan. The professional community has put considerable effort into developing more sophisticated DSS through an attempt of integrating different models with GIS. Under a similar case, a hybrid approach for flood risk zones mapping and impact of flood occurrences by integrating GIS and HEC-RAS was testified with reliable outputs (Yerramilli, 2012). It is becoming difficult to ignore the current systems of decision analysis that consider the policy concerns. A web-based, DSS prototype tool developed by (Salewicz and Nakayama, 2004) is an example of focusing on the consequences of relevant policies for river management. Another leading cause is a shift from flood protection towards flood risk management. This shift represents a progressive change to avoid uncertainties in different decision situations (Liu et al., 2013).

4. Movement of Flood Waves

The movement of a flood wave down a channel or through a reservoir, and the associated change in timing or attenuation of the wave constitutes an important topic in floodplain hydrology. It is essential to understand the theoretical and practical aspects of flood routing to predict the temporal and spatial variations of a flood wave through a river reach or reservoir. Flood routing methods can also be used to predict the outflow hydrograph from a watershed subjected to a known amount of precipitation. The storage routing concept is most easily understood by referring to Figure 1. Inflow and outflow hydrographs for a small level surface reservoir have been plotted on the same graph (Figure 2). Area A represents the volume of water that fills available storage up to time t_1. Inflow exceeds outflow and the reservoir is filling. At time t_1, inflow and outflow are equal and the maximum storage is reached. For times exceeding t_1, outflow exceeds inflow and the reservoir empties. Area C represents the volume of water that flows out of the reservoir and must equal area A if the reservoir begins and ends at the same level. The peak of the outflow from a reservoir should intersect the inflow hydrograph as shown in Figure 2, since outflow is uniquely determined by reservoir storage or level.

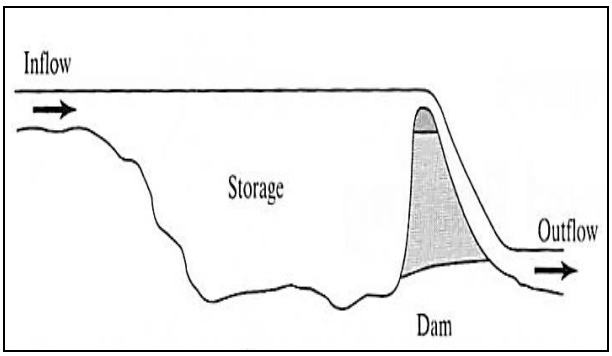


Figure 1: Reservoir Storage Concept

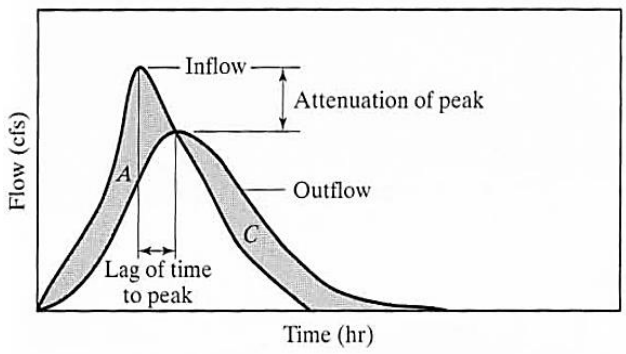


Figure 2: Inflow and Outflow of a Reservoir

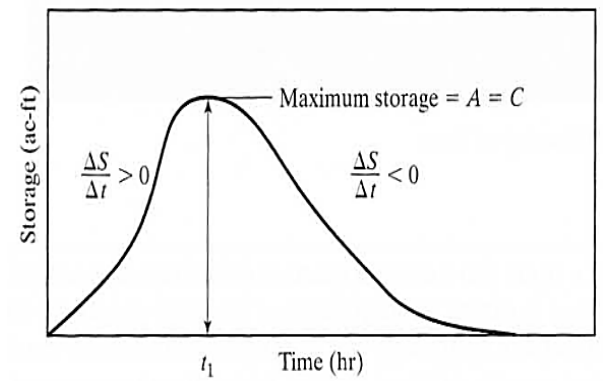


Figure 3: Storage in a Reservoir

It can be seen that storage routing through a reservoir will generally attenuate the peak outflow and lag the time to peak for the outflow hydrograph (Figure 3).

The rate of change of storage can be written as the continuity equation

$$I - Q = {}^{\Delta S}/_{\Delta t} \qquad (1)$$

Where I = inflow
Q = outflow
ΔS = change in storage
Δt = change in time

5. Research Organization

A research methodology is a set of procedures and tools that are used to perform the research and target the main agenda. To ensure the accuracy of results, different ways of data handling and modeling are planned. Further sections of this paper will elaborate all procedural approaches and tools that are used to produce the results-oriented research (Figure 4).

6. Components of IDSS and Methodology

There are limitations with the methodology provided in Figure 4 due to the linear relation between the involved processes.

The second issue would be the longer time to get the alternatives. These limitations are avoided to develop a modified methodology to develop the Intelligent Decision Support System (IDSS) for flood mitigation. This developed methodology is used (see Figure 5).

This developed methodology would serve a major role to make an effective Planning Support System for strategic flood mitigation of the Pahang River Basin. The salient features of this IDSS-PRB are elaborated in a radial diagram (see Figure 6).

7. Development of IDSS and Implementation

In this research, flood related issues are investigated and a framework of data analysis, simulation, and practical implementation is developed. However, system reliability and accuracy is the main focus during all the steps involved to generate such a system.

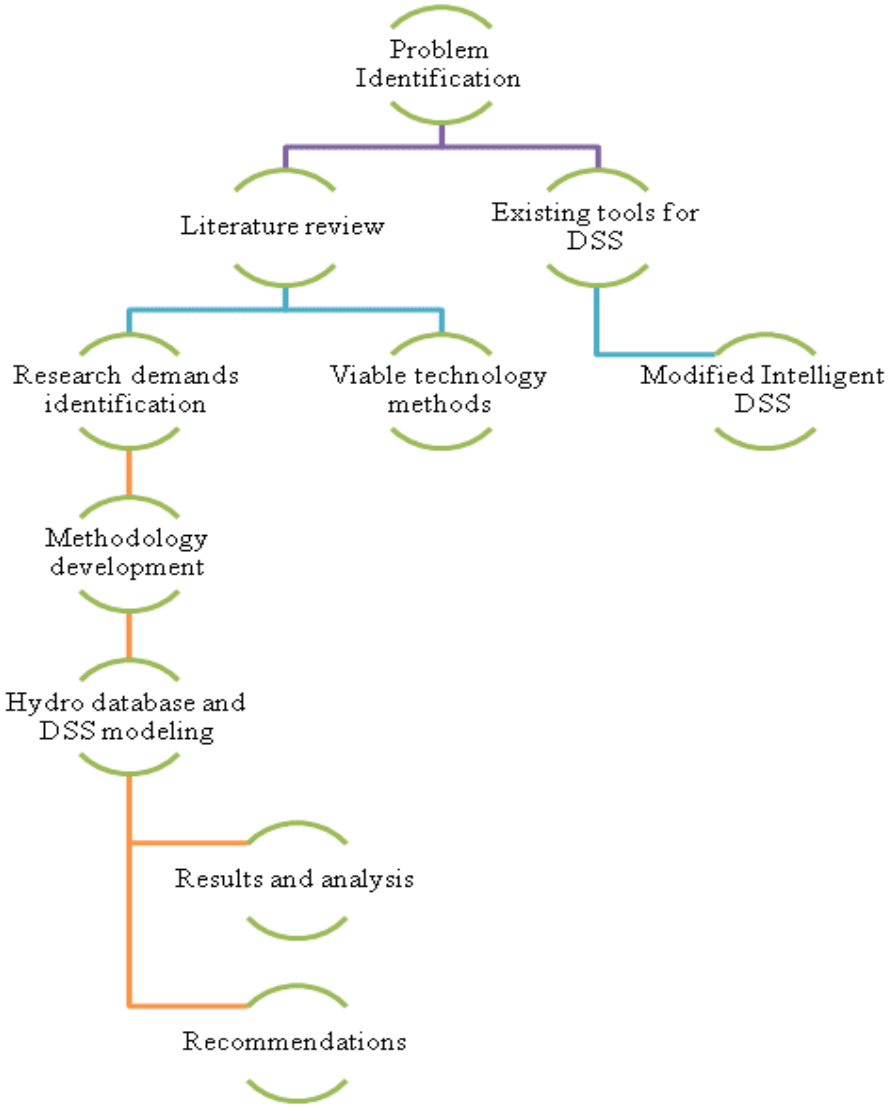


Figure 4: Research Organization Chart

To make a smooth flow for the research work, and finally its deployment in the field, would be done through three phases. These phases and involved processes are provided in Figure 7.

8. Visual Aided DSS Prototype

Figure 8 gives the simulated results for the Pahang River flows under impact of flood mitigation programs.

As a comparison, other studies demonstrated that combining GIS outputs and XP-SWMM for hydrodynamic simulation, the obtained results would prove to be more sophisticated as a tool for flood forecasting and a flood warning system (Mastura et al., 2009). In this case, we may consider these facts to involve the flexibility in the proposed prototype so that users would be able to use different models. This situation will lead to a more adoptive system of integration for improved DSS process. A GIS model transferred to XP-SWMM model is shown in Figures 9 and 10.

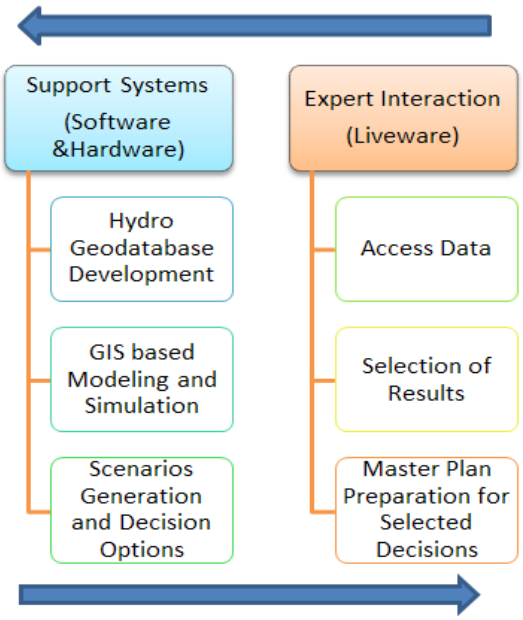


Figure 5: Intelligent Decision Support System for the Pahang River Basin

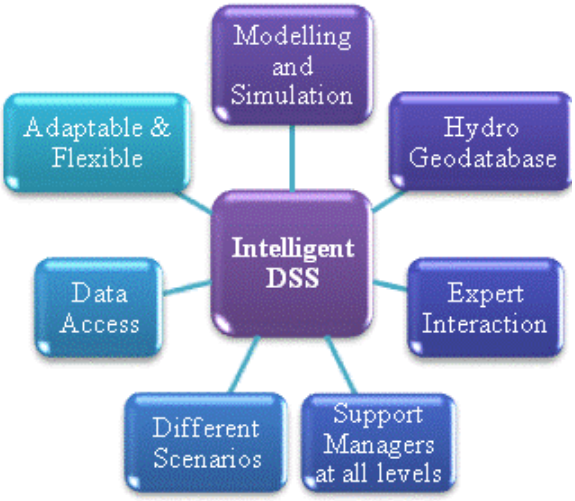


Figure 6: Salient Features of IDSS-PRB

9. Summary of Major Findings

In recent years, a methodology has been discussed for improving the interactions between the professionals and other stakeholders for decision-making processes in water management (Ceccato et al., 2011). Keeping in view all the participants concerned with the decision, it shows the importance of a system capable of depicting the datasets with visual aids.

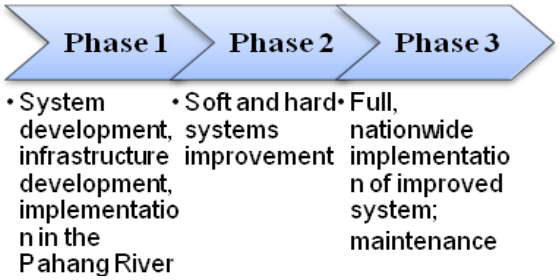


Figure 7: Phasewise Application of IDSS and System Improvement

During the study of flood behaviour of rivers, the impact of tidal cannot be spared, as it becomes necessary to predict the routing of floods under tidal influence. This issue was highlighted by (Leung et al., 2005). The problem is to include these factors at one platform to forecast flood risk and accordingly preparation of mitigation plan. The present study is designed to determine the problem solution and to adopt more sophisticated decision-making tools. In the future, the risk of floods to our lives is dependent on the existing flood measures (Mirfenderesk, 2009). As a policy for future planning, a system of water monitoring would be required to improve the decision support systems as an effective source of planning (Dlamini, 2007). Several attempts have been made to develop a user-friendly system of DSS at windows environment with a capacity to select the appropriate model for analysis (Leung et al., 2005, De Martino et al., 1998).

The limitation of these systems is the demonstration of the decision options as dynamic views. This dynamic visualization can enhance the mapping features (Kubíček and Staněk, 2006). Some other researchers use the concept of dynamic graphing tools and dynamic 3D flood information (Halls, 2003, Schulte and Coors, 2008). Simultaneously, use of the integration concept is stimulated through the growing tendency of visual enhancement processes. In decision sciences, the decision process involves different tools, such as artificial intelligence, data mining, online analytical processing, and knowledge management (Rayed, 2012). The DSS may focus on four categories: I) data, II) improving the user interface, III) models, and IV) development of web-based applications (Aggarwal, 2001). The current study has considered the enhancement of user interface with dynamic display of data and results.

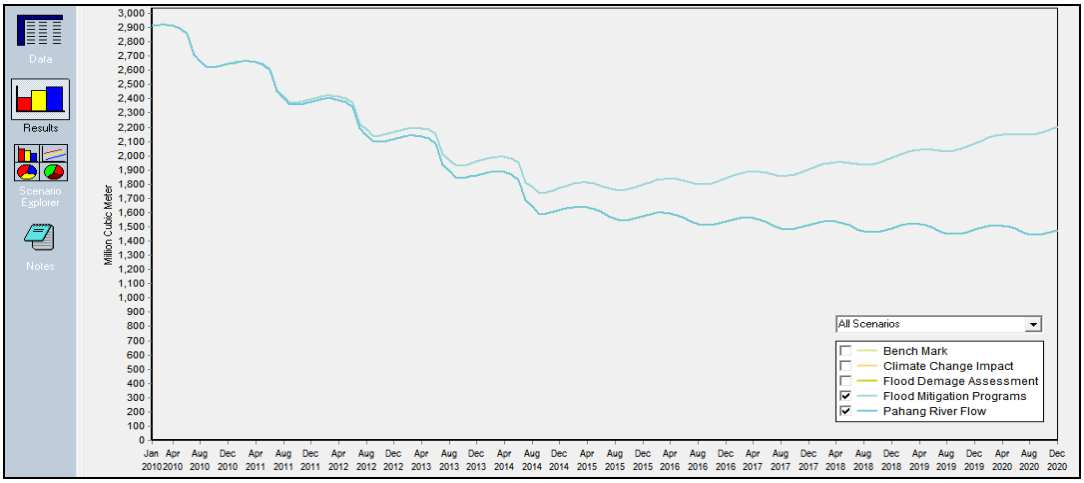


Figure 8: Pahang River Flow Predictions under Impact of Flood Mitigation

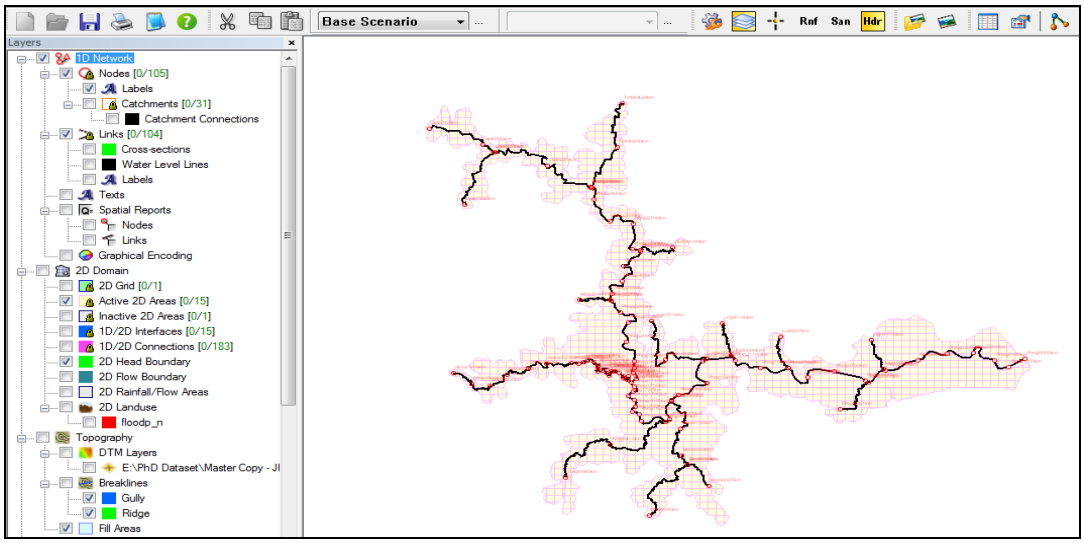


Figure 9: Modelling with XP-SWMM

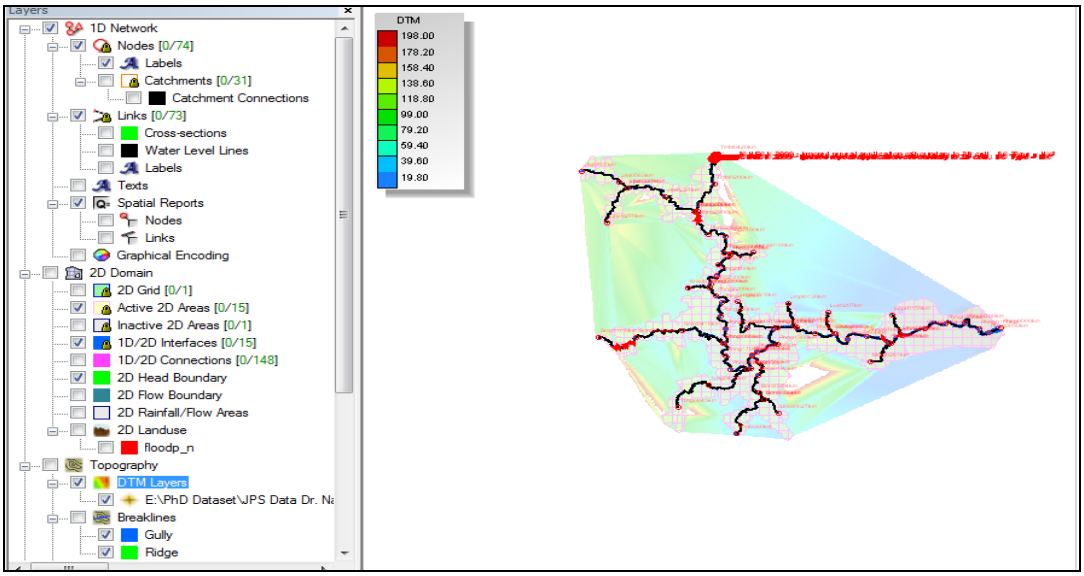


Figure 10: XP-SWMM Pahang River Model

10. Conclusions

It is concluded that adopting the tools of hydro-informatics is considered the best option with the continued process of fine tuning of informatics resources and to explore more intelligent models. This fine tuning can be done through research and knowledge sharing as an effective measure against floods. A continuous development, improvement, and modification in global flood defence products, according to local requirements, is needed in Malaysia. It is obvious that floods can't be avoided, but improved efforts and use of technology tools of flood forecasting, warning, and response system can be utilized to minimize the possible losses. Under this study, a developed geo-database for the Pahang River Basin (PRB) would be used by flood-concerned institutions to take advantage at the planning phase of a master plan for flood mitigation as a joint research venture with the University Malaysia Pahang.

The contemporary measures against floods in the Pahang River are the newly computer aided management. The future challenges include a sustainable flood mitigation master plan under innovative approaches. Tools of hydro-informatics, like simulation modelling, information handling, and data communication, under the environment of GIS, has been proving its worth for the last two decades. Implementation of these tools to strengthen flood forecasting and warning systems would prove an effective method for emergency responses. This aspect covers informatics, but on the other hand, some structural efforts and plans are required for the mitigation process. This study has reviewed concerned aspects to put forward a roadmap to develop and integrate geo-informatics tools. This study has also focused on improved and intra-institutional network of information sharing as a platform of decision making for authorities. To achieve this goal, a geo-database consisting of different hydro-informatics data layers has been developed.

Adopting innovative products for flood mitigation requires local design transformation. However, the methodology for demarcation of potential catchments is a more efficient, economical, and interchangeable approach. The degree of accuracy and precision of the results is directly related to the resolution of a digital elevation model (DEM). Moreover, placement of all datasets in the geo-database is a convenient option to perform operations of geo-informatics tools.

11. Recommendations

The findings of this research study have investigated the potential of state-of-the-art tools to manage the river water to minimize the flood hazards; however, further work needed to be carried out to improve the tools for sustainable management of floods. Following are recommendations which would be taken as future research milestones:

- Future works as next phase of this study would address hydrology model development and its integration with improved wireless monitoring network of the Pahang River.
- Role of international and national institutions for collaboration and further advances in hydro-informatics is direly needed.
- Further work on modified models for better forecasting under real-time data input and design of innovative, self-protecting flood mitigation at the industrial and household level would be further explored and investigated.
- The roadmap for the future to make the best utilization of this database is to use high resolution datasets of imagery and quality field-based surveys for river water quality.
- A promising approach for reducing the risks of floods would be developed as a strategy based on lesson learning from past projects. While Malaysia already has an existing web-based flood warning system, it is a good idea to disseminate river flows and flood situations at the public as well as the management level.
- The developed geo-database is very much dependent upon the input datasets as the geo-database is not any extra information. It could rather be called a data management system, which facilitates analysers to conduct query and integrate different combinations of datasets in one template. However, this database can be improved through investigating other possible formats of databases.
- Further work is possible in the area of hydrology to develop a methodology for spatial and temporal scaling in order to

examine the minimum resolution required for analysing acceptable results.

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