DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR DAM TYPE AND DESIGN, AND FLORISTIC EVALUATION

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DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR DAM TYPE AND DESIGN, AND FLORISTIC EVALUATION

By

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Dams are built to provide water for domestic and industrial consumption, meet energy needs and support economic development. However, the selection of a potential dam site results in the loss of value and viability of the forests which lead to ecosystem loss and fragmentation. On the other hand, heuristic rules and empirical knowledge from experts are not readily available in the selection of the optimal type of dam and its preliminary design. Addressing these issues objectively and conveying the results effectively to the decision makers are critical in attaining sustainable development. Hence, developing a Decision Support System (DSS) prototype can help in solving these problems. This interactive computer-based system which utilized data and modules was developed using Macromedia Dreamweaver 8. It was designed based on the knowledge acquired from journals and interviews with experts within the field. There are three modules in the prototype: floristic evaluation, dam type Delphi-Analytical Hierarchy Process (D-AHP) and preliminary dam design. The floristic evaluation module aims to incorporate floristic consideration in selecting the dam site. Ecosystem loss and fragmentation were quantified by estimating the rarity of flora species and calculating the smaller and isolated ecosystem patches in each forest ecosystem respectively. The dam type D-AHP module develops a set of influential attributes in selecting the optimal type of dam for the site by using Delphi technique and Analytical Hierarchy Process. The preliminary dam design module suggests the design of the type of dam at the early stage by using *if-then* rules. The developed DSS prototype, DSSDPro was verified using the case study of the Bengoh catchment. Based on floristic evaluation, dam site 4 is chosen to be the potential dam site as it has the least ecosystem loss ($3.3km^2$) and fragmentation ($1.5km^2$). By considering engineering, environmental and social factors, the type of dam that suits the chosen site is the gravity dam with the preliminary dam design of roller compacted concrete dam. DSSDPro was validated by experts who were involved in dam construction projects. The experts agree that DSSDPro is helpful in problem solving and good in its overall performance. In conclusion, the DSSDPro developed can be a significant contributor for the

conservation of forest ecosystems by proposing a potential dam site based on a comprehensive attributes and rules on dam types and dam design, as well as on floristic considerations.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN SISTEM SOKONGAN KEPUTUSAN UNTUK JENIS DAN REKA BENTUK EMPANGAN, DAN PENILAIAN FLORISTIK

Oleh

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Pembinaan empangan adalah bertujuan membekalkan air untuk kegunaan domestik dan perindustrian, memenuhi keperluan tenaga serta menyokong pembangunan ekonomi. Walau bagaimanapun, pemilihan tapak empangan mengakibatkan kawasan hutan kehilangan nilai dan daya maju yang membawa kepada kehilangan dan pemecahan ekosistem. Selain itu, peraturan heuristik dan pengetahuan empirikal dari para pakar tidak tersedia di dalam proses pemilihan jenis empangan optimum dan reka bentuk awalnya. Menangani isu-isu ini secara objektif dan penyampaian keputusan dengan berkesan kepada pembuat keputusan adalah penting untuk mencapai pembangunan yang mampan. Oleh itu, membangunkan prototaip Sistem Sokongan Keputusan (SSK) boleh membantu menyelesaikan masalah ini. Sistem interaktif yang berasaskan komputer ini menggunakan data dan modul yang dibangunkan melalui *Macromedia Dreamweaver 8*. Ia direka berdasarkan pengetahuan yang diperoleh daripada jurnal dan wawancara bersama dengan pakar di dalam bidang tersebut. Terdapat tiga modul dalam prototaip: penilaian floristik, Delphi-Proses Analisis Hierarki (D-PAH) empangan dan reka bentuk awal empangan. Modul penilaian floristik bertujuan untuk mempertimbangkan isu floristik dalam memilih tapak empangan. Kehilangan dan pemecahan ekosistem dinilai dengan menganggarkan spesies tumbuh-tumbuhan yang jarang (*rarity*) dan mengira kawasan ekosistem yang lebih kecil dan terpencil di setiap ekosistem hutan. Modul D-PAH empangan membentuk satu set parameter yang berpengaruh dalam memilih jenis empangan yang optimum untuk tapak empangan dengan menggunakan teknik Delphi dan Proses Analisis Hierarki. Modul reka bentuk awal empangan mencadangkan reka bentuk jenis empangan pada peringkat awal dengan menggunakan peraturan *If-Then*. Prototaip SSK yang dibangunkan, iaitu SSKPE diuji dengan menggunakan kajian kes di tadahan Bengoh. Berdasarkan penilaian floristik, tapak empangan nombor 4 dipilih untuk menjadi tapak empangan dengan kehilangan ekosistem (3.3km^2) dan pemecahan (1.5km^2) yang paling minimal. Dengan mempertimbangkan faktor kejuruteraan, alam sekitar dan sosial, jenis empangan yang sesuai dengan tapak yang dipilih adalah empangan graviti dengan reka bentuk awal empangan *roller*

compacted concrete. Prestasi SSKPE dinilai oleh pakar-pakar yang terlibat di dalam projek pembinaan empangan. Pakar-pakar bersetuju bahawa SSKPE membantu menyelesaikan masalah dan prestasi keseluruhannya adalah baik. Pada kesimpulannya, SSKPE yang dibangunkan boleh menjadi penyumbang penting untuk pemuliharaan ekosistem hutan dengan mencadangkan tapak empangan berdasarkan satu set parameter dan peraturan yang komprehensif mengenai jenis dan reka bentuk awal empangan, serta pertimbangan isu floristik.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
BARISS	Basin and River Information and Simulation System
BDS	British Dam Society
CBA	Cost Benefit Analysis
CI	Consistency Index
CR	Consistency Ratio
CSS	Cascading Style Sheet
D-AHP	Delphi-Analytical Hierarchy Process
DID	Department of Irrigation and Drainage
DOE	Department of Environment
DSS	Decision Support System
DSSDPro	Decision Support System for Dam Project
DWS	Department of Water Supply
EIA	Environmental Impact Assessment
ELECTRE	Elimination and Choice Expressing Reality
GIS	Geographical Information System
GUI	Graphic User Interface
HTML	HyperText Markup Language
ICOLD	International Commission on Large Dams
IUCN	International Union for Conservation of Nature
IVI	Important Value Index
MCDM	Multi Criteria Decision Making
MySQL	My Structured Query Language
PHP	Hypertext Preprocessor
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations
RCI	Random Consistency Index
WCD	World Commission on Dams
WRM	World Rainforest Movement
WWW	World Wide Web

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Forests are one of the most significant components of the Earth's biosphere (Gao & Liu, 2012). They play an important role in regulating the Earth's surface temperature and precipitation, preserving soil nutrients, minimizing flooding, fixing carbon, and serving as a valuable habitat for wildlife (Gao & Liu, 2012). In spite of these functions, however, human activities have depleted the forest resources around the world especially in the tropics. According to Hosonuma et al. (2012), commercial agriculture, subsistence agriculture, urban expansion, mining and infrastructure (roads, railroads, pipelines and dams) are identified as the five categories of deforestation drivers. These drivers have attracted steadily growing concerns as they are accelerating forest fragmentation, reducing forest regrowth (Nagendra et al., 2003; Fearnside, 2008), and thus threatening the tropical forests (Nepstad et al., 2001; Fearnside, 2007) by contributing to environmental degradation, increasing flooding, exacerbating soil erosion and reducing biodiversity (Gao & Liu, 2012).

In recent years, the development of infrastructure - dams in particular, is perceived as a rapidly emerging source that poses anthropogenic threat to forests in the tropics (Benchimol & Peres, 2015) as compared to other deforestation drivers. This is because dams are built for multiple purposes which include providing water for irrigated agriculture, domestic and industrial consumption as well as providing an alternative to meet energy needs and support economic development (BDS, 2010). Dams provide water to irrigate one fifth of the world's agricultural land (WCD, 2000) in order to sustain the world's population by supplying them with food. With the demand for food set to double in the next 50 years, there will be more land to grow crops and irrigation reservoirs will be one of the most effective means of providing water for this purpose (BDS, 2010). Besides irrigation, dams and reservoirs also provide water supply for urban areas, rural areas, industrial areas and even mining sites (Woodward, 2005). With this stable distribution of water supply, daily living activities and working lifestyles can be improved even during the dry season. In addition, electricity generated in hydroelectric power plants is one of the most useful opportunities offered by dams.

In the past centuries, fresh water supplies were constantly available to the human population and supported different standards of living, although there were local or periodical shortages which resulted in famine and migration (Singh & Sharma, 1976; Pan & He, 2000; Ratnayaka et al., 2009). However, the still continuing population explosion coupled with economic development have made it imperative to use the water resources found in all parts of the world (Beck et al., 2013). As a result, the design and construction of a safe and environmentally sound dam to store surplus river waters has thus assumed much greater urgency.

1.2 Problem Statement

In building a dam, one of the important elements to consider is the selection of dam site. There are a number of important engineering parameters to be examined when selecting a dam site: the site topography and valley shape, geological structure and foundation conditions, availability of construction materials, roadway, site safety, climatic conditions, hydrologic conditions, length and height of dam (Thomas, 1976; Pan & He, 2000; Ratnayaka et al., 2009). These parameters are also part of the influencing factors in selecting the type of dam and the respective design (Emiroglu, 2008; Gonzalez de Vallejo & Ferrer, 2011; Brandt et al., 2016).

The selection of a potential dam site, which satisfies the above mentioned parameters, will result in the change of natural land cover permanently. Tropical forests, the natural land covers, are converted to an alternative permanent non-forested land use (van Kooten & Bulte, 2000), mainly by the removal and inundation of native vegetation (Bauni et al., 2015). The clearing of pristine forests for the construction of dams (Benchimol & Peres, 2015) and the inundation have led to the fragmentation of ecosystems by reducing the core area, increasing in isolation and causing external disturbance (Forman, 1995; WCD, 2000; Keken et al., 2011; Kusta et al., 2014). The ecosystem fragmentation has been recognized as one of the major causes of forest ecosystem loss (Wu et al., 2003; Bauni et al., 2015). Moreover, ecosystem loss has not only threaten floristic diversity and wildlife habitats, but also the provision of ecosystem services for the well-being of humans (Hoekstra et al., 2005).

According to Department of Water Supply (2012), there are 80 dams being built throughout Malaysia and this figure indicates that more forest ecosystems are being exploited to impound these large artificial structures. As a result, the rich sources of medicinal, rare, and endemic plants that are important to the local community (Alsarhan et al., 2014), food sources for the wildlife (Gao & Liu, 2012), as well as the balance of the ecosystem services are permanently lost (Sukumaran et al., 2008). Moreover, forests as the centres of seed dispersal and wildlife habitats are fragmented into smaller and isolated areas (Whittaker, 1972; Linder, 2001; Jeeva et al., 2005; Jeeva et al., 2006; Sukumaran & Raj, 2010). Hence, incorporating floristic consideration into the current dam site selection parameters enables the loss of the forest ecosystem and fragmentation to be addressed in order to salvage and conserve the rich sources of flora and habitats of fauna.

On the other hand, the selection of the optimal type of dam together with the respective dam design is related to the selected dam site. As mentioned earlier, the parameters for the selection of a dam site are also part of the influencing factors in selecting the type of dam and design. The selection of the optimal dam type that suits the selected dam site involves heuristic rules, expert opinions and inferences as well as rules of thumb (Emiroglu et al., 2002). These heuristic rules and empirical knowledge from experts are vital parts of any water resources planning process.

However, only a small percentage of such rules are well documented in the literature (Emiroglu, 2008). In addition, experienced engineers with exclusive expertise in selecting the optimal type of dam and designing the dam in the preliminary stage based on the dam sites are not readily available and it is also difficult to obtain all relevant knowledge at the same time. As a result, addressing the engineering, environmental and social factors in selecting an optimal type of dam and dam design enable decision to be made objectively.

Consequently, the selection of dam site, dam type and dam design can be complex as it is important to know how to present the evaluations of these three elements to the decision makers who may appear to be non-technical professionals. In order to make the results of the evaluations operational, they must be conveyed to decision-makers in the most efficient and transparent way. This means that the framework adopted during the evaluations (i.e. the criteria and indicators that have been selected) must be made explicit, so as to allow tracking of the influence of each factor on the evaluation results (Geneletti, 2004a) for all possible scenarios. This can optimally be achieved by resorting to a Decision Support System (DSS).

1.3 Research Objectives

The main objective of the study is to design and develop the theoretical framework of a DSS prototype for dam projects in selecting the dam site, dam type and the preliminary dam design. These are the specific objectives of the study:

1. To incorporate floristic consideration in DSS for dam site selection;
2. To develop a set of influential attributes in selecting the potential dam type using Analytical Hierarchy Process and Delphi technique; and
3. To develop a DSS prototype for the selection of suitable dam design at the preliminary stage.

1.4 Research Questions

With respect to the first objective, this study focuses on the questions of:

i. What are the indicators and formulae to evaluate the ecosystem loss and ecosystem fragmentation?
ii. What is the important value index for each flora species in each type of forest ecosystem?
iii. What are the flora species diversity indices for each type of the forest ecosystem?
iv. What are the rarity and viability values for each flora species in each type of forest ecosystem?
v. How does floristic diversity evaluation assist in generating ecosystem loss impact score and ecosystem fragmentation impact score for assessing the potential dam site?

With respect to the second objective, this study seeks to investigate the following questions:

vi. By using Delphi technique, what are the influential attributes in selecting the potential type of dam?
vii. By using Analytical Hierarchy Process, what are the total weights for each type of dam?
viii. How does the integration of the Delphi technique and the Analytical Hierarchy Process help in selecting the optimal type of dam for the potential dam site?

With respect to the third objective, this study investigates the following:

ix. What are the important parameters in designing the dam at preliminary stage?
x. By considering the type of dam, what is the suitable dam design for the selected dam site at the preliminary stage?

1.5 Scope of Study

The scope of the study is focused on the development of DSS prototype for dam project. It is also emphasized on the application of modular system in selecting the dam site, dam type and the preliminary dam design. The programming languages used in developing the DSS prototype are HTML, PHP and MySQL. The synchronization of these programming languages enables the developed prototype to be used with internet application. The validation of the DSS prototype is carried out by a total of four officers from the Department of Irrigation and Drainage and Public Works Department.

There are three modules in this DSS prototype, namely floristic evaluation module, dam type D-AHP module and preliminary dam design module. Floristic evaluation module is the first module of the DSS prototype. It incorporates floristic consideration in the selection of potential dam site. The encoded formulae in the module are used to quantify the ecosystem loss and ecosystem fragmentation at the dam sites. The verification of this module is based on the secondary floristic data of the case study of Bengoh catchment retrieved from the study by Met (2016).

Dam type D-AHP module is the second module of the DSS prototype. It focuses on developing a set of influential attributes in selecting the potential dam type by integrating Delphi technique and Analytical Hierarchy Process. The potential dam type is to be determined by considering the engineering, environmental and social factors. Furthermore, the second module serves as the preparatory stage for the third module which is designing the dam in the preliminary stage. A set of rules is to be developed based on the engineering and environmental factors in the second module. These rules make up the rule-based system in the third module. In this module, based on the conditions of the potential dam site, suggestions on the preliminary design of the selected type of dam are disseminated. Both of these modules are verified based on the primary data consulted from 12 experts in the relevant fields to this study.

1.6 Significance of Study

DSS can be defined as an interactive computer-based system that can help to support complex decision making and problem solving (Goswami & Barua, 2008). The developed DSS prototype facilitates access to information by users (stakeholders and decision makers) which address their concerns on the development of dam, specifically on the selection of dam site, dam type and dam design. This enables non-technical professionals (stakeholders and decision makers may not be technical people) to obtain answers to their questions. Furthermore, data used by the DSS prototype can be accessed and modified to allow users to explore various situations and scenarios. Results obtained by the users can be stored for further use; working sessions can be suspended and then started again without loosing information and data created during commenced sessions.

In the first module of the DSS prototype, the selection of dam site is based on the assessment of floristic impacts rather than fauna impacts because flora species makes up the natural land cover of forest ecosystems and provides ecosystem services to the fauna, human and even the environment. In view of the importance of forest ecosystems, the incorporation of floristic consideration into the engineering parameters (as mentioned in section 1.2) in selecting a dam site enables the enhancement of current floristic study carried out in the Environmental Impact Assessment (EIA) for dam projects in Malaysia.

Subsequently, the selection of the type of dam (second module) and its design (third module) for a dam site often involve heuristic rules, expert opinions and inferences as well as rules of thumb (Emiroglu et al., 2002). These rules and opinions may complicate the decision making process as they lead to subjective decision making in selecting the type of dam and designing it. As a result, the development of a set of influential attributes in selecting a potential dam type by using Delphi technique coupled Analytical Hierarchy Process enables the decision making process to be conducted objectively. Furthermore, the development of *if-then* rules in designing the selected dam type at the preliminary stage enables precautionary measures to be taken. With the aid of the rule-based system developed from the engineering and environmental factors, it ensures that the dam site is prepared for the construction of the selected type of dam.

In summary, this study has significant contributory outcomes towards the conservation of forest ecosystems in selecting a potential dam site, provides a comprehensive set of parameters and rules in selecting the type of dam and suggesting the dam design. Furthermore, the adoption of the DSS framework plays a significant role in conveying the evaluation results of each module to the decision makers efficiently and explicitly.

1.7 Thesis Organization

Overall, this dissertation consists of five chapters, which is organized as follows:

Chapter 2 presents critical and comprehensive reviews of various literatures regarding dam development, the impacts of dam development, the mitigation measures of terrestrial impacts and the importance of forests ecosystems. This chapter further unravels the floristic evaluation in selecting a potential dam site by assessing floristic diversity and quantifying the ecosystem loss and ecosystem fragmentation. Literature review further elaborates on the factors influencing the selection of the type of dam and the integration of the Delphi technique and the Analytical Hierarchy Process in selecting the type of dam. This chapter also reviews the preliminary design of the type of dam by applying the rule-based system. Last but not least, this chapter unravels the advantages and architecture of DSS.

Chapter 3 provides the description of the overall study framework and research design of the DSS prototype applied in this study. This chapter explains the approach used to evaluate the flora species at the potential dam site, the integration of the Delphi technique and the Analytical Hierarchy Process in selecting the type of dam and the preliminary design method for the selected type of dam. The DSS development tools and the evaluation of the DSS prototype are also described in this chapter.

Chapter 4 discusses the architecture of the DSS prototype in relation to the objectives and research questions. This chapter presents the evaluation of the developed DSS prototype and reveals the results of the floristic evaluation module, the dam type using the D-AHP module and the preliminary dam design module.

Chapter 5 concludes the main findings and significance of this study before drawing the conclusions with respect to each of the objectives and research questions. In this chapter, the limitations of this study and the relevant recommendations for future research are also discussed.

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