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RANKING OF SKUDAI RIVER SUB-WATERSHEDS FROM SUSTAINABILITY INDICES – APPLICATION OF PROMETHEE METHOD

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ABSTRACT: In this study, ranking of sub-watersheds in the Skudai River watershed was developed from the sustainability index. The watershed sustainability index (WSI) was developed by considering two important parameters such as potential flood damages (PFD) and potential water quality deterioration (PWQD) parameters. Preference Ranking Organization Method (PROMETHEE), a multicriteria decision making (MCDM) method, was used and WSI scores for 25 Skudai River sub-watersheds were produced. Based on the WSI score, a ranking of sub-watersheds was developed to locate the more problematic areas in the Skudai River watershed. The middle and lower parts of the Skudai River watershed were found to have considerably low sustainability score which suggested the degradation of sub-watersheds from water quality and flood damage parameters. The ranking of sub-watersheds in this study will assist planners and decision makers to identify the problematic areas within the watershed so that priority interventions can be built before the problem gets worse and affects other areas of the Skudai River watershed.

Keywords: WSI, Sustainability, Water resources, Skudai River, Indicator, Index, Relative weight, Priority ranking, D-Sight PROMETHEE

1. INTRODUCTION

Due to rapid developments and mismanagement, many watersheds all around the world (e.g., Chittagong Hill Tracts in Bangladesh [1]; Yangtze River Basin in China [2]; and Bernam Watershed in Malaysia [3]) are undergoing degradation and this results in reducing the quantity of water resources and lowering water quality in a watershed. Noticing the watershed problems that bring so much loss to human and the environment, many studies have been done to devise effective watershed managements that can prevent and mitigate the problems related to watersheds [4]-[5].

Watershed sustainability index (WSI) is a quantitative output of various sustainability indicators in a watershed. The index provides a simplified and multidimensional view of a system [6]. Sustainability indicators and aggregation of these indicators into a single quantitative unit (e.g. WSI) is being increasingly used by the decision-makers [7]-[8]. WSI alone may not be adequate for sustainable management of a watershed as additional information unique to each watershed is also needed [9]. Although WSI does not cover all aspects of the watershed especially the intangible qualities which are difficult to present in monetary units, it is useful in providing an initial assessment of the watershed's health and guides decision-makers to make better and timely decisions for preventing watersheds from degradation.

The literature suggests that the Skudai River watershed is under threat from rapid economic development activities [10]. Kulai, Senai, Tampoi and Johor Bahru City are the areas where high levels of development activities are being carried out under the Iskandar Malaysia development plan. The major problems identified in Skudai River watershed are polluted rivers and flooding. Two rivers in the Skudai River watershed (i.e. Skudai and Melana rivers) were classified as slightly polluted by the Department of Environment [11]. Besides that, some areas in Skudai River watershed are prone to flooding.

In this study, the development of WSI for the Skudai River watershed using Pressure-State-Response (PSR) model was proposed and priority ranking of Skudai River sub-watersheds based on WSI was presented by applying PROMETHEE method through D-Sight software. Employing PSR model which was developed by the Organization for Economic Co-operation and Development [12] is useful to determine the suitable watershed indicators for gaining the information about the watershed [13]. The WSI for Skudai River watershed were categorized into two main components (i.e. PWQD and PFD). The application of WSI in the watershed will assist decision makers to have better knowledge on overall water resource conditions, and water-related issues and problems for sustainable management of water resources. Furthermore, the PROMETHEE method applied in this study is a new application in developing priority ranking of sub-watersheds. The application of PROMETHEE will guide decision makers to identify the problematic sub-watersheds so immediate actions for protection of river water quality may be taken.

2. METHODOLOGY

2.1 Study Area

The Skudai River watershed is located in Johor Bahru, Malaysia and bounded by latitudes 1° 26' 55" N and 1° 44' 58" N and longitudes 103° 29' 4" E and 103° 44' 58" E (Fig. 1). The watershed is under three local authorities (i.e. Majlis Perbandaran Johor Bahru Tengah, Majlis Perbandaran Kulai, and Majlis Bandaraya Johor Bahru). It covers approximately 342 km^2 and encompasses highly developed areas such as Kulai, Senai, Tampoi and Johor Bahru. Primary land cover types within the watershed (as of 2006) comprise 70% of urban area. The Skudai River is the main river in the watershed with length of 47.43 km. Other rivers in the watershed are Senai River (16.01 km), Melana River (20.02 m), Kempas River (4.5 km), and Danga River (17.01 km) [10]. The Department of Environment identified two rivers in the watershed (Skudai River and Melana River) as slightly polluted [11]. In the flood event occurred in 2007, Kulai area was among the areas affected [14].

ArcGIS 10 was used for delineating Skudai River watershed. A total of 25 sub-watersheds were defined and land use of each sub-watershed was identified. Twenty-five Skudai River sub-watersheds are shown in Fig. 2.

2.2 Sustainability indicators

Sustainability indicators for the Skudai River watershed were selected by using four main criteria including relevancy, availability, measurability, and spatial and temporal variability. These criteria were used to check whether the indicator was relevant to watershed sustainability and data on the indicator was available from secondary sources and/or can be easily collected using realistic time with limited human and financial resources. The indicator was also checked whether it can be measured on any quantitative or qualitative scales. If any indicator was not measureable, it was not considered for further analysis. Selected indicators were then grouped into two categories, i.e. potential flood damage (PFD) and potential water quality deterioration (PWQD).

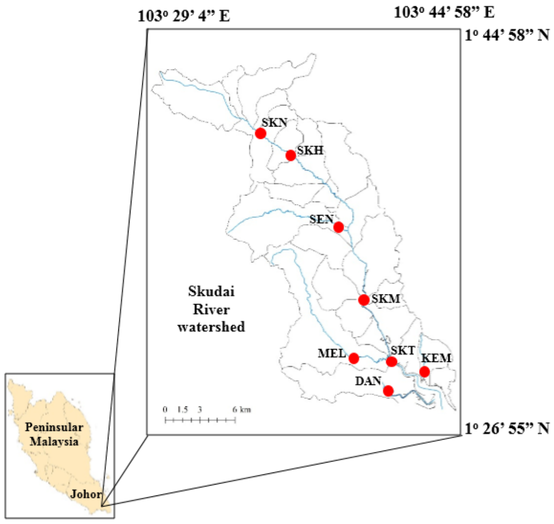

Fig. 1 Location of Skudai River watershed on the Peninsular Malaysia map

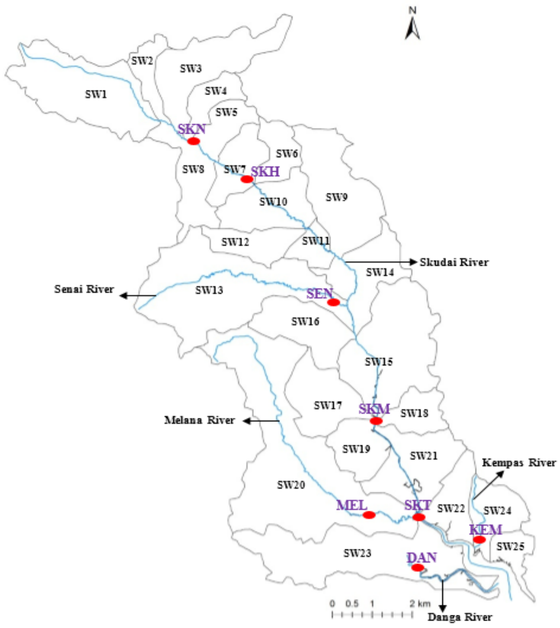

Fig. 2 Skudai River sub-watersheds

The list of sustainability indicators along with respective data for PFD and PWQD parameters are shown in Table 1 and Table 2 respectively. These two categories were used in identifying and quantifying the problems in each sub-watershed of the Skudai River watershed. PFD can include the risk associated to watershed resources (human, properties, land, water, etc.) during any flood events. High population density could be the main factor where PFD damages may be likely higher than the watersheds where population density is comparatively low. Higher rainfall with low evaporation rate could be another main factor that can cause floods in a watershed and can result in higher damages to properties. Potential water quality deterioration (PWQD) is assessed based on its physical, chemical or biological parameters but it is difficult to interpret the data of these parameters without one index that integrates them. WQI is a well-known method of expressing water quality which offers a simple unit of measure [15]. The value of WQI is used to categorize river health into different classes ranging from very bad to excellent or polluted to clean [16]. The weights of the sustainability indicators were taken from the work of [10].

2.3 PROMETHEE method

The selection of PROMETHEE in this study was made by using rigorous criteria including simplicity, applications in water resources especially in watershed management, and availability of various software such as PROMCALC, Decision Lab, and D-Sight. Brans et al. [17] stated that PROMETHEE rankings were more stable than ELECTRE rankings. The steps involve in the implementation of PROMETHEE method include defining the preference function, calculating the preference index, constructing the valued outranking graph, ranking the actions by a partial preorder and ranking the actions by a total preorder (PROMETHEE II). PROMETHEE II offers a complete ranking of actions and can be obtained by balancing the outgoing and incoming flows (Eq. 1). The outgoing flow is a measure of the alternatives' strength and the incoming flow is a measure of the alternatives' weakness.

$$\varphi = \varphi^{+} - \varphi^{-} \qquad \text{Eq. 1}$$

Where φ = net flow, φ^{+} = outgoing flow, φ^{-} = incoming flow

3. RESULTS AND DISCUSSION

3.1 PROMETHEE application to rank sub-watersheds

D-sight software is built to run PROMETHEE in input and output interfaces which provide ease to researchers and decision makers to observe real time effects of criteria on ranking of alternatives. D-sight also facilitates the users to attach priority weights to the criteria accordance to their importance in finding the solution of any problem. Input data on PFD and PWQD are shown in Tables 2 and 3 respectively. These values were computed from ArcGIS application to maps of the Skudai River watershed and other input data collected from the Department of Irrigation and Drainage, Department of Environment, Department of Agriculture, and local authorities. The data of PFD and PWQD sustainability indicators and the weights of each indicator [10] produced score and ranking of Skudai River sub-watersheds. These sub-watersheds had different characteristics. For example, some sub-watersheds had 'flood warning system' and others do not. Having 'flood warning system' is the vote in favor to the sub-watershed and vice versa.

D-Sight provides properties and input windows in defining characteristics of criteria considered in a problem. A criterion can either be maximized or minimized depending on how its value contribution to the problem. Minimizing a criterion means that lower criterion value is better for the result and maximizing a criterion means higher value of a criterion is better. In this study, 'maximum' and 'minimum' options for the sustainability indicators were assigned by scrutinizing the effects of each criterion on the watershed sustainability. The function is based on the PROMETHEE preference functions, which can be either linear, usual, V-shape. U-shape or Gaussian. The 'function' for each criterion was decided from the uniqueness of the sustainability indicator.

The selection of a function for a particular sustainability indicator was mostly made from the type of data (quantitative or qualitative). 'Indifference' and 'preference' values for the indicators were decided from literature review. For example, 'soil type' indicator was assigned 'level' function with clay soil type was given level-1 (score 1) and sandy soil as level-3 (score 3). Higher score indicated better level of 'soil type' indicator in flood mitigation strategy as more and more runoff will infiltrate with sandy soil profile compared to clayey soil. Silty soil was assigned with score of 2 which has intermediate infiltration rate compared to clayey and sandy soils. Ozgen et al. [18] provide detailed information on the preference functions. D-Sight also facilitates users to define qualitative criterion and use it the evaluation process. 'River classes' was defined by assigning numerical values to difference river classes. For example, river class according to water quality index (WQI), Class V will get the lowest score (score 1) as water quality was very poor. On the other hand, Class I river will get score of 5 which interpreted that this river was sustainable in terms of water quality.

Table 1 Input data on PFD indicators

Sub-watershed	Potential Flood Damages (PFD)									
	Pressure (PF)			State (SF)				Response (RF)		
	Population density	Percent of impervious area	Frequency of flood occurrence	Rainfall	Evaporation rate	Soil type	Topography (slope)	Flood warning system	Revegetating	Dam storage capacity
SW1	199	2.6	0	2252.1	854.8	Clay	24.4	Yes	Yes	24.9
SW2	1019	0	0	2252.1	819.2	Clay	18.3	Yes	Yes	24.9
SW3	1019	0.3	0	2252.1	822.8	Clay	13.7	Yes	Yes	24.9
SW4	809	0.2	0	2445	826.2	Clay	18.3	Yes	Yes	24.9
SW5	809	0.6	0	2445	843.7	Clay	13.7	Yes	Yes	24.9
SW6	809	2.1	0	2445	906.6	Clay	18.3	Yes	No	24.9
SW7	809	2.6	0	2445	916	Clay	24.4	Yes	Yes	24.9
SW8	809	3.5	0	2445	914.4	Clay	24.4	Yes	No	24.9
SW9	809	5.8	0	2445	917.3	Clay	13.7	Yes	No	24.9
SW10	809	4.2	10	2445	917.3	Clay	18.3	Yes	Yes	24.9
SW11	4195	1.5	3	2445	916.8	Clay	18.3	Yes	No	24.9
SW12	810	2.6	0	2445	917.3	Clay	13.7	Yes	No	24.9
SW13	1263	7.5	2	2029.5	888.6	Clay	39.4	Yes	Yes	24.9
SW14	1263	4.6	0	2029.5	914.2	Clay	18.3	Yes	No	24.9
SW15	15512	9.5	0	2029.5	916.6	Clay	13.7	Yes	No	24.9
SW16	1263	4.4	6	2029.5	917.3	Clay	39.4	Yes	No	24.9
SW17	15507	4.5	0	2029.5	917.3	Sand	18.3	Yes	No	24.9
SW18	15507	1.9	0	2029.5	917.3	Clay	39.4	Yes	No	24.9
SW19	15507	2.7	1	2029.5	916.7	Clay	13.7	Yes	No	24.9
SW20	15507	14.1	0	2029.5	900.6	Clay	24.4	No	Yes	24.9
SW21	15507	5.7	0	2029.5	917.3	Clay	18.3	No	No	24.9
SW22	1941	4.2	0	2029.5	917.3	Clay	24.4	No	No	24.9
SW23	6752	8.3	0	2029.5	906.2	Clay	18.3	No	Yes	24.9
SW24	1939	4.4	0	2029.5	917.3	Clay	24.4	No	Yes	24.9
SW25	1939	2.2	0	2029.5	917.3	Clay	53.7	No	Yes	24.9

Table 2 Input data on PWQD indicators

Sub-watershed	Potential Water Quality Deterioration (PWQD)									
	Pressure (PQ)				State (SQ)			Response (RQ)		
	Population density	Percent of agricultural area	Percent of urbanized area	Proximity to industrial area	Rainfall	Water quality index	River Class	Water quality monitoring	Riparian vegetation	Flood awareness
SW1	199	22.8	2.6	0.1	2252.1	81.8	Class II	Yes	Yes	Yes
SW2	1019	7.8	0	22	2252.1	81.8	Class II	Yes	Yes	Yes
SW3	1019	26.4	0.3	22	2252.1	81.8	Class II	Yes	Yes	Yes
SW4	809	8.3	0.2	0.1	2445	81.8	Class II	Yes	Yes	Yes
SW5	809	7.5	0.6	0.1	2445	81.8	Class II	Yes	Yes	Yes
SW6	809	0.2	2.1	2.5	2445	80.0	Class II	Yes	Yes	Yes
SW7	809	2.0	2.6	1.6	2445	80.0	Class II	Yes	Yes	Yes
SW8	809	0.5	3.5	0.1	2445	81.8	Class II	Yes	Yes	Yes
SW9	809	0	5.8	0.1	2445	72.7	Class III	Yes	Yes	Yes
SW10	809	0	4.2	1.6	2445	72.7	Class III	Yes	Yes	Yes
SW11	4195	0	1.5	0.2	2445	72.7	Class III	Yes	Yes	Yes
SW12	810	0	2.6	0.1	2445	72.7	Class III	Yes	Yes	Yes
SW13	1263	1.2	7.5	0.9	2029.5	73.0	Class III	No	Yes	No
SW14	1263	0.8	4.6	0.1	2029.5	72.7	Class III	Yes	Yes	Yes
SW15	15512	0.4	9.5	0.9	2029.5	72.7	Class III	Yes	Yes	Yes
SW16	1263	0	4.4	1.2	2029.5	72.7	Class III	Yes	Yes	Yes
SW17	15507	0	4.5	1.4	2029.5	72.7	Class III	Yes	Yes	Yes
SW18	15507	0	1.9	2.8	2029.5	72.7	Class III	Yes	Yes	Yes
SW19	15507	0.1	2.7	22	2029.5	72.7	Class III	Yes	Yes	Yes
SW20	15507	16.1	14.1	0.4	2029.5	68.0	Class III	Yes	No	No
SW21	15507	0	5.7	0.1	2029.5	67.8	Class III	Yes	No	No
SW22	1941	0	4.2	0.4	2029.5	67.8	Class III	Yes	No	No
SW23	6752	5.8	8.3	1.2	2029.5	55.9	Class III	Yes	No	No
SW24	1939	0	4.4	0.5	2029.5	61.9	Class III	Yes	Yes	Yes
SW25	1939	0	2.2	1.1	2029.5	61.9	Class III	Yes	Yes	Yes

3.2 Sub-watersheds on GVA Plane

In order to identify the problematic sub-watersheds in terms of flood damages and water quality deterioration levels, Global Visual Analysis (GVA) plane of D-Sight was used. GVA represents a problem that combines all criteria and alternatives in two dimensions. Sub-watersheds (SW1 to SW25) are in orange dots and the groups of sustainability indicators (PF, SF, RF, PQ, SQ, RQ) are in green axes (Fig. 3). The decision stick is shown in red color. The Delta value on the right side shows the estimation of the representation quality. Zardari et al. [19] stated that the delta value above 60% is acceptable as lots of information still retained while producing results. The Delta value obtained in this study was 87.3%, which indicated a high reliability in the final results. The GVA plane was generated in the D-Sight software from sub-watersheds sustainability indicators value in Tables 1 and 2. There are at least four observations which can be performed by using GVA plane, i.e. relative position of alternatives, relative position of criteria, relative position of alternatives for a given criterion, and the decision stick.

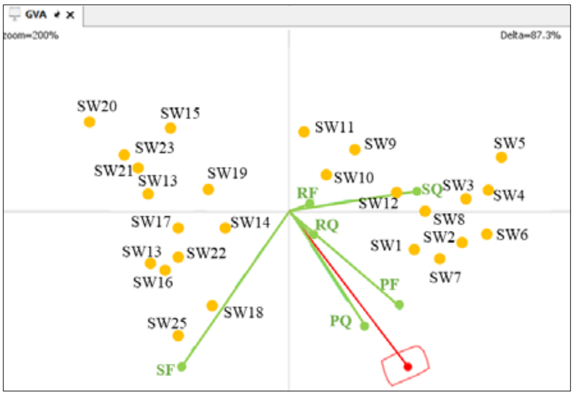

Fig. 3 Global Visual Analysis (GVA) plane

Sub-watersheds which are close together in GVA plane have similar properties and distant sub-watersheds have major differences in their properties with respect to all sustainability indicators. For example, SW1, SW2, SW6, and SW7 sub-watersheds were very close to each other on GVA plane (Fig. 3). This means that the characteristics of these sub-watersheds were similar, which also indicates that the levels of sustainability are similar. The least sustainable sub-watershed in this study was SW20 as this sub-watershed on GVA plane was in the opposite direction of the 'decision stick'. Other sub-watersheds (e.g. SW15, SW21, and SW23) which were very close to SW20 had the similar characteristics and these sub-watersheds may need urgent attention in planning, management, and rehabilitation measures.

The relative position of sustainability indicators can also be observed from the GVA plane. Sustainability indicators agree to each other if they are close together in the plane. In Fig. 3, PQ and RQ were close to each other which interpreted that on average, sub-watersheds that obtained good score from *pressure* for PWQD also obtained good score from *response* for PWQD. This was a good indication showing that more efforts were put to reduce the pressure effects on the sub-watersheds. The sustainability indicators can be in conflict if they are in opposite directions. A problem was found considering the PF and RF as these two groups of sustainability indicators were in conflict. To reduce the flood damage, more efforts must be done through *response* towards reducing flood damage.

3.3 PROMETHEE II ranking

The PROMETHEE II ranking offers a total ranking of the alternatives from the best (the first rank) to the worst (the last rank). They are scored between 1 and -1; 1 being the best. The ranking of the sub-watersheds is represented in Fig. 4. The sub-watershed SW2 was at the first rank with a score of 0.223, closely followed by SW7 and SW6, with scores 0.220 and 0.219 respectively.

SW20 obtained the last rank with -0.338 score implying that it is the most problematic area in Skudai River watershed assessed from flood damages and water quality deterioration.

4. CONCLUSION

This study provided a procedure in applying WSI to the Skudai River watershed using PROMETHEE method through D-Sight software. WSI in this study takes these two main parameters into account, i.e. potential water quality deterioration (PWQD) and potential flood damage (PFD). Twenty important sustainability indicators related to flood and water quality parameters were considered. The sustainability index score for every sub-watershed was calculated by employing D-Sight software. Higher score gives a sub-watershed a higher rank. The sub-watershed SW20 obtained the last rank with sustainability index score of -0.338 and SW2 was at the first rank with the score of 0.223. Since the purpose of the study was to propose a WSI that can help watershed managers and decision makers to put management focus on the unsustainable sub-watersheds in the Skudai River watershed, the ranking produced was important. The ranking suggested that management focus should be given to SW20, SW23, SW21, SW15 and SW13 which obtained the bottom five ranks. These are mainly Skudai and Senai areas.

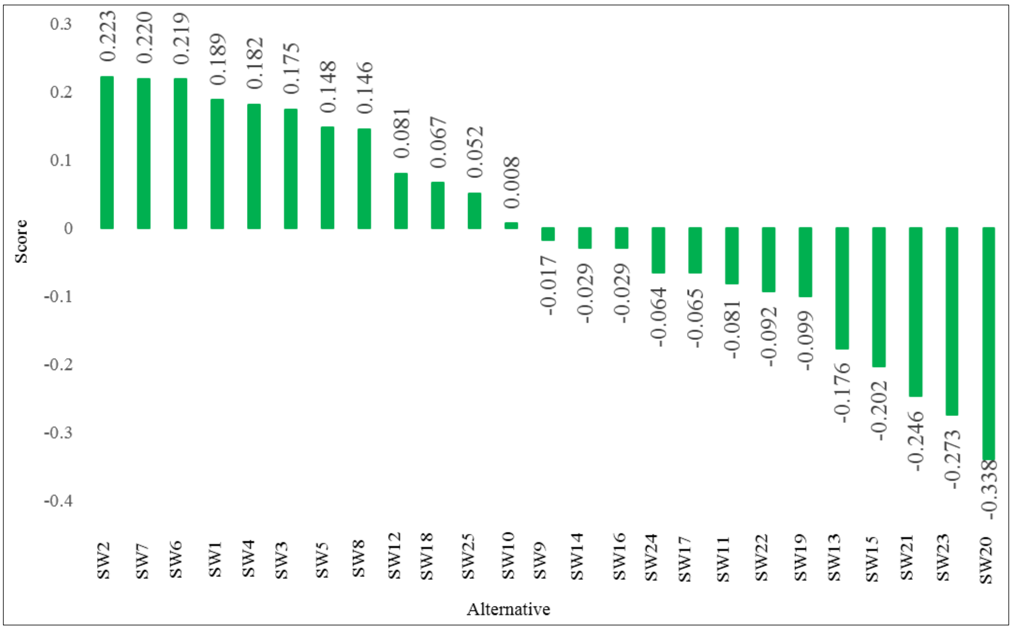

Fig. 4 PROMETHEE II ranking of sub-watershed along with respective scores

For future research, more categories and sustainability indicators can be proposed for better assessment of the watershed. There are other important sustainability indicators such as climate effects and land use patterns. Other MCDM methods (e.g. AHP and VIKOR) can be used for the same data to check whether ranking of the sub-watersheds is stable of changing with the application of different MCDM methods.

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