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Multicriteria approach for selecting the most vulnerable watershed for developing a management plan

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Abstract

Listing of watershed management goals/targets is one of the integral parts of the management plan for a watershed. In this paper, we have listed 18 watershed management targets for which the Malaysian watersheds could possibly be managed in future. Based on the listed watershed management targets, the priority ranking of 18 targets is developed from the relative importance weights obtained from a survey conducted from 29 stakeholders. Three weighting methods (SWING, SMART, and SMARTER) were applied to elicit weights. We found that the SMART (Simple Multi-Attribute Rating Technique) weighting method was a favorable method for eliciting stable sets of weights for the watershed management targets. The SWING weighting method produces better weights than the SMARTER method. The listed watershed management targets will assist watershed managers and decision makers in decision making to use available resources (e.g. water quality, land-use, groundwater, and many other resources) in a more efficient and sustainable manner. The efficient utilization of all resources within a watershed will ultimately save watersheds (more specifically the urbanized watersheds) from further deterioration caused by unchecked infrastructure development activities.

Key words: *relative importance weights, SMARTER, SWING, watershed management targets, watershed vulnerability, weighting method*

INTRODUCTION

Watershed management is the process of guiding and organizing the use of land and other resource in a watershed to provide desired goods and services without adversely affecting the environment or ecological balance. It involves multiple resource types and requires understanding of the relationships among land use, soil, water, flora, fauna and human communities. Watershed management is the implementation of a set of resource management practices with the goal of ensuring water quality while sustaining the ecosystems [TOMER 2004].

The terms goals, targets, objectives, and practices should not be confused when these are used for managing watersheds as these all terms convey the similar meaning. There could be many targets for restoration of vulnerable watersheds and/or preventing these watersheds from further degradation depending on the priorities of watershed management authorities. We had an extensive literature review on the watershed management targets which may be encompassed in a framework for managing watersheds in a more rational and sustainable manner. The watershed management targets include improving river water quality, providing better habitat for fish and aquatic species, boosting economic development in the region, and controlling floods. Table 1 shows the complete list of targets which are more important and need to be taken into account while preparing a restoration, conservation, and/or management plan for a vulnerable watershed. The watershed management targets in this study were selected from the literature including [ARNETTE *et al.* 2010; BALOCH, TANEK 2008; CHESS, GIBSON 2001; DARGHOUTH *et al.* 2008; GERMAN *et al.* 2007; MIODUSZEWSKI 2009; NELSON, WSCHLER 1998; SHEELANEREA *et al.* 2013; TTF 2005]. We applied few criteria to choose the management targets that are appropriate for the Malaysian watersheds. The applied criteria are: 1) the selected watershed management target must be implementable; 2) it can be measured with the available tools, 3) it can be understandable to all stakeholders; and 4) the target must be relevant to watershed management.

Table 1. Watershed management targets with their description

Acronyms	Watershed management targets	Description
T-1	Provide good water quality	Improving water quality in the rivers that are integral part of a river basin or watershed
T-2	Provide good habitat for fish and aquatic species	Improving habitat quality for fish and other aquatic species so that they can stay in the river system
T-3	Provide economic development incentives	The watershed management may bring many opportunities of investment in the country
T-4	Provide adequate flood control	To build structure in the watershed which can directly protect lives and safeguard properties from all types of floods in a watershed
T-5	Provide high quality of life by increasing green space	It is believed that the more green area is symbol of high quality of life
T-6	Provide adequate protection from droughts	Proper management of watersheds may protect us from droughts. However, this may not be crucial for the Malaysian watersheds
T-7	Controlling soil erosion	The watershed intervention may control soil erosion and this will ultimately improve the quality of water in the rivers
T-8	Protect natural/cultural heritage and forests	Most of the watersheds play main role in culture of local people and this objective of managing a watershed should always be included in the management plans
T-9	Promote recreational activities	The watershed management activities may increase recreational activities in the watershed
T-10	Protection of sensitive lands (e.g. flood plains and valley lands)	Protecting sensitive soils should be given priority in developing a watershed management plan
T-11	Efficient use of resources (land and water)	Land and water resources in the watershed should be integrated in management plans
T-12	Balancing ecological, economic and social interests of watershed	There should be balance in all types of interests in the watershed. Boosting economic interests may not be on the cost of social interests
T-13	Improve water supply reliabilities to inhabitants	Water reliability is important as it should be further improved to win confidence of the water users
T-14	Improve nutrient management	There should be balance in nutrients in river water and it should be further enhanced
T-15	Protect woodlands, wetlands and habitats	Wetlands and woodlands are important and these should be given priority in watershed management plans
T-16	Protect life and property from natural hazards	Natural hazards intensities and frequencies are increasing because of the climate variability. The watershed management plan should protect life and properties from the unexpected natural hazards
T-17	Safeguarding rivers, lakes and streams	Rivers and lakes are souls of a watershed and thus these should be safeguarded in the management plans
T-18	Improve groundwater and surface water quantity and quality	There is interaction between surface waters and groundwater. So actions may be taken to improve quality and quality of both resources in a watershed

Source: own study.

Watershed development, protection, and restoration efforts in Malaysia are falling behind the efforts put by the developed countries (For example, Singapore) for protecting watersheds. Thus, it is imperative to gather more information required for protecting our watersheds from further degradation. This information may include categorization of country's watersheds according to their level of sustainability, vulnerability, damages done to the watershed, integration process where all watershed parameters can put together to manage them on sustainable way, listing parameters according to their priority in the watershed restoration and management plans, and including more and more new parameters in decision making process and in the management plans that have been previously overlooked or under weighted.

Deforestation and infrastructure construction are the most important activities adversely affecting the health of Malaysia's watersheds and river basins [JAHI 2011]. Moreover, stakeholders are not being consulted for managing watersheds in Malaysia [EL-FITHRI *et al.* 2011]. RHOADS *et al.* [1999] developed a conceptual model of the interaction among scientists, scientific information, nonscientists, and local knowledge in community-based approaches to watershed management. The report by the United States Environmental Protection Agency published in 2013 discusses the importance of stakeholders in watershed management. The report enlists reasons for which most of the watershed management plans failed to meet the management targets. Including the other reasons for failure of watershed management plans, one reason was the lack of stakeholder involvement and local ownership in developing watershed management plans [EPA 2013]. There are many other issues which need to be put together to make our watersheds sustainable and prevent them from any further deterioration caused by some unchecked deforestation, construction, and development activities. Therefore, it is very important to know which targets for managing a watershed need to be considered and thus more attention to be paid by the watershed managers, planners, decision makers, and the local as well as federal governments. In this study, we have listed major targets of watershed management and have determined priority weights from a survey completed from 29 respondents. The study has two-fold objectives. The first, objective was to enlist important watershed management targets believed to be important for the Malaysian watersheds. A broad review of literature was carried out to get the first objective done. The second objective of the study was to see which weighting method produces better and stable sets of weights to the shortlisted watershed management targets. The selection of weighting methods was based on four criteria: 1) the selected weighting method should be simple in administration to the stakeholders with limited knowledge on watershed management targets; b) the method requires less time input from stakeholders; c) it requires minimum statistical analysis skills of the analyst; and d) the process behind calculating weights should be simple and understandable to stakeholders and later to the watershed managers or decision makers.

MATERIAL AND METHODS

We used three weighting methods to elicit weights of 18 watershed management targets. The selected weighting methods are SWING [VON WINTERFELDT, EDWARDS 1986], SMART (Simple Multi-Attribute Rating Technique) [EDWARDS 1977], and SMARTER [EDWARDS, BARRON 1994]. We emphasis that the selection of the weighting methods in this study is based on broad literature review especially on advantages and disadvantages of popular weighting methods given in [HOBBS 1980; JIANG, SHEN 2013; YANG *et al.* 2012; ZARDARI 2008; ZARDARI *et al.* 2010]. The methodology can be split into four steps:

1) definition of watershed management targets;
2) definition of the weighting methods;
3) application of the weighting methods in a survey;
4) priority ranking of the watershed management targets.

The survey on determining relative importance of watershed management targets was completed from two groups of students (postgraduate (PG) and undergraduate (UG) students) enrolled in Faculty of Civil Engineering, Universiti Teknologi Malaysia. The survey was conducted separately in two different occasions. A total of 30 students from both groups participated in the survey (15 PG and 15 UG students). A detail description of each and every watershed management target was given to the both groups of the survey participants. Each question of the survey was presented separately to the survey participants and they were given 5 minutes to complete it by showing preferences on watershed management targets. However, this time limit was extendable if somebody needed extra time to fill the questionnaire and show his/her preferences on the watershed management targets.

We emphasis that this study was not aim to solve any real-world problem, rather to focus on developing a comprehensive and logical-based methodology for eliciting relative importance (weights) of targets for managing any watershed. Later the proposed methodology can be used for solving some real-world watershed and water resources problems.

ASSIGNING WEIGHTS TO WATERSHED MANAGEMENT TARGETS

Not all criteria in a multicriteria decision analysis (MCDA) having equal importance. Some of the criteria may have more importance and play bigger role in final decisions. Therefore, relative importance weights for the criteria included in a MCDA problem are first determined. These weights are usually carried out by the decision makers and thus reflect their preferences on the criteria used in a MCDA problem [KOJADINOVIC 2004]. The importance of criteria can be expressed by using several methods. The importance of criteria can be expressed by using the methods based on ordinal (e.g. SMARTER), interval (e.g. SWING and SMART) and the ratio scale (e.g. AHP), or by direct weighting [BELTON, STEWART 2001]. In this paper, we applied three weighting methods namely the SWING, the SMART, and the SMARTER to produce various sets of weights for the watershed management targets. Simplicity and transparency are two main advantages of all three selected weighting methods. RABL, SPADARO [2005] recorded main characteristics of the SWING method: it is simple and transparent; less inconsistent in preference communication; capable of handling problems with small or large number of alternatives or criteria; and sensitive to impact range.

THE SURVEY QUESTIONNAIRE

A survey questionnaire was designed to get relative importance weights of 18 watershed management targets. The questionnaire had five questions. In Quesiton-1, the survey participants were presented a list of 12 watershed management targets (T-1 to T-6 and T-13 to T-18) and were asked to select 'the most important' target first and assign 100 points to it (SWING method). The second most important target and other watershed management targets may be given points between 0 and 99 according to their importance in developing a management plan for any watershed. The second question was consisted of same management targets that were presented in Quesiton-1. However, in Quesiton-2 the participants were asked to choose 'the least important' management target first and assign 10 points to it. The second least important management target and other watershed management targets may get points multiple of 10 with respect to their importance in watershed management plan (SMART method). The weighting methodologies in Questions 3 & 4 were similar to Questions 1 & 2 respectively with one difference, i.e. 50% change in watershed management targets. However, total number of targets in Questions 3 & 4 was also kept as same (i.e. 12 targets). There were two main purposes of dividing 18 targets into two categories. First to eliminate biasness in listing the watershed management targets if they were presented in the same order and second to lessen burden from the survey respondents as providing preferences on 18 targets may be time consuming for them. The last question of the questionnaire was very easy. In this question, the survey participants had to show their preferences by assigning simple ranks to the watershed management targets according to their importance in developing management plan for a watershed (SMARTER method). Here, all eighteen watershed management targets were presented and given ranks by the participants. In data analysis, these ranks were reciprocated for deriving relative importance weights for the watershed management targets.

DESCRIPTION OF WEIGHTING METHODS

As stated previously, we applied three weighting methods to elicit relative importance weights of watershed management targets from the survey respondents. The weighting methods are SWING, SMART, and SMARTER. The chosen weighting methods were simple in survey administration and less congitive efforts were required from the survey partcipants to show their preferences on the presented watershed management targets.

The SMARTER method

The SMARTER method is very attractive, due to its simplicity. However, practical usefulness of this method is limited by the number of criteria to be ranked. In general, the larger the number of criteria used, the less appropriate is the method [EDWARDS, BARRON 1994]. However, in this study we had only 18 watershed management targets to be ranked, and which we believe are not too many. Thus, the weights obtained from the application of SMARTER method can still be stable and useful in any decision making process.

The SMARTER procedure builds upon the SMART methods. The decision makers are asked to rank all the criteria in decreasing order of importance. The weights are then calculated as:

$$w_i = N + 1 - R_i \quad (1)$$

where:

N – number of criteria,

R_i – rank assigned to criteria i.

The weights are then normalized.

VON WINTERFELDT, EDWARDS [1986] present a detail discussion on standardization and transformation rules for converting ranks into scores on an interval scale.

The SWING method

In the SWING method [VON WINTERFELDT, EDWARDS 1986], the decision-maker (DM) is asked to consider his/her worst consequence in each criterion and to identify which criterion he/she would prefer most to change from its worst level to its best level (swing). This criterion will be given the highest number of points (say 100) [HAMALAINEN, ALAJA 2008], and this criterion is excluded from the repeated process. The DM will repeat this procedure with the remaining criteria. The next criteiron with the most important swing will be assigned points relative to the most important one. This process is repeated till all criteria have been given some points according to their relative importance. Finally, the actual criteria weights are calculated by normalizing the sum of the given points to one. The procedure is outlined in different steps as below:

Step 1: Rank the criteria in the order of importance.

Step 2: Suppose that the criteria are at their worst level and that you can shift one criterion to its highest level and assign it with 100 points.

Step 3: Select another criterion to be shifted to the highest level and give it points relative to the first criterion.

Step 4: Continue until all criteria have been given some points.

Step 5: Normalise the weights.

The mathematical expressions for the SWING method are:

$$w_j = \frac{p_j}{\sum_{j=1}^{m} p_j} \quad (2)$$

Where p_j corresponds to the points given to the j^{th} criterion, and m is the number of criteria.

$$\sum_{j=1}^{m} w_i = 1 \quad 0 \le w_i \le 1 \quad (3)$$

The resulting weights are then normalized to sum to one. These weights can also be converted into percent of the total weight given to a particular criterion.

The SMART method

Simple Multiattribute Rating Technique (SMART) [EDWARDS 1977] is probably the most commonly used weighting method [CANCER 2012]. In this method, the survey participants are asked to select the least important criterion first and assigned this criterion a certain number of points (say 10 points). The points assigned to the least important criterion are the reference points for determining relative importance of other criteria in a multicriteria decision analysis (MCDA) problem. After assigning 10 points to the least important criterion, all the other criteria are given more than 10 points relative to the least important criterion. The maximum number of points given to the most important criterion is not fixed and this can be 200, 500, or even more depending how the respondent feel the difference between the least and most important criteria. This weighting method can be presented in different steps.

Step 1: Assign 10 points to the least important criterion ($w_{least} = 10$)

Step 2: Compare other criteria with the least important criterion and weigh them accordingly ($w_i > 10$, i ≠ least)

Step 3: Calculate normalised weights ($w'_k = w_k/(\Sigma_i w_i)$, $i = 1 \dots n$, n = number of criteria)

As the literature does not clearly state on the conformability of survey respondents in selecting the best criterion first or in selecting the worst criterion first, therefore, we used both weighting methods (SMART and SWING) to get relative importance weights of the watershed management targets. We also applied SMARTER weighting method where all 18 watershed management targets were presented to the respondents and their preferences on rank-order scale were elicited. The application of SMARTER method in this study has also a secondary objective – to check consistency of the respondents' understanding on criteria and points allocation in SWING and SMART methods.

RESULTS AND DISCUSSION

In this section, survey results for both groups (postgraduate and undergraduate students) are presented and interpreted. The different sets of relative importance weights of watershed management targets obtained from three weighting methods are also presented in this section.

SURVEY DATA ANALYSIS

Preliminary survey data analysis revealed that one PG student was very inconsistent in responding all five questions in the survey, thus his/her response was excluded from the final data analysis process. The survey results suggest that the PG students assigned highest relative importance weight (11.8%) to the watershed management target T-1 and the lowest weight (2.1%) to the watershed management target T-9. The range between these weights were assigned was calculated as 9.7% (i.e. 11.8–2.1). Similar to the PG students, UG students also assigned the highest relative importance weight (8.3%) to the watershed management target T-1 and the lowest relative importance weight (1.7%) to the watershed management target T-9. The range in which these weights were assigned to all 18 targets has been calculated as 6.6%, which was lower than the range calculated for PG students (i.e. 9.7%). This shows that the PG students were more flexible assigning weights to the watershed management targets compared to the UG students. This can be interpreted as the PG students had more understanding on the scales applied in all five questions of the survey questionnaire. After analyzing survey data for each group separately, we determined aggregate weights of watershed management targets. Figure 1 shows relative importance of watershed management targets for PG and UG groups along aggregate relative importance weights of 18 watershed management targets.

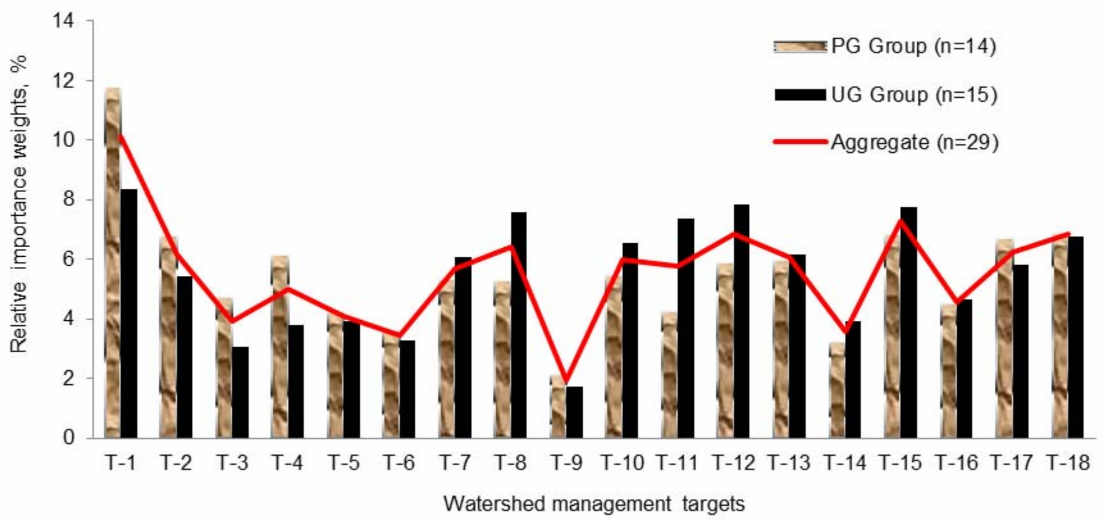

Fig. 1. Relative importance weights of watershed management targets (PG, UG, and aggregate); source: own study

COMPARATIVE ANALYSIS OF RELATIVE IMPORTANCE WEIGHTS

In this section we do comparative analysis of weights obtained from three weighting methods to see which method was deriving stable weights for watershed management targets and that can be further applied in future studies where stable weights are preferred to process with the decision making for managing watersheds. Relative importance weights of watershed management targets calculated from three different weighting methods are shown in Figure 2. We also plot aggregate relative importance weights obtained by taking average of weights determined from all three weighting methods. The survey data analysis for different weighting methods suggests that SMART weighting method provides more flexibility compared to SWING and SMARTER methods. The flexibility of the method was computed from the range (i.e. difference between maximum relative importance weights to minimum relative importance weights) in which survey participants showed their preferences. The range of relative importance weights of watershed management targets using SMART method was found as 15.7%. This value was at least two times higher than the values obtained by using SWING (6.8%) and SMARTER (7.4%) weighting methods. Thus, we conclude that the SMART method should be preferred over the SWING and the SMARTER methods in future studies on determining weights for watershed management targets. It is important to emphasize that the preference of SMART method over other two weighting methods (SWING and SMARTER) is based on the analysis of 29 responses and this preference could possibly vary if a greater sample size was used in future studies.

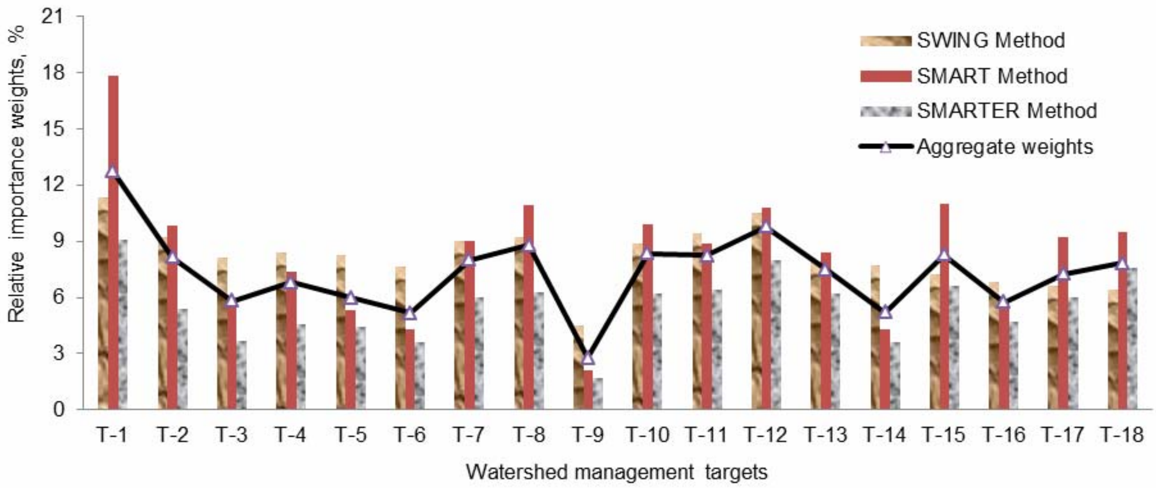

Fig. 2. Comparison of relative importance weights of watershed management targets, T1–T-18 – as in Table 1; source: own study

Table 2. Final ranking of watershed management targets

Watershed management goals/targets	Acronyms	Aggregate relative importance weights, %	Final ranking of watershed management targets
Provide good water quality	T-1	9.5	1
Balancing ecological, economic and social interests of watershed	T-12	7.2	2
Improve groundwater and surface water quantity and quality	T-18	7.1	3
Protect woodlands, wetlands and habitats	T-15	7.0	4
Protect natural/cultural heritage and forests	T-8	6.3	5
Safeguarding rivers, lakes and streams	T-17	6.1	6
Improve water supply reliabilities to inhabitants	T-13	6.0	7
Protection of sensitive lands (e.g. flood plains and valley lands)	T-10	5.9	8
Efficient use of resources (land and water)	T-11	5.8	9
Provide good habitat for fish and aquatic species	T-2	5.7	10
Controlling soil erosion	T-7	5.6	11
Provide adequate flood control	T-4	4.9	12
Protect life and property from natural hazards	T-16	4.7	13
Provide high quality of life by increasing green space	T-5	4.3	14
Provide economic development incentives	T-3	3.9	15
Improve nutrient management	T-14	3.7	16
Provide adequate protection from droughts	T-6	3.6	17
Promote recreational activities	T-9	2.0	18

Source: own study.

Based on the aggregate weights of watershed management targets, a final ranking of all eighteen watershed management targets was produced and shown in Table 2. The survey results reveal that the both groups of respondents' (PG and UG students) preferred 'provide good water quality' watershed management target by assigning aggregate relative importance weight of 9.5% to this management target. They gave second top priority to 'balancing ecological, economic and social interests of watershed' management target with assigning 7.2% of aggregate relative importance weight. On the other side, survey participants placed 'promote recreational activities' as the least important management target (relative importance weight = 2.0%) for developing management plan for a watershed.

CONCLUSIONS

Listing of watershed management targets most appropriate for the Malaysian watersheds and determining the relative importance weights for the watershed management targets are main contributions of this study. The paper provides a generic methodology for listing and prioritizing the management targets for watersheds, which can further be extended to make it applicable for solving real-world problems related to identify the vulnerable watersheds and management of watersheds in Malaysia in particular and watersheds in the other parts of the world in general. The survey results revealed that the target 'Provide good water quality' was the most important watershed management target with aggregate relative importance weight of 9.5%. The survey respondents placed 'promote recreational activities' as the least important target for managing the Malaysian as relative importance weight assigned to this target was just 2.0%.

While analyzing survey data for generating relative importance weights for the watershed management targets by using three weighting methods, we had some interesting findings. We found that the SMARTER weighting method generated a narrow set of weights for the watershed management targets as this weighting method was rigid in nature where the respondents may not had much flexibility to show their preferences on given the watershed management targets. On the other hand, SMART weighting method produced a higher range of relative importance weights for the watershed management targets which mean that this method provides a good flexibility to the respondents for showing their preferences on the given management targets. Thus, we conclude that the choice of weighting method for solving a real world watershed management problem is crucial and much attention of the researchers and decision makers is required before proceeding with next steps in the problem solving framework.

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Użycie wielu kryteriów do wyboru najbardziej wrażliwej zlewni w projektowaniu planu zarządzania

STRESZCZENIE

Określenie celów zarządzania zlewnią jest jedną z integralnych części planu zarządzania. W prezentowanej pracy ustalono 18 celów, do których w przyszłości zmierzać będzie zarządzanie zlewniami Malezji. Na podstawie tych celów ustalono ranking priorytetów, stosując wagi względnego znaczenia uzyskane w wyniku ankietowania 29 udziałowców. Dla uzyskania wag zastosowano trzy metody ważenia (SWING, SMART i SMARTER). Stwierdzono, że metoda SMART (Simple Multi-Attribute Rating Technique) była przydatna do ustalenia zestawu wag dla poszczególnych celów zarządzania zlewnią. Wagi ustalone metodą SWING były bardziej przydatne niż ustalone metodą SMARTER. Uporządkowana lista celów zarządzania będzie pomocna zarządcom i decydentom w podejmowaniu decyzji o wykorzystaniu dostępnych zasobów (jakość wody, użytkowanie ziemi, wód podziemnych i innych) w sposób bardziej efektywny i zrównoważony. Efektywne użytkowanie wszystkich zasobów zlewni uchroni je (szczególnie zlewnie zurbanizowane) od dalszego pogorszenia jakości wskutek niekontrolowanego rozwoju infrastruktury w przyszłości.