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Using the Analytic Hierarchy Process to identify parameter weights for developing a water quality index

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A B S T R A C T

One of the most common approaches used to evaluate the state of water quality in a water body is through the use of water quality indices (WQIs). This paper presents one of the most important steps in the development of a WQI, which is that of establishing the weights of the water quality parameters. The Analytic Hierarchy Process (AHP) was employed to calculate weights based on 13 selected parameters from within 7 water quality groupings for rivers in West Java, Indonesia. Thus, two AHP models were employed in this study, the first had 13 pairwise questionnaires to be compared (individual form) and the second model had 7 comparisons (group form). A pool of respondents from related stakeholders with different backgrounds in West Java was surveyed to obtain their judgement independently. In the first AHP model, both chemical oxygen demand (weights in the range 0.102–0.185) and dissolved oxygen (weights in the range 0.103–0.164) consistently received relatively high weights, compared to other water quality parameters. Meanwhile, in the second model, oxygen depletion (weights in the range 0.160–0.233) and microbiology (weights in the range 0.098–0.249) had high weights. Thus, both models estimated relatively high weights for COD, DO and FC. However, considering that the second AHP model can provide individual weights as well as weights of parameter groupings, this model was preferred in this study. Therefore the results of the second AHP model will be used for the remaining steps in the development of the West Java WQI in the future.

1. Introduction

One of the most common approaches used to evaluate the state of water quality in a water body is through the use of water quality indices (WQIs). A WQI transforms and aggregates selected water quality parameters into a dimensionless number so that the status of river water quality can be defined in a simple manner. Even though the WQI approach has certain limitations, e.g. it cannot determine the quality of water for all uses nor can it provide complete information on water quality (Cude et al., 1997), it is able to express the general state of water quality spatially and temporally, and is easy to interpret and can be used as a basis for improvement of river water quality through various implementation programs. More importantly, this approach can be used for reporting to policy makers and the public in a simple and an understandable manner (CCME, 2001). Therefore, the WQI has been one of the most effective ways to communicate information about water quality in a water body (Walsh and Wheeler, 2012).

The West Java is situated in the western part of Java Island, Indonesia. It is the second most densely populated province in the country (BPS, 2016; Juwana et al., 2016b). There are several main rivers across this province, which are valuable sources of water for various needs. However, as reported by the West Java Environmental Protection Agency (WJEPA) (WJEPA, 2013), most of the rivers are vulnerable to pollution and have poor water quality due to domestic, agricultural and industrial activities. To assess the general status of river water quality, the WJEPA uses two indices, namely the Storet and the Water Pollution Index (WPI) (MoE, 2003). Although these WQIs have been used with some success, they both had been developed based on other specific case study areas without considering local knowledge or local conditions of the West Java, e.g. stakeholder's opinion on parameter weights. Therefore, the West Java WQI will be specifically developed taking into account the above notions, after which appropriate programmes can be designed to improve the water quality of rivers throughout the province.

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There are in general four steps undertaken for the development of a WQI, which are the selection of parameters, obtaining sub-index values, establishing the weights of water quality parameters and aggregation of sub-indices to produce the final index (Abbasi and Abbasi, 2012). The establishing parameter weights aims to provide relative importance of the parameters and their influence on the final index value (Sutadian et al., 2016a). Equal weights are assigned if the parameters of an index are equally important, whereas unequal weights are assigned if some parameters have greater or lesser importance than others.

A few methods are available in the literature for estimating unequal weights of parameters or indicators in the development of an index. However, there is no generally accepted method to determine such weights (Böhringer and Jochem, 2007). Moreover, all methods have their own advantages and disadvantages (Fetscherin and Stephano, 2016; OECD, 2008). In general, in assigning different weights on parameters or indicators, OECD (2008) classifies weighting techniques into two broad categories, which are statistical-based methods (objective) and participatory-based methods (subjective). In the first category, weights are assigned based on the analysis on the data of the parameters or indicators using statistical-based approaches. In the second category, weights are assigned using judgement of related experts, policy makers and practitioners from different agencies of a certain area. As highlighted in OECD (2008), regardless of which method is used, weights are essentially value judgements. Therefore, although the first category seems to be more objective than the second category, the first is still subjective as it relies on the data provided for analysis. Also the statistical-based methods are less acceptable because of two reasons, namely the weight identification procedure is not very clear compared to that of the participatory-based methods (Zardari et al., 2015) and parameters or indicators that are theoritically insignificant could have high values (Böhringer and Jochem, 2007).

Methods such as the principal component/factor analysis (PCA/PFA) and the objective dynamic weight method are examples of the statistical-based methods. The weight identification procedure of the PCA/PFA has been applied in the environmental sustainable index (Esty et al., 2005), social sustainable development index (Panda et al., 2016) and the Langat River WQI (Mohd Ali et al., 2013). The PCA/PFA assigns weights based on the loading factor of each indicator. The PCA/PFA considers interrelationships between the parameters, and the weights cannot be estimated if no correlation exists between indicators (OECD, 2008). The disadvantage of the PCA/PFA is that this method has a strict assumption of linear relationships among parameters, but in general nonlinear relationships exist among parameters (Mohd Ali et al., 2014). In addition, regarding the required sample sizes, Hutcheson and Sofroniou (1999) recommended that at least 150–300 cases are needed to obtain satisfactory results in using PCA/PFA. Meanwhile, this study had small sample sizes due to limited data availability. Considering these disadvantages, the PCA/PFA was not considered in this study for identifying the parameter weights.

The objective dynamic weight method assumes different weights on a monthly or seasonally basis for each station (Yan et al., 2015) or based on site-specific polluting parameters (Sargaonkar et al., 2008). The weight identification procedure of the objective dynamic weight method has been applied in a dynamic WQI (Sargaonkar et al., 2008; Yan et al., 2015). The weights are assigned using the concentration ratio (water quality data over the surface water quality standards). This method has flexibility with respect to degree of pollution of the parameters that frequently varies with time, wherein it cannot be reflected with fixed weights. However, there is difficulty in making comparisons of the final index value among monitored stations, since different stations have different weights (although they are monitored at the same period monitoring) and hence is not considered in this study.

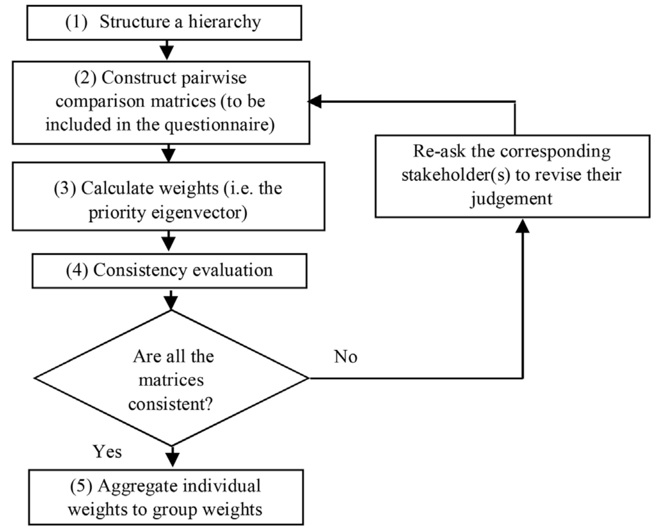

Fig. 1. Steps used in the AHP for establishing the weights.

In the participatory-based methods, techniques such as the revised Simos' procedure, the subjective dynamic weight, the Delphi and the Analytic Hierarchy Process (AHP) methods are available. The revised Simos' procedure is simple and easy to use (Zardari et al., 2015). The weights of the indicators are computed based on order of cards representing the stakeholder's preferences (Figueira and Roy, 2002). However, the revised Simos' procedure method is less popular in WQI studies. This method has been applied to determine weights of indicators for indices other than WQIs. For example, this method has been used in the development of water sustainability index by Juwana et al. (2016a). In the subjective dynamic weight method, weights are assigned based on relative significance of parameters obtained using researchers' own judgements (Yan et al., 2015). As discussed in the objective dynamic weight method in the previous paragraph, this method was not selected in this study mainly because of the inability to compare the final index values among stations or rivers. The Delphi method has been commonly used for summing up individual expert opinions to establish parameter weights for various WQIs (Almeida et al., 2012; Brown et al., 1970; Dunnette, 1979; House, 1989; Semiromi et al., 2011; Smith, 1990; SRDD, 1976). It is undertaken based on opinions of the stakeholders involved in a research through several rounds of questionnaries. Nevertheless, to reach convergence of the stakeholders' opinion, it is a lengthy and time consuming process (Franklin and Hart, 2007; Hartwich, 1999). As a result, it is more expensive than other methods (Zardari et al., 2015). Therefore, the Delphi method was not selected to be used in this study. On the other hand, the AHP is a mature and easy concept to gain experts judgement for assigning weights to the parameters. This method collects the related stakeholders' judgement using a sequence of pairwise comparison on a relative value of one over another between two quantities, wherein the judgement might be based on thoughts, experiences, and knowledge of the related stakeholders (Saaty, 1980). The advantages and disadvantages, along with a number of studies that have used the AHP method for estimating weights of parameters or indicators are discussed in Section 2.

Methods to identify weights of the currently used WQIs in the case study area (West Java Province), namely the Storet and the WPI were also investigated. Both methods assign equal weights. In addition, these two methods do not provide any guidelines for the selection of parameters. Consequently, applications of such WQIs