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A Review of the Analytical Hierarchy Process (AHP): An Approach to Water Resource Management in Thailand

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Abstract

The analytical hierarchy process (AHP) is an approach for decision making with complex problems that can be applied in water resources management. This paper reviews the literature on application of AHP in water resource management from 2009-2013 in 46 peer reviewed journal articles, analyzes the strengths and limitations of the technique using SWOT analysis, and then focuses on its utility when integrated with other methods for water resource management in Thailand. The findings indicate that AHP can be utilized for all types of water resource management focused on criteria concerning social, economic and environmental factors. Furthermore, the efficacy of AHP can be enhanced when integrated with other techniques. Application of AHP in Thailand could be combined with the Delphi technique to identify key criteria for resolving bias problems regarding goal and criteria.

Keywords: Multi-criteria decision analysis (MCDA); analytical hierarchy process (AHP); water resources management

Introduction

In Thailand, the importance of water as a vital resource for all aspects of life has always been respected. His Majesty King Bhumibol Adulyadej, in a speech delivered to executives of the Office of the Royal Development Project

Board at the Chitralada Villa on March 17, 1986, advised: "It is important for us to have water to drink and use because if there is water, we can survive. If there's no electricity, we also can survive. But if there is electricity, but no water, we cannot survive." Water resource management is therefore fundamentally important as a basis for economic development in Thailand.

Nevertheless, water management strategies in Thailand have been oriented towards supply side management with an emphasis on construction of irrigation dams and water distribution systems, rather than on demand factors. Because of the multiple objectives of such a complex issue, water resource management should be implemented to cover entire watersheds, from upstream to downstream, and involving the active participation of all stakeholders within the watershed [1].

Multi-criteria decision analysis (MCDA) is an approach to decision making in the assessment process and can be used in combination for water resource management in order to address multiple objectives and analyze multiple variables in complex situations. This method has been used to identify optimal choices to inform the decision-making process. The conceptual framework for analyzing the characteristics of the problem is also complex, and typically uses a weighted ranking system according to defined situation-specific evaluation criteria [2-6]. Many MCDA methods are available. The analytical hierarchy process (AHP) was developed by T.L. Satty (1980) and, since, has been applied as a tool for multiple criteria decision-making in several fields, for example, in engineering, economics, industry, medicine and healthcare, social science, environmental management, and water management.

AHP is a decision-making method for prioritizing alternatives based on criteria. This approach comprises three steps. The first step is the construction of a hierarchy by decision makers in order to provide a structure for complex problems involving multiple criteria. The second step comprises priority analysis, whereby decision makers compare each pairwise comparison to obtain a ratio scale of measurement (Table 1). The third stage provides verification by computing the degree of consistency among the pairwise comparisons [8-9].

Table1 Definition and explanation of comparative importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favour one over the other
5	Much more important	Experience and judgement strongly favour one over the other
7	Very much more important	Experience and judgement very strongly favour one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favouring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Source [7]

Normally, the goal is set as the highest level of the hierarchy; the following levels define criteria and sub-criteria, whilst alternatives are placed at the base of the hierarchy. The results of the comparison are placed as compared matrices, and finally decisions are created. Hence, local priorities for criteria, sub-criteria and alternatives were calculated using the principal eigenvector of a comparison matrix, following T.L. Satty (1980). The analysis was performed by multiplying the criteria-specific priority vector of the alternatives with the corresponding criterion weight, in order to evaluate the results to obtain the final composite alternatives priorities with respect to the goal. The highest value of the priority vector indicates the best-ranked alternative [10].

The objectives of this paper are 1) review and analyze empirical publications describing applications of the AHP method in water resource management from 2009 to 2013, 2) analyze the strengths and limitations of the AHP technique using SWOT analysis, and 3) focus on the utility of AHP integrated with other methods for water resource management in Thailand.

Method

This paper focused on studies of the application of AHP for water resource management. 46 peer-reviewed publications from 2009-2013 were identified by searching via ScienceDirect, SpringerLink, ProQuest and Emerald Insight. The scope of the topic was related to water resource management using AHP. The analysis of the AHP application was structured in 4 parts as follows: (1) goal and criteria for water resources applications; (2) characteristics of the AHP process; (3) type of water resources; and (4) integration of other methodological approaches with AHP in water resource management. SWOT analysis was used to analyze these publications in order to explain the methodological strengths and limitations of AHP and assess its utility as an approach to water resource management in Thailand.

Results and Discussion

AHP has been widely used to analyze problems in many fields, including business and marketing [11-15], computers and industrial engineering [16-17], healthcare [18-20], and environmental management [21-24]. This study focused on the specific application of AHP for water resource management.

1) Overview of application of AHP for natural resources management

This part presents a literature review on the application of AHP for natural resources management from 2009 to 2013. The 130 reviewed articles were classified into 4 categories: 1) environmental management, 2) soil resources, 3) water resources, and 4) forest resources. The largest number of articles was found in water resources (Table 2).

Table 2 Application of AHP method in natural resources management from 2009-2013

Year	Natural resources management				Total
	Environmental management	Soil resources	Water resources	Forest resources	
2009	5	3	4	2	14
2010	6	5	7	2	20
2011	3	8	6	5	22
2012	6	6	12	5	29
2013	8	17	17	3	45
Total	28	39	46	17	130

From the overview of application of AHP method for natural resources management, water resources had the most solutions using the AHP method. This is because water resources management is characterized by strong competition among different groups of consumptive water uses, and also the presence of diverse interest groups [25]. Multi-criteria assessment models as a tool for conflict management are thus very useful in water resources management. The major strength of multi-criteria methods is their ability to deal with issues marked by various conflicting evaluations [26]. AHP is one of the most popular MCDA techniques and was developed by T.L. Satty (1980) with this purpose in mind. This approach is a decision making method for prioritizing alternatives when multiple criteria must be considered and stakeholders can participate to set the goals, criteria, and alternatives.

2) Analysis of AHP classified by goal and criteria for water resources management

Over the period 2012-2013 AHP has been increasingly adopted as a tool for water resource management and planning (Figure 1). A total of 46 publications were classified by four categories: reference, year of publication, research goal, and criteria (Table 3).

Overall, the majority of research papers focused on water resource management as their primary goal, with criteria under this goal focused on social, economic and environmental aspects. Since water resources management involves a wide range of stakeholders with multiple objectives, all individuals, groups and community-based organizations should be engaged and participate fully in decision-making processes. According to Hermans et al. (2006) of the Food and Agriculture Organization of the United Nations (FAO), stakeholders should be supported in making choices and to reach a common understanding on the necessary arrangements for sharing and equitable allocation of water related to goods and services. Evaluating different strategies in water management are therefore implicit in this process. Water evaluation expresses the value of water-related goods and services in order to inform sharing and allocation decisions [27-29]. This review found that the following researchers focused on criteria concerning social, economic and environmental factors: [10, 29-35].

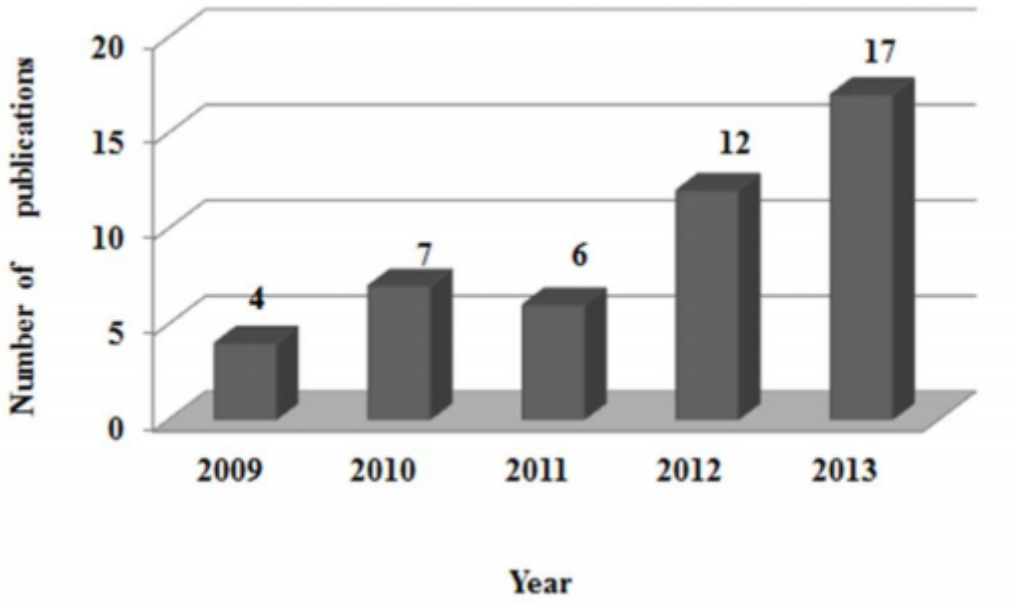

Figure 1 Numbers of publications relating to AHP, classified by year (2009-2013)

Table 3 Overview of application of AHP in water resource management

No.	Year	Goal	Criteria	Ref.
1	2009	To develop an eco-environmental vulnerability assessment	1. Land resources 2. Water and meteorological 3. Topographical 4. Human impact	[4]
2		Measure the water resources constraint force on urbanization	1. Water resources condition 2. Population urbanization level 3. Economic urbanization level 4. Social urbanization level 5. Spatial urbanization level	[36]
3		Integrated benefits of the measures for urban water resources	1. Technical economy 2. Ecological and environmental 3. Social economy	[37]
4		Reasonable allocation of water conservancy in investment of capital construction	1. Reservoir 2. Irrigation 3. Flood control and prevention 4. Waterlog control 5. Water supply 6. Hydropower 7. Water and soil conservation	[38]
5	2010	Identifying potential sites for groundwater recharge	1. Soil 2. Geomorphology 3. Geology 4. Flow accumulation 5. Groundwater	[39]
6		Leakage management alternatives	1. Planning development cost 2. Damage to properties 3. Supply disruptions	[40]
7		Integrated Water Resources Management (IWRM) strategy	1. Environmental 2. Social 3. Economic	[29]
8		Eco-environmental vulnerability assessment	1. Sediment 2. Runoff 3. Nutrient	[41]
9		Ranking Global Water Productivity (GWP) of irrigation networks	1. Canal 2. Status of regulation and distribution structures 3. Water distribution approach 4. Potential evapotranspiration 5. Annual average rainfall 6. Yearly water regime 7. Crops value 8. Crops water requirement 9. Cropping pattern 10. Water price 11. Available water for distribution	[42]

Table 3 Overview of application of AHP in water resource management *(continued)*

No.	Year	Goal	Criteria	Ref.
9		Ranking Global Water Productivity (GWP) of irrigation networks (continued)	12. Water quality 13. Cultural issues 14. Status of the water user organizations	
10		Preparation of groundwater potential map	1. Geomorphology 2. Soil 3. Land slope 4. Drainage density 5. Recharge 6. Proximity to surface water bodies	[43]
11		Integrated comparative methodology using a GIS based distributed runoff model	1. Climate conditions 2. Topographic 3. Type of discharge 4. Landuse	[44]
12	2011	Propose a disaster logistics center location selection decision support system	1. Suitability of climate 2. Geographic locations 3. Infrastructure 4. Transportation 5. Cost	[45]
13		To identify the choice of the most sustainable technology for cheese factory wastewater treatment	1. Economic aspects 2. Technological aspects 3. Environmental aspects	[46]
14		Evaluation of wetland restoration suitability	1. Stream order 2. Overland flow length 3. Stream water quality 4. Saturation index 5. Hydric soil 6. Landuse	[47]
15		Selection of Produced Water (PW) management	1. Environmental 2. Technical 3. Cost 4. Health and safety	[48]
16		Water program evaluation	1. Human development 2. Technical water supply	[49]
17		Flood risk assessment	1. Condition 2. Triggering 3. Social 4. Economic 5. Physical	[50]
18	2012	Water-conservation and waste-reduction cleaner production indicator system in textile-printing industry	1. Water resource 2. Raw materials 3. Pollutants 4. Utilization	[51]
19		Evaluate the potential of groundwater inflow	1. Geological 2. Tunnel 3. Hydrologic	[52]

Table 3 Overview of application of AHP in water resource management *(continued)*

No.	Year	Goal	Criteria	Ref.
20		Select the most suitable sites for irrigation	1. Land suitability 2. Resources 3. Cost 4. Social 5. Environmental	[31]
21		Evaluate management strategies for mountain watersheds	1. Policy planning 2. Economic 3. Ecological 4. Risk factors 5. Livelihood of people 6. Planning	[53]
22		Sustainability of urban water supply service deliver	1. Environmental 2. Economic 3. Technical 4. Institutional 5. Social-cultural	[32]
23		Evaluation factors of spatial potential water demand	1. Socio-economic 2. Physical 3. Urban planning 4. Infrastructures 5. Water policies	[54]
24		Evaluating watershed nutrient planning strategies	1. Watershed 2. Agriculture 3. Water supply 4. Appropriate development 5. Cost effectiveness 6. Community 7. Quality of life 8. Appropriate technology 9. Reduce hassle 10. Cost equitably	[55]
25		Developed for a specific class of water management problems	1. Political 2. Economic 3. Social 4. Technical 5. Legal 6. Environmental	[33]
26		Selecting suitable sites for Managed Aquifer Recharge (MAR) systems	1. Landuse 2. Topography 3. Infiltration rate 4. Sub-surface impermeable layer thickness 5. Groundwater 6. Aquifer thickness 7. Groundwater quality 8. Residence time	[56]

Table 3 Overview of application of AHP in water resource management *(continued)*

No.	Year	Goal	Criteria	Ref.
27		Best management practices for mussel-farming	1. Average productivity 2. Quality of mussel production 3. Social benefits 4. Labour force 5. Environmental risk	[57]
28		Urban drainage system (UDS) sustainability	1. Environments 2. Operational status 3. Institutional 4. Human 5. Structural quality 6. Economic and Financial 7.Prospective	[58]
29		Selection of sustainable water management strategies	1. Social 2. Environmental 3. Economic	[59]
30	2013	Assess the performance of irrigation projects	1. Technical 2. Management 3. Environmental 4. Economic 5. Social	[34]
31		Stability of wetland ecosystem	1. Function value 2. Environmental 3. Socio-economic	[60]
32		Sustainability assessment of coastal beach exploitation	1. Environmental 2. Economic 3. Social 4. Ecosystem	[35]
33		Potential groundwater recharge zones	1. Geology 2. Geomorphology 3. Slope 4. Land use and land cover 5. Lineament density 6. Drainage density 7. Soil depth 8. Soil texture 9. Soil permeability 10. Aquifer transmissivity 11. Rainfall	[61]
34		Selecting suitable areas for flood spreading	1. Geomorphology 2. Geology 3. Drainage density 4. Slope 5. Aquifer transmissivity 6. Land use 7. Water quality 8. Alluvium thickness	[62]

Table 3 Overview of application of AHP in water resource management *(continued)*

No.	Year	Goal	Criteria	Ref.
35		Establishment of flood risk assessment index system and assessment standards	1. Flood numerical simulation 2. Precipitation data 3. Elevation data 4. Landuse data 5. Population data 6. Socioeconomic data	[63]
36		Flood risk assessment	1. Rainfall 2. Water area ratio 3. City area ratio 4. Topographic slope 5. Per capita fixed assets 6. Population density 7. Industrial 8. Flood control standard 9. Density of drainage pipelines 10. Post-disaster reconstruction capability	[64]
37		Evaluate water inrush vulnerability from underlying aquifers	1. Aquiclude 2. Brittle rock thickness 3. Distribution of fault and fold 4. Distribution of fault intersection points and endpoints 5. Fault-scale index 6. Hydraulic pressure in aquifers 7. Water abundance of aquifers	[65]
38		Flood risk evaluation and prediction	1. Hazard 2. Disaster environment 3. Property characteristics 4. Society	[66]
39		Assessment of groundwater vulnerability	1. Depth to water 2. Net Recharge 3. Aquifer media 4. Soil media 5. Topography 6. Impact of vadose zone 7. Hydraulic Conductivity	[67]
40		Watershed Prioritization	1. Potential Erosion Index (PEI) 2. Sediment Delivery Ratio (SDR)	[68]
41		Groundwater utilization risk assessment	1. Land Subsidence area 2. Salt water area 3. Groundwater polluted area 4. Water Supply area 5. Natural Reserve area 6. Fragile marsh area	[69]
42		Evaluation of physical status of water mains	1. Pipes Vulnerability Index (PVI) 2. Water Distribution Systems (WDS)	[70]

Table 3 Overview of application of AHP in water resource management *(continued)*

No.	Year	Goal	Criteria	Ref.
43		Appropriate Wastewater Treatment Alternatives	1. Global warming 2. Eutrophication 3. Life Cycle Costs 4. Land requirement 5. Manpower 6. Robustness of the System 7. Sustainability	[71]
44		Prioritize the rehabilitation of water mains	1. Pipe 2. Operational 3. Community	[72]
45		Selection of Waste Water Treatment Technology	1. Social and Environmental 2. Technical 3. Economic	[73]
46		Develop the best watershed management strategy	1. Agricultural 2. Environment 3. Watershed management 4. Water consumption 5. Water quality 6. Water usage in rural areas and agriculture	[25]

3) Analysis of characteristics and use of AHP in combination with other techniques for application and types of water resources management

Applications of AHP in water resource management were analyzed by classification into three groups according to the stages of the AHP process, namely: selection, evaluation, and prioritization. The numbers of publications relevant to each process are shown in Figure 2, which clearly highlights that the evaluation process is the most frequent published application of AHP.

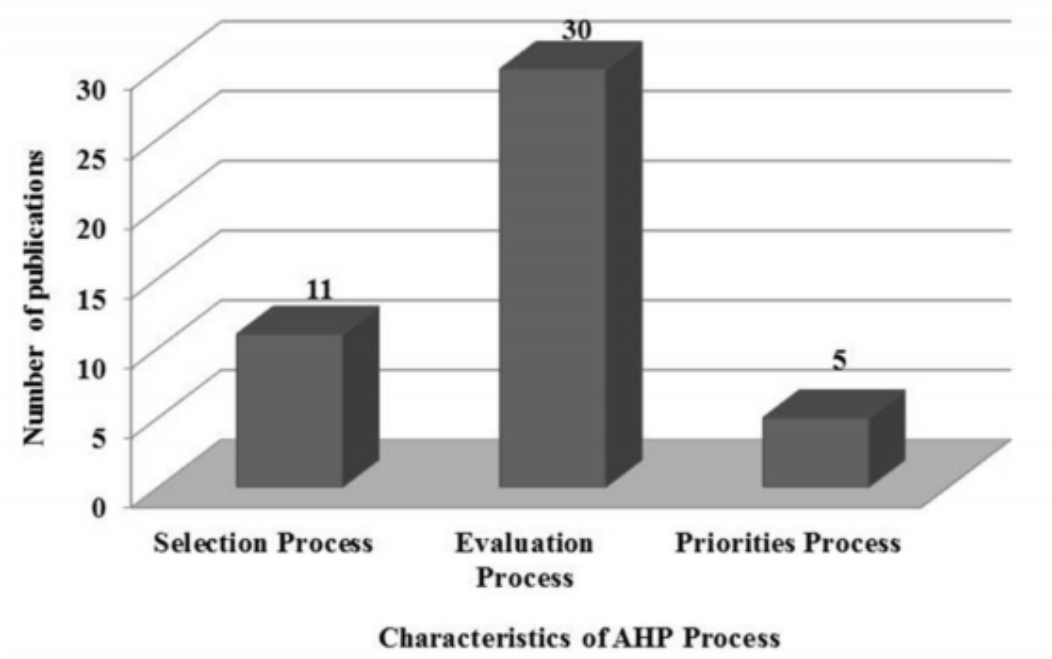

Figure 2 Numbers of publications versus characteristics of AHP process

Water resource management depends on many factors including eco-environmental, social and economic; the results of the evaluation process demonstrated the complexity inherent in water resource management. Many researchers applied the AHP approach to water resource management because stakeholders can use AHP to evaluate and select strategies to realize their goals at the watershed level [33, 36-37, 44, 53, 55, 65, 69]. Flood risk assessment in particular has been evaluated by many groups including [19, 63-64, 66]. These groups used AHP to assess flood risk factors, flood risk prediction, hazard, vulnerability and response measures. Moreover, AHP can provide a helpful integrated tool to evaluate groundwater conditions at a basin scale; AHP combined with alternative techniques can be used for groundwater assessment [43, 52, 67, 69]. AHP was also combined with spatial information to facilitate comprehensive and quantitative decisions based on a multi-criteria system. The comprehensive evaluation model of groundwater exploitation and utilization risks has been built, based on analysis of influencing factors, including water abundance, exploitation intensity and well density, and risk factor classification using AHP and GIS. These applications in water resources management using the AHP approach can explain why the evaluation process has the highest number of publications compared with the other two processes.

4) Analysis of publications on AHP application in combination with other methods

This section focuses on research in which AHP was combined with other methodologies to provide integrated methodologies for water resources management assessment. This review found that AHP was most frequently applied in combination with other methods, rather than as a stand-alone tool (Figure 3).

AHP is an approach that can accommodate both qualitative and quantitative criteria in a multiple-criteria decision making environment; this can allow an assessment bias of the evaluator, resulting in an inconsistent comparison judgment matrix [85]. As AHP developed as a theory of measurement for dealing with quantifiable and intangible criteria that has been applied to numerous areas, such as decision theory and conflict resolution [86], researchers have proposed its integration with other techniques to improve efficiency and address the evaluation bias problem in AHP.

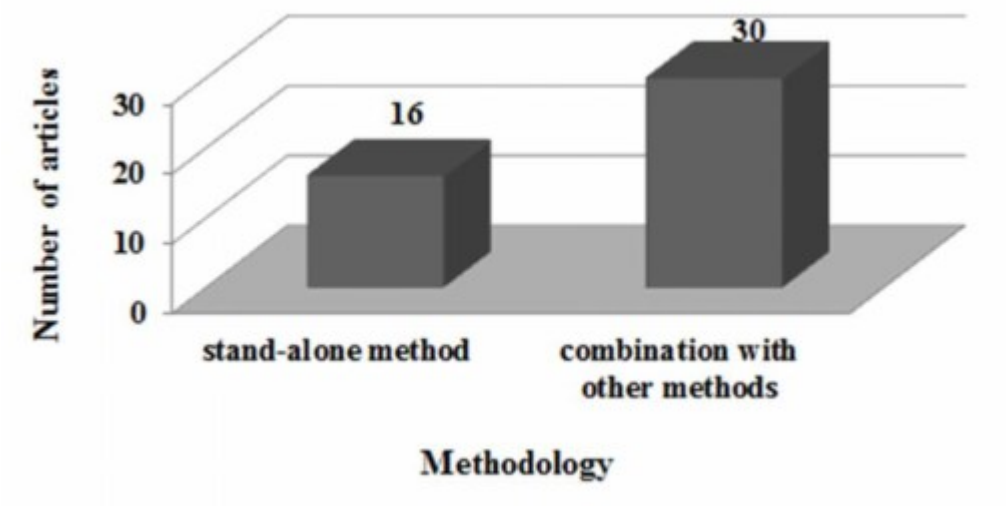

Figure 3 Application of AHP classified by combination with other methods

AHP is most frequently paired with GIS [4, 31, 39, 43-44, 50, 54, 61, 67-69], because GIS is a powerful tool for spatial and statistical analysis and overlaying information layers, essential in planning and managing water resources. AHP is also combined with PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations), ANP (Analytic Network Process), Criteria and Indicators (C&I) assessment, social choice, SWOT analysis(Strengths, Weaknesses, Opportunities and Threats), WLC (Weighted Linear Combination), GDM (Group Decision-Making), GRA (Grey Relation Analysis), SD (System Dynamics) and SPA (Set Pair Analysis). These techniques can all complement the AHP approach and enhance its effectiveness in water resources management.

5) Types of water resources management for AHP application

This section focuses on the type of water resources management for AHP applications, as follows:

1) Water resources planning
2) Watershed management
3) Groundwater management
4) Irrigation planning
5) Water quality
6) Flood management and
7) Wetland management

In Figure 4, the frequency of utilizing AHP application in seven categories above is drawn to water resources planning. AHP was used to assess several projects related to water planning strategies for sustainability planning. In addition, AHP can help stakeholders make decisions on a watershed scale, especially in the area of groundwater management, water quality management and flood management.

6) Analysis of AHP by SWOT methodology

This section summarizes the strengths and limitations of AHP as indicated in the cited publications [40, 48, 66, 68, 74-79]. The SWOT analysis (Table 4) presents the strengths, weaknesses, opportunities and threats of AHP.

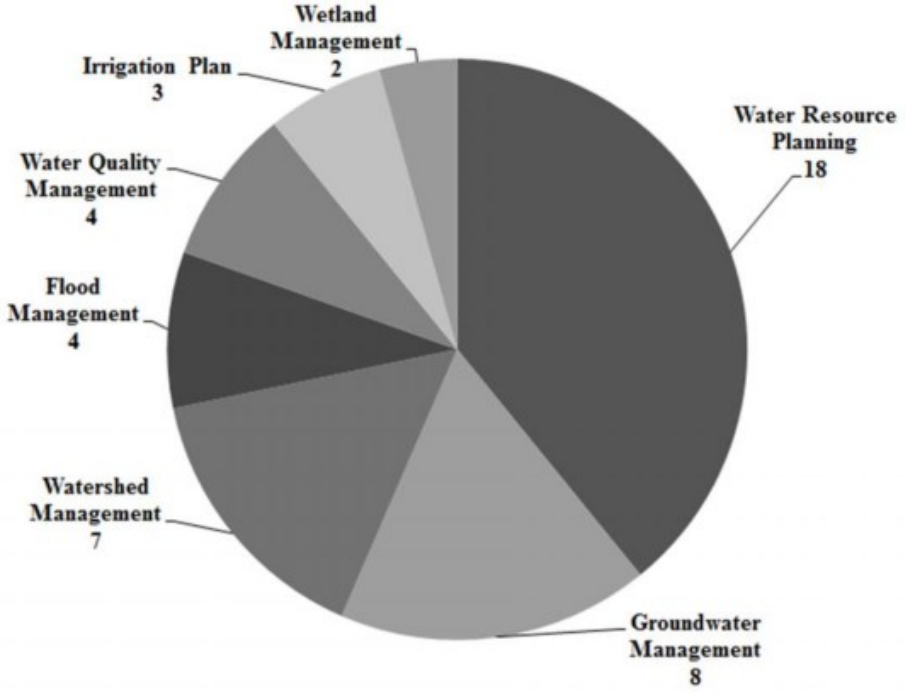

Figure 4 Types of water resources management classified by AHP application

Table 4 Summary and classification of the AHP by SWOT analysis

Analysis of AHP by SWOT method	
Strengths	**Weaknesses**
AHP is an efficient method for decision analysis and can be used to calculate weighting criteria for solving complex problems	AHP users almost never use the 7 (very strongly important) or 9 (extreme important) on the scale because they do not perceive them to be significantly different from a score of 5 (essential or strong importance).
AHP is designed in a way that represents the human mind and natural structuring of a decision problem.	An arbitrary beginning reference point is required in pairwise comparison that may bias perceptions of a multiple criteria problem.
AHP has the capability to rank decisions within the order of their effectiveness in meeting conflicting objectives.	Pairwise comparisons eliminate the longer chains of interdependence which users perceive during an AHP evaluation.
The inconsistency measure permits AHP users to remember the seriousness of any inconsistent judgments.	Priority rankings are confined to within stakeholder groups and little assistance is provided for dispute resolution.
A systematic approach is provided for identification of stakeholder objectives and preferences.	The subjective nature of preference weightings and the rapid process in eliciting them can result in questionable validity.
AHP shows excellent performance in dealing with interdependent criteria and local issues, both quantitative and qualitative.	AHP-based results are not always widely accepted.
AHP is useful as a tool to channel knowledge from as many experts as needed and organize it systematically to obtain a clear and organized solution.	Problems with inconsistencies in preferences between objectives typically arise.
AHP offers the possibility of searching and evaluating causality relationships between goal, factors, sub-factors, and alternatives by deconstructing the problem.	
Opportunities	**Threats**
The AHP offers flexibility and can be integrated with other methods; the availability of mathematical axiomatic principles and techniques to obtain group preferences and priorities.	AHP users could rely too heavily on their experience and intuitive judgment.
AHP could serve as an appropriate MCDA tool for water resource management planning characterized by conflicting objectives followed by diverse stakeholders groups.	Stakeholder interviews will be long and demanding for both interviewer and interviewee.
Both quantitative and non-quantitative factors can be accommodated within the analysis.	Questionnaire development can be difficult and time consuming.
The AHP approach can offer an assessment of the relative importance of criteria for assessment of alternative options.	Lack of agreement exists on how to identify stakeholder groups, and how to select samples or representatives from them.
AHP provides a means to combine scientific judgment with personal opinion within the analysis of policy alternatives.	
Relatively simple pairwise comparison permits elicitation of preferences for objectives by stakeholder groups.	

7) Application of AHP method for water resources management in Thailand

In Thailand, researchers have attempted to apply the AHP approach for water resources management and planning at the watershed level, irrigation project level, and provincial level. Kongjun and Vudhivanich (2003) and Opanuruks (2011) were concerned with the watershed level. Kongjun and Vudhivanich (2003) studied multi-criteria decision making for multi-reservoir water allocation during a shortage in the upper Mun Basin, Thailand. The purpose of this study was to identify the water shortages and generate water allocation alternatives which take into consideration profitability, equity, and reliability of the multi-reservoir system. Then the alternatives were selected by the analytical hierarchy process (AHP). Opanuruks (2011) used multi-criteria decision analysis model for water allocation in Rayong, KhlongYai basin, Thailand. The analysis comprised 2 parts: (1) analysis of the water resources potential within the area; and (2) the priority process of water allocation alternatives during water shortage periods when the reserved water supply is insufficient to meet demand. The prioritization process for water allocation under water shortage conditions demonstrates the framework of joint operation of the Fuzzy Analytic Hierarchy Process (FAHP), the Delphi technique, and Maximize Agreement Heuristic (MAH). Together these techniques support stakeholder participation to create the water allocation alternatives to increase its social dimension, by using a feedback process. This helped ensure satisfaction and acceptance with application of Delphi technique to compile expert opinions, and comparing to reach consensus on prioritization of water allocation alternatives by using FAHP and MAH to support future decision making. In addition, Suk-Aphinya (2005) studied integrated decision making for water allocation at the Lam Pra Plerng irrigation project using AHP. The project aimed to propose alternative allocations that generated maximum satisfaction and water utilization for all activities. The alternative should also be capable of minimizing water conflicts among users. In this study, economic, social, and engineering criteria were used to evaluate the best solution from eight alternative options. However, Koontanakulvong et al. (2008) studied area-based water resources management system development along with the decision support system and the social process in the Rayong province area. Hence, there is a need to develop tools to help manage water in various forms in order to find suitable countermeasures for the area. The information system, which is an area-based water resource management system, was developed through a social participation process and aims to help achieve better understanding among stakeholders to grasp the problem situations and to guide stakeholders towards mutually agreeable countermeasures.

Conclusions

This paper reviewed the application of the Analytical Hierarchy Process (AHP) for water resource management in 46 peer-reviewed journal articles from 2009 to 2013, as well as research studies in Thailand, focusing on application of the AHP method for water resource management. The objectives of this paper are to (1) review and analyze empirical publications describing applications of AHP in water resource management from 2009 to 2013; (2) analyze the strengths and limitations of the AHP technique using SWOT analysis; and (3) focus on the utility of AHP integrated with other methods for water resource management in Thailand. From the 46 publications, it was found that AHP is one of the best known and most popular used in MCDA, which can be evaluated to all types of water resource management focused on criteria concerning social, economic and environmental factors. Furthermore, AHP has been used in combination with other techniques for solving the evaluation bias problem in AHP. However, considering the constraints for application of AHP, its use in water resource

management in Thailand should be combined with the Delphi technique in determining key criteria. This will help minimize researcher bias regarding to goal and criteria. Therefore AHP in combination with other analytical tools and models are recommended, in order to develop a robust method to improve the effectiveness of current water resource management and planning processes in Thailand.

References

[1] Kaosa-ard, M., Sayamwala, A., Isvilanonda, S., Sattarasart, A., Rayanakorn, K., Saehae, S., Meetom, P., Wijakprasert, P., Plangpraphan, J., Kaewmeesri, T., Laingchareon, P., Uprasit, U., Tianteeravit, P., Chutabtim, P., Raksasuk, W., Tansaenee, J., Choodnok, R. 2001. Water Resources Management Policy Directions for Thailand. 1 vols. (in Thai, English summary). Thailand Development Research Institute, Bangkok.

[2] Guitouni, A. and Martel, J.M. 1998. Tentative guidelines to help choosing an appropriate MCDA method. European Journal of Operational Research. 109: 501-521.

[3] Roy, B. 2005.Paradigms and challenges, pp4-18. In Figueira, J., Greco, S., and Ehrgott, M. (eds.).Multiple Criteria Decision Analysis: State of the art surveys. New York, Springer-Verlag.

[4] Li, L., Shi, Z.-H., Yin, W., Zhu, D., Ng, S.L., Cai, C.-F., and Lei, A.-L. 2009. A fuzzy analytic hierarchy process (FAHP) approach to eco-environmental vulnerability assessment for the danjiangkou reservoir area, China. Ecological Modelling. 220: 3439-3447.

[5] Simonovic, S. 2009.A new method for spatial and temporal analysis of risk in water resources management. Journal of Hydroinformatics. 11:320-329.

[6] Mutikanga, H.E., Sharma, S.K., and Vairavamoorthy, K. 2011. Multi-criteria Decision Analysis: A strategic planning tool for water loss management. Water Resource Manage-ment.25:3947-3969.

[7] Satty, T.L.1980. The Analytic Hierarchy Process. New York, McGraw-Hill. 287 p.

[8] Ho, W. 2008. Integrated analytic hierarchy process and its applications - A literature review. European Journal of Operational Research. 186: 211-228.

[9] Liberatore, M. and Nydick, R. 2008.The analytic hierarchy process in medical and health care decision making: A literature review. European Journal of Operational Research. 189: 194-207.

[10] Srdjevic, B. and Srdjevic, Z. 2008. Multilevel participatory model for decision making on regional hydro-system basis Serbian case study, pp 201-213. In Gönenç I.E., Vadineanu, A., Wolflin, J.P. and Russo, R.C. (eds.). Sustainable Use and Development of Watersheds. Publ Springer. Netherlands.

[11] Lee, S. and Ross, S.D. 2012. Sport sponsorship decision making in a global market: An approach of Analytic Hierarchy Process (AHP). Sport, Business and Management: An International Journal. 2: 156-168.

[12] Strasser, S.E., Ozgur, C., and Schroeder, D.L. 2002. Selecting a business college major: An analysis of criteria and choice using the Analytical Hierarchy Process. American Journal of Business. 17: 47-56.

[13] Davies, M. 2001. Adaptive AHP: a review of marketing applications with extensions. European Journal of Marketing. 35: 872-894.

[14] Jackson, J. 2001. Prioritising customers and other stakeholders using the AHP. European Journal of Marketing. 35: 858-873.

[15] Eddie, W.L., Cheng, E.W.L., and Li, H. 2001. Analytic hierarchy process: an approach to determine measures for business performance. Measuring Business Excellence. 5:30-37.

[16] Liao, C.-N., 2011. Fuzzy analytical hierarchy process and multi-segment goal programming applied to new product segmented underprice strategy. Computers & Industrial Engineering. 61: 831-841

[17] Chen, S.H., Wang, P.W., Chen, C.M., and Lee, H.T. 2010. An analytic hierarchy process approach with linguistic variables for selection of an R&D strategic alliance partner. Computers & Industrial Engineering. 58: 278-287.

[18] Büyüközkan, G. and Çifçi, G. 2012. A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry. Expert Systems with Applications.39: 2341-2354.

[19] Wang, J., Fan, K., and Wang, W. 2010. Integration of fuzzy AHP and FPP with TOPSIS methodology for aeroengine health assessment. Expert Systems with Applications.37: 8516-8526.

[20] Vidal, L.-A., Sahin, E., Martelli, N., Berhoune, M., and Bonan, B. 2010. Applying AHP to select drugs to be produced by anticipation in a chemotherapy compounding unit. Expert Systems with Applications. 37: 1528-1534.

[21] Vizzari, M., and Modica, G. 2013. Environmental effectiveness of swine sewage management: Amulticriteria AHP-based model for a reliable quick assessment. Journal of Environmental Management. 52:1023-1039.

[22] Ying, X., Zeng, G.-M., Chen, G.Q., Tang, L., Wang, K.-L., and Huang, D.Y. 2007. Combining AHP with GIS in synthetic evaluation of eco-environment quality-A case study of Hunan Province, China. Ecological Modelling.209: 97-109.

[23] Tesfamariam, S., and Sadiq, R.2006. Risk-based environmental decision-making using fuzzy analytic hierarchy process (F-AHP). Stochastic Environmental Research and Risk Assessment. 21: 35-50.

[24] Ramanathan, R. 2001. A note on the use of the analytic hierarchy process for environmental impact assessment. Journal Environmental Management. 63: 27-35.

[25] Yavuz, F., and Baycan, T. 2013. Use of SWOT and analytic hierarchy process integration as a participatory decision making tool in watershed management. Procedia Technology 8: 134-143.

[26] Ash, N., Thonell, J. 2005. Analytical approaches for assessing ecosystem condition and human well-being, pp 37-72. In Hassan R.M, Scholes R., Ash N., editors. Ecosystems and human well-being: current state and trends: findings of the condition and trends working group of the millennium ecosystem assessment, Millennium Ecosystem Assessment (Program) Condition and Trends Working Group. Island Press.

[27] Hermans, C., Erickson, J., Noordewier, T., Sheldon, A., and Kline, M. 2006. Collaborative environmental planning in river management: An application of Multicriteria Decision Analysis in the White River Watershed in Vermont. Journal of Environmental Management. 84: 534-546.

[28] Anagnostopoulos, K.P., Petalas, C., and Pisinaras, V. 2005. Water resources planning using the AHP and PROMETHEE multicriteria methods: the case of Nestos River-Greece, pp 39-44. In proc. The 7th Balkan Conference on Operational Research BACOR 05, Constanta, May 2005, Romania.

[29] Calizaya, A., Meixner, O., Bengtsson, L., and Berndtsson, R. 2010. Multi-criteria Decision Analysis (MCDA) for Integrated Water Resources Management (IWRM) in the Lake Poopo Basin, Bolivia. Water Resource Management. 24: 2267-2289.

[30] Srdjevic, B. and Medeiros, Y.D.P. 2008. Fuzzy AHP assessment of water management plans. Water Resources Management. 22: 877-894.

[31] Anane, M., Bouziri, L., Limam, A., and Jellali, S. 2012. Ranking suitable sites for irrigation with reclaimed water in the Abeul-Hammamet region (Tunisia) using GIS and AHP-multicriteria decision analysis. Resources, Conservation and Recycling. 65: 36-46.

[32] Okeola, O.G. and Sule, B.F. 2012. Evaluation of management alternatives for urban water supply system using Multicriteria Decision Analysis. Journal of King Saud University – Engineering Sciences. 24: 19-24.

[33] Srdjevic, Z. Bajcetic, R., and Srdjevic, B. 2012. Identifying the criteria set for Multicriteria Decision Making based on SWOT/ PESTLE analysis: A case study of reconstructing a water intake structure. Water Resource Management. 26: 3379-3393.

[34] Montazar, A. Gheidari, O.N., and Snyder, R.L. 2013.A fuzzy analytical hierarchy methodology for the performance assessment of irrigation projects. Agricultural Water Management. 121: 113-123.

[35] Tian, W.,Bai, J., Sun, H., and Zhao, Y. 2013. Application of the analytic hierarchy process to a sustainability assessment of coastal beach exploitation: A case study of the wind power projects on the coastal beaches of Yancheng, China. Journal of Environmental Management. 115: 251-256.

[36] Chao, B. and Chuang-lin, F. 2009. Integrated assessment model of water resources constraint intensity on urbanization in arid area.Journal of Geographical Sciences. 19: 273-286.

[37] Xiaoqin, W. 2009. A proposal and application of the integrated benefit assessment model for urban water resources exploitation and utilization. Water Resource Management. 23:1171-1182.

[38] Zhang, H. 2009. The analysis of the reasonable structure of water conservancy investment of capital construction in China by AHP Method. Water Resource Management. 23: 1-18.

[39] Sargaonkar, A.P. Rathi, B., and Baile, A. 2010. Identifying potential sites for artificial groundwater recharge in sub-watershed of River Kanhan, India. Environmental Earth Sciences. 62: 1099-1108.

[40] Delgado-Galván, X., Pérez-García, R., Izquierdo, J., and Mora-Rodríguez, J. 2010. An analytic hierarchy process for assessing externalities in water leakage management. Mathematical and Computer Modelling. 52: 1194-1202.

[41] Huang, P.H., Tsai, J.S., and Lin, W.T. 2010.Using multiple-criteria decision-making techniques for eco-environmental vulnerability assessment: A case study on the Chi-Jia-Wan Stream watershed, Taiwan. Environmental Monitoring and Assessment. 168: 141-158.

[42] Montazar, A. and Zadbagher, E. 2010. An Analytical Hierarchy Model for assessing global water productivity of irrigation networks in Iran. Water Resource Management. 24: 2817-2832.

[43] Jha, M.K. Chowdary, V.M., and Chowdhury, A. 2010.Groundwater assessment in Salboni Block, West Bengal (India) using remote sensing, geographical information system and multi-criteria decision analysis techniques. Hydrogeology Journal. 18: 1713-1728.

[44] Park, J.H. 2010. A study on the comparative method using AHP and GIS based distributed runoff model. KSCE Journal of Civil Engineering. 14: 953-960.

[45] Turgut, B.T., Tas, G., and Herekoglu, A. 2011. A fuzzy AHP based decision support system for disaster center location selection and a case study for Istanbul. Disaster Prevention and Management. 20: 499-520.

[46] Bottero, M., Comino, E., and Riggio, V. 2011. Application of the Analytic Hierarchy Process and the Analytic Network Process

for the assessment of different wastewater treatment systems. Environmental Modelling & Software. 26: 1211-1224.

[48] Mofarrah, A., Husain, T., Hawboldt, K., and Veitch, B. 2011. Decision-making tool for produced water management. Produced Water, pp 573-586. In Lee, K. and Neff, J.(eds.). Environmental Risks and Advances in Mitigation Technologies. Springer, UK.

[47] Ouyang, N.L., Lu, S.L., Wu, B.F., Zhu, J.J., and Wang, H. 2011. Wetland restoration suitability evaluation at the watershed scale: A case study in upstream of the Yongdinghe River. Procedia Environmental Sciences. 10: 1926-1932.

[49] Garfi, M., Ferrer-Martí, L., Bonoli, A., and Tondelli, S. 2011. Multi-criteria analysis for improving strategic environmental assessment of water programmes A case study in semi-arid region of Brazil. Journal of Environmental Management. 92: 665-675.

[50] Wang, Y., Li, Z., Tang, Z., and Zeng, G. 2011. A GIS-based spatial multi-criteria approach for flood risk assessment in the Dongting Lake Region, Hunan, Central China.Water Resource Management. 25: 3465-3484.

[51] Tong, O., Shao, S., Zhang, Y., Chen, Y., Liu, S.L., and Zhang, S.S. 2012. An AHP-Based water-conservation and waste-reduction indicator system for cleaner production of textile-printing industry in China and technique integration. Clean Techn Environ Policy. 14: 857-868.

[52] Aalianvari, A., Katibeh, H., and Sha- rifzadeh, M. 2012. Application of fuzzy Delphi AHP method for the estimation and classification of Ghomrud tunnel from groundwater flow hazard. Arabian Journal of Geosciences.5:275-284.

[53] Biswas, S., Vacik, H., Swanson, M.E., and Haque, S.M. 2012. Evaluating Integrated Watershed Management using multiple criteria analysis-a case study at Chittagong Hill Tracts in Bangladesh. Environmental Monitoring and Assess-ment. 184: 2741-2761.

[54] Panagopoulos, G.P., Bathrellos, G.D., Skilodimou, H.D., and Martsouka, F.A. 2012. Mapping urban water demands using multi-criteria analysis and GIS. Water Resource Management. 26: 1347-1363.

[55] Bosch, D. Pease, J., Wolfe, M.L., Zobel C., Osorio J., Cobb T.D., and Evanylo, G. 2012. Community DECISIONS: Stakeholder focused watershed planning. Journal of Environmental Management. 112: 226-232.

[56] Rahman, M.A., Rusteberg, B., Gogu, R.C., Ferreira, J.P.L., and Sauter, M. 2012. A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge. Journal of Environmental Management. 99: 61-75.

[57] Latinopoulos, D., Konstantinou, Z., and Krestenitis, Y. 2012. Simulation and multicriteria analysis in sustainable coastal planning: The case of aquaculture in Thermaikos Gulf, Greece. Environment, Development and Sustainability. 14: 1027-1045.

[58] Benzerra, A., Cherrared, M., Chocat, B., Cherqui, F., and Zekiouk, T. 2012. Decision support for sustainable urban drainage system management: A case study of Jijel, Algeria. Journal of Environmental Management. 101: 46-53.

[59] Freitas, A.H.A. and Magrini, A. 2012. Multi-criteria decision-making to support sustainable water management in a mining complex in Brazil. Journal of Cleaner Production. 47: 118-128.

[60] Zhang, R., Zhang, X., Yang, J., and Yuan, H. 2013. Wetland ecosystem stability evaluation by using Analytical Hierarchy Process (AHP) approach in Yinchuan Plain, China. Mathematical and Computer Modelling. 57: 366-374.

[61] Kaliraj, S., Chandrasekar, N., and Magesh, N.S. 2014. Identification of potential groundwater recharge zones in Vaigai-upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arabian Journal of Geosciences. 7: 1385-1401.

[62] Nasiri, H.,Boloorani, A.D., Sabokbar, H.A., Jafari, H.R., Hamzeh, M., and Rafii, Y. 2013. Determining the most suitable areas for artificial groundwater recharge via an integrated PROMETHEE II-AHP method in GIS environment (case study: Garabaygan Basin, Iran). Environmental Monitoring and Assessment. 185: 707-718.

[63] Zou, Q., Zhou, J., Zhou, C., Song, L., and Guo, J. 2013. Comprehensive flood risk assessment based on set pair analysis-variable fuzzy sets model and fuzzy AHP. Stochastic Environmental Research and Risk Assessment. 27: 525-546.

[64] Li, G.-F., Xiang, X.Y., Tong, Y.Y., and Wang, H.M. 2013.Impact assessment of urbanization on flood risk in the Yangtze River Delta.Stochastic Environmental Research and Risk Assessment. 27: 1683-1693.

[65] Wu, Q., Fan, S., Zhou, W., and Liu, S. 2013. Application of the Analytic Hierarchy Process to assessment of water inrush: A case study for the No. 17 coal seam in the Sanhejian Coal Mine, China. Mine Water and the Environment. 32: 229-238.

[66] Yang, X., Ding, J.-H., and Hou, H. 2013. Application of a triangular fuzzy AHP approach for flood risk evaluation and response measures analysis. Nat Hazards. 68: 657-674.

[67] Sener, E. and Davraz, A. 2013. Assessment of groundwater vulnerability based on a modified DRASTIC model, GIS and an analytic hierarchy process (AHP) method: the case of Egirdir Lake basin (Isparta, Turkey). Hydrogeology Journal. 21: 701-714.

[68] Chowdary, V.M., Chakraborthy, D., Jeyaram, A., Krishna Murthy, Y.V.N., Sharma, J.R., and Dadhwal, V.K. 2013. Multicriteria decision making approach for watershed prioritization using hierarchy process technique and GIS. Water Resource Management. 27: 3555-3571.

[69] Dong, D., Sun, W., Zhu, Z., Xi, S., and Lin, G. 2013. Groundwater Risk Assessment of the Third Aquifer in Tianjin City, China.Water Resource Management. 27: 3179-3190.

[70] Nazif, S., Karamouz, M., Yousefi, M., and Zahmatkesh, Z. 2013. Increasing water security: An algorithm to improve water distribution performance. Water Resource Management. 27: 2903-2921.

[71] Kalbar, P.P., Karmakar, S., and Asolekar, S.R. 2013. The influence of expert opinions on the selection of wastewater treatment alternatives: A group decision-making approach. Journal of Environmental Management. 128: 844-851.

[72] Zayed, T., and Mohamed, E. 2013. Budget allocation and rehabilitation plans for water systems using simulation approach. Tunnelling and Underground Space Technology. 36: 34-45.

[73] Ilangkumaran, M. Sasirekha , V., Anojkumar, L., Sakthivel, G., Boopathi Raja, M., RubanSundara Raj, T., Siddhartha, C.N.S., Nizamuddin, P., and Praveen Kumar, S. 2013. Optimization of wastewater treatment technology selection using hybrid MCDM. Management of Environmental Quality: An International Journal. 24: 619-641.

[74] Carlsson, C. and Walden, P., 1995. AHP in political group decisions: A study in the art of possibilities. Interfaces. 25: 14-29.

[75] Qureshi, M. and Harrison S.R. 2003. Application of the Analytic Hierarchy Process to riparian revegetationpolicy options.Small-Scale Forest Economics. Management and Policy. 2: 441-458.

[76] Kumar, S. and Vaidya, O. 2006. Analytic hierarchy process: An overview of applications. European Journal of Operational Research. 169: 1-29.

[77] Cabrera, E., Cobacho, R., Estruch, V., and Aznar, J. 2011. Analytical hierarchical process (AHP) as a decision support tool in water resources management. Journal of Water Supply Research and Technology-Aqua. 60: 343-351.

[78] Pourghasemi, H.R., Pradhan, B., and Gokceoglu, C. 2012. Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed, Iran. Nat Hazards. 63: 965-996.

[79] Gallego-Ayala, J. and Juízo, D. 2014. Integrating stakeholders' references into water resources management planning in the Incomati River Basin.Water Resource Management. 28: 527-540.

[80] Kongjun, T. and Vudhivanich, V. 2003. Multicriteria decision making for multi-reservoir water allocation during shortage: A case study of Upper Mun Basin, pp.45-54. Proceedings of 41th Kasetsart University Annual Conference: Engineering and Architecture. Bangkok.

[81] Opanuruks, J. 2011. Multi-criteria decision analysis model for water allocation in Rayong, KlongYai basin. Master of Engineering Program in Water Resources Engineering Department of Water Resources EngineeringFaculty of Engineering Chulalongkorn University.

[82] Suk-Aphinya, P. 2005. An integrated decision making for water allocation using analytical hierarchy process: a case study of Lam PraPlerng Irrigation Project. Environmental Planning for Community and Rural Development, Mahidol University.

[83] Koontanakulvong, S., Suksri, C., Bhatti, A-M., Santithamnon, P., Boonyapukana, P., Suchatoa, A., Sertpitayakul, S., Suthidhummajit, C., Suthinon, P., Sakulthai, S., Pakoksung, K., Jampanil, D., Duangmanee, P., Thongbai, S., Angsurak, P., Bureerak, A., Butsalatas, P., Kaosaiyoi, W. 2008. Area-based Water Resources Management System Development Along With Decision Support System and Social Process in Rayong Province Area. Thailand Research Fund (TFD).

[84] Kao, J. J., & Lin, H. Y. 1996. Multifactor spatial analysis for landfill siting. Journal of Environmental Engineering, 122 (10), 902-908.

[85] Aydogan, E.K. 2011. Performance measurement model for Turkish aviation firms using the rough-AHP and TOPSIS methods under fuzzy environment. Expert Syst Appl 38: 3992-3998.

[86] Vargas, L.G., 1990: An overview of the analytic hierarchy process and its applications. European Journal of Operational Research, 48: 2-8.