

THE APPLICATION OF GIS BASED MULTI-CRITERIA ANALYSIS FOR
SELECTING AN OPTIMUM WATER RESERVOIR SITE

BAKHTYAR ALI AHMAD

A dissertation submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Science (Geoinformatics)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

SEPTEMBER 2014

This work is dedicated to my beloved parents, my father **ALI AHMAD** and my mother **TUBA TAHA** for their resilience in insisting to educate me amidst the absolute poverty in which they raised me.

To **PESHMARGA**, Kurdish forces who devote their entire life to defending the holy land of Kurdistan.

ACKNOWLEDGEMENT

In The Name Of Allah, Most Gracious, Most Merciful

First and foremost, I must be thankful to Allah for finishing the research and I would like to express my sincere thanks and appreciation to my supervisor **Assoc. Prof. Mohd Safie Mohd**, for his precious guidance, encouragement, constructive criticisms, advice, knowledge and motivation. Without his continual support and interest, this project report would not have been that same as presented here.

I would like to thank to all my family members for their prayers and all their supports and encouragements. I am also grateful to my all friends.

Besides, I would like to thank the authority of Universiti Teknologi Malaysia (UTM) for providing me with a good environment and facilities.

ABSTRACT

Malaysia is well endowed with abundance of natural water resources, which has significantly contributed to the socio-economic development of the country. However, the situation has somewhat changed over the last decade. The water demand was 174.22 M/l/d in year 2010 and it is projected to be 270.77 M/l/d in 2050. In such scenario, a reliable and safe supply of water for future generations, more and more reservoirs will be required. The aim of this study is to apply GIS in identifying the most suitable location for water reservoir for area of Batu Pahat, Johor, West Malaysia. Methodology is designed in such a way to achieve the objectives of this study as to identify the important criteria for locating water reservoir, to model the location of reservoir using Analytical Hierarchy Process (AHP) and to analyze and evaluate the most potential sites for water reservoir using ArcGIS 10.1 software. Based on the criteria chosen, the data are processed and analyzed the existing 52 reservoir locations and their capacities. Based on the projected number of population for the year 2050, as a result, 5 new reservoir locations have been identified to fulfill the future demands of water for the study area. Thus, it can be concluded that the weights derived from AHP integrated in ArcGIS can be a useful tool in GIS analysis for the determination of suitable locations for water reservoir in the study area.

ABSTRAK

Malaysia dikurniakan dengan banyak sumber-sumber air semula jadi yang telah banyak menyumbang kepada pembangunan sosio-ekonomi negara. Walau bagaimanapun, keadaan agak berubah dalam beberapa dekad mutakhir. Permintaan air adalah sebanyak 174.22 M/l/d pada tahun 2010 dan ia dijangka akan meningkat kepada 270.77 M/l/d pada tahun 2050. Dalam senario sebegini, bekalan air yang boleh digunakan dan selamat untuk generasi akan datang, memerlukan lebih banyak takungan air untuk masa hadapan. Kajian ini bertujuan untuk mengaplikasi GIS dalam mengenal pasti lokasi yang paling sesuai untuk takungan air bagi kawasan Batu Pahat, Johor, Malaysia Barat. Metodologi kajian ini direka sedemikian rupa untuk mencapai objektif-objektif kajian ini yakni untuk mengenalpasti kriteria penting untuk mengesan takungan air, untuk pemodelan lokasi takungan menggunakan proses analisis hirarki (AHP) dan untuk menganalisis dan menilai kawasan yang berpotensi untuk takungan air menggunakan perisian ArcGIS 10.1. Berdasarkan kriteria-kriteria yang dipilih, data diproses dan dianalisis berasaskan 52 lokasi takungan yang sedia ada termasuklah keupayaan masakini. Berdasarkan unjuran bilangan penduduk pada tahun 2050, hasilnya, 5 lokasi takungan baru telah dikenalpasti untuk memenuhi permintaan masa hadapan air bagi kawasan kajian. Oleh itu, ianya dapat disimpulkan bahawa pemberat yang diperolehi daripada AHP yang diintegrasikan dengan ArcGIS boleh menjadi alat yang berguna dalam analisis GIS bagi menentukan lokasi yang sesuai untuk takungan air di kawasan kajian.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF ACRONYMS	xiv
1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Study Area	3
	1.4 Main Research Question	4
	1.5 Aim of Study	4
	1.6 Objectives of Study	4
	1.7 Specific Research Questions	4
	1.8 Scope of Study	5
	1.9 Need of Study	5
	1.10 Summary	6
2	LITERATURE REVIEW	
	2.1 Introduction	7

2.2	Global Water Source	7
2.3	Water Availability in Malaysia	8
2.4	Population in Malaysia	10
2.5	Water Demand	10
2.6	Water Supply and Distribution	13
2.7	Reservoir	14
2.7.1	Factors Influencing Reservoir Site Selection	15
2.8	Geographic Information Systems (GIS)	18
2.8.1	GIS History and Development	18
2.8.2	GIS Functions	20
2.8.2.1	Data Capture	20
2.8.2.2	Data Compilation	20
2.8.2.3	Data Storage	21
2.8.2.4	Manipulation	21
2.8.2.5	Analysis	21
2.9	Data Models	22
2.9.1	Vector-based Data Model	22
2.9.2	Raster-based Data Model	23
2.10	GIS Data Source	24
2.11	Multi-Criteria Decision Analysis	24
2.11.1	Framework of Spatial Multi Criteria Decision Analysis	27
2.11.2	Fuzzy Logic	28
2.11.3	Weighted Linear Combination	29
2.11.4	Analytic Hierarchy Process (AHP)	30
2.11.4.1	Strengths and Weaknesses	31
2.12	Summary	33

3 METHODOLOGY

3.1	Introduction	34
3.2	Data Collection Technique	39
3.2.1	Creation of the DEM Layer	40
3.2.2	Creation of the Slope Layer from DEM	42
3.2.3	Questionnaire	42

3.3	The Distance of Maps (River, Road Network and Pipeline)	43
3.3.1	The Euclidean Distance Algorithm	43
3.3.2	The Euclidean Distance Output Raster	44
3.4	Classifications of the Layers (DEM, River, Slope, Road Network and Pipeline)	46
3.4.1	Reclassification and Define Priority for DEM	47
3.4.2	Reclassification and Define Priority for Slope	47
3.4.3	Reclassification and Define Priority for River	48
3.4.4	Reclassification and Define Priority for Road Network	48
3.4.5	Reclassification and Define Priority for Pipeline	49
3.5	AHP Approach	49
3.5.1	Problem Solving and Decision Making	50
3.5.2	Sitting Steps	50
3.5.3	Factor Generation	50
3.5.4	Factor Standardization	51
3.5.5	Factor Weights Determination by AHP	51
3.5.6	Making Comparison Matrix	53
3.6	Weighted Overlay	54
3.7	Summary	56

4 RESULTS AND ANALYSIS

4.1	Introduction	57
4.2	Population in Batu Pahat	57
4.3	Water Supply in Batu Pahat	58
4.4	Analysis of the Map Layers of (Digital Elevation Model, Slope and Land Use)	61
4.4.1	Digital Elevation Model (DEM) Map	61
4.4.2	Analysis of Slope Map	62

4.4.3	Analysis of Land Use Map	62
4.5	Analysis of the Results of Distance Maps (River, Road Network and Pipeline)	63
4.5.1	Distance from the River	64
4.5.2	Distance from the Pipelines	64
4.5.3	Distance from the Road Network	65
4.6	Analysis of Classifications the Layers (DEM, River, Slope, Road Network and Pipeline)	66
4.6.1	Reclassification for DEM	67
4.6.2	Reclassification for Slope	68
4.6.3	Reclassification for River	69
4.6.4	Reclassification for Road Network	70
4.6.5	Reclassification for Pipeline	71
4.7	Comparative between Criteria	72
4.8	Weighted Overlay	74
4.9	Summary	77
5	CONCLUSION	
5.1	Introduction	79
5.2	Discussion	79
5.3	Suggestion and Recommendation	80
5.4	Conclusion	81
	REFERENCES	82
	APPENDIX	86

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Water Demand Projections for Johor M/I/d (DID, 2010)	11
2.2	Intakes and Capacity of Sungai Bekok and Sungai Sembrong M/I/d (DID, 2010)	12
3.1	Point Intensity of Relative Importance Scale	52
3.2	Number of Comparison (Do and Kim, 2012)	52
4.1	Future Growth Population of Batu Pahat (DID, 2010)	58
4.2	Existing Water Reservoir in Batu Pahat (SAJ Holdings Sdn Bhd)	59
4.3	Comparative between Criteria	72
4.4	The Result of Weight of Criteria	74

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
1.1	Study Area	3
2.1	Earth Water Percentages (Wright and Nebel, 2004)	8
2.2	Water Demand Projections and Planning Curve for Batu Pahat District	12
2.3	Distribution of Major Lakes and Reservoir in Malaysia	14
2.4	Hierarchy Model for Water Reservoir Siting	17
2.5	Growth of Multi-criteria decision analysis	25
3.1	Research Methodology	35
3.2	Basemap of Study Area	39
3.3	Mosaic to New Raster	40
3.4	Projection of Dem (Geographic To Cassini)	41
3.5	Extracted DEM by Boundary	41
3.6	Created Slope Map from DEM	42
3.7	Shown Euclidean Distance is Calculate (Cerchiai, Fiore, and Madore, 2001)	44
3.8	Distance Layer for River	45
3.9	Distance Layer for Road Network	45
3.10	Distance Layer for Pipeline	46
3.11	Reclassify of Dem	47
3.12	Reclassify of Slope	47
3.13	Reclassify River of Distance	48
3.14	Reclassify Road of Distance	48
3.15	Reclassify of Pipeline Distance	49
3.16	Weight Overlay for Site Selection (Optimal Site)	55
3.17	The Optimal Site with High Value According the Priority	56

4.1	Distribution of Existing Reservoir in Batu Pahat District	60
4.2	Digital Elevation Model	61
4.3	Slope Map	62
4.4	Land Use Map	63
4.5	Distance from River	64
4.6	Distance from Pipelines	65
4.7	Distance from the Road Network	66
4.8	Reclassify of Dem	67
4.9	Reclassify of Slope	68
4.10	Reclassify River of Distance	69
4.11	Reclassify of Road Distance	70
4.12	Reclassify of Pipeline Distance	71
4.13	The Optimal Site Selection Reservoir	75
4.14	Optimum Sites for New Reservoirs	76
4.15	Selection of Suitable Site for Reservoir	77

CHAPTER 1

INTRODUCTION

1.1 Introduction

Water is absolutely fundamental to life and luckily the earth is almost submerged in with water. An amount 325 mi^3 occupies 71% of the globe. Salt water of the oceans and sea accounts for about 97.5% of this volume. The remaining 2.5% is fresh water (Wright and Nebel, 2004) of the 2.5% though; two/third is stored in glaciers and polar ice caps. Thus, only 0.77% of all water is available in atmosphere, soil, groundwater, rivers, wetland and lakes (Wright and Nebel, 2004).

Malaysia is fully blessed with plentiful supply of water naturally; this has prominently assisted importantly to the socio-economic advancement of the country. However, in recent years the condition has transformed to that of shortage of water (Moorthy and Jeyabalan, 2011). In certain river basins, paucity of water is experienced in periods of prolong droughts while flooding and surplus of water is present in the rainy season (Husaini, 2007). The rapid increase in population, urbanization, industrialization and increased in irrigated agriculture imposing increasing water demand and inserting extra pressure on existing water resources. There is a need to construct new water reservoirs for meeting the future water demand effectively. The selection of suitable site for water reservoir is very important as many parameters need to be considered such as topographical and geological conditions, hydrological features, and availability of construction material, safety, environmental issues and economic evaluation (Arai and Hiros, 2003). It is necessary to identify and quantify

these factors for selecting a suitable area for water reservoir in a particular area. A Geographic Information System (GIS) can be used effectively for this purpose to combine different themes objectively and analyse those systematically for identifying suitable places (Shahid, Nath, and Roy, 2000)

The aim of this research is to identify the suitable sites for water reservoir. The evaluation system is based on number of multiple criteria indicators. The main criteria selected for this study are pipe line, elevation, river, Land use, road network, water supply network and slope. The Analytical Hierarchy Process (AHP) proposed for use to derive weights. The Batu Pahat a district in Johor state is selected as the study area. The water demand was 174.22 M/l/d in year 2010 and it is projected to be 270.77 M/l/d in 2050 (DID, 2010). In such scenario, a reliable and safe supply of water for future generations, more and more reservoirs will be required.

1.2 Problem Statement

The rising tendency in urbanization and population has increased the water demand. This rising tendency in urbanization and population has raised the demand for new water reservoirs to meet the growing need of water. To ensure a reliable and safe supply for future generations, more and more reservoirs will be required. The selection of suitable site for water reservoir is extremely difficult in recent years as the proper selection of suitable site considers many factors such as hydrological, geological and socio-economic parameters. The water demand was 174.22 M/l/d in year 2010 and it is projected to be 270.77 M/l/d in 2050 (DID, 2010). In such scenario, a reliable and safe supply of water for future generations, more and more reservoirs will be required.

1.3 Study Area

Batu Pahat is a town under Johor state of Malaysia. Geographically it is located between Longitudes $102^{\circ}56'$ and 102.933°E and Latitudes $1^{\circ}51'\text{N}$ and 1.850°N . The town share borders with Pontian, Muar, Kluang to the southeast, west and east respectively and in the north Ledang and Segamat . The area of Batu Pahat is $1,999 \text{ km}^2$ with a population of 406,000 and is the second populous district in Johor state. The population density is 203 person/ km^2 with a growth rate (DOS, 2010). The urbanization rate is related to population growth. It is projected that urbanization will be 95% in 2050. The long term mean monthly rainfall at Batu Pahat station is 2057 mm and mean potential evaporation rate is 1324 mm. The water demand was 174.22 Million litter per day (M/l/d) and it is projected to be 270.77 M/l/d in 2050 (DID, 2010) Figure1.1 shows the study area.

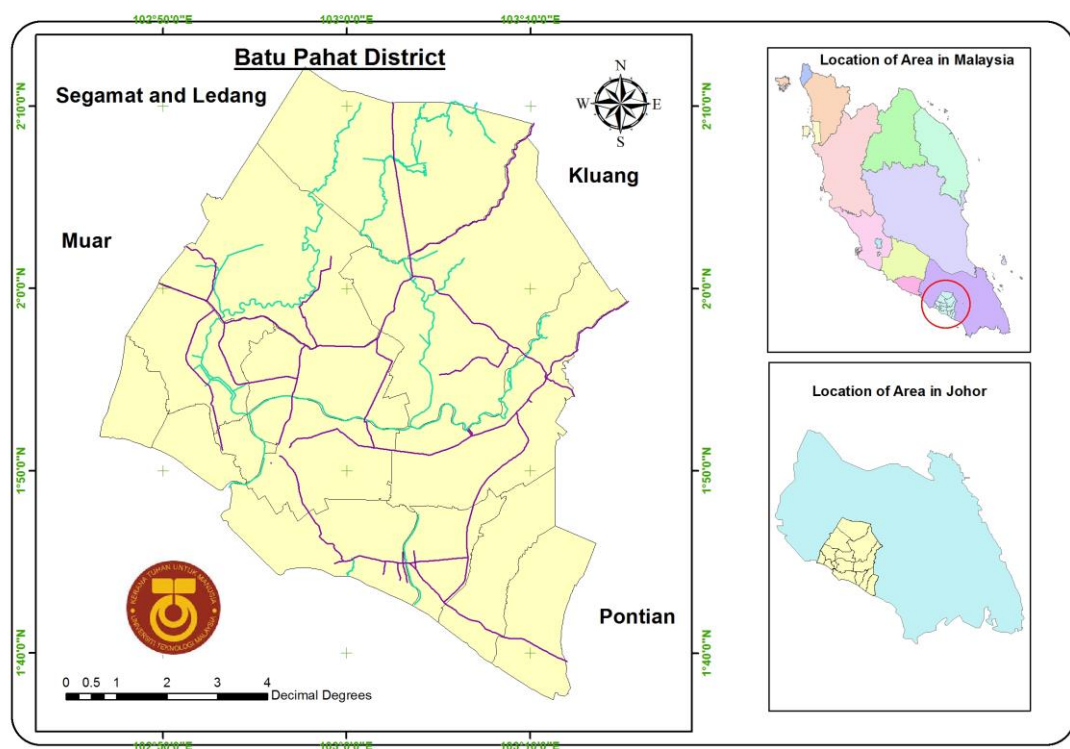


Figure 1.1 Study Area

1.4 Main Research Question

How to use a GIS based on Multi-criteria Analysis (MCA) for selecting the suitable location of water reservoir.

1.5 Aim of Study

The aim of study is to utilise GIS model analysis in identifying the suitable location for water reservoir in the area of Batu Pahat, Johor.

1.6 Objectives of Study

1. To identify the important criteria for locating water reservoir.
2. To model the location of Reservoir using Analytic Hierarchy Process (AHP).
3. To analyse and evaluate the most potential sites for water reservoir.

1.7 Specific Research Questions

1. What are the important criteria for locating water reservoir in Batu Pahat?
2. What are the population and the water demand of the study?
3. What is Analytic Hierarchy Process and it uses?

4. How to use Analytic Hierarchy Process to analysis a suitable location for water reservoir?
5. How to apply GIS model and analysis to show the potential sites for water reservoir?

1.8 Scope of Study

The applications of GIS are numerous in different fields of Sciences and Engineering. In this study, GIS is used to identify the suitable sites for water reservoir to meet the future water demand. The selection of suitable site is challenging as it is based on multiple criteria. AHP is popular multiple criteria methods for deriving the importance of one criteria over the other. The proposed study area will be conducted for Batu Pahat covering an area of 1,999 km² located in Johor state of Malaysia.

1.9 Need of the Study

The rapid increase in population, urbanization, industrialization and increased in irrigated agriculture imposing increasing water demand and inserting extra pressure on existing water resources. There is a need to construct new water reservoirs for meeting the future water demand effectively. The selection of suitable site for water reservoir is very important. The urban planners and decision makers take proper decision on allocation of land for future expansion.

1.10 Summary

This chapter highlights the importance of water to human lives. As the population increased the demands for water consumption also increased and becoming more critical and hard to manage. As a result, the needs for water supply also increased tremendously. Thus, the existing reservoir's capacity could not cope for future water demands. In relation to this, aim and objectives of this study are determined in this chapter. Similarly, the scope of study, methodology to be used, expected results and significance of the study have been identified and specified.

In relation to this chapter, Chapter 2 is dedicated to literature reviews and related studies whereas Chapter 3 is focused on the methodology used in this study. The results and analysis are discussed and presented in Chapter 4 and conclusion is drawn in Chapter 5.

REFERENCES

- Adinarayana, J., Rama Krishna, N. and Gopal Rao, K. (1995). An integrated approach for prioritisation of watersheds. *Journal of environmental management* 44(4): 375-384.
- Aerts, J., Van Herwijnen, M. Janssen, R. and Stewart, T. (2005). Evaluating spatial design techniques for solving land-use allocation problems. *Journal of Environmental Planning and Management* 48(1): 121-142.
- Al-Adamat, R., Diabat, A. and Shatnawi, G. (2010). Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan. *Journal of Arid Environments* 74(11): 1471-1477.
- Antenucci, J. C., Brown, K. Croswell, P. L., Kevany, M. J. and Archer H. (1991). *Geographic Information Systems: a guide to the technology*.
- Arai, O., Baba, K. and Hiro, T. (2003) Selection of Types of Dams and Reservoirs, Water Storage, Transport, and Distribution in *Encyclopedia of Life Support Systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publishers, Paris, France.
- Baban, S. M. and Wan-Yusof, K. (2003). Modelling optimum sites for locating reservoirs in tropical environments. *Water Resources Management* 17(1): 1-17.
- Belton, V. and Goodwin, P. (1996). Remarks on the application of the analytic hierarchy process to judgmental forecasting. *International Journal of Forecasting* 12(1): 155-161.
- Burrough, P. A., McDonnell, R. (1998). *Principles of geographical information systems*. Oxford university press Oxford.
- Cerchiai, B., Fiore, G. and Madore, J. (2001). Geometrical tools for quantum Euclidean spaces. *Communications in Mathematical Physics* 217(3): 521-554.

- Chang, K.T. (2012). Introduction to geographic information systems. McGraw-Hill New York.
- Do, J. Y., and Kim, D. K. (2012). AHP-Based Evaluation Model for Optimal Selection Process of Patching Materials for Concrete Repair: Focused on Quantitative Requirements. *International Journal of Concrete Structures and Materials* 6(2): 87-100.
- David, J., and Saaty, D. (2007). Use Analytic Hierarchy Process for Project Selection. Paper presented at the ASQ Six Sigma Forum Magazine.
- DOS (2010). Basic Population Charecteristics by Districts, Department of Statistics.
- DID- Department of Irrigation and Drainage (2010). Review of the National Water Resource (2000-2050) and Formulation of Natural Water Resources Policy, Selangor Federal Territory of Kuala Lumpur and Putrajaya.
- Harris, T. M. and Elmes, G. A. (1993). The application of GIS in urban and regional planning: a review of the North American experience. *Applied Geography* 13(1): 9-27.
- Husaini, A. (2007). Flood and drought management in Malaysia. Kuala Lumpur: Department of Drainage and Irrigation Malaysia, Ministry of Natural Resources and Environment.
- Johnson, K. M. and Lichter, D. T. (2008). Natural increase: A new source of population growth in emerging Hispanic destinations in the United States. *Population and Development Review* 34(2): 327-346.
- Malczewski, J. (1999). GIS and multicriteria decision analysis. John Wiley & Sons.
- Marler, R. T. and Arora, J. S. (2010). The weighted sum method for multi-objective optimization: new insights. *Structural and multidisciplinary optimization* 41(6): 853-862.
- Malczewski, J. (2004). GIS-based Land-Use Suitability Analysis: A Critical Overview. *Progress in Planning*, 62(1), 3-65.
- Malczewski, J. (2006). GIS- based Multicriteria Decision Analysis: A Survey of the Literature. *International Journal of Geographical Information Science*, 20(7), 703-726.

- Maurer, Jr., Qi, R. and Raghavan, V. (2003). A linear time algorithm for computing exact Euclidean distance transforms of binary images in arbitrary dimensions. *Pattern Analysis and Machine Intelligence, IEEE Transactions on* 25(2): 265-270.
- McCoy, J. (2004). *ArcGIS 9: Using ArcGIS Spatial Analyst*. Esri Press.
- McHarg, I. L. (1992). *Design with Nature*. New York: J, Wiley.
- Mohan, D., Pittman, C. U. and Steele, P. H. (2006). Pyrolysis of wood/biomass for bio-oil: a critical review. *Energy & Fuels* 20(3): 848-889.
- Moorthy, R., and Jeyabalan, G. (2011). Ethics and sustainability: a review of water policy and management. *American Journal of Applied Sciences* 9(1): 24.
- Ross, L. (1998). The use of Geographical Information Systems in Aquaculture: A Review. Paper presented at the I Congreso Nacional de Limnologia, Michoacan, Mexico. Rio De Janeiro, Brazil. August 2008.
- Ruslan, A. (2014). Is Malaysia Facing a Future Water Shortage? Retrieved 11th Feb, 2010, from <http://www.businessinsider.my/is-malaysia-facing-a-future-water-shortage>.
- Saaty, T. L. (1988). *What is the analytic hierarchy process?*, Springer.
- Saaty, T. L. and J. S. Shang (2007). Group decision-making: Head-count versus intensity of preference. *Socio-Economic Planning Sciences* 41(1): 22-37.
- Sharip, Z., and Zakaria, S. (2007). Lakes and Reservoir in Malaysia: Management and Research Challenges. Paper presented at the Proceedings of Taal 2007: The 12th World Lake Conference. 1349-1355.
- Shahid, S., Nath, S. and Roy, J. (2000). Groundwater potential modelling in a soft rock area using a GIS. *International Journal of Remote Sensing* 21(9): 1919-1924.
- Şener, Ş., Şener, E. Nas, B. and Karagüzel, R. (2010). Combining AHP with GIS for landfill site selection: a case study in the Lake Beyşehir catchment area (Konya, Turkey). *Waste Management* 30(11): 2037-2046.
- Thomas, H. H. (1976). *Investigations in the Engineering of Large Dams*. John Wiley & Sons. London, U.K., pp. 70–79.
- Triantaphyllou, E. and Sánchez, A. (1997). A Sensitivity Analysis Approach for Some Deterministic Multi-Criteria Decision Making Methods. *Decision Sciences* 28(1): 151-194.

- Wright, R.T, and Nebel, B.J. (2004). Environment Science: Toward a Sustainable Fu-ture. Prentice Hall.
- Zadeh, L. A. (2008). Is there a need for fuzzy logic? Information Sciences 178(13): 2751-2779.
- Zopounidis, C. and Doumpos, M. (2002). Multicriteria classification and sorting methods: A literature review. European Journal of Operational Research 138(2): 229-246.