Development of a Water Sustainability Index for West Java, Indonesia

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Abstract

Sustainability of water resources is essential to ensure that available water can be used by both present and future generations. To ensure sustainability, a comprehensive knowledge of the current conditions of water resources is necessary. Once this information is obtained, relevant programs can be designed to improve the quality and use of water resources. A water sustainability index is a useful tool to obtain information on the current conditions of water resources. It can also be used to identify all factors contributing to these conditions, to assist decision makers prioritising water issues, to design programs related to water resource improvement, and to communicate the current status of existing water resources to the general community.

In the recent past, several indices related to water resource sustainability have been developed. Even though there have been some successful experiences with the implementation of existing sustainability indices, they are not fully applicable in other regions or countries, since most of these indices have been developed for specific regions or countries. This study aims at developing a new water sustainability index for West Java, Indonesia, which can be used as a tool to improve the management of water resources in West Java. The development of the West Java Water Sustainability Index (WJWSI) involved the design of the conceptual framework, the application of Delphi technique to refine and finalise the conceptual framework, the application of WJWSI in three West Java catchments, and finally the robustness analysis of WJWSI through uncertainty and sensitivity analysis.

Results of WJWSI applications provided information on the current conditions of water resources, as well as the priority of water issues, in these three catchments. This information can be used by relevant water authorities in respective catchments to design appropriate programs to improve the conditions of water resources. This index can be applied to all catchments in West Java and, with some modifications, can also be applied in catchments in other provinces in Indonesia and worldwide.

Declaration

I, Iwan Juwana, declare that the PhD thesis entitled 'Development of a Water Sustainability Index for West Java, Indonesia' is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, references and footnotes.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Iwan Juwana
March 2012

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Table of Contents

Abstract i
Declaration ii
Acknowledgments iii
Table of Contents iv
List of Tables vii
List of Figures viii
Abbreviations ix
Published Manuscripts x

CHAPTER 1: INTRODUCTION
1.1 BACKGROUND 1-1
1.2 AIMS OF THE RESEARCH 1-3
1.3 SIGNIFICANCE OF THE RESEARCH 1-3
1.4 RESEARCH METHODOLOGY 1-4
1.5 THESIS STRUCTURE 1-7

CHAPTER 2: INDICATOR-BASED SUSTAINABILITY ASSESSMENT
2.1 INTRODUCTION 2-1
2.2 SUSTAINABLE DEVELOPMENT DEFINITIONS AND SUSTAINABILITY PRINCIPLES 2-3
2.3 SUSTAINABLE WATER RESOURCE MANAGEMENT: DEFINITIONS, CRITERIA AND GUIDELINES 2-6
2.4 ELEMENTS OF INDICATOR-BASED SUSTAINABILITY ASSESSMENT 2-9
2.4.1 Selection of components and indicators 2-10
2.4.2 Obtaining sub-index values 2-12
2.4.3 Weights 2-18
2.4.4 Aggregation 2-19
2.4.5 Robustness analysis 2-23
2.5 EXISTING WATER SUSTAINABILITY INDICES 2-23
2.5.1 Water Poverty Index (WPI) 2-24
2.5.1.1 Selection of component and indicators 2-24
2.5.1.2 Obtaining sub-index values 2-25
2.5.1.3 Weighting 2-25
2.5.1.4 Aggregation 2-26
2.5.1.5 Final index value interpretation 2-26
2.5.2 Canadian Water Sustainability Index (CWSI) 2-27
2.5.2.1 Selection of components and indicators 2-27
2.5.2.2 Obtaining sub-index values 2-28
2.5.2.3 Weighting 2-29
2.5.2.4 Aggregation 2-29
2.5.2.5 Final index value interpretation 2-29
2.5.3 Watershed Sustainability Index (WSI) 2-30
2.5.3.1 Selection of components and indicators 2-30
2.5.3.2 Obtaining sub-index values 2-32
2.5.3.3 Weighting 2-32
2.5.3.4 Aggregation 2-32
2.5.3.5 Final index value interpretation 2-33
2.5.4 Comparative analysis of water sustainability indices 2-33
2.6 OTHER INDICES 2-35
2.6.1 Human Development Index 2-35
2.6.1.1 Selection of dimensions and indicators 2-35

2.6.1.2 Obtaining sub-index values 2-36
2.6.1.3 Weighting of dimensions and indicators 2-36
2.6.1.4 Aggregation of dimensions and indicators 2-37
2.6.1.5 Final index value interpretation 2-37
2.6.2 Environmental Sustainability Index 2-38
2.6.2.1 Selection of indicators and variables 2-38
2.6.2.2 Obtaining sub-index values 2-40
2.6.2.3 Weighting of variables and indicators 2-40
2.6.2.4 Aggregation of indicators and variables 2-41
2.6.2.5 Robustness analysis 2-41
2.6.2.6 Final index value interpretation 2-42
2.7 SUMMARY 2-43

CHAPTER 3: DEVELOPMENT OF WEST JAVA WATER SUSTAINABILITY INDEX

3.1 INTRODUCTION 3-1
3.2 CONCEPTUAL FRAMEWORK 3-3
3.2.1 Identification of Components, Indicators and Thresholds 3-3
3.2.2 Justification for the Selection of Components, Indicators and Thresholds 3-8
3.2.2.1 Justification for the Component Water Resources and its Indicators and Thresholds 3-8
3.2.2.2 Justification for the Component Water Provision and its Indicators and Thresholds 3-11
3.2.2.3 Justification for the Component Capacity and its Indicators and Thresholds 3-13
3.2.2.4 Justification for the Component Human Health and its Indicators and Thresholds 3-14
3.3 FINAL FRAMEWORK 3-16
3.3.1 The Delphi Technique 3-16
3.3.2 Identification of Water-related Stakeholders 3-19
3.3.3 Design of the Questionnaires 3-20
3.3.4 Method to Analyse the Responses of the Respondents 3-21
3.3.5 Distribution and Collection of Completed Questionnaires 3-22
3.3.5.1 Round One of the Delphi Application 3-22
3.3.5.2 Round Two of the Delphi Application 3-29
3.3.6 In-Depth Interview with Key stakeholders 3-33
3.4 WEIGHTING 3-36
3.4.1 Equal Weighting 3-37
3.4.2 Non-equal Weighting 3-37
3.4.2.1 The procedure 3-38
3.4.2.2 Results and Calculations 3-38
3.4.3 Weights Given by Different Respondent Groups 3-41
3.5 INDEX INTERPRETATION 3-44
3.6 SUMMARY 3-45

CHAPTER 4: APPLICATION OF WEST JAVA WATER SUSTAINABILITY INDEX

4.1 INTRODUCTION 4-1
4.2 METHODOLOGY USED FOR APPLICATIONS 4-2
4.2.1 Obtaining Sub-index Values 4-2
4.2.2 Final Index 4-5
4.2.3 Robustness Analysis 4-6
4.3 WEST JAVA 4-12
4.3.1 Climatic Conditions 4-13
4.3.2 Socio-Economic Conditions 4-13
4.3.3 Water Management 4-14
4.3.3.1 Water Authorities 4-15
4.3.3.2 Policies and Regulations 4-16
4.3.3.3 Current Water Management Programs 4-17
4.4 CITARUM CATCHMENT 4-19
4.4.1 Description of the Catchment 4-19
4.4.2 Application of WJWSI for 2008 4-21

4.4.2.1 Sub-index Values and Final index ... 4-22
4.4.2.2 Robustness Analysis of WJWSI ... 4-27
4.4.3 Application for Different Years ... 4-33
4.4.4 Recommendations for Water Authorities ... 4-37
4.5 CILIWUNG CATCHMENT ... 4-40
4.5.1 Description of the Catchment ... 4-40
4.5.2 Application of WJWSI for 2006, 2007 and 2008 ... 4-42
4.5.2.1 Sub-index Values and Final index ... 4-42
4.5.2.2 Robustness Analysis of WJWSI ... 4-48
4.5.2.3 Recommendations for Water Authorities ... 4-52
4.6 CITANDUY CATCHMENT ... 4-55
4.6.1 Description of the Catchment ... 4-55
4.6.2 Application of WJWSI for 2006, 2007 and 2008 ... 4-57
4.6.2.1 Sub-index Values and Final index ... 4-57
4.6.2.2 Robustness Analysis of WJWSI ... 4-60
4.6.2.3 Recommendations for Water Authorities ... 4-63
4.7 CORRELATION ANALYSIS OF INDICATORS AND SUB-INDICATORS ... 4-65
4.8 COMPARATIVE ANALYSIS OF RESULTS OF DIFFERENT CATCHMENTS ... 4-68
4.9 SUMMARY ... 4-71

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY ... 5-1
5.2 CONCLUSIONS AND RECOMMENDATIONS TO WATER AUTHORITIES ... 5-3
5.2.1 Conceptual Framework of WJWSI ... 5-4
5.2.2 The Use of Delphi Technique ... 5-4
5.2.3 In-depth Interview with Selected Key Stakeholders ... 5-4
5.2.4 Weights for Indicators and Sub-indicators ... 5-5
5.2.5 Uncertainty and Sensitivity of the Index ... 5-5
5.2.6 Correlation of Indicators and sub-indicators ... 5-6
5.3 RECOMMENDATIONS TO WATER AUTHORITIES ... 5-7
5.3.1 The Citarum Catchment ... 5-8
5.3.2 The Ciliwung Catchment ... 5-9
5.3.3 The Citanduy Catchment ... 5-10
5.4 RECOMMENDATIONS FOR FURTHER RESEARCH ... 5-11

REFERENCES ... 6-1

APPENDICES

APPENDIX A: QUESTIONNAIRE OF ROUND ONE – DELPHI TECHNIQUE APPLICATION ... A-1
APPENDIX B: QUESTIONNAIRE OF ROUND TWO – DELPHI TECHNIQUE APPLICATION ... B-1
APPENDIX C: INTERVIEW GUIDE FOR IN-DEPTH INTERVIEWS WITH KEY STAKEHOLDERS ... C-1
APPENDIX D: WEIGHTING SCHEME QUESTIONNAIRE ... D-1

List of Tables

Table 2.1 Indicators of Water Poverty Index 2-25
Table 2.2 Correlation coefficients of WPI, Falkenmark Water Stress Indicator and HDI 2-26
Table 2.3 Indicators of Canadian Water Sustainability Index 2-28
Table 2.4 Indicators of Watershed Sustainability Index 2-31
Table 2.5 Obtaining sub-index values for EPI parameter of WSI 2-32
Table 2.6 Comparisons of CWSI, WPI and WSI 2-34
Table 2.7 Interpretation of final HDI values 2-38
Table 2.8 Cluster analysis based on values of ESI themes 2-44

Table 3.1 Components and indicators of existing water sustainability indices 3-5
Table 3.2 Regrouping of indicators of existing water sustainability indices 3-6
Table 3.3 Conceptual framework of the WJWSI 3-7
Table 3.4 Thresholds suggested in Round One 3-27
Table 3.5 Modified WJWSI framework after Round One of Delphi application 3-28
Table 3.6 Framework of WJWSI as agreed after Delphi application Round Two 3-33
Table 3.7 Final framework of WJWSI after the in-depth interview 3-36
Table 3.8 Weight calculation for one respondent 3-40
Table 3.9 Normalised weights for 13 indicators and sub-indicators from all respondents 3-42
Table 3.10 Interpretations of sub-indices and aggregated Index 3-45

Table 4.1 Criteria for sub-index values of *Information Disclosure* 4-4
Table 4.2 Criteria for sub-index values of *Governance Structure* 4-5
Table 4.3 Criteria for sub-index values of *Law Enforcement* 4-5
Table 4.4 Upper and lower values of thresholds of non-categorical indicators and sub-indicators 4-7
Table 4.5 Uncertainties of categorical indicators and sub-indicators 4-7
Table 4.6 Example of input for the triangle distribution function 4-11
Table 4.7 Categories for industry in *Proper Prokasih* program 4-18
Table 4.8 Sub-indices of Citarum catchment for 2008 4-26
Table 4.9 Results of uncertainty analysis for Citarum catchment 4-28
Table 4.10 Correlation coefficients between final index and thresholds for Citarum catchment 4-31
Table 4.11 Aggregation based on different weighting schemes and aggregation methods 4-32
Table 4.12 Sub-indices of Citarum catchment for 2006 and 2007 4-35
Table 4.13 Dams for irrigation along Ciliwung River 4-41
Table 4.14 Sub-indices of Ciliwung catchment for 2006, 2007 and 2008 4-43
Table 4.15 Percentage of *Water Loss* in Ciliwung catchment 4-44
Table 4.16 The rainfall and water used in Ciliwung catchment, 2006 to 2008 4-48
Table 4.17 Results of uncertainty analysis for Ciliwung catchment 4-50
Table 4.18 Correlation coefficients between final Index and thresholds 4-51
Table 4.19 Aggregation results based on different weighting schemes and aggregation methods 4-52
Table 4.20 Coverage areas of sub-catchments in Citanduy catchment 4-56
Table 4.21 Sub-indices of Citanduy catchment for 2006, 2007 and 2008 4-59
Table 4.22 Results of uncertainty analysis for Citanduy catchment 4-61
Table 4.23 Correlation coefficients between final Index and thresholds 4-62
Table 4.24 Aggregation results based on different weighting Schemes and aggregation methods 4-63
Table 4.25 Correlation coefficients of WJWSI indicators and sub-indicators 4-66

List of Figures

Figure 1.1 Thesis structure 1-7

Figure 2.1 The prism of sustainability 2-5
Figure 2.2 Illustration of the continuous rescaling method 2-15
Figure 2.3 An example of use of the categorical scaling method 2-16
Figure 2.4 Stages of aggregation of an index 2-20
Figure 2.5 Comparisons of arithmetic and geometric aggregation methods 2-22
Figure 2.6 The Pressure-State-Response (PSR) model 2-31
Figure 2.7 The DPSIR model (Smeets et al., 1999) 2-39

Figure 3.1 Flowchart for identification of potential components and indicators of WJWSI 3-4
Figure 3.2 Percentage of responses agreed on components – Round One 3-23
Figure 3.3 Percentage of responses agreed on indicators – Round One 3-25
Figure 3.4 Percentage of responses agreed on thresholds – Round One 3-26
Figure 3.5 Percentage of responses agreed on all components together – Round Two 3-30
Figure 3.6 Percentage of responses agreed on indicators and sub-indicators – Round Two 3-31
Figure 3.7 Percentage of responses agreed on thresholds – Round Two 3-32
Figure 3.8 Response of a respondent in the Revised Simos' procedure 3-39
Figure 3.9 Weights given by different groups of respondents 3-43

Figure 4.1 Uncertainty and sensitivity analysis scheme for WJWSI 410
Figure 4.2 Distribution function for *Water Availability* 4-11
Figure 4.3 West Java province 4-13
Figure 4.4 Citarum catchment in West Java 4-20
Figure 4.5 Sub-index values of indicators and sub-indicators for Citarum catchment 4-36
Figure 4.6 Ciliwung catchment in West Java 4-41
Figure 4.7 Sub-index values of indicators and sub-indicators for Ciliwung catchment 4-47
Figure 4.8 The Citanduy catchment in West Java 4-56
Figure 4.9 Sub-index values of indicators and sub-indicators for Citanduy catchment 4-58
Figure 4.10 Scatter plot of data points of sub-index values of *Poverty* and *Sanitation* 4-68
Figure 4.11 Scatter plot of data points between sub-index Values of *Coverage* and *Health Impact* 4-68
Figure 4.12 Sub-index values of three West Java catchments for 2008 4-70

Abbreviations

The following list of abbreviations is used frequently in the thesis. The other abbreviations, which were used only in particular sections, are defined in those sections.

WJWSI	West Java Water Sustainability Index
WPI	Water Poverty Index
CWSI	Canadian Water Sustainability Index
WSI	Watershed Sustainability Index
HDI	Human Development Index
ESI	Environmental Sustainability Index
MC	Monte Carlo
PSR	Pressure State Response
DPSIR	Driving force Pressure State Impact Response
WSP	Water Service Provider

Published Manuscripts

The following manuscripts were published or under review on journals and conferences, which materials were taken from this thesis:

Juwana, I., Muttil, N., & Perera, B. J. C. (2012). Application of West Java Water Sustainability Index (WJWSI) in Three Water Catchments. Paper in preparation for *Science of the Total Environment: An International Journal for Scientific Research into the Environment and its Relationship with Humankind*.

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Juwana, I., Perera, B., & Muttil, N. (2010b). A water sustainability index for West Java - Part 2: refining the conceptual framework using Delphi technique. *Water science and technology: a journal of the International Association on Water Pollution Research, 62*(7), 1641-1652.

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Juwana, I., Perera, B. J. C., & Muttil, N. (2009). *Conceptual framework for the development of West Java water sustainability index.* Paper presented at the 18th World IMACS/MODSIM Congress 13-17 July 2009, Cairns, Australia.

Chapter 1

Introduction

1.1 BACKGROUND

> *"In an age when man has forgotten his origins and is blind even to his most essential needs for survival, water along with other resources has become the victim of his indifference" (Carson, 1962, p. 50)*

The importance of water to living creatures is all too evident. Human beings, for example, cannot live without water, even for a few days. Therefore, it is of utmost importance to maintain the sustainability of water resources, so that these resources can be utilised by humans and others, now and in the future. To maintain and improve the quality of water resources, an adequate understanding of current conditions of such water resources is required.

In one of the most densely populated provinces of Indonesia, West Java, the conditions of water resources are poor. The increase in population in the province has resulted in the increased demand for clean water. To fulfill the demand, both surface and groundwater resources in West Java are utilised. Both resources are dependent on rainfall. The availability of these water resources is abundant, due to high rainfall in most areas of West Java. However, this abundance of water is not properly managed, and has resulted in water shortages in some areas of the province (Rahmat & Wangsaatmadja, 2007). In terms of their quality, most surface and groundwater resources in West Java are polluted by domestic, agricultural and industrial activities. Regular monitoring by the Environmental Protection Agency (EPA) of West Java during the period 2004–2006 showed that water quality parameters of most rivers in West Java did not meet the requirements of provincial and national regulations (Rahmat & Wangsaatmadja, 2007).

In the last decade, the provincial government of West Java has implemented various programs to improve the performance of water resources. However, these programs have not been successful. The quality of surface water is decreasing and the quantity of groundwater is depleting. The main cause for the failure of these programs is lack of awareness of the people of West Java on the importance of water resources. In general, people in West Java are not aware that valuable water resources are deteriorating and need to be sustained (Rahmat & Wangsaatmadja, 2007).

It is therefore important to obtain a comprehensive understanding on the current status of water resource conditions in West Java. Once this information has been obtained, relevant programs can be designed to improve the quality of the water resources. A water sustainability index is a useful tool to address this situation. Such an index comprises indicators related to the sustainability of water resources, and offers the following benefits:

(i) It can be used to identify all factors contributing to the improvement of water resources (Chaves & Alipaz, 2007; Policy Research Initiative, 2007; Sullivan, 2002), so that the resources can be used to fulfill present and future needs.

(ii) It can be used to assist decision makers to prioritise issues and programs related to water resource management.

(iii) It can be used to communicate the current status of existing water resources to the wider community (Policy Research Initiative, 2007).

In the recent past, several indices related to water resource sustainability have been developed. They are the Water Poverty Index (WPI) by Sullivan (2002), the Canadian Water Sustainability Index (CWSI) by the Policy Research Initiative (2007), and the Watershed Sustainability Index (WSI) by Chaves and Alipaz (2007). Even though there have been some successful experiences with the implementation of these sustainability indices, they are not fully applicable in other regions or countries, since they have been developed for use in specific regions or countries.

Therefore, a new water sustainability index, which is specifically developed with the involvement of local water stakeholders and based on West Java natural and socio-economic characteristics, is needed to help improve water resources management in West Java. The index will be able to not only obtain information on current conditions of water resources in West Java, but also to prioritise water issues in water resource management in West Java. The prioritization of water issues is especially important since such prioritization were not found in existing documents related to water resources management in West Java. This study was aimed at developing a water sustainability index for the West Java Province, called the West Java Water Sustainability Index (WJWSI).

1.2 AIMS OF THE RESEARCH

The aim of this study was to develop the West Java Water Sustainability Index (WJWSI), which can be used as a tool to assess the sustainability of West Java water resources, prioritise water issues, and communicate water issues to the wider community. The application of WJWSI in West Java catchments will assist decision makers in the province to have better knowledge of the overall water resource conditions, and to prioritise water-related issues and their respective programs towards a more sustainable water resources management. The results of WJWSI application will also be used to increase the awareness of the wider community and to encourage them to participate in the improvement of water resource performance in West Java.

1.3 SIGNIFICANCE OF THE RESEARCH

In the past few decades, the increased water demand in West Java Province has resulted in excessive groundwater extractions, both by industries and households. This situation is worsened by the increase of surface water pollution, caused by wastewater discharges by industries, households and agriculture. Even though these water resource deteriorations are evident, the awareness by people in West Java is poor due to a lack of understanding about comprehensive conditions and the importance of those water resources.

The development of a West Java Water Sustainability Index (WJWSI) is proposed in this study to meet the need to obtain comprehensive information on the conditions of water resources in West Java, specifically developed through the involvement of water stakeholders in West Java. The WJWSI will be an important part of sustainable water resources management in

West Java, as it provides a holistic tool to assess the current status of water-related issues, as well as providing a tool for communicating water issues in the wider community. Having communicated this message to the wider community about the status of water sustainability in the area, they will become more aware of the conditions and therefore willing to participate in the improvement of water resource performance.

The applications of WJWSI in West Java catchments will give decision makers information on current conditions of water issues in the respective catchments. Consequently, these decision makers will be able to design and deliver better programs to improve the overall water resource management. In the near future, the developed index can also be modified for application in other areas in Indonesia, as well as in other countries. Modifications might be needed to include any unique characteristics of other areas, and ensure that the unique characteristics are included in the calculation and analysis.

Furthermore, the Delphi technique used in this study offers new insights into the selection of components and indicators of the water sustainability index, since the Delphi technique has not been used in the selection of components and indicators of previous water sustainability indices.

1.4 RESEARCH METHODOLOGY

The development of the WJWSI included the following tasks:

1. Design of the conceptual framework of WJWSI
2. Fieldwork preparation
3. Delphi application and results analysis
4. Applications of WJWSI in West Java catchments
5. Robustness analysis of WJWSI

Task 1 – Design of the conceptual framework of WJWSI

The conceptual framework of WJWSI includes the identification of components, indicators and thresholds of indicators. The components and indicators were identified, based on the literature review on sustainability criteria, water resource sustainability guidelines, and existing water sustainability indices of WPI, CWSI and WSI. The relevancy of these components and indicators to water resources, environmental, social and economic characteristics of West Java, and the availability of data for use in the index applications were also considered. Once the components and indicators were identified, thresholds for the indicators were obtained from relevant policies, regulations and guidelines.

Task 2 – Fieldwork preparation

Fieldwork in Indonesia consisted of two parts: the Delphi application and WJWSI applications in West Java catchments. In this study, the Delphi technique was used to refine the components, indicators and thresholds identified in the literature review (i.e. Task 1). The preparation for the Delphi technique application included identifying stakeholders as respondents, making initial contact with stakeholders and preparing questionnaires. The stakeholders who participated in this study were selected from university lecturers, governmental officials, environmental consultants and community groups. For applications of WJWSI in West Java catchments, the preparation included identifying potential areas for application and contact persons for collecting data related to the catchments. The identification of contact persons is important to ensure that the required data for the WJWSI applications are available during fieldwork.

Task 3 – Delphi application and results analysis

As indicated earlier, the Delphi technique was used in this study to seek opinions from water-related stakeholders in West Java on the identified components, indicators and thresholds of WJWSI. Steps undertaken in the Delphi application included revising the list of selected stakeholders (where applicable), distributing series of questionnaires, and analysing the information obtained through these questionnaires. In this study, the main questions for the initial questionnaire focused on the components, indicators and thresholds emanating from the literature review. During the questionnaire distribution, the respondents were asked about their agreement on the components, indicators and thresholds. In addition, they were also allowed to add, modify or remove the components, indicators and thresholds from the list. Using the Delphi technique, questionnaires were distributed to respondents in multiple rounds to seek consensus among respondents. After each round of questionnaire distribution, the information obtained through the questionnaires was analysed. Based on the information, a new WJWSI framework was developed and used in the next round. Due to consensus being reached for all components and most of the indicators after two rounds of questionnaire distribution, an in-depth interview with key stakeholders followed the Delphi technique application.

Task 4 – *Applications of WJWSI in West Java catchments*

The WJWSI framework was finalised and applied in three catchments in West Java. Each application commenced with collecting required data and information related to the WJWSI indicators and sub-indicators. Data was collected from past studies, institutional databases and other relevant sources. The data was used to compute the sub-index values of each WJWSI indicator and sub-indicator. These sub-index values were then calculated and aggregated to produce the final WJWSI value. The results of these applications were used to analyse the performance of the catchments, so that recommendations to improve the management of water resources in these catchments could be provided to respective catchment authorities.

Task 5 – Robustness analysis of WJWSI

Robustness analysis is an important step in index development because the inputs for developing an index are generally based on some assumptions, which might lead to variation in the index values as outputs (Esty et al., 2005). The robustness of WJWSI was analysed in this study by performing an uncertainty and sensitivity analysis on the index. In general, the uncertainty analysis focused on how the upper and lower values of thresholds, different weighting schemes and aggregation methods affect the values of sub-indices and the final index. The sensitivity analysis was undertaken to answer the following questions:

- Which thresholds of the indicators and sub-indicators were the most sensitive to the changes in their upper and lower values?
- How important was the upper and lower values of the thresholds of the indicators and sub-indicators in determining the final index value?
- Which weighting schemes or aggregation methods were more sensitive to the final index value?

1.5 THESIS STRUCTURE

This thesis presents five chapters as shown in Figure 1.1. The growing information on sustainable water resource management (Chapter 2) led to the development of a water sustainability index in West Java (Chapter 3), which was then applied in three West Java catchments (Chapter 4). Detailed explanations for each chapter are described in the following sub-sections.

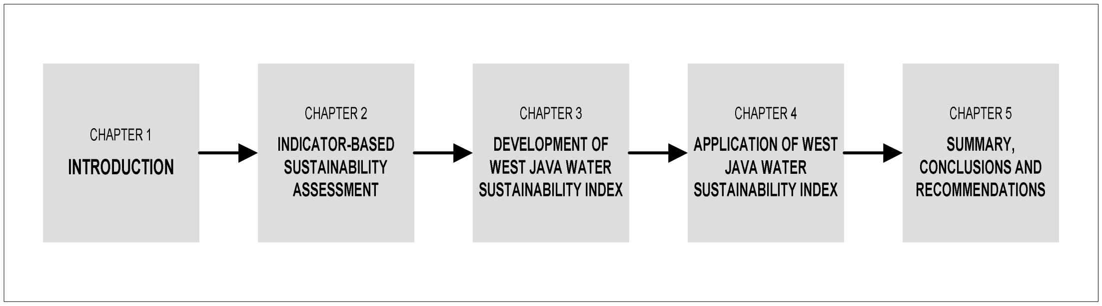


Figure 1.1 Thesis structure

Chapter 1. Introduction

This chapter presents the general overview of the overall thesis, which assists readers in comprehending the main ideas explored in the thesis. It briefly describes the current conditions of water resource management in West Java, as well as identifying growing studies on sustainable water resource management. These led to the development of a water sustainability index for West Java.

The aims of the research are clearly defined in this chapter, which highlights general objectives of the research, and how the results can be used by relevant decision makers in West Java, Indonesia. To emphasise the importance of the study, its significance is presented after the aims of the research. The chapter continues with a brief methodology used in the study, where various tasks undertaken are presented and discussed.

Chapter 2. Indicator-based sustainability assessment

This chapter provides a state-of-the-art review of sustainability and water resource management that leads to the development of WJWSI. Under the sub section on sustainability, past studies on sustainability definitions are presented, followed by important principles and criteria of sustainability. Under the sub section on sustainable water resource management, criteria and guidelines for sustainable water resource management are described. These principles, criteria and guidelines are then analysed for use during the identification of components and indicators of WJWSI.

This chapter then discusses the indicator-based sustainability assessment. Here, general issues on the method and a detailed explanation of elements of the indicator-based sustainability assessment are presented. Finally, this chapter concludes by presenting the examples of three existing water sustainability indices: the Canadian Water Sustainability Index (CWSI), Water Poverty Index (WPI) and Watershed Sustainability Index (WSI). For each index, issues on the selection of components and indicators, obtaining sub-index values, aggregation of indicators, and interpretation of the final index are discussed.

Chapter 3. Development of the West Java Water Sustainability Index

This chapter focuses on development of the West Java Water Sustainability Index (WJWSI). It comprises design elements and how the WJWSI conceptual framework is finalised. The design of the framework discusses how the components, indicators and thresholds are identified and selected. In addition, justification for the selection of components, indicators and thresholds is provided.

Following discussion on the development of the conceptual framework, this chapter explores the use of the Delphi technique to refine the conceptual framework. Here, definitions, advantages and disadvantages of the Delphi technique are described, followed by detailed steps of Delphi application. These steps include the identification of water-related stakeholders as respondents, the design of questionnaires for Delphi application, the distribution and collection of questionnaires, and analysis of the information obtained from questionnaires. Finally, in-depth interviews with key stakeholders follow the application of Delphi technique to finalise WJWSI components, indicators and thresholds.

Chapter 4. Applications of West Java Water Sustainability Index

This chapter presents the application of WJWSI to three different catchments in West Java. The applications are undertaken to provide valuable insights into the improvement of water resource management in West Java, Indonesia.

Prior to WJWSI applications, this chapter discusses various factors related to water resource management in West Java, which include demographic facts, socio-economic issues, and environmental aspects of water resource management. Detailed applications of WJWSI in Citarum, Ciliwung and Citanduy catchments are then discussed. In each application, descriptions of the respective catchments, calculations and analysis, and relevant recommendations to decision makers are presented. Finally, a comparative analysis of different catchments and correlation analysis of WJWSI indicators, sub-indicators and final index are provided.

Chapter 5. Summary, conclusions and recommendations

This chapter provides a summary of the tasks undertaken in this study, conclusions drawn from the analysis provided in the main chapters, identified limitations of the study, and potential areas of future research.

Chapter 2

Indicator-based Sustainability Assessment

2.1 INTRODUCTION

> *Consumption, economic growth and environmental degradation impact sustainable development in complex and often apparently contradictory ways. The question is: how do we know whether overall we are on a sustainable development path? If the rhetoric of policy makers committed to sustainable development is to be judged against the reality of performance, then means must be found to measure and monitor sustainable development (Atkinson et al., 2007, p. 13)*

The United Nations Conference on the Human Environment in 1972 sparked environmental awareness globally. The conference also inspired the publication of the Brundtland Report, (also known as Our Common Future), where the notion of sustainable development was first introduced by the Brundtland Commission (Brundtland, 1987). Since the publication of this Report, studies and efforts to define sustainability and sustainable development have been extensively carried out by various institutions and organizations at all levels: local, national, regional and international.

According to Harding (2002), sustainability is the ultimate goal of sustainable development. If a project development includes sustainability in its goals, the sustainability status of issues related to the project needs to be assessed. The assessment should be completed during the planning and evaluation stages. At the planning stage, sustainability assessment ensures that project design follows sustainability guidelines. At the evaluation stage, assessment monitors the sustainability progress of project development.

In the past few decades, there have been extensive efforts on measuring sustainability. One example is the development of assessment tools based on sustainability indicators. Several individuals and organisations have suggested various indicators for assessing sustainability. Some authors have developed general sustainability indicators, such as the Environmental Sustainability Index (Esty et al., 2005), Corporate Sustainability Indicators (Spangenberg & Bonniot, 1998), the Barometer of Sustainability (Prescott-Allen, 2001), Environmental Pressure Indices (Jesinghaus, 1999), Taking Sustainability Seriously (Portney, 2003), Sustainability Indicator Systems (Spangenberg & Bonniot, 1998) and Pressure-State-Response (PSR) based sustainability indicators (Spangenberg & Bonniot, 1998). Some sustainability indicators are field-specific, such as indicators for environment (Esty et al., 2005), agriculture (Parris, 1998; Van Ittersum et al., 2008), fossil fuel (Ediger et al., 2007) and water resources. Indicators for water resource sustainability, for example, are the Water Poverty Index – WPI (Lawrence et al., 2003), Canadian Water Sustainability Index – CWSI (Policy Research Initiative, 2007) and Watershed Sustainability Index – WSI (Chaves & Alipaz, 2007). All these indices have the same goal to measure sustainability, which can further be used to assist decision makers and other stakeholders achieve sustainability.

This chapter focuses on the review of water resource sustainability using the indicator-based approach. In its early sub-sections, the chapter discusses major definitions of sustainable development proposed by various individuals and institutions. These definitions re-affirm the definition of sustainable development in the Brundtland Report (Brundtland, 1987), which highlighted the concerns for future generations. Based on these definitions, more specific concepts of sustainability are then presented through a discussion of sustainability principles and criteria.

Having completed the discussion on sustainability definitions, principles and criteria; this chapter proceeds with the review of existing definitions, principles and guidelines on sustainable water resource management. Later, these definitions, principles and criteria are used as the basis for the identification of components and indicators in the development of a water sustainability index for West Java, Indonesia.

Following the above mentioned review, this chapter explores elements of an indicator-based sustainability assessment. These elements include the selection of components and indicators, obtaining sub-index values, weighting schemes for components and indicators, aggregation of components and indicators, robustness analysis of the index, and interpretation of the final index value.

To provide an in-depth understanding of how such indicators are applied in actual cases, three existing water sustainability indices are discussed: the Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI) and Watershed Sustainability Index (WSI). For each of these indices, issues related to the following are discussed: selection of components and indicators, obtaining sub-index values, weighting of components and indicators, aggregation of components and indicators, and classification of the aggregated index value. Similarities and differences are studied with the aim of using these concepts to develop the WSI for West Java, Indonesia.

Finally, in the last section of the chapter, the Human Development Index - HDI (Rodriguez, 2010) and the Environmental Sustainability Index - ESI (Esty et al., 2005) are discussed to provide analysis on the applications of the indicator-based assessment approach in areas other than water resources. The ESI and HDI were selected as they have been widely used for years by various institutions (Cooke et al., 2004; Cui et al., 2004; Erker, 2003; Mohanty & Ray, 2002; Reed et al., 2006; Samuel-Johnson & Esty, 2002; Stapleton & Garrod, 2007; Thapa, 1995) to measure human development and environmental sustainability issues respectively.

2.2 SUSTAINABLE DEVELOPMENT DEFINITIONS AND SUSTAINABILITY PRINCIPLES

Liverman (1988) states that efforts to measure sustainable development can only be achieved when this concept is clearly defined. Since it was introduced in 1987 (Brundtland, 1987), there have been extensive studies to define sustainable development. The first definition of sustainable development was proposed by the Brundtland Commission (Brundtland, 1987), which defined sustainable development as:

> *…development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, 1987, p. 87)*

This definition was followed by other definitions, such as the following:

> *…to maximize simultaneously the biological system goals (genetic diversity, resilience, biological productivity), economic system goals (satisfaction of basic needs, enhancement of equity, increasing useful goods and services), and social system goals (cultural diversity, institutional sustainability, social justice, participation). (Barbier, 1987)*

> *…meeting human needs while conserving the Earth's life support systems and reducing hunger and poverty. (Palmer et al., 2005, p. 5)*

Even though the above definitions are presented in different forms, the messages are comparable. These definitions urge human actions to care for present and future environments, while at the same time utilising natural resources to fulfill human needs. The Brundtland definition focuses on the balance of present and future generations, while the other two definitions further address the need for concern for environmental, social and economic interests.

These definitions on sustainable development were further explained by the growing studies on sustainability principles. One of the most well-known sustainability principles is the "triple bottom line approach", which includes the environmental, economic and social aspects of sustainability (Cui et al., 2004; Ekins et al., 2003; Farsari & Prastacos, 2002). Spangenberg (2004) proposes similar principles labeled as challenges, namely environmental, social and institutional challenges. The environmental challenge emphasises the degradation of natural resources for human use; the social challenge highlights the unequal distribution of wealth and poverty; and the institutional challenge focuses on peace and security.

Other sustainability principles are presented in different forms. Parkin (2000) introduced the capital flow concept, which stated that any development for achieving sustainability needs to manage different capital flows. These capital flows are natural, human, social, manufactured and financial. Any development proposal has to contribute to improving, or at least maintaining, these five different capital flows (Parkin, 2000).

Spangenberg & Bonniot (1998) labeled their sustainability principles "sustainability dimensions". These dimensions are packed in the so-called "prism of sustainability", as presented in Figure 2.1. This prism, reflecting sustainability, has four dimensions, which are institutional, environmental, social and economic. Each dimension is then further explored to identify relevant indicators. For example, for the institutional dimension, the sustainability indicators are participation, justice and gender balance. For the environmental dimension, resource use and state indicators are identified. For the social dimension, the indicators are health care, housing, social security and unemployment. Finally, for the economic dimension, the indicators are Gross National Product (GNP), growth rate, innovation and competitiveness (Spangenberg & Bonniot, 1998).

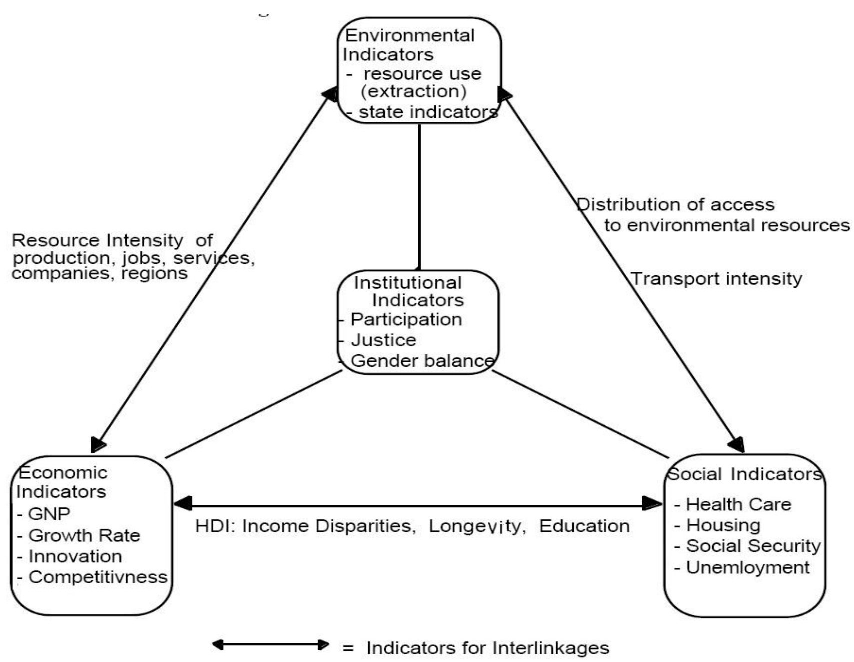


Figure 2.1 The prism of sustainability (Spangenberg & Bonniot, 1998)

Apart from the indicators of individual dimensions, the prism of sustainability also offers a framework to identify the inter-linkage indicators between dimensions. The inter-linkages can be two, three or even four dimensional, which seek to compromise and synergise dimensions. Indicators based on two-dimensional inter-linkages are illustrated in Figure 2.1. For example, the Human Development Index (HDI) indicators are derived from the inter-linkage between economic and social dimensions. Similarly, distribution of access to environmental resource and transport intensity are indicators derived from the interaction of environment and social dimensions. Furthermore, the inter-linkage of environment and economic dimensions has resulted in indicators such as jobs, services and resource intensity of production (Spangenberg & Bonniot, 1998).

2.3 SUSTAINABLE WATER RESOURCE MANAGEMENT: DEFINITIONS, CRITERIA AND GUIDELINES

As the complexity of issues related to water resources has increased, there have been extensive studies (Ashley et al., 2004; Giuppponi et al., 2006; Loucks & Gladwell, 1999; Loucks et al., 2000; Mays, 2006; Policy Research Initiative, 2007; Starkl & Brunner, 2004) to combine the concept of sustainability with water resource management issues. By applying sustainability principles, it is expected that available water resources can be responsibly utilised, not only by the current generation, but also by future generations. Loucks & Gladwell (1999) emphasise the importance to re-examine current water resource planning and management approaches to achieve more sustainable water resources. This approach needs to be more integrated, not only in terms of the issues, but also in terms of the stakeholders. In relation to the issues, all economic, environmental, ecological and social interests need to be addressed in the planning of water-related programs. For the stakeholders, contributions from different sectors, such as academic, engineering, economy and politics, need to be integrated.

Nardo et al. (2005) note that in measuring sustainability, defining what will be measured is important. Thus, to develop a water sustainability index, a clear understanding of the sustainability is required. Once sustainability is clearly defined, different indicators can be appropriately identified. Loucks & Gladwell (1999) define water resource sustainability as:

> *…water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity. (Loucks & Gladwell, 1999, p. 30)*

Other authors have defined water resource sustainability as:

> *…the ability to provide and manage water quantity so as to meet the present needs of humans and environmental ecosystems, while not impairing the needs of future generations to do the same. (Mays, 2006, p. 4)*

> *…the ability to use water in sufficient quantities and quality from the local to the global scale to meet the needs of humans and ecosystems for the present and the future to sustain life, and to protect humans from the damages brought about by natural and human-caused disasters that affect sustaining life. (Mays, 2006, p. 4)*

> *…a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. (GWP-TAC, 2000, p. 1)*

These definitions on water sustainability urge any water-related decision maker and/or other stakeholders to consider every impact of their water-related programs on both present and future generations. Considerations on purely technical criteria are no longer sufficient as the complexity and uncertainty of water-related issues intensify. Inclusion of environmental, economic and social criteria is critical to address such complex and uncertain water-related problems (Loucks & Gladwell, 1999).

The above definitions also clearly indicate that sustainable water resource management can only be achieved through the integration of water-related issues and stakeholders. Savenije & Van der Zaag (2002) highlight the importance of Dublin principles on integrated water resource management, which state that:

1. Water is an essential resource, to be used and managed appropriately.
2. All relevant stakeholders should be involved in the development and management of water resources.

3. The central role of women in the provision, management and protection of water resources is recognized and acknowledged.
4. Economic value of water in all uses should be emphasized and taken into account in the decision making.

Mays (2006) accentuates three domains of integrated water resource management, which include scope, scale and governance. Scope covers social and developmental issues related to water resources, its related sectors, gender empowerment, poverty eradication and fairness among the community. Scale ranges from local to national, and also possibly the river basin level. Governance needs to include public sector, business community and wider community representation.

The need for the integration of water-related issues is also noted by Loucks & Gladwell (1999). They state that water sustainability endorses water-related programs to be directed towards a more integrated or holistic approach. Water-related projects can no longer be emphasised from a purely technical view, ignoring social and economic concerns (Loucks & Gladwell, 1999).

Towards a better understanding of water sustainability principles, Loucks & Gladwell (1999) provide water sustainability guidelines, which include the importance of water infrastructure, environmental quality, economics and finance, institutions and society, human health and welfare, as well as planning and technology. In line with these guidelines, Mays (2006) introduces seven requirements to ensure the sustainability of water resource systems. They are basic water needs to maintain human health; minimum standard of water quality; basic water needs to maintain ecosystem health; long-term renewability of available water resources; accessible data on water resources for all parties; institutional schemes to resolve water conflict; and democratic water-related decision making.

Jakeman et al. (2005) introduce issues to be addressed in integrated water resource management, which include water supply and demand, poverty alleviation and subsistence production, agricultural land use, and environmental issues such as erosion and forest maintenance. All these issues are essential because they can be used as the basis for developing water resource improvement programs to consider how these different issues impact present and future generations.

Loucks & Gladwell (1999) emphasise the flexibility and resilient characteristics of water sustainability. Flexibility is defined as the ability of the system to adapt due to changes of demand and purpose in the future. Resilience is defined as the ability to recover, with appropriate treatment, after the occurrence of unpredictable damage. The current criteria may no longer be fully applicable in the future due to these unpredictable changes. Reliable sustainable water resource management is required to be flexible due to these changes, and still function effectively in protecting water resources and maintaining human needs (Loucks & Gladwell, 1999).

To summarise, the main characteristic of water resource sustainability lies in the attitude of key stakeholders to constantly review and re-examine their approaches to address the changing issues of water resources. At all times, in all plans and processes, water stakeholders need to strive for decisions that fulfill economic, environmental and social demands (Loucks & Gladwell, 1999).

2.4 ELEMENTS OF INDICATOR-BASED SUSTAINABILITY ASSESSMENT

In general, the indicator-based sustainability assessment seeks to identify indicators to measure sustainability. An indicator is a measure, either qualitative or quantitative, of facts or conditions of particular issue(s). If the indicators are observed regularly, they can analyse changes during the observed period (Nardo et al., 2005). Some indicators might be grouped to form a component, or particular indicator(s) might be further explained by having sub-indicators. A group of indicators and/or components, which are combined together, is called an index or composite indicator. Nardo et al. (2005) emphasise that ideally an index should measure multi-dimensional ideas that cannot be explained by one indicator.

To apply the indicator-based sustainability assessment, common elements to be considered include component and indicator selection, obtaining sub-index values of components and indicators, weighting of components and indicators, aggregation of components and indicators, and robustness analysis of the index. The components and indicators provide a framework for indicator-based sustainability assessment, as it identifies all the components and indicators of the index. To assess sustainability using this approach, all identified indicators must have common unit values. The values of the indicators in common units are known as sub-index values. After all the sub-index values of the indicators are obtained, they can be aggregated to a single index value. In the aggregation, the indicators might be assigned equal or non-equal weights. The robustness analysis of the index is conducted to study the uncertainty of inputs on the index.

2.4.1 Selection of components and indicators

Components and indicators are the main elements in an index. Therefore, in developing an index, selection of components and indicators is extremely important. Components and indicators for an index are commonly selected through a literature review on previous sustainability frameworks and existing sets of components and indicators (Chaves & Alipaz, 2007; Policy Research Initiative, 2007; Sullivan & Meigh, 2007). Generally, an initial set of components and indicators is identified, based on those reviews. This initial set is then refined through discussion with key stakeholders (Policy Research Initiative, 2007; Sullivan & Meigh, 2007).

Liverman & Hanson (1988) suggest the following characteristics for the selection of indicators:

- *Sensitive to change in time*

  A reliable indicator must be observable throughout the particular time series of data; otherwise the indicator will not be able to provide information on how the issues related to the indicator have changed over time.

- *Sensitive to change across space or within groups*

  An indicator should reflect the changes occurred across space or within groups. If not, the indicator will be less useful to measure a condition. The Gross National Product (GNP) is an example of an economic indicator which is not sensitive to change within groups. The GNP value may increase even though for the majority of community groups the economic condition worsens. In this case, such an indicator might be replaced by one that measures the distribution of income.

- *Predictive or anticipatory*

  With regard to sustainability, reliable indicators should be able to predict or anticipate the signs of unsustainable conditions. Then, once the signal is received, the indicators can be traced to identify the main causes for the unsustainable signal.

  The water stress indicator by Falkenmark (1989), for example, is an indicator which can provide an early signal, if water availability in a particular area is under threat. As this indicator is derived from two variables – population and available fresh water – further analysis can demonstrate which variable has caused the stress to water resources. Once specific causes of the unsustainable condition are identified, appropriate action to address these causes can be deployed.

- *Reference or threshold values available*

  Indicators which have been identified will be less useful when reference or threshold values to assess the indicators are not available. Therefore, if the data or reference value is not available for an indicator, the indicator might have to be replaced by a 'similar' indicator, for which its data is available.

  In developing countries, this is a major concern as required data to assess the identified indicators might not be available or inaccurate (West Java Environmental Protection Agency, 2008). Therefore, it is important that during the indicator selection process, the issue of data availability is included as one of the selection criteria.

- *Unbiased*

  Biases in the selection of sustainability indicators may occur due to various reasons, such as the existing knowledge of the index developer, political interests, and the background given in the existing literature. It might not be possible to eradicate these biases. Therefore it is important, for the index developer, to identify the potential sources of biases and take necessary measures to minimise them.

- *Appropriate data transformation*

  For most indicators, the identified indicator is not the raw data. Therefore, to obtain the value for the indicator, appropriate data transformations or calculations are needed. It is important to carefully develop or adopt the appropriate method for transforming the data into the meaningful indicator value.

- *Integrative*

  The importance of integrative or composite indicators is to provide the signs on relative conditions that are not sustainable. Senior decision makers need to be informed on the conditions based on these signs, which will be analysed to trace the main causes that lead to conditions that are not sustainable.

Some concerns regarding the importance of indicator selection are presented by Nardo et al. (2005), who emphasise the quality of basic data for indicators and procedures to carry out the selection of indicators. The concerns for quality of basic data include their relevance, accuracy, timeliness, accessibility, interpretability and coherence. The concerns for procedures include design of the theoretical framework, obtaining sub-index values, linkage to other indicators and robustness analysis.

2.4.2 Obtaining sub-index values

In general, the identified indicators for an index have their own units. For example, the Water Availability indicator of the Canadian Water Sustainability Index (CWSI) has the unit of m^3/cap/year. The amount of available water for one person per year in a certain area (presented in m^3/cap/year), is known as the actual value of *Water Availability* indicator. As the actual values of indicators of an index are presented in different unit values, they cannot be aggregated or compared. The indicators can only be aggregated or compared when they have the same unit value. The values of indicators, which have the same unit, are known as sub-index values. Different methods to obtain the sub-index value of indicators are currently available. The selection of the most appropriate method will be based on properties of the data and the purpose of developing the index (Nardo et al., 2005). Special attention and careful analysis is needed, as different methods may result in different outcomes (Ebert & Welsch, 2004). Some of these methods are discussed below.

a) Ranking method

The ranking method is the simplest method, as the sub-index is obtained, based on the relative importance of identified indicators. This method is used to compare the values of a particular indicator for different areas. Once the values are obtained, they are simply arranged in ascending or descending order, and the rankings are defined. In some cases (Jencks et al., 2003), the values for the indicator for different areas across different years are also compared. The equation to calculate sub-index values using this method is:

$$S_i = Rank\ (X_i) \qquad \textbf{(2.1)}$$

where S_i is the sub-index value for indicator *i* and X_i is the actual value for indicator *i*.

This method was used in assessing the Medicare Beneficiaries Indicators (Jencks et al., 2003) and applications of the Technology Achievement Index (TAI) to obtain the sub-index values of TAI indicators (Cherchye et al., 2007). In these applications, this method was useful in prioritising the identified indicators. Based on the prioritisation, relevant policy actions were formulated to each indicator.

The advantage of using this method is its simplicity. However, once the rankings are presented, the information attached to each indicator becomes less meaningful (Nardo et al., 2005). Consequently, a comparative analysis between indicators cannot be achieved in absolute terms of their values; rather it is based on relative importance.

b) Continuous re-scaling

The continuous rescaling method is used to produce an identical range for the values of indicators, e.g., 0 – 1 or 0 – 100. These values assist decision makers to better understand the performance of respective indicators, and allow them to formulate more specific action plans to address the issues related to certain indicators.

This method has been widely used in the development of various indices, such as the Canadian Water Sustainability Index (Policy Research Initiative, 2007), Water Poverty Index (Lawrence et al., 2003), Human Development Index (Rodríguez, 2010), and Environmental Sustainability

Index (Esty et al., 2005). The general equation to calculate the sub-index values using this method is as follows:

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \tag{2.2a}$$

$$S_i = \frac{X_i - X_{min}}{X_{max} - X_{\min}} \times 100 \tag{2.2b}$$

where S_i is the sub-index value for indicator *i*, X_i is the actual value for indicator *i*, and X_{min} and X_{max} are the minimum and maximum threshold values of the indicator.

Eq. (2.2a) gives the sub-index value in 0 – 1 scale, while Eq. (2.2b) provides a 0 – 100 scale.

These two equations are used when the X_{min} is the least preferred value and the X_{max} is the most preferred value. If X_{min} and X_{max} are the most and least preferred values respectively, Eq. (2.2a) and Eq. (2.2b) are modified to:

$$S_i = 100 - \left(\frac{X_i - X_{min}}{X_{max} - X_{\min}}\right) \tag{2.3a}$$

$$S_i = 100 - \left(\frac{X_i - X_{min}}{X_{max} - X_{\min}} \times 100\right) \tag{2.3b}$$

In order to use the continuous rescaling method, maximum and minimum threshold values for each indicator must be defined. The actual values for the indicator are then re-scaled, based on the range of threshold values. For example, as illustrated in Figure 2.2, the maximum and minimum threshold values for *Availability* indicator in CWSI are 1,700 m^3/cap/yr and 500 m^3/cap/yr respectively.

If the actual value for this indicator, for instance, is 1000 m^3/cap/yr, then its sub-index value is calculated as follows:

$$S_i = \frac{1000 - 500}{1700 - 500} \times 100 = 41.67$$

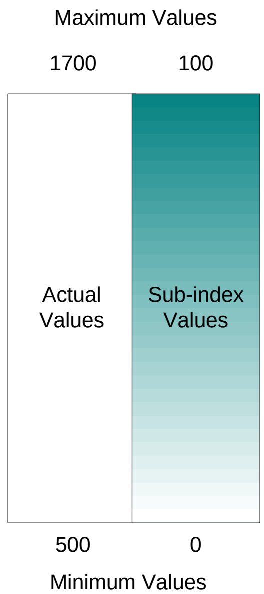


Figure 2.2 Illustration of the continuous rescaling method

c) Percentage of annual differences over two consecutive years

This method calculates the sub-index value of a particular indicator based on the difference of an actual value in a particular year compared to the previous year. The use of this method is subject to time-series data availability for the identified indicators (Nardo et al., 2005).

The general equation for this method is:

$$S_i = \frac{X_{i,t} - X_{i,t-1}}{X_{i,t}} \qquad \textbf{(2.4)}$$

where S_i is the sub-index value of indicator *i*, $X_{i,t}$ is the actual value of indicator *i* at the time *t* , $X_{i,t-1}$ is the actual value of indicator *I* at the time *t-1*.

This method was used in the application of the Internal Market Index (Nardo et al., 2005).

d) Categorical scaling

The categorical scaling method assigns categories for indicators based on some defined criteria. The categories can be numerical (values such as 1 – 5) or qualitative (such as 'very good', 'good' or 'poor'). Compared to the continuous rescaling method, instead of having the sub-index values in continuous form, this method produces the sub-index values in categories. The use of this method using numerical categories is illustrated in Figure 2.3.

Maximum Values

1700	100
1460 - 1700	5
1220 - 1460	4
980 - 146	3
740 - 980	2
500 - 740	1
500	0

Minimum Values

Figure 2.3 An example of use of the categorical scaling method

In this application, the distance between the maximum threshold (1700 m^3/cap/yr) and minimum threshold (500 m^3/cap/yr) of *Availability* indicator is divided into five criteria, each representing a certain range of actual value for *Availability*. Each criterion corresponds to one category of the sub-index values. Thus, for example, if the actual value water availability is 1,000 m^3/cap/yr, its sub-index value is '3'.

This method can also be used with quantitative data to obtain the sub-index values of certain indicators when they are not available. For example, to assess the *Institutional Capacity* indicator of the WSI, there was no quantitative information available. Thus, the WSI developer suggested two indicators to assess the *Institutional Capacity*, they were *Legal Framework* and

Participatory Management. Each of these two indicators has a criterion, which was divided into five scales (very poor, poor, medium, good and excellent) (Chaves & Alipaz, 2007). Each criterion corresponded with a sub-index value. The sub-index value for the Institutional Capacity was the average of sub-index values of *Legal Framework* and *Participatory Management.*

The general equation for using this method is:

$$S_i = \begin{matrix} Z_j & if & X_i \; meets \; criteria \; 1 \\ Z_j & if & X_i \; meets \; criteria \; 2 \\ \cdots & & \cdots \\ Z_n & if & X_n \; meets \; criteria \; n \end{matrix} \qquad \textbf{(2.5)}$$

where S_i is the sub-index value of indicator *i*, X_i is the actual value of indicator *i*, Z_j is the category for X_i that meets criteria *j*, and n is the number of categories.

e) Distance to a reference

Nardo et al. (2005) discussed the use of this method by Parker (1991) in 'Concern About Environmental Problems'. In this application, the values of indicators of one country (or the average values of different countries) are used as a reference. The sub-index values of respective indicators of other countries are assessed, based on their relative conditions to the reference value(s).

The general equation to use this method is:

$$S_i = \frac{X_i}{X_r} \qquad \textbf{(2.6)}$$

where S_i is the sub-index value for the indicator, X_i is the actual value for the indicator, and X_r is the actual value used as reference.

2.4.3 Weights

In the index development, weights are used in the indicator aggregation, allowing index developers (or users) to assign different weights on the indicators. In general, Nardo et al. (2005) classify weighting techniques in two broad categories, which are statistical-based methods and participatory-based methods. In the former method, weights are assigned based on the analysis on the data of the indicators. In the latter method, weights are given based on opinion from experts or the general public. As the selection of experts might involve subjective judgment, justifications for the selection of these experts are required.

Methods such as Factor Analysis (FA)/Principal Component Analysis (PCA) and Unobserved Component Model (UCM) are examples of the statistical-based weighting approach. In general, the FA/PCA assigns weights based on the loading factor of each indicator to the final index. The use of FA/PCA to determine weights involves four steps. The first step is to analyse the correlation of the indicators. If no correlation exists, it is likely that the indicators do not share common factors. Then, in such cases where the indicators are not correlated, the indicators are assigned equal weights. If the correlation existed, the second step is to identify common factors, representing group(s) of indicators. In PCA, the factors are known as (principal) components. Each factor indicates how well the factor in explaining the overall variance. The third step is to determine the contribution of each indicator to its corresponding factor using the factor loading analysis. Then, the final step is to compute the weights based on the common factor and factor loading analysis. Higher weights are given to the indicators with high loading factor, and high percentage in explaining the overall variance (Nardo et al., 2005).

The UCM method assumes that indicators of an index are dependent on other unknown factors. These factors are labeled as unobserved component(s) (Harvey & Koopman, 2000; Nardo et al., 2005). The dependency on the unobserved component(s), as well as errors associated with each indicator of an index, is shown by the variance of each indicator. To use this method, the first step is to calculate the variance of each indicator of the index. Then, the sum of variance of other indicators is calculated. The weight for an indicator increases as the variance of that indicator decreases, and as the sum of variance of other indicators increases (Nardo et al., 2005).

In the participatory-based approach, methods such as Budget Allocation (BAL), Analytical Hierarchical Process (AHP) and Revised Simos' Procedure are available. The BAL method is used to assign weights for different indicators based on allocation of budget by selected experts. The experts are requested to allocate certain budgets to each indicator. Once the budget is allocated, weights are calculated based on the budget. If necessary (optional), the budget allocation is repeated until convergence among experts is reached (Nardo et al., 2005).

The AHP method is a multi-criteria decision-making technique used in different fields such as customer service (Kwong & Bai, 2002), operational design (Macharis et al., 2004) and water conservancy (Zhang, 2009). This method is used to determine weights of different criteria in decision making. Using AHP, weights are determined through pair wise comparison of the identified criteria. The method was found to be useful to determine weights of criteria where qualitative judgment from experts or the general public was involved.

The Revised Simos' Procedure seeks to assign weights to different indicators based on the preference of selected decision makers - DM (Kodikara et al., 2010). Using this method, weights for different indicators were assigned by distributing cards to the selected DMs. Each card represented one indicator. Along with the cards to represent each indicator, the DM is also given blank cards. Then, the DMs are asked to arrange the cards in order of importance, from the least important to the most important. The weights of the indicators are computed, based on card order. An example of this method can be found in the study of multi-objective operation of urban water supply systems by Kodikara (2008).

2.4.4 Aggregation

In developing an index, aggregation may occur in sequential stages, as illustrated in the example in Figure 2.4, assuming that the index has components, indicators and sub-indicators. In this figure, the values of sub-indicators are aggregated to obtain the values of the indicators. The values of the indicators are then aggregated to obtain the values of components. Finally, the values of components are aggregated to obtain the final index value.

In some cases the final index is not obtained from the aggregation of the components. Instead it is obtained from the aggregation of indicators or sub-indicators. The Environmental Sustainability Index (ESI) is such an example. Even though the ESI has five components, the final index value is obtained through the aggregation of 21 sub-index values, instead of the aggregation of sub-index values of components (Esty et al., 2005).

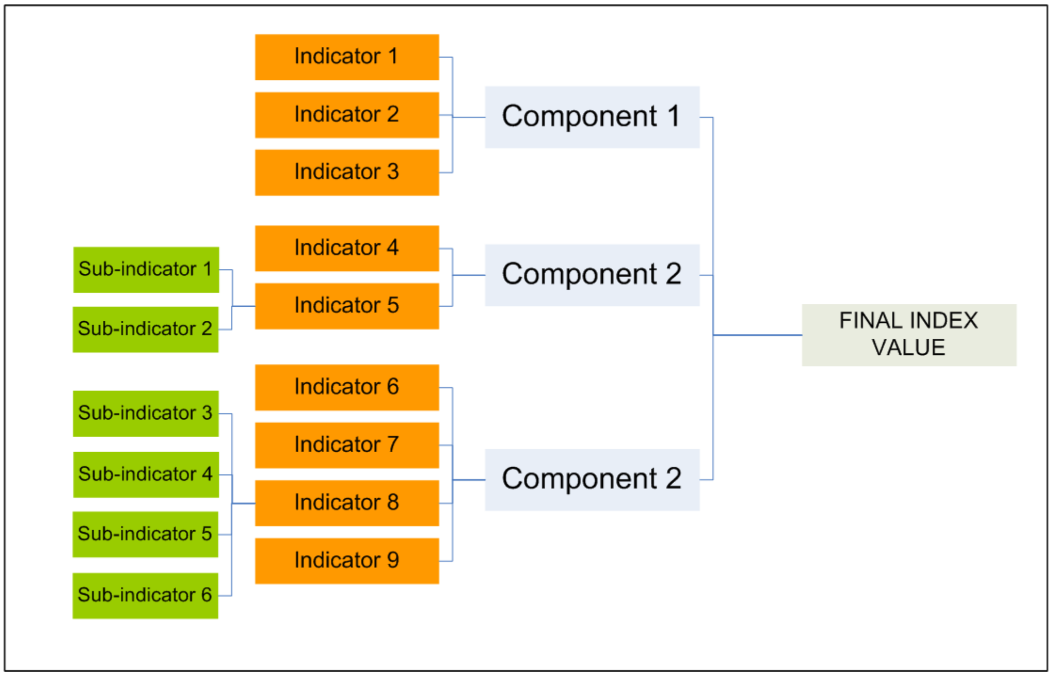


Figure 2.4 Stages of aggregation of an index

The two most common methods for aggregation of sub-indices are the arithmetic and geometric methods. The former method is widely used to aggregate sub-indices of various indices including the existing water sustainability indices of CWSI, WPI and WSI (Chaves & Alipaz, 2007; Policy Research Initiative, 2007; Sullivan, 2002). This method is applied through the summation of weighted sub-index values (Nardo et al., 2005), as given in Eq. (2.6).

$$I = \sum_{i=1}^{N} w_i S_i$$

(2.7)

where *I* represents the aggregated index, N is the number of indicators to be aggregated, S_i is the sub-index for indicator *i* and w_i is the weight of indicator *i*.

With this method, perfect substitutability and compensability among all sub-indices occurs (Nardo et al., 2005). This means low values of some sub-indices are compensated with high values of other sub-indices. Consequently, it is possible for an index to have the same aggregated index values for different cases, even if the sub-index values for each of these cases differ quite considerably, but the weighted average sub-index values of all cases are identical. Consider the following example of an index with two indicators and different sets of values of indicators. In the first case, the sub-index values of the two indicators are 40 and 40 (maximum scale of 100) and in the second case, they are 10 and 70. If the arithmetic method with equal weights is applied to aggregate the indicators, both cases will have aggregated index values of 40. The extreme difference in sub-index values of the two indicators (10 and 70) in the second case compensated each other to produce the average value of 40 for the index.

The other common method used for aggregation is the geometric method. This method is used by multiplying weighted sub-index values, as shown in the following equation (Swamee & Tyagi, 2000):

$$I = \prod_{i=1}^{N} S_i^{W_i} \quad \textbf{(2.8)}$$

the symbols for Eq. (2.8) are the same as for Eq. (2.7).

In contrast to the arithmetic method, the geometric method does not create perfect substitutability and compensability among the sub-index values of the indicators. Consequently, two cases with a significant difference in their sub-indices will have different aggregated index values, even if their weighted average sub-index values are identical. If the above hypothetical example is used with the geometric method with equal weights, both cases will have different aggregated index values. The aggregated index value is 40 for the first case and 26.5 for the second case. Here, the low sub-index value (10) of the second case is not fully compensated by the high value of the other sub-index (70). Rather, the difference of these two sub-indices is reflected in the aggregated index value.

The above hypothetical example is extended with first indicator values changing linearly from 0 – 100, while at the same time the second indicator value changing linearly from 100 – 0. The results from the two aggregation methods are shown in Figure 2.5. Both cases use equal weights for the two indicators. In the first case (the arithmetic aggregation method), regardless of extreme differences between the two sub-index values, the aggregated index values remain constant. This is because the average values of the two sub-indices are the same. However, in the second case (the geometric aggregation method), the aggregated index values varied according to differences between sub-index values. A higher difference on the sub-index values results in lower aggregated index values.

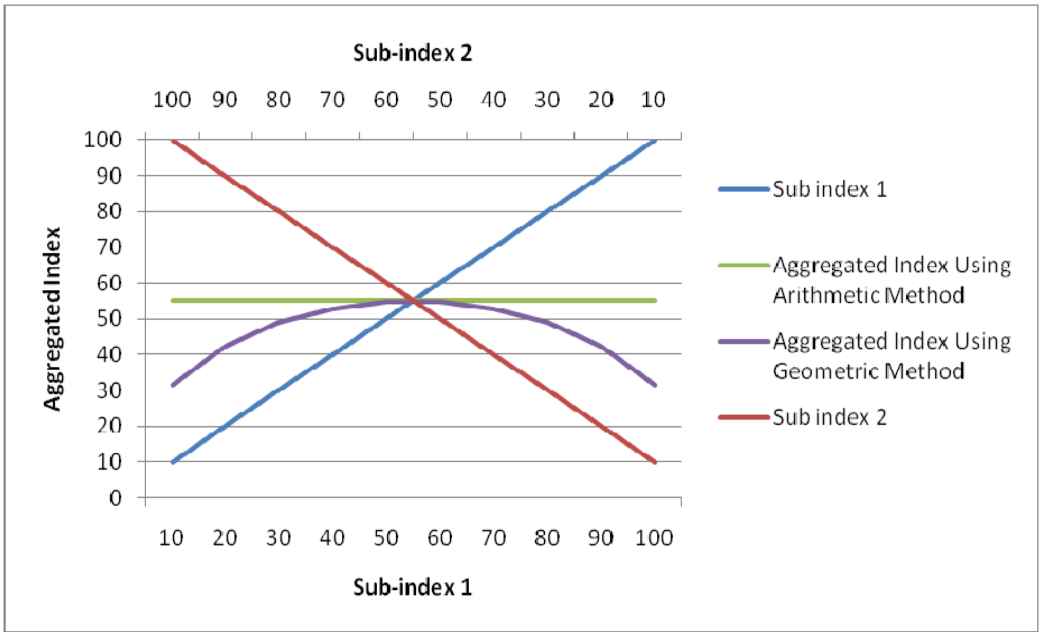


Figure 2.5 Comparisons of arithmetic and geometric aggregation methods

If the difference of sub-index values is important, the geometric method is more appropriate. The geometric aggregation method takes into account the differences in the sub-index values when aggregating indicators, while the arithmetic aggregation method does not take these differences into account. Using the geometric aggregation method, substitutability and compensability among the sub-index values do not occur. Poor indicator performances, shown by the low sub-index values, will be reflected in the aggregated index value. In contrast, when the arithmetic aggregation method is used, poor indicator performances will not be reflected in the aggregated index value if other indicators perform well.

Note that in Eq. (2.7) and Eq. (2.8), the aggregated index is obtained from the indicators. However, the same form of equation(s) can be used at different levels of aggregation.

2.4.5 Robustness analysis

The robustness analysis of the index is concerned with the ability of the index to be applied under different circumstances, such as different locations, sets of indicators, and methods involved in calculating the final index. The robustness analysis is useful to provide a better understanding to relevant stakeholders, particularly users of the index, on the limitations of the index. The robustness analysis is commonly carried out by undertaking uncertainty and sensitivity analysis on the index.

Uncertainty analysis deals with uncertainties, related to the index development, affecting the final index value. Uncertainty analysis aims at identifying input variables that are varied, and potentially lead to error or uncertainty in the outputs (Esty et al., 2005; Nardo et al., 2005). It attempts to analyse the effects of uncertainties in the input on the output values (Saisana et al., 2005).

Sensitivity analysis aims to assess and apportion the effects of variation in input variables on outputs (Nardo et al., 2005; Saltelli et al., 2004). It seeks out, mostly quantitatively, which input variation has mostly affected output variation (Esty et al., 2005; Saltelli et al., 2004). The sensitivity analysis will provide information on how much the variation in output is influenced by input uncertainty (Nardo et al., 2005).

The Monte Carlo technique performs both uncertainty and sensitivity analysis. It operates by randomly considering different input variables, based on their range and appropriate probability distribution, and simulating the corresponding output values (Clemen & Reilly, 2001). With this technique, all uncertainties in the input factors can be taken into account simultaneously or individually (Saisana et al., 2005). The factors to improve the accuracy of Monte includes performing more simulations and reducing uncertainty ranges in the input variables (Clemen & Reilly, 2001).

2.5 EXISTING WATER SUSTAINABILITY INDICES

The indicator-based sustainability assessment approach has been used in the past to develop water sustainability indices. Widely used indices are: the Water Poverty Index (WPI) by Sullivan

(2002), Canadian Water Sustainability Index (CWSI) by the Policy Research Initiative (2007) and Watershed Sustainability Index (WSI) by Chaves & Alipaz (2007). These indices have common objectives: to provide information on current conditions of water resources, provide inputs to decision makers and prioritise water-related issues (Chaves & Alipaz, 2007; Lawrence et al., 2003; Policy Research Initiative, 2007). However, these indices also have some differences. In developing a new water sustainability index, consideration and analysis of similarities and differences will be of utmost importance.

2.5.1 Water Poverty Index (WPI)

The Water Poverty Index (WPI) was developed to assess the link between poverty and water availability (Sullivan, 2002). The developers of WPI believed there is a strong correlation between water availability and poverty. The indicators of WPI were developed to assess this correlation. The first pilot project was applied internationally in 2003, involving 147 countries worldwide (Lawrence et al., 2003). The results from the application were compared with the results of other indices such as the Falkenmark Water Stress Indicator and HDI.

2.5.1.1 Selection of component and indicators

The selection of components and indicators for WPI was based on the consensus of physical and social experts, water practitioners, researchers and other stakeholders (Lawrence et al., 2003). These experts were concerned about the relationship between water poverty and income poverty.

Water poverty is illustrated in cases where people have access to water resources, but the availability of water is not adequate, whereas income poverty is shown when the availability of water is adequate but people do not have access to the water resources. Therefore, assessing the performance of water resources cannot be achieved by ignoring socio-economic factors related to water resources (Lawrence et al., 2003). The final framework for WPI, resulting from expert consensus, is shown in Table **2.1**

Table 2.1 Indicators of Water Poverty Index

Components	Indicators (Sub-components)
Resources	Internal water resources External water resources
Access	Population with access to safe water Population with access to sanitation Irrigated land
Capacity	Gross Domestic Product (GDP) Under-5 mortality rate Education Gini coefficient
Use	Domestic water use Industrial water use Agricultural water use
Environment	Water quality Water stress Regulation and management capacity Informational capacity Biodiversity

2.5.1.2 Obtaining sub-index values

To obtain sub-index values of WPI indicators, the *continuous rescaling* technique was used in Eq. (2.2a). As the first application of WPI assessed the performance of participating countries, maximum and minimum values used in Eq. (2.2a) for each WPI indicator were the highest and lowest actual values among these countries. The sub-index values of WPI indicators ranged from 0 – 1.

2.5.1.3 Weighting

In the original WPI framework, no specific weighting scheme was suggested. Sullivan et al. (2006) believe that the responsibility in determining indicator weights should be given to decision makers, not to the researchers. In using WPI, the users are allowed to define their own weights to be assigned to WPI indicators. However, Sullivan et al. (2006) emphasised the importance of transparent consultation with relevant stakeholders in defining weights. During the first WPI application, equal weights among all indicators and components were applied (Lawrence et al., 2003).

2.5.1.4 Aggregation

Two aggregation processes are used in WPI. The first aggregation is used to combine sub-index values of different indicators into components using the arithmetic aggregation method. As the indicators are equally weighted, the index value for each component is the average of the sub-index values. Once these values for the five WPI components are obtained, they are aggregated using the arithmetic method to obtain the final index value, ranging from 0 – 100 (Lawrence et al., 2003).

2.5.1.5 Final index value interpretation

In general, higher values of WPI are preferred. However, in its first application, the performance of a country is interpreted by comparing its final WPI value, as well as the sub-index values of the components, with those of other countries. During the application, it was found that most of the rich or developed countries performed better, compared to the less-developed countries. However, Lawrence et al. (2003) noted few anomalies, such as Guyana which was unexpectedly ranked fifth out of the 147 participated in the pilot study, even though this country is not one of the rich or developed countries. Guyana performed well on Resource, Access and Use components.

To better interpret these results, the correlation of final WPI values and the values of other existing indices such as the Falkenmark Water Stress Indicator and Human Development Index (HDI) in different countries was analysed. The analysis showed moderate to strong positive correlation between WPI and HDI (correlation coefficient = 0.81), explained by the fact that some of WPI indicators were taken from HDI components and/or indicators. The correlation coefficient of WPI and the Falkenmark Water Stress Indicator is 0.35, which indicates low to moderate correlation (Lawrence et al., 2003). The correlation coefficients of the abovementioned indices, based on their applications in 2003, are shown in Table 2.2.

Table 2.2 Correlation coefficients of WPI, Falkenmark Water Stress Indicator and HDI

	WPI	Falkenmark Water Stress Indicator	HDI
WPI	1	0.35	0.81
Falkenmark Water Stress Indicator	0.35	1	0.11
HDI	0.81	0.11	1

2.5.2 Canadian Water Sustainability Index (CWSI)

The application of WPI in 2003 on an international scale, involving most countries in the world, has inspired the Policy Research Initiative (PRI) to develop the CWSI. In the application of WPI in 2003, Canada was ranked second (of 147 participating countries). Even though the performances of Canadian water resources were considered excellent at that time, PRI believes that Canada still has water resource issues, particularly among its rural communities. It was believed that the benefits from these water resources, received by local communities, were compromised.

The CWSI was developed to specifically point out these disparities. Similar to WPI, the development of the CWSI framework seeks to integrate physical, environmental and socio-economic aspects of water resources in Canada. The application of CWSI in various Canadian communities is expected to identify important water issues and prioritise water-related issues, to communicate the conditions of Canadian water resources to the wider public, and to raise awareness of the Canadian stakeholders about water resources at the community level.

2.5.2.1 Selection of components and indicators

The selection of components and indicators for CWSI was based on the literature review on water resource management and existing indicators of the Water Poverty Index (WPI). In the preliminary document of CWSI (Policy Research Initiative, 2007), indicators of WPI were modified to suit Canadian water resource characteristics. The document was then brought into a two-day workshop and experts finalised the selection of components and indicators to be included in the final CWSI framework, as shown in Table 2.3.

The selection criteria used by these experts include scope, scale, applicability, relevancy, data and scoring (Policy Research Initiative, 2007). The scope criterion is concerned with the numbers of indicators to be included under each component. The experts believed that appropriate trade-off was made between a ‘too narrow’ and ‘too broad’ scope of indicators for each component. As for the scale, the concern was the difficulty in assessing the performance of water resources purely based on one particular community or area. In many cases, water conditions in one area are highly influenced by other areas. Therefore, in CWSI, physical availability of water resources and ecosystem health are monitored at the river basin scale, instead of the community scale. For other issues such as education, poverty and infrastructure, they are assessed at the community scale (Policy Research Initiative, 2007).

Table 2.3 Indicators of Canadian Water Sustainability Index

Components	Indicators
Resource	Availability Supply Demand
Ecosystem Health	Stress Quality Fish
Infrastructure	Demand Condition Treatment
Human Health	Access Reliability Impact
Capacity	Financial Education Training

The next four criteria, which are applicability, relevancy, data and scoring, are highly related. They are concerned with the applicability of the index due to data availability, how the sub-index values of the indicators are obtained, and how meaningful these results are to the communities they serve. If an indicator will only be meaningful to particular communities, and much less meaningful for others, this indicator is replaced with another indicator (Policy Research Initiative, 2007).

2.5.2.2 Obtaining sub-index values

In obtaining sub-index values, CWSI adopted the *continuous rescaling* technique. With this technique, the actual values of CWSI indicators were computed to be within the range of 0 – 100 (refer to Eq. (2.2b)). To do this, maximum and minimum threshold values for each indicator were determined, based on specific targets or benchmarks. These targets or benchmarks were obtained from literature reviews. The maximum and minimum threshold values of the *Availability* indicator, for example, were taken from the Falkenmark Water Stress Indicator. The maximum and minimum values for this indicator were 1700 m^3/cap/yr and 500 m^3/cap/yr respectively (Falkenmark et al., 1989).

2.5.2.3 Weighting

In the CWSI, an equal weighting scheme was used to aggregate the indicators. This means each indicator has the same weight during the aggregation process. The decision to apply the equal weighting scheme (along with the finalisation of components and indicators) was made by selected experts during the abovementioned two-day workshop. However, each catchment or community is also allowed to make changes for the weighting scheme, if justifications can be provided.

2.5.2.4 Aggregation

To aggregate CWSI indicators, the arithmetic method was used (Eq. (2.6)). In CWSI, aggregation occurs both at the component and indicator levels. The three indicators in each component are aggregated to obtain the sub-index value of the component. The five sub-index values of components are then aggregated to obtain the final index value. As CWSI has equal numbers of indicators in each component and all indicators have equal weights, the final aggregated index value is also the average of sub-index values. The equal weights applied to all indicators also imply that each component value is the average value of its respective indicator values (Policy Research Initiative, 2007).

2.5.2.5 Final index value interpretation

Higher values of the final index show higher water sustainability. If a particular community or catchment scored 100, it means this community has the perfect status of water sustainability. Further interpretation of the final CWSI value was based on comparison of CWSI applications among various communities. It was found that the index was more useful when applied to communities in the same region, or communities which shared similar water resource conditions (Policy Research Initiative, 2007). Based on these results, the communities were able to work together to formulate relevant water policies at the regional scale.

2.5.3 Watershed Sustainability Index (WSI)

The Watershed Sustainability Index (WSI) was specifically applied at the basin level. It attempted to integrate issues of hydrology, environment and life and policy into a single and comparable number (Chaves & Alipaz, 2007). The developers of the index indicated that previous indices on water resources had not been specifically designed for use at the basin scale, and did not take into account the cause–effect relationship of their indicators. The application of sustainability indices at the basin level is important as the assessment of water resource sustainability cannot be bordered by jurisdictional frontiers (Chaves & Alipaz, 2007). To follow up on the cause–effect relationships among indicators, the WSI has used the Pressure-State-Response (PSR) model to address each of the HELP dimensions (Hydrology-Environment-Life-Policy) (Chaves & Alipaz, 2007).

2.5.3.1 Selection of components and indicators

As mentioned earlier, the indicators of WSI were selected, based on the HELP platform, designed by UNESCO's International Hydrologic Program (Chaves & Alipaz, 2007). For each indicator, different parameters (or sub-indicators) were developed using the PSR model illustrated in Figure 2.6.

The PSR model seeks to analyse the causality of the following three issues (Smeets et al., 1999):

- The *pressures* of human activities on various environmental issues
- How these pressures affect the *states* of the natural systems
- The *responses* by governments and general communities to address the environmental changes through different policies and regulations

Using the HELP platform and the PSR model, WSI indicators and parameters were developed. At the end of the selection process, the authors of the WSI proposed four different indicators: **H**ydrology, **E**nvironment, **L**ife and **P**olicy. *Pressures, states* and *responses* for each of these indicators were then identified and labeled as parameters. The Hydrology indicator comprises *pressure* parameters, two *state* parameters and two *response* parameters. For the other three indicators, each has one parameter representing *pressure, state* and *response*. In total, 15 parameters were identified. WSI indicators and parameters are shown in Table 2.4.

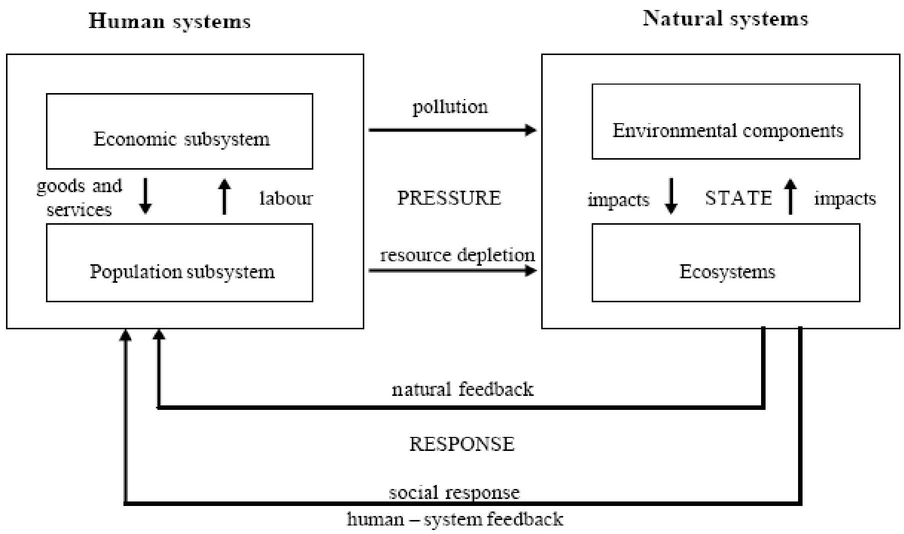


Figure 2.6 The Pressure-State-Response (PSR) model (Smeets et al., 1999)

Table 2.4 Indicators of Watershed Sustainability Index

Indicator	Parameter
Hydrology	Variation in basin water availability (P) Variation in basin BOD (P) Per capita water availability (S) Basin BOD (S) Improvement in water-use efficiency (R) Improvement in adequate sewage treatment (R)
Environment	Basin Environmental Pressure Index - EPI (P) Natural vegetation (S) Evolution in basin conservation (R)
Life	Variation in income (P) Human Development Index - HDI (S) Evolution in HDI (R)
Policy	Variation in HDI-Education (P) Institutional capacity (S) Evolution in expenditures (R)

P = Pressure, S = State, R = Response

2.5.3.2 Obtaining sub-index values

To obtain sub-index values of the parameters, WSI uses the *categorical scale* technique (Section 2.4.2), with the minimum value of 0, and maximum value of 1. For each parameter, criteria describing five different categories were determined. Actual values of each parameter were compared to obtain the sub-index values. For example, for the *Environmental Pressure Index* (EPI) parameter of a particular basin, its EPI value is compared against the criteria shown in Table 2.5. The criteria for obtaining the sub-index values of all other parameters were also provided.

Table 2.5 Obtaining sub-index values for EPI parameter of WSI

Criteria	Sub-index value
EPI≥20%	0.00
20%>EPI≥10%	0.25
10%>EPI≥5%	0.50
5%>EPI≥0%	0.75
EPI<0%	1.00

2.5.3.3 Weighting

In the WSI, the equal weighting scheme was used to aggregate the indicators. Chaves & Alipaz (2007) believe there is no clear and significant evidence to assign different weights on WSI indicators. However, if non-equal weights are needed during the application of WSI in particular basin(s), Chaves & Alipaz (2007) suggest a consensus among relevant stakeholders to assign appropriate and reliable weights for indicators.

2.5.3.4 Aggregation

In WSI, the arithmetic method was used. There were two levels of aggregation. First, the parameters of an indicator were aggregated using the following equation:

$$I = \frac{(P + S + R)}{3} \quad \textbf{(2.9)}$$

where *I* is the sub-index value of the indicator, *P* is the average sub-index value for *pressure* parameters, *S* is the average sub-index value for *state* parameters and R is the average sub-index value for *response* parameters.

Once the sub-index values for all indicators were obtained, they were aggregated using the following equation:

$$WSI = \frac{(H + E + L + P)}{4} \quad \textbf{(2.10)}$$

where *WSI* is the final index, *H* is the sub-index value for the *Hydrology* indicator, *E* is the sub-index value for the *Environment* indicator, *L* is the sub-index value for the *Life* indicator and *P* is the sub-index value for the *Policy* indicator. The values of H, E, L and P are obtained from Eq. (2.9).

2.5.3.5 Final index value interpretation

For the interpretation of the final index, WSI adopted the Human Development Index (HDI). According to HDI interpretation, the performance of a basin is considered low if the final index of WSI is < 0.5; intermediate if WSI is between 0.5 and 0.8; and high if WSI is > 0.8. This HDI interpretation, adopted by WSI, was based on the 2000 HDI Report (Chaves & Alipaz, 2007).

2.5.4 Comparative analysis of water sustainability indices

In terms of their structure, all three indices comprise a set of indicators covering various water resources aspects. WPI and CWSI indicators are grouped to form components. The WSI indicators are known as parameters, and the components are known as indicators. Table 2.6 summarises similarities and differences of these three indices.

It is previously shown in Table 2.6 that the components and indicators of these three indices were initially identified, based on literature reviews. For CWSI and WPI, in particular, the literature review was followed by stakeholder consultations. The literature review in CWSI and WPI was undertaken to produce the initial set of components and indicators. This set was then brought into stakeholder consultations or expert meetings to be discussed and finalized (Lawrence et al., 2003; Policy Research Initiative, 2007).

The selection of the method to be used in obtaining sub-index values of indicators is determined by the purpose for developing the index, as well as the availability of data to obtain sub-index values (Nardo et al., 2005). The continuous rescaling method allows any values within the minimum and maximum values of the index (for example, values between 0 - 100), while the categorical scale method assigns discrete values for different categories within the index range (Nardo et al., 2005).

Table 2.6 Comparisons of CWSI, WPI and WSI

Index	Component Selection	Obtaining Sub-index Values Method	Weighting Scheme	Aggregation Method	Final Index Value Interpretation
CWSI (Canadian Water Sustainability Index)	Literature review, then expert workshop	Continuous rescaling	Equal weights	Arithmetic	**0 - 100**
WPI (Water Poverty Index)	Literature review, then consensus opinion of experts and other stakeholders	Continuous rescaling	Equal weights	Arithmetic	**0 - 100**
WSI (Watershed Sustainability Index)	Literature review by authors	Categorical scaling	Equal weights	Arithmetic	**0 - 1** ≤ 0.5: Low 0.5 – 0.8: Intermediate ≥ 0.8: High

The continuous rescaling method was used in both WPI and CWSI to obtain the sub-index values of the indicators. Typically, the WPI and CWSI used local, regional, national or internationally recognised policies, regulations or standards to determine maximum and minimum threshold values, which were then used to compute sub-index values (Nardo et al., 2005). The categorical scale method was used by WSI to obtain sub-index values. Criteria for each indicator were identified to obtain sub-index values using the categorical method. These criteria were divided into different groups, representing the categories of the sub-index values.

The interpretation of the final index value for CWSI and WPI is based on the 0 - 100 range. The final index value for these indices are preferred if it is closer to 100, and less preferred if it is closer to 0. The interpretation of WSI value is based on the 0 - 1 range, with 1 being the most preferred and 0 the least preferred. In WSI, further interpretation was given based on the 2000 HDI Report. The performance of a basin is considered low, intermediate or high if the WSI value is ≤ 0.5, between 0.5 and 0.8, or > 0.8 respectively.

2.6 OTHER INDICES

The indicator-based approach has been widely used in fields other than water resources, such as economics or human development. The applications of indices in these fields were considerably useful for decision makers in their respective fields. The following sub-sections discuss the developments and applications of two indices, namely the Human Development Index (HDI) and Environmental Sustainability Index (ESI).

2.6.1 Human Development Index

The Human Development Index (HDI) was proposed by the Pakistani economist, Mahbub ul Haq (Haq, 1989) and was published by the United Nations Development Program - UNDP (Rodríguez, 2010) in 1990. Since then, its applications have been widely used to assess performances of various countries in three areas: health, knowledge and income (Rodríguez, 2010). These areas are known as dimensions, which are similar to components in other indices. The index was proposed as the alternative to previous human development measurements, which focused solely on economic issues (Haq, 1989). Haq argued that human development cannot be assessed solely on economic growth, but other areas, such as knowledge and health, should be considered (Haq, 1989). The following sub-sections discuss some HDI issues, which include the selection of dimensions and indicators, obtaining sub-index values, weighting and aggregation methods of HDI dimensions and indicators, and the interpretation of final HDI values.

2.6.1.1 Selection of dimensions and indicators

Originally, the selection of dimensions and indicators of HDI, including threshold values to assess the indicators, was published by the index founder (Haq, 1989). When this paper was published, it received enormous response from various stakeholders, including public officials, policy makers, media and others (Rodríguez, 2010). Compared to the Gross National Product (GNP) measure, the stakeholders considered HDI a more comprehensive tool to measure human development. Having global and positive attention from various stakeholders, the HDI was then adopted by UNDP to assess the performance on human development among countries. This assessment is updated regularly and still reported today. The dimensions, indicators and threshold values of HDI are regularly reviewed by a panel of experts, and necessary changes have been made during the review. The latest HDI framework of 2010 has four indicators in its three major dimensions: health, knowledge and income. Each of the health and income dimensions has one indicator, while knowledge has two indicators: literacy and children in schools.

2.6.1.2 Obtaining sub-index values

In HDI, the sub-index values of health, knowledge and income dimensions are obtained using the *continuous rescaling method* (Eq. (2.2a)). In HDI, the minimum and maximum threshold values to be used with this method are known as target values. To obtain the sub-index value of the health dimension, for example, the target values used for the maximum value is a life expectancy of 85 and the minimum value is a life expectancy of 25.

If the average life expectancy of one country is 71.4, the sub-index value of the health dimension is calculated as follows:

$$S_i = \frac{71.4 - 25}{85 - 25} = \mathbf{0.773}$$

As the health dimension has only one indicator (life expectancy), the sub-index value of this indicator is the same as the sub-index value of health dimension.

2.6.1.3 Weighting of dimensions and indicators

The HDI uses equal weights for all three dimensions. Under the knowledge dimension, the literacy indicator, a higher weight (two-thirds) is assigned than for the children in schools indicator (one-third), as the former indicator is deemed more important than the latter (Rodríguez, 2010). Once the index values for all dimensions are obtained, the aggregated index is computed with equal weights for all dimensions.

2.6.1.4 Aggregation of dimensions and indicators

As each of the health and income components has only one indicator, the sub-index values of these indicators are also considered as respective dimensions. The sub-index values of indicators for the knowledge dimension are aggregated using the geometric method to obtain the sub-index value of the knowledge dimension.

Once the sub-index values for all three dimensions are obtained, they are aggregated to produce the final HDI value. The sub-index values of HDI dimensions are aggregated using the geometric method and the equation used in the aggregation process is as follows (Rodríguez, 2010).

$$HDI = I_{Life}^{\frac{1}{3}} \times I_{Education}^{\frac{1}{3}} \times I_{Income}^{\frac{1}{3}} \qquad \textbf{(2.11)}$$

With this method, a country with considerably high and low sub-index values for three dimensions will have a lower HDI value, compared to another country with the same sub-index values for all three dimensions.

2.6.1.5 Final index value interpretation

In the 2010 HDI Report (Rodríguez, 2010), changes have been made to the interpretation of the final HDI value. In previous HDI reports, absolute HDI values were used to interpret country performance. In the 2010 HDI Report however, the interpretation of the final HDI values were based on relative HDI values among participating countries. The changes of classification and interpretation of the HDI are shown in Table 2.7.

Based on performance, it is intended that each country will develop relevant policies for improving low performance. Different countries with similar HDI values or dimension values can also work together in designing appropriate policy actions.

Table 2.7 Interpretation of final HDI values

Year	Final HDI Value	Performance
Pre 2010	HDI <0.5	Low
	0.5 < HDI < 0.8	Intermediate
	HDI > 0.8	High
2010	HDI: 0-25 percentiles	Low
	HDI: 26-50 percentiles	Medium
	HDI: 51-75 percentiles	High
	HDI: 76-100 percentiles	Very High

2.6.2 Environmental Sustainability Index

The Environmental Sustainability Index (ESI) was developed to measure the overall environmental sustainability achievement of countries worldwide (Esty et al., 2005). Since its first application in 2001, the ESI has been regularly applied until now. Even though the index was previously used to compare environmental sustainability performances of countries worldwide, it is emphasized that the rankings are not the main concern. Rather, the information on the underlying indicators and variables (or sub-indicators), and how the information is used to formulate relevant policies, are the most essential (Esty et al., 2005).

The ESI aims at providing a logical, systematic and empirical framework to assess environmental sustainability performance within and among countries. It also attempts to identify which environmental issues need higher priority. In many countries, the index is used as a starting point for addressing environmental-related issues. In Indonesia, for example, along with the Millennium Development Goals, the Ministry of Environmental Affairs of the Republic of Indonesia has used the ESI to create and develop relevant programs for improving environmental conditions in Indonesia (Sinta, 2011).

2.6.2.1 Selection of indicators and variables

The ESI comprises 21 indicators, with each indicator having 2 to 13 variables. In total, there are 76 variables used in the ESI. The 21 indicators are classified in 5 environmental themes, namely (1) Environmental Systems, (2) Reducing Environmental Stresses, (3) Reducing Human

Vulnerability to Environmental Stresses, (4) Societal and Institutional Capacity to Respond to Environmental Challenges, and (5) Global Stewardship.

The indicators and variables of ESI were selected by experts and based on existing analytical frameworks. As the index was meant to be applied globally, availability of data sources across these countries was considered during the selection of ESI indicators and variables. The indicators and variables of ESI were selected using the improved PSR method known as Driving force Pressure State Impact Response (DPSIR). This method is illustrated in Figure 2.7.

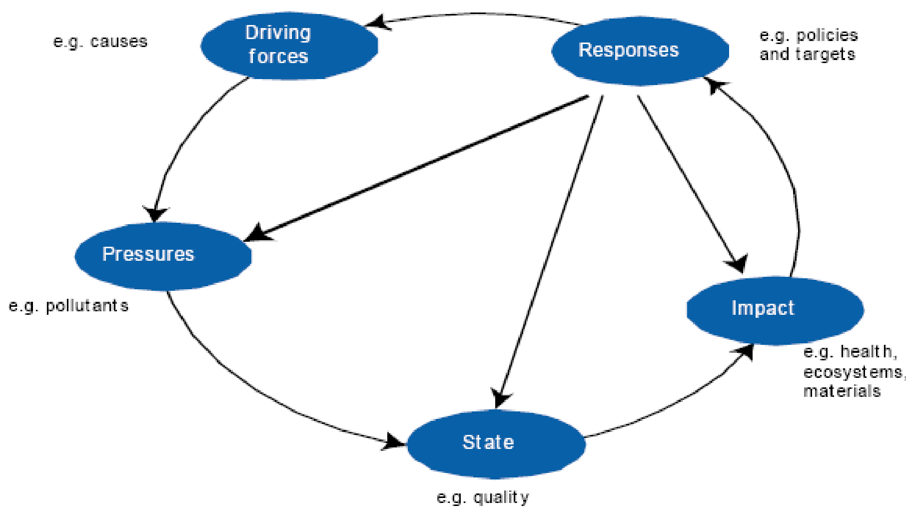


Figure 2.7 The DPSIR model (Smeets et al., 1999)

The DPSIR, while maintaining PSR components, also includes *driving forces* and *impact*. Indicators derived from *driving forces* are related to the development on social, economic and population sectors. The population growth is an example of indicators derived from *driving forces*. These *driving forces* lead to the increase of *pressures* on the natural resources. These *pressures* are indicated by the use of resources, as well as the increase of pollutants. Thus, the use of resources and pollutants are examples of indicators from *pressures*.

Then, as *pressure* increases, the *state* of natural resources will be affected. Figure 2.7 provides quality as an example of indicator changes in the *state*. When the natural resources are affected, human health and other functions of the environment may be impacted, explained by indicators such as human health and ecosystem degradation.

Further, to address these *impacts*, society needs to respond to these situations. Examples of indicators as the response of society are policies and regulations for preventing, reducing and (if possible) eliminating the negative impacts. As illustrated in Figure 2.7, these responses might be directed to address *driving forces, pressures, state* or *impacts* separately, or in the combination of DPSIR components (Smeets et al., 1999).

2.6.2.2 Obtaining sub-index values

The sub-index values of ESI are obtained using the *continuous rescaling* method (Eq. (2.2b)). The maximum and minimum threshold values used in the equation were based on the actual values of variables of participating countries.

2.6.2.3 Weighting of variables and indicators

The analysis of the non-equal weighting schemes during the development of the ESI has shown that no ESI indicators or variables were significantly superior to other indicators or variables (Esty et al., 2005). One of the non-equal weighting schemes used in the ESI was based on Principal Component Analysis (PCA), which showed that 76% of the data variation was explained by six principal components of the 21 ESI indicators. To determine the weights based on this analysis, the loading of each ESI indicator on each of the six principal components was calculated. The analysis shows that the loading factors of all indicators are nearly equal (Esty et al., 2005).

Another non-equal weighting scheme used in the ESI was based on the *Budget Allocation* scheme, in which experts were provided with 100 points as a ‘budget’. The experts were requested to allocate the budget to all 21 ESI indicators, based on their importance. In the end, it was found that the weights of the indicators differed insignificantly from the equal weighting results (Esty et al., 2005).

Therefore, based on analysis of these two non-equal weighting schemes, the ESI uses equal weights to aggregate its indicators and variables.

2.6.2.4 Aggregation of indicators and variables

To aggregate the ESI indicators and variables, the arithmetic method was used at both levels (Eq. (2.6)). With this method, the value of each indicator is the weighted sum of its variables and the value of the final ESI is the weighted sum of all 21 indicators.

2.6.2.5 Robustness analysis

Robustness analysis of ESI was done by undertaking an uncertainty and sensitivity analysis of the index, using the Monte Carlo simulation. During the Monte Carlo (MC) simulation, different scenarios were performed, based on identified uncertainties. The scenarios performed in the MC simulation were the combinations of the following uncertainties:

(i) Imputed missing data or non-imputed missing data
(ii) Equal weighting scheme or expert opinion weighting scheme
(iii) Aggregation at the component level or aggregation at the indicator level
(iv) Linear (arithmetic) aggregation method or multi-criteria aggregation method

More specifically, the uncertainty and sensitivity analysis of ESI were undertaken to answer the following questions (Esty et al., 2005):

1. <u>How can the ESI values in a particular year change under different scenarios?</u>

The results of the Monte Carlo robustness analysis of ESI 2005 showed that for 90 countries (of 146 countries), the changes on their rankings under different scenarios are less than 10 positions (Esty et al., 2005). It was claimed that these results confirmed the robustness of the index.

2. <u>What is the most preferable scenario for each country?</u>

The results of the simulations showed that few countries, such as Congo, the Netherlands and Japan, improved their rankings at least 20 positions under the combinations of all scenarios. Under a particular scenario, other countries even improved to at least 40 positions (Burkina

Faso and Algeria) and 50 positions (Belgium, South Korea and Guatemala). The change of rankings for Burkina Faso and Guatemala occurred when the dataset imputation changed. As for Algeria, Belgium and South Korea, their rankings changed when different aggregation methods were applied.

3. <u>Which countries are vulnerable to changes in uncertainties?</u>

The final ESI values of 15 participating countries were the most vulnerable to identified uncertainties. For these countries, their initial rankings were between 13 and 39. When the different scenarios performed, their rankings changed between 50-80 positions. In particular, changes on the rankings of these countries occurred when the imputation datasets was changed, due to the large problem of missing data for these countries. For other countries, as indicated earlier, the changes are less than 10 positions.

4. <u>Which of the uncertainty factors affect the countries' rankings at the most?</u>

Finally, the robustness analysis of ESI also indicated which of the uncertainty factors that have mostly affected the rankings of the countries. The uncertainty on the imputation of missing data was found to have an average impact of 10 positions, while the weighting schemes have an impact of 5 positions. For the other two uncertainties, which are the aggregation level and aggregation method, both have an average impact of 8 positions. Based on these average position changes, the imputation of missing data is considered as the factor that has the largest effect on overall rankings of the countries (Esty et al., 2005).

2.6.2.6 Final index value interpretation

The interpretation of the final ESI value was not purely based on its absolute value. The absolute value of ESI is preferred if it is closer to 100, and less preferred if it is closer to 0. Further interpretation is undertaken by comparing the results of one country with other countries. One of the comparisons were based on the cluster analysis (Esty et al., 2005) of sub-index values of ESI themes. In the cluster analysis, countries with similar sub-index values of themes are grouped together. There were seven clusters or groups identified, as shown in Table 2.8.

2.7 SUMMARY

The use of indicators to measure sustainability has been growing rapidly in the last decade. The applications of different sustainability indices in different fields have had great benefits for environmental decision makers around the world. One of the major benefits of sustainability index applications is related to their capability to signal sustainability performance in a particular area to decision makers.

In this chapter definitions of sustainable development and principles of sustainability were presented. These definitions and principles have provided guidance on how to perceive sustainability. Various definitions of sustainable development presented in this chapter have common messages. The key message was the concern on the quality of natural resources now, so that they can be utilised by future generations. Based on these definitions, various sets of sustainability principles were identified.

Table 2.8 Cluster analysis based on values of ESI themes (Esty et al., 2005)

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7
Low *System*& *Stress* scores; low *Vulnerability* & high *Capacity*; moderate *Stewardship*	Moderate *System* &*Stress* scores; high *Vulnerability* & low *Capacity*; above average *Stewardship*	Above average *System* score; low *Vulnerability*; high *Capacity*; moderate *Stress*& *Stewardship*	Moderate *System*, *Stress*, &*Capacity* scores; low *Vulnerability*& *Stewardship*	Above average *System* score, moderate *Stress*, *Vulnerability*, *Capacity*, & *Stewardship*	Moderate *System, Stress*, &*Vulnerability* scores; low *Capacity*& *Stewardship*	Low *System* score; moderate *Stress*, *Vulnerability*, *Capacity*, & *Stewardship*
Austria	Angola	Australia	Bosnia	Argentina	Algeria	Albania
Belgium	Benin	Canada	Bulgaria	Bolivia	Belarus	Bangladesh
Denmark	Bhutan	Finland	Croatia	Brazil	Azerbaijan	China
France	Burkina Faso	Iceland	Czech	Chile	Belarus	Cuba
Germany	Burundi	New Zealand	Estonia	Colombia	Iraq	Dominican Republic
Ireland	Cambodia	Norway	Greece	Costa Rica	Kazakhstan	Egypt
Israel	Cameroon	Sweden	Hungary	Ecuador	Kuwait	El Salvador
Italy	Central Africa	United States	Jamaica	Gabon	Kyrgyzstan	Georgia
Japan	Chad		Latvia	Guatemala	Libya	India
Netherlands	Congo		Lebanon	Guyana	Moldova	Indonesia
Portugal	Cote de Ivoire		Lithuania	Honduras	Mongolia	Iran
Slovenia	Dem. Republic of Congo		Macedonia	Namibia	North Korea	Jordan
South Korea	Ethiopia		Poland	Nicaragua	Oman	Malaysia
Spain	Gambia		Romania	Panama	Russia	Mexico
Switzerland	Ghana		Serbia	Paraguay	Saudi Arabia	Morocco
Taiwan	Guinea		Slovakia	Peru	Turkmenistan	Pakistan
United Kingdom	Haiti		Trinidad & Tobago	Uruguay	Ukraine	Philippines
	Mali		Turkey	Venezuela	UAE	South Africa
	Mauritania				Uzbekistan	Sri Lanka
	Mozambique					Syria
	Myanmar					Thailand
	Nepal					Tunisia
	Nigeria					

Note: The ESI themes are: System, Stress, Vulnerability, Capacity and Stewardship

One set of sustainability principles is “the triple bottom line approach”. Other sets are “sustainability challenges”, “capital flow concept” and “prism of sustainability”. However, they all have common sustainability principles: environmental, economic and social. They were the basis for the identification of sustainability indicators. In this study, as the indicator-based sustainability assessment will be applied in the field of water resources, definitions, criteria and guidelines for sustainable water resource management were also discussed. Later, these sustainability principles and sustainable water resource management guidelines are used as the basis for identifying a water sustainability index.

Further, to properly understand the use of the indicators for measuring sustainability, it is important to study the elements of the indicator-based sustainability assessment tools. In general, these elements include the selection of components and indicators, the method to obtain sub-index values, the method for weighting and aggregation of components and indicators, the interpretation of the aggregated index value, and robustness analysis of the index to better understand the uncertainty and sensitivity factors of the index. Each of these elements was discussed in this chapter to assist the development of the water sustainability index.

The discussion on the selection of components and indicators provided key characteristics for good indicators. The presentation of available methods to obtain sub-index values of indicators offered information on the suitability of each method for obtaining different indicators. The equations for each of these methods, presented in this chapter, have indicated the requirement of data for using these methods. Such information was useful in developing a new water sustainability index.

Similar to the previous elements, discussion on different methods available for other elements of indicator-based sustainability assessment (weighting, aggregation and interpretation of the final index) has also provided insights to index developers on available methods. In addition, discussions on methods for each element provided information on their advantages and disadvantages.

Following detailed discussion of each of these elements of indicator-based sustainability assessment, this chapter also explored how these elements shaped the existing water sustainability indices, as well as two other indices. Three existing water sustainability indices outlined were: the Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI) and Watershed Sustainability Index (WSI). The other two indices mentioned were the Human Development Index (HDI) and Environmental Sustainability Index (ESI). Methods that were used in each element of the existing indices were carefully analysed and considered for the development of the Water Sustainability Index for West Java, which will be discussed in Chapter 3.

Chapter 3

Development of West Java Water Sustainability Index

3.1 INTRODUCTION

In assessing water resource management for West Java in Indonesia, the development of a water sustainability index is critical. As the index will be applied to many different catchments in West Java, it needs to represent the general characteristics of water resource conditions. To ensure the acceptability of the index among West Java water-related stakeholders, it also needs to accommodate the views of all stakeholders. The inclusion of relevant and important water issues in the water sustainability index, coupled with stakeholders' views, will provide a strong basis for the application of the index to different catchments in West Java.

The main parts of the West Java Water Sustainability Index (WJWSI) include the conceptual framework, the final framework, weights of indicators and sub-indicators, and index interpretation. These parts are discussed in this chapter. The conceptual framework of WJWSI was developed through an extensive literature review on available sustainability criteria, water resource guidelines and existing water sustainability indices, as previously mentioned, namely the Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI) and Watershed Sustainability Index (WSI). Once the conceptual framework was developed, it was refined through the application of the Delphi technique and an in-depth interview with key stakeholders. The application of the Delphi technique ensured that the views of relevant water-related stakeholders in West Java were included.

To accommodate the overall tasks in the development of the index, this chapter consists of four main sections. The first two sections discuss the development of the conceptual framework and the refinement of the framework through the application of the Delphi technique, followed by analysis on in-depth interviews. The third section describes weighting schemes developed for WJWSI components, indicators and sub-indicators, and their aggregations. The classification of the index value, which aims to help with index interpretation, is presented in the final section of this chapter.

Under the sub-heading Conceptual Framework, the identification of components, indicators and thresholds for the conceptual framework is explained. A flow chart, that describes the processes for developing the conceptual framework, is presented to provide a clear understanding of how the potential WJWSI components, indicators and thresholds are adopted. At the end of this section, justification for the selection of each component, indicator and threshold is provided.

Having discussed the development of the conceptual framework, the sub-section Final Framework proceeds with the refinement of the conceptual framework. Here, the application of Delphi technique to refine the conceptual framework is elaborated, which includes the identification of water-related stakeholders as respondents in the Delphi process, the design of questionnaires and method to analyse responses, and the distribution and collection of completed questionnaires. This is followed by discussion on in-depth interviews with key stakeholders. There are four groups stakeholders participated in the Delphi application and the in-depth interview, they are: Community, University Lecturer, Environmental Consultant and Government Official.

In the next section, two weighting schemes (equal and non-equal) considered in the application of WJWSI are discussed. Particularly for the non-equal weighting scheme, the procedure to calculate the weights of WJWSI components, indicators and sub-indicators is explicated. In addition to the explanation of this scheme, the analysis of different weighting preferences by different groups of respondents is also presented. The weight preferences of four different groups of respondents (as in the Delphi application and in-depth interview), are also presented.

Finally, this chapter concludes by presenting the interpretation of WJWSI index values to be used in the index applications. The discussion on WJWSI interpretation includes a review on existing literature of index value interpretation, with specific attention to how existing water sustainability indices have classified their indices.

3.2 CONCEPTUAL FRAMEWORK

The WJWSI conceptual framework is essential in the overall index development. This framework provides early and comprehensive understanding of the WJWSI to relevant and interested stakeholders, particularly to identified Delphi respondents. The framework consists of three main parts: components, indicators and thresholds. The indicators represent issues that are covered in the index, which later need to be addressed through formulating policies and designing programs. The thresholds are required to compute the value of these indicators. Furthermore, to better address these indicators during the policy formulation, indicators with the same theme are grouped. The group of indicators is called a component.

In the following sub-sections, the processes to identify potential components, indicators and thresholds, as well as justifications for their selection, are provided. To help understand the processes better, a flow chart showing the sequence of tasks is provided, as shown in Figure 3.1.

3.2.1 Identification of Components, Indicators and Thresholds

As mentioned above, the main elements of the conceptual framework are the components, indicators and thresholds. Therefore, the main task of developing the WJWSI conceptual framework is their selection, relevant to West Java water resource characteristics. Generally, the identification of potential components, indicators and thresholds is undertaken through an extensive literature review, as was the case with the development of existing water sustainability indices of Water Poverty Index – WPI (Sullivan & Meigh, 2007), Canadian Water Sustainability Index – CWSI (Policy Research Initiative, 2007), and Watershed Sustainability Index – WSI (Chaves & Alipaz, 2007).

As illustrated in Figure 3.1, the identification of WJWSI components and indicators was initiated by reviewing (a) sustainability criteria, (b) water resource sustainability guidelines, and (c) existing water sustainability indices of WPI, CWSI and WSI. With respect to the review of the sustainability criteria, WJWSI attempted to address all dimensions of the "prism of sustainability", namely social, economic, environmental and institutional (Spangenberg, 2002), when identifying its components and indicators.

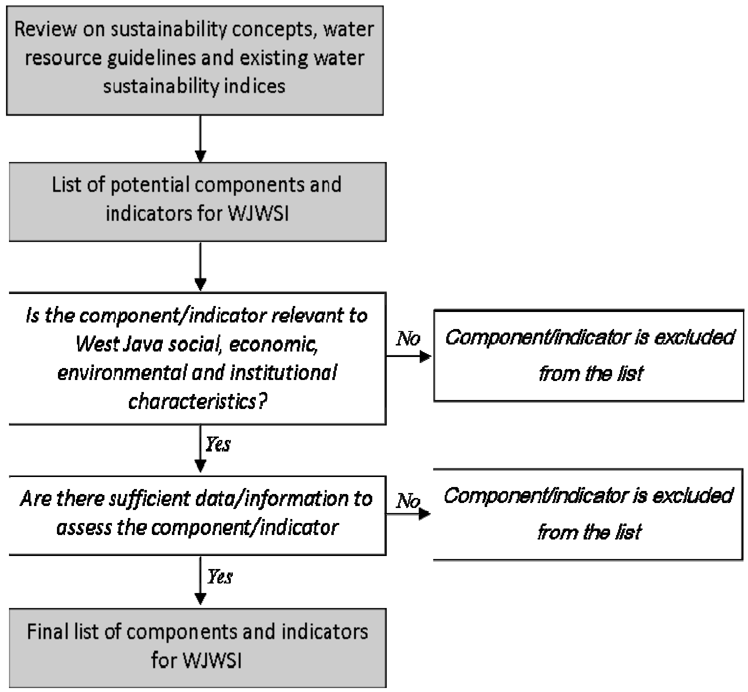


Figure 3.1 Flowchart for identification of potential components and indicators of WJWSI

The environmental dimension of the sustainability prism (refer to section 2.2) has given insight into the conceptual framework of WJWSI for its inclusion of the *Water Resources* component. In the sustainability prism, the environmental dimension mainly deals with sustainability of natural resources. Furthermore, the economic dimension of the prism has resulted in the inclusion of *Finance* and *Poverty* indicators in the conceptual framework. And finally, the *Capacity* and *Human Health* components of the conceptual framework of WJWSI, along with their respective indicators, were inspired by the social and institutional dimensions of the sustainability prism.

The water resource sustainability guidelines concern with water infrastructure, environmental quality and availability, institutional and human health (Loucks & Gladwell, 1999; Mays, 2006). The water infrastructure and institutional requirement were addressed in the conceptual framework of WJWSI by including *Water Provision* as one of its components. The next requirement, which was environmental quality and availability, was addressed by including *Water Availability*, *Water Quality* and *Land Use Changes* indicators in the component of *Water Resources*. And finally, to account for human health in the water resource sustainability guidelines, the conceptual framework of WJWSI has included a component called *Human Health*.

From these reviews on sustainability principles and water resource sustainability guidelines, four components (i.e. *Water Resources, Water Provision, Capacity* and *Human Health*) and five indicators (*Finance, Poverty*, *Water Availability*, *Water Quality* and *Land Use Changes*) of the conceptual framework were identified. For further identification, the indicators of the three existing water sustainability indices (i.e. WPI, CWSI and WSI) were reviewed. The components and indicators of these indices are presented in Table 3.1.

Table 3.1 Components and indicators of existing water sustainability indices

WPI		**CWSI**		**WSI**	
COMPONENT	**INDICATOR**	**COMPONENT**	**INDICATOR**	**COMPONENT**	**INDICATOR**
Resources	Internal flows External flows Population	Resource	Availability Supply Demand	Hydrology	Water Availability BOD
Access	Clean water Sanitation Irrigation	Ecosystem Health	Stress Quality Fish	Environment	EPI Vegetation Conservation
Capacity	Income Mortality Education Income distribution	Infrastructure	Demand Condition Treatment	Life	Income
Use	Domestic Industry & Agriculture	Human Health	Access Reliability Impact	Policy	Education Institutional Capacity IWRM Expenditure
Environment	Water quality Pollution Regulation Information Biodiversity	Capacity	Financial Education Training		

These indicators in Table 3.1 were grouped under the components of the conceptual framework of WJWSI to form potential indicators of the conceptual framework, as shown in the second column in Table 3.2. The relevancy of these indicators to water resources, environmental, social and economic characteristics of West Java, and the availability of data for use in the index applications were then considered. If the indicators were not relevant to

West Java, they were excluded from the third column. Data and information for the remaining indicators (which were not excluded) were also analysed. If sufficient data and information were not available to measure a particular indicator, it was excluded from the list. The results of this step are shown in the fourth column of Table 3.2**.** Finally, similar indicators are combined into single indicators for the conceptual framework of WJWSI, as shown in the fifth column.

Table 3.2 Regrouping of indicators of existing water sustainability indices

COMPONENT	POTENTIAL INDICATORS	RELEVANCY TO WEST JAVA	DATA AVAILABILITY	WJWSI INDICATORS
Water Resources	Internal flows External flows Availability Supply Availability Population	Internal flows External flows Availability Supply Availability Population	Internal flows External flows Availability Supply Availability Population	Water Availability
	Water Demand Stress Water Use Domestic Use Industry & Agriculture Use Irrigation	Water Demand Stress Water Use Domestic Use Industry & Agriculture Use Irrigation	Water Demand Stress Water Use Domestic Use Industry & Agriculture Use Irrigation	Water Demand
	Quality Fish BOD5	Quality Fish BOD5	Quality	Water Quality
	Basin Pressure Vegetation	Basin Pressure Vegetation	Basin Pressure	Land Use Changes
Water Provision	Condition Reliability	Condition Reliability	Condition	Coverage Water Loss
	Finance Institutional IWRM Expenditure Treatment	Finance Institutional Treatment	Finance	Finance
Capacity	Income Mortality	Income	Income	Poverty
	Education Training	Education Training	Education	Education
Human Health	Clean water Access	Clean water Access	Clean water Access	Water Access
	Sanitation	Sanitation	Sanitation	Sanitation
	Impact	Impact	Impact	Health Impact

It is to be noted that the names of some of the WJWSI indicators in the fifth column of Table 3.2 are changed as per the terminology commonly used by water stakeholders in West Java, although they convey the same meaning as that of the potential indicators from previous studies. For example, the potential indicator *Income* in the fourth column was changed to *Poverty* in the fifth column of Table 3.2.

Once the indicators for the conceptual framework of WJWSI were identified, their initial respective thresholds were obtained through a literature review on existing policies, guidelines and regulations, as further discussed in section 3.2.2. Table 3.3 shows the components and indicators of the conceptual framework, as well as their thresholds. Further justifications for their selection are discussed in section 3.2.2.

Table 3.3 Conceptual framework of the WJWSI

Component	Indicator	Thresholds		
		Unit	Max	Min
Water Resources	Water Availability	m^3/cap/yr	1700 [a]	500 [b]
	Water Demand	%	40 [b]	0 [a]
	Water Quality	-	0 [a]	-31 [b]
	Land Use Changes	-	1 [b]	0 [a]
Water Provision	Coverage	%	80 [a]	0 [b]
	Water Loss	%	15 [b]	0 [a]
	Finance	-	0 [c]	0 [c]
Capacity	Poverty	%	100 [b]	0 [a]
	Education	%	100 [a]	0 [b]
Human Health	Water Access	%	100 [a]	0 [b]
	Sanitation	%	100 [a]	0 [b]
	Health Impact	(*cases/1000 people)*	100 [b]	0 [a]

a: preferable; b: not preferable and c: > 0 preferable, < 0 not preferable

The maximum and minimum values of thresholds are the highest and lowest possible values for the indicator, respectively. The preferable values reflect the ideal conditions to be achieved for each indicator. On the other hand, the not preferable values reflect the worst condition possible for each indicator.

3.2.2 Justification for the Selection of Components, Indicators and Thresholds

The following sub-sections discuss how components, indicators and thresholds of the conceptual framework of WJWSI were selected. In particular, each sub-section attempts to justify the selection of one component of the conceptual framework, as well as its respective indicators and thresholds.

3.2.2.1 Justification for the Component Water Resources and its Indicators and Thresholds

The *Water Resources* component was selected, based on the ultimate goal of sustainable water management: to have healthy water resources that can be utilised by present and future generations. In recent years, most areas in the West Java Province faced water-resource-related problems, such as inadequate water supply from public water companies, and extreme water conditions during dry and rainy seasons. In addition, as shown in Table 3.1, each of the existing water sustainability indices has included the water resource component in its index (in WSI the component is *Environment*), which shows the importance of this component in a water sustainability index. Therefore, the inclusion of *Water Resources* for WJWSI was inevitable. The justification for each indicator included in this component is discussed below.

(a) Water Availability

In the existing water sustainability indices, this indicator was included in various forms. In WPI, for example, the *Water Availability* indicator was represented by the indicators of internal flows and external flows. The former were concerned with water resources generated internally in a country and the latter were concerned with water resources generated in other countries (Lawrence et al., 2003). Together, these flows represented the availability of water resources for WPI. If the index is applied at the catchment level, the internal flows are related to water resources generated in the catchment, while the external flows represented water resources generated in other catchments.

This indicator is a valuable entry point to any policy for improving the management of water resources. An area with adequate water availability needs to manage the resources so they can be used to fulfill water demand. On the other hand, an area with low availability may need to find other sources of water. Therefore, the inclusion of this indicator is extremely important for developing a water sustainability index, including WJWSI.

The *Water Availability* indicator considers the amount of water available for each person per year in a particular area. Falkenmark & Rockstrom (2004) stated that ideally a person needs as much as 1,700 m^3/year to support his or her life, with minimum usage of 500 m^3/year. This figure was based on the amount of water required to fulfill the needs for household, agriculture, industry and energy, as well as for the environment (Falkenmark et al., 1989). This information will also be used as thresholds of the *Water Availability* indicator in WJWSI.

(b) Water Demand

This indicator considers the amount of water used for different purposes compared to renewable water available. It gives an idea of the stress on water resources caused by water consumption by the community. High levels of stress on water resources will affect sustainability of water resources. This indicator is necessary to assess the current situation and take appropriate action for reducing the stress on water resources in the future.

In West Java, the increased demand on fresh water is triggered by the expansion of industries in the province. As people migrate to West Java to meet the demand for labourers for industries, the population in West Java is increasing. Consequently, the need for fresh water to support various activities (such as domestic, agriculture and industry) also increases. To analyse this issue, *Water Demand* was included as one of the WJWSI indicators.

For thresholds, the United Nations Commission on Sustainable Development (UNCSD) standard (a maximum of 40% available water withdrawn) was used. Studies show that the uptake of 40% (or above) of renewable fresh water will cause severe stress to water resources, and values under 40% reflect less stress on water resources (Rijsberman, 2006). The 0% was used as the minimum threshold for this indicator.

(c) Water Quality

Water Quality is an important issue when assessing the sustainability of water resources because poor water quality cannot be used for various purposes, and can affect social, health and economic aspects of water sustainability. According to Wangsaatmaja (2004), water quality monitoring in three major West Java catchments (i.e. Citarum, Ciliwung and Citanduy) in the last five years shows that average water quality in these catchments is very poor. Samples taken from at least 10 different sections of these waterways indicate that water quality in these catchments is below Indonesian water quality standards. Therefore, the inclusion of the *Water Quality* indicator in WJWSI is essential, which is also in line with guidelines for water resource sustainability by Mays (2006), Loucks & Gladwell (1999) and various indicators of previous water sustainability indices (Chaves & Alipaz, 2007; Lawrence et al., 2003; Policy Research Initiative, 2007).

In WJWSI, the Storet water quality index was used to define thresholds for the *Water Quality* indicator (Cude, 2001). This water quality index has been used by West Java governments to monitor the quality of water streams in West Java catchments in the last decade. Using the Storet index, various physical, chemical and biological water quality parameters are assessed, which provide a comprehensive understanding of the general surface water quality (Cude, 2001). The maximum and minimum thresholds for this indicator, as adopted from the Storet index, are 0 and -31 respectively.

(d) Land Use Changes

Past studies have shown that changes in land use have a strong relationship with water quality. Falkenmark & Rockstrom (2004) believe that land use changes contribute not only to the amount of runoff, but also to the level of evaporation and rainfall in respective local areas. In Indonesia, particularly in the West Java Province, studies have shown that land use regulation is not properly implemented. For example, the area in the upper part of Bandung City, designed as a conservation area, has been extensively built for housing and commercial purposes.

Rahmat & Wangsaatmadjaja (2007) reported considerable land use changes in West Java, which have resulted in lowering groundwater levels. Land use that is dominated by forestry allows rainfall to infiltrate into the ground, which then increases groundwater levels. On the other hand, land use that is dominated by impermeable material prevents rainfall from infiltrating into the ground, increasing surface runoff volume. This increase will eventually lead to more erosion and degradation of surface water quality.

Based on the above reasons, *Land Use Change* was included as one of WJWSI indicators. For thresholds of this indicator, the maximum value of 1 and minimum value of 0 are used. The maximum value reflects maximum flow of runoff, allowing no rainfall to infiltrate (not preferable). On the other hand, the minimum value reflects maximum infiltration of runoff (preferable).

3.2.2.2 Justification for the Component Water Provision and its Indicators and Thresholds

Another vital component of the management of water sustainability is infrastructure. In Indonesia, issues related to water infrastructure are best explained by the performance of water service providers (WSPs). For every city in Indonesia, water is supplied by one public water company. This company is responsible for treatment of water and its distribution to the community in its respective city. The importance of water service provision in overall water sustainability management has been emphasized by many authors {e.g. Foxon et al., (2002); Butler et al., (2003)}, by having the water service provision as a parameter to assess the performance of water management.

For WJSWI, three indicators of the *Water Service Provision* component were identified: *Coverage*, *Water Loss* and *Finance*. The justification for their selection is given below.

(a) Coverage

This indicator considers the number of WSP customers compared to the total population, which gives an indication of the coverage of company infrastructure. Low coverage has allowed non-WSP-customers to 'misuse' water resources, due to lack of government control of the individual use of available groundwater and surface water (Rahmat & Wangsaatmadja, 2007). In Indonesia, the WSPs cover approximately 60% of the total population in their respective areas (Kirmanto, 2007). As far as West Java is concerned, on average, water companies currently supply only about 40% of the total water needs of the West Java population (Syarief, 2008). This means that a large percentage of the population have to find alternative water supply. The analysis on the coverage issue will make a significant contribution to overall water resource management in the catchments. Therefore, *Coverage* was included as one of the WJWSI indicators.

As indicated earlier, the average coverage of water companies in West Java is only 40%. Ideally, as stated in the national regulation on water provision development, WSPs are expected to supply fresh water to at least 80% of the total population in their respective areas (Kirmanto, 2007). In WJWSI, 80% coverage will be used as the maximum threshold, with a minimum threshold of 0%.

(b) Water Loss

Loss of water, both in production and distribution, is considered waste. The importance of using available water resources wisely, especially by reducing water loss, has been emphasised in many studies (e.g. Loucks & Gladwell, 1999; Butler et al., 2003) . Falkenmark & Rockstrom (2004) emphasise that water scarcity in many places throughout the world can be overcome by reducing water loss. Therefore, it is important to include *Water Loss* as one of the WJWSI indicators.

The Association of Water Service Providers in Indonesia has noted that the average loss in WSPs in West Java is 50-60% during the period of 2006–2008. This value is very high, compared to the maximum loss recommended by government. The national government of Indonesia has set a maximum water loss target of 15% for every WSP. Based on this percentage, maximum and minimum thresholds for *Water Loss* in WJWSI are set to 15% and 0% respectively.

(c) Finance

This indicator concerns the profitability of WSP. It considers the difference between company earnings and water production costs. Ideally, to maintain the sustainability of the water company, production expenses at least need to be covered by the water tariff. This indicator was included because many water companies in Indonesia have expressed water tariff dissatisfaction. They argued that the current water tariff is too low to cover production cost (Kirmanto, 2007). Failure to include willingness on the part of society to pay will surely affect the sustainability of water resources management. Therefore, this indicator was selected as one of the WJWSI indicators. As thresholds, the 0 point was used. Any value above 0 for the comparison of company earnings and production cost is considered as profit, and any value below 0 is considered as loss.

3.2.2.3 Justification for the Component Capacity and its Indicators and Thresholds

The justification for the third component, *Capacity*, is based on the fact that sustainability of water resources is not only determined by its availability, but also by the affordability of the community and the ability to maintain water resources. There are cases where water resources are available and reliable, but the community cannot afford the water supply service due to low income. Other cases show that people have sufficient income, but water is not adequately available due to poor quality (Sullivan, 2002). Therefore, it is important to analyse issues surrounding the ability of the community to access and pay for water resources. Two indicators were identified for the *Capacity* component, namely *Poverty* and *Education*.

(a) Poverty

Issues related to poverty have been strongly linked to sustainability by many authors (Antle & Stoorvogel, 2008; Karami & Hayati, 2005; Kates & Dasgupta, 2007; Sullivan, 2002). More specifically, Sullivan (2002) defined the relationship between poverty and sustainability. She concluded that sustainability of water resources could be effectively achieved by reducing poverty within the community. In Indonesia, people are considered poor if their income falls below the poverty line. In 2008, the poverty line for West Java was Rp. 182,636.00 per person/month (approximately AUD 20.29). BPS Team (2009) reported that as much as 13% of the population in West Java lived below the poverty line. These people spend most of their income on food, and thus have no allocation for accessing clean water. Their inability to afford legal water service leads to their resorting to illegal water connections, which in turn have caused huge water losses to the water companies. Therefore, poverty is an issue that needs to be considered in developing the WJWSI. For initial thresholds, zero poverty was used as the minimum value (preferable) and 100% poverty as the maximum value (not preferable).

(b) Education

Education is believed to have an important role in the sustainability of water resources. Sullivan (2002) claims that there is a strong correlation between the level of education of a community and the sustainability of its water resources. People with a higher education level are believed to have a better water sustainability awareness, compared to those with a lower education level. With regards to formal education, in 2007 only 14% of the West Java population completed primary education (Bappeda Team, 2008). And only recently, environmental issues were included in the curriculum of primary schools in West Java (Salim, 2011). Syarief (2008) believes that community education is one of the key factors for the successful management of water resources in West Java. The importance of education in West Java, particularly its role in water resource management, has led to the inclusion of *Education* as one of the WJWSI indicators.

The 0% (not preferable) and 100% (preferable) of the total population who completed primary education were used as minimum and maximum thresholds respectively for this indicator.

3.2.2.4 Justification for the Component Human Health and its Indicators and Thresholds

Human health is one of the important social principles of sustainability. Past studies have indicated the influence of human health on the sustainability of water resources (Loucks & Gladwell, 1999). The importance of human health in managing water resources is also acknowledged by Loucks et al. (2000) and the Policy Research Initiative (2007), by the inclusion of *Human Health* as a component of their water sustainability guideline and framework respectively. In West Java, poor management of water resources has resulted in the decrease in quality health in the community. Past studies show that areas with low access to clean water suffer from a high number of water-borne diseases (Wangsaatmaja, 2004). Three indicators were identified under the component of *Human* Health, as discussed below.

(a) Access

This indicator considers how much water is accessible to the community, through the WSP, compared to actual community need. Past studies have shown that most water companies in Indonesia, including West Java Province, cannot cover all the needs of its total population in service areas (Cahyono, 2007; Yuwono, 2009). Since water companies in West Java are not able to meet the demand, some people are forced to live with inadequate water supply, while others draw groundwater without appropriate consideration of sustainability of groundwater sources. With regard to human health, it is also believed that communities with adequate water supply will have better health quality compared to those with inadequate water supply.

For these reasons, *Access* (i.e. accessibility to water) is included as an indicator under the component *Human Health* in the WJWSI. The thresholds used for this indicator are 0% (not preferable) and 100% (preferable) for minimum and maximum values respectively.

(b) Sanitation

This indicator is concerned with the number of people who have access to basic sanitation facilities. In Indonesia, people with no access use the river to discharge their wastewater, which leads to the deterioration of river water quality. This is also happening in West Java, one of the most populated provinces in Indonesia. Recent studies by the West Java Environmental Protection Agency show that river quality in three major West Java catchments fail to meet minimum requirements (Badan Pengendalian Lingkungan Hidup Daerah Jabar, 2008). Therefore, the inclusion of *Sanitation* as an indicator of water sustainability is critical. At the time of developing the conceptual framework of WJWSI, no specific policies and guidelines were available to be used as thresholds for the *Sanitation* indicator. Therefore, 0% (not preferable) and 100% (preferable) for minimum and maximum values were used respectively.

(c) Health Impact

This indicator considers the number of cases affected by water-borne diseases in the community. In the past, insufficient water supply has caused some health issues in communities (Sullivan, 2002). In West Java, water-borne disease cases are very common, both in urban and sub-urban areas. In urban areas, the diseases are mostly caused by poor quality water consumed daily by poor people. For these people, consuming poor quality water is the only option, as they cannot afford well-treated water from the water company. In sub-urban areas, diseases are mostly caused by lack of awareness of basic health and hygiene behaviors. As the programs on water resource sustainability rely on community health, the decrease of human health will affect sustainability of water resources. As for thresholds of this indicator, 100 water-borne diseases per 1000 head of population was used as the maximum threshold (not preferable) and 0 cases per 1000 head of population as the minimum threshold (preferable).

3.3 FINAL FRAMEWORK

The identification of components and indicators is a critical stage in developing a water sustainability index. As the issue of water sustainability is considerably complex, and comprises environmental, social, and economic aspects, inputs from a wide range of stakeholders are needed. Of the many group decision methods, the Delphi method was chosen as it ensures that inputs from a wide range of stakeholders are properly addressed.

In this section, the application of the Delphi technique is discussed, followed by in-depth interviews with key stakeholders, to refine the conceptual WJWSI framework in section 3.2. The Delphi application includes the design of questionnaires, the selection of respondents, the distribution and collection of completed questionnaires, and data analysis. The stakeholders selected for this study were university lecturers, governmental officials, environmental consultants and water stakeholders from community groups, who were asked to add, modify or remove components and/or indicators provided in the questionnaires.

3.3.1 The Delphi Technique

The Delphi Technique is a method to extract opinion from identified stakeholders without them congregating at an agreed time and place (Delbecq et al., 1975; Dunham, 1998). This technique aims to reach consensus among the wider public or groups of people through questionnaire distribution (Delbecq et al., 1975; Toward & Ostwald, 2002). To reach consensus, questionnaire distribution in the Delphi technique is undertaken in multiple rounds (Delbecq et al., 1975; Hasson et al., 2000; Hsu & Sandford, 2007; Jolson & Rossow, 1971). In each round, opinions of respondents are sought, and their responses analysed. If consensus has not been reached in the first round, the questions are repeated in the next round(s), where responses from the previous round are disseminated to other respondents. In this way, some respondents may change answers from previous round(s), which leads to consensus being reached after a few rounds (Hasson et al., 2000; Hsu & Sandford, 2007; Raskin, 1994; Rayens & Hahn, 2000).

In the past, the Delphi technique has been applied for indicator or parameter selection in various fields, such as health services (Toward & Ostwald, 2002), health industries (Hudak et al., 1993), marketing (Jolson & Rossow, 1971; Lunsford & Fussell, 1993), education (Olshfski &

Joseph, 1993), information systems (Niederman et al., 1991), transportation and engineering (Saito & Sinha, 1991), strategic planning (Javed, 1994), water quality (Cude, 2001; Dinius, 2007), and nursing and midwifery (Annells & Australian Institute of Nursing Research, 1997). In these applications, the Delphi technique has shown advantages, particularly in the selection of variables or parameters in different stages of group decision-making processes. The method has effectively contributed to reaching consensus among participants. Considering the past successful applications of the Delphi technique, it is believed that this method will be a useful tool for achieving consensus in the identification of components, indicators and thresholds of a water sustainability index.

One of the advantages of the Delphi technique is that it compiles several judgments from different stakeholders from various backgrounds (Best, 1974; Delbecq et al., 1975; Franklin & Hart, 2007; Lang, 1995; Linstone & Turoff, 1975). Later, the information obtained from consensus of these stakeholders in initial rounds of Delphi technique application will provide a strong basis for contribution in further group decision-making processes (Toward & Ostwald, 2002). Even though majority views are sought, minority views are not completely rejected using the Delphi technique. These views are taken into account and discussed. The discussion on minority views is essential to ensure that important issues, raised by minority groups, are not overlooked.

The Delphi method is also believed to produce a more accurate result compared to other alternative group decision-making methods (Jolson & Rossow, 1971; Rowe & Wright, 1999). This is due to the fact that the method removes biases occurred in face-to-face group meetings (Annells & Australian Institute of Nursing Research, 1997). The Delphi method also provides more time for stakeholders to analyse issues or problems (Franklin & Hart, 2007) and has a better accuracy rate as it reduces variance (Rowe & Wright, 1999). The variance is reduced because some respondents change their views after the results of previous round(s) are provided. Another advantage of the Delphi technique is that it provides an initial framework of problems or issues for respondents (Franklin & Hart, 2007; Uhl, 2006). In most cases, the initial framework included in the first questionnaire deepens the existing knowledge of respondents (Linstone & Turoff, 1975).

In spite of these advantages, the Delphi technique also has some limitations. One is that the extreme views of respondents are potentially rejected (Bardecki, 1984). As the method seeks consensus, the views of the majority tend to dominate extreme (minority) opinions, which might lead to the minority view being rejected. In such cases, researchers need to be aware of this possibility and analyse the minority view carefully, as it might conceal important insights (Hosokawa & Zweig, 1990).

Further limitation of the method is the preparation of the initial questionnaire, which is time consuming (Annells & Australian Institute of Nursing Research, 1997; Franklin & Hart, 2007), the overwhelming inputs and comments from stakeholders, which might lead to an over-expanded research topic (Franklin & Hart, 2007), and the possibility of important stakeholder(s) not selected as Delphi respondents (Annells & Australian Institute of Nursing Research, 1997).

Some researchers also highlighted other limitations regarding the analysis of feedback from the stakeholders. Moore (1987) believes that the process of refining and redeveloping further questionnaires is controlled by previous and existing knowledge of the researchers (Annells & Australian Institute of Nursing Research, 1997; Linstone & Simmonds, 1977). In addition, the technique also suffers from the extended duration of questionnaire distribution, as participants become less enthusiastic towards the end of the study (Franklin & Hart, 2007).

With a focus on the advantages, but taking into account the disadvantages, the Delphi technique will provide valuable insights when applied to water resource sustainability. To achieve sustainability of water resources management, the involvement of water-related stakeholders is essential. The Delphi technique is a tool used to involve these stakeholders. This technique encourages various water resource stakeholders to be involved in finalizing components, indicators and thresholds of the WJWSI. Once the consensus among stakeholders is reached, it will provide a strong and sustainable basis to conduct further work by stakeholders in managing water resources in West Java.

The application of the Delphi technique in this study comprises the following steps:

(i) identification of water-related stakeholders

(ii) design of the questionnaires

(iii) distribution and collection of completed questionnaires

(iv) analysis of the results.

Each of these steps is discussed below.

3.3.2 Identification of Water-related Stakeholders

One of the critical steps in the Delphi application is the identification of water-related stakeholders. In this study, these stakeholders were identified, as previously mentioned, from four different categories in West Java: University Lecturer, Government Official, Environmental Consultant and Community Group. These categories are considered to represent stakeholders with strong interests in the development of a water sustainability index in West Java. Importantly, the stakeholders were chosen from West Java as they are considered to have extensive knowledge of issues related to water resource management in West Java, compared to stakeholders from other areas. For Round One of the Delphi application, 40 to 50 stakeholders were targeted to represent four respondent categories.

The targeted stakeholders were contacted via email or by phone. Most expressed their willingness to participate in this study. Finally, 43 stakeholders were confirmed to participate in the study. The numbers of stakeholders from each category are as follows: 15 university lecturers, 10 government officials, 10 environmental consultants and 8 community groups. Initially, it was planned to have equal numbers of stakeholders in each category, targeted to a minimum of 10 stakeholders for each category. However, it was difficult to find the stakeholders from community groups, especially those with extensive knowledge of the overall water resource issues in West Java. Thus, only 8 community group stakeholders agreed to participate.

There are many universities in West Java with many lecturers and researchers who have interests in water resource issues, thus more university lecturer stakeholders were included. The relatively higher number of such stakeholders may create biases in the analysis, for example, their opinion dominating other stakeholders' opinions. However, this can also be an advantage, as these university lecturers are known to have extensive knowledge on water resource issues in West Java and have therefore been involved in various water resource projects. It is worth mentioning that the gender composition of the stakeholders was 22 females (51.6%) and 21 males (48.4%).

3.3.3 Design of the Questionnaires

In this study, several rounds of questionnaires were planned. However, only two rounds of questionnaire distribution were necessary, due to consensus being reached for all components and most indicators after two rounds.

Round One

In Round One, the major part of the questionnaire was based on the conceptual framework, which comprises potential components, indicators and thresholds of WJWSI as discussed in Section 3.2. Through this questionnaire, respondents were asked whether they agreed or disagreed with the components, indicators and thresholds. Also, they were allowed to add, change and modify these components, indicators and thresholds. Along with the questionnaires, justifications for selection of these components, indicators and thresholds were provided to respondents.

After the questionnaire for Round One was developed, it was distributed to a few selected respondents in Melbourne as a pilot study, to seek early inputs and comments on questionnaire layout and clarity of questions. Since the distribution of the questionnaire was meant to be in Indonesia, the draft questionnaire was distributed to several Indonesian students in Melbourne, who had previous water resource related backgrounds. Based on these comments (mainly on the clarity of the questions), some questions were revised, and the questionnaire for Round One was finalised. The final version of the questionnaire for Round One is provided in Appendix A.

Round Two

The questionnaire for Round Two was designed, based on the results from the previous round (Round One). Questions in this questionnaire included suggestions that related to the components by some respondents; indicators and thresholds not agreed on by the majority of respondents; and new indicators and thresholds suggested by some respondents. Similar to the questionnaire in Round One, respondents were asked whether they agreed with the above issues. They were also allowed to add, modify and change components, indicators and thresholds presented in the questionnaire. The questionnaire for Round Two can be found in Appendix B.

3.3.4 Method to Analyse the Responses of the Respondents

In both rounds, Likert-scales were used to assess the responses of the respondents on the potential components, indicator and thresholds. A study by Matell & Jacoby (1972) on the use of Likert-scales show that uncertain and neutral responses were found more often in 3-point and 5-point scales, and less uncertain and neutral responses were found in 7-point and above scales. Recent studies also show that 7-point scales were used in numerous Likert applications (Bayley et al., 2004; Brouwer et al., 2008; Frick, 1993; Hardy et al., 2004; Martens & Zywietz, 2006). Another advantage in using the 7-point scale is that it provides more options for respondents to assess the relative importance among all indicators, compared to 5-point scales. As a result, better accuracy for answers is expected. For these reasons, in this study a 7-point scale is used in the questionnaires.

Thus, in both rounds of the Delphi application, respondents were asked whether they agreed with the potential components, indicators and thresholds using the 7-point Likert-scale. Respondents were considered to 'agree' if they answered 6 or 7 on the Likert-scale, and 'disagree' if they answered 1 or 2 on the Likert-scale. An answer of 3, 4 or 5 on the Likert-scale is considered a neutral response. As indicated earlier, after respondents were asked whether they agreed, they were also given the opportunity to add, modify and change components, indicators and thresholds, if necessary.

With regards to analysis, Alexandrov et al. (1996) considered that a consensus is achieved if more than 67% of respondents agree on the offered option. This percentage (or two-thirds cut-off line) has also been used by Chang et al. (2009) and Lehmann et al. (2004). In statistical terms, 67% is considered significant to be used as the decision threshold (Alexandrov et al., 1996). In the Delphi application for WJWSI, 67% cut-off was also used. In this study, it was considered that consensus was reached if at least 67% of respondents agreed on the 'important' options (by selecting 6 or 7 on the Likert-scale) for each question. If the components, indicators and thresholds were agreed on by less than 67% of responses, they were repeated in the following round.

3.3.5 Distribution and Collection of Completed Questionnaires

The questionnaires were distributed to selected respondents in the West Java Province. A face-to-face meeting was chosen to distribute the questionnaires in Round One to provide comprehensive details on the research topic. During these face-to-face meetings, respondents were allowed to raise questions on the topic. The majority of respondents raised some questions that led to further discussion on the water sustainability index, as well as general water resource management in West Java. The main objective of these meetings was to ensure that all respondents fully comprehended the questionnaire and were able to complete the questionnaire within the agreed time limit. At the end of the meetings, respondents were informed about the date for collection of the questionnaire. In general, respondents were asked to complete the questionnaire within a week.

At the point of collection, the completed questionnaires were checked to see whether all questions were answered. Respondents were also asked about the possibility of their participation in the next round of the Delphi application. In total, two rounds of questionnaire distribution were carried out. The results of both rounds are discussed below.

3.3.5.1 Round One of the Delphi Application

In Round One, after the distribution of questionnaires to the selected 43 respondents, 41 respondents (93.2%) returned the questionnaires. Two respondents, who did not return the questionnaires, were both from the University Lecturer category. In general, respondents were asked to agree on the initial set of components, indicators and thresholds; the results were presented in Section 3.2.1 as Table 3.3. These responses for Round One are presented as follows.

Components

The responses on component-related questions are shown in Figure 3.2, which shows that for *Water Resources*, 100% respondents agreed on the component (choosing 6 or 7 on the 7-point Likert-scale), whereas for *Water Service Provision*, *Capacity* and *Human Health*, 68%, 68% and 72% of respondents respectively agreed. As mentioned previously, in this study, a consensus is achieved when more than 67% of respondents agree on the option offered in the Delphi technique. It means that for this study, all the offered components in the first-round questionnaire were agreed by respondents.

For the component of *Water Resources*, none of the respondents disagreed nor had a neutral response. For the components of *Water Service Provision, Capacity,* and *Human Health*, 29%, 29% and 22% were neutral responses respectively. This shows that respondents valued *Water Resources* more than the other components. In addition, with less percentage of 'disagree' and neutral responses, the component of *Human Health* is valued more compared to *Water Service Provision* and *Capacity*.

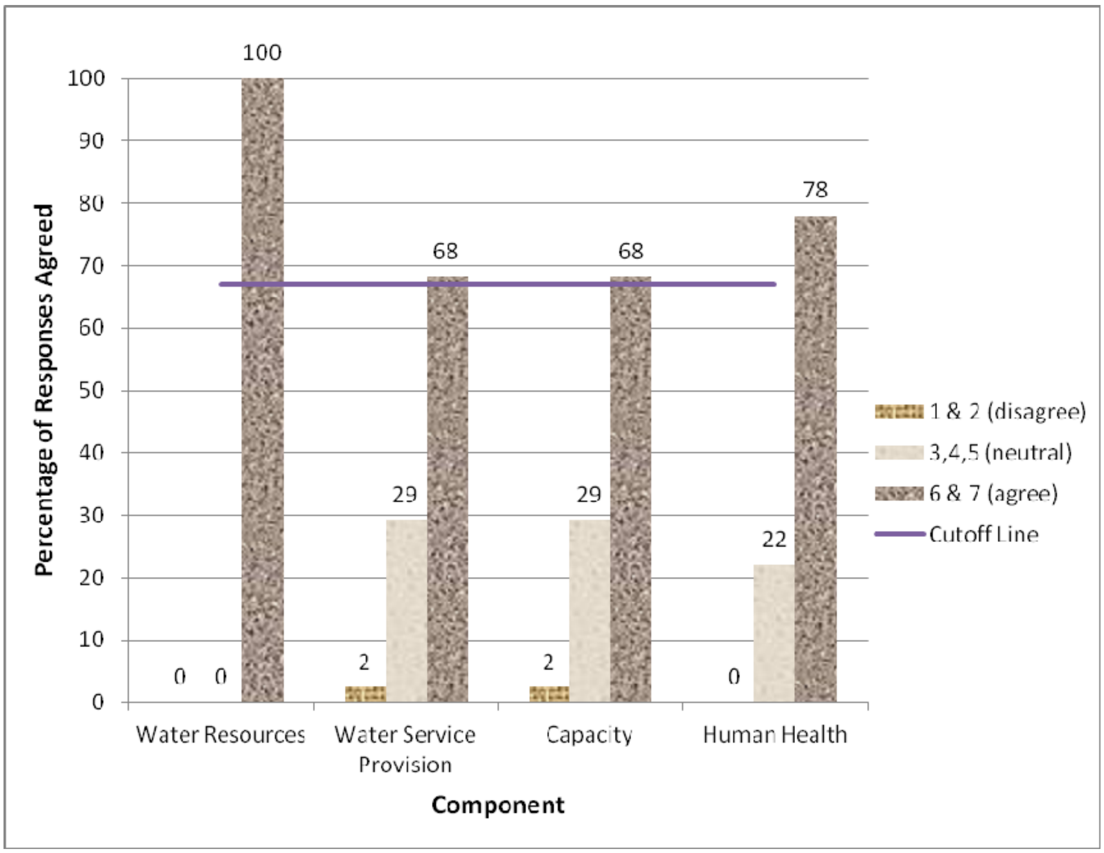


Figure 3.2 Percentage of responses agreed on components – Round One

However, despite agreement on these components, few respondents suggested that components should be modified to reflect the National Regulation No. 7/2004 on Water Resources (Presiden Republik Indonesia, 2004). According to this Regulation, *Water Resources* should be *Conservation*, *Water Service Provision* should be *Water Use*, and *Capacity* and

Human Health components together should be *Policy and Governance*. This suggestion, provided by few respondents, was included in the next round to obtain further opinions from all respondents.

Indicators

With regard to the initially identified indicators of the WJWSI, responses are shown in Figure 3.3. More than 67% of respondents answered 6 or 7 on the 7-point Likert-scale for 9 indicators, namely, *Water Availability, Water Demand, Water Quality, Land Use Changes, Coverage, Water Loss, Water Access, Sanitation* and *Health Impact*. For these indicators and as consensus was reached, they were not brought into the next round(s) of the Delphi application. For the other three indicators, *Finance, Poverty* and *Education*, 6 or 7 on the Likert-scale was chosen by 56%, 66% and 61% of respondents respectively. As the percentages fell below 67%, these indicators were taken into Round Two of the Delphi application.

It is also important to note that 'disagree' percentages for all indicators are 2% or less, which indicated the majority of the respondents preferred indicators to be included in the WJWSI framework. However, as the 'neutral' responses for *Finance*, *Poverty* and *Education* were high, they were brought into Round Two of the Delphi application.

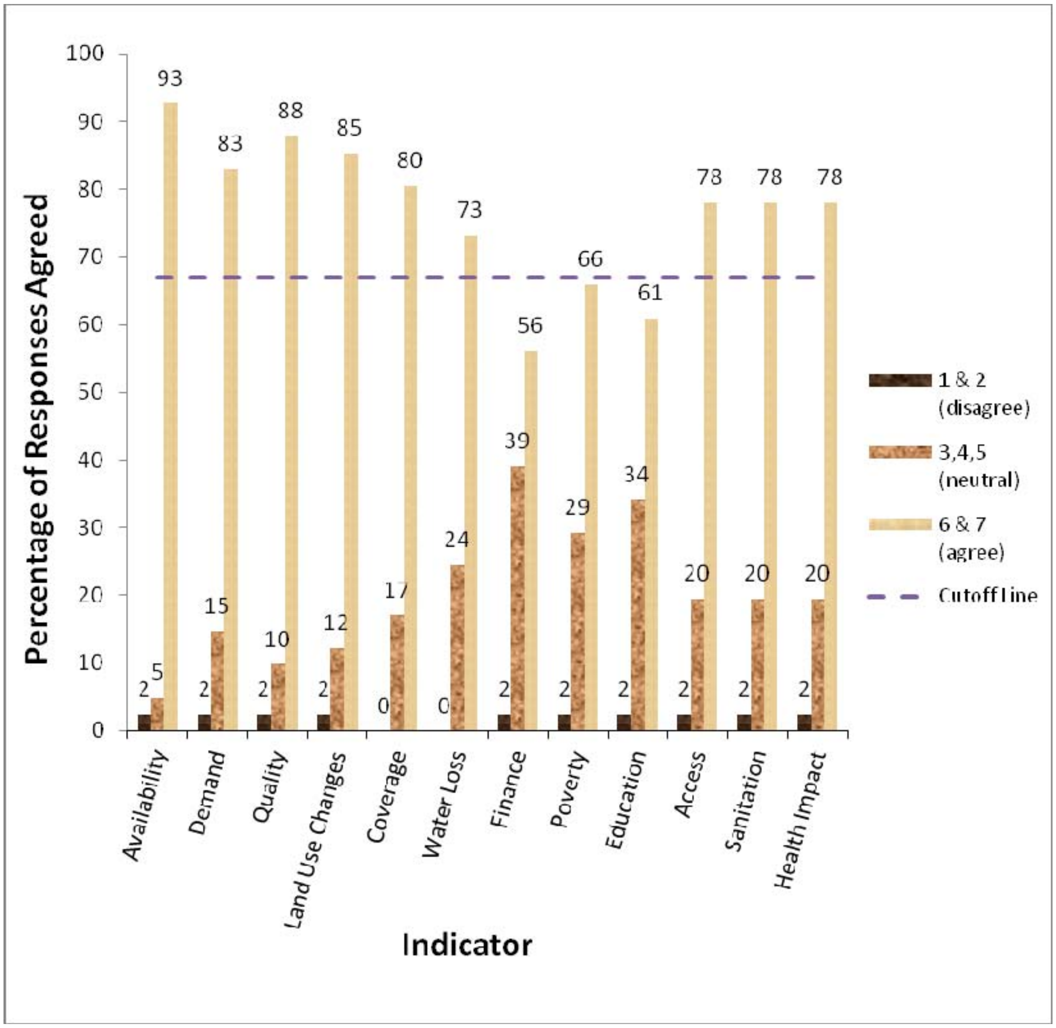


Figure 3.3 Percentage of responses agreed on indicators – Round One

Apart from the indicators in the conceptual framework, few respondents suggested new indicators be included in the WJWSI framework. Indicators that were suggested by respondents were *Population Pressure, Information Disclosure, Governance Structure, Public Participation* and *Law Enforcement*. This was addressed by having these indicators in the next round to seek further comments from respondents.

Thresholds

The conceptual framework of the WJWSI also included thresholds for their respective indicators. Respondents were asked to assess these thresholds (both maximum and minimum thresholds together); their responses are illustrated in Figure 3.4.

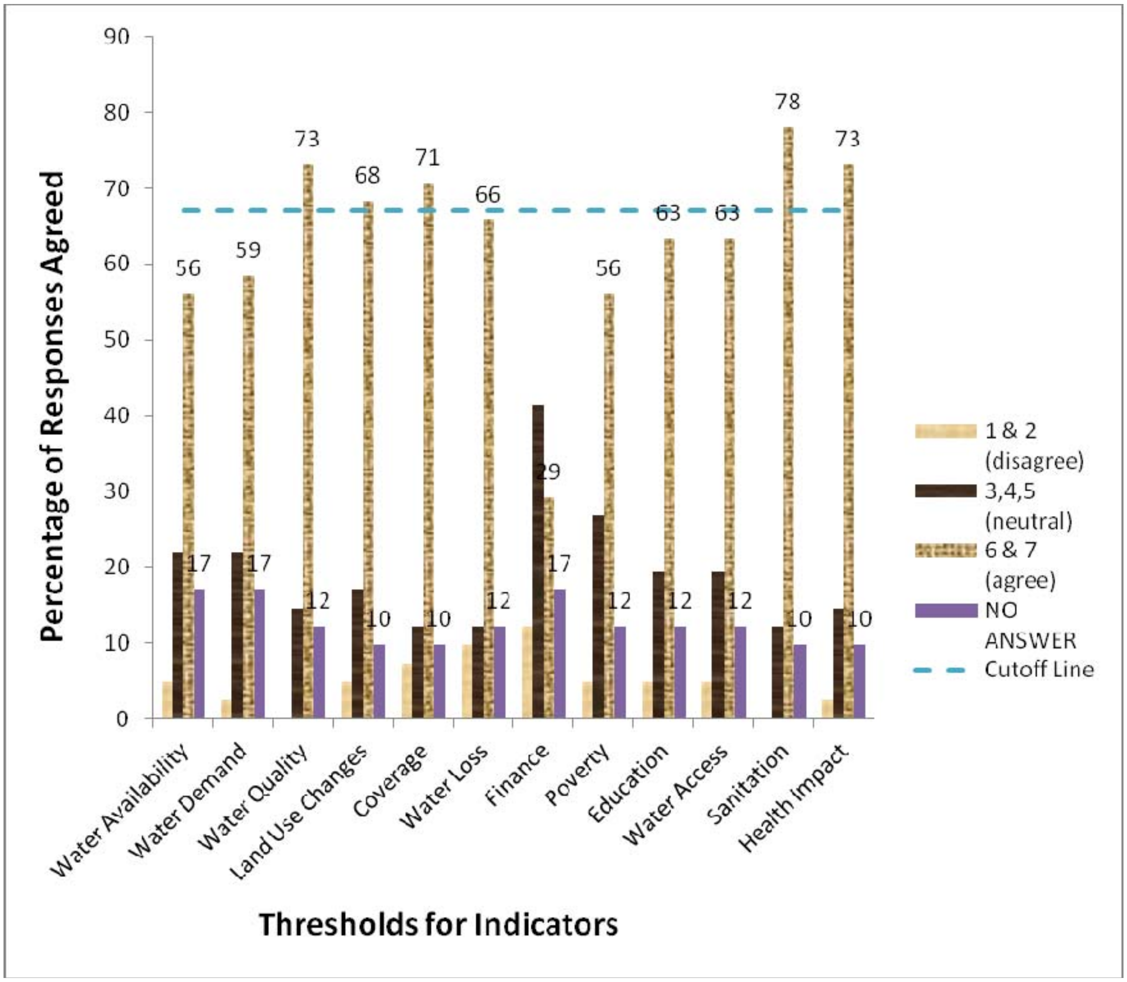


Figure 3.4 Percentage of responses agreed on thresholds – Round One

Figure 3.4 shows that consensus was reached for few thresholds, considering the 67% cut-off. Thresholds above the 67% cut-off are for *Water Quality, Land Use Changes, Coverage, Sanitation* and *Health Impact*. For thresholds of these indicators, as the consensus was reached, they were not brought into the next round of the Delphi application.

For other thresholds that have not been agreed (i.e. thresholds for *Water Availability, Water Demand, Water Loss, Finance, Poverty, Education* and *Access*), most have 'neutral responses', 'disagree' or give 'no answer'. Most respondents did not have alternative thresholds, and only a few respondents provided alternative thresholds for some indicators. Compared to the responses for components and indicators, responses on thresholds gave higher percentages on 'disagree', 'neutral' and 'no answer'. These responses showed that respondents were less confident to include these thresholds in the WJWSI framework. Some respondents also suggested new thresholds for *Poverty, Coverage* and *Water Demand* indicators. Their suggestions are presented in Table 3.4.

Table 3.4 Thresholds suggested in Round One

Indicator	Thresholds	
	Old	New
Poverty	0 [a] – 100% [b]	0% [a] - 20% [b]
Coverage	0 [b] – 80% [a]	0 [b] – 60% [a]
Water Demand	0 [a] – 40% [b]	10 [a] – 40% [b]

a: preferable; b: not preferable

Conclusions on Round One

Based on the results from Round One, the conceptual framework of WJWSI was modified, as shown in Table 3.5. This modified framework was then brought to the next round of Delphi application. This modified framework incorporated suggestions from Round One to correspond with three major components of water resource management, stated in the National Regulation on Water Resources: *Conservation*, *Water Use* and *Policy and Governance*. Table 3.5 also includes new indicators and sub-indicators from Round One: *Population Pressure*, *Information Disclosure, Governance Structure, Public Participation* and *Law Enforcement*.

In Round One, consensus was reached on thresholds for the following indicators and sub-indicators: *Land Use Changes, Water Quality, Coverage, Sanitation* and *Health Impact*. However, even though consensus was reached for the threshold of *Coverage*, few respondents suggested new thresholds for this indicator. For other indicators and sub-indicators, as shown by the shaded areas in Table 3.5 below, their thresholds have not been agreed. The thresholds for new indicators suggested in Round One (i.e. *Population Pressure, Information Disclosure, Governance Structure* and *Law Enforcement*) were not available. Due to low responses in Round One, these thresholds for new indicators were not used in Round Two, but discussed in the in-depth interviews instead.

Table 3.5 Modified WJWSI framework after Round One of Delphi application

Component	***Indicator***	***Sub-indicator***	***Thresholds***		
			Unit	***Max***	***Min***
Conservation	*Water Availability*		m^3/cap/yr	1700 [a]	500 [b]
	Land Use Changes		-	1 [b]	0 [a]
	Water Quality		-	0 [a]	-31 [b]
Water Use	*Water Demand*		%	40 [b]	0 [a]
	Water Access		%	100 [a]	0 [b]
	Water Service Provision	*Coverage*	%	80 [a]	0 [b]
		Water Loss	%	15 [b]	0 [a]
		Finance	-	0 [c]	0 [c]
	Population Pressure				
Policy and Governance	*Information Disclosure*				
	Governance Structure				
	Public Participation	*Education*	%	100 [a]	0 [b]
		Poverty	%	100 [b]	0 [a]
		Sanitation	%	100 [a]	0 [b]
		Health Impact	*(cases/1000 people)*	100 [b]	0 [a]
	Law Enforcement				

a: preferable; b: not preferable and c: >0 preferable, <0 not preferable

Thus, in Round Two, respondents were asked for their agreement on:

- modification of the components to correspond with the National Regulation of Water Resources
- indicators that had not been agreed in Round One (*Finance, Poverty* and *Education)*
- new indicators suggested in Round One (*Population Pressure*, *Information Disclosure, Governance Structure, Public Participation* and *Law Enforcement)*
- indicators and/or sub-indicators under different components, or indicators in the new framework as compared to the old framework (*Sanitation* and *Health Impact),* and
- new thresholds suggested in Round One (*Poverty*, *Coverage* and *Water Demand* indicators – Table 3.4).

3.3.5.2 Round Two of the Delphi Application

In Round Two, the questionnaire was distributed to 37 of 43 respondents in Round One, as some withdrew after Round One due to other commitments. The numbers of respondents in Round Two, in each category, were 13 for University Lecturer, 8 for Environmental Consultant, 10 for Government Official and 6 for Community Group.

In this round, respondents had the opportunity to review and refine their answers provided in Round One of questionnaire distribution. As the responses of Round One were provided in the beginning of Round Two, respondents were able to analyse the answers of other respondents (along with their justifications) and were more confident to provide their answers in Round Two. This process has contributed to the convergence of respondents' answers in Round Two. The responses in Round Two are described in the sub-sections below.

(a) Components

As the components were modified to correspond with the National Regulation No. 7/2004 on Water Resources, in this round respondents were asked to assess the modified components. The responses are illustrated in Figure 3.5. This figure shows that 75% respondents agreed on modifications to correspond with the national regulation on water resources management. Another 16% respondents did not agree. As 67% was the cut-off in this application, the new set of components was used in the WJWSI.

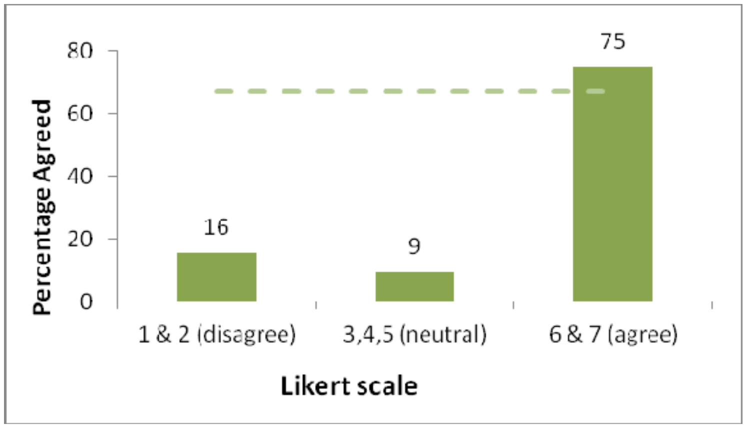


Figure 3.5 Percentage of responses agreed on all components together – Round Two

(b) Indicators and sub-indicators

In Round Two, respondents were asked to agree on nine indicators and sub-indicators. These were the indicators that less than 67% of respondents agreed in Round One, and the new indicators or sub-indicators suggested by respondents during Round One of the Delphi application. These indicators and sub-indicators as well as their responses are shown in Figure 3.6.

Figure 3.6 shows that eight of nine indicators had the response percentage of 67% or above. Only *Finance* was below 67% (in the first round only *Finance* was agreed by 56% of respondents). Indicators with 67% or above (i.e. *Population Pressure, Information Disclosure, Governance Structure, Education, Poverty, Sanitation, Health Impact* and *Law Enforcement*) were then finalised.

Figure 3.6 also shows there is no 'disagree' response for all indicators, including *Finance*. However, as the 'agree' percentage for *Finance* is below 67%, this indicator was brought into in-depth interviews in Round Two (explained in Section 3.3.6) with key stakeholders for further analysis.

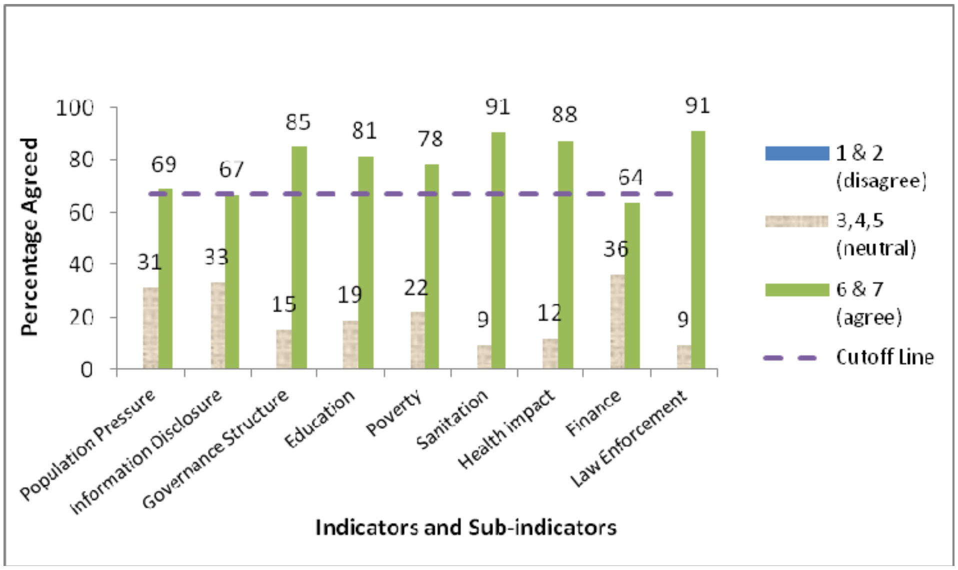


Figure 3.6 Percentage of responses agreed on indicators and sub-indicators – Round Two

(c) Thresholds

There were only three new thresholds (both maximum and minimum) suggested by respondents in Round One: *Poverty*, *Coverage* and *Water Demand*. Therefore, in Round Two only these thresholds were presented to respondents. As the respondents in Round One had neutral responses for other thresholds (i.e. shaded areas in Table 3.5, except the above new thresholds), they were not included in Round Two. Instead, they were brought to in-depth interviews with key stakeholders (Section 3.3.6).

Respondents in Round Two were requested to compare these thresholds with the old values in Round 1. They were also asked which thresholds (new or old) were preferred. The old thresholds (proposed in the conceptual framework for Round One) and the new thresholds (suggested by respondents during Round One of the Delphi application) are shown in Table 3.4. Responses on these questions are shown in Figure 3.7. This figure shows that for *Poverty* and *Water Demand*, 81% respondents (compared to 56% in Round One) and 89% respondents (compared to 59% in Round One) preferred new thresholds respectively. For *Coverage*, 65% respondents chose old thresholds. In Round One, 71% agreed with old thresholds, although some suggested new thresholds. Based on these responses, considering the 67% cut-off, new thresholds for *Poverty* and *Water Demand* were used in WJWSI, and the old thresholds for *Coverage* were used.

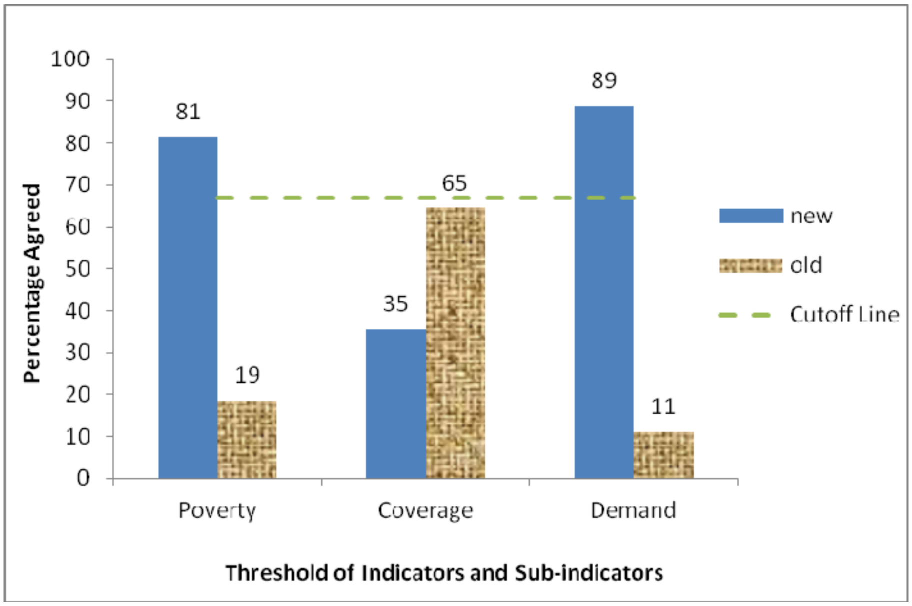


Figure 3.7 Percentage of responses agreed on thresholds – Round Two

Conclusions on Round Two

Based on the results of Round Two, further modifications were made to the WJWSI components, indicators and thresholds, as shown in Table 3.6. This table includes components, indicators and sub-indicators, and thresholds which have been agreed based on the two rounds of the Delphi application.

Thresholds which have not been agreed to are presented in the shaded area in Table 3.6. They are *Water Availability*, *Water Access, Water Loss, Population Pressure, Information Disclosure, Governance Structure, Education* and *Law Enforcement*. These thresholds were brought to the in-depth interviews with the key stakeholders (Section 3.3.6).

Table 3.6 Framework of WJWSI as agreed after Delphi application Round Two

Component	***Indicator***	***Sub-indicator***		***Thresholds***	
			Unit	***Max***	***Min***
Conservation	*Water Availability*		m^3/cap/yr	1700 [a]	500 [b]
	Land Use Changes		-	1 [b]	0 [a]
	Water Quality		-	0 [a]	-31 [b]
Water Use	*Water Demand*		%	40 [b]	10 [a]
	Water Access		%	100 [a]	0 [b]
	Water Service Provision	*Coverage*	%	80 [a]	0 [b]
		Water Loss	%	15 [b]	0 [a]
	Population Pressure		*Not discussed in Round Two*		
Policy and Governance	*Information Disclosure*		*Not discussed in Round Two*		
	Governance Structure		*Not discussed in Round Two*		
	Public Participation	*Education*	%	100 [a]	0 [b]
		Poverty	%	20 [b]	0 [a]
		Sanitation	%	100 [a]	0 [b]
		Health Impact	(*cases/1000 people)*	100 [b]	0 [a]
	Law Enforcement		*Not discussed in Round Two*		

a: preferable; b: not preferable

To finalise the framework after two rounds of the Delphi application, in-depth interviews were conducted. This was an effective way to finalise the framework, as the results from two rounds were already converged to a greater level. The time spent in conducting in-depth interviews was believed to be less than the time spent in more round(s) of questionnaire distribution.

3.3.6 In-Depth Interview with Key stakeholders

A limitation of the Delphi technique is its time-consuming nature, particularly with a large number of rounds (Annells & Australian Institute of Nursing Research, 1997). Some other researchers also found that the accuracy of the Delphi technique diminishes after the completion of a few early rounds (Boje & Murnighan, 1982), as the willingness and motivation of some respondents have declined (Franklin & Hart, 2007).

Therefore, for this study, as consensus has been reached for all components, and most indicators and sub-indicators after the completion of Delphi Round Two, in-depth interviews with a few key stakeholders were conducted to finalise the framework. These interviews were meant to increase the effectiveness for reaching consensus (of other remaining indicators and thresholds which have not been agreed in the two rounds of Delphi application), as well as motivate participants.

Criteria for the selection of key stakeholders for in-depth interviews includes their understanding and advance expertise on water resource issues; their interest and motivation in the study; their influence in the decision-making process related to water resources in West Java; and recommendations from other respondents. Prior to interview, representations from each respondent group participating in the Delphi application were identified. During the selection process, no one from the Environmental Consultant group was available for the interview. Then, for this study, four key stakeholders were chosen representing three respondent groups: University Lecturer (two stakeholders), Community Group (one stakeholder) and Government Official (one stakeholder).

The two university lecturers were senior lecturers in reputable universities in Bandung, with extensive research on water resources. They have also been involved in policy formulation on water resources in West Java in the last decade. The representative for the Community Group has been actively writing on water resource issues, and these articles published in different newspapers and magazines. The representative for the Government Official is influential in formulating water-related policies in West Java.

Due to their tight schedules, it was not possible to arrange a specific time and place to meet. Therefore, interviews were conducted separately. In interview, key stakeholders were asked their opinion on the results of the Delphi application, and invited to make further comments to refine the WJWSI framework. The questions focused on components, indicators and thresholds. The questions to guide the interview are provided in Appendix C.

All key stakeholders considered consensus had been reached for the WJWSI components, based on two rounds of the Delphi application. The agreed components were *Conservation,* *Water Use,* and *Policy and Governance*. With regard to indicators and sub-indicators, key stakeholders concluded that indicators and sub-indicators were not important. The main aspect was the inclusion or exclusion of these indicators and sub-indicators in the framework. This finding was also supported by the results of the Delphi application, which showed no comments given by the Delphi respondents when some indicators in Round One were changed in Round Two.

In-depth interviews also concluded that *Access* and *Coverage,* as well as *Population Pressure* and *Water Availability* needed to be combined. Both *Access* and *Coverage* concern with the coverage of water supply for the community. The *Population Pressure* concerns with the growing population which is included in the *Water Availability*. Therefore, in the final framework of the WJWSI, *Access* was represented by *Coverage* and *Population Pressure* was included in *Water Availability*. It was decided to remove *Finance* from the WJWSI framework due to low responses in Round One and Round Two of the Delphi application (56% and 64% respectively).

The key stakeholders also expressed their concerns on the thresholds of the three indicators: *Information Disclosure, Governance Structure* and *Law Enforcement*. They believed these indicators have unique characteristics, in terms of data availability. The key stakeholders suggested further literature reviews on similar cases of previous indices, such as WPI, CWSI and WSI.

In relation to thresholds of other indicators that have not been agreed during the Delphi application (i.e. *Information Disclosure, Governance Structure* and *Law Enforcement*), key stakeholders highlighted the importance of carefully identifying these thresholds. They considered that, at this stage, most of these values are not available at relevant water-resource institutions. Relevant agencies and institutions responsible for water resources have not recognised the importance of these indicators, let alone their respective thresholds.

Table 3.7 illustrates the final framework of the WJWSI based on in-depth interviews. The thresholds, neither finalised nor available, are shown in the shaded areas. It is to be noted that the threshold values for WJWSI (finalized as well as not finalized ones after the in-depth interviews) may have to be updated in the future, as and when new data or information is available.

Table 3.7 Final framework of WJWSI after the in-depth interview

Component	***Indicator***	***Sub-indicator***	***Thresholds***		
			Unit	***Max***	***Min***
Conservation	*Water Availability*		m^3/cap/yr	1700 [a]	500 [b]
	Land Use Changes		-	1 [b]	0 [a]
	Water Quality		-	0 [a]	-31 [b]
Water Use	*Water Demand*		%	40 [b]	10 [a]
	Water Service Provision	*Coverage*	%	80 [a]	0 [b]
		Water Loss	%	15 [b]	0 [a]
Policy and Governance	*Information Disclosure*		*Not yet identified*		
	Governance Structure		*Not yet identified*		
	Public Participation	*Education*	%	100 [a]	0 [b]
		Poverty	%	20 [b]	0 [a]
		Health Impact	(*cases/1000 people)*	100 [b]	0 [a]
		Sanitation	%	100 [a]	0 [b]
	Law Enforcement		*Not yet identified*		

a: preferable; b: not preferable

3.4 WEIGHTING

One of the aims for developing the WJWSI is to analyse the performance of different catchments by comparing their aggregated index values. To aggregate the indicators and sub-indicators of WJWSI, index developers (or users) have the option to assign equal or different weights. During the Delphi application and interview, water-related stakeholders in West Java considered some WJWSI indicators and sub-indicators to be more important than others. Therefore, for this study, both equal and non-equal weighting schemes were considered.

During the Delphi application and interview (as discussed in Section 3.3), water-related stakeholders in West Java considered the position of indicators and sub-indicators in the WJWSI framework unimportant. Therefore, during the weighting and aggregation, the indicators and sub-indicators of WJWSI are treated the same.

3.4.1 Equal Weighting

With this scheme, each indicator and sub-indicator was assigned an equal weight during aggregation. The weight was obtained using Eq. (3.1), as follows:

$$W_i = \frac{1}{n} \tag{3.1}$$

where W_i is the weight for indicator or sub-indicator i and n is the total number of indicators and sub-indicators. Using Eq. (3.1), the weight for each WJWSI indicator and sub-indicator was calculated as 0.077, since n = 13.

3.4.2 Non-equal Weighting

The non-equal weightings for WJWSI were obtained using the Revised Simos procedure (Figueira & Roy, 2002). This procedure has been used by various researchers to assign weights for sets of indicators or parameters (Fontana et al., 2011; Kodikara et al., 2010; Milani et al., 2007; Shanian et al., 2008). The main advantage is that respondents are requested to provide their preferences on the weights of indicators or parameters in an ordinal scale. The respondents participating in studies using this method found that providing weight preference on an ordinal scale was easier, compared to providing weight preference using numerical scales (Fontana et al., 2011; Kodikara et al., 2010; Milani et al., 2007; Shanian et al., 2008).

With this procedure, WJWSI indicators and sub-indicators were assigned different weights based on the input from water-related stakeholders in West Java. The stakeholders who participated in this part of the study were a subset of stakeholders who participated in the Delphi technique application. Of 37 respondents who participated in Round Two of the Delphi application, 33 respondents agreed to provide information to compute the weights for WJWSI indicators and sub-indicators. The information was obtained through a survey, as discussed in Section 3.4.2.1. Of these 33 respondents, 31 returned the questionnaires during the survey. The questionnaire used in the survey can be found in Appendix D.

3.4.2.1 The procedure

In the survey, each respondent was asked to assign weights on WJWSI indicators and sub-indicators through the following procedure:

1. Respondents were given a set of cards, with each card representing WJWSI indicators and sub-indicators. Even though all respondents were familiar with these indicators, they were briefed on each indicator and sub-indicator. Along with the oral explanation, the respondents were also given written explanation in separate documents. These documents included the final WJWSI framework, explanation and justification of indicators and sub-indicators, and an example of how the cards should be arranged to provide information on weights (as shown in Appendix D).
2. With the given set of cards, respondents were asked to arrange the cards in order of importance, with the indicator or sub-indicator ranked least important or least preferred. If respondents considered two or more indicators or sub-indicators equally important, their cards were grouped together.
3. When arranging the cards, respondents were allowed to place blank card(s) between indicators and sub-indicators to indicate smaller or greater weights. Several blanks cards were also given to the respondents.
4. Finally, respondents were also asked: *"How many times more important is the most preferred indicator or sub-indicator relative to the least preferred indicator or sub-indicator?"*

3.4.2.2 Results and Calculations

An example from one respondent is shown in Figure 3.8. The respondent considered *Law Enforcement* as the least preferred indicator and *Governance Structure* the most preferred indicator. Other information that can be retrieved from Figure 3.8 as follows :

- *Governance Structure* is considered 22.5 times more important than *Law Enforcement*
- Indicators with equal weights: *Education* and *Poverty*, as well as *Water Loss* and *Coverage*

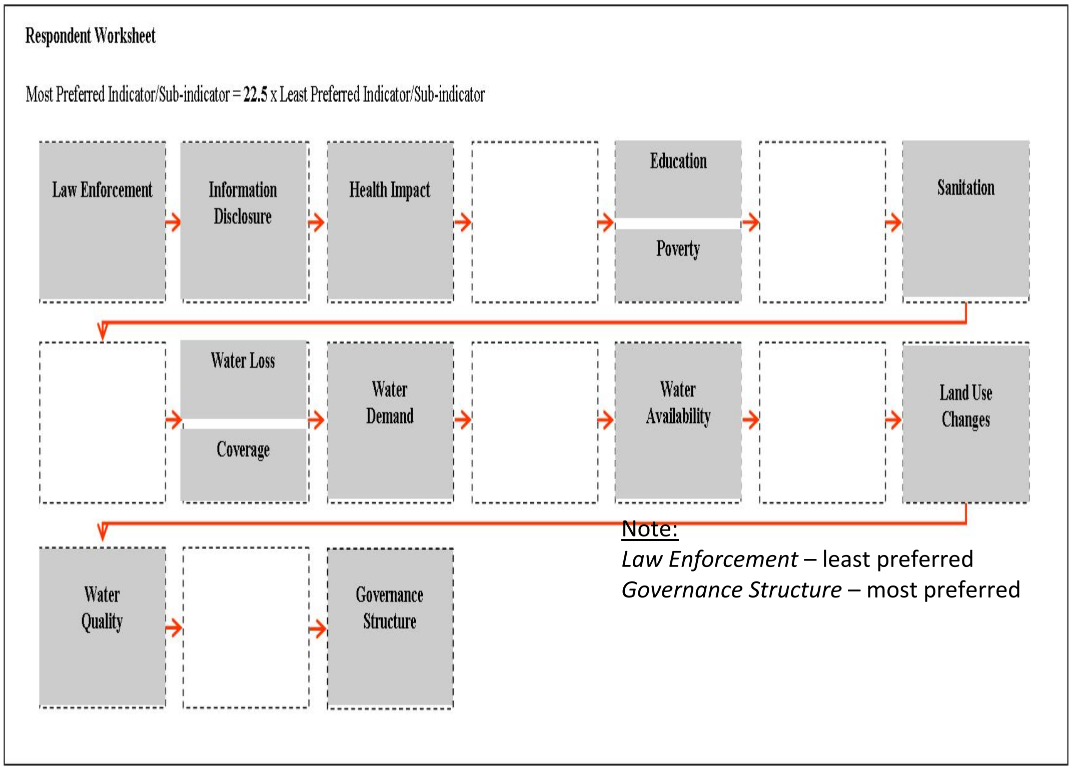


Figure 3.8 Response of a respondent in the Revised Simos' procedure

Based on responses during the survey (Figure 3.8), weights for indicators and sub-indicators were calculated using the Revised Simos' Procedure (Figueira & Roy, 2002). The results of the calculation are presented in Table 3.8.

First, the Rank, (*r*) is defined in order of increasing importance as in Figure 3.8 and presented as column (1) in Table 3.8, '*z*' being the value given by respondents to the question: *"How many times more important is the most preferred indicator or sub-indicator relative to the least preferred indicator or sub-indicator?"* In this case z = 22.5.

Then, 'x' is defined as the number of gap(s) existed between two indicators and sub-indicators (column (4) of Table 3.8) based on number of blank cards placed after cards representing indicators and sub-indicators (column (3)). If no blank cards are inserted between two indicators and/or sub-indicators, one gap is considered between them. Similarly, if two blank cards are inserted, three gaps are considered between the indicators or sub-indicators. It is also important to note that if two or more indicators or sub-indicators are grouped together (indicators or sub-indicators are considered equally important), then the number of blank cards between them is considered as -1, resulting in zero gap between indicators or sub-indicators.

Table 3.8 Weight calculation for one respondent

Rank *(r)*	**Indicator/Sub-indicator**	**Number of Blank Cards After**	**No of Gaps**	**Non Normalised Weight** *(k(r))*	**Normalised Weight**
(1)	(2)	(3)	(4)	(5)	(6)
1	*Law Enforcement*	0	1	1.00	0.70
2	*Information Disclosure*	0	1	2.34	1.65
3	*Health Impact*	1	2	3.69	2.60
4	*Education*	-1	0	6.38	4.49
5	*Poverty*	1	2	6.38	4.49
6	*Sanitation*	1	2	9.06	6.38
7	*Water Loss*	-1	0	11.75	8.27
8	*Coverage*	0	1	11.75	8.27
9	*Water Demand*	1	2	13.09	9.22
10	*Water Availability*	1	2	15.78	11.11
11	*Land Use Changes*	0	1	18.47	13.01
12	*Water Quality*	1	2	19.81	13.95
13	*Governance Structure*			22.50	15.85
		0	X = 16	142	100
z = 22.5, **u** =1.34					

X is the total number of gaps obtained from the respondent, which is 16 in this example. Then *u = (z - 1) / X* is computed, which is used to calculate the non-normalised weights of indicators and sub-indicators. In this example, u is calculated as *= (22.5 – 1) / 16 = 1.344*. Then, the non-normalised weights, *k(r)* (column (6) of Table 3.8), for indicators and sub-indicators are calculated as follows (Kodikara, 2008; Kodikara et al., 2010):

$$k(r) = 1 + u \sum_{i=0}^{r-1} x_i$$

where x_i is the number of gaps between indicators/sub-indicators with ranks *i* and (*i* + 1), and x_o = 0.

To give the sum of 100%, for weights of all indicators and sub-indicators these non-normalised weights are then normalised, as shown in the last column of Table 3.8.

This procedure was repeated to calculate weights from all respondents. The summary of the calculations of all respondents is shown in Table 3.9, with respondent 1 representing the calculation of Table 3.8. It shows that, based on the mean value of weights given by all respondents, *Water Availability* has the highest weight and *Information Disclosure* has the lowest weight.

Table 3.9 also shows that there is significant difference between minimum and maximum values of each indicator or sub-indicator. Minimum weights range from 0.30 to 2.34, while maximum weights range from 11.68 to 17.73. The difference between minimum and maximum weight values given by respondents indicates significant variation in responses.

These variations are also reflected in values of coefficient variation, which range from 0.37 to 0.95 (shown in the last column of Table 3.9). The largest variation belongs to the *Information Disclosure*, and the lowest variation belongs to the *Water Demand*. These means of the calculated weights were then used in the aggregation of WJWSI indicators and sub-indicators, as well as in the robustness analysis of WJWSI. Results from the aggregation and robustness analysis are discussed in Chapter 4.

3.4.3 Weights Given by Different Respondent Groups

As previously mentioned, four categories of respondents participated in the survey to obtain weights for WJWSI indicators and sub-indicators. The average weights varied. The Community Group and University Lecturer group responses were contradictory on *Water Availability, Water Demand, Information Disclosure, Law Enforcement, Poverty* and *Water Quality*, as shown in Figure 3.9. The University Lecturer group assigned relatively high weights on *Water Availability*, *Water Demand* and *Water Quality*, while the Community Group assigned relatively low weights on these indicators and sub-indicators. In contrast, the Community Group assigned high weights on *Information Disclosure*, *Law Enforcement* and *Poverty,* while the University Group assigned low weights to these indicators.

Table 3.9 Normalised weights for 13 indicators and sub-indicators from all respondents

	Indicator/Sub-indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	*Law Enforcement*	0.70	4.65	4.42	5.52	2.74	9.04	2.19	7.06	3.51	11.41	11.98	8.85	8.64	3.70	2.70	4.09	12.99
2	*Information Disclosure*	1.65	5.97	0.66	2.27	4.53	2.87	0.91	1.18	1.33	1.17	5.27	2.41	1.03	1.71	4.05	4.90	1.30
3	*Health Impact*	2.60	6.63	6.92	14.20	8.10	5.95	12.41	8.24	10.04	4.01	6.43	9.92	2.93	10.68	8.78	12.97	5.19
4	*Education*	4.49	7.95	1.91	13.12	1.85	9.04	6.02	3.53	5.68	10.84	11.11	7.77	4.84	4.70	4.73	10.55	1.30
5	*Poverty*	4.49	3.33	5.67	6.61	0.96	3.90	6.02	2.35	6.77	11.98	10.52	4.56	3.89	7.69	9.46	11.35	5.19
6	*Sanitation*	6.38	2.67	9.43	8.78	7.21	3.90	9.85	8.24	8.95	6.86	9.06	8.85	5.79	11.68	10.14	10.55	2.60
7	*Water Loss*	8.27	9.26	9.43	4.44	9.89	6.98	7.30	9.41	7.86	9.71	8.48	3.49	7.69	6.70	7.43	12.97	10.39
8	*Coverage*	8.27	9.26	10.68	12.03	9.00	10.06	11.13	11.76	11.12	9.14	2.34	6.70	7.69	8.69	5.41	8.13	7.79
9	*Water Demand*	9.22	10.58	9.43	10.95	10.78	6.98	8.58	10.59	12.21	8.00	6.73	6.70	10.55	12.68	6.76	8.13	7.79
10	*Water Availability*	11.11	13.88	14.44	3.35	12.57	16.23	13.69	12.94	12.21	7.43	8.19	12.06	13.40	13.68	12.16	3.29	15.58
11	*Land Use Changes*	13.01	11.90	13.19	7.69	11.68	11.09	4.74	4.71	2.42	10.28	9.94	12.06	11.50	5.70	11.49	0.86	14.29
12	*Water Quality*	13.95	13.22	8.17	9.86	14.36	13.15	13.69	14.12	13.30	8.57	9.65	10.99	13.40	9.69	13.51	*7.32*	9.09
13	*Governance Structure*	15.85	0.69	5.67	1.18	6.32	0.81	3.47	5.88	4.59	0.60	0.30	5.63	8.64	2.71	3.38	4.90	6.49

18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean	Min	Max	Std. Deviation	Coeff. Variation
7.59	13.47	11.09	14.18	15.79	5.91	13.75	11.03	9.72	4.87	12.84	13.26	3.05	1.38	7.81	0.68	15.79	4.47	0.57
1.27	11.68	4.46	17.73	1.47	3.59	0.91	8.00	6.42	13.16	14.72	6.41	11.17	15.34	5.14	0.66	17.73	4.90	0.95
6.33	0.95	8.15	7.09	7.20	5.91	2.62	0.94	4.77	11.97	10.01	3.48	13.49	12.73	7.47	0.94	14.20	3.74	0.50
3.80	11.68	3.72	13.48	0.75	3.59	12.04	9.01	6.42	10.79	8.13	4.46	8.85	13.60	7.08	0.75	13.60	3.84	0.54
3.80	2.74	2.99	6.38	5.76	12.87	3.48	2.96	14.68	9.61	7.18	4.46	12.33	4.00	6.44	0.96	14.68	3.54	0.55
6.33	2.74	9.62	2.13	7.91	3.59	6.05	1.95	4.77	10.79	9.07	2.50	10.01	7.49	6.96	1.95	11.68	2.98	0.43
1.27	4.53	6.67	2.84	2.18	8.23	8.61	13.05	14.68	7.24	5.30	11.30	7.69	9.24	7.82	1.27	14.68	3.10	0.40
5.06	4.53	5.93	2.84	2.90	12.87	5.19	3.97	11.38	8.42	6.24	12.28	6.53	10.98	8.03	2.34	12.87	3.04	0.38
12.66	6.32	5.20	5.67	4.33	15.19	4.33	5.98	1.47	7.24	6.24	8.37	4.21	11.85	8.24	1.47	15.19	3.05	0.37
15.19	8.10	13.30	4.26	11.49	12.87	11.18	12.04	1.47	1.32	2.47	7.39	1.89	3.13	9.74	1.32	16.23	4.78	0.49
12.66	9.89	12.57	12.77	17.23	1.27	15.46	14.06	11.38	4.87	0.59	9.35	0.73	0.51	9.02	0.51	17.23	4.94	0.55
15.19	8.10	15.52	9.93	9.35	10.55	9.47	6.99	3.12	3.68	3.42	1.52	5.37	3.13	9.71	1.52	15.52	3.96	0.41
8.86	15.26	0.78	0.71	13.64	3.59	6.90	10.02	9.72	6.05	13.78	15.22	14.65	6.62	6.53	0.30	15.41	4.90	0.75

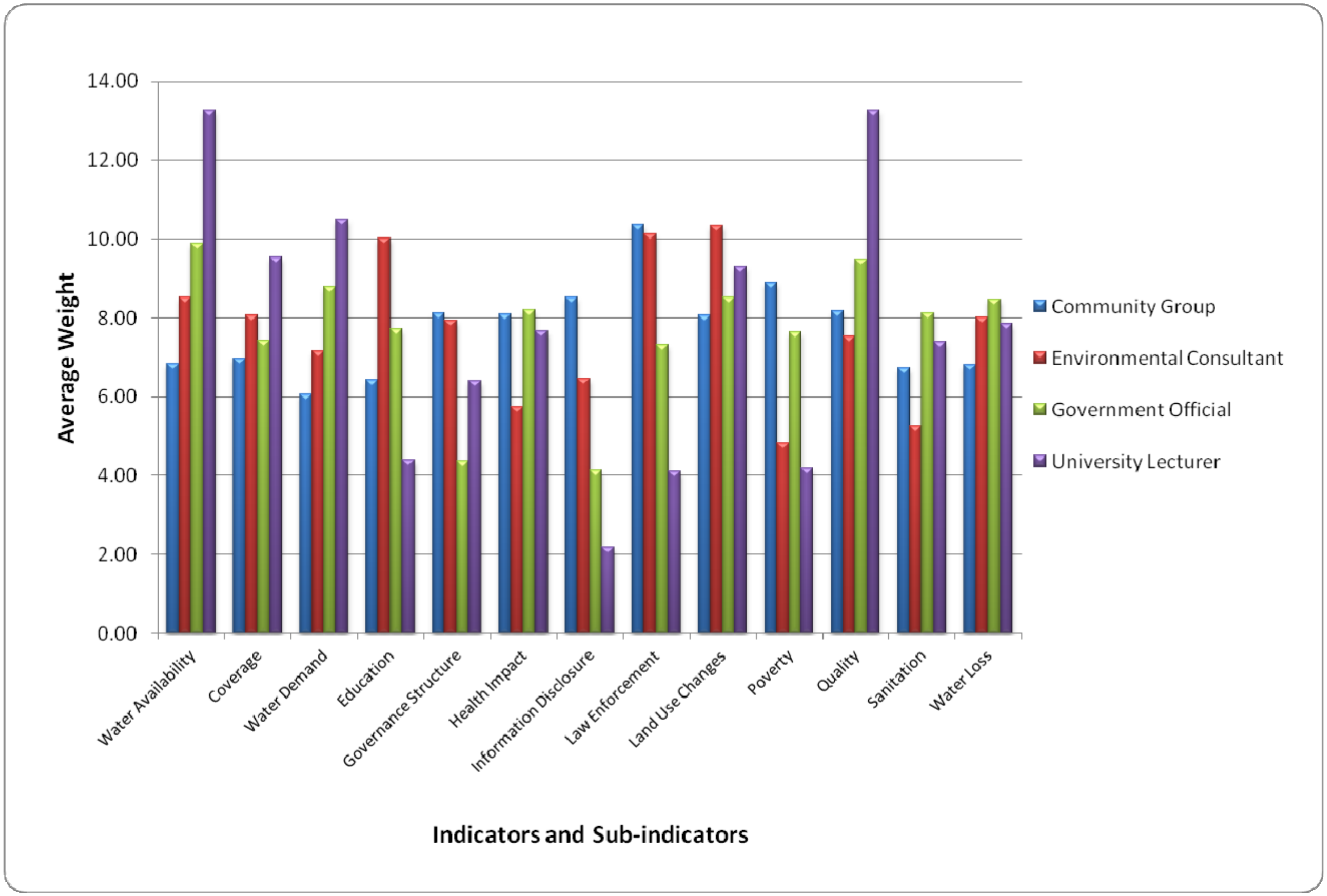


Figure 3.9 Weights given by different groups of respondents

The preference of the University Lecturer group on *Water Availability*, *Water Demand* and *Water Quality* is likely to be driven by 'hard' data and facts related to these indicators. Recent studies in West Java have shown that *Water Availability, Water Demand* and *Water Quality* conditions are deteriorating considerably. On the other hand, the Community Group is more interested in community or social-related issues, such as *Information Disclosure*, *Law Enforcement* and *Poverty*. Even though 'hard' data on these socially related issues are not available, these issues have been constantly discussed and criticized through public media widely.

3.5 INDEX INTERPRETATION

Index interpretation is important to understand the sub-index and aggregated index values. In the existing water sustainability indices (i.e. WPI and CWSI), the interpretation of these values is based on the maximum range of both values. As both WPI and CWSI used the 0-100 index scale, the value of an indicator is considered preferable if it is closer to 100 and not preferable if the value is closer to 0.

The other existing water sustainability index, the WSI, uses the Human Development Index (HDI) with its thresholds to classify its aggregated index. The HDI, which comprises three main components (*Health*, *Knowledge* and *Income*), classifies the calculated index value into three groups. The value of HDI < 0.5 is considered to have low performance, the HDI between 0.5 and 0.8 having intermediate performance, and the HDI > 0.8 having high performance (Anand & Sen, 1994). Thus, for WSI, once the value for an indicator is computed, it is classified, based on the above HDI classification scheme. For example, the final WSI value for the Verdadeiro basin, Brazil, was 0.65 (Chaves & Alipaz, 2007). According to the HDI classification, this index value was considered to be at the intermediate performance level. Based on this classification, further recommendations were provided to relevant decision makers to improve the sustainability of the basin.

For the WJWSI, the interpretation for sub-indices and their aggregated index will be based on a quartile scale. Using this scheme, the WJWSI maximum value of 100 and minimum value of 0 are classified, as shown in Table 3.10.

Table 3.10 Interpretations of sub-indices and aggregated Index

Aggregated index and Sub-indices	***Performance***	***Priority of Action***
0 – <25	Poor	High
25 – <50	Poor – Medium	High – Medium
50 – <75	Medium – Good	Medium – Low
75 – 100	Good	Low

This scheme provides four levels of index performance, compared to three HDI groups. This performance classification is used as the basis for relevant priority action to improve the water resource management at the catchment scale. In the WJWSI, *Performance* reflects the condition of issue(s) related to an indicator, a sub-indicator, or the overall water resource condition at a particular time of assessment. The *Priority of Action* reflects the priority of action(s) required to address the issue(s).

3.6 SUMMARY

The development of the West Java Water Sustainability Index (WJWSI) involved two main stages. The first stage was the development of the conceptual framework, based on the extensive literature review. Available sustainability criteria, water resource guidelines and existing water sustainability indices are valuable sources of input to identify components, indicators and thresholds as main constituents of the conceptual WJWSI framework. These previous studies, combined with data availability and relevancy to West Java conditions, have eventually shaped the conceptual framework. A well-developed conceptual framework is critically important to major initial input in the Delphi application. A sound conceptual framework ensures that water-related stakeholders have a comprehensive understanding of the proposed water sustainability index.

The second stage of development was the Delphi application, which aimed at refining the WJWSI conceptual framework. In the application of the Delphi technique, several steps were involved. They were the identification of respondents, the design of questionnaires, the distribution and collection of completed questionnaires, and analysis of results. In the Delphi application for this study, two rounds of questionnaire distribution were involved.

Round One has provided valuable input and views from stakeholders on how to improve the conceptual framework. This input was carefully analysed and included in the Round Two questionnaire. At the end of Round One, respondents reached consensus for most of the WJWSI components, indicators and thresholds. After Round Two, respondents reached consensus for all components, most indicators and sub-indicators, and some thresholds. The remaining indicators, sub-indicators and thresholds (that have not been agreed) were brought into in-depth interviews with key stakeholders. Here, all indicators and sub-indicators were finalised, and remaining thresholds were finalised with a further literature review on available policies and guidelines.

In this study, a survey was conducted to obtain the weights for WJWSI indicators and sub-indicators. In the survey, respondents who participated in Delphi applications were asked to provide their weight preferences on WJWSI indicator and sub-indicators. Based on this information, weights of indicators and sub-indicators were calculated using the Revised Simos' procedure. Calculation results revealed that the highest weight belonged to the *Water Availability* and the lowest weight belonged to the *Information Disclosure*. It was also found that the University Lecturer group and Community group had reverse preference on some indicators. The University Lecturer group had a high preference on *the Water Availability*, *Water Demand* and *Water Quality* indicators, while the Community group had a low preference for these indicators. In contrast, the Community group had a high preference on *Information Disclosure*, *Law Enforcement* and *Poverty* indicators, while the University Lecturer group had a low preference for these indicators.

Performance and *Priority of Action* for WJWSI were introduced for index interpretation. *Performance* reflects the condition of issue(s) related to an indicator, a sub-indicator or the overall water resource condition at a particular time of assessment. The *Priority of Action* reflects the priority of action(s) required to address the above issue(s). High *Performance* corresponds to low *Priority of Action* for the catchment, and vice versa.

Having finalised the development of WJWSI, the next task will be the application of the index in different West Java catchments. In this study, as mentioned, the index will be applied to three catchments: Citarum, Ciliwung and Citanduy. In these case studies, the water sustainability performance of each catchment will be assessed, and necessary programs to address important issues will be identified. During the case studies, the aggregated index values of the three catchments will be compared to determine which catchments need higher priority. The detailed process of application in these catchments is presented in Chapter 4.

Chapter 4

Application of West Java Water Sustainability Index

4.1 INTRODUCTION

Having developed the West Java Water Sustainability Index (WJWSI), it was then applied to three water catchments in West Java, Indonesia. These applications provided valuable information on (1) how the index was applied systematically, (2) what data were needed to apply the index and (3) how the results could be used for improvement of water resource management in these catchments. The main outcome of these case studies was the assessment on the conditions of water resource issues for each catchment, used as the basis for recommendations to relevant decision makers in respective catchments.

Through applications of WJWSI in different catchments, methods to obtain the sub-index values and methods to aggregate the final index were tested. These applications clearly indicated the data requirement to perform each task and demonstrated the link between the results of the applications and the recommendations suggested to relevant authorities managing these water catchments.

This chapter discusses the applications of WJWSI in three West Java catchments in Indonesia: Citarum, Ciliwung and Citanduy. At the time of the applications (and, in particular, during the field study), the latest available data for all three catchments was for 2008. Therefore, all relevant calculations for all catchments were first completed for that year. To compare these results with previous years, the WJWSI was also applied to these catchments for 2006 and 2007.

This chapter first explains the methodology used for WJWSI applications. This includes the methods used to obtain the sub-index values of WJWSI indicators, aggregate the final index, and perform the robustness analysis of the index. The chapter then describes the general conditions of West Java Province, where the three catchments are located. In this section, general climatic and socio-economic conditions in West Java are presented, followed by current water management practices. This includes discussion on relevant water authorities, available policies and regulations, as well as current water management programs.

The applications of WJWSI in three catchments are then presented. The application in Citarum catchment is presented in more detail as compared to Ciliwung and Citanduy catchments. This approach is to avoid any unnecessary repetition of similar tasks performed in these catchments. For each catchment, the following information is provided: description of the catchment, application of the index in the catchment for 2006, 2007 and 2008, robustness analysis, and suggested recommendations to water authorities that relate to results of these applications.

Finally, following a discussion of WJWSI applications in each catchment, a comparative analysis for the three different catchments is also presented. This analysis highlights similarities and differences in applications and provides useful benchmarking for water authorities to further improve water resource management practices in their respective catchments.

4.2 METHODOLOGY USED FOR APPLICATIONS

In general, this sub-section discusses the methods used to obtain sub-index values, aggregate indicators and sub-indicators, and perform robustness analysis. Two methods were used to obtain sub-index values for various indicators and sub-indicators, which were *continuous rescaling* and *categorical scale* methods. To aggregate all indicators, arithmetic and geometric methods were considered.

4.2.1 Obtaining Sub-index Values

As outlined in Section 2.4.2, the methods used to obtain sub-indices are *ranking, continuous rescaling, percentage of annual differences over consecutive years, categorical scale* and *distance to reference*.

The *ranking* method will not be used in this study, as this method provides only a rank for each indicator and sub-indicator, and does not provide information on the conditions of indicators and sub-indicators. In the WJWSI, information on these conditions is required to further formulate necessary policies and programs for improving overall water resource management.

The *percentage of annual differences* method will not be used for the WJWSI due to lack of data. To be useful, this method requires several years of data, which is not available in West Java. The rationale for not using the *distance to reference* method was because this method requires prior knowledge of the values of indicators, so they can be used as reference values. With regards to water resource management in West Java, such indicators with known values are not available.

The *continuous rescaling* and the *categorical scale* methods were chosen because they are able to provide information on the conditions of WJWSI indicators and sub-indicators, which is reflected in their respective sub-indices. Also, these methods were used, as required information to use these methods was also available. Based on the characteristics of available data, three groups of indicators and sub-indicators were identified to compute their sub-index values.

The first group of indicators and sub-indicators are *Water Availability, Land Use Changes, Coverage, Education* and *Sanitation*. The sub-index values for this group were obtained using the continuous rescaling method (Eq. (2.2b)). Eq. (2.2b) is reproduced below as Eq. (4.1). Indicators and sub-indicators of the second group are *Water Quality, Water Demand, Water Loss, Poverty* and *Health Impact*. The sub-index values for this group were obtained using the modified continuous rescaling method (Eq. (2.3b)). Eq. (2.3b) is reproduced below as Eq. (4.2).

$$S_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \times 100 \qquad \textbf{(4.1)}$$

$$S_i = 100 - \left(\frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \times 100 \right) \qquad \textbf{(4.2)}$$

where S_i is the sub-index value for indicator *i*, X_i is the actual value for indicator *i*, and X_{min} and X_{max} are the minimum and maximum threshold values of the indicator.

The third group consists of three indicators: *Information Disclosure, Governance Structure* and *Law Enforcement*. Due to their qualitative nature, minimum and maximum thresholds to calculate the sub-indices of these indicators and sub-indicators using the continuous rescaling method are not available. Therefore, for these indicators, the categorical scale was used to obtain their sub-indices, as shown in Eq. (4.3). A quartile scale was proposed in Eq. (4.3). This equation was modified from Eq. (2.5).

$$S_i = \begin{cases} 0 - < 25 & \text{if } X_i \text{ meets criteria 1} \\ 25 - < 50 & \text{if } X_i \text{ meets criteria 2} \\ 50 - < 75 & \text{if } X_i \text{ meets criteria 3} \\ 75 - 100 & \text{if } X_i \text{ meets criteria 4} \end{cases} \quad \textbf{(4.3)}$$

where X_i is the actual condition (similar to actual values for the non-categorical indicators and sub-indicators) assessed in a particular catchment. The four criteria (1 to 4) that are used to obtain sub-indices for each of these three categorical indicators and sub-indicators are defined as follows:

Information Disclosure

The *Information Disclosure* indicator examines the availability and accessibility of key data related to water resource management, for public use. Table 4.1 shows the quartile scale that was proposed to quantify the sub-index for this indicator, with its criteria. Key data include rainfall, population, water quality, water use, coverage, water losses, education, poverty, sanitation, water-related diseases and land use.

Table 4.1 Criteria for sub-index values of *Information Disclosure*

Criteria	***Sub-index***
Few key data (25% or less) are available	0 – <25
Key data are available, but only a few are accessible through the internet	25 – <50
Key data are available, accessible, but not regularly updated	50 – <75
Key data are available, accessible and regularly updated	75 – 100

Governance Structure

Governance Structure analyses the governance structure of water-related institutions in West Java, particularly with respect to job descriptions, and overlaps among different institutions. Table 4.2 shows the criteria, based on the quartile scale, which was proposed to quantify the sub-index of this indicator.

Table 4.2 Criteria for sub-index values of *Governance Structure*

Criteria	***Sub-index***
Only few institutions (25% or less) responsible for managing water resources have clear structures	0 – <25
All institutions responsible for managing water resources have clear structures	25 – <50
Structure of the institutions are clear, but overlap of tasks occur	50 – <75
Clear structure and no overlap of tasks among different institutions	75 – 100

Law Enforcement

This indicator considers the enforcement of regulation on water resources, particularly on stream quality. Table 4.3 shows the criteria, based on the quartile scale, which was proposed to quantify the sub-index for *Law Enforcement*.

Table 4.3 Criteria for sub-index values of *Law Enforcement*

Criteria	***Sub-index***
Procedure for enforcement is not available	0 – <25
Procedure for enforcement is available, but no supporting resources (human, budget)	25 – <50
Procedure for enforcement and supporting resources (human, budget) are available, but not implemented	50 – <75
Procedure for enforcement and supporting resources (human, budget) are available, and implemented	75 – 100

4.2.2 Final Index

The sub-index values of indicators and sub-indicators were aggregated using arithmetic and geometric aggregation methods. The detail explanation of these aggregation methods can be found in Section 2.4.4. The sub-index values of WJWSI indicators and sub-indicators were also aggregated using different weighting schemes. Thus, the final index values were computed, based on the combinations of different weighting schemes and aggregation methods.

4.2.3 Robustness Analysis

The robustness of WJWSI was analysed through uncertainty and sensitivity analysis of the index. In general, uncertainty analysis focuses on how uncertainties of thresholds affect respective sub-index values and the final index value. It also attempts to analyse the variation in the final index caused by changes in weighting schemes and aggregation methods. Sensitivity analysis evaluates the importance of each threshold of indicators and sub-indicators in determining the final index value. Sensitivity analysis of the WJWSI was undertaken to answer the following questions:

- Which thresholds were the most sensitive to the changes in their upper and lower values?
- How important were the upper and lower values of the thresholds in determining the final index value?
- Which of the weighting schemes or aggregation methods was more sensitive to the final index value?

The uncertainty and sensitivity analysis for WJWSI included three major tasks: (1) identification of uncertainty sources, (2) defining the upper and lower values for thresholds and their probability distributions and (3) Monte-Carlo simulations. In this study, three sources of uncertainties were identified including different thresholds of indicators and sub-indicators, weighting schemes and aggregation methods. These uncertainties were then analysed, based on the Monte-Carlo simulation. The simulation was performed using @Risk software from Palisade Corporation (Clemen & Reilly, 2001). The Monte Carlo (MC) simulation sampled various values of the upper and lower thresholds of WJWSI indicators and sub-indicators, and calculated their respective sub-indices. In this study, the uncertainty and sensitivity analysis was conducted using data for Citarum, Ciliwung and Citanduy catchments for 2008, as they were the latest available data during the analysis.

(a) Thresholds of Indicators and Sub-indicators

Due to different characteristics of categorical and non-categorical indicators and sub-indicators, upper and lower values of thresholds for these two groups are different. The review on existing policies and guidelines has identified different values for thresholds of the majority of non-categorical indicators and sub-indicators. These were used as the upper and lower values of respective thresholds in the uncertainty analysis. For the remaining non-categorical indicators and sub-indicators, ±10% of the base value (Table 3.7) was used as the upper and lower values for respective thresholds. Base values are the maximum or minimum threshold for each indicator or sub-indicator, used to obtain the sub-index values of WJWSI indicators and sub-indicators. These upper and lower values are shown in Table 4.4.

Table 4.4 Upper and lower values of thresholds of non-categorical indicators and sub-indicators

Indicator/Sub-indicator	Unit	Thresholds of Indicators and Sub-indicators			
		Max	Upper/Lower Values	Min	Upper/Lower Values
Water Availability	m^3/cap/yr	1700 [a]	1300 - 1800	500 [b]	500 - 600
Land Use Changes	%	100 [a]	80 - 100	0 [b]	+10%
Water Quality	-	0 [a]	- 10%	-31 [b]	+ 10%
Water Demand	%	40 [b]	± 10%	10 [a]	0 – 10%
Coverage	%	80 [a]	± 10%	0 [b]	+10%
Water Loss	%	30 [b]	25 – 30	15 [a]	0 - 15
Education	%	100 [a]	-10%	0 [b]	0 – 20%
Poverty	%	20 [b]	15 - 25	0 [a]	+10%
Health Impact	(cases/1000 population)	2 [b]	± 10%	0 [a]	+10%
Sanitation	%	100 [a]	- 10%	0 [b]	0 – 20%

a: preferable; b: not preferable

The uncertainty analysis was based on the thresholds of categories. The 0 - 100 spectrum in the quartile method used to define the categories in this study has three boundary values as the source of uncertainties. These values are 25, 50 and 75 (refer to Tables 4.1, 4.2 and 4.3), which define boundaries for criteria. Based on these values, upper and lower values for the thresholds of boundary values were defined. These values are shown in Table 4.5.

Table 4.5 Uncertainties of categorical indicators and sub-indicators

Original Categories	***Upper and Lower***
0 – <25	0 – <(12.5-37.5)
25 – <50	(12.5-37.5) – <(37.5-62.5)
50 – <75	(37.5-62.5) – <(62.5-87.5)
75 – 100	(62.5-87.5) – <(12.5-37.5)

(b) Weighting Schemes

Two weighting schemes were considered in the analysis: equal and non-equal. Using the equal weighting scheme, all indicators and sub-indicators were assigned equal weights in the aggregation. With the non-equal weighting scheme, however, indicators and sub-indicators were assigned different weights. The non-equal weighting scheme used in this study was based on opinions from water-related stakeholders in West Java, using the Revised Simos' procedure (refer to section 3.4.2).

(c) Aggregation Methods

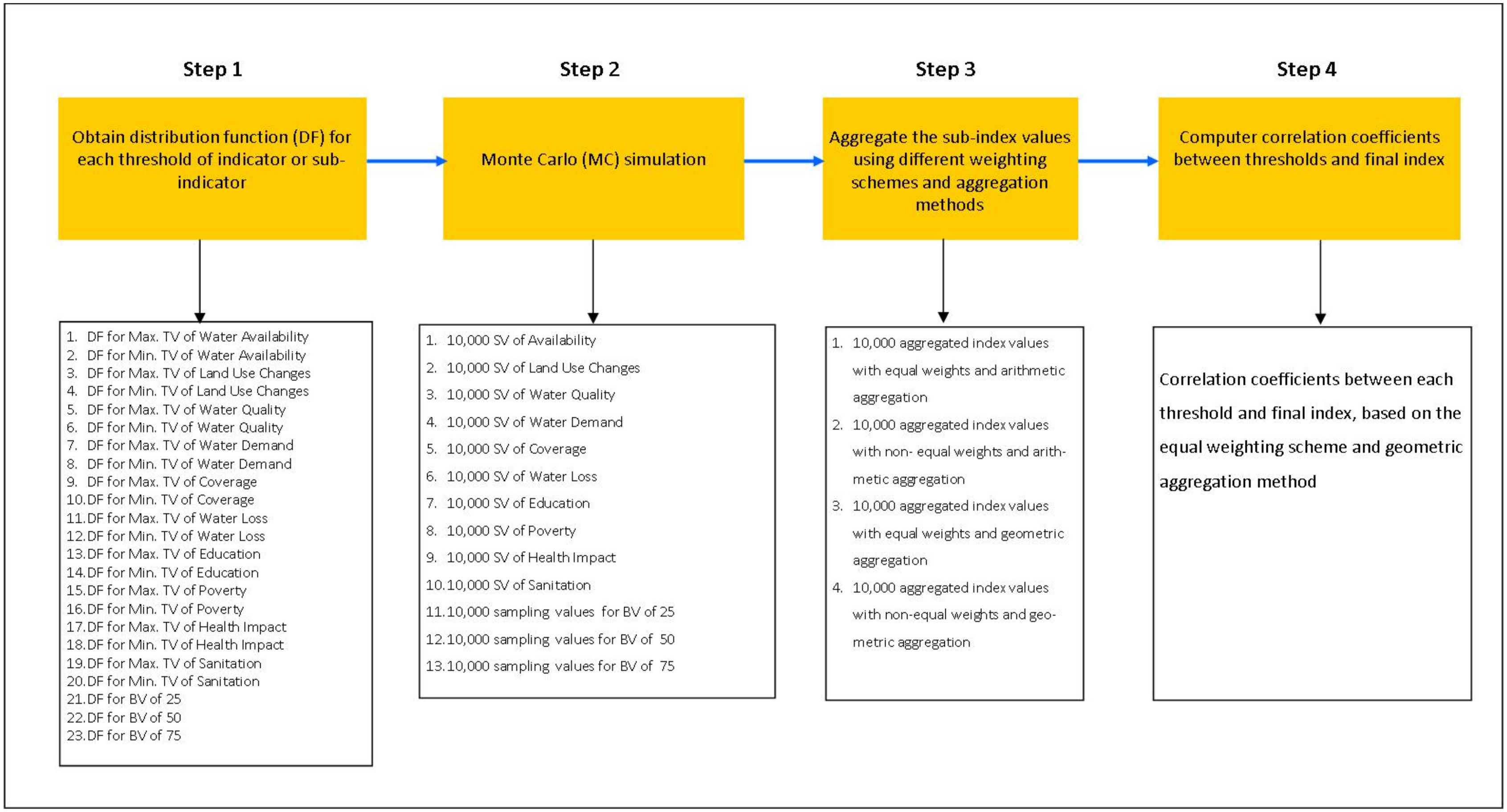
The other source of uncertainty in the WJWSI is the aggregation method. Two aggregation methods were considered: arithmetic and geometric. Details of these aggregation methods are presented in section 2.4.4 of Chapter 2.

(d) Procedures for the Uncertainty and Sensitivity Analysis

As indicated earlier, these uncertainties (upper and lower values of thresholds, weighting schemes and aggregation methods) were analysed based on Monte-Carlo (MC) simulation results. The procedures to assess these uncertainties are illustrated in DF - *Distribution Function; TV – Threshold Value; BV – Boundary Value (for the categorical indicators and sub-indicators); SV – Sub-index Value*

Figure 4.1. This figure shows that uncertainty and sensitivity analysis for this study involves four major steps. The first step is to obtain the distribution functions for the maximum and minimum thresholds of each indicator or sub-indicator. For the non-categorical indicators and sub-indicators, only the upper, base and lower values for thresholds are available. Therefore, considering the availability of data for thresholds of these indicators and sub-indicators, the triangular distribution function was used for each threshold. For categorical indicators and sub-indicators, the uniform distribution function was used.

In the case of non-categorical indicators and sub-indicators, the upper and lower values are respectively the highest and lowest values possible for the threshold of the indicator or sub-indicator. The base value is used to calculate the sub-index value in the application of WJWSI, taken from the final WJWSI framework (Tables 3.7, Table 4.4). As an example, the three required values (i.e. upper, base and lower) for defining the distribution function of the maximum threshold of *Water Availability* are shown in Table 4.6, which are extracted from Table 4.4.



DF - Distribution Function; TV – Threshold Value; BV – Boundary Value (for the categorical indicators and sub-indicators); SV – Sub-index Value

Figure 4.1 Uncertainty and sensitivity analysis scheme for WJWSI

Table 4.6 Example of input for the triangle distribution function

Thresholds	Upper	Lower	Base
Maximum Threshold of *Water Availability* *(m^3/cap/year)*	1800	1300	1700

The values shown in Table 4.6 were used to obtain the triangular distribution function of the maximum threshold of the *Water Availability* indicator, which is shown in Figure 4.2. This figure also shows the statistics of 10,000 samplings from the distribution, which is later used in the MC simulation. Using 95% confidence intervals, Figure 4.2 shows that the mean, and lower and upper confidence limits of this threshold are 1,600, 1370.7 and 1,764.6 m^3/cap/year respectively.

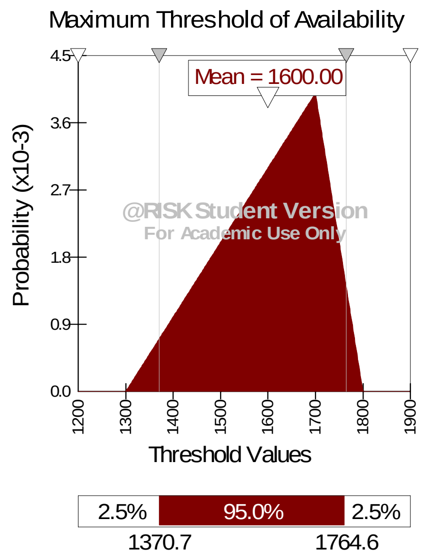


Figure 4.2 Distribution function for *Water Availability*

After distribution functions of all indicators and sub-indicators (both non-categorical and categorical) were obtained, they were used in the Step (2) of MC simulation. In this step, 10,000 sampling points were performed. Each sampling point consists of minimum and maximum thresholds of non-categorical indicators and sub-indicators (10 such indicators and sub-indicators) and three boundary values defining categories of categorical indicators and sub-indicators. These boundary values are the same for all three categorical indicators and sub-indicators.

For non-categorical indicators and sub-indicators, the maximum and minimum thresholds were used with the actual values using Eq. (4.1) and Eq. (4.2) to compute their sub-index values. These 10,000 sub-index values of non-categorical indicators and sub-indicators were used to identify their *Performance*, and to evaluate the changes of the *Performances* against their original *Performances* (based on the base values of these thresholds). For categorical indicators and sub-indicators, their sub-index values remain constant, since the values are not affected by the boundary values sampled in the MC simulation (section 4.2.1). However, the boundary values sampled in the MC simulation might affect *Performances* (Tables 4.1, 4.2 and 4.3).

In Step 3, the 10,000 sub-index values of indicators and sub-indicators (from the MC simulation) were aggregated using different combinations of weighting schemes and aggregation methods.

Finally, Step 4 calculates correlation coefficients between thresholds of each indicator or sub-indicator and the final index value, using SPSS software. To calculate correlation coefficients, 10,000 data of each threshold from the MC simulation, and the corresponding 10,000 final index values from Step 3 (using equal weighting and geometric aggregation methods) were used. These correlation coefficients were also used to evaluate which thresholds were more sensitive to the final index value.

4.3 WEST JAVA

The West Java Province is one of the most highly populated provinces in Indonesia. The province is located and adjacent to the Jakarta Province, as shown in Figure 4.3. Currently, the Jakarta Province relies on the West Java Province for various needs such as labourers, raw materials for industries and daily household needs. The West Java Province plays an important role in national development, because of its natural resources and economic potential. The natural resources in West Java have been utilised by various sectors and stakeholders in Indonesia, which have resulted in the degradation of environmental resources, including water resources (Rahmat & Wangsaatmadja, 2007).

The West Java Province is located between $5^0$50'-$7^0$50' S and $104^0$48'-$108^0$48' E. To the north, it is bordered by the Java Sea, while to the west it is bordered by Jakarta and Banten Provinces. To the south and east, the province is bordered by the Indonesian Ocean and Central Java Province respectively (Rahmat & Wangsaatmadja, 2007).

According to its topography, the West Java Province is divided into three sections. The first section constitutes the steep mountainous area, with an altitude higher than 1,500 metres above mean sea level. The second section is the hillside area, with an altitude between 100 and 1,500 metres above mean sea level. And the third section is the extensive plains area, with an altitude of 0 to 10 metres above mean sea level.

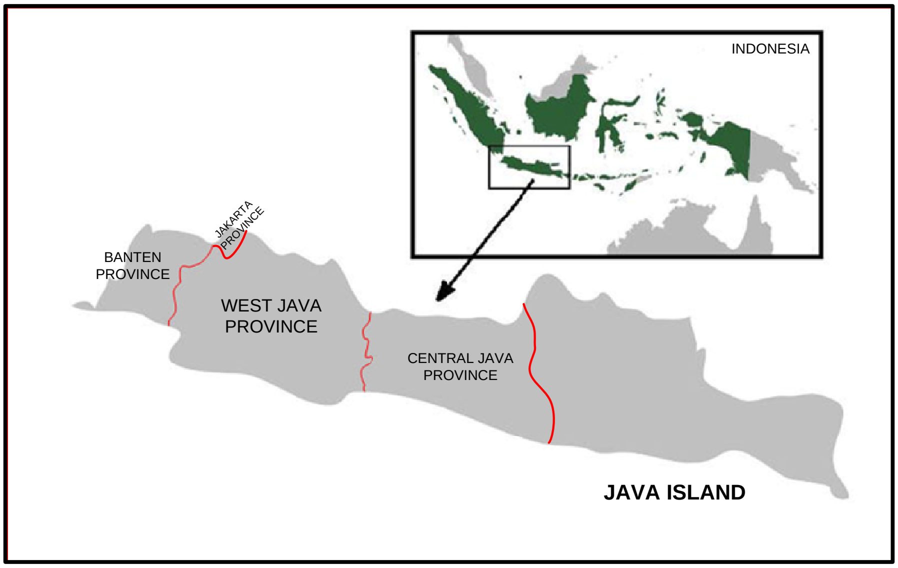


Figure 4.3 West Java province

4.3.1 Climatic Conditions

The West Java Province has a tropical climate. Average temperatures in the steep mountains and coastal areas are 9^0C and 34^0C respectively. The average temperature in the extensive plains is between 17.4^0C and 30.7^0C (Dinas Pertanian Jawa Barat, 2011). The average annual rainfall in mountain areas is between 3,000 and 5,000 mm/year, whereas in other areas the average annual rainfall is 2,000 mm/year.

4.3.2 Socio-Economic Conditions

(a) Population

The population in West Java has increased progressively from year to year. In 2006, for example, the population was 40.74 million. Three years later, in 2009, the total population was 43.02 million (18.11% of the national population). The population of the capital, Bandung City, was 2.40 million in 2009 (5.56 % of the total population in the province). The density of the population in West Java in 2009 was 1,159 people/km^2, with Bandung City having the largest concentration of 14,228 people/km^2.

(b) Land Use

The increased population in West Java has impacted land use to support various activities. Apart from the need for housing, the demand from industries in the Jakarta Province has led to changes in West Java land use, and also the Banten Province (Bappeda Team, 2004). As a result, forestry and agricultural areas in these provinces have significantly changed.

During 1994 to 2005, the highest increase in land use was for housing. In the same period, the forestry area was significantly reduced. These land use changes have resulted in a decrease in conservation areas in West Java Province (Rahmat & Wangsaatmadja, 2007). These changes are believed to be the main factor responsible for increased floods and droughts in different parts of the West Java Province (Gandapurnama, 2008; Ginting, 2007; Helmy, 2008).

4.3.3 Water Management

The West Java Province has 40 catchments. Of these catchments, 22 flow into northern parts of the province and 18 flow into southern parts of the province. The main river in the catchment, the Citarum River, flows across two provinces (i.e. West Java and Jakarta). A study by Hasibuan (2005) reported that 18 West Java catchments were in a critical condition, based on various factors including the quality of major rivers, land use and soil saturation.

In general, the conditions of water resources in catchments, both quality and quantity, are far from satisfactory. In terms of water quality, five main rivers in West Java catchments including Citarum, Ciliwung, Citanduy, Cileungsi and Cimanuk Rivers are considered critical (Tarigan, 2009). The water quality in these rivers did not meet the national standards for water quality during 2005 to 2009. The main contributors to the low water quality of these rivers are industries polluting the rivers, as well as domestic and agricultural discharge. The Environmental Protection Agency (EPA) of West Java (West Java Environmental Protection Agency, 2008) stated that as many as 542 industries were polluting rivers in West Java. The rivers also suffered from the improper discharge of 79.8 hectares of agriculture waste and domestic waste of 8.6 million of people. In terms of water quantity, in the last two decades, many areas in West Java have suffered drought and floods (Wangsaatmaja, 2004).

Of the 40 catchments in West Java, three catchments are considered highly important for various reasons. The three catchments are Citarum, Ciliwung and Citanduy. In the Citarum catchment, three reservoirs were built, which are used to supply water for various purposes, such as domestic, agriculture, power plant and fishery. In the Ciliwung catchment, the Ciliwung River flows across two main provinces, West Java and Jakarta. The Ciliwung catchment is the most densely populated catchment, with approximately 3.5 million people live along the Ciliwung River banks. The Citanduy River, as the main river in the Citanduy catchment, flows across two provinces (West Java and Central Java), which make the catchment highly important. The Citanduy River also supplies water needs for different kinds of farming in the Citanduy catchment.

4.3.3.1 Water Authorities

Various authorities are responsible for the management of water resources in West Java. These authorities include the West Java Environmental Protection Agency (EPA), West Java Water Resource Management Agency (WRMA) and the Catchment Authority. Both West Java EPA and WRMA function at the provincial level, while the Catchment Authority functions at catchment level.

The main role of the West Java EPA in managing water resources is to formulate environmental policies (including water resource management) within the West Java Province, with particular emphasis on coordination of environmental monitoring, and providing environmental management assistance to local governments.

The West Java Water Resource Management Agency (WRMA) has the responsibility to formulate policies on water resource management in West Java at the operational level, and specifically to (Indonesian Ministry of Public Works, 2010):

1. Formulate operational and technical policies on water resource management
2. Facilitate investment on water resource utilisation
3. Provide consent on the use of water source
4. Monitor and evaluate programs on water resource management

At the catchment level, catchment authorities are responsible for the implementation of water resource management in their respective catchments, which include planning, construction, operation, and maintenance of all aspects of water resource management. In most cases, one catchment authority is responsible for one catchment. However, in some cases, one catchment authority is responsible for several catchments, as the size of some catchments is too small to have a separate catchment authority. For example, the Citarum Catchment Authority is responsible only for the Citarum catchment, whereas the Ciliwung Catchment Authority is responsible for both Ciliwung and Cisadane catchments.

4.3.3.2 Policies and Regulations

In 2006, the National Ministry of Internal Affairs, the Ministry of Forestry and the Ministry of Public Works together released a decree on the importance of water catchments (Indonesian Ministry of Public Works, 2006). The decree stated that high priority is given to a catchment that meets at least one of the following criteria: (1) availability of water resources is at least 20% of the total availability in the province, (2) population in the catchment is at least 30% of the total population in the province and (3) the impact of the catchment on the national development is highly significant.

There were other policies and regulations related to water resource management in West Java's catchments. They include:

(1) National Regulation No 7/2004, Provincial Decree on Water Resource Management
(2) National Regulation No 82/2001 on Water Quality Management and Water Pollution Control
(3) Provincial Decree No 3/2004 on Water Quality Management and Water Pollution Control
(4) Ministry of Environment of Indonesia Decree No 51/1995 on Effluent Standard for Industries
(5) Ministry of Environment of Indonesia Decree No 35-A/1995 on Performance Assessment of Industries in Pollution Control Management
(6) Provincial Decree No 2/2006 on Management of Conservation Areas

These policies and regulations accommodate necessary tools to improve water resource management in Indonesia, particularly in West Java. However, these policies and regulations have not been implemented effectively. For example, with regard to the conservation area, the Provincial Decree No. 2/2006 on Management of Conservations Areas clearly defined areas designated for water conservation, however some of these areas are also used for housing and commercial purposes (Wangsaatmaja, 2004).

4.3.3.3 Current Water Management Programs

For more than a decade, water management programs in West Java have mainly focused on improving the quality of its major rivers. There were two main programs implemented in West Java to improve river quality. The first program is known as *Proper Prokasih*. This is a national program, started in 1995 by the Indonesian Ministry of Environment, implemented under the coordination of the Environmental Protection Agency (EPA) of Indonesia. The other program is called Environmental Pollution Control Manager (EPCM), and was started in 2005. However, these two programs have not significantly contributed to the improvement of river quality in West Java. The monitoring of five major rivers in West Java in 2010 shows that water quality at all sampling points was below the national standard (Turindra, 2011).

(a) Proper Prokasih

The objective of this program is to improve the compliance of industries through regulations that are relevant to environmental impact management, particularly on waste water quality (Environmental Protection Agency (EPA) of West Java, 2008). This program was expected to reduce the level of pollutants discharged into the river systems by industries. At implementation stage, the program was conducted in three phases (Wheeler & Afsah, 2000):

1. *Identification and selection of industries to participate in the program*

   Journalists, local government and universities were involved in the identification process. As industrial development was concentrated on the island of Java, the majority of industries that participated in the program were from Java. Of the total industries participating in the program, 75% were from Java and the other 25% were from Sumatera, Sulawesi, and Kalimantan. In June 1995, a pilot study for the program was conducted, and 187 factories were assessed. In 1998 as many as 350 factories voluntarily participated in the program (Wheeler & Afsah, 2000).

2. *Waste water Sampling of industries*

   Sampling of effluent quality of industries was carried out twice yearly by a designated team from the EPA Indonesia.

3. *Results Monitoring*

Effluent samplings are compared and analysed against the National Effluent Standard, specified in the Environmental Ministerial Decree of Indonesia No.122/MENLH/2004. Based on this analysis, industries are classified according to Table 4.7 (Wheeler & Afsah, 2000).

The monitoring process is conducted every six months, and announced to the public via local and national media. The monitoring of the program in 2010 showed that the number of industries participating in the program has increased. In total, 691 industries were monitored at the end of 2010. Of these industries, two were classified as Gold, 54 (8%) as Green, 435 (63%) as Blue, 153 (22%) as Red and the remaining 47 (7%) as Black (Tamin & Reliantoro, 2010). The monitoring in 2010 also noted that the number of industries under compliance categories of Gold, Green and Blue have improved from 432 industries (end of 2009) to 491 industries (end of 2010). Based on these results, the Ministry of Environment of Indonesia has claimed that the program had been successful in improving environmental performances of participating industries. In future, as many as 2000 industries (about 25% of the total industries in Indonesia) will be targeted to participate in the program.

Table 4.7 Categories for industry in *Proper Prokasih* program (Wheeler & Afsah, 2000)

TYPE	CRITERIA	REQUIREMENTS
GOLD	EXCEED COMPLIANCE	All requirements for Green, plus similar levels of pollution control for air and hazardous waste. Industries reach high international standards by the extensive use of clean technology, waste minimization, pollution prevention, recycling, etc.
GREEN		Pollution level is lower than waste water standards by at least 50 percent. Factory ensures proper disposal of sludge, good housekeeping, accurate pollution records, and reasonable maintenance of the waste water treatment system
BLUE	IN COMPLIANCE	Factory only applies sufficient effort to meet the minimum discharge standards.
RED	NOT IN COMPLIANCE	Factory makes some effort to control pollution, but it is not sufficient to achieve compliance
BLACK		Factory makes no effort to control pollution, or causes serious environmental damage

(b) Environmental Pollution Control Manager

The Environmental Pollution Control Manager (EPCM)is designed by the West Java EPA, in collaboration with the Japan External Trade Organization *(JETRO),* which aims at improving the capacity of human resources responsible for managing industrial pollution at the company level (Wangsaatmadja, 2009).

Currently, in the West Java Province, many industries are believed to discharge their waste water without proper treatment. Therefore, the improvement of river quality cannot be achieved without the involvement of industries. One of the reasons for such bad practice is the lack of capable human resources to manage waste water problems. To address this issue, the provincial government of West Java requires every industry in West Java to employ a certified pollution control manager, through the *Environmental Pollution Control Manager (EPCM)* program. This is undertaken by providing training to the company manager responsible for waste water treatment. To support the EPCM program, the Provincial Government of West Java enacted a Provincial Decree on Industrial Waste water Treatment, which states that every industry is obliged to have a certified person, responsible for waste water treatment and discharge(Asdep Standardisasi, 2008). The certification is organised by the Environmental Protection Agency of West Java. Since its implementation in 2005, 285 managers have been certified through this scheme as of early 2011.

According to Resmiani (2010), the success of the EPCM program is determined by its constant dissemination to all industries and district governments. In addition, Resmiani (2010) also emphasises the need to monitor the performance of certified pollution control managers, through compliance of industries with effluent standard regulations. It is expected that the increase in compliance will improve the quality of rivers in the West Java Province.

4.4 CITARUM CATCHMENT

4.4.1 Description of the Catchment

The Citarum catchment occupies an area of approximately 7,400 km^2, which can be divided into three parts; upper (1,771 km^2), middle (4,242 km^2) and lower (1,387 km^2). As illustrated in Figure 4.4, three reservoirs have been built in the catchment, which are used to supply water for various purposes, such as domestic, agriculture, power plant and fishery. From upstream of the catchment, there are three reservoirs: Saguling, Cirata and Jatiluhur. Average rainfall over the catchment is 2,300 mm/year, and the flow of the Citarum River, gauged at the inlet of Saguling, approximately equals 5.7 billion m^3/year.

According to the decree of the National Ministry of Internal Affairs, Ministry of Forestry and Ministry of Public Works of 2006, the Citarum catchment is a highly prioritised catchment, as has made a significant impact on the national development of Indonesia, particularly the economic sector (Tarigan, 2009). Irrigation and industrial sectors in West Java and Jakarta provinces highly rely on the Citarum River. Also, the reservoirs in the Citarum catchment generate electricity for use in West Java and Jakarta provinces respectively.

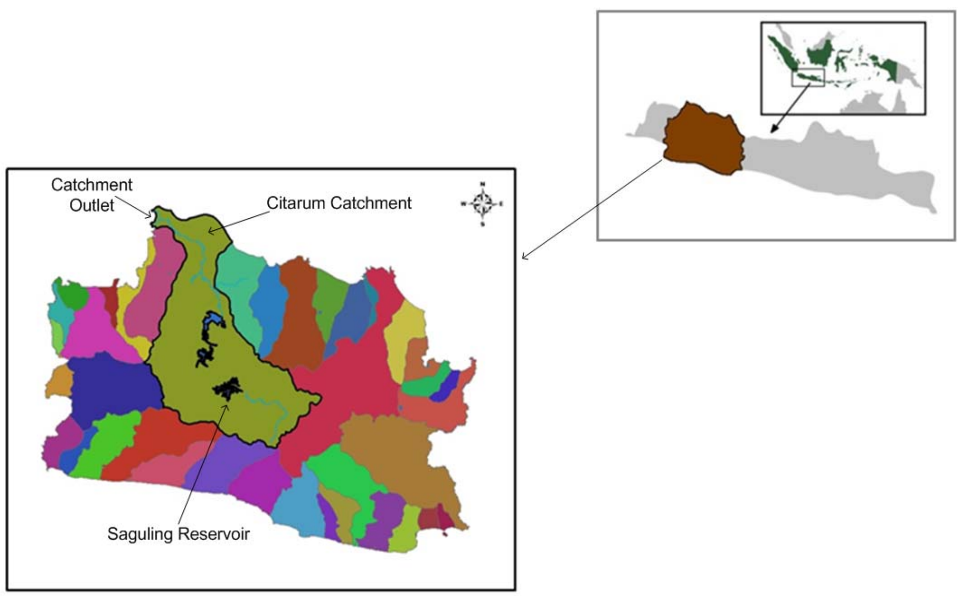


Figure 4.4 Citarum catchment in West Java

In 2008, the total population within the catchment was just over 11 million. The majority live along the river banks, and have directly used the river for various domestic uses, including drinking water. Several water service companies in the catchment have also built water intakes to use raw water in their water treatment plants. Pressures on the catchment and its rivers come from pollutants from various activities within the catchment. Pollutants from the domestic sector originate from both direct and indirect discharge of *black water* and *grey water* of households. Hundreds of industries located along the river also pollute the river due to lack of awareness, as well as lack of law enforcement from relevant authorities. In addition, agriculture and livestock have also contributed to river pollution in the catchment.

4.4.2 Application of WJWSI for 2008

The application of WJSWI in the Citarum catchment requires collecting data for each indicator and sub-indicator. Data were collected from past studies, institutional databases and other relevant sources. After all required data had been collected, sub-index values for WJWSI indicators and sub-indicators were calculated. These sub-index values were then aggregated to produce the final index.

4.4.2.1 Sub-index Values and Final index

As indicated earlier, the sub-index values of non-categorical indicators and sub-indicators are obtained using Eq. (4.1) and Eq. (4.2). To compute these sub-index values, maximum and minimum thresholds, as well as the actual values of indicators and sub-indicators need to be obtained.

The maximum and minimum thresholds are presented in Table 4.4. The actual value for each indicator or sub-indicator is obtained, based on relevant data and information available from various West Java institutions. The details on how these actual values were obtained are discussed in the following sub-sections. For categorical indicators and sub-indicators, sub-index values are obtained using the criteria presented in Tables 4.1, 4.2 and 4.3.

Water Availability

According to Falkenmark (2004), the maximum amount of water available for human use is approximately 60% of the total rainfall, and this amount is used in the WJWSI application. This amount is then divided by the total population in the catchment to obtain the actual value of *Water Availability*. Based on this information, the actual value was calculated as 587m^3/person/year for the Citarum catchment in 2008. Eq. (4.1) was then used to calculate the sub-index for *Water Availability* as 7.28. The low sub-index for *Water Availability* in the Citarum catchment is caused by the large population living within the catchment. Recently the big cities in the catchment, such as Bandung, Depok and Bogor, have attracted people from other areas. Currently, there is no appropriate regulation to prevent this growing influx of people.

However, minority of people in the catchment have practised the recycle and reuse of water in their daily activities. Unfortunately, these practices have not been systematically implemented through the coordination of water authorities in West Java. The availability of water in West Java is also a concern for non-governmental organisations, such as the IUWASH (Indonesia Urban Water, Sanitation and Hygiene). The USAID-based organisation has started to increase the availability of groundwater resources in West Java by injecting rainfall directly to the ground (USAID Indonesia, 2011). Since this program has only been started at the end of 2011, its results has not yet been confirmed.

Land Use Changes

Ideally, the actual value of the *Land Use Changes* indicator is obtained by comparing actual land use in the catchment with land use planning, issued by the Regional City Planning Body. However, in the Citarum catchment such land use data were not available. Therefore, the sub-index for land use changes was obtained by calculating the percentage of identified conservation areas within the catchment, which are supported with necessary planning documents. It was found that in 2008, as much as 84.68% of the total conservation area was supported with necessary planning documents. Using Eq. (4.1), the sub-index for this indicator was calculated as 84.68.

Water Quality

The actual value of *Water Quality* was obtained by calculating the Storet value (Cude, 2001; Indonesian Ministry of Environment, 2003) for 10 sampling points of water quality along the Citarum river, as practised by the West Java Environmental Protection Agency (EPA). In the 2008, the average Storet value for all 10 sampling points was -96.1. Based on its Storet value, water quality is classified into 4 groups: *very good* (Storet value of 0), *good* (Storet value of -1 to -10), *medium* (Storet value of -11 to -30) and *bad* (Storet value less than -31) (Indonesian Ministry of Environment, 2003).

Using Eq. (4.2), the sub-index for *Water Quality* was calculated as 0. Poor water quality is caused by different factors. The major factor is pollution from various activities along the rivers, particularly from domestic and industrial discharge. Lack of awareness by the general public has resulted in daily discharge of large amounts of pollutants into the rivers. This situation is worsened by the inadequacy of law enforcement and corrupt practice by relevant authorities, which allow some companies to discharge their untreated waste water directly into the river.

Water Demand

The first step to obtain the actual value of *Water Demand* was to summarise water used for different purposes including domestic, public facility, irrigation and industry. This sum was then expressed as a percentage of the availability of water resources for the catchment to obtain the actual value of the *Water Demand* indicator. For the Citarum catchment in 2008, this was calculated as 23.04%. The sub-index for this indicator was then computed using Eq. (4.2) as 56.54.

Coverage

Within the Citarum catchment, there are 12 water service providers. The actual value of the *Coverage* indicator was obtained by considering the ratio of the population covered by the pipeline distributions of water companies to the total population within the catchment. Once this actual value was obtained (34.96%), the sub-index for *Coverage* was calculated using Eq. (4.1) as 43.70.

Water Loss

The actual value of *Water Loss* was obtained by considering the average loss of water both in the processes of water production and water distribution of all 12 water service providers. In 2008, this was calculated as 40.10%. After the actual value was obtained, the sub-index for the *Water Loss* indicator was calculated using Eq. (4.2) as 0. The sub-index value for *Water Loss* shows that all water companies in the catchment suffer from a high level of water loss.

Information Disclosure

The sub-index for *Information Disclosure* considered the availability and accessibility of key data, as well as regular data updates. The key data includes rainfall, population, water quality, water use, water distribution coverage, water losses, education, poverty, sanitation, water-borne diseases and land use. Each of these data was assessed using the criteria in Table 4.1. The values for all these data were then averaged to obtain the sub-index of the *Information Disclosure* sub-indicator. For the Citarum catchment, most of these data were available, but they could not be accessed by the public through the internet. The sub-index value for this indicator was calculated as 37.27.

Governance Structure

The sub-index for *Governance Structure* was obtained by assessing the structure, job description and tasks of various water-related institutions. Clarity of structures and job descriptions, and identification of any tasks overlapping institutions are the criteria to obtain the sub-index for this indicator, as presented in Table 4.2. The analysis for the Citarum catchment in 2008 shows that only a few institutions, which are responsible for the management of water resource issues in the Citarum catchment, have clear institutional structure and job descriptions. In some cases, overlaps of tasks occur among different institutions. For these reasons, the sub-index for *Governance Structure* was estimated as 35.

Education

The actual value of *Education* was obtained by calculating the percentage of people in the Citarum catchment who have completed primary education. In 2008, this was calculated as 14.19%. The sub-index of the *Education* indicator was then calculated using Eq. (4.1) as 14.19.

Poverty

The actual value of *Poverty* in the Citarum catchment was calculated using the percentage of people who fell below the poverty standard, defined by the Indonesian national government. According to this standard, poverty is defined as the inability of an individual to meet monthly basic living standard (BPS Team, 2009). This standard is known as the poverty line, which is updated once every three years. In 2008, the poverty line for West Java is Rp. 182,636.00 per person/month, equal to approximately AUD 20.29 (1 AUD = Rp. 9,000.00). The percentage of people under the poverty standard was calculated as 15.23%. Using this percentage value, the sub-index of the *Poverty* indicator was computed using Eq. (4.2) as 23.87.

Health Impact

The actual value of *Health Impact* was calculated by considering the number of haemorrhagic dengue cases for every 1000 people. In the Citarum catchment for 2008, the actual value was calculated as 0.99. The sub-index for this indicator was then calculated using Eq. (4.2) as 50.60.

Sanitation

The actual value of the *Sanitation* indicator was obtained by calculating the percentage of people having basic sanitation facilities, in accordance with the national regulation on the minimum standard of sanitation facilities. According to this regulation, basic sanitation is defined as having any sanitation facility, such as pit latrine or closet (MDG Indonesia Team, 2007). The actual value was calculated as 61.86%. Once this value was obtained, the sub-index was calculated using Eq. (4.1) as 61.86. This value reflects that there were still around 40% of the population in the catchment (about 4 million) who had no access to basic sanitation facilities.

Law Enforcement

The sub-index for *Law Enforcement* was obtained by assessing procedures to enforce water-resource-related policies and regulations, compared with the actual implementation of the procedures. Currently, the West Java EPA already has procedures for regulation enforcement, but is not fully implemented, due to lack of support from other relevant institutions. For this reason, the sub-index for the *Law Enforcement* indicator in the Citarum catchment (based on detailed criteria in Table 4.3) was estimated as 40.

Sub-index Values of Indicators and Sub-indicators

The sub-index values of the indicators and sub-indicators, calculated earlier, and their respective performances and priority of actions are presented in Table 4.8.

Table 4.8 Sub-indices of Citarum catchment for 2008

Indicator/sub-indicator	***Unit***	***Actual Value***	***Sub-index***	***Performance***	***Priority of Action***
Water Availability	m^3/cap/yr	587.32	7.28 [a]	Poor	High
Land Use Changes	*%*	84.68	84.68 [a]	Good	Low
Water Quality	-	-96.1	0.00 [b]	Poor	High
Water Demand	*%*	23.04	56.54 [b]	Medium-Good	Medium-Low
Coverage	*%*	34.96	43.70 [a]	Poor-Medium	High-Medium
Water Loss	*%*	40.10	0.00 [b]	Poor	High
Information Disclosure	-	-	37.27[c]	Poor-Medium	High-Medium
Governance Structure	-	-	35.00 [d]	Poor-Medium	High-Medium
Education	*%*	14.19	14.19 [a]	Poor	High
Poverty	*%*	15.23	23.87 [b]	Poor	High
Health Impact	(*cases/1000 pop)*	0.99	50.60 [b]	Medium-Good	Medium-Low
Sanitation	*%*	61.86	61.86 [a]	Medium-Good	Medium-Low
Law Enforcement	-	-	40.00 [e]	Poor-Medium	High-Medium
Final Index (arithmetic aggregation method)			35.00	Poor-Medium	High-Medium
Final Index (geometric aggregation method)			20.04	Poor	High

a = obtained using Eq. (4.1); b = obtained using Eq. (4.2); c = obtained using Table 4.1; d = obtained using Table 4.2; e = obtained using Table 4.3

The third column shows the actual value for each indicator, followed by its sub-index value in the fourth column. The next two columns are *Performance* and *Priority of Action* for the indicators and sub-indicators, which were obtained using Table 3.10 (Section 3.5). The *Performance* was based on the sub-index value of the respective indicator or sub-indicator. There are four levels of performance: Good, Medium-Good, Poor-Medium, and Poor. *Priority of Action* reflects the priority of action to improve the *Performance* of indicators or sub-indicators, which is the opposite of its respective *Performance*. If *Performance* of an indicator/sub-indicator is Poor, the *Priority Action* of the indicator/sub-indicator is High. Conversely, if *Performance* is Good, the *Priority of Action* is low.

Table 4.8 shows that some indicators and sub-indicators have performed poorly. They are *Water Availability, Water Quality, Water Loss, Education* and *Poverty*. Only one indicator performed well, which is *Land Use Changes*. The other indicators are considered either Poor-Medium or Medium-Good.

4.4.2.2 Robustness Analysis of WJWSI

The robustness of the WJWSI was analysed by performing the uncertainty and sensitivity analysis on the index, based on data of 2008, as discussed in section 4.2.3. The outcomes of various steps in the uncertainty and sensitivity analysis of the Citarum catchment are presented in Tables 4.9, 4.10 and 4.11.

To analyse uncertainty, the coefficient of variation and percentage of unchanged performance of 10,000 sub-index values were used. The coefficient of variation was the ratio of the standard deviation to the mean value. The percentage of unchanged performance was obtained by comparing 10,000 *Performances* obtained from outputs of the Monte-Carlo simulation with the original *Performances* of indicators and sub-indicators shown in Table 4.8. In this study, the *Performance* reflects the condition of issue(s) related to an indicator or sub-indicator, which was obtained based on the sub-index value of an indicator or sub-indicator.

Table 4.9 Results of uncertainty analysis for Citarum catchment

1	2	3	4	5	6	7	8			9
Thresholds	**Unit**	**Base Value**	**Mean**	**Std. Deviation**	**Coefficient of Variation**	**Indicators/Sub-Indicators**	**Sub-index values**			**Unchanged Performance (%)**
							Mean (Original Values)	**Standard Deviation**	**Coefficient of Variation**	
Water Availability – Maximum	m^3/cap/yr	1,700	1,599.8	108.50	0.07	*Water Availability*	5.09 (7.28)	2.24	0.44	100
Water Availability – Minimum	m^3/cap/yr	500	533.2	23.80	0.05					
Land Use Changes – Maximum	*%*	100	93.3	4.69	0.05	*Land Use Change*	90.53 (84.68)	4.66	0.05	100
Land Use Changes – Minimum	*%*	0	3.4	2.36	0.70					
Water Quality – Maximum	-	0	-1.0	0.72	0.71	*Water Quality*	0.00 (0.00)	0.00	-	100
Water Quality – Minimum	-	-31	-30.0	0.73	0.02					
Water Demand - Maximum	%	40	40.0	1.64	0.04	*Water Demand*	50.94 (56.54)	4.29	0.08	59.97
Water Demand – Minimum	%	10	6.6	2.39	0.36					
Coverage – Maximum	%	80	80.0	3.23	0.04	*Coverage*	41.81 (43.70)	2.26	0.05	100
Coverage – Minimum	%	0	2.6	1.87	0.71					
Water Loss – Maximum	%	30	28.3	1.18	0.04	*Water Loss*	0.00 (0.00)	0.00	-	100
Water Loss - Minimum	%	15	10.0	3.52	0.35					
Education – Maximum	%	100	96.7	2.35	0.02	*Education*	8.41 (14.19)	4.52	0.54	100
Education – Minimum	%	0	6.6	4.66	0.71					
Poverty - Maximum	%	20	20.0	2.04	0.10	*Poverty*	23.85 (23.87)	8.23	0.35	100
Poverty - Minimum	%	0	0.7	0.47	0.70					
Health Impact – Maximum	*(cases/1000 pop)*	2	2.0	0.08	0.04	*Health Impact*	52.29 (50.60)	2.39	0.05	82.74
Health Impact – Minimum	*(cases/1000 pop)*	0	0.1	0.05	0.70					
Sanitation – Maximum	*%*	100	96.7	2.37	0.02	*Sanitation*	61.23 (61.86)	2.68	0.04	100
Sanitation – Minimum	*%*	0	6.7	4.74	0.71					
Boundary Value of 25	-	25	25.1	7.2	0.29	*Information Disclosure*	37.27 (37.27)	-	-	98.95
Boundary Value of 50	-	50	50.0	7.2	0.14	*Governance Structure*	35.00 (35.00)	-	-	89.86
Boundary Value of 75	-	75	75.1	7.2	0.10	*Law Enforcement*	40.00 (40.00)	-	-	90.26

Data in columns 4, 5 and 6 in Table 4.9 were obtained from the results of MC simulation. For each threshold of non-categorical indicators and sub-indicators and each boundary value defining categories of categorical indicators and sub-indicators, the mean, standard deviation and coefficient variation of 10,000 data generated from its distribution function were computed. Table 4.9 shows that higher coefficients of variation belong to the minimum thresholds of *Land Use Changes, Coverage, Education, Poverty, Health Impact* and *Sanitation,* and the maximum threshold of *Water Quality*. This implies that upper and lower values of these thresholds have resulted in the higher variation compared to other thresholds. For future use, it is important to collect more specific information on these thresholds, so that the uncertainty can be reduced.

The lowest coefficients of variation values belong to the maximum thresholds of *Education* and *Sanitation,* and the minimum threshold of *Water Quality,* all having a value of 0.02. However, there are several other thresholds which were less than 0.1 coefficient of variation.

Table 4.9 also provides links between thresholds and respective sub-index values of non-categorical indicators and sub-indicators. It should be noted that for categorical indicators and sub-indicators, for all 10,000 sampling points, their sub-index values are the same, since the boundary values do not affect the sub-index values of these indicators and sub-indicators. Each pair of minimum and maximum thresholds has produced a sub-index value of an indicator or sub-indicator. For each indicator or sub-indicator, the mean, standard deviation and coefficient of variation of its sub-index value were calculated. This information is also used to analyse how the upper and lower values of thresholds affect the sub-index value of its respective indicator or sub-indicator.

For most indicators and sub-indicators, the differences in coefficients of variation of their maximum and minimum thresholds compensate each other in producing the sub-index values, as reflected in their coefficients of variation (e.g. *Poverty, Education* and *Land Use Change*). For example, the coefficients of variation for maximum and minimum thresholds for the *Poverty* indicator (0.10 and 0.70 respectively) compensate each other to produce the coefficient variation of 0.35 for *Poverty*.

The above pattern does not apply to *Water Availability, Water Quality* and *Water Loss*. Low values of coefficients of variation of maximum and minimum thresholds for *Water Availability* (0.07 and 0.05 respectively) have resulted in a higher coefficient of variation (0.44). The coefficients of variation for sub-indices of *Water Quality* and *Water Loss* cannot be computed because their sub-index values were 0 (zero) throughout the analysis (as shown in Table 4.8).

Table 4.9 (column 9) also presents how 10,000 *Performances* of each indicator or sub-indicator resulted from the MC simulation, as compared to its original performance. It shows that performance has changed only ± 10% or less compared to original performance (except for *Water Demand* and *Health Impact*). According to Esty (2005), these changes of approximately 10% during simulation of uncertainties are considered insignificant. The performances of *Water Demand* and *Health Impact* indicators have changed 4,003 times (40.03%) and 1,726 times (17.26%) during the MC simulation from Medium-Good to Medium respectively, as sub-index values were close to the performance boundary.

Sensitivity analysis of the WJWSI was undertaken, based on the correlation coefficients of the thresholds of the non-categorical indicators and final index value. The boundary values of categorical indicators were not included as they do not affect their sub-index values and the final index value. The correlation was based on the Spearman correlation method, with the two-tailed probability value for its significance. This value (the hypothesis used in the analysis) is non-directional, i.e. there is no preference as to whether the correlation value is either positive or negative. The correlation coefficients for the thresholds and the final index value are shown in Table 4.10.

Table 4.10 shows that the upper and lower values for the maximum threshold of *Poverty* have produced the highest correlation coefficient (0.520), while the minimum threshold of *Water Quality* produced the lowest correlation (0.004). The correlation coefficient should lie between the values of -1 and 1. A perfect correlation is shown by the value of -1 or 1. The correlation coefficient of 0 represents no correlation between variables (Caldwell, 2010; Corty, 2007; Gravetter & Wallnau, 2011; Howell, 2011; Lind et al., 2000; Steinberg, 2011; Urdan, 2010). Further interpretations on correlation coefficients are provided by different authors. Lind et al. (2000) consider correlation coefficients as strong (>0.67), moderate (between 0.33 and 0.67) and weak (<0.33). Caldwell (2010) interprets correlation coefficients as follows: no correlation (0 - 0.2), weak (0.2 - 0.4), moderate (0.4 - 0.6), strong (0.6 - 0.8) and very strong (0.8 – 1).

Table 4.10 Correlation coefficients between final index and thresholds for Citarum catchment

No	Thresholds of Indicators and Sub-indicators	Correlation Coefficient
1.	*Water Availability / Maximum Threshold*	-0.049*
2.	*Water Availability / Minimum Threshold*	-0.111*
3.	*Land Use Changes / Maximum Threshold*	-0.254*
4.	*Land Use Changes / Minimum Threshold*	-0.015
5.	*Water Quality / Maximum Threshold*	0.004
6.	*Water Quality / Minimum Threshold*	-0.014
7.	*Water Demand / Maximum Threshold*	0.132*
8.	*Water Demand / Minimum Threshold*	0.199*
9.	*Coverage / Maximum Threshold*	-0.101*
10.	*Coverage / Minimum Threshold*	-0.074*
11.	*Water Loss / Maximum Threshold*	0.023
12.	*Water Loss / Minimum Threshold*	-0.011
13.	*Education / Maximum Threshold*	-0.005
14.	*Education / Minimum Threshold*	-0.265*
15.	*Poverty / Maximum Threshold*	0.520*
16.	*Poverty / Minimum Threshold*	0.043*
17.	*Health / Maximum Threshold*	0.107*
18.	*Health / Minimum Threshold*	0.069*
19.	*Sanitation / Maximum Threshold*	-0.082*
20.	*Sanitation / Minimum Threshold*	-0.136*

** Significant, based on the two-tailed probability value (p value< 0.05)*

According to the above interpretations, only the maximum threshold of *Poverty* has a significant effect on the aggregated value (the most sensitive). This means that changes in the maximum threshold of *Poverty* will have the most statistically significant impact on the final index value, compared to changes in any other thresholds. The positive correlation value of the *Poverty* indicator implies that the increase in its maximum threshold will produce an increase value in the final index. In this study, 20% was used as the maximum threshold, which means that the actual *Poverty* value of 20% and above will result in the sub-index value of 0 (zero). If the maximum threshold for *Poverty* is increased to 40%, for example, actual values of 40% and above will result in the sub-index value of 0 (zero). This change on the maximum threshold of *Poverty* might also change its priority of action.

The sensitivity analysis in this study also aims to answer the question: "Which of the weighting schemes or aggregation methods mostly affect the final index?" To answer this question, different aggregation combinations, based on different weighting schemes and aggregation methods, were analysed. Results for the Citarum catchment are shown in
Table 4.11.

Table 4.11 Aggregation based on different weighting schemes and aggregation methods

Scenario	Arithmetic	Geometric	*Changes*
Equal weights	34.67	19.00	**15.67**
Non-equal weights	30.97	20.52	**10.45**
Changes	**3.7**	**1.52**	

Table 4.11 shows that changes in the final index values as a result of changes from equal to non-equal weights were 3.7 and 1.52. These changes as a result of changes from arithmetic to geometric aggregation methods were 15.67 and 10.45. Based on these results, it is concluded that the aggregation method is more sensitive to the final index value, compared to the weighting schemes.

Therefore, for future use of the WJWSI, either the equal or non-equal weighting scheme can be used, as it will not significantly affect the final index. The aggregation method recommended for the WJWSI is geometric. This method is more appropriate for the WJWSI as the differences of sub-index values among indicators are important and these differences are reflected better in the final index obtained through the geometric aggregation method than through the arithmetic method (Section 2.4.4).

By using the geometric aggregation method, the differences in sub-index values of WJWSI indicators and sub-indicators are taken into account. Poor indicator performances, shown by low sub-index values, will be reflected in the aggregated index value. In contrast, when using the arithmetic aggregation method, poor indicator performances will not be reflected in the aggregated index value if other indicators perform well. Thus, it is recommended that the geometric aggregation method is used to aggregate WJWSI indicators and sub-indicators.

4.4.3 Application for Different Years

To obtain the sub-index values of WJWSI indicators for 2006 and 2007, the rationales and equations for 2008 were also used. The sub-index values of *Water Availability, Land Use Changes, Coverage, Education* and *Sanitation* were computed using Eq. (4.1), while the sub-index values of *Water Quality, Water Demand, Water Loss, Poverty* and *Health Impact* were computed using Eq. (4.2). The sub-index values of the categorical indicators and sub-indicators, which are *Information Disclosure, Governance Structure* and *Law Enforcement*, were obtained using criteria in Tables 4.1, 4.2 and 4.3 respectively. As indicated from the results of the robustness analysis (Section 4.4.2.2), the final index was computed using the equal weighting scheme and geometric aggregation method. Results of the computation for these sub-indices are presented in Table 4.12. The comparison of results for 2006, 2007 and 2008 is illustrated in Figure 4.5.

Figure 4.5 shows that the final index of the Citarum catchment in 2007 is slightly higher, compared to 2006 and 2008. During this three year period, the sub-index values for most indicators remain constant or change slightly, with exceptions for *Water Availability* and *Water Demand*. These latter indicators are affected by climate. The sub-index value of *Water Availability* in 2007 was very high due to high rainfall. The annual rainfall in the Citarum catchment in 2007 was 2273 mm, which was much higher, compared to the annual rainfall in 2006 (1778 mm) and 2008 (1612 mm). As the sub-index value of *Water Availability* is dependent on rainfall in the catchment, higher rainfall in 2007 (coupled with insignificant population growth) has resulted in the significant increase in the sub-index value of *Water Availability*.

The sub-index value of *Water Demand* has also been affected by the significant increase in rainfall in 2007. The actual value of *Water Demand* was obtained by comparing the use of water for various activities with the availability of water in the area. Since the availability of water increased considerably in 2007 (the result of high rainfall) and the use of water was relatively constant, the actual value of *Water Demand* has decreased significantly. This decrease was reflected in the high sub-index value of *Water Demand* (Eq. 4.2).

For indicators and sub-indicators other than *Water Availability* and *Water Demand*, during 2006-2008, there were not significant changes on the variables of these indicators and sub-indicators. Consequently, the sub-index values of these indicators and sub-indicators have only slightly changed.

Table 4.12 Sub-indices of Citarum catchment for 2006 and 2007

Indicator/sub-indicator	*Unit*	*2006*				*2007*			
		Actual Value	*Sub-index/ Final Index*	*Performance*	*Priority of Action*	*Actual Value*	*Sub-index/ Final Index*	*Performance*	*Priority of Action*
Water Availability	m^3/cap/yr	672.40	14.37 [a]	Poor	High	849.32	29.11 [a]	Poor-Medium	High-Medium
Land Use Changes	%								
Water Quality	-	-130.9	0.00 [b]	Poor	High	-68.4	0.00 [b]	Poor	High
Water Demand	%	17.34	75.54 [b]	Good	Low	14.71	100.00 [b]	Good	Low
Coverage	%	30.84	38.54 [a]	Poor-Medium	High-Medium	35.20	44.00 [a]	Poor-Medium	High-Medium
Water Loss	%	39.36	0.00 [b]	Poor	High	40.41	0.00 [b]	Poor	High
Information Disclosure	-	37.27	37.27 [c]	Poor-Medium	High-Medium	37.27	37.27 [c]	Poor-Medium	High-Medium
Governance Structure	-	35	35.00 [d]	Poor-Medium	High-Medium	35	35.00 [d]	Poor-Medium	High-Medium
Education	%	15.17	15.17 [a]	Poor	High	15.32	15.32 [a]	Poor	High
Poverty	%	15.17	24.14 [b]	Poor	High	15.21	23.97 [b]	Poor	High
Health Impact	(*cases/1000 pop)*	0.88	56.03 [b]	Medium-Good	Medium-Low	1.00	49.65 [b]	Poor-Medium	High-Medium
Sanitation	%	65.14	65.14 [a]	Medium-Good	Medium-Low	60.64	60.64 [a]	Medium-Good	Medium-Low
Law Enforcement	-	40	40.00 [e]	Poor-Medium	High-Medium	40	40.00 [e]	Poor-Medium	High-Medium
Geometric Final index	-		21.77	Poor	High		23.08	Poor	High

a = obtained using Eq. (4.1); b = obtained using (Eq.4.2); c = obtained using Table 4.1;
d = obtained using Table 4.2; e = obtained using Table 4.3

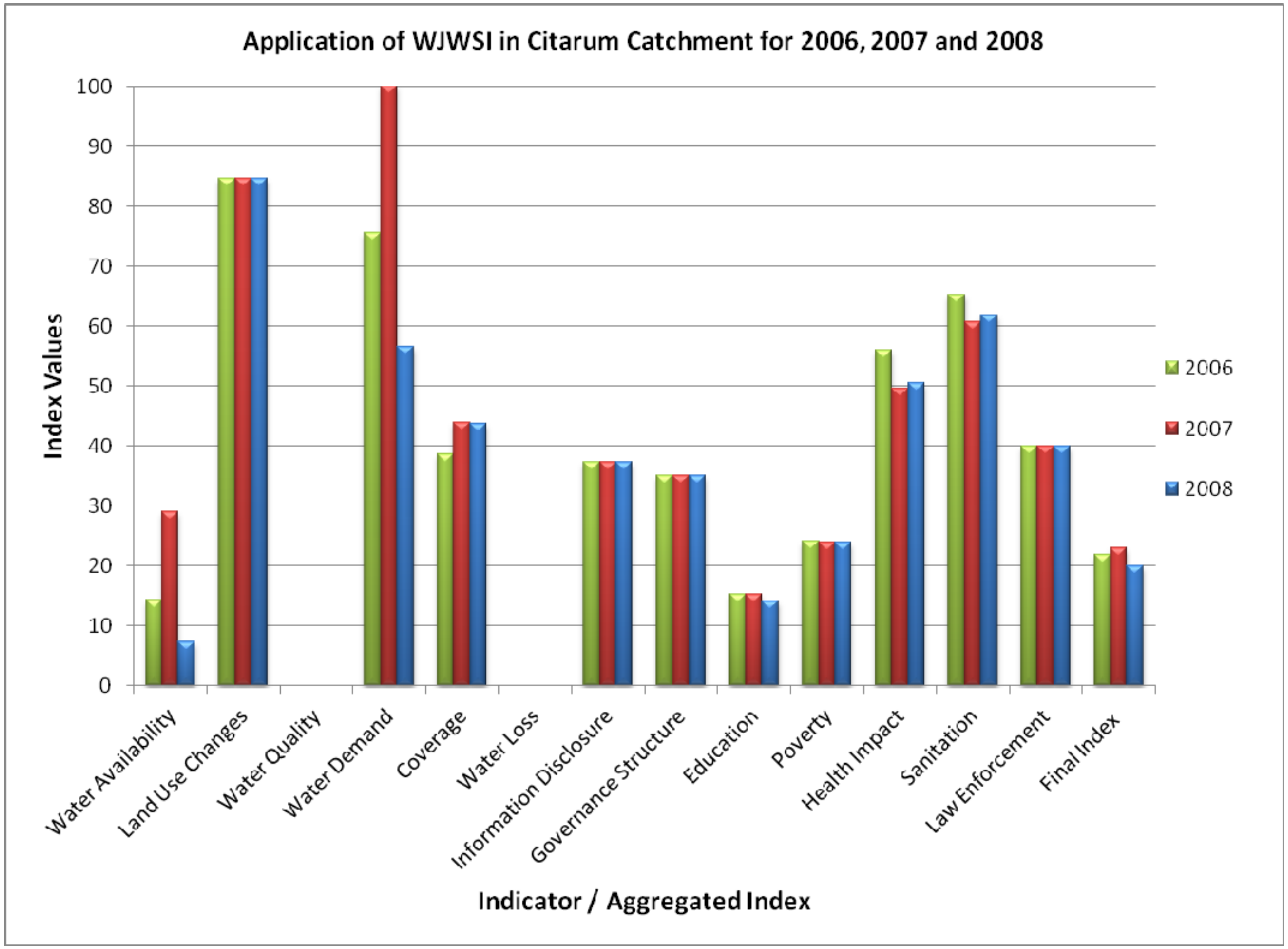


Figure 4.5 Sub-index values of indicators and sub-indicators for Citarum catchment

4.4.4 Recommendations for Water Authorities

Better quality and management of water resources in the Citarum catchment can be best achieved by providing higher priority to the improvement of the indicators and sub-indicators that are Poor in *Performance.* Based on WJWSI applications in 2006 to 2008, the indicators and sub-indicators that are Poor in *Performance* are *Water Availability, Water Quality, Education, Water Loss* and *Poverty*. The following sub-sections provide recommendations to improve poor performance indicators and sub-indicators to achieve at least a sub-index value of 25, and to move up to Poor-Medium performance. If these Poor indicators and sub-indicators are improved to at least 25 of their sub-indices, the final index value will be improved from 20.04 to 37.19 (Poor to Poor-Medium). It is recommended that water authorities in the Citarum catchment take appropriate actions to improve the sub-index values of these Poor indicators and sub-indicators. Some actions are presented below, which were as previously mentioned based on the data from 2008.

Water Availability

According to the WJWSI results, the actual availability of water in West Java in 2008 was 587 m^3/year. To increase the performance to at least Poor-Medium (or a sub-index value of 25), the actual availability needs to be increased to at least 812 m^3/person/year.

As mentioned earlier, the main factor causing low availability of water resources in the Citarum catchment is the density of population. Thus, the most effective way to increase the availability of water resources is by managing the population. One way to manage the population in the area is through the re-introduction of the 'transmigration' program, initiated in the early 1960s (Gondowarsito, 1986). Through this program, people were encouraged to be relocated to less-dense areas, outside the Java Island. They were given a piece of land, housing, and an establishment allowance to start a new life in a less dense area. However, this program was discontinued because people who had agreed to be relocated were unable to manage the land and housing given by the government, due to lack of skills (Gondowarsito, 1990). Therefore, if this program is to be re-initiated in the future, government needs to provide the necessary skills for people to manage the land in the proposed areas.

Another way of managing the population is to create centres of activities in less dense population areas within the West Java Province. At this stage, these centres (such as reliable shopping centres, leisure places and business areas) are concentrated in Bandung City in the Citarum catchment. Creating these centres in other areas will significantly reduce the motivation of people to migrate to Bandung City and other highly populated areas in the Citarum catchment. This can be done through the involvement and coordination of related stakeholders, particularly the Regional Planning Council as the responsible authority in planning and development, along with other business sectors, local governments and the community.

Water Quality

According to WJWSI results, in order to move from Poor to Poor-Medium performance, the actual value of *Water Quality* needs to be increased from -96.1 to -8.06.

Poor water quality in the catchment, as previously mentioned, has mainly been caused by lack of awareness of stakeholders. To address this issue, the government, West Java EPA and community groups need to develop programs to improve community awareness on water resources. To be successful, program targets should be clearly stated and progress regularly monitored.

Along with these community awareness programs, relevant authorities also need to enforce laws and regulations on river quality. To do this, close monitoring of the operation of waste water treatment plants is required to ensure that industrial waste water discharge meets the designated standard.

Education

The WJWSI results indicate that for the *Education* indicator, in order to move from Poor to Poor-Medium performance, the actual value needs to be increased from 14.19% to 25%.

In the last few years, the Ministry of Education in Indonesia has launched programs to improve the quality of primary education, namely *Bantuan Operasional Sekolah* (School Operational Grant) and *Sekolah Gratis* (Free School for Everyone). These programs include the exemption of education fees for all primary students in Indonesia, providing necessary books to most elementary schools, and improving the quality of school infrastructure. However, these programs have not yet been fully implemented. There are still cases where schools collect money from students by giving various excuses (Auditan, 2006; Widjajanti, 2006). Consequently, students from low income families are prevented from enrolling in these schools. Therefore, to effectively improve the quality of primary education, these obstacles need to be eliminated.

Water loss

Based on the WJWSI results, in order to move from Poor to Poor-Medium performance, the average actual value of *Water Loss* in the Citarum catchment needs to be reduced from 40.10% to 18.50%. The actual value of 18.50% will give the sub-index value of 25, as the minimum value for Poor-Medium performance.

According to Sukmayeni (2007), the water losses of water service providers (WSPs) in Indonesia, including the Citarum catchment, were caused by both physical and non-physical factors. The physical causes that lead to water losses are leakages in water treatment plants, transmission systems and distribution systems. As for the non-physical causes, the losses mainly come from unbilled consumption, inaccuracies of customer metering and illegal connections (Djamal et al., 2009). Yuwono (2009) suggests that higher priorities should be given to reducing the non-physical losses, as programs for reducing non-physical losses are more cost-efficient. The reduction of the non-physical losses will be an important starting point for the overall reduction of water losses by water service providers, even though the physical leakages are not yet addressed. It is believed that even though the non-physical losses are not real losses, they contribute to approximately 50% of the total unaccounted water of WSPs in West Java (Yuwono, 2009).

Poverty

For *Poverty*, WJWSI results indicate that a decrease of 0.43% of its actual value is needed to move from Poor to Poor-Medium performance. In the last few years, local, provincial and national governments have launched programs such as ‘direct cash assistance’ and ‘cheap rice’ to reduce the poverty level. The authorities reported that these programs have significantly reduced poverty in most provinces in Indonesia. However, such programs benefited the poor for a short period of time and some of these programs have been terminated. Once the programs were terminated, poverty levels increased. Also, due to lack of monitoring, it was found that some of these subsidy programs did not reach needy people. Thus, in the future, closer monitoring of implementation and continuation of these programs is crucial to ensure that benefits are received by those who most need them.

4.5 CILIWUNG CATCHMENT

4.5.1 Description of the Catchment

The main river in the Ciliwung catchment is the Ciliwung River. This river flows across two main provinces, West Java and Jakarta. The river originates from Talaga Warna spring, located in the Bogor region, and flows to Depok and Jakarta (Pusair, 2008), as illustrated in Figure 4.6. The catchment occupies an area of approximately 440 km^2, along the 119 km length of the Ciliwung River. According to the flow gauge in Satuduit Station, river flows vary during rainy and dry seasons. In 2007, a maximum flow of $125 m^3/s$ and a minimum flow of $49.4 m^3/s$ were recorded at this gauge (Pusair, 2008).

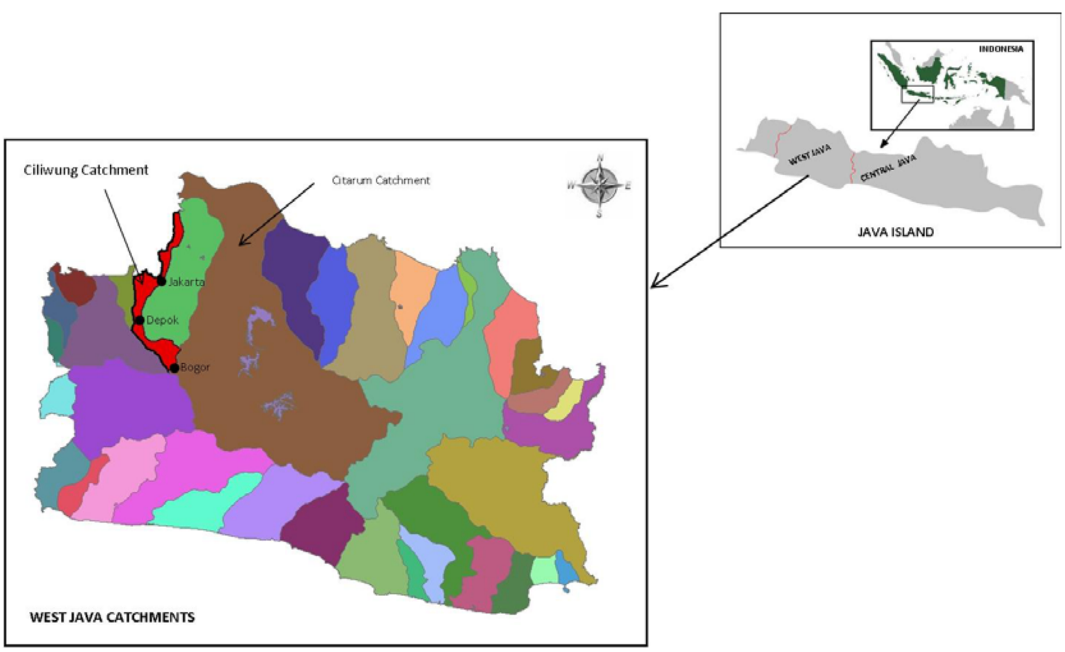


Figure 4.6 Ciliwung catchment in West Java

Currently, the Ciliwung River serves different users including domestic, industries and farmers. People along the river have built small water intakes to collect water for various domestic needs including drinking water. In many cases, people simply boil the water for drinking. As reported by Pusair (2008), approximately 3.5 million people live along the Ciliwung River banks, with the majority using river water for their daily activities. The river is also used by water companies in the catchment as the source of raw water for their water treatment plants. Bogor City, Bogor Regency and Depok City built water intakes in the upper, middle and lower parts of the river, with capacities of 20, 200 and 400 l/s respectively (Pusair, 2008).

The river is also used in the production of various kinds of chemicals, textiles, paints, batteries, pharmaceuticals, cosmetics, food and beverages, pulp and paper, and metals. Approximately, 120 l/s water from the Ciliwung River is used to meet industrial needs (Pusair, 2008).These industries also use groundwater for production activities. The other major use of the Ciliwung River is irrigation, for which small dams were built to supply water needs for various plantations, particularly rice paddy fields. Some of the dams are Katulampa and Cibanon, which serve irrigation areas of 1,494 ha and 652 ha respectively. Others dams used for irrigation purposes along the Ciliwung River are shown in
Table **4.13** (Pusair, 2008).

Table 4.13 Dams for irrigation along Ciliwung River

Dams	Coverage Area (ha)
Cibalok	187
Bantarjati	200
Karedanan	210
Citarim	142
Cikao	376
Ciseuseupan	79
Cikemasan	10

Various activities by 5.17 million people living in the Ciliwung catchment are the potential source of river polluters. Pusair (2008) reported that approximately 40% of the total population discharge their waste water, both directly and indirectly, into the river. The river also suffers from industrial and agricultural waste. At least 101 industries in the Ciliwung catchment constantly discharge their waste into the river. Some of these industries discharge their untreated waste water because they neither operate nor own a waste water treatment plant (Pusair, 2008).

Other potential pollutants come from agricultural and poultry activities. Agricultural waste includes the use of fertilisers and pesticides. Pusair (2008) reported that as much as 0.25 tonnes/day of nitrogen, 0.12 tonnes/day of phosphate and 0.013 tonnes/day of potassium were disposed in the river as fertilisers and pesticides. As for poultry, 583.5 kg of BOD/day and 1,540 kg/day of suspended particles and 90.5 kg/day of nitrogen were discharged (Pusair, 2008).

4.5.2 Application of WJWSI for 2006, 2007 and 2008

Similar to the Citarum catchment, the WJWSI was applied to the Ciliwung catchment for 2006, 2007 and 2008. Applications in different years were undertaken to provide a better understanding of water resource conditions.

4.5.2.1 Sub-index Values and Final index

The WJWSI was applied to the Ciliwung catchment using the same rationales as the application in the Citarum catchment. This includes the use of equations to obtain the sub-index values of indicators and sub-indicators, as well as the weighting scheme and aggregation method used to aggregate the indicators and sub-indicators. The results of the application are shown in Table 4.14. The sub-index values of *Information Disclosure, Governance Structure and Law Enforcement* in the Ciliwung catchment are the same as those in the Citarum catchment. This is due to centralised management at the provincial level. As both catchments are located in the West Java Province, the approach and actions related to indicators and sub-indicators are the same.

In general, the water sustainability performance of the Ciliwung catchment during 2006 to 2008 is considered Poor (geometric aggregation method). In 2008, 6 of 13 performance indicators are considered Poor (*Water Availability, Water Quality, Water Demand, Water Loss, Education* and *Health Impact*) and 4 are considered Poor-Medium (*Coverage, Information Disclosure, Governance Structure* and *Law Enforcement*). Of the Poor indicators, some indicators and sub-indicators have sub-index values of 0 including *Water Availability*, *Water Quality* and *Water Loss*. The following sub-sections discuss these indicators and sub-indicators with Poor performances based on data for 2008.

Table 4.14 Sub-indices of Ciliwung catchment for 2006, 2007 and 2008

Indicator/sub-indicator	***Unit***	***2006***				***2007***				***2008***			
		Actual Value	***Sub-index/ Final Index***	***Performance***	***Priority of Action***	***Actual Value***	***Sub-index/ Final Index***	***Performance***	***Priority of Action***	***Actual Value***	***Sub-index/ Final Index***	***Performance***	***Priority of Action***
Water Availability	m^3/cap/yr	463.21	0.00 [a]	Poor	High	375.00	0.00 [a]	Poor	High	485.22	0.00 [a]	Poor	High
Land Use Changes	*%*	98.56	98.56 [a]	Good	Low	98.56	98.56 [a]	Good	Low	98.56	98.56 [a]	Good	Low
Water Quality	-	-100.67	0.00 [b]	Poor	High	-50.22	0.00 [b]	Poor	High	-55.78	0.00 [b]	Poor	High
Water Demand	*%*	30.30	32.54 [b]	Poor	High	40.49	0.00 [b]	Poor	High	34.72	17.60 [b]	Poor	High
Coverage	*%*	32.54	40.68 [a]	Poor-Medium	High-Medium	32.67	40.84 [a]	Poor-Medium	High-Medium	32.63	40.79 [a]	Poor-Medium	High-Medium
Water Loss	*%*	29.94	0.00 [b]	Poor	High	30.31	0.00 [b]	Poor	High	30.26	0.00 [b]	Poor	High
Information Disclosure	-	37.27	37.27 [c]	Poor-Medium	High-Medium	37.27	37.27 [c]	Poor-Medium	High-Medium	37.27	37.27 [c]	Poor-Medium	High-Medium
Governance Structure	-	35	35.00 [d]	Poor-Medium	High-Medium	35	35.00 [d]	Poor-Medium	High-Medium	35	35.00 [d]	Poor-Medium	High-Medium
Education	*%*	23.54	23.54 [a]	Poor	High	20.70	20.70 [a]	Poor	High	19.49	19.49 [a]	Poor	High
Poverty	*%*	5.22	73.87 [b]	Medium-Good	Medium-Low	5.23	73.84 [b]	Medium-Good	Medium-Low	5.24	73.81 [b]	Medium-Good	Medium-Low
Health Impact	(*cases/1000 pop)*	1.36	32.27 [b]	Poor-Medium	High-Medium	1.60	19.99 [b]	Poor	High	1.57	21.32 [b]	Poor	High
Sanitation	*%*	86.51	86.51 [a]	Good	Low	83.78	83.78 [a]	Good	Low	82.81	82.81 [a]	Medium-Good	Medium-Low
Law Enforcement	-	40	40.00 [e]	Poor-Medium	High-Medium	40	40.00 [e]	Poor-Medium	High-Medium	40	40.00 [e]	Poor-Medium	High-Medium
Geometric Final index			**18.64**	Poor	High		**13.59**	Poor	High		**16.94**	Poor	High

a = obtained using Eq. (4.1); b = obtained using (Eq.4.2); c = obtained using Table 4.1;
d = obtained using Table 4.2; e = obtained using Table 4.3

The actual value of *Water Availability* in the Ciliwung catchment in 2008 is 485.22 m^3/cap/yr, which is below the minimum threshold. This means available water resources in the catchment are not sufficient to support basic water needs for the entire population within the catchment (Falkenmark & Rockström, 2004). As stated in Section 4.4.2.1, two variables were used to calculate the actual value of this indicator, which are rainfall and population. Even though the average annual rainfall in the area for 2008 is well above the average annual rainfall in the West Java Province (3867 mm/year compared to the average of 2000 mm/year), the catchment is densely populated. Consequently, available fresh water is not sufficient to support the demand. The main factor for highly populated areas in the Ciliwung catchment is the proximity of the catchment to Jakarta, the capital city of Indonesia. As Jakarta offers job opportunities, people from different regions of Indonesia continuously come to live in Jakarta. These people, due to various economic reasons, are forced to live in areas adjacent to Jakarta, including the Ciliwung catchment.

Water Quality is also a poor indicator with the sub-index value of 0 (zero). The value of 0 (zero) indicates that water quality along the Ciliwung River does not meet national water quality standards. Lack of resources and commitment to the implementation of stream regulations are the factors that lead to deterioration of water quality in the catchment. At national, regional and local levels, regulations on stream use are already available, but these regulations are not adequately implemented. For example, even though regulations on the discharge of waste water along the river are available, community groups report that many industries and households directly discharge their waste water into the river, without proper treatment (Febrian et al., 2004). These households discharge waste water because of the lack of treatment facilities and lack of awareness about river water quality. The improper practices of industries are mainly caused by weakness in law enforcement by the relevant authorities.

Water Demand is another indicator with Poor performance, calculated as the ratio of water use for different purposes (domestic, industry and agriculture), to the total available water. In 2008, the actual value for *Water Demand* was calculated as 34.72%. The value nearly reached the standard for maximum percentage of water use set by the United Nations Commission on Sustainable Development (40%), also the minimum threshold used in the WJWSI. The high percentage of water demand in the Ciliwung catchment for 2008 was mainly caused by high population density (331 people/km^2).

In addition to high population density, as mentioned, there are a large number of industries along the Ciliwung River (101 different industries) and considerable agricultural areas (1,200 hectares) dependent on the river for water needs. These factors have led to the increase of water use in the Ciliwung catchment, and consequently contributed to the low sub-index value of the *Water Demand* indicator.

The *Water Loss* indicator has a sub-index value of 0. This was calculated, based on the average water loss of 7 WSPs in the Ciliwung catchment. This water loss for 2006 to 2008 is shown in Table 4.15. It indicates that these losses for the three year period are considerably high, and well above the threshold of 15% regulated by the National Government of Indonesia (Kirmanto, 2007), which is also the maximum threshold used in the WJWSI. Both physical and non-physical losses have contributed to the high value of water loss by WSPs.

As previously mentioned, common physical losses are leakages in water treatment plants, transmission systems and distribution systems, whereas non-physical losses are unbilled consumption, inaccuracies of customer metering and illegal connections (Djamal et al., 2009). Therefore, genuine efforts must be made to achieve the maximum water loss target (15%) in the Ciliwung catchment, as required by government.

Table 4.15 Percentage of *Water Loss* in Ciliwung catchment

City/District	2006 (%)	2007 (%)	2008 (%)
Bogor Regency	35	38	35
Sukabumi Regency	49	43	39
Cianjur Regency	29	36	32
Bekasi Regency	40	39	39
Bogor City	30	30	33
Bekasi City	23	23	23
Depok City	35	35	35

The sub-index value of 19.49 for *Education* in the Ciliwung catchment means that only 19.49% of the total population have completed basic education (or primary school) during 2008. Since 2005, the government has introduced programs to increase the number of enrolled students in primary schools.

As stated in section 4.4.4, these programs include *Bantuan Operasional Sekolah* (School Operational Grant) and *Sekolah Gratis* (Free School for Everyone*)*. These programs were mainly designed to improve the enrolment rate of primary school students in Indonesia. As the programs were started in 2005, assessment on their success in increasing student numbers who complete primary school (6 years) can only be completed after 2011. Therefore, the sub-index value of *Education* does not reflect the effect of these programs.

The last indicator for Poor performance is *Health Impact*. During 2006 to 2008, the average actual value for this indicator was 1.51, which means of 10,000 people, 15 were reported to suffer from haemorrhagic dengue, well above the target of 0 (zero) cases issued by the Health Ministry of Indonesia. Most of these cases in the Ciliwung catchment were caused by the quality of water consumed. Many people utilise water from the Ciliwung River for their daily needs, including drinking water, without proper treatment. These practices, along with the poor quality of river water, are believed to be the causes for high cases of haemorrhagic dengue in the Ciliwung catchment (Health Department of Republic of Indonesia, 2005).

In addition to Table 4.14 which shows the results of WJWSI applications in the Ciliwung catchment,

Figure 4.7 illustrates the comparison for 2006 to 2008. This figure shows that the sub-index values remain constant or slightly change over this period, except for *Water Demand* and *Health Impact*. The sub-index value for *Water Demand* in 2007 equals 0 (zero), whereas in 2006 and 2008, sub-index values were 32.54 and 17.60 respectively.

Table 4.16 shows the variables that compose the sub-index value of *Water Demand*, which constitutes the water used for various activities and available water (shown by rainfall).

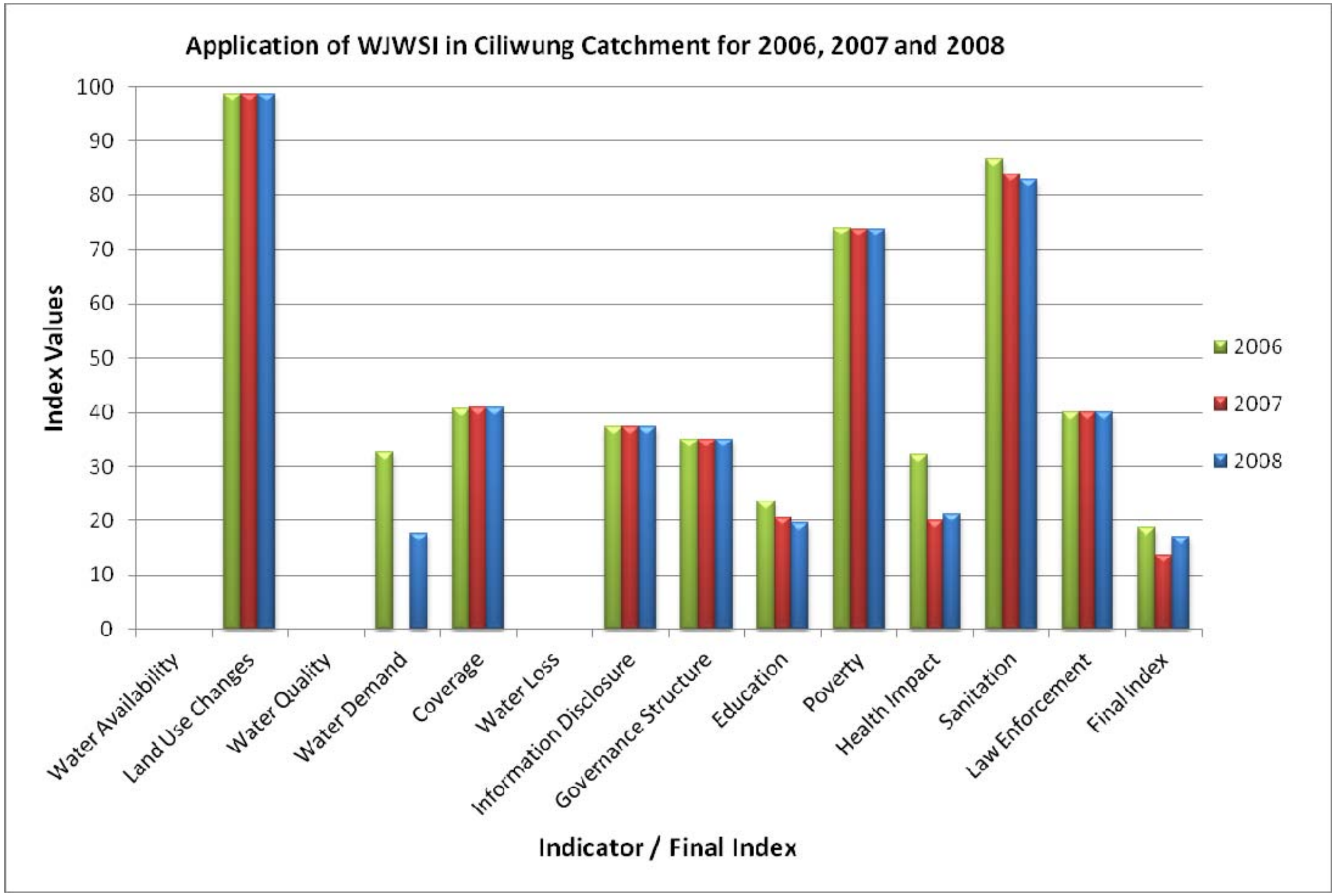


Figure 4.7 Sub-index values of indicators and sub-indicators for Ciliwung catchment

Table 4.16 The rainfall and water used in Ciliwung catchment, 2006 to 2008

Variables	2006	2007	2008
Rainfall (mm/year)	3575.40	2952.63	3866.67
Total water used (million m^3/year)	1.24	1.35	1.49

As shown in Table 4.16, the water used for various purposes in the Ciliwung catchment increased gradually from 2006 to 2008. However, during the same period, rainfall fluctuated significantly. The average rainfall in 2007 has shown a considerable decrease from the previous year, and then increased substantially in 2008. These changes have resulted in fluctuation of sub-index values of the *Water Demand* indicator. The relatively low rainfall in 2007, which implies the decrease of water availability, has resulted in the increase of actual value for *Water Demand*. This increase in actual value has resulted in the demand for water in the area above 40%, as the maximum threshold of *Water Demand* indicator (refer to Eq. 4.2). As the actual demand was above 40%, the sub-index value for *Water Demand* was calculated as 0. Fluctuation in rainfall also affected the actual values of *Water Availability* in the same period. However, as these actual values are below the minimum threshold, the sub-index values of *Water Availability* are 0.

Figure 4.7 also shows that final index values for the Ciliwung catchment are below 20, and considered Poor in performance. In 2006, the final index value was slightly higher compared to 2007 and 2008, due to better performances in Water Demand, Education and Health Impact. The lowest final index value was in 2007, due to low performances of Water Demand and Health Impact indicators.

4.5.2.2 Robustness Analysis of WJWSI

Similar to the Citarum catchment, the robustness of the WJWSI based on the Ciliwung catchment was analysed by performing uncertainty and sensitivity analysis on the index, based on data of 2008. The outcomes of various steps are presented in Table 4.17, 4.19 and 4.20.

Similar to robustness analysis for the Citarum catchment, the robustness analysis for the Ciliwung catchment is based on the methodology explained in section 4.2.3. Uncertainty analysis seeks to understand how thresholds affect sub-index values and the final index. The results of uncertainty analysis for the Ciliwung catchment are shown in Table 4.17. This table shows that coefficients of variations of the thresholds are varied. These results are similar to those of the Citarum catchment, as the distribution function of minimum and maximum thresholds of indicators and sub-indicators used in the MC simulation are the same. The only difference is the actual value of indicators and sub-indicators.

It is also shown in Table 4.17 that coefficients of variation compensate each other to produce sub-index values (shown in Column 8). Table 4.17 shows that minimum thresholds of *Land Use Changes, Coverage, Education, Poverty, Health Impact* and *Sanitation,* and the maximum threshold of *Water Quality* have higher coefficients. Thus, it is important to collect more specific information on these thresholds, so that uncertainty can be reduced. The coefficients of variation of *Water Availability*, *Water Quality* and *Water Loss* cannot be computed as their sub-index values are calculated as 0 during the MC simulation.

Table 4.17 (column 9) also presents how 10,000 *Performances* of each indicator or sub-indicator resulted from the MC simulation, compared to its original performance. It shows that *Performances* of most indicators and sub-indicators have changed by only ±10% or less compared to their original performance (except for *Poverty*). This indicates that performance of these indicators and sub-indicators are not sensitive to changes in thresholds. *Performances* of the *Poverty* indicator have changed 3,480 times (34.8%) during the simulation from Medium-Good to Good, as the means of the sub-index values resulting from the MC simulation of 76.1 (original sub-index value of 73.8) was close to the performance boundary of 75,and it has crossed the performance boundary 3,480 times. The *Performance* reflects the condition of issue(s) related to an indicator or sub-indicator, which was obtained based on the sub-index value of an indicator or sub-indicator.

Table 4.17 Results of uncertainty analysis for Ciliwung catchment

1	2	3	4	5	6	7	8			9
Thresholds	Unit	Base Value	Mean	Std. Deviation	Coefficient of Variation	Indicators/Sub-Indicators	Sub-index values			Unchanged Performance (%)
							Mean	Std. Deviation	Coefficient of Variation	
Water Availability – Maximum	m^3/cap/yr	1,700	1,600.3	107.9	0.07	*Water Availability*	0.0 (0.0)	0.0	-	100
Water Availability – Minimum	m^3/cap/yr	500	532.9	23.5	0.04					
Land Use Changes – Maximum	%	100	93.2	4.8	0.05	*Land Use Change*	99.9 (98.6)	0.3	0.00	100
Land Use Changes – Minimum	%	0	3.4	2.4	0.71					
Water Quality – Maximum	-	0	-1.0	0.7	0.70	*Water Quality*	0.0 (0.0)	0.0	-	100
Water Quality – Minimum	-	-31	-30.0	0.7	0.02					
Water Demand – Maximum	%	40	40.0	1.6	0.04	*Water Demand*	15.7 (17.6)	4.3	0.27	100
Water Demand – Minimum	%	10	6.7	2.4	0.35					
Coverage – Maximum	%	80	79.9	3.3	0.04	*Coverage*	38.8 (40.8)	2.2	0.06	100
Coverage – Minimum	%	0	2.7	1.9	0.71					
Water Loss – Maximum	%	30	28.3	1.2	0.04	*Water Loss*	0.0 (0)	0.0	-	100
Water Loss – Minimum	%	15	10.0	3.5	0.35					
Education – Maximum	%	100	96.7	2.4	0.02	*Education*	14.0 (19.49)	4.7	0.33	100
Education – Minimum	%	0	6.7	4.7	0.71					
Poverty – Maximum	%	20	20.0	2.0	0.10	*Poverty*	76.1 (73.8)	3.2	0.04	65.2
Poverty – Minimum	%	0	0.7	0.5	0.71					
Health Impact – Maximum	*(cases/1000 pop)*	2	2.0	0.1	0.04	*Health Impact*	21.9 (21.3)	3.4	0.15	100
Health Impact – Minimum	*(cases/1000 pop)*	0	0.1	0.1	0.71					
Sanitation – Maximum	%	100	96.7	2.4	0.02	*Sanitation*	84.6 (82.8)	2.4	0.03	100
Sanitation – Minimum	%	0	6.7	4.7	0.70					
Boundary Value of 25	-	25	25.1	7.2	0.29	*Information Disclosure*	37.27 (37.27)	-	-	98.95
Boundary Value of 50	-	50	50.0	7.2	0.14	*Governance Structure*	35.00 (35.00)	-	-	89.86
Boundary Value of 75	-	75	75.1	7.2	0.10	*Law Enforcement*	40.00 (40.00)	-	-	90.26

The sensitivity analysis in relation to the Ciliwung catchment was performed as for the Citarum catchment. The correlation of the thresholds of non-categorical indicators and sub-indicators and the final index value were analysed. To do this, the correlation coefficients of 10,000 threshold data and corresponding final index values resulting from the MC simulation were computed. The correlation coefficients are shown in Table 4.18.

Table 4.18 Correlation coefficients between final Index and thresholds

Thresholds of Indicators and Sub-indicators	Correlation Coefficient
Water Availability / Maximum Threshold	0.010
Water Availability / Minimum Threshold	-0.002
Land Use Changes / Maximum Threshold	0.007
Land Use Changes / Minimum Threshold	-0.001
Water Quality / Maximum Threshold	-0.006
Water Quality / Minimum Threshold	0.006
Water Demand / Maximum Threshold	-0.009
Water Demand / Minimum Threshold	-0.002
Coverage / Maximum Threshold	-0.016
Coverage / Minimum Threshold	0.002
Water Loss / Maximum Threshold	-0.008
Water Loss / Minimum Threshold	-0.006
Education / Maximum Threshold	-0.030*
Education / Minimum Threshold	0.009
Poverty / Maximum Threshold	-0.013
Poverty / Minimum Threshold	-0.005
Health / Maximum Threshold	0.013
Sanitation / Maximum Threshold	0.001
Health / Minimum Threshold	0.015
Sanitation / Minimum Threshold	-0.015

** Significant, based on the two-tailed probability value (p value< 0.05)*

Table 4.18 shows that only the correlation coefficient for the maximum threshold of *Education* is statistically significant. Thus, any changes in other thresholds will not significantly increase or decrease the final index value. Based on this finding, it is concluded that the final index value of the Ciliwung catchment is not sensitive to most of the thresholds, using the analysis for 2008. With regards to *Education*, its correlation with the final index is considered weak (although statistically significant), as shown by the value of its correlation coefficient (-0.030). This weak correlation coefficient means that changes in the sub-index value of *Education* will not significantly change the final index value.

The sensitivity analysis in this study also aims to answer the question: “Which weighting scheme or aggregation method mostly affects the final index?” In order to answer this question, different aggregation combinations, based on different weighting schemes and aggregation methods, were analysed as for the Citarum catchment. Results of these aggregations are shown in Table 4.19.

Table 4.19 Aggregation results based on different weighting schemes and aggregation methods

Scenario	Arithmetic Aggregation Method	Geometric Aggregation Method	*Changes*
Equal weights	35.64	20.18	**15.46**
Non-equal weights	31.26	20.52	**10.74**
Changes	**4.38**	**0.34**	

Table 4.19 shows the changes on final the index values due to the changes from equal to non-equal weights. They were 4.38 and 0.34 respectively for arithmetic and geometric aggregation methods. Changes to final index values from the arithmetic method to the geometric aggregation method were 15.46 and 10.74 for equal weights and non-equal weights respectively. Similar to the results for the Citarum catchment, Ciliwung catchment results show that the aggregation method is more sensitive to the final index value, compared to the weighting schemes.

Therefore, similar to the recommendation given based on the results of robustness analysis in the Citarum catchment, for future use of the WJWSI, either the equal or non-equal weighting scheme can be used. For the aggregation method, it is recommended to use the geometric method.

4.5.2.3 Recommendations for Water Authorities

The results of the WJWSI applications in the Ciliwung catchment for 2006 to 2008 have shown that indicators of *Water Availability, Water Quality, Water Demand, Water Loss* and *Health Impact* require immediate action, as they have performed poorly. For each indicator, specific issues that cause low performances need to be adequately addressed.

Relevant authorities should carefully design appropriate programs to address these issues, and supported by reasonable and achievable target(s). For example, as the low sub-index value of the *Water Quality* indicator was mainly caused by the discharge of waste water by industries, the West Java Environmental Protection Agency (EPA) along with other relevant authorities need to strictly enforce the industries to abide by the law on waste water discharge and treatment. The following sub-sections provide recommendations to improve poor performing indicators and sub-indicators to achieve at least the sub-index value of 25, in order to move to the next best performance (Poor-Medium). If these indicators and sub-indicators with Poor performance can be improved, at least to 25 sub-indices, the final index value in the Ciliwung catchment will improve from 16.94 to 37.72 (Poor to Poor-Medium). These recommendations were based on 2008 data.

Water Availability

The actual value of *Water Availability* in the Ciliwung catchment in 2008 is 428.22 m^3/year. To increase the performance to Poor-Medium (or a sub-index value of 25), the actual value needs to be increased by at least 812 m^3/person/year.

Similar to the Citarum catchment, the main factor causing low value of *Water Availability* in the Ciliwung catchment is the high density of population living in the area. As mentioned earlier, the only way to increase *Water Availability* in the area is by managing the population. This can be done through the re-introduction of the 'transmigration' program and creating centres of activities in less dense population areas within the West Java Province. Details of these programs were presented under the 'Recommendation to Water Authorities' for the Citarum catchment (section 4.4.4).

Water quality

According to the WJWSI application in the Ciliwung catchment for 2008, the actual value for *Water Quality* was -55.78. In order to move from Poor to Poor-Medium performance, the actual value of the *Water Quality* needs to be increased to -8.06.

Similar to the Citarum catchment, poor water quality in the Ciliwung catchment was mainly caused by the lack of awareness of stakeholders (particularly domestic and industries along the rivers). Relevant approaches that can be used to address these issues for the Ciliwung catchment were explained in section 4.4.4.

Water Demand

Table 4.14 on the application of the WJWSI to the Ciliwung catchment for 2008 shows that the actual value of *Water Demand* is 34.72%, which gives the sub-index value of 17.60 (*Poor* performance). In order to increase the sub-index to 25, as the minimum value for Poor-Medium performance, the actual value of 34.72% needs to be reduced to 32.5%.

The actual value of *Water Demand* was the ratio of water use to available water in the catchment. As the available water was dependent on rainfall, the reduction of actual value of *Water Demand* can only be achieved by controlling the use of water in the catchment. Water uses in the catchment are mainly for domestic, industry and irrigation. Therefore, the water authorities in the Ciliwung catchment, in coordination with other relevant authorities, should carefully determine the combination of water use reduction from domestic, industry and irrigation sectors. The reduction in water use for domestic needs can be achieved by controlling the population in the catchment, which will also improve *Water Availability*. The reduction of water use for industry can be done through controlling the number of industries, or introducing new practices with significant reduction in water uses. Similar ideas can also be applied to irrigation, where new cultivation practices can be introduced to reduce the amount of water used for irrigation.

Water loss

According to the results of WJWSI application in the Ciliwung catchment in 2008, in order to move from Poor to Poor-Medium performance, the actual value of *Water Loss* needs to be reduced from 30.26% to 18.50%. The actual value of 18.50% will give the sub-index value of 25, as the minimum value for the Poor-Medium performance. Similar to the recommendations given for the Citarum catchment, WSPs in the Ciliwung catchment should focus on reducing non-physical losses to improve the performance of *Water Loss*, as the non-physical losses in WSPs contribute to approximately 50% of the total losses (Yuwono, 2009). After significant progress is made on the reduction of non-physical losses, programs on the reduction of the physical losses should also be initiated.

Health Impact

During the application of the WJWSI to the Ciliwung catchment for 2008, it was found that the actual value of *Health Impact* was 1.57. This needs to be reduced to 1.5, in order to move from Poor to Poor-Medium performance.

The high actual value of *Health Impact* in the Ciliwung catchment was caused by poor water quality and sanitation (Health Department of Republic of Indonesia, 2005). The only way to lower the actual value of this indicator is by reducing haemorrhagic dengue cases within the catchment. The Ministry of Health in Indonesia has introduced simple programs to prevent the proliferation of disease. These programs mainly aim at abating the mosquitoes responsible for spreading the disease (Pujiyanto et al., 2008), which include cleaning water storages regularly, closing the lids of water storages properly, and removing any bins that can be used by mosquitoes to reproduce. To implement these programs, relevant authorities in the Ciliwung catchment should set reasonable targets, and monitor them. To effectively implement these programs, the involvement of relevant health centres and other community-based organisations is essential.

4.6 CITANDUY CATCHMENT

4.6.1 Description of the Catchment

The Citanduy catchment is one of the largest in the West Java Province, and also one of the critical catchments in terms of erosion, sedimentation and flood risk (Hasibuan, 2005; Prasetyo, 2004). The main river in the catchment is the Citanduy River, which flows across two provinces, in West Java and Central Java. The river originates from Tasikmalaya in West Java and ends in the Indian Ocean (Nair et al., 2010).

The Citanduy catchment covers a total area of approximately 346,000 ha, divided into five sub-catchments. The coverage area of each sub-catchment is shown in Table 4.20. The Citanduy catchment is located on the eastern part of the West Java Province, bordered by the Central Java Province, as shown in Figure 4.8.

Table 4.20 Coverage areas of sub-catchments in Citanduy catchment

Sub-Catchments	Approximate Coverage Area (ha)
Upper Citanduy	70,000
Cimuntur	60,000
Cijolang	48,000
Cikawung	70,000
Ciseel	98,000

The Citanduy catchment occupies several cities and regencies in the West Java Province. These cities are Banjar and Tasikmalaya, and the regencies are Ciamis, Tasikmalaya, Kuningan, Majalengka, Cilacap and Banyumas. Compared to the other two catchments (i.e. Citarum and Ciliwung), the Citanduy catchment is the least densely populated. In each sub-catchment, the population density varies. The most populated area is the sub-catchment of Upper Citanduy and the least populated is the sub-catchment of Cimuntur (Nair et al., 2010). In the Citanduy catchment, farms constitute the most dominant land use. As much as 54.6% of the catchment area is used for farming, such as fruit gardens, perennial crop-lands and agro-forests(Nair et al., 2010). The next dominant land use is paddy fields (20.5%) and forestry (14.6%).

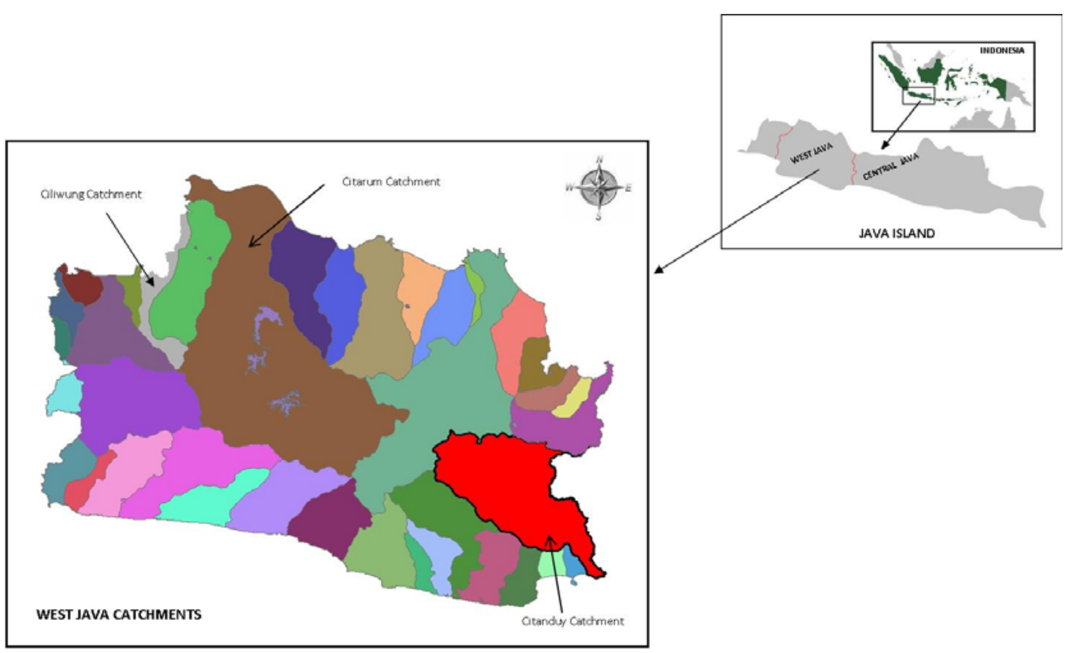


Figure 4.8 The Citanduy catchment in West Java

4.6.2 Application of WJWSI for 2006, 2007 and 2008

Similar to the other catchments in this study, the application of the WJSWI in the Citanduy catchment was initiated by collecting the required data for each indicator and sub-indicator. The sub-index values for WJWSI indicators and sub-indicators were then calculated. These sub-index values were then aggregated to produce the final index. This process was followed for 2006, 2007 and 2008.

4.6.2.1 Sub-index Values and Final index

The same equations that were used for the Citarum and Ciliwung catchments were used for the Citanduy catchment. This includes the use of equations to obtain the sub-index values of indicators and sub-indicators, as well as the weighting scheme and aggregation method used to aggregate the indicators and sub-indicators. The results are shown in Figure 4.9 and Table 4.21. Table 4.21 (as well as Tables 4.8, 4.12 and 4.14) shows that the sub-index values of *Information Disclosure, Governance Structure and Law Enforcement* in the Citanduy catchment are the same as those in the Citarum and Ciliwung catchments. This is due to centralised management at the provincial level. As all three catchments are located in the West Java Province, the approach and actions related to indicators and sub-indicators are the same.

Figure 4.9 shows that during the three year period from 2006 to 2008, the sub-index values of WJWSI indicators and sub-indicators in the Citanduy catchment are relatively constant. Apparently, during 2006-2008, there were not significant changes on the variables of the indicators and sub-indicators in the Citanduy catchment. Consequently, the sub-index values of these indicators and sub-indicators have only slightly changed.

It is also noticeable that during this period, *Water Availability* and *Water Demand* indicators have sub-index values of 100. The sub-index value of *Water Availability* reached its maximum value because the relatively high rainfall in the catchment was sufficient to accommodate the water needs of the entire population. Compared to the Citarum and Ciliwung catchments, population density in the Citanduy catchment is considerably low. Consequently, available water is abundant, as reflected in the high sub-index value of *Water Availability* of the Ciliwung catchment.

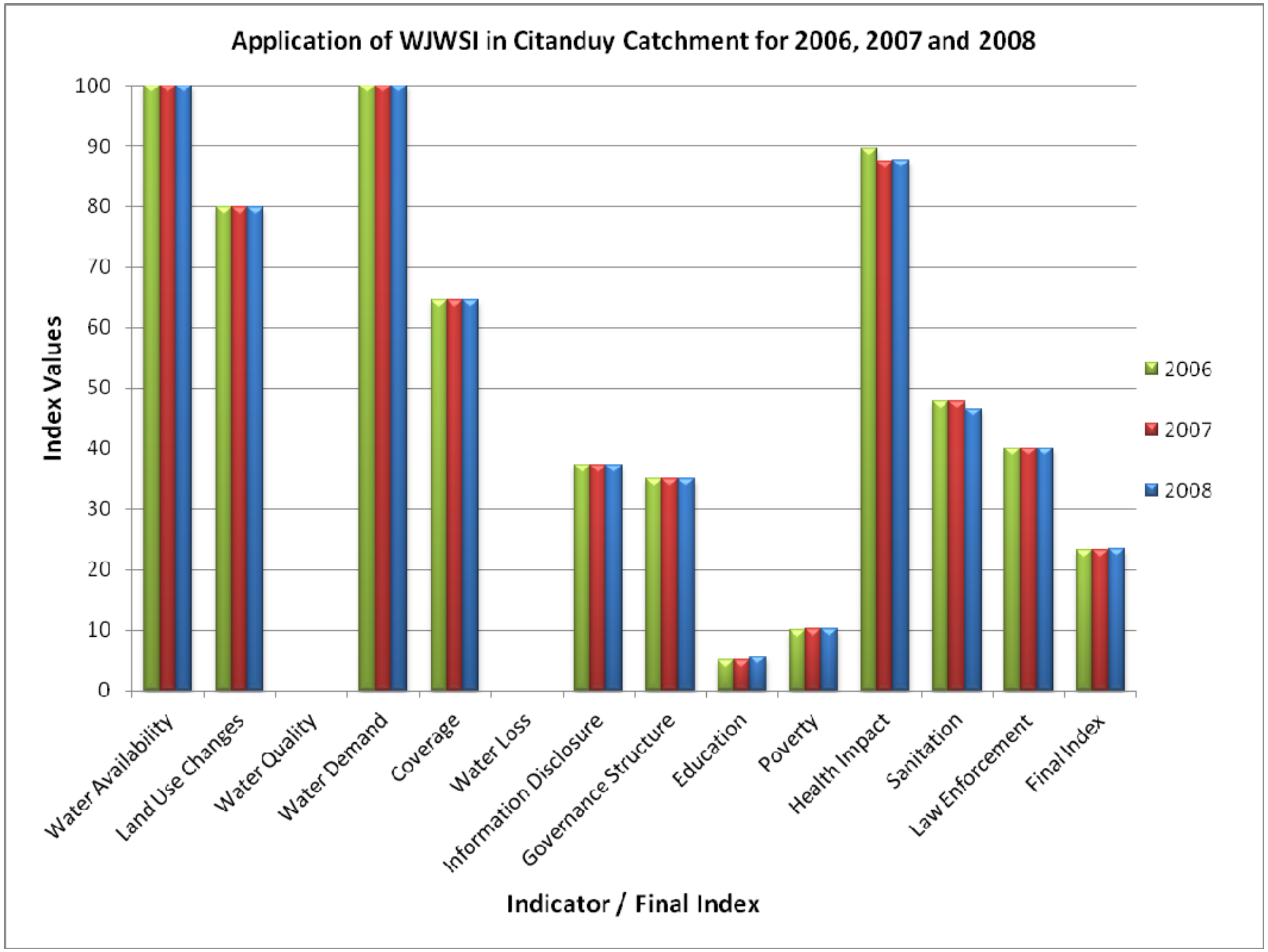


Figure 4.9 Sub-index values of indicators and sub-indicators for Citanduy catchment

Table 4.21 Sub-indices of Citanduy catchment for 2006, 2007 and 2008

Indicator/sub-indicator	*Unit*	*2006*				*2007*				*2008*			
		Actual Value	*Sub-index/ Final Index*	*Performance*	*Priority of Action*	*Actual Value*	*Sub-index/ Final Index*	*Performance*	*Priority of Action*	*Actual Value*	*Sub-index/ Final Index*	*Performance*	*Priority of Action*
Water Availability	m^3/cap/yr	3299.29	100.00 [a]	Good	Low	3723.32	100.00 [a]	Good	Low	2507.87	100.00 [a]	Good	Low
Land Use Changes	*%*	79.86	79.86 [a]	Good	Low	79.86	79.86 [a]	Good	Low	79.86	79.86 [a]	Good	Low
Water Quality	-	-91.33	0.00 [b]	Poor	High	-40.33	0.00 [b]	Poor	High	-68.67	0.00 [b]	Poor	High
Water Demand	*%*	2.50	100.00 [b]	Good	Low	2.24	100.00 [b]	Good	Low	4.93	100.00 [b]	Good	Low
Coverage	*%*	51.57	64.47 [a]	Medium-Good	Medium-Low	51.61	64.51 [a]	Medium-Good	Medium-Low	51.65	64.56 [a]	Medium-Good	Medium-Low
Water Loss	*%*	44.29	0.00 [b]	Poor	High	35.42	0.00 [b]	Poor	High	33.70	0.00 [b]	Poor	High
Information Disclosure	-	37.27	37.27 [c]	Poor-Medium	High-Medium	37.27	37.27 [c]	Poor-Medium	High-Medium	37.27	37.27 [c]	Poor-Medium	High-Medium
Governance Structure	-	35.00	35.00 [d]	Poor-Medium	High-Medium	35.00	35.00 [d]	Poor-Medium	High-Medium	35.00	35.00 [d]	Poor-Medium	High-Medium
Education	*%*	5.04	5.04 [a]	Poor	High	5.04	5.04 [a]	Poor	High	5.62	5.62 [a]	Poor	High
Poverty	*%*	17.98	10.12 [b]	Poor	High	17.97	10.13 [b]	Poor	High	17.97	10.15 [b]	Poor	High
Health Impact	(*cases/1000 pop)*	0.21	89.50 [b]	Good	Low	0.25	87.50 [b]	Good	Low	0.25	87.70 [b]	Good	Low
Sanitation	*%*	47.74	47.74 [a]	Poor-Medium	High-Medium	47.74	47.74 [a]	Poor-Medium	High-Medium	46.55	46.55 [a]	Poor-Medium	High-Medium
Law Enforcement	-	40.00	40.00 [e]	Poor-Medium	High-Medium	40.00	40.00 [e]	Poor-Medium	High-Medium	40.00	40.00 [e]	Poor-Medium	High-Medium
Geometric Final index			23.26	Poor	High		23.23	Poor			23.39	Poor	High

a = obtained using Eq. (4.1); b = obtained using Eq. (4.2); c = obtained using Table 4.1;
d = obtained using Table 4.2; e = obtained using Table 4.3

The sub-index value of *Water Demand* is also high, as the water use for different purposes in the catchment was low compared to the availability of water in the catchment. The percentage of water use compared to the availability of water in Citanduy in 2008, for example, is relatively low (3.36%), compared to those of in Citarum (23.04%) and Ciliwung (34.72%). In spite of 100% sub-index values for *Water Availability* and *Water Demand*, the indicators and sub-indicators of *Water Quality, Water Loss, Education* and *Poverty* in the Citanduy catchment show the sub-index values are below 25 (Poor). These low sub-index values were also observed in the Citarum and Ciliwung catchments, and the causes for such low values are similar (refer to sections 4.4.4 and 4.5.2.1).

4.6.2.2 Robustness Analysis of WJWSI

Similar to the Citarum and Ciliwung catchments, uncertainty and sensitivity analysis were carried out for the Citanduy catchment based on the uncertainty and sensitivity analysis scheme using the data of 2008**,** as described in Section 4.2.3. The outcomes of this analysis of the Citanduy catchment are presented in Table 4.22, 4.24 and 4.25.

Table 4.22 shows that the coefficients of variation of the sub-indices for *Education* and *Poverty* are relatively high, compared to those for other indicators and sub-indicators. Therefore, for future use, it is important to collect more specific information on the thresholds related to *Education* and *Poverty*, so that uncertainty related to these thresholds and their sub-index values can be reduced. In the last column of Table 4.22, it is also shown that the performances of indicators and sub-indicators have changed only by 10% or less. This implies that *Performances* are not sensitive to changes in their thresholds. The *Performance* reflects the condition of issue(s) related to an indicator or sub-indicator, which was obtained based on the sub-index value of an indicator or sub-indicator.

The sensitivity analysis in relation to the Citanduy catchment was performed using the same procedures as for previous catchments. The correlation of thresholds and final index value was analysed. To do this, the correlation coefficients of 10,000 threshold data and 10,000 final index values resulting from the MC simulation were computed. These correlation values reflect the effects of changes in thresholds in the final index value. Results of the computation of correlation coefficients of these two variables are shown in Table 4.23, with significant correlation coefficients marked with asterisks.

Table 4.22 Results of uncertainty analysis for Citanduy catchment

1	2	3	4	5	6	7	8			9
Thresholds	Unit	Base Value	Mean	Standard Deviation	Coefficient of Variation	Indicators/Sub-Indicators	Sub-index values			Unchanged Performance (%)
							Mean (original values)	Standard Deviation	Coefficient of Variation	
Water Availability – Maximum	m^3/cap/yr	1,700	1,600.0	107.9	0.07	*Water Availability*	100.0 (100.0)	0.0	0.0	100
Water Availability – Minimum	m^3/cap/yr	500	533.4	23.6	0.04					
Land Use Changes – Maximum	%	100	93.3	4.7	0.05	*Land Use Change*	85.3 (79.9)	4.7	0.1	100
Land Use Changes – Minimum	%	0	3.3	2.4	0.71					
Water Quality – Maximum	-	0	-1.0	0.7	0.71	*Water Quality*	0.0 (0.0)	0.0	-	100
Water Quality – Minimum	-	-31	-30.0	0.7	0.02					
Water Demand – Maximum	%	40	40.0	1.7	0.04	*Water Demand*	98.9 (100)	2.4	0.0	100
Water Demand – Minimum	%	10	6.7	2.4	0.36					
Coverage – Maximum	%	80	80.0	3.2	0.04	*Coverage*	63.4 (64.6)	2.8	0.0	100
Coverage – Minimum	%	0	2.7	1.9	0.71					
Water Loss – Maximum	%	30	28.3	1.2	0.04	*Water Loss*	0.0 (0.0)	0.0	-	100
Water Loss – Minimum	%	15	10.0	3.6	0.36					
Education – Maximum	%	100	96.7	2.4	0.02	*Education*	1.5 (5.6)	1.9	1.3	100
Education – Minimum	%	0	6.8	4.7	0.70					
Poverty – Maximum	%	20	20.0	2.0	0.10	*Poverty*	10.5 (10.2)	7.9	0.8	100
Poverty – Minimum	%	0	0.7	0.5	0.71					
Health Impact – Maximum	(cases/1000 pop)	2	2.0	0.1	0.04	*Health Impact*	90.8 (87.7)	2.3	0.0	100
Health Impact – Minimum	(cases/1000 pop)	0	0.1	0.1	0.71					
Sanitation – Maximum	%	100	96.6	2.4	0.02	*Sanitation*	44.3 (46.6)	3.2	0.1	98.92
Sanitation – Minimum	%	0	6.6	4.7	0.71					
Boundary Value of 25	-	25	25.1	7.2	0.29	*Information Disclosure*	37.27 (37.27)	-	-	98.95
Boundary Value of 50	-	50	50.0	7.2	0.14	*Governance Structure*	35.00 (35.00)	-	-	89.86
Boundary Value of 75	-	75	75.1	7.2	0.10	*Law Enforcement*	40.00 (40.00)	-	-	90.26

Table 4.23 shows that the correlation coefficient of the maximum threshold of *Poverty* is relatively higher when compared to other thresholds (most sensitive). This means that changes will have a larger effect on the final index (the most sensitive), compared to changes for other thresholds. The positive sign (0.425) of maximum threshold of *Poverty* means that the increase in the maximum threshold of *Poverty* will increase the value of final index. In practical terms, as discussed in the Citarum catchment, the increase in the maximum threshold of *Poverty* means lowering the Poverty standard. The negative sign of the correlation coefficient of an indicator or sub-indicator implies that the increase of the threshold will decrease the final index value.

Table 4.23 Correlation coefficients between final Index and thresholds

Thresholds of Indicators and Sub-indicators	Correlation Coefficient
Water Availability / Maximum Threshold	-0.006
Water Availability / Minimum Threshold	0.018
Land Use Changes/ Maximum Threshold	-0.184*
Land Use Changes/ Minimum Threshold	-0.020
Water Quality / Maximum Threshold	-0.006
Water Quality / Minimum Threshold	-0.005
Water Demand / Maximum Threshold	0.017
Water Demand / Minimum Threshold	0.074*
Coverage / Maximum Threshold	-0.120*
Coverage / Minimum Threshold	-0.033*
Water Loss / Maximum Threshold	-0.015
Water Loss / Minimum Threshold	0.000
Education / Maximum Threshold	0.006
Education / Minimum Threshold	-0.084*
Poverty / Maximum Threshold	0.425*
Poverty / Minimum Threshold	0.013
Health / Maximum Threshold	0.037*
Health / Minimum Threshold	0.101*
Sanitation / Maximum Threshold	-0.061*
Sanitation / Minimum Threshold	-0.151*

** Significant, based on the two-tailed probability value (p value< 0.05)*

Sensitivity analysis in this study also aims to answer the question: "Which weighting schemes or aggregation methods mostly affect the final index?" To answer this question, different aggregation combinations, based on different weighting schemes and aggregation methods, were analysed as was done for the other two catchments. Results of these aggregations of sub-indices for the Citanduy catchment are shown in Table 4.24.

Table 4.24 Aggregation results based on different weighting Schemes and aggregation methods

Scenario	Arithmetic Aggregation Method	Geometric Aggregation Method	*Changes*
Equal weights	46.70	15.48	**31.22**
Non-equal weights	45.80	20.25	**25.55**
Changes	**0.90**	**4.77**	

Table 4.24 shows that the changes in final index values are due to equal to non-equal weights as 0.90 and 4.77 respectively for arithmetic and geometric aggregation methods. The changes on the final index values from the arithmetic method to the geometric method were 31.22 and 25.55 for equal weights and non-equal weights respectively. Similar to the results for the other catchments, these results for the Citanduy catchment show that the aggregation method is more sensitive to the final index value, compared to the weighting schemes. Therefore, it is recommended that geometric aggregation method is used, with any weighting scheme, to aggregate WJWSI indicators and sub-indicators in future use.

4.6.2.3 Recommendations for Water Authorities

In general, the water sustainability performance of the Citanduy catchment (using the equal weighting scheme and geometric aggregation method) are considered Poor, with the aggregated WJWSI value of 23.39 (application in 2008). The highest priority of actions should be given to indicators with Poor performances, which are *Water Quality*, *Water Loss* and *Poverty*. If the performances of these indicators are improved to the Poor-Medium level, the overall final index value will be improved to Poor-Medium. It is recommended that water authorities in the Citanduy catchment take appropriate actions to improve the sub-index values of these Poor indicators and sub-indicators. Some actions are given below, which were based on data for 2008.

Water Quality

Based on the information provided in Table 4.21, the actual value for *Water Quality* in the Citanduy catchment for 2008 was calculated as -68.67 (Poor). In order to move from Poor to Poor-Medium performance, the actual value of *Water Quality* needs to be increased from -68.67 to -8.06.

The low water quality in the Citanduy catchment was mostly caused by improper waste water discharges from domestic and agricultural practices. This is due to the lack of awareness of the relevant stakeholders on the importance of the rivers, as well as sustainability of water resources for future use. To address this issue, similar approaches are recommended to water authorities in the other two catchments. The West Java EPA, along with other relevant authorities, should initiate programs to improve awareness. These programs need to have clear and reasonable targets to be achieved. Along with these programs, the implementation of laws and regulations related to water quality also need to be re-enforced. Currently, laws and regulations on water quality are available, but they are not fully implemented.

Water Loss

The application of WJWSI in the Citanduy catchment, as presented in Table 4.21, shows that the actual value of *Water Loss* is 33.70, which is considered Poor in performance. In order to move from Poor to Poor-Medium, the average actual value of *Water Loss* in the Citanduy catchment needs to be reduced to 18.50%. The actual value will give the sub-index value of 25, as the minimum value for Poor-Medium performance. Similar to the recommendations for the previous two catchments, reducing the non-physical losses of all WSPs within the catchment should be a priority.

Poverty

For the *Poverty* indicator, the application of the WJWSI in the Citanduy catchment shows that the actual value of *Poverty* was 17.97%, which gives the sub-index value of 10.15. To improve the performance to the Poor-Medium level, the actual value should be decreased to at least 14.78%. Similar to the recommendations given to authorities in the Citarum catchment, the immediate programs to reduce poverty (i.e. ‘direct cash assistance’ and ‘cheap rice’) should be implemented consistently. Consistent implementation of these programs also includes government monitoring and/or monitoring by other institutions to ensure that the poor benefit from these programs. Eventually, this will lead to the reduction of the poverty level in the catchment.

4.7 CORRELATION ANALYSIS OF INDICATORS AND SUB-INDICATORS

To better understand how some of the indicators and sub-indicators relate, a correlation analysis is performed in this study. The analysis is based on the sub-index values of indicators and sub-indicators for 2006 to 2008 in three different catchments. The correlation analysis for WJWSI indicators and sub-indicators are based on the Spearman correlation coefficient with a two-tailed probability value.

The correlation analysis was undertaken by computing correlation coefficients between sub-index values of indicators and sub-indicators. The values used to compute these correlation coefficients were the sub-index values already mentioned for 2006 to 2008. The computation of the correlation coefficients used SPSS version 19.0 (Field, 2005). The results of the computation of these correlation coefficients are provided in Table 4.25. Table 4.25 shows that for some indicators and sub-indicators, their coefficient correlations are not applicable (N/A). These indicators and sub-indicators are *Water Quality, Water Loss, Information Disclosure, Governance Structure,* and *Law Enforcement*. The coefficient correlations for these indicators and sub-indicators cannot be computed as their sub-index values were constant throughout the analysis.

The correlations of some indicators and sub-indicators are highlighted in Figures 4.10 and 4.11 (i.e. *Poverty* and *Sanitation*, as well as *Coverage* and *Health Impact*). The correlation between *Poverty* and *Sanitation* is highlighted as these indicators are significantly correlated with all other indicators and sub-indicators. The correlation coefficients of these two indicators with other indicators and sub-indicators were high, ranging from 0.8 to 0.982 (as shown in Table 4.25). According to Caldwell (2010), correlation coefficients above 0.8 are considered very strong. Figure 4.10 illustrates how each data point of the sub-index values of *Poverty* is correlated with each data point of the sub-index values of *Sanitation*. The nine data points show a clear pattern in their relationship.

Table 4.25 Correlation coefficients of WJWSI indicators and sub-indicators

	Water Availability	Land Use Changes	Water Quality	Water Demand	Coverage	Water Loss	Information Disclosure	Governance Structure	Education	Poverty	Health Impact	Sanitation	Law Enforcement
Water Availability	1.000	-.982*	N/A	.955*	.794	N/A	N/A	N/A	-.901*	-.914*	.914*	-.953*	N/A
Land Use Changes		1.000	N/A	-.908*	-.791	N/A	N/A	N/A	.953*	.949*	-.949*	.953*	N/A
Water Quality			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Water Demand				1.000	.714	N/A	N/A	N/A	-.787	-.827*	.853*	-.892*	N/A
Coverage					1.000	N/A	N/A	N/A	-.728	-.800*	.617	-.879*	N/A
Water Loss						N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Information Disclosure							N/A	N/A	N/A	N/A	N/A	N/A	N/A
Governance Structure								N/A	N/A	N/A	N/A	N/A	N/A
Education									1.000	.979*	-.904*	.899*	N/A
Poverty										1.000	-.883*	.929*	N/A
Health Impact											1.000	-.854*	N/A
Sanitation												1.000	N/A
Law Enforcement													N/A

** Significant, based on the two-tailed probability value (p value< 0.05)*

N/A: Not applicable.

In contrast, correlation coefficients for *Coverage* with other indicators and sub-indicators were not statistically significant, except with *Poverty* and *Sanitation*. The relationship of the nine data points for *Coverage* and *Health Impact* indicators, as shown in Figure 4.11, is different from those of *Poverty* and *Sanitation.* In the scatter plot for *Coverage* and *Health Impact*, there is no clear pattern of the relationship between their data points, as was observed in the data points for *Poverty* and *Sanitation*.

The above correlation analysis was based only from nine data points, due to the data availability in West Java catchments. These nine data points were obtained from three different catchments. For each catchment, three data points were used, reflecting the sub-index values of different years.

Due to this limitation on the data points, it is important to be cautious on the results of this correlation analysis. Nevertheless, the results can be used as starting point for further research on the correlation of WJWSI indicators and sub-indicators. In the future, further analysis can be undertaken with additional data from other catchments (if possible for all 40 catchments in West Java) for a longer time period. Additional data points to analyse the correlations among WJWSI indicators and sub-indicators will increase the accuracy of correlation, shown by correlation coefficients.

If the correlation analysis with more data points shows strong correlations of some indicators and sub-indicators, the reasons for the highly correlated indicators and sub-indicators should be investigated. Then, appropriate actions need to be undertaken. For these highly correlated indicators and sub-indicators, they can be assigned less weight (compared to other indicators and sub-indicators with no significant correlation) during the aggregation to compute the final index. Also, the weights given based on the correlation can be used as another source of uncertainty during the robustness analysis of the index. The robustness analysis will then indicate whether weights obtained from the correlation analysis significantly affect the final index value.

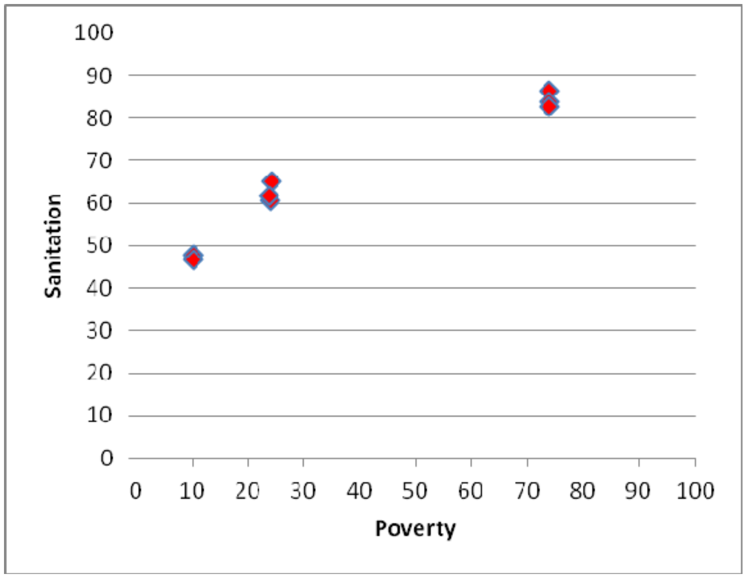


Figure 4.10 Scatter plot of data points of sub-index values of *Poverty* and *Sanitation*

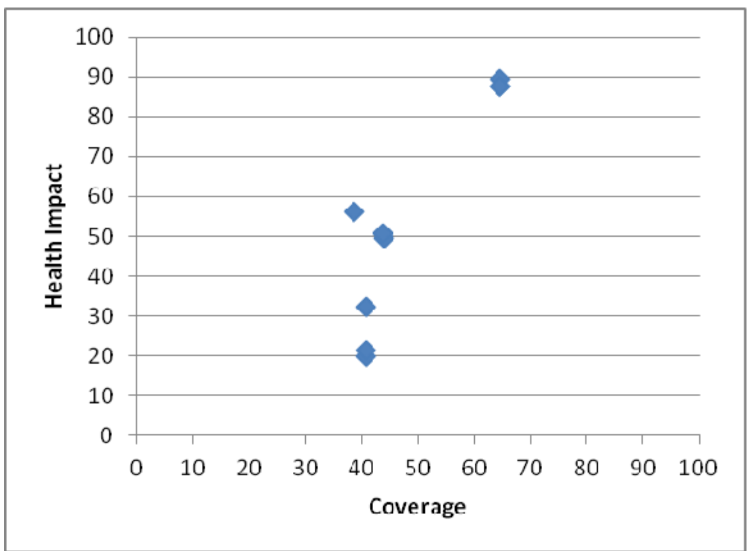


Figure 4.11 Scatter plot of data points between sub-index Values of *Coverage* and *Health Impact*

4.8 COMPARATIVE ANALYSIS OF RESULTS OF DIFFERENT CATCHMENTS

Due to limited financial support provided by the National Government of Indonesia for managing water resources in West Java, it is important to compare current water resource conditions among West Java catchments for distributing the available budget effectively. An effective water resource management in West Java cannot be achieved by providing equal financial support to all catchments. A needs analysis for each catchment is required to distribute funding appropriately. A comparative analysis of WJWSI applications for different catchments is one way to provide information on the general conditions of water resources in each catchment, as well as their specific needs.

A comparative analysis of WJWSI applications for different catchments can also be used to cluster catchments with similar conditions. The catchment authorities under the same clusters will be able to share and discuss water resource conditions in their areas, and further develop programs for the improvement of water resource management. This comparative analysis can be undertaken, based on final index or sub-index values. An overview of this comparative analysis is illustrated in Figure 4.12, where the comparison of sub-index and final index values of three West Java catchments is provided, based on applications for 2008.

As can be seen from Figure 4.12 (particularly the final index value), performances for Citarum and Ciliwung catchments are similar. The final index value of the Citanduy catchment is higher than the other two catchments. In general, this is because there is less demand in the Citanduy catchment for various water uses (domestic and industries), due to less population. Thus, with regard to catchment improvement, the Citarum and Ciliwung catchments should be given higher priority than the Citanduy catchment. The main improvement for the Citarum and Ciliwung catchments is to manage growing pressure resulting from various water use activities, as a consequence of population growth in these catchments.

With regards to sub-index values, Figure 4.12 shows that, in general, there are similarities across the three catchments, particularly regarding *Water Quality* and *Water Loss.* The causes for low sub-index values are also similar in the Citarum and Ciliwung catchments. The low quality of rivers in West Java is mainly caused by lack awareness of users on the importance of rivers and sustainability. In addition, river pollution is not adequately handled by relevant authorities.

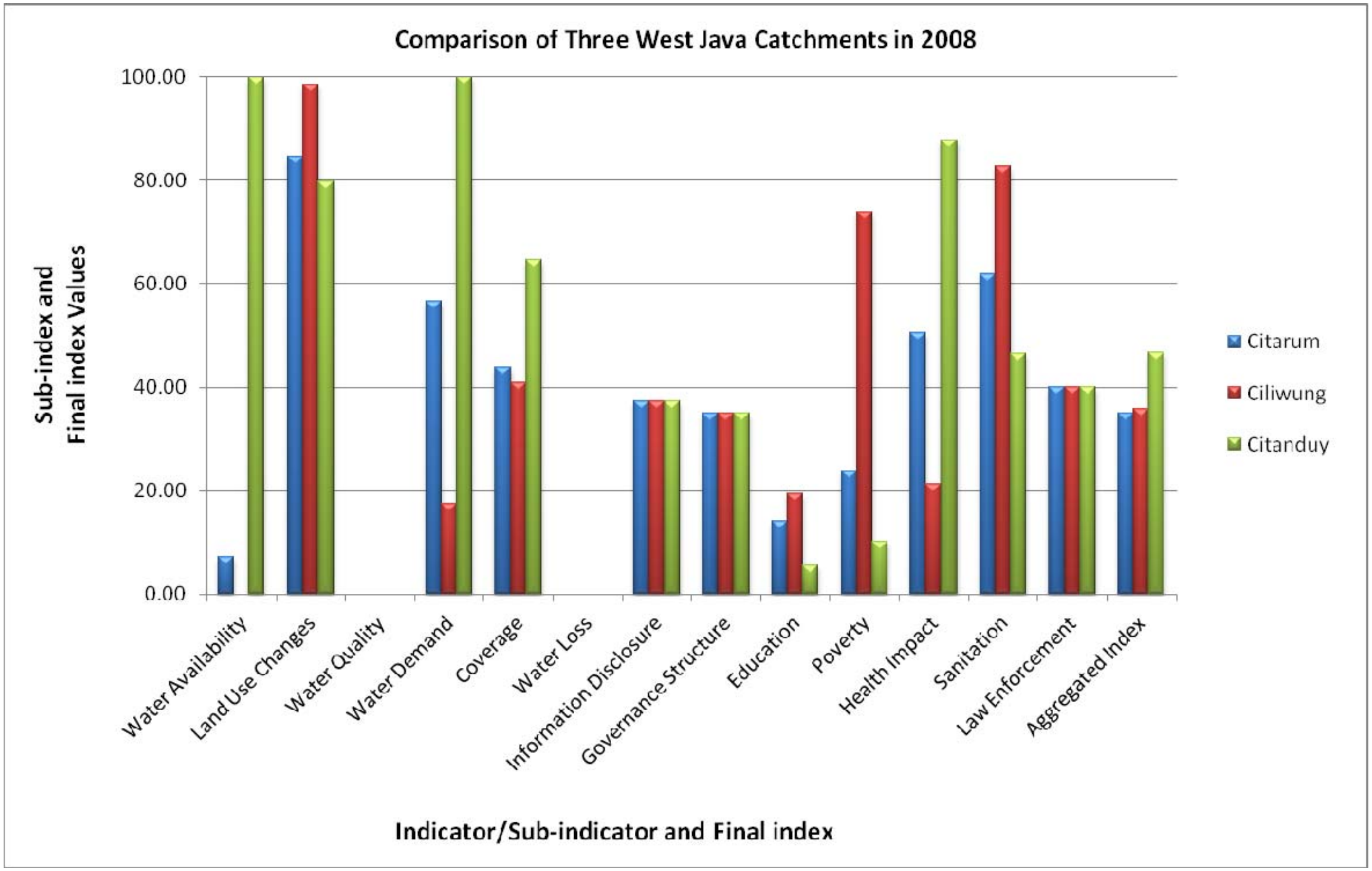


Figure 4.12 Sub-index values of three West Java catchments for 2008

The other indicators and sub-indicators with similar performances in these three catchments are *Information Disclosure, Governance Structure and Law Enforcement*. The similarity for these indicators and sub-indicators is due to centralised management at the provincial level. As all the catchments are located in the West Java Province, the approach and actions related to indicators and sub-indicators are the same.

In the future, comparative analysis can also be carried out in all West Java catchments (40 in total).

4.9 SUMMARY

The West Java Province is one of the most populated regions in Indonesia, with over 43 million people in 2010 (more than 20% of the total Indonesian population) and increasing rapidly. The increase in population has also correspondingly increased the demand for a fresh water supply. In the last few decades, due to this increased demand, and lack of knowledge on water resource management and lack of water sustainability awareness, water resources in West Java have faced serious threats. The most apparent indication is the deterioration of surface water quality. From 2006 to 2008, the water quality of major rivers in West Java was far below local and national standards. Another indication of the water problem in West Java is the lack of fresh water supply to the community. To address these water issues, the West Java authorities need to properly assess the conditions, and formulate critical water improvement programs.

The WJWSI was designed to assess current water resource conditions and prioritise water issues, which can be used by decision makers to design appropriate water improvement programs. In this chapter, the applications of the WJWSI in three major West Java catchments were discussed. They were the Citarum, Ciliwung and Citanduy catchments. Each application discussed sub-index values of indicators and sub-indicators and how they were obtained, the aggregation of indicators and sub-indicators, the robustness analysis of the index, the application of the index for different years, and finally, recommendations to water authorities.

The main recommendations related to the performance of indicators and sub-indicators in respective catchments, based on the applications of the WJWSI for 2006 to 2008. It strongly recommended that indicators and sub-indicators with Poor performances be given higher priority, in relation to the improvement of the conditions of the catchments. In the Citarum catchment, the indicators and sub-indicators with Poor performances, based on 2006 to 2008, were *Water Availability, Water Quality, Water Loss, Education* and *Poverty.* In the Ciliwung catchment, they were *Water Availability, Water Quality, Water Demand, Water Loss, Education* and *Health Impact.* In the Citanduy catchment, they were *Water Quality*, *Water Loss, Education* and *Poverty*. If these indicators and sub-indicators with Poor performance can be improved, at least to 25 sub-indices, the final index value in the Citarum catchment will improve from 20.04 to 37.19. In the Ciliwung and Citanduy catchments, the final index will also improve from 16.94 to 37.72, and from 23.39 to 46.13 respectively.

Comparative analysis for different catchments indicates that the Citarum and Ciliwung catchments are similar, with regard to their final index value. The Citanduy catchment had significantly higher final index values compared to the other two catchments. The comparative analysis shows that some indicators and sub-indicators have similar performances across the three catchments. Catchment authorities with similar performances of indicators and sub-indicators should work together, during planning and implementation, to improve the conditions of water resources of the catchments.

Chapter 5

Summary, Conclusions and Recommendations

5.1 SUMMARY

The emergent studies on sustainability will be less useful if methods to measure sustainability are not available. Therefore, studies on these methods are essential. One of the approaches to measure sustainability is the indicator-based sustainability assessment. Using this approach, sustainability is measured through the assessment of a set of identified indicators (and sub-indicators). In the past decade, studies on the use of indicators to measure sustainability of various fields have been carried out. This includes the indicator-based assessment on water resources.

To develop an indicator-based sustainability assessment on water resources, a review on the sustainability definitions and principles is essential. Comprehensive understanding on these definitions and principles will provide a strong basis in the selection of indicators of water resource sustainability. In this study, sustainability definitions and principles from various researchers were presented and reviewed. Then, to specifically address the issue of water resources, some definitions, criteria and guidelines on sustainable water resource management were analysed. These definitions, criteria and guidelines have provided valuable inputs on the identification of water sustainability indicators.

In the recent past, there have been studies on developing indicator-based sustainability assessment on water resources, such as Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI) and Watershed Sustainability Index (WSI). In this study, elements of these three existing indices were reviewed. In each index, the review includes the selection of components and indicators, method to obtain sub-index values, weighting and aggregation methods, and finally the interpretation of the final index.

To compare these existing water sustainability indices with indices in other areas, the Human Development Index (HDI) and Environmental Sustainability Index (ESI) were also reviewed in this study. Together, the review on the sustainability definitions and principles, the sustainable water resource management definitions, criteria and guidelines, and the existing indices have provided a strong basis that underpinned the development of WJWSI.

The main tasks for developing WJWSI were the design of the conceptual framework, the application of Delphi technique and the in-depth interview. The conceptual framework was designed to identify an initial set of components, indicators and thresholds of WJWSI. To identify the components and indicators of the conceptual framework of WJWSI, the followings (as discussed in the previous sub-section) were considered:

- Sustainability definitions and principles
- Sustainable water resource definitions, criteria and guidelines
- Existing water sustainability indices (i.e. WPI, CWSI and WSI)

Once the components and indicators were identified, thresholds of the indicators were sought from local and national policies and regulations in Indonesia. If they were not available, thresholds that have been widely used globally were adopted. Then, to refine the conceptual framework, the Delphi technique was used. In this study, two rounds of questionnaire distributions were undertaken. The questionnaires were distributed to water-related stakeholders in West Java, selected from the following categories: university lecturers, government officials, environmental consultants, and community groups.

The stakeholders from these categories were asked their agreement on the provided components, indicators and thresholds. In addition, they were also allowed to make changes on the components, indicators and thresholds. After two rounds of questionnaire distributions, consensus was reached for all the components and most of the indicators. The respondents in the Delphi application were not confident about most of the thresholds as the information on these thresholds was not available.

After the application of the Delphi technique, an in-depth interview with key stakeholders was undertaken to finalise the components, indicators and thresholds of the indicators. These key stakeholders discussed components, indicators and thresholds that have not been agreed by the respondents during the two rounds of questionnaire distributions. After the interview, these key stakeholders agreed on all the components, indicators and most of the thresholds to be included in the final framework of WJWSI. Once the framework was finalised, it was then applied in three selected West Java catchments.

The applications of WJWSI in three selected catchments have provided valuable information on the current conditions of water resource performances in the respective catchments. In each catchment, the following information was obtained:

- Sub-index values of indicators and sub-indicators
- Aggregated index value
- Analysis of robustness of the index

The robustness analysis of WJWSI was undertaken by performing uncertainty and sensitivity analysis of the index based on the data for Citarum, Citanduy and Ciliwung catchments of 2008. Results of the robustness analysis indicated that the recommended aggregation method to aggregate indicators and sub-indicators was the geometric aggregation method. If other aggregation method(s) is preferred, users of the index should be aware of significant changes that might occur in the final index.

5.2 CONCLUSIONS

The main objective of the study was to develop a water sustainability index for West Java, Indonesia, as an attempt to address the lack of tools for obtaining the information on current water resource conditions in the province. The index was also expected to be used to prioritise water issues and to communicate the water issues with wider community. These objectives were achieved in this study. A new water sustainability index was developed, and it has been applied to three different catchments in West Java.

The following sub-sections present major conclusions of the study. They are presented under different headings: conceptual framework of WJWSI, the use of Delphi technique, in-depth interview with selected key stakeholders, weights for indicators and sub-indicators, and correlations of indicators and sub-indicators.

5.2.1 Conceptual Framework of WJWSI

In this study, the conceptual framework of WJWSI, which was developed prior to the Delphi application, was found useful in assisting the respondents to identify WJWSI components, indicators and thresholds. The conceptual framework helped the respondents to understand the main issues of water resource management in West Java, and eventually to provide their opinions and ideas on identification of WJWSI components, indicators and sub-indicators, and thresholds.

5.2.2 The Use of Delphi Technique

As in previous applications of Delphi technique in various disciplines, the Delphi technique used in this study has provided numerous benefits when it was used to refine the conceptual framework of WJWSI. The main benefit from the use of Delphi technique in this study was the ability of the technique to obtain ideas and opinions from a wider range of water stakeholders in West Java without having the stakeholders to congregate at one time and place. This has resulted in an effective time management of the overall management of this study.

The other benefit from the use of this technique was that the respondents of the Delphi applications had the opportunity to review and refine their answers provided in Round One of questionnaire distribution. As the responses of Round One were provided in the beginning of Round Two, respondents were able to analyse the answers of other respondents (along with their justifications) and were more confident to provide their answers in Round Two. This process has contributed to the convergence of respondents' answers in Round Two.

5.2.3 In-depth Interview with Selected Key Stakeholders

The in-depth interview with the key stakeholders was found to be an effective way of finalising the components, indicators and sub-indicators, and most of the thresholds. For some thresholds that have not been agreed, valuable inputs were obtained from the discussions with these stakeholders. These valuable inputs were then used to finalise the remaining thresholds, later in this study. In the process of finalising these components, indicators and sub-indicators, and majority f the thresholds, these stakeholders were able to identify indicators and sub-indicators to be removed or replaced in the overall framework.

5.2.4 Weights for Indicators and Sub-indicators

The weights of WJWSI indicators and sub-indicators were obtained based on the input from water-related stakeholders in West Java. The stakeholders participated in this part of the study were a subset of the stakeholders participated in the Delphi technique application. After the calculation of weights using the Revised Simos' procedure, it was revealed that there were significant difference on weights among the indicators and sub-indicators. It is concluded that even though the stakeholders agreed on the indicators and sub-indicators, these stakeholders have different preferences on some indicators and sub-indicators.

This is supported by the results of weighting groups based on the categories of stakeholders. The results of the weighting groups showed that the Community Group and University Lecturer have contradictory responses on several indicators and sub-indicators. Therefore, it is important to note (again) that the involvement of wide range of stakeholders in a study on water resource management is essential, due to different views that those stakeholders have.

In this study, the different weights given by the stakeholders were used in the robustness analysis of the index, which aimed to analyse whether the non-equal weights given by the stakeholders significantly affect the final index value. The robustness analysis showed that the weighting scheme was not sensitive to the final index value. Therefore, for future use of the WJWSI, either the equal or non-equal weighting scheme can be used.

5.2.5 Uncertainty and Sensitivity of the Index

The uncertainty analysis on the index, undertaken in this study, was able to identify the sources of uncertainty in developing WJWSI, which included:

- Thresholds of indicators and sub-indicators
- Weighting schemes
- Aggregation methods

The uncertainty analysis on the three catchments, as part of the applications of WJWSI in this study, has indicated that changes in the thresholds of WJWSI indicators and sub-indicators have not significantly affected the sub-index values of most indicators and sub-indicators. In the Citarum catchment, for example, only the sub-index value of *Water Availability* was affected significantly by the changes in its thresholds. In consequence, if water authorities (or other users of the index) in the Citarum catchment preferred different thresholds for this indicator, the index users need to be aware of the possible significant changes on the sub-index value of the indicator.

Based on the sensitivity analysis in the three catchments, for future use of the aggregation of WJWSI indicators and sub-indicators, either the equal or non-equal weighting scheme can be used. As shown in the sensitivity analysis, the changes on the weighting schemes will not significantly affect the final index.

The sensitivity analysis on the three catchments has also showed that the final index values were most sensitive to the aggregation methods compared to the weighting schemes or threshold values. In this study, the recommended aggregation method to aggregate indicators and sub-indicators was the geometric aggregation method. The geometric aggregation method is recommended to be used for WJWSI over the arithmetic aggregation method. Using the geometric method, the differences in the sub-index values of WJWSI indicators and sub-indicators are taken into account. Poor indicator performances, shown by the low sub-index values, will be reflected in the aggregated index value. In contrast, when using the arithmetic aggregation method, poor indicator performances will not be reflected in the aggregated index value if other indicators perform well. If other aggregation method(s) is preferred, users of the index should be aware of significant changes that might occur in the final index.

5.2.6 Correlations of Indicators and Sub-indicators

The correlation analysis on the WJWSI indicators and sub-indicators was based on the sub-index values of the indicators and sub-indicators in the three catchments (i.e. Citarum, Ciliwung and Citanduy) during the period of years 2006 to 2008. The correlation analysis was based from nine data points, due to the data availability in West Java catchments. These nine data points were obtained from three different catchments. For each catchment, three data points were used, reflecting the sub-index values of different years. Due to this limitation on the data points, it is important to be cautious on the results of this correlation analysis.

Using the nine data points, it was found that most of the indicators and sub-indicators were correlated. However, it is recommended to water authorities in West Java (as well as to users of the WJWSI) to further study the correlations among the indicators and sub-indicators using more data points for the sub-index values. The 9 data points used in this study to compute the correlation coefficients might not reflect the actual correlations among the indicators and sub-indicators.

If the correlation analysis with more data points shows strong correlations of some indicators and sub-indicators, appropriate actions need to be undertaken. For these highly correlated indicators and sub-indicators, they can be assigned less weight (compared to other indicators and sub-indicators with no significant correlation) during the aggregation to compute the final index. Then, the weights given based on the correlation can be used as one source of uncertainty during the robustness analysis of the index. The robustness analysis will then indicate whether weights obtained from the correlation analysis significantly affect the final index value.

5.3 RECOMMENDATIONS TO WATER AUTHORITIES

The water authorities in West Java can be benefited from both the development of WJWSI and the results of WJWSI applications in the three catchments. The water authorities in West Java are now able to understand how a water sustainability index is developed, and make necessary modifications (if required). Results from the applications of WJWSI have provided information on the current conditions of water resource in each study catchment, which can be regularly monitored by the water authorities, as well as by general public. The applications of WJWSI in this study also proposed relevant programs to the water authorities, which can be used to improve the performance of the water resources in each catchment.

In addition, based on the results of the applications, the provincial government of West Java is now able to compare the water resource performances of these three catchments in West Java, and take appropriate actions to improve the performances of the catchments. In the future, the comparison of different catchments can be extended to all catchments in West Java.

In general, the applications of WJWSI in three selected catchments have provided valuable information on the current conditions of water resource performances to respective water authorities. The sub-index values of indicators and sub-indicators, obtained through the applications of WJWSI in different catchments, were able to inform water authorities in West Java about the conditions of water resources, related to each of the indicator or sub-indicator.

The applications of WJWSI in different catchments have also indicated water resource issues that needed higher priority, due to poor performances of relevant indicators and sub-indicators.

The final index values for the three catchments obtained in this study were used to analyse the overall conditions of water resource management in the three catchments. The final index values of the catchments were also used to compare the performances of the three catchments. With the information on the performances of different catchments, water authorities at the provincial level are now able to identify catchments that need higher priorities, and to allocate more funding on these catchments so that they can improve their catchment performances.

The information on the sub-index values of indicators and sub-indicators, as well as the final index values, of the three different catchments in this study can also be used by water authorities in respective catchments to communicate the water resource conditions to the community. The final index and sub index values of WJWSI can be easily understood by the general public and as they become aware of the water conditions in their respective catchments, they are expected to participate in programs to improve the water resource conditions.

More specific recommendations to water authorities in three different catchments are presented in the following sub-sections:

5.3.1 The Citarum Catchment

The Citarum catchment is the largest catchment in the West Java Province. It has a significant contribution to the development of the province, as well as to the Jakarta Province. The application of WJWSI in the Citarum catchment showed that several indicators and sub-indicators performed poorly. Overall results indicate that water resource performance in the catchment is Poor.

To improve the water resource performance of the catchment, it is recommended that water authorities take immediate actions on the indicators and sub-indicators that are *Poor* in their performances. These indicators and sub-indicators are: *Water Availability, Water Quality, Water Loss, Education* and *Poverty.* The improvement of these poorly-performed indicators and sub-indicators is important to ensure that none of the indicators and sub-indicators having the sub-index value below 25.

The uncertainty analysis on the Citarum catchment showed that changes in the thresholds of WJWSI indicators and sub-indicators have not significantly affected the sub-index values of most indicators and sub-indicators. For the Citarum catchment, only the sub-index value of *Water Availability* was affected significantly by the changes in its thresholds. In consequence, if water authorities (or other users of the index) in the Citarum catchment preferred different thresholds for this indicator, the index users need to be aware of the possible significant changes on the sub-index value of the indicator.

The sensitivity analysis of the index was performed to analyse the effect of the upper and lower values of the thresholds on the final index values. It was done by analysing the correlation between the changes on the thresholds and the final index values. The correlation analysis showed that several thresholds of indicators and sub-indicators had statistically significant correlation with the final index. It means that for these indicators and sub-indicators, changes on the thresholds will significantly change the final index. However, for these indicators and sub-indicators, changes on their thresholds will have low impact to the final index value as the correlation coefficient was low (ranging from 0.043 to 0.520).

5.3.2 The Ciliwung Catchment

The Ciliwung Catchment was selected as one of the case study catchments due to its importance for the national development of Indonesia. The main river of the catchment, the Ciliwung River, flows across two provinces: the West Java and Jakarta provinces. This catchment is the most densely-populated catchment in West Java.

The application of WJWSI in the Ciliwung catchment showed that the overall performance of the catchment is *Poor*. Indicators and sub-indicators with *Poor* performances are *Water Availability, Water Quality, Water Demand, Water Loss, Education* and *Health Impact.* Similar to the Citarum catchment, it is recommended that water authorities in the Ciliwung catchment take immediate actions to improve the poorly-performed indicators and sub-indicators.

The uncertainty analysis of WJWSI indicated that coefficients of variation of the maximum and minimum thresholds of the indicators and sub-indicators were compensated each other, as shown in the coefficients of variation of the sub-index values of their respective indicators and sub-indicators. The coefficient of variations of sub index values for some indicators and sub-indicators cannot be analysed as their sub-index values were calculated as 0 throughout the simulations. These indicators and sub-indicators were Water *Availability, Water Quality* and *Water Loss*.

Similar to the sensitivity analysis based on the data of the Citarum catchment, the sensitivity analysis of the index was also performed based on the data of the Citanduy catchment. It was done by analysing the correlation between the changes on the thresholds and the final index values. The correlation analysis showed that only the maximum threshold of *Education* had statistically significant correlation with the final index. It means that for most indicators and sub-indicators, changes on the thresholds will not significantly change the final index. Even for the maximum threshold of *Education*, changes on its thresholds will have low impact to the final index value as the correlation coefficient was very low (-0.03).

5.3.3 The Citanduy Catchment

The population in the Citanduy catchment is less dense compared to the other two catchments (i.e. Citarum and CIliwung catcments). However, in terms of the catchment size, the Citanduy catchment is the second largest catchment in the province, next to the Citarum catchment.

Application of WJWSI in the Citanduy catchment indicated that the overall performance of the in the catchment was *Poor-Medium*. The indicators that performed poorly are *Water Quality, Water Loss, Education* and *Poverty*. Similar to recommendations related to the previous two catchments, these indicators and sub-indicators need to be improved to reach their basic standards (the sub-index value of 25).

In the Citanduy catchment, the uncertainty analysis on WJWSI showed that coefficients of variation of the sub-index values for *Education* and *Poverty* were high. Similar to the previous two catchments, the sensitivity analysis of the index was also performed using the data of the Citanduy catchment. It was done by analysing the correlation between the changes on the thresholds and the final index values. The correlation analysis showed that several thresholds of indicators and sub-indicators had statistically significant correlation with the final index. However, for these indicators and sub-indicators, changes on their thresholds will have low impact to the final index value as the correlation coefficient was low (ranging from 0.033 to 0.425).

5.4 RECOMMENDATIONS FOR FURTHER RESEARCH

One of the main elements of the WJWSI is the thresholds. These thresholds are based on policies, regulations and relevant studies available in Indonesia and internationally at the time of developing WJWSI. Due to the growing studies on the issues related to these thresholds, it is important to renew these thresholds based on current studies. For WJWSI, thresholds based on the studies in Indonesia are more preferred than studies in other countries. The thresholds for *Water Availability* can be used as the example. In this study, the thresholds for this indicator were based on research from other countries, as this information for Indonesia was not available. It will be very useful if a study on the amount of fresh water needed by one person per year is conducted in Indonesia, in the near future. Such results can be used as the thresholds of the *Water Availability* indicator in WJWSI. Thus, the users of WJWSI are recommended to be aware of current studies, and (when applicable) include the information for thresholds of WJWSI indicators and sub-indicators.

With regards to questionnaire distributions, in this study, two questionnaire distributions were undertaken to obtain respondents' responses on the components, indicators and thresholds. Then, after few months, a survey was undertaken to obtain the information on the weights of the indicators and sub-indicators. It was found that this survey could have been included in the questionnaire distributions undertaken earlier. Combining the survey on weights and questionnaire distributions together would have resulted in more effective time management. Therefore, if similar studies are undertaken in the future, the survey for obtaining the weights should be included in the questionnaire distributions.

Another area for improvement of the study was found during the application of WJWSI in three West Java catchments. In this study, WJWSI was applied in the catchments based on data of 2006-2008, as data for some indicators was available only from 2006. In future applications, longer time series for WJWSI indicators and sub-indicators can be applied. The longer time series of data in the applications will allow the index users to better analyse the trend of water resource performance (both individual sub-index values of indicators and sub-indicators, as well as the final index values) during the available time period.

For applying the WJWSI to water disaster prone areas, the list of indicators, the threshold values and weighting preferences of the stakeholders on the indicators will need to be revised. For instance, if WJWSI is going to be applied in a flood prone area, the list of indicators should be reviewed to include flood-related indicators, such as water infrastructure, emergency measures and procedures, etc. If needed, another Delphi questionnaire or other methods can be employed to develop a new set of indicators for the index. The threshold values of the revised set of indicators should also be carefully identified. Few threshold values of existing indicators (such as *Land Use Change*, *Information Disclosure*, *Government Structure* and *Law Enforcement*) should also be reviewed for modifications, to include the flood-related issues.

Finally, it is also important to note that this water sustainability index has the potential for applications in other provinces in Indonesia. The index users in other provinces might consider reviewing the components, indicators and thresholds of the WJWSI as they might not be completely relevant to the characteristics of water resources in the respective provinces. Considering the importance of stakeholder participation in the water sustainability, it is important to ensure that the review on the components, indicators and thresholds is undertaken through the involvement of relevant water-related stakeholders in the respective provinces.

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APPENDIX A

QUESTIONNAIRE OF ROUND ONE – DELPHI TECHNIQUE APPLICATION

APPENDIX B

QUESTIONNAIRE OF ROUND TWO – DELPHI TECHNIQUE APPLICATION

APPENDIX C

WEIGHTING SCHEME QUESTIONNAIRE

APPENDIX D

INTERVIEW GUIDE

Respondent Name:

RESEARCH QUESTIONNAIRE
Round One

Development of West Java Water Sustainability Index (WJWSI)

I. General information about this research

Water resources management in Indonesia, particularly in Java Island, faces severe water problems. A sustainable and integrated water management to engage all stakeholders is therefore needed; such water management has demonstrated to be capable of integrating all issues of water resources management (Loucks & Gladwell, 1999; Jakeman, Letcher, Rojanasoonthon et al., 2005). One approach to achieve sustainable and integrated water management is through the application of the indicator-based approach (Jakeman et al., 2005). In the past, this approach has been used to develop water sustainability indices, namely Water Poverty Index (WPI), Canadian Water Sustainability Index (CWSI) and Watershed Sustainability Index (WSI).

This research project proposes to develop the West Java Water Sustainability Index (WJWSI), which can be used as a tool to assess the sustainability of West Java water resources and to communicate water issues with wider community. The application of WJWSI in case studies will assist decision makers in the West Java Province to have better knowledge of the overall water resource conditions, and to prioritise water-related issues and their respective programs towards more sustainable and integrated water resources management. The results of WJWSI application will also increase the awareness of the wider community and encourage them to participate in the improvement of water resources management.

The tasks for developing WJWSI include the identification of components/indicators, thresholds, methods for obtaining sub-index values and index aggregation, fieldwork, and robustness analysis. The identification of component/indicators and thresholds will be carried out through the distribution of questionnaires to water-related experts in West Java, Indonesia.

This is the first Round questionnaire of maximum three rounds to be completed by selected stakeholders. This questionnaire consists of three parts, which are the information for respondents (Section II), questions to be answered by respondents (Section IV to VI) and an attachment to help respondents answering the questions. In order to have a better understanding of some terms used in the questionnaire, respondents are advised to read the attachment before answering the questions.

II. What is expected from the respondents? *(information only)*

At this stage, WJWSI is being developed. WJWSI requires inputs from water management-related stakeholders. You have been chosen as one of the respondents for this project. The WJWSI currently has a proposed conceptual framework, consists of three main sections, they are: the Components, Indicators and sub-indicators (if any) and Thresholds. The proposed framework is illustrated as follows:

COMPONENT	INDICATOR	EXPLANATION	THRESHOLD	
			MAX	MIN
WATER RESOURCES	Availability	Average annual flow of surface water (*m^3/cap/yr*)	1700 [a]	500 [b]
	Demand	Use of available water sources (*%*)	40 [b]	0 [a]
	Quality	*Water Quality Index*	0 [a]	-31 [b]
	Land Use Changes	*Runoff Coefficient*	1 [b]	0 [a]
WATER SERVICE PROVISION	Coverage	Coverage of water company (*%*)	80 [a]	0 [b]
	Water loss	Unaccounted for water of water company (*%*)	15 [b]	0 [a]
	Finance	Profitability of water company	0 [c]	0 [c]
CAPACITY	Poverty	People under the poverty line (*%*)	100 [b]	0 [a]
	Education	People completed elementary/primary education (*%*)	100 [a]	0 [b]
HUMAN HEALTH	Access	Water accessible by the community supplied by water company compared to water needed (*%*)	100 [a]	0 [b]
	Sanitation	People with access to basic sanitation (*%*)	100 [a]	0 [b]
	Health Impact	Number of water-borne diseases (*cases/1000 pop)*	100 [b]	0 [a]

a: preferable
b: not preferable
c: >0 preferable, <0 not preferable

With regards to the proposed WJWSI framework, in this questionnaire, the respondents are expected to:

1. Assess the proposed *Components*[1] and provide inputs for component(s) to be added, modified and or removed from the proposed list
2. Assess the proposed *Indicators*[2] and provide inputs for indicator(s) or to be added, modified and/or removed from the proposed list
3. Assess the proposed *Thresholds*[3] and provide inputs for thresholds to be modified from the proposed list

If needed, respondents may provide their inputs on a separate additional sheet.

III. Personal Information *(to be completed by respondents)*

Name* :

Institution (optional) :

Phone :

E-mail (optional) :

IV. Component-Related Questions *(to be completed by respondents)*

V.1. Do you agree with the following components to be included in the WJWSI framework?

COMPONENT	YOUR ASSESSMENT (please circle or cross the number)						
WATER RESOURCES	1	2	3	4	5	6	7
WATER SERVICE PROVISION	1	2	3	4	5	6	7
CAPACITY	1	2	3	4	5	6	7
HUMAN HEALTH	1	2	3	4	5	6	7

1= disagree, 7 = agree; 1-7 ranges from disagree to agree with 4 being neutral

IV.1. Of the above components, do you think there are component(s) to be modified or removed? Are there other component(s) to be added?

Yes **No**

[1] A component is a group of two or more indicators.
[2] An indicator is an instrument to measure water resource phenomena.
[3] A threshold is a number or figure used to assess an indicator. In this questionnaire, the thresholds have maximum and minimum values as the range of indicator's performance quality. These values are adopted from standards, policies or guidelines issued by governments or other legitimate institutions.

IV.2. If your answer is No for Question IV.2, please continue to Part V. If your answer is Yes for Question IV.2, what are the components to be modified or removed? What are the components to be added?

V. Indicator–Related Questions *(to be completed by respondents)*

V.2. Do you agree with the following indicators to be included in the WJWSI framework?

COMPONENT	INDICATOR	YOUR ASSESSMENT (please circle or cross the number)						
WATER RESOURCES	Availability	1	2	3	4	5	6	7
	Demand	1	2	3	4	5	6	7
	Quality	1	2	3	4	5	6	7
	Land Use Changes	1	2	3	4	5	6	7
WATER SERVICE PROVISION	Coverage	1	2	3	4	5	6	7
	Water loss	1	2	3	4	5	6	7
	Finance	1	2	3	4	5	6	7
CAPACITY	Poverty	1	2	3	4	5	6	7
	Education	1	2	3	4	5	6	7
HUMAN HEALTH	Access	1	2	3	4	5	6	7
	Sanitation	1	2	3	4	5	6	7
	Health Impact	1	2	3	4	5	6	7

1= disagree, 7 = agree; 1-7 ranges from disagree to agree with 4 being neutral

V.3. Of the above indicators, do you think there are indicator(s) to be modified or removed? Are there other indicator(s) to be added?

Yes **No**

V.4. If your answer is No for Question V.2, please continue to Part VI. If your answer is Yes for Question V.2, what are the indicator(s) to be modified or removed? What are the indicator(s) to be added?

VI. Threshold- Related Questions *(to be completed by respondents)*

VI.1. Do you agree with the following threshold for respective indicators and sub-indicators?

COMPONENT	INDICATOR	EXPLANATION	THRESHOLD		YOUR ASSESSMENT (please circle or cross the number)						
			MAX	MIN							
WATER RESOURCES	Availability	Average annual flow of surface water *(m^3/cap/yr)*	1700	500	1	2	3	4	5	6	7
	Demand	Use of available water sources *(%)*	40	0	1	2	3	4	5	6	7
	Quality	*Water Quality Index*	100	0	1	2	3	4	5	6	7
	Land Use Changes	*Land Conservation Index*	1	0	1	2	3	4	5	6	7
WATER SERVICE PROVISION	Coverage	Coverage of water company *(%)*	80	0	1	2	3	4	5	6	7
	Water loss	Unaccounted for water of water company *(%)*	50	15	1	2	3	4	5	6	7
	Finance	Profitability of water company	0	0	1	2	3	4	5	6	7
CAPACITY	Poverty	People under the poverty line *(%)*	100	0	1	2	3	4	5	6	7
	Education	People completed elementary/primary education *(%)*	100	0	1	2	3	4	5	6	7
HUMAN HEALTH	Access	Water accessible by the community supplied by water company compared to water needed *(%)*	100	0	1	2	3	4	5	6	7
	Sanitation	People with access to basic sanitation *(%)*	100	0	1	2	3	4	5	6	7
	Health Impact	Number of water-borne diseases *(cases/1000 pop)*	100	0	1	2	3	4	5	6	7

1= disagree, 7 = agree; 1-7 ranges from disagree to agree with 4 being neutral

VI.2. Of the above thresholds, do you think there are threshold(s) to be modified?

Yes **No**

VI.3. If your answer is No for Question VI.2, please continue to Part VII. If your answer is Yes for Question VI.2, what are the threshold(s) to be modified, identifying the relevant indicator(s)?

VII. Closing

We thank you for your participation in this Round 1 questionnaire. The results of this questionnaire will be analysed soon, and will be included in the development of the Round 2 questionnaire.

We hope that you, as the respondents of Round 1, will also participate to provide more inputs and suggestions in the Round 2 questionnaire. We believe that the time and effort given to fill-in this questionnaire will be highly beneficial to the improvement of water resources management in Indonesia, particularly in West Java.

At the end of this research, recommendation report of this project will be distributed to decision makers related to water management in West Java. As a tribute, with your consent, your name will appear in the report.

Best Regards,

Researchers
School of Engineering and Science
Victoria University
Melbourne, Australia

Respondent Name:

RESEARCH QUESTIONNAIRE
Round Two

Development of West Java Water Sustainability Index (WJWSI)

I. Information for Round Two

We would like to thank all respondents for responses given in Round One. The responses in Round One were used to formulate the questionnaire of Round Two. The responses on Round One questions can be found in this questionnaire (Round Two).

In this questionnaire, respondents are expected to provide answers on the given questions. If the questions in this questionnaire are the same with the questions in Round One, respondents are allowed to provide the same or different answers. However, we encourage respondents to consider responses from other respondents in Round One when providing answers in Round Two.

Based on the suggestions in Round One, the proposed WJWSI framework in this questionnaire is shown in the following table.

Table 1 Modified WJWSI Framework

Component	***Indicator***	***Sub-indicator***
Conservation	Water Availability	
	Land Use Changes	
	Water Quality	
Water Use	Water Demand	
	Water Access	
	Water Service Provision	Coverage
		Water Loss
		Finance
	Population Pressure	
Policy and Governance	Information Disclosure	
	Governance Structure	
	Public Participation	Education
		Poverty
		Sanitation
		Health Impact
	Law Enforcement	

This questionnaire consists of several parts, which are the information for respondents (Section I), responses from respondents in Round One (Section II), instructions for respondents (Section III), and questions to be answered by respondents (Section IV to VI)

II. Results from Round One

Components

The responses from respondents on the component-related questions are shown in **Error! Reference source not found.**. It shows that for the component of *Water Resources*, 100% of the respondents agreed on the component (chose 6 or 7 on the 7-point Likert-scale), whereas for *Water Service Provision*, *Capacity* and *Human Health* components, 68%, 68% and 72% of the respondents respectively agreed. As mentioned previously, in this study, a consensus is considered to be achieved if more than 67% of the respondents agreed on the option offered in the Delphi technique. It means that for this study, all the offered components in the first-round questionnaire were agreed by the respondents.

For the component of *Water Resources*, none of the respondents disagreed nor had a neutral response. For the components of *Water Service Provision, Capacity,* and *Human Health*, there were 29%, 29% and 22% neutral responses respectively. This shows that the respondents valued the component of *Water Resources* higher than other three components. In addition, with less percentage of 'disagree' and neutral responses, the component of *Human Health* is valued more by the respondents compared to the components of *Water Service Provision* and *Capacity*.

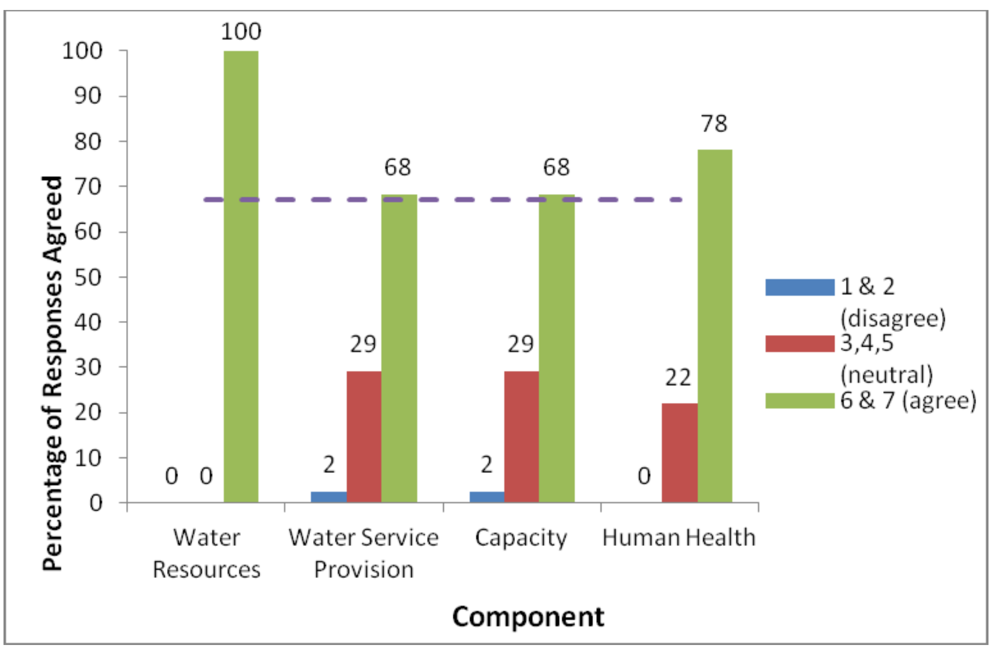


Figure 1 Percentage of Responses Agreed on Indicators – Round One

However, despite their agreement on the provided components, few respondents suggested that the names of the components were modified to reflect the National Regulation No. 7/2004 on Water

Resources (Presiden Republik Indonesia, 2004). According to this regulation, the component of *Water Resources* should be named *Conservation*, *Water Service Provision* should be *Water Use*, and the *Capacity* and *Human Health* components should be *Policy and Governance*. This suggestion, provided by some respondents, was decided to be included in the next round for further views and opinions from other respondents.

Indicators

With regards to the initially identified indicators of the WJWSI, the responses are shown in Figure . It shows that more than 67% of the respondents answered 6 or 7 on the 7- point Likert-scale for 9 indicators, namely, the *Water Availability, Water Demand, Water Quality, Land Use Changes, Coverage, Water Loss, Water Access, Sanitation* and *Health Impact*. For these indicators, as the consensus was reached, they were not brought into the next round(s) of the Delphi application. For the other 3 indicators, which were *Finance, Poverty* and *Education*, 6 or 7 Likert-scale was chosen by 56%, 66% and 61% of the respondents respectively. As the percentages of these three indicators fell below 67%, these indicators were taken into Round Two of the Delphi application.

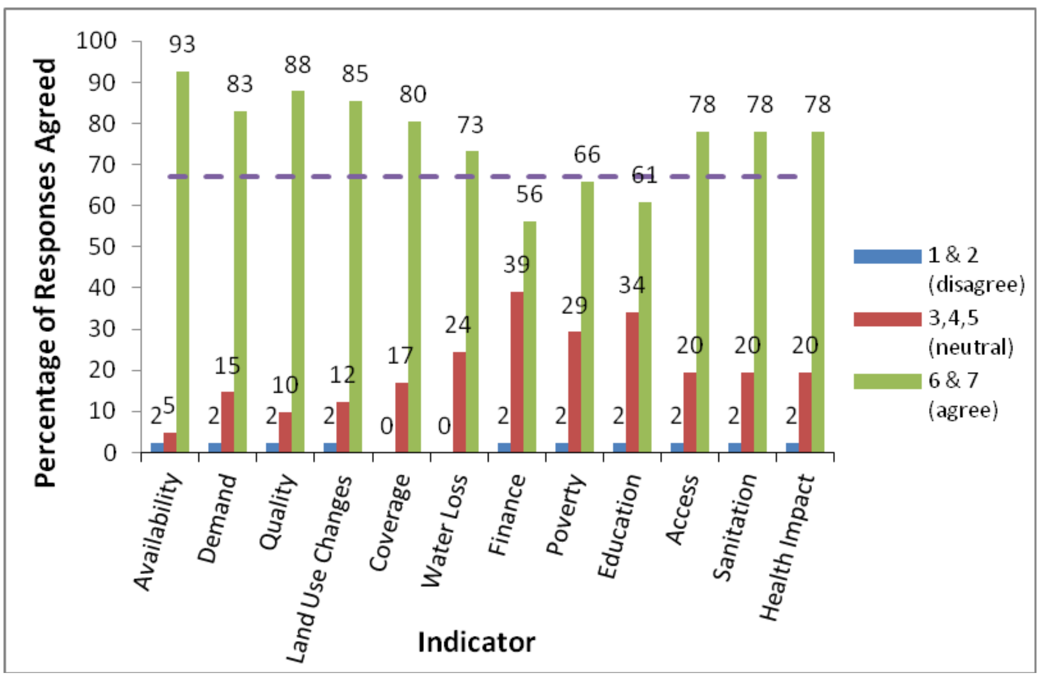


Figure 2 Percentage of Responses Agreed on Indicators – Round One

It is also important to note that 'disagree' percentages for all indicators are 2% or less, which indicated the majority of the respondents preferred the indicators to be included in the WJWSI framework. However, as the 'neutral' responses for the indicators of *Finance*, *Poverty* and *Education* were high, they were brought into Round Two of the Delphi application.

Apart from the indicators in the conceptual framework, few respondents also suggested new indicators be included in the WJWSI framework. Indicators that were suggested by the respondents were

Population Pressure, Information Disclosure, Governance Structure, Public Participation and *Law Enforcement*. The suggestion was addressed by having these indicators in Round Two to seek further comments from other respondents.

Thresholds

The conceptual framework of WJWSI also included thresholds for their respective indicators. The respondents were asked to assess these thresholds; their responses are illustrated in Figure 3.

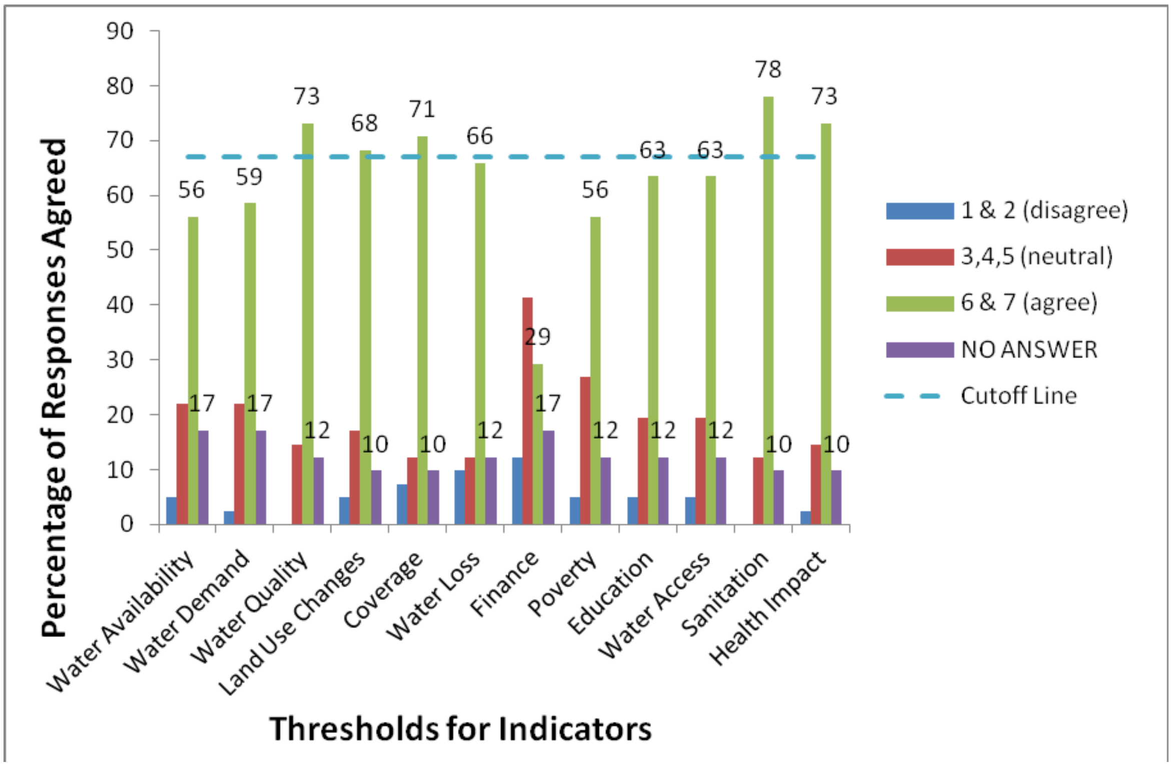


Figure 3 Percentage of Responses Agreed on Thresholds – Round One

Figure 3 shows that consensus was reached for few thresholds, considering the 67% cut-off. The thresholds above 67% cut-off are for *Water Quality, Land Use Changes, Coverage, Sanitation* and *Health Impact*. For thresholds of these indicators, as the consensus was reached, they were not brought into the next round of the Delphi application.

For other thresholds that have not been agreed (i.e. thresholds for indicators of *Water Availability, Water Demand, Water Loss, Finance, Poverty, Education* and *Access*), most of the respondents have 'neutral responses', 'disagree' or 'no answer'. Compared to the responses for components and indicators, responses on thresholds had higher percentages on 'disagree', 'neutral' and 'no answer'.

Some of the respondents also suggested new thresholds for *Poverty, Coverage* and *Water Demand* indicators. Their suggestions on the thresholds of these indicators are presented in
Table .

Table 2 Thresholds Suggested in Round One

Indicator	Thresholds	
	Old	New
Poverty	0 – 100%	0% - 20%
Coverage	0 – 80%	0 – 60%
Water Demand	0 – 40%	10 – 40%

Conclusions on Round One

Based on the results from Round One, the conceptual framework of WJWSI was modified, as shown in Table 3. This modified framework was then brought to the next round of Delphi application.

The modified framework in Table 3 incorporated suggestions from Round One to correspond with the components with three major components of water resource management stated in the National Regulation on Water Resources; *Conservation*, *Water Use* and *Policy and Governance*. Table 3 also includes new indicators and sub-indicators suggested in Round One. The new indicators and sub-indicators were *Population Pressure*, *Information Disclosure, Governance Structure, Public Participation* and *Law Enforcement*. The sub-indicators are existed in the proposed framework to accommodate suggestions from respondents on the components and indicators in Round One. These suggestions required some indicators to be re-arranged as sub-indicators.

Table 3 The Modified WJWSI Framework After Round One of Delphi Application

Component	***Indicator***	***Sub-indicator***	***Thresholds***		
			Unit	***Max***	***Min***
Conservation	Water Availability		m^3/cap/yr	1700 [a]	500 [b]
	Land Use Changes		-	1 [b]	0 [a]
	Water Quality		-	0 [a]	-31 [b]
Water Use	Water Demand		%	40 [b]	0 [a]
	Water Access		%	100 [a]	0 [b]
	Water Service Provision	Coverage	%	80 [a]	0 [a]
		Water Loss	%	15 [b]	0 [a]
		Finance	-	0 [c]	0 [c]
	Population Pressure				
Policy and Governance	Information Disclosure				
	Governance Structure				
	Public Participation	Education	%	100 [a]	0 [b]
		Poverty	%	100 [b]	0 [a]
		Sanitation	%	100 [a]	0 [b]
		Health Impact	*(cases/1000 pop)*	100 [b]	0 [a]
	Law Enforcement				

a: preferable; b: not preferable and c: >0 preferable, <0 not preferable

In Round One, consensus was reached on thresholds for the following indicators and sub-indicators: *Land Use Changes, Water Quality, Coverage, Sanitation and Health Impact*. For other indicators and sub-indicators, shown by the shaded area in the table, their thresholds have not been agreed.

III. Instruction to Respondents

In this questionnaire, the respondents are expected to:

1. Assess the new structure of *Component*
2. Assess the newly proposed *Indicators*
3. Assess the newly proposed *Thresholds*

IV. Component-Related Question *(to be completed by respondents)*

IV.1. Do you agree with the new structure of WJWSI components?

YOUR ASSESSMENT (please circle or cross the number)						
1	2	3	4	5	6	7

1= disagree, 7 = agree; 1-7 ranges from disagree to agree with 4 being neutral

V. Indicator–Related Questions *(to be completed by respondents)*

V.1. Do you agree with the following indicators and sub-indicators to be included in the WJWSI framework?

COMPONENT	INDICATOR	SUB-INDICATOR	YOUR ASSESSMENT (please circle or cross the number)						
WATER RESOURCE CONSERVATION	Water Availability								
	Land Use Changes								
	Water Quality								
WATER USE	Water Demand								
	Water Service Provision	Coverage							
		Water Loss							
		Finance							
	Population Pressure		1	2	3	4	5	6	7
POLICY AND GOVERNANCE	Information Disclosure		1	2	3	4	5	6	7
	Governance Structure		1	2	3	4	5	6	7
	Public Participation	Education	1	2	3	4	5	6	7
		Poverty	1	2	3	4	5	6	7
		Sanitation	1	2	3	4	5	6	7
		Health Impact	1	2	3	4	5	6	7
	Law Enforcement		1	2	3	4	5	6	7

1= disagree, 7 = agree; 1-7 ranges from disagree to agree with 4 being neutral

V.2. Is there any other indicator(s) to be added? Or rem0ved? Or modified?

Yes **No**

V.3. If your answer is No for Question V.2, please continue to Part VI. If your answer is Yes for Question V.2, what are the indicator(s) to be modified or removed? What are the indicator(s) to be added?

VI. Threshold- Related Questions *(to be completed by respondents)*

VI.1. Which of the thresholds (old or new) is more appropriate?

INDICATOR	*THRESHOLD VALUES*		YOUR ASSESSMENT (please circle or cross the number)		
	Old	New			
Poverty	0 – 100%	0% - 20%	**Old**	**New**	**No answer**
Coverage	0 – 80%	0 – 60%	**Old**	**New**	**No Idea**
Water Demand	0 – 40%	10 – 40%	**Old**	**New**	**No Idea**

VI.2. Of the above thresholds, do you think there are threshold(s) to be modified?

Yes **No**

VI.3. If your answer is No for Question VI.2, please continue to Part VII. If your answer is Yes for Question VI.2, what are the threshold(s) to be modified, identifying the relevant indicator(s)?

VII. Closing

We thank you for your participation in Round Two questionnaire. The results of this questionnaire will be analysed soon, and will be informed to the respondents.

We believe that the time and effort given to fill-in this questionnaire will be highly beneficial to the improvement of water resources management in Indonesia, particularly in West Java.

At the end of this research, recommendation report of this project will be distributed to decision makers related to water management in West Java. As a tribute, with your consent, your name will appear in the report.

Best Regards,

Researchers
School of Engineering and Science
Victoria University
Melbourne, Australia

INTERVIEW GUIDE - In-depth Interview with Selected Key Stakeholders

Based on the results from two rounds of questionnaire distributions,

- Has consensus been reached on all components? Why?
- Has consensus been reached on all indicators? Why?
- Has consensus been reached on all thresholds? Why?
- If consensus has not been reached for particular components/indicators/thresholds, what suggestions do you have for these components/indicators/thresholds?
- Is there any important issues noted from the results of the two rounds of questionnaire distributions?

Note:

- During the interview, further questions were expanded based on the answers from the interviewees on the above questions
- Answers from each interviewee were also discussed with other interviewees

Respondent Name:

RESEARCH QUESTIONNAIRE
Weighting Scheme

Development of West Java Water Sustainability Index (WJWSI)

Introduction

Few months ago, questionnaires related to the identification of components, indicators and sub-indicators of WJWSI were distributed. At the moment, the components, indicators and sub-indicators for WJWSI have been finalised. Some papers related to WJWSI have been produced, and they were published and presented in the following journal and conferences:

- Water Science & Technology Journal, IWA Publishing, 2010
- MODSIM International Conference, Cairns-Australia, Juli 2009
- Hydrology Symposium, Newcastle-Australia, November 2009

To refine the WJWSI, we would like to assign weights for the indicators and sub-indicators. This questionnaire is developed to seek inputs from respondents on the weights for WJWSI indicators and sub-indicators. The results from this questionnaire will be used to aggregate the WJWSI indicators and sub-indicators, as well as to be used in the robustness analysis of the index.

Best Regards,

Researchers
School of Engineering and Science
Victoria University
Melbourne, Australia

INSTRUCTIONS

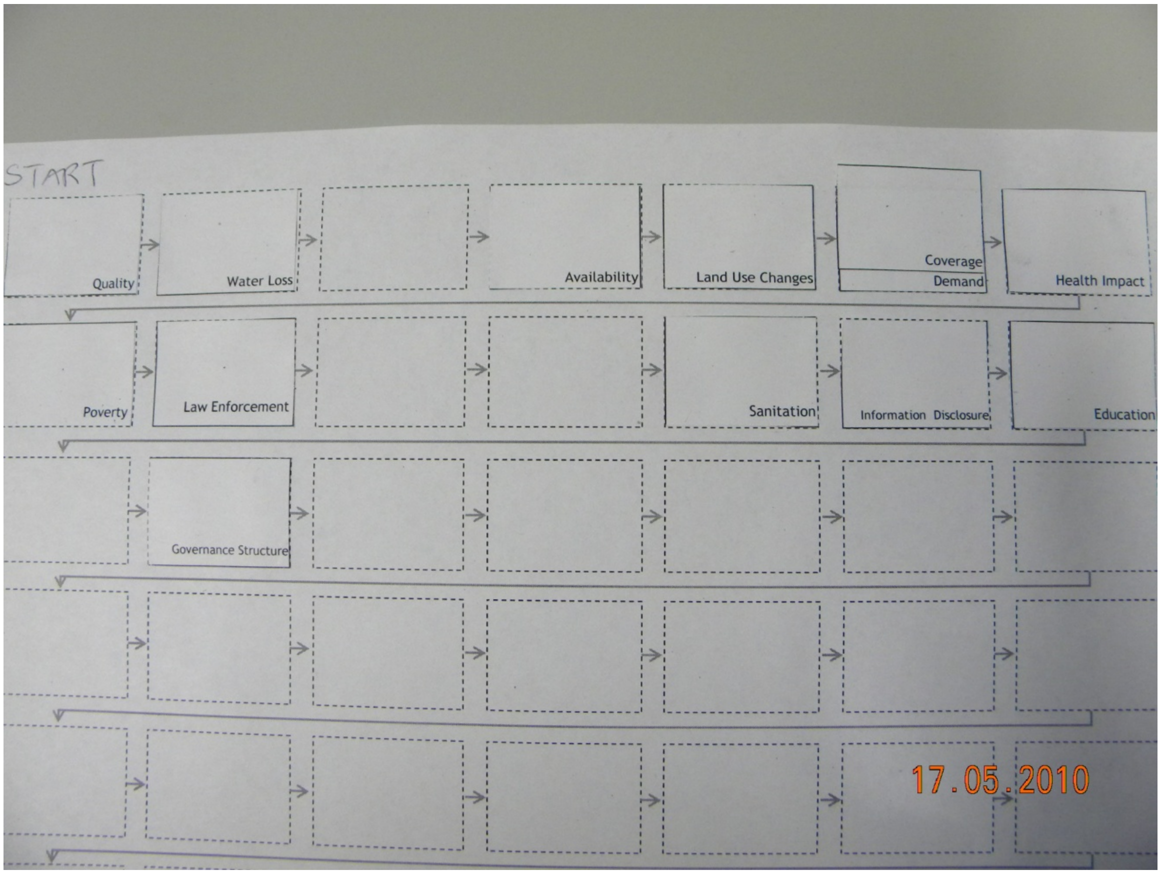
Information for respondents:

- In total, there are 13 indicators and sub-indicators to be assigned weights
- Respondents are asked to arrange the cards in the order of importance, with the indicator or sub-indicator ranked the first is the least important or least preferred
- If the two or more indicators or sub-indicators are considered equally important, their cards are grouped together
- When arranging the cards, respondents are allowed to place blank card(s) between indicators and sub-indicators, to indicate smaller or greater weights between the indicators and sub-indicators

The procedure:

1. Arrange the cards in the order of importance, with the indicator or sub-indicator ranked the first is the least preferred
2. Answer the following question: *"How many times more important is the most preferred indicator or sub-indicator relative to the least preferred indicator or sub-indicator?"*
3. If necessary, place blank card(s) between indicators and sub-indicators, to indicate smaller or greater weights between the indicators and sub-indicators

AN EXAMPLE OF COMPLETED QUESTIONNAIRE



"How many times more important is the most preferred indicator or sub-indicator relative to the least preferred indicator or sub-indicator?"

Answer: 20 times

Explanations of the above response:

- *Quality* is considered as the least preferred indicator, and *Governance Structure* is considered as the most preferred indicator
- The *Governance Structure* indicator is considered 20 times more important than the *Quality*
- Indicators with equal weights: *Coverage and Demand*