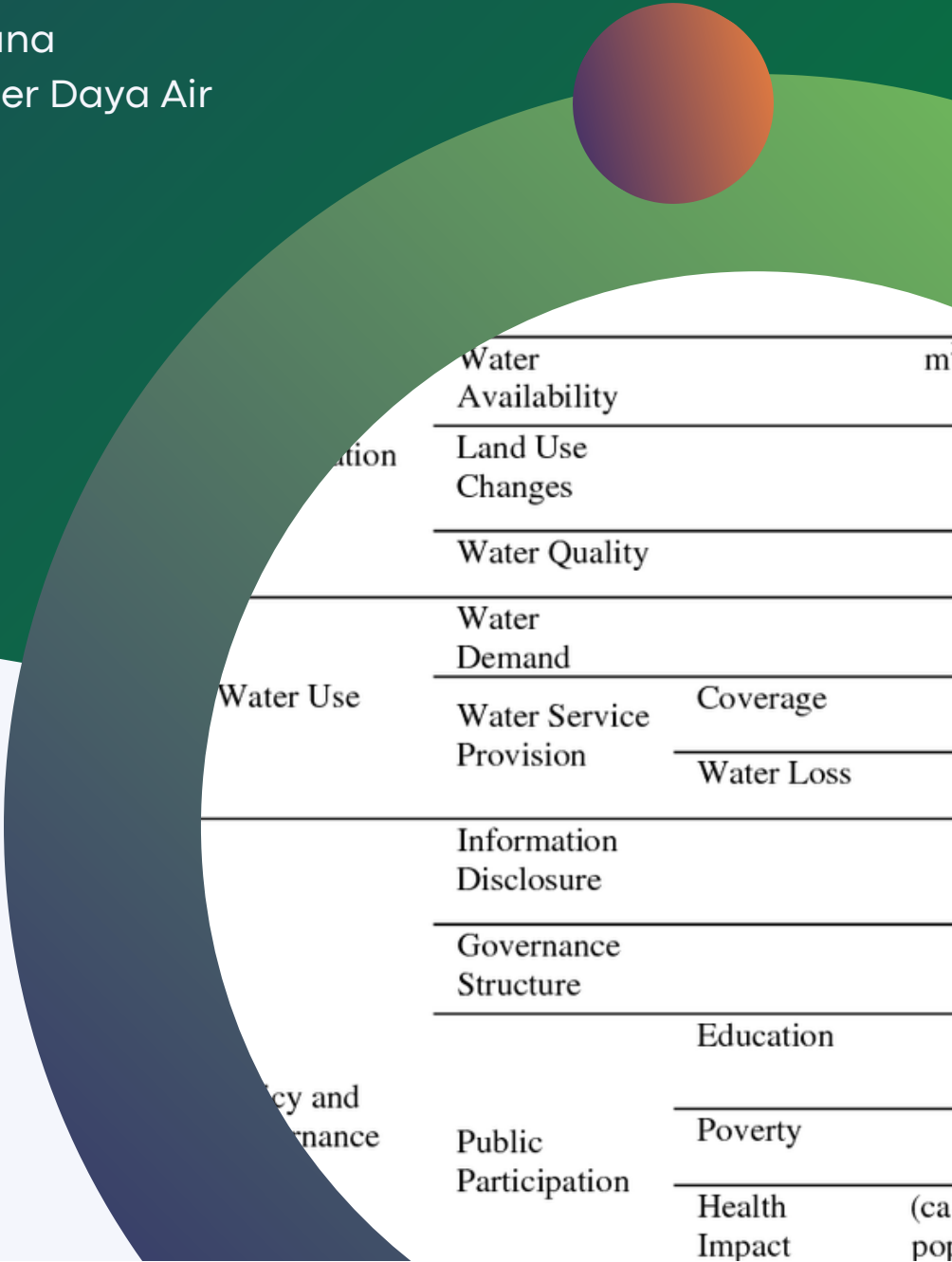




West Java Water Sustainability Index

Penyusunan Rencana
Pengelolaan Sumber Daya Air
Jawa Barat

IWAN JUWANA
Teknik Lingkungan



	Water Availability	m
ation	Land Use Changes	
	Water Quality	
	Water Demand	
Water Use	Water Service Provision	Coverage Water Loss
	Information Disclosure	
	Governance Structure	
		Education
ey and nance	Public Participation	Poverty Health Impact (ca por

DESKRIPSI IMPLEMENTASI

West Java Water Sustainability Index

Pengguna

Badan Pengelolaan Lingkungan Hidup Daerah Jawa Barat

Waktu

Tahun 2012

Lokasi

Provinsi Jawa Barat

Manfaat

Indeks keberlanjutan sumber daya air yang khusus dikembangkan untuk Provinsi Jawa Barat ini digunakan oleh Pemerintah Provinsi Jawa Barat, khususnya Badan Pengelolaan Lingkungan Hidup Provinsi Jawa Barat, untuk menganalisis kondisi Daerah Aliran Sungai yang ada di Provinsi Jawa Barat. Adanya indeks ini memudahkan Pemerintah Daerah untuk mengembangkan perencanaan pengelolaan Daerah Aliran Sungai di wilayah Provinsi Jawa Barat.



Development of a Water Sustainability Index for West Java, Indonesia

Iwan Juwana

Thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

School of Engineering and Science
Faculty of Health, Engineering and Science
Victoria University, Australia

March 2012

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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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., Muttill, 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*.
- Juwana, I., Muttill, N., & Perera, B. J. C. (2012). Indicator-based Water Sustainability Assessment – A Review. Paper under review in *Science of the Total Environment: An International Journal for Scientific Research into the Environment and its Relationship with Humankind*.
- Juwana, I., Muttill, N., & Perera, B. J. C. (2012). Application and robustness analysis of West Java water sustainability index Citarum catchment. Paper under review in *Water science and technology: a journal of the International Association on Water Pollution Research*.
- Juwana, I., Muttill, N., & Perera, B. J. C. (2011). *Application of West Java water sustainability index in Citarum catchment*. Paper presented at the 20th World IMACS/MODSIM Congress 12-16 December 2011, Perth, Australia.
- Juwana, I., Perera, B., & Muttill, N. (2010a). A water sustainability index for West Java - Part 1: developing the conceptual framework. *Water science and technology: a journal of the International Association on Water Pollution Research*, 62(7), 1629-1640.
- Juwana, I., Perera, B., & Muttill, 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.
- Juwana, I., Perera, B. J. C., & Muttill, N. (2009). *Application of Delphi Technique for Development of a Water Sustainability Index for West Java, Indonesia*. Paper presented at the 32nd Hydrology and Water Symposium 30 November - 3 December 2009, Newcastle, Australia.
- Juwana, I., Perera, B. J. C., & Muttill, 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.

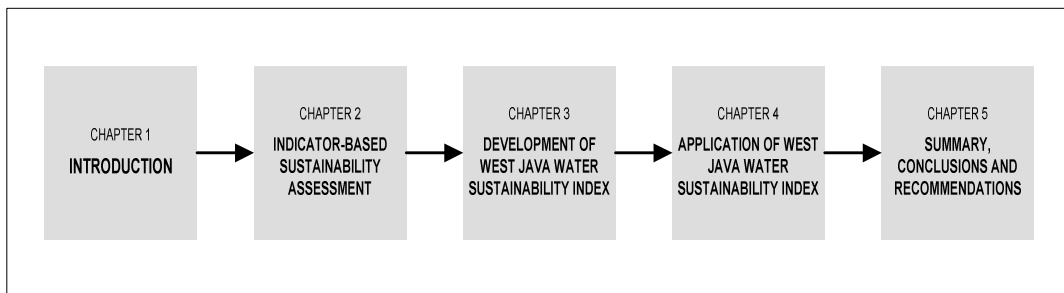


Figure 1.1 Thesis structure

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.

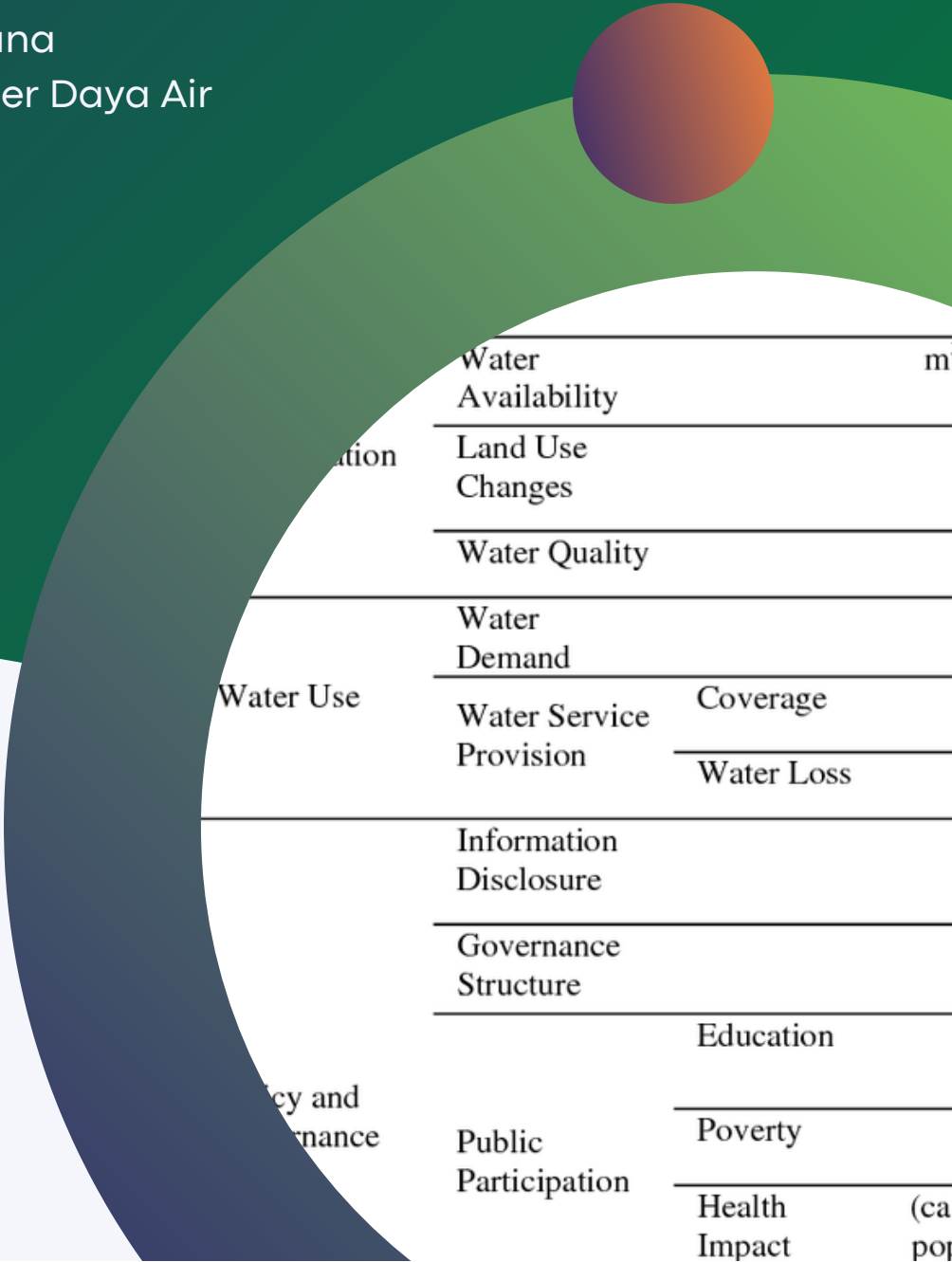
Following discussion on the development of the conceptual framework, this chapter explores the use of the Delphi technique to refine the conceptual framework. Here, definitions, advantages and disadvantages of the Delphi technique are described, followed by detailed steps of Delphi application. These 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.



West Java Water Sustainability Index

Penyusunan Rencana
Pengelolaan Sumber Daya Air
Jawa Barat

IWAN JUWANA
Teknik Lingkungan



	Water Availability	m
ation	Land Use Changes	
	Water Quality	
	Water Demand	
Water Use	Water Service Provision	Coverage Water Loss
	Information Disclosure	
	Governance Structure	
		Education
ey and rnance	Public Participation	Poverty Health Impact (ca por

DESKRIPSI IMPLEMENTASI

West Java Water Sustainability Index

Pengguna

Badan Pengelolaan Lingkungan Hidup Daerah Jawa Barat

Waktu

Tahun 2012

Lokasi

Provinsi Jawa Barat

Manfaat

Indeks keberlanjutan sumber daya air yang khusus dikembangkan untuk Provinsi Jawa Barat ini digunakan oleh Pemerintah Provinsi Jawa Barat, khususnya Badan Pengelolaan Lingkungan Hidup Provinsi Jawa Barat, untuk menganalisis kondisi Daerah Aliran Sungai yang ada di Provinsi Jawa Barat. Adanya indeks ini memudahkan Pemerintah Daerah untuk mengembangkan perencanaan pengelolaan Daerah Aliran Sungai di wilayah Provinsi Jawa Barat.

