POLICY ASSESSMENT OF RIVER RESTORATION BASED ON ANALYTIC HIERARCHY PROCESS AND SYSTEM DYNAMICS FOR SUSTAINABLE WATER RESOURCES MANAGEMENT

By

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Abstract

The focus of this study is to assess river restoration efficiently according to the users of the rivers. The AHP method is used to select the priority of river restoration goals were: restoration of species, restoration of ecosystems or landscapes and restoration of ecosystem services. The next step is to assess water balance in a river basin using a hydrological model to calculate water availability and use a water demand model to calculate water requirements. The hydrological model used was chosen between the NRECA and FJ. Mock. The last step is to build a system dynamics model consisting of population sub-models, water storage, and water demand. The SD model is to assess the impact of river restoration plans were: reclaimed water, increased water demand efficiency, reduction of agricultural land, and inter-basin water transfer. The case study used is the Ciliwung River Basin which has a high population and economic growth.

CHAPTER ONE: BACKGROUND AND OBJECTIVES

1-1 Introduction

The river supplies many ecological services function such as water supply, biological protection, and landscape amusement to promote urban development with its social, economic and environmental values. But the urban size expansion is adding disturbances to rivers, such as dam building, water resources exploitation, water allocation, disturbed river flow regime and water cycle process. They have resulted in degradation of the river ecosystem.

The issue of degradation of the river includes forest ecological damage, decrease in base flow, increased peak discharge, high sediment load, flooding, garbage in the water river, river water pollution by fertilizers and pesticides, domestic waste, industrial, hospitality, farm, water use conflicts, biodiversity decrease, decreasing population of species, water river pollution [1].

River restoration aims to (1) restore the natural conditions of the river, (2) restore river function to support biodiversity, recreation, flood management and landscape development, (3) improve the resilience of the river system, and (4) create the framework for utilization of the river in a sustainable, multifunctional manner [2].

The earliest river restoration projects are launched in Europe. The US started the activities in 1976, and latest in China. Theoretically, existing research mainly focus on the river restoration strategy, river restoration in catchment's scale, and restoration of river elements as flow and riverbanks, etc. [1]. Various river restoration projects have been done in many countries including Japan, South Korea, and the United States with different focus and activities. The most restoration activities are to restore vegetation, improve the water quality of the river and beautify the environment around the river. As the response to the technical procedure of the planning, the key point of urban river restoration planning should involve diagnosis of river health, prediction of river ecological trend, river restoration target and indicator system, optimization of river restoration scenario.

One of the restoration activities failures is that the benefits of post-restoration are inconsistent with the needs of river-use stakeholders. This is due to less involving stakeholders utilizing the river. Besides, restoration activities do not have a standard which can be used as a reference while the time spent in restoration is very long and the cost is very expensive so it takes an instrument in determining the policy to perform river restoration.

Based on the things mentioned above, some questions can be formulated as follows:

(1) What is the goal of river restoration?

(2) How to determine the river restoration priority according to river stakeholders?

(3) How to know the influencing factors in river basin policy making in the context of sustainable water resources management?

(4) How to choose the best river restoration policy?

This study aims to build an instrument of river restoration policy for sustainable management of water resources. In this research, AHP method is used to find out the focus of river restoration for river stakeholders, the water balance method is used to find out the sustainable water, and the system dynamics model to find out the efficient river restoration impact.

1-2 Objectives and structure

The objectives of the dissertation are as follows:

(1) To investigate the goal of river restoration

(2) To determine the goal of the river restoration model using the AHP method

(3) To build hydrological model and SD model for simulation of sustainable water resource management

(4) To select the best policy using SD model with several river restoration plans.

This dissertation is organized in six chapters. The first chapter provides an introduction, giving background information about how river restoration projects have become important over the last decades.; the second chapter of the literature review includes a literature review (hydrology, watershed, decision-making methods, hydrological models, and system dynamics models) and study framework; chapter three contains application of the analytical hierarchy process; chapter four contains the application of hydrological methods for sustainable water management; chapter five contains system dynamics model to assess the impact of restoration; chapter six conclusions and future research.

1-3 Scope and limitation

The scope and limitation of the dissertation are as follows:

(1) To choose the priority of river restoration policy, the AHP method is used with a case study in the Sugutamu watershed

(2) River restoration for ecosystem services purposes, especially for raw water supply, a hydrological model is used to calculate water balance in a river basin with a case study of the Upper and Middle Ciliwung river basin

(3) Hydrological models used to calculate water availability, namely FJ.Mock and NRECA

(4) Designing dynamic models to find out water resources sustainability in a river basin is limited to sub-systems namely population, water demand and water storage

(5) Recommendations for river restoration plans to maintain water balance in a river basin.

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CHAPTER TWO: LITERATURE REVIEW AND STUDY FRAMEWORK

2-1 Introduction

Clean water needs are increasing as population and economic growth are increasing in a region. In a river basin, rivers are used as a source of water for various needs of users such as water for domestic, industrial, agricultural, and industrial. Stakeholders in the river basin have their own interests in using river water.

To understand the behavior and the operation of this watershed system we must first look at reservoir behavior and hydrology. A basic understanding of hydrology and reservoir system dynamics is an important step in determining our own recommendations for the sustainable river basin water resources management.

Whereas various objectives, activities and stakeholders related to river restoration need to be studied and assessed so that efforts to restore degraded rivers can be achieved. So that the water need in a river basin can be sustainable.

2-2 Hydrology

Water is a vital requirement for all living organisms on this planet. For centuries, people have been examining where water comes from and where it goes. Hydrology provides an understanding of the distributions, movement and quality of water above, on and below the earth surface. Principles and concepts of hydrologic processes facilitate understanding and design of water management systems. In fact, a good understanding of the hydrologic processes is important for the evaluation of the water resources in accordance to management and conservation both on global and regional scales [1].

2-2-1 Hydrologic cycle

The hydrologic cycle is a result of the relations of meteorological, biological, chemical and geological phenomena which keeps water in constant motion. These processes consist of evaporation, condensation, precipitation, interception, transpiration, infiltration, storage, run off and groundwater flow. Some of these processes can be seen in action in **Figure 1.**

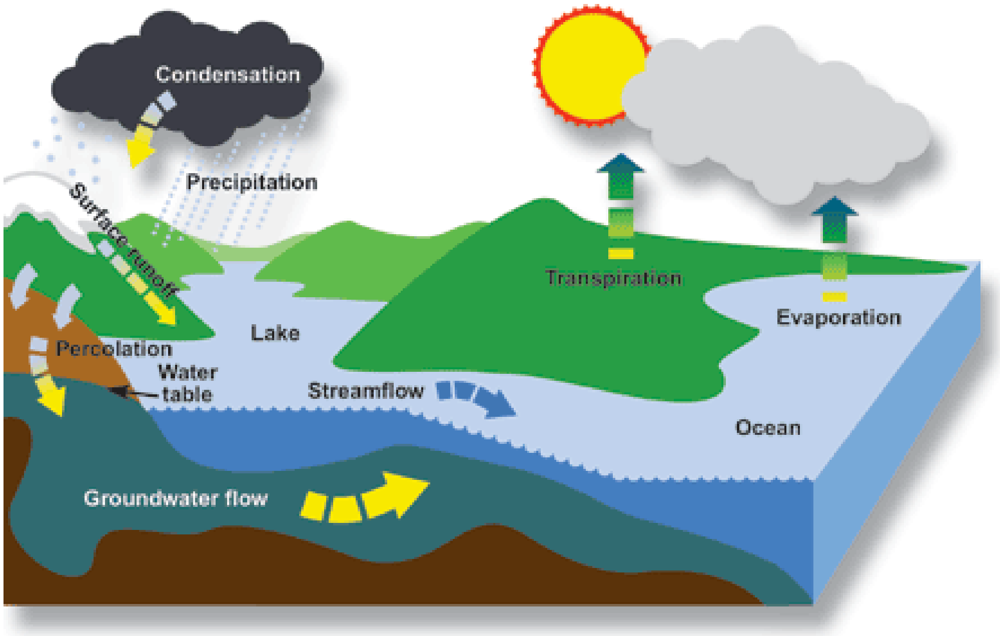

Fig.1. Hydrological Cycle

The flowing definitions and terminology are according to the United State Geological Survey (USGS) and the Nevada Division of Water Resources.

2-2-2 Precipitation

Precipitation (P) is the downward movement of water in liquid or solid phase from the atmosphere due to cooling of the air below the dew point. Precipitation can come in the liquid form as rainfall or solid form as snow and ice. Rainfall is usually quantified by use of a network of rain gauges [1]. The Regional rainfall is transformed from monthly rainfall data.

Rainfall data is calculated based on several methods, namely Algebra, Polygon Thiessen and Isohyet. The algebraic method calculates the area's rainfall by making the average rainfall data from the observer station. Polygon Thiessen method is used because it is easy and accurate with a minimum of data from 3 observer stations to make triangles (polygons). The Isohyet method is the most accurate because it connects the same rainfall lines, but rainfall must be spread evenly across the watershed.

An algebraic method was used because the catchment area is between 250 and 50,000 ha. The formula of the algebraic method is as follows:

$$R_H = \frac{H_1 + \cdots + H_n}{n} \qquad (1)$$

R_H: is the average regional rainfall (mm),

H: is the monthly rainfall data from gauge station 1, 2, …n, and

n: is the number of gauge stations.

2-2-3 Evapotranspiration

Evapotranspiration (ET) is actually the sum of the two hydrologic processes of evaporation and transpiration from a given land area. Evaporation (E) is the cooling process of liquid water becoming water vapor including vaporization from water surfaces, land surfaces and snow fields. Transpiration (T) is the second process in which water moves for the soil or groundwater into the atmosphere via the stomata in plant cells [1].

Evapotranspiration is the total volume of evaporation from the surface of the soil, ground surfaces, wetlands, natural water bodies and transpiration of plants [2-3].

The Penman's equation is:

$$ETp = F_1.R(1-r) - F_2(0.1 + 09\,S) + F_3(k + 0.01\,w) \qquad (2)$$

$$F_1 = A\frac{0.18 + 0.55S}{(A + 0.27)} \qquad (3)$$

$$F_2 = AB\frac{0.56 - 0.092\,ed^{0.5}}{(A + 0.27)} \qquad (4)$$

$$F_3 = \frac{(0.27)(0.35)(ea - ed)}{(A + 0.27)} \qquad (5)$$

A: is the slope of the vapor pressure curve (Hg/°F),

B: is the black body radiation based on the value of temperature (Hg/°F),

ea: is the saturation vapor pressure for the measured air temperature (mm Hg),

ed: is the actual vapor pressure of the air (mm Hg) = ea x relative humidity (%),

S: is the average percentage of monthly of sun-shine,

R: is the solar radiation (mm/day),

r: is the reflection coefficient,

k: is the evaporation surface roughness coefficient = (1,0), and

w: is the wind velocity (mile/day).

The actual Evapotranspiration is described as follows:

$$\Delta E = ETp.\left(\frac{m}{20}\right).(18 - h) \qquad (6)$$

$$ETa = ETp - \Delta E \quad (7)$$

ET_p: is the potential evapotranspiration (mm/day),

ΔE: is the difference between potential evapotranspiration and limited evapotranspiration,

ETp: is the potential evapotranspiration,

ETa: is the actual evapotranspiration,

h: is the number of rainy days in a month, and

m: is the percentage of land covered vegetation (m = 0 % dense forest, m = (10 – 40) % eroded land, and m = (30 – 50) % agricultural land).

2-2-4 Runoff, Stream flow, and Surface and Groundwater flow

Runoff (R) is the portion of precipitation that moved from land to surface water bodies that is neither intercepted by vegetation, absorbed into the soil, nor evaporated into the atmosphere. The local land uses, percent impervious cover, and vegetation all affect the time it takes runoff to reach a surface water body. Often surface runoff will travel along favorable topographical features until the water is fed into a stream. Stream flow itself is the discharge that occurs through a channel into a receiving water body. Base flow of the stream is often maintained through groundwater; however, stream levels can severely fluctuate according to precipitation changes and especially drought conditions. Sub surface flow is the water which infiltrates the ground surface and travels underground, often in large aquifers, until a water body is reached. These aquifers are often recharged through precipitation; however, groundwater levels may drop in times of high water demand, drought conditions, and as a result of seasonal variability. This is often proofed by the fluctuations of depth to the water table throughout the year.

There are several methods for calculating runoff, stream flow and surface and groundwater flow including NRECA and FJ. Mocks model.

Description of NRECA model

The NRECA model was developed by Norman H. Crawford (USA) in 1985. This model is a simplification of the Standard Watershed Model IV (SWM).

NRECA model is developed in the USA which is a subtropical country while Indonesia has a tropical climate so the rainfall conditions are different. Besides, the kind of soil and land covering vegetations are also different.

NRECA model has five parameters to count the water debit in a river basin where each parameter has its own certain value regarding the rainfall condition, kind of soil, and the land covering vegetation. To count the water discharge, trials and errors are done towards the value of the parameter mentioned so the water discharge result is counted with the tolerance limit at $\leq$ 10% if validated towards the measurement result. Those five parameters of the NRECA model are:

- NOM or Nominal: is an index of the soil moisture storage capacity in the watershed, with values NOM = 100 + C × average annual rainfall, where C is approximately 0.2 in watersheds with precipitation throughout the year and 0.25 in watersheds with seasonal rainfall;
- GWF: is an index to the rate of discharge from the groundwater storage to the stream, with values ranging from 0.2-0.9;
- PSUB: is the fraction of runoff that moves out of the watershed as base flow or groundwater flow, with values ranging from 0.3-0.8;
- SMSSTOR: is initial moisture storage, with values ranging from 500-760;
- GWSTOR: is initial groundwater storage, with values ranging from 200-330.

A diagram of the calculations is shown in **Figure 2**.The water balance equation is:

$$run\ off = precipitation - actual\ evapotranspiration + storage \tag{8}$$

The total river discharge was analyzed with the following formula [4]:

$$Q = (direct\ flow + groundwater\ flow) \times A \tag{9}$$

A: is the number area (km^2),

Direct flow: is the excess moist minus the recharge to groundwater,

Excess moist: is the excess moist ratio × water balance,

Water balance: is the Precipitation minus the AET,

AET: is PET × (AET/PET) ratio from **Figure 3**,

The excess moist ratio = 0 if the water balance is negative. If the water balance is positive the moist ration is obtained by the soil moisture storage ration, **Figure 4**,

Storage ratio: is the moisture storage/nominal,

NOM: is given by 100 + 0.2 × average annual rainfall,

NOMINAL: an index of the soil moisture storage capacity in the watershed,

Recharge to groundwater: is given by PSUB × excess moist, PSUB: is the fraction of runoff that moves out of the watershed as base flow or ground water flow, with values ranging from 0.3-0.8,

Groundwater flow: is given by GWF × (recharge to groundwater + BEGIN STOR GW),

PET: is the potential evapotranspiration,

GWF: is an index to the rate of discharge from the groundwater storage to the stream, with values ranging from 0.2-0.9

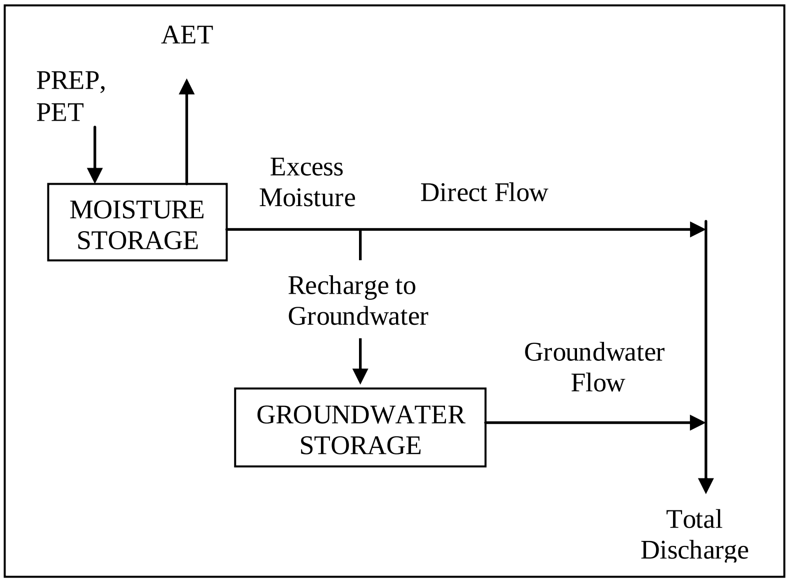

Fig. 2 A sketch of monthly runoff calculations from rainfall and potential evapotranspiration data [4].

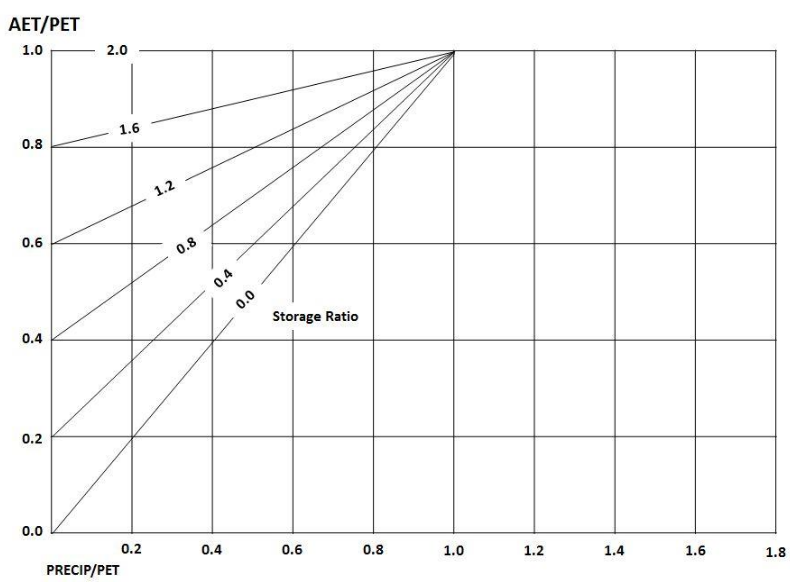

Fig. 3 AET/PET ratio as a function of PRECIP/PET and soil moisture ratio.

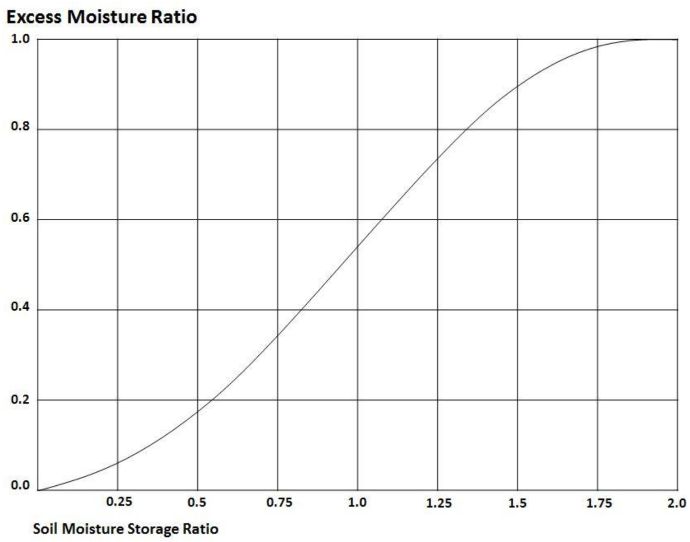

Fig. 4 Soil moisture storage ratio.

Description of FJ. Mock model

A flowchart of the calculations is shown in **Figure 5**.

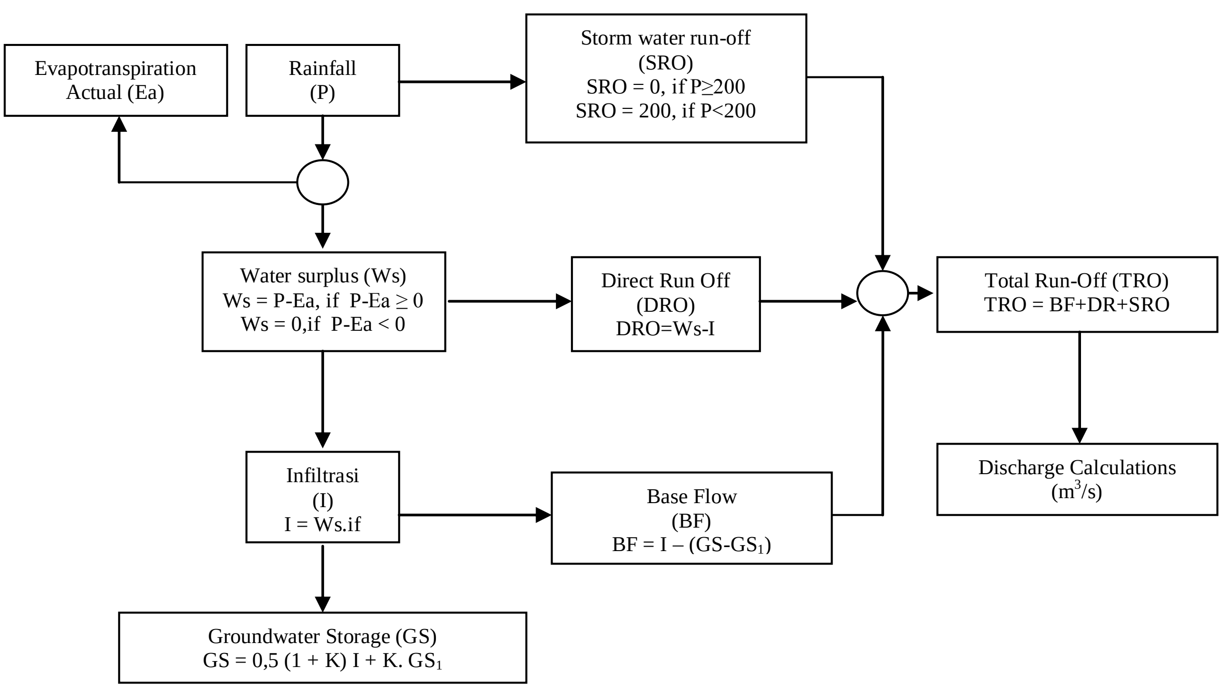

Fig. 5 Flowchart Mock calculation [5].

2-3 Watershed management

2-3-1 Watershed characteristic

A watershed consists of the area of land which contributes to water drainage along topographical slopes draining to a stream or river. Eventually these streams and rivers will flow into a water body and may even contribute to a larger watershed system. Such a large watershed system can be made up of several sub basins for each of the smaller tributary streams and rivers, **Figure 6**.

A reservoir watershed can consist of several large watersheds for major stream inflows. Each of these watershed can consist of a network of smaller sub basins for each tributary to the larger stream. The streams follow a basin order where streams can be ranked according to the degrees of separation from the main channel. A fourth order basin would mean the main channel is of the fourth order, indicating a nest hierarchy of three stream orders, **Figure 7** [1].

Fig. 6 Net Watershed (CGIS)

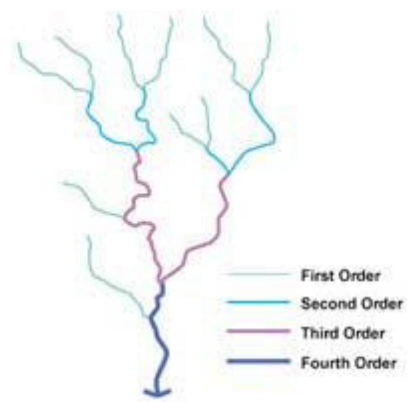

Fig.7 Stream Order Classification (CGIS)

Land use can severely alter and change a watershed system and the drainage networks. A high percentage of imperious surfaces can alter and change runoff conditions which will adversely affect the watershed. The canalizing and piping of streams which hinder human development, lead to severe alteration to the behavior of the watershed. Even though a natural drainage network can be pruned the overall networks are often enlarged and intensified. Lower infiltration rates, extensive impervious over, coupled with pruning will lead to increase in the volume of runoff, a decrease in the quality of surface water runoff, and shorter times of concentration [1].

2-3-2 Water Budgets in the watershed

The equation 1 shows a typical mass balance:

$$Y = V + P + Qin + R + Gin - ET - S \qquad (10)$$

Where P is the precipitation; V is the volume; Qin is the surface inflow; Gin is the groundwater inflow; ET is the evapotranspiration; Y is the yield; R is the run off; S is the seepage.

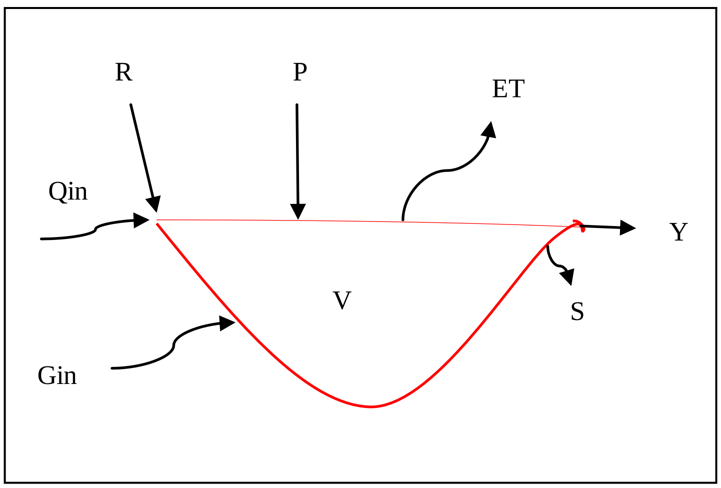

Fig.8 Water budgets in the watershed

2-3-3 Watershed stakeholders

In a river basin there are a variety of stakeholders, namely voluntary organizations, local authority, environmental body, academic institution, non-departmental public body, design organization, private, local community liaison, land owners, local people and business [6]. River restoration involves a wide range of stakeholders from the public and private sector including policy makers, practitioners, scientists and non-government organizations, as well as citizens groups potentially impacted. By actively drawing these various stakeholders into the process, visions can be shared and tuned towards each other. This makes for different interests to be met, and increases support for restoration efforts [7].

2-3-4 Water demand model

The water demand model consists of the domestic, industrial, agricultural, and environmental water demand [5].The formula for calculating water requirements is as follows:

$$\text{Water requirement} = \text{water demand unit} \times \text{standard} \quad (11)$$

The standard can be seen in **Table 1** [8]. Domestic water requirements are calculated based on the projected population according to the Geometric method:

$$Pn = Po\,(1+r)^n \quad (12)$$

Pn: is the projected population in the future,

Po: is the initial population,

r: is the annual population growth rate, and

n: is the time or period.

Table 1. Standard water demand for unit water demand.

No.	Unit water demand	Standard
1	Domestic	160 L/people/day
2	Big Industrial process	65000 L/day/unit
3	Small Industrial process	1000 L/day/unit
4	Industrial worker	60 L/people/day
5	Agriculture	1.2 L/ha/sec
6	Environmental	300 L/people/day

2-4 River restoration

River restoration refers to a large variety of ecological, physical, spatial and management measures and practices. These are aimed at restoring the natural state and functioning of the river system in support of biodiversity, recreation, flood management and landscape development. By restoring natural conditions, river restoration improves the resilience of the river systems and provides the framework for the sustainable multifunctional use of estuaries [7].

River restoration aims to improve the quality and function of rivers and to restore them to support healthy and thriving ecosystems [6].

River restoration can significantly increase the services provided by a healthy ecosystem, too often neglected by decision makers, such as flood control, groundwater recharge, pollution removal, recreational opportunities, and increased property values due to the increasing demand for more natural surroundings. Conversely, river restoration schemes may imply significant changes in water management and land use and hence negative economic impacts on certain economic activities; it may hamper navigation or agriculture for instance [7].

The benefits of improving our rivers: A better quality of life's, makes economic sense, better flood protection, the benefits of river restoration to land use professionals [6].

River restoration contributes to biodiversity by restoring ecosystems and ecosystem processes that are heavily modified. Physical restoration works include re-meandering (i.e. bringing back the curves of a natural river) creating green natural river banks where previously banks were encased in concrete, and fish passes that enable the migration of fish past sluices, dams, and other obstacles [7]. River restoration can help support the adaption of biodiversity in several ways, including: upstream wetland restoration and managed realignment to help increase water storage, planting of riparian trees in order to provide shade and reduce water temperature, and the removal of obstructions to increase connectivity and open up upstream or downstream habitat for migratory fish. Moreover, through its contributions to maintaining and improving conditions for biodiversity, river restoration can be a powerful tool for achieving the objectives of the habitats and birds directives, and the water framework directive [7].

Develop and implement a river restoration project in Europe. Follow the step-by-step process on the following pages in order to plan, design and review a successful project. Step I-planning, Step-II design, objective, and pre-monitoring, Step-III project construction, Step-IV sharing best practice [7].

The objectives of selecting river restoration policy: (1) securing abundant water resources against water scarcity; (2) implementing comprehensive flood control; (3) improving water quality and restoring ecosystems; (4) creation of multipurpose spaces for local residents; and (5) regional development centered on rivers [9].

Activities to achieve the five objectives:

- Water storage: waterways, weirs.
- Flood control: flood control areas and underflow area
- Water quality and ecological restoration: create wetlands, relocate farmlands in the rivers to rehabilitate the river ecosystem
- Creation of multipurpose spaces for local residents: to create the riverfront as a multipurpose area for improving lifestyle, leisure, tourism, cultural activities, and green growth, bicycle lanes, walkways and sports facilities.
- River-oriented community development through various plans that utilize the infrastructure planned in the project and the scenery.

River restoration efforts typically focus on one of three types of goals: restoration of species, restoration of ecosystems or landscapes, and restoration of ecosystem services (e.g., recreation, clean water, and fish production) [10]. To help river restoration practitioners structure the process of identifying and prioritizing restoration, we propose a four-step process that connects watershed analyses to prioritization through [10]:

(1) Setting a clear goal for restoration activities,

(2) Choosing a prioritization scheme,

(3) Using watershed analyses to identify restoration actions necessary to meet the goal and

(4) Prioritizing restoration actions based on assessment results

2-5 Theory of Analytic Hierarchy Process (AHP)

The AHP is a mathematical method for analyzing complex determination problems under multiple criteria [11]. The model consists of five phases: (1) structuring a problem into a hierarchy with objectives, criteria, sub criteria and alternatives, (2) extracting a stakeholder's opinions using criteria, sub-criteria and alternatives those opinions with numbers, (3) using these opinions to estimate the priorities of the criteria, and the alternatives in the hierarchy, (4) checking the consistency of judgments (5) comparing the synthesis of priority in order to determine the best choice [12].

Analytic Hierarchy Process (AHP) is the use of pair-wise comparisons, which are used both to compare the alternatives with respect to the various criteria weights. Areas of application: performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning. Advantages: easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive. Disadvantages: problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.

2-6 Theory of System Dynamics (SD) model

System dynamics (SD), a method for operational system thinking, can help water resource researchers comprehend the interactions among various connected subsystems that drive long-term dynamic behaviors [13]. SD uses feedback as an elementary unit to describe a system, a causal relationship to show the connections among system elements, flow graphs to represent the structure and nature of system elements, and difference equations to quantitatively describe the system. SD is a decision support tool for sustainable water resources management [14].

The objective of some SD model applications in the field of water resources are: (1) to compare the potential effects of water infrastructure, cropland expansion, and dry conditions on communities [15], (2) to investigate water resource management strategies that minimize water losses from evaporation and groundwater depletion through aquifer storage and recovery (ASR) [16], (3) to improve our understanding of both the short- and long-term effects of flooding and irrigation [17], (4) to assess agricultural efficiency, as well as the impacts of climate change, artificial recharge, and changes in the allocation of water supplies [18], (5) to assess the effectiveness of water resource management practices relative to economics and environmental development by combining a dynamic input-output model, economy model, water resource cycle model, and a water pollutant flow model [19], (6) to assess restoration plans for a drying lake, it is found that increasing irrigation efficiency by 4% annually and controlling irrigated lands would have around 60% effect in revitalizing the lake to its ecological level, among those considered restoration plans [20].

The system dynamic modeling process consists of 5 steps: (1) problem definition, (2) system conceptualization, (3) model formulation, (4) simulation, and (5) policy analysis [21].

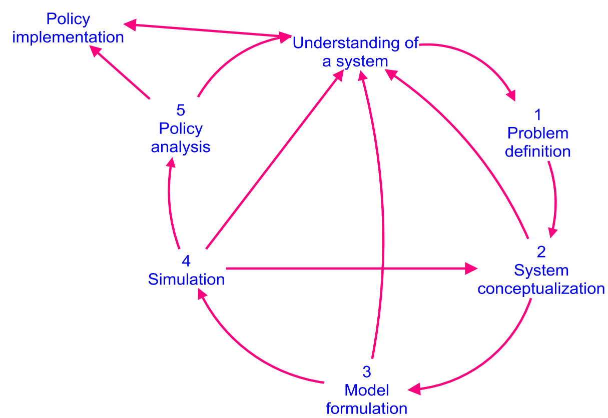

Fig. 9 Process system dynamics model.

2-7 Study frame work

The main focus of this research is to build an instrument of river restoration policy for sustainable management of water resources. In this research, AHP method is used to find out the focus of river restoration for river stakeholders, the water balance method is used to find out the sustainability of river water, and the system dynamics model to find out the effective river restoration impact. The data used in this study include secondary data and primary data. Primary data collection is carried out through field surveys, interviews and dissemination of questionnaires to experts and stakeholders as input for selecting priority objectives of river restoration activities. Secondary data was collected from various sources and stakeholders related to water resource management and river basin, both central government institutions to sub-districts, private sector, tertiary institutions, and communities. Secondary data includes statistical data, research results, planning documents, regulations, maps and others.

The explanation of each stage is as follows. The research approach is carried out with 3 stages of implementation, **Figure 10**.

Stage I Selection of River Restoration Policy

This stage aims to choose the best type of goal restoration, we use the AHP (Application of the Analytic Hierarchy Process) model.

Based on the literature study the hierarchy of the AHP model structure consists of four levels, namely 4 levels: level I Goal Selecting river restoration priority, level II criteria: river water, habitat, cost, land use, and action, level III Sub criteria, there are 20 sub criteria, level IV alternatives, i.e.: restoration of species (RS), restoration of ecosystems of landscapes (REL), and restoration ecosystems services (RES).

The AHP model was then compiled into a questionnaire distributed to a number of respondents divided into two parts, experts and related stakeholders in a river basin.

The results of the analysis at this stage used Expert Choice software to prioritize the objectives of the river restoration based on expert opinion and managerial opinion regarding the river.

Stage II Selection of a hydrological model

At this stage a water balance analysis is carried out in a river basin. The river is used as a source of raw water so that river restoration is carried out to maintain the sustainability of water resources. Calculation of water availability uses 2 hydrological models namely NRECA and FJ. Mock. Calculation of water requirements is calculated based on water requirements for users in a river basin.

At this stage the values of the water balance parameters are obtained which can be used to input the system dynamic model in stage III.

Stage III Selection of an efficient river restoration

At this stage an assessment of the efficiency of river restoration is carried out on river water availability or the sustainability of water resources. The model used is a system dynamic model consisting of several sub-models which are interrelated in a continuous water supply system.

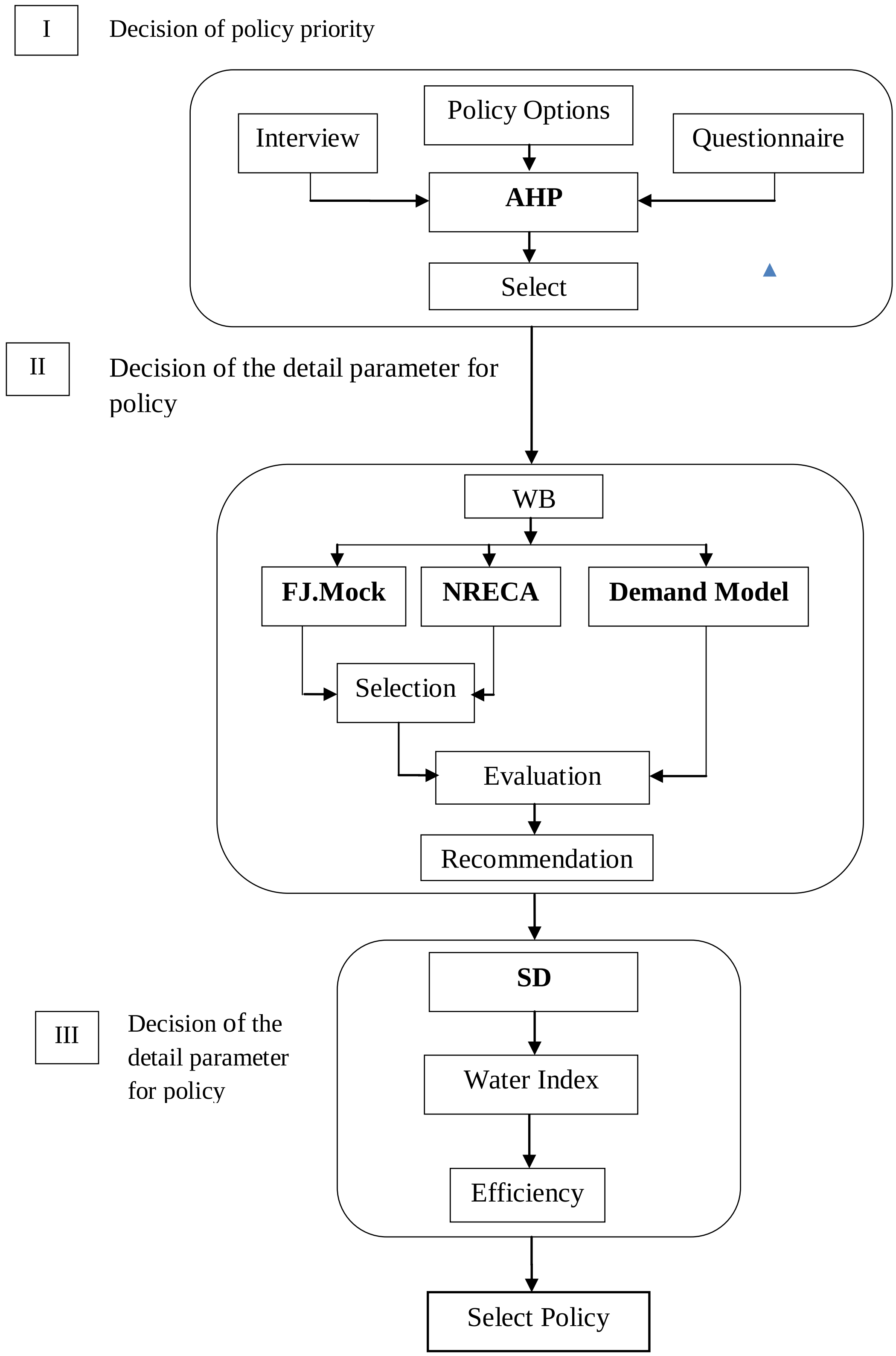

Figure 10 Research Framework

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CHAPTER THREE: APPLICATION OF THE ANALYTIC HIERARCHY PROCESS

3-1 Investigation of the expert communities awareness of the urban river water quality, case study of Sugutamu river, Indonesia

3-1-1 Introduction

Urban rivers is defined as a stream where a significant part of the contributing catchment consists of development where the combined area of roofs, roads and paved surfaces results in an impervious surface area characterizing greater than 10% of the catchment [1]. Many rivers located in the urban area were functioned as the raw water source for the drinking purposes. Therefore, the qualities of the water need to be maintained. Unfortunately, rivers in urban area are experiencing severe pollution due to activities that take place in the area of the river. Not only from the riverbanks, but the waste that was discharged into the river water also came from the area of the basins. Many kinds of efforts have been conducted to recover the river water quality in Indonesia [2]. River restoration becomes priority in improving the environment in Indonesia especially in big cities. It has been regulated by the Indonesian Government since 2011. Restoration efforts had positive effects even in the small restoration projects investigated but did not increase with project size. No "single best" measure could be identified, but river widening generally had a larger effect compared to other restoration measures [3].

Depok is a city located closed to Jakarta City. It plays an important role as the supporting area for the capitol city of Indonesia, especially in providing the residential area of the people working at Jakarta City. Sugutamu River is one of rivers passing through the Depok City. High population densities is resulting critical land usage. Many people use land at the riverbank as their residential place, mostly illegally. These kinds of areas are not supported by the proper infrastructure, including waste management facility. Domestic and non-domestic activities generate solid waste and wastewater which are directly discharged into the river without any prior treatment.

Sugutamu River is the tributary of the Ciliwung River. Main part of this river is located in the administrative area of Depok. The downstream of this river is in the Sukmajaya District while the upstream is in Cibinong District, Bogor. In general, the river has a watershed elongated shape. Sugutamu River function is the primary channel to drain the flooding from the upstream of the river located in Bogor.

Profile of river water quality of Sugutamu on upstream part was 6.71 pH, 15.67 mg/L TSS, 3.14 mg/L DO (dissolved oxygen), 32.97 mg/L BOD (biochemical oxygen demand), and 186 mg/L COD (chemical oxygen demand). Profile of downstream part was 6.78 pH, 15.33 mg/L TSS, 1.56 mg/L DO, 19.63 mg/L BOD, and 124.27 mg/L COD [4]. Considering the government regulation, the Sugutamu River water exceed the water quality standard, especially for the BOD and COD concentration.

Considering the water quality condition, Sugutamu River obviously needs a massive improvement. Urban stream rehabilitation decisions are usually dominated by conflicting triple bottom line pressures of social (including political), economic and environmental factors [1]. The rehabilitation effort has to be under the scope of an integrated water resources management. To strengthen water resources management, the capacity building is important. It will generate and analyzed data, develop sustainable water management plans, use conflict resolution techniques, or encourage stakeholders' participation, and religious groups [5]. Stakeholders of the river management come from various institutions and communities, not only from government, but also from private sectors, researchers, people communities, environmentalists, etc [1].

River restoration contains many aspects to be considered. The most obvious part is water quality condition. The interaction between teams preparing syntheses and expert entrepreneurs helped influence the construction of strategic policy narratives. Those narratives increased the impact of scientific evidence by communicating and framing key policy-salient messages, and brokering between broad ecosystem-based and environmental economics narratives [6].

When implementing a participatory process, stakeholder participation should be considered right from the outset, from concept development and planning, through implementation, to monitoring and evaluation of outcomes [7]. River restoration might generate various problems. The complex and dynamic nature of environmental problems requires flexible and transparent decision-making that embraces a diversity of knowledge and values [7]. In this research, the awareness of expert community of river water quality was investigated. When the high awareness was found, river water pollution measurement can be started early from the source. In the contrary, if the expert communities' awareness is low, the first effort to improve the river water quality is complete treatment facilities that require high budget preparation.

3-1-2 Methodology

Prior to the main research, an interview was conducted to investigate the surrounding Sugutamu River community activities and events involving the river, i.e.:

- Benefits acquired from the river
- River water utilization
- River recreation
- Flooded river experience
- Benefits acquired from the river restoration
- Community participation interest in the river restoration

Survey on the community is very important. The main reasons for pollution in the river are mainly lack of management for both liquid and solid wastes, as well as lack of community participation in river management [8].

Data for this research was acquired mainly using questionnaire distribution. Expert communities were defined in 4 categories, i.e.:

- Economists
- Environmental experts
- River engineers
- Urban planners

Total number of the respondents is 38 experts: 4 economists, 9 environmental, 15 river engineer, and 10 urban planners. In this research, expert communities define as group or individual who can affect or are affected by the achievement of river water quality.

In order to obtain the awareness of the community, the questionnaire asks on the improvement priority sequence among 5 criteria, i.e.:

- River water, which considers water quality, water quantity, water use, and water usage.

- Habitat, which considers biodiversity, species, biota population, terrestrial species.
- Cost which considers financial need for river construction, routine maintenance, recreation facility development, wastewater treatment plant construction and operation.
- Land use, which considers residential area, crop/plantation, industrial area, recreation places.
- Action, which considers activities in community education, law and regulation enforcement, sanction and penalty, improvement of river construction.

Further investigation was taken place to discover the importance sequence among 4 aspects, i.e.:

1. Water quality

   First aspect is considering all variables influencing the life of river's biota, such as color, turbidity, temperature, dissolved oxygen concentration, pH, ammonia, and alkalinity.
2. Water quantity

   It is considering the amount of water available in the river body.
3. Water use

   Water use means the type of area using the water, such as residential, irrigation, industry.
4. Water usage

   Usage of water represents the type of activities using the river water, such as raw water of drinking water, power plant.

Data from the questionnaire was analyzed to obtain the percentage of each expert community in prioritizing the criteria and aspects. This result would show whether the expert communities aware of the river water quality and put it as the top priority in river restoration.

3-1-3 Result and discussion

Sugutamu River is positioned at 06°22'30" South Latitude, 106°50'20" East Longitude, 06°28'35" South Latitude, and 106°50'50" East Longitude. The total area of Sugutamu River Watershed is 13.21 km^2, with 13.74 km length. **Figure 1** shows the map of Sugutamu River.

In the interview activity, several findings on surrounding community were obtained. Most all of the communities (94%) realize the important role of the river, but not many of them utilize its water for daily purposes. **Figure 2** shows the percentage of people living near Sugutamu River who are using river water for several purposes. It shows that percentage of community using the river water often, occasionally, and never is similar respectively.

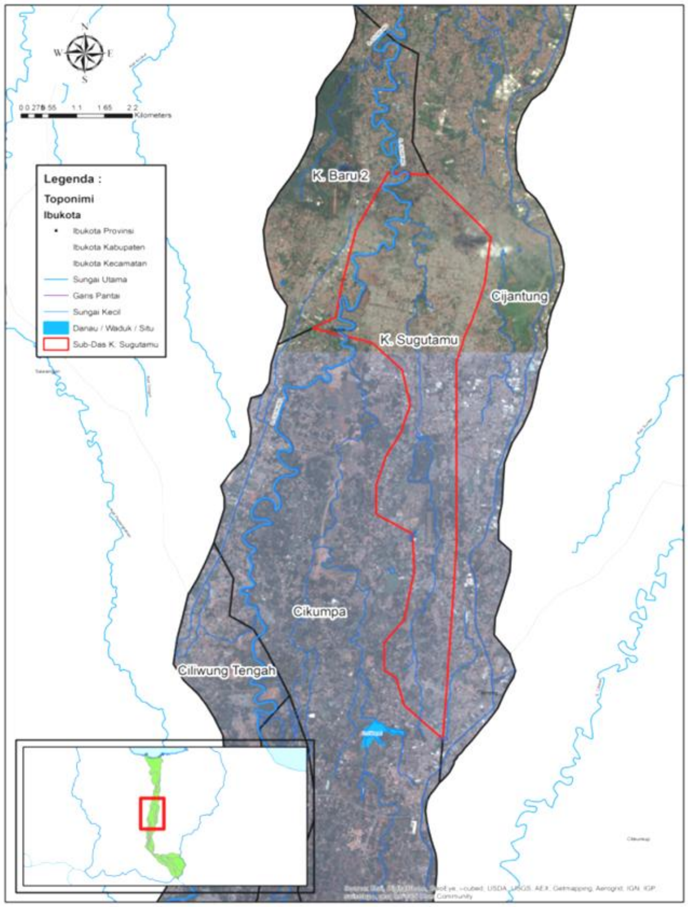

Fig.1 Map of Sugutamu Watershed.

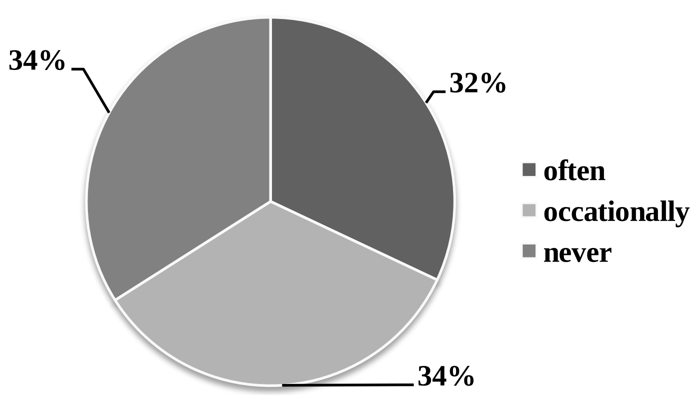

Fig.2 Utilization of river water by the surrounding community.

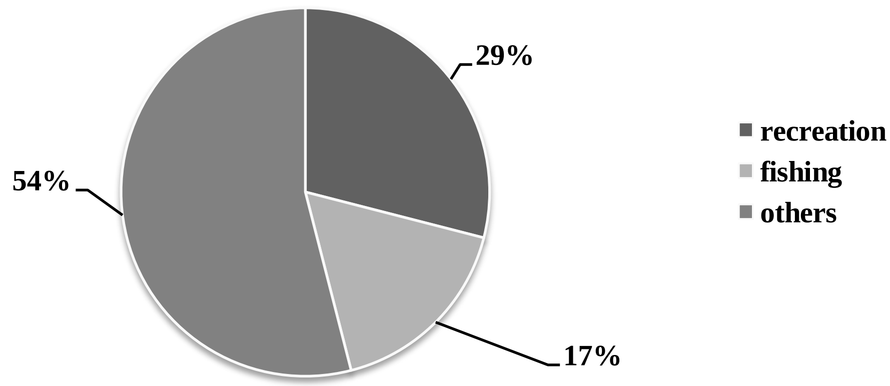

Fig.3 Utilization of river water by the surrounding community.

When questioned on river restoration, the respondents mostly show the interest on participate to support the activity of the restoration. About 48% will participate directly, 50% will participate when being asked, and 2% will not participate.

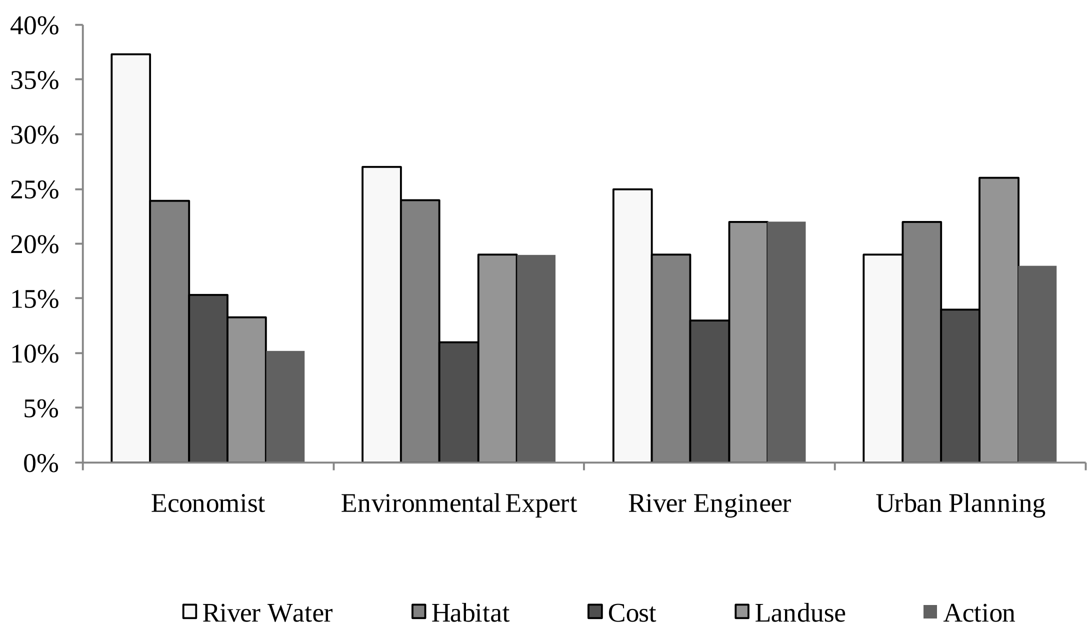

Fig.4 Percentage of each community category to prioritize each criterion.

Questionnaire on the prioritizing criteria gave the result shown in **Figure 4**. Three expert communities, i.e. economists, environmental experts and river engineers mainly put the river water improvement as the first priority in river restoration.

The urban planner community put the land use re-management and improvement as the first priority. This community considers the river water in the third priority after habitat rehabilitation.

All expert communities put the cost category in the last priority. It shows that river construction, routine maintenance, recreation facility development, wastewater treatment plant construction and operation that need high budget can be considered after river water, habitat, and action categories.

Overall data shows that the first priority put by all of the communities is river water. Habitat category was placed in the second concern. It can be indicated by **Figure 5** the cost category was pointed as the lowest priority. Having this result, it can be seen that dominantly, the expert communities are aware on the importance of river water. The highest percentage of river water category was shown in the economist's community. It implies that this community is the most aware expert on the river water improvement.

Figure 6 shows the questionnaire result on the sub-category of river water which is defined as aspects. It indicates that three expert communities, i.e. economists, environmental expert and river engineers, identified the water quality as the first priority in improving the river water. The urban planners' community put the water use improvement as main concern. It considers the land use management. This result is in line with the prioritizing category result, where the urban planners' community concerns the land use as the first priority. The water quality was put in the last priority by the community in the river water sub-category after other aspects, i.e. water usage and water quantity. It is also showing that first three expert communities agree to put the second, third, and forth priority is water quantity, water use, and water usage, respectively.

In total, 35% of all the expert communities put the water quality improvement as the first priority for river restoration. The water usage improvement is considered to be the lowest priority. The water quantity and water use were put as the second and third priority, respectively. The result of the prioritizing aspect shows that awareness of the expert communities is quite high on the water quality improvement. The most aware community for the water quality aspect was the economists'.

High awareness of the expert community will simplify the process of the river restoration project. It will direct to the participation of the communities to the project. Participation should be considered as early as possible and throughout the process, representing relevant stakeholders systematically [7]. The increase of awareness of the expert communities can stimulate the people community awareness as well. There is little evidence to support claims that stakeholder participation in environmental decision-making can promote or enhance social learning [7].

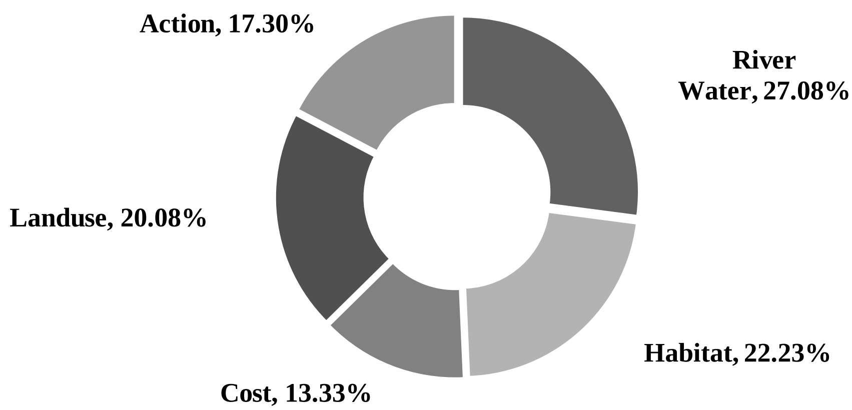

Fig.5. Percentage of each category for total respondents from all expert communities.

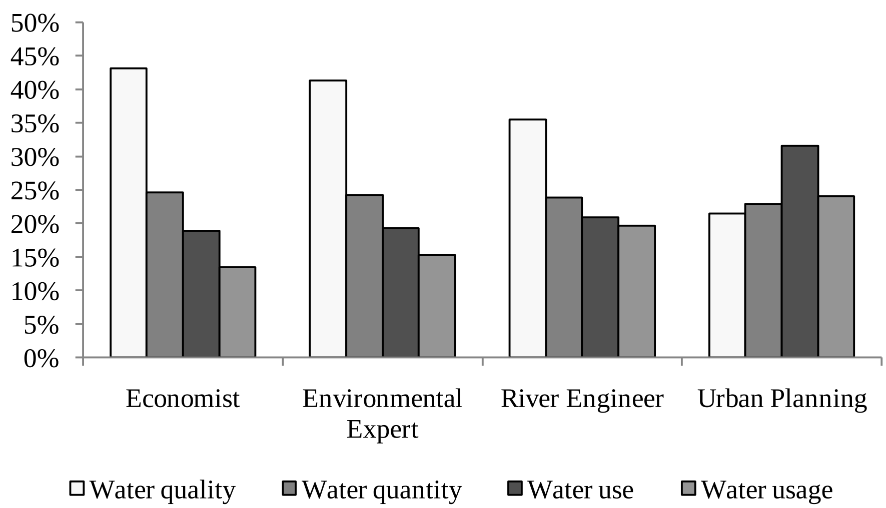

Fig.6 Percentage of each community category to prioritize each aspect in river water

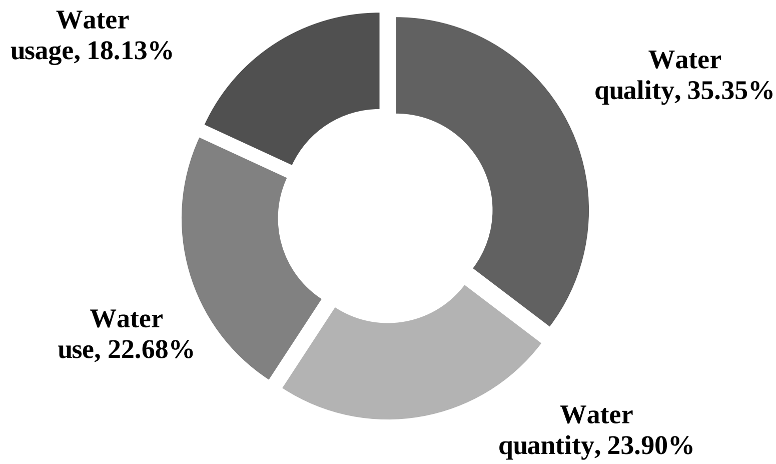

Fig.7 Percentage of each aspect for total respondents from all expert communities.

3-1-4 Conclusion

Most all of the people communities realize the important role of the river, but not many of them utilize its water for daily purposes due to unpleasant condition, especially the water quality.
The expert communities are aware on the importance of river water. The highest percentage of river water category was shown in the economist's community. It implies that this community is the most aware expert on the river water improvement. Awareness of the expert communities is also quite high on the water quality improvement. The most aware community for the water quality aspect was the economists'.

The high awareness of the expert communities will simplify the river restoration project, especially in the river water quality improvement. However, the involvement of either people or expert communities need to be designed effectively and appropriate to have a success participatory process in river restoration.

3-2 Decision making and consciousness of stakeholders for river in Indonesia

3-2-1 Introduction

Since early 2011s, the Indonesian government issued a regulation regarding the river restoration. It states that river restoration is very important to be implemented because the river quality has been degraded. Degradation caused silt of river erosion, settlement on the river banks, riparian land use changes, a decrease in river water quality due to domestic waste, agricultural, and industrial [9]. River restoration action aims to improve the quality and function of rivers [10]. Actual action has been done for landscape function. Several river restoration alternatives namely: restoration of species, restoration of ecosystem of landscapes, and restoration ecosystem services (flood control, raw water, and hydropower plants) [11]. To implement river restoration required the following four stages, namely: setting a clear goal for restoration activities, choosing a prioritization scheme, using watershed analyses, prioritizing restoration actions based on assessment results [11].

The selection of river restoration priority is very complex because there is a conflict of interest from river stakeholders namely public and private sector including policy makers, practitioners, scientists and non-government organizations, as well as river community potentially impacted [12]. By actively drawing these various stakeholders into the process, visions can be shared and tuned towards each other. This makes different interests meet, and increases support for restoration efforts [12]. James A.F. Stoner, decision making is the process of selecting actions to solve the problem that is done by formulating a problem, search for causative factors, and seek alternative solutions, choose the best alternative in accordance with certain criteria and priorities [13].

Problems and the need for the river restoration described into five criteria: river water, habitat, cost, land use, and action. To select priority river restoration, we have distributed questionnaire to stakeholders that are expert in economics, rivers, urban-planning, and environment. We formulated experts' opinions to determine the interest level of criteria and sub-criteria in the selection of priority the restoration of the river so that the river restoration alternatives were selected according to the needs. The method used is the method of Multi-Criteria Decision Making analysis tool AHP (Analytical Hierarchy Process).

This paper presents the level of importance of criteria and sub-criteria and river restoration alternatives in experts' opinions and consciousness of river restoration community of Sugutamu River community based on socio-economic report.

3-2-2 Methodology and data

Decision Making Methodology

Decision making methodology for selecting river restoration priority in Indonesia uses AHP. The AHP was developed to optimize decision making when one is faced with a mix of qualitative, quantitative, and sometimes conflicting factors that are taken into consideration. Principles of AHP: 1) decomposition of problems into hierarchies, 2) comparative judgment synthesis of priority, 3) logical consistency. AHP uses matrix algebra to sort out factors to arrive at a mathematically optimal solution. Decision-making framework river restoration can be seen in **Figure 8**. The criteria and sub-criteria specified and structured based on existing problems, stakeholder needs, constraints, and the impact of the implementation of river restoration. Weights of criteria and sub criteria are calculated using expert choice 11. Solution alternatives are defined based on best practices and stakeholder needs.

In general, the selection of river restoration priority is determined by the assessment of the level of importance criteria or between sub-criteria. The weight is explanations for the standard nine-point preference scoring system used for the AHP. The weight criteria of selection used the relative weights between criteria in a matrix comparison.

Data used to select the restoration of the river is the primary data from river stakeholders namely economists, environmental experts, river engineer, and urban planner. A total of 38 experts: 4 economist, 9 environmental, 15 river engineer, and 10 urban planner were analyzed to get the weights of criteria and sub-criteria and alternatives restoration selected.

The collection of primary data for the analysis of alternative decision making river restoration uses questionnaires distributed by email to stakeholders.

Consciousness of Stakeholders for River Restoration in Indonesia

Consciousness of stakeholders for river restoration in this study used data of socio-economic report for Study of River Restoration Sugutamu. The data used for the analysis of stakeholders' consciousness from secondary data on The Socio-Economic Study Report Sugutamu River Restoration. Data used in this report are based on the results of questionnaires from 100 people who live around The River Sugutamu [14].

3-2-3 Discussion

Decision Making of Stakeholders for River Restoration in Indonesia

River restoration goal is to provide water security, flood control, and ecosystem vitality. This objectives to securing abundant water resources, implementing flood control, improving water quality and restoring ecosystems, creation of multipurpose spaces for local residents, regional development on rivers [15].

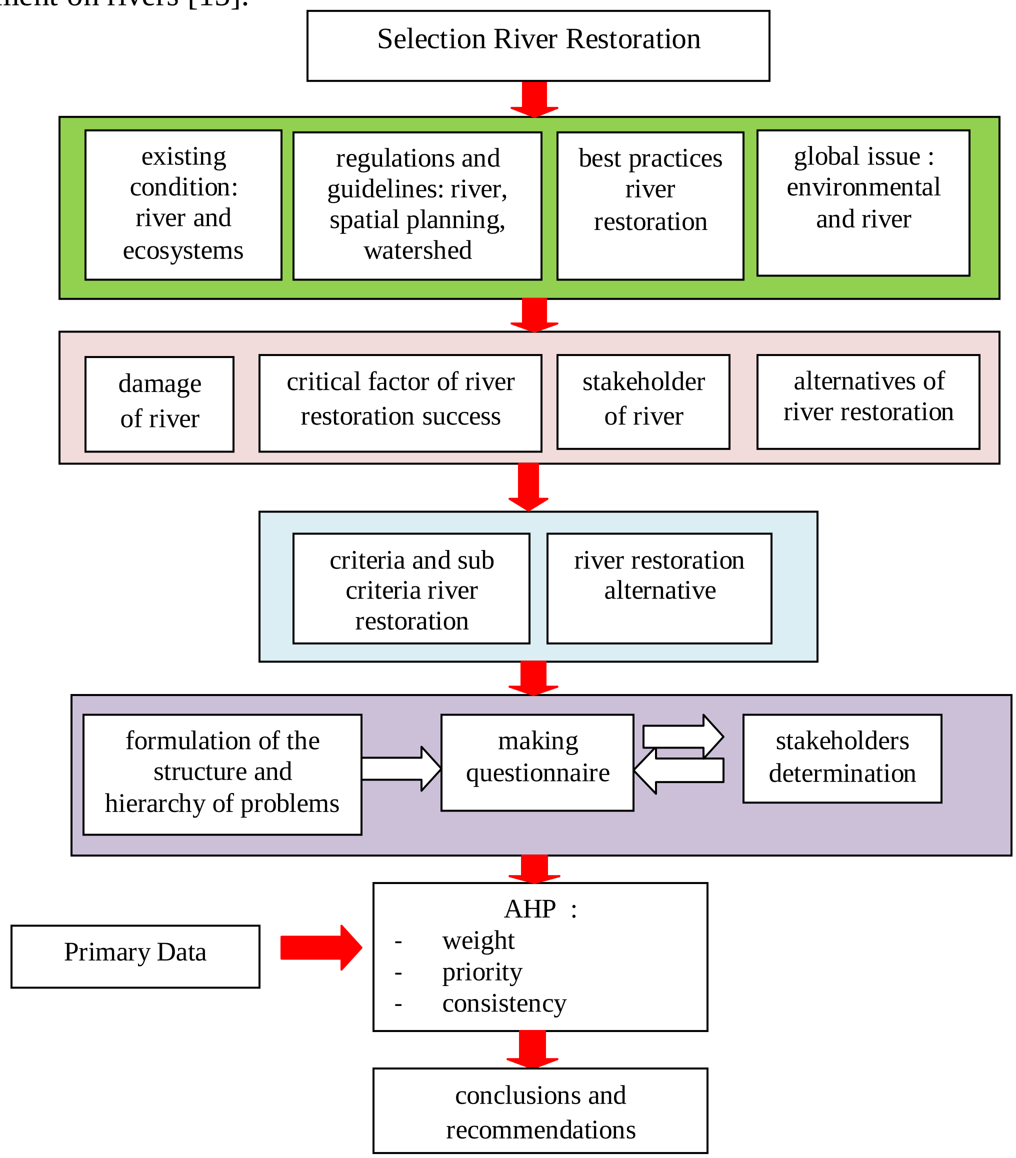

Fig.8 Decision Making River Restoration Framework

The impacts human activities to river systems: flow regime, habitat structure, water quality, food source, biotic interactions [16]. On the global scale of water pollution problem in developing countries due to increase in population and urbanization, increased industrials developments, deforestation, intensified agriculture, engineering works, such as the damming of rivers and the destruction of wetlands.[17]. The environment requires flow of water (seasonality), depth of water, velocity, quality of water, and temperature [17].

Freeman (1984) defines stakeholders as a group or individual who can affect or are affected by the achievement of certain goals [18]. Stakeholders for the users and beneficiaries of the river consist of government, private, and community. In this study, the stakeholders used are the experts that are divided into groups namely, economists, environmental experts, river engineers, and urban planning. A total of 38 experts: 4 economist, 9 environmental, 15 river engineer, and 10 urban planner questionnaires were analyzed and there were 8 respondents (1 economist, 2 environmental, 3 river engineer, and 2 urban planner) representing experts who can use the results of the analysis. The analysis used is the result of analysis with a consistency ratio rate of below 0.15.

Hierarchy structure of selecting river restoration priority

The hierarchy structure consists of four level (**Figure 9**) : level I Goal Selecting river restoration priority, level II criteria : river water, habitat, cost, land use, and action, level III Sub criteria , there are 20 sub criteria, level IV alternatives , i.e.: restoration of species (RS), restoration of ecosystems of landscapes (REL), and restoration ecosystems services (RES)

Analysis of criteria for selecting priority river restoration

Clustering of criteria for selecting river restoration are river water, habitat, cost, land use, and action. Based on the results of questionnaires processed using software expert choice 11 obtained the following results: Based on the analysis results in **Table 1** it can be seen that the importance criteria for selecting priority of river restoration is a river water about 26% according to total experts. Meanwhile, an important criterion for selecting priorities river restoration according to each expert is the criteria of river water with values varying from 25% to 37.3%. Except urban planning expert who chose land use as an important criteria with a value of 26%.

Table 1 Criteria for selecting priority river restoration

No.	Criteria	Economist (%)	Environmental Expert (%)	River Engineer (%)	Urban Planning (%)	Total (%)
1	River Water	**37.30**	**27.00**	**25.00**	19.00	**26,00**
2	Habitat	23.90	24.00	19.00	22.00	20,00
3	Cost	15.30	11.00	13.00	14.00	14,00
4	Landuse	13.30	19.00	22.00	**26.00**	21,00
5	Action	10.20	19.00	22.00	18.00	20,00

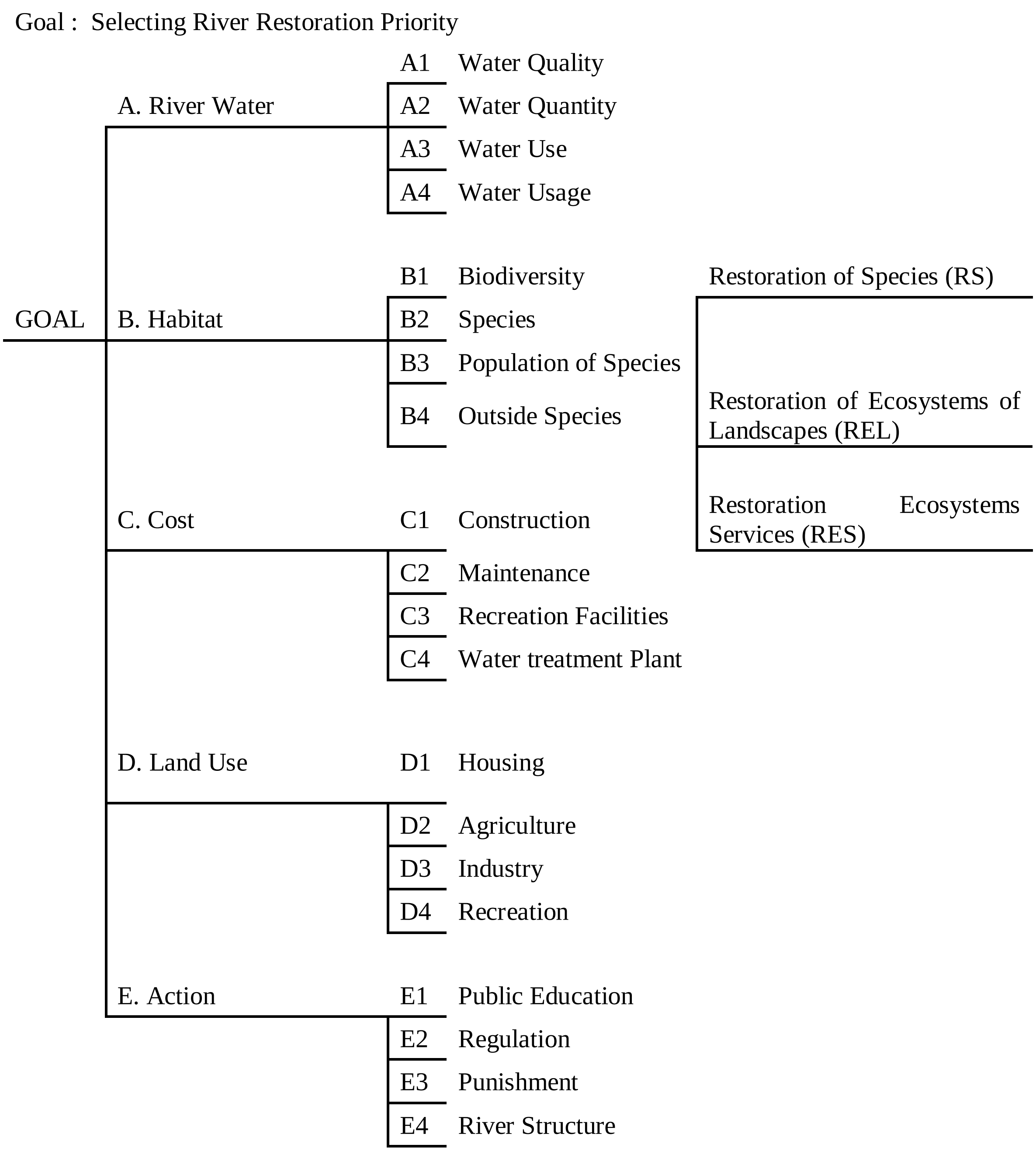

Fig. 9 Hierarchy Structure of Selecting River Restoration Priority

Based on the analysis results in **Table 2** it can be seen that the important sub criterion for water criteria is a water quality 32.60 % according to total experts. Meanwhile, an important sub criterion for river water criteria according to each expert is the sub criteria of water quality with values varying between 35.50 % and 43.10%, except urban planning expert who chose water use's sub criteria with a value of 31.6%.

Based on the analysis results in **Table 3** it can be seen that the important sub criteria for habitat criteria is a biodiversity of 40.10 % according to total experts.

Based on the analysis results in **Table 4** it can be seen that the important sub criteria for cost criteria is 42.50 % maintenance according to total experts. Meanwhile, the important sub criteria for cost criteria according to each expert are the sub criteria of maintenance with values varying between 43.40 % and 50.80%, except environmental expert who chose water treatment plant as an important sub criterion with a value of 47 %.

Table 2 Sub criteria for river water criteria

Criteria/ sub criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)
Water quality	**43.10**	16.08	**41.30**	11.03	**35.50**	8.88	21.50	4.09	**32.60**	8.61
Water quantity	24.60	9.18	24.20	6.46	23.90	5.98	22.90	4.35	24.20	6.39
Water use	18.90	7.05	19.30	5.15	20.90	5.23	**31.60**	6.00	21.90	5.78
Water usage	13.50	5.04	15.30	4.09	19.70	4.93	24.00	4.56	21.30	5.62

Table 3 Sub criteria for habitat criteria

Criteria/ sub criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)
Biodiversity	**36.80**	8.79	**43.80**	10.60	**41.40**	7.87	**37.30**	8.21	**40.10**	7.94
Species	**36.80**	8.79	21.80	5.28	28.20	5.36	25.90	5.70	28.80	5.70
Population	16.90	4.04	20.80	5.03	21.30	4.05	21.60	4.75	20.60	4.08
Outside species	9.60	2.29	13.60	3.29	9.10	1.73	15.20	3.34	10.50	2.08

Table 4 Sub criteria for cost criteria

Criteria/ sub criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)
Construction	26.50	4.06	19.80	2.12	20.50	2.67	13.90	1.95	18.90	2.57
Maintenance	**50.80**	7.77	25.20	2.70	**43.40**	5.64	**43.50**	6.09	**42.50**	5.78
Recreation Facilities	7.50	1.15	8.00	0.86	14.30	1.86	12.30	1.72	14.60	1.99
Water Treatment Plant	15.10	2.31	**47.00**	5.03	21.70	2.82	30.30	4.24	23.90	3.25

Based on the analysis results in **Table 5** it can be seen that the important sub criteria for land use criteria is a recreation 41.40 % according to total experts. Meanwhile, an important sub criterion for land use criteria according to each expert is the sub criteria of recreation with values varying between 40.40 % and 43.20%, except economist and urban planning expert who chose agriculture as an important sub criterion with values varying between 37.00 % and 48.70 %.

Based on the analysis results in **Table 6** it can be seen that important sub criteria for action criteria is a public education 35.30 % according to total experts.

Based on the analysis results in **Table 7** it can be seen that the important sub criteria for selecting priority of river restoration are water quality, water quantity, water use, water usage, biodiversity, species, maintenance, agriculture, recreation, and public education total 67.92 %.

Table 5 Sub criteria for land use criteria

Criteria/ sub criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)
Housing	27.60	3.67	17.50	3.40	14.20	3.12	21.50	5.59	15.30	3.14
Agriculture	**48.70**	6.48	31.00	6.01	33.20	7.30	**37.00**	9.62	32.50	6.66
Industry	11.80	1.57	11.20	2.17	9.40	2.07	12.10	3.15	10.80	2.21
Recreation	11.80	1.57	**40.40**	7.84	**43.20**	9.50	29.40	7.64	**41.40**	8.49

Table 6 Sub criteria for action criteria

Criteria/ sub criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)	LW (%)	GW (%)
Public Education	**47.50**	4.85	**42.90**	8.11	**35.00**	7.70	**36.60**	6.59	**35.30**	6.95
Regulation	27.50	2.81	19.90	3.76	23.40	5.15	18.70	3.37	22.90	4.51
Punishment	9.20	0.94	21.80	4.12	23.60	5.19	22.20	4.00	23.50	4.63
River Structure	15.80	1.61	15.50	2.93	18.00	3.96	22.40	4.03	18.30	3.61

Table 7 Sub Criteria for selecting priority of river restoration

Sub Criteria	Economist		Environmental Expert		River Engineer		Urban Planning		Total	
	GW (%)	Rank	GW (%)	Rank	GW (%)	Rank	GW (%)	Rank	GW (%)	Rank
A1. Water quality	16.08	1	11.03	1	8.88	2	4.09	13	**8.61**	1
A2. Water quantity	9.18	2	6.46	5	5.98	6	4.35	11	**6.39**	6
A3.Water use	7.05	6	5.15	8	5.23	9	6.00	6	**5.78**	7
A4. Water usage	5.04	8	4.09	12	4.93	12	4.56	10	**5.62**	9

B1. Biodiversity	8.79	3	10.60	2	7.87	3	8.21	2	**7.94**	3
B2. Species	8.79	4	5.28	7	5.36	8	5.70	7	**5.70**	10
B3. Population	4.04	11	5.03	9	4.05	13	4.75	9	4.08	13
B4. Outside species	2.29	15	3.29	15	1.73	20	3.34	17	2.08	19
C1. Construction	4.06	10	2.12	19	2.67	17	1.95	19	2.57	17
C2. Maintenance	7.77	5	2.70	17	5.64	7	6.09	5	**5.78**	8
C3. Recreation Facilities	1.15	19	0.86	20	1.86	19	1.72	20	1.99	20
C4. Water Treatment Plant	2.31	14	5.03	10	2.82	16	4.24	12	3.25	15
D1. Housing	3.67	12	3.40	14	3.12	15	5.59	8	3.14	16
D2. Agriculture	6.48	7	6.01	6	7.30	5	9.62	1	**6.66**	5
D3. Industry	1.57	17	2.17	18	2.07	18	3.15	18	2.21	18
D4. Recreation	1.57	18	7.84	4	9.50	1	7.64	3	**8.49**	2
E1. Public Education	4.85	9	8.11	3	7.70	4	6.59	4	**6.95**	4
E2. Regulation	2.81	13	3.76	13	5.15	11	3.37	16	4.51	12
E3. Punishment	0.94	20	4.12	11	5.19	10	4.00	15	4.63	11
E4. River Structure	1.61	16	2.93	16	3.96	14	4.03	14	3.61	14

Analysis comparative alternative

Based on the **Table 8** the results are as follows: environmental expert and urban planning choose Restoration of Ecosystems of Landscape but economist and river engineer choose Restoration Ecosystems Services. The economist experts choose sub-criteria maintenance for the cost criteria and sub-criteria agriculture for the land use criteria.

The environmental expert chooses sub-criteria water treatment plant for cost criteria and sub-criteria recreation for land use criteria.

Table 8 Alternatives Priority Weights

Alternative	Economist (%)	Environmental Expert (%)	River Engineer (%)	Urban Planning (%)	Total (%)
Restoration of Species	32.00	31.60	35.90	27.40	25.70
Restoration of Ecosystems of Landscape	27.60	**34.60**	27.90	**36.40**	30.10
Restoration Ecosystems Services	**40.40**	33.90	**36.30**	36.20	**44.20**

Consciousness of Stakeholders for River Restoration in Indonesia

The definition of consciousness comes from the word conscious that means to know and understand. Consciousness is born from the community by habit in society, influenced by the environment, regulations and the role of government.

This study was conducted to determine comprehension and understanding of the community about the importance of the River Sugutamu restoration plan.

Location of the study includes the District Sukmajaya and Cilodong in Depok and District Cibinong in Bogor City with a total population of 507, 026 people. Sugutamu River is in a position 06º22'30 "LS - 106º50'20 " BT and 06º28'35 " LS - 106º50'50 " BT. The total watershed area of Sugutamu is 13.21 km² and 13.74 km length of the river. These areas included in the administrative area and Cilodong Sukmajaya Subdistrict, Depok City, and also partly in the District of Cibinong, Bogor, West Java. In Sub Sukmajaya there are Sidomukti Lake with an area of 7.5 hectares, whereas in District Cilodong there are Cilodong Lake with an area of 1 ha and volume of 3,000 m^3.

Knowledge and understanding of the river and river restoration by community:

- For the people in the district of Sukmajaya: use the river 32%, sometimes 34%, never 34%
- River used for recreation 29%, fishing 17%, and others 54%
- River flooded 42% and never 58%
- Responsible for the cleanliness of rivers and lakes is the government 61%, 5% developer community 34%
- Knowledge of sanctions throwing garbage around rivers and lakes are: there is no doubt 76% and no sanctions 24%
- Benefits of rivers and lakes in the community: helpful 94%, not helpful 1%, do not know 5%
- The response to the planned River Sugutamu restoration: agree 95%, ordinary course 4%, disagree 1%
- The response of citizens to benefit 88% of the river after restoration useful and 12% are not useful
- Participation of the community towards the river restoration activities, participating 48%, 50% participate if asked, and did not participate 2%.

3-2-4 Conclusions and future study

All criteria have relationship with the goal. This indicated the great value. The river water is the most important criteria for the expert except planner expert (land use). Important sub criteria component for river restoration are: water quality, water quantity, water use, water usage, biodiversity, species, maintenance, agriculture, recreation, and public education. The river restoration alternatives for each expert are based on their interests. The expert choose restoration ecosystems services.

Public awareness of the importance of the restoration is 95%. Communities around expecting rivers and lakes can be used for recreation, tourism, and fishing.

Furthermore, the next questionnaire survey includes stakeholders and community of watershed, and selecting river restoration public education for community of watershed.

3-3 Application of Analytic Hierarchy Process for selecting river restoration policy

3-3-1 Introduction

River water may suffer from pollution due to increasing in population and urbanization, industrials developments, deforestation, and intensified agriculture. In early 2011, Indonesian government issued a regulation regarding river restoration. It states that in view of the degraded water quality of rivers, it is very important for river restoration to be implemented. River restoration aims to (1) restore the natural conditions of the river, (2) restore river function to support biodiversity, recreation, flood management and landscape development, (3) improve the resilience of the river system, and (4) create the framework for utilization of the river in a sustainable, multifunctional manner [19-20]. Based on the experience of countries that have been a project of restoration, not every restoration project provides benefits to the expectations of river users. There are some failures of the restoration project which can only be recognized after the restoration project is completed. The gap between the plan and the expected results of a restoration project makes the choice of selecting priority river restoration very important. The success of a project is affected by the accuracy in selecting the method of restoration in accordance with the needs of users of the river. There are various alternative ways to restore the river, and conflicting interests of stakeholders require a method of making the right decision in choosing a river restoration.

The objective of this study is to develop a model of river restoration to select policy using AHP. The location chosen for this research is the Sugutamu River because a river restoration is planned to be done in the Sugutamu River and the result of this research is expected to be a consideration for the public decision maker.

Sugutamu River is a tributary of the Ciliwung mostly across the Depok with a length of 13.74 km. Condition River water Sugutamu not appropriate water quality standards for the following parameters: Nitrate 68.6 mg / L, Nitric 0:01 mg / L, BOD 11.8 mg /L, Fecal Coliform 5x106 total / 100 ml, Total Coliform 16 x 106 total / 100 ml [21]. Levels of Fecal Coliform and Total Coliform is very high due to domestic sewage directly into the river. Flooding in some locations by narrowing the width of the river, sedimentation, and waste dumped directly into the river. There are two potential contained in Sugutamu River as a source of raw water and recreation. Based on the literature reviewed, several multi-criteria decision analysis are summarized in **Table 9** [22].

Table 9 Multi-criteria decision analysis method

No	Method
1	Multi-Attribute Utility Theory (MAUT) is an expected utility theory that assign a utility to every possible consequence and calculating the best possible utility. Areas of application: economics, finance, actuarial, water management, energy management, agriculture. Advantages: takes uncertainty into account; can incorporate preferences. Disadvantages: needs a lot of input; preferences need to be precise.
2	Analytic Hierarchy Process (AHP) is the use of pair-wise comparisons, which are used both to compare the alternatives with respect to the various criteria weights. Areas of application: performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning. Advantages: easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive. Disadvantages: problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.
3	Case-Based Reasoning (CBR) is an MCDM method that proposes a solution to a decision-making problem based on the most similar cases. Areas of application: businesses, vehicle insurance, medicine, and engineering design. Advantages: not data intensive; requires little maintenance; can improve over time; can adapt to changes in environment. Disadvantages: sensitive to inconsistent data; requires many cases.
4	Data Envelopment Analysis (DEA) is a method that used wherever efficiencies need to be compared. Areas of application: economics, medicine, utilities, road safety, agriculture, retail, and business problems. Advantages: capable of handling, multiple inputs and outputs; efficiency can be analyzed and quantified. Disadvantages: doesn't deal with imprecise data; assumes that all input and output are exactly known.
5	Fuzzy Set Theory is a method that is solving a lot of problems related to dealing the imprecise and uncertain data. Areas of application: engineering, economics, environmental, social, medical, and management. Advantages: allows for imprecise input; takes into account insufficient information. Disadvantages: difficult to develop; can require numerous simulations before use.
6	Simple Multi-Attribute Rating Technique (SMART) is a method that requires two assumptions, namely utility and preferential independence. Areas of application: environmental, construction, transportation and logistics, military manufacturing and assembly problems. Advantages: simple; allows for any type of weight assignment technique; less effort by decision makers. Disadvantages: procedure may not be convenient considering the framework.

7	Goal Programming (GP) is a method that is able to choose from an infinite number of alternatives. Areas of application: production planning, scheduling, health care, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management. Advantages: capable of handling large- scale problems; can produce infinite alternatives. Disadvantages: it's ability to weight coefficients; typically needs to be used in combination with other MCDM methods to weight coefficients.
8	ELECTRE is an outranking method based on concordance analysis. Areas of application: energy, economics, environmental, water management, and transportation problems. Advantages: takes uncertainty and vagueness into account. Disadvantages: it is process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and weakness of the alternatives to not be directly identified.
9	PROMETHEE is similar to ELECTRE in that it also has several iterations and also an outranking method. Areas of application: environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture. Advantages: easy to use; doesn't require assumption that criteria are proportionate. Disadvantages: doesn't provide a clear method by which to assign weights.
10	Simple Additive Weighting (SAW is a value function is used based on a simple addition of scores that represent the goal achievement under each criterion, multiplied by the particular weights. Areas of application: water management, business, and financial management. Advantages: ability to compensate among criteria; intuitive to decision makers; calculation is simple doesn't require complex computer programs. Disadvantages: estimates revealed do not always reflect the real situation; result obtained may not be logical.
11	Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) is a method to identify an alternative which is closest to the ideal solution in a multi-dimensional computing space. Areas of application: supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management. Advantages: has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes. Disadvantages: difficult to weight and keep consistency of judgment.

In choosing a river restoration policy required the opinion of the stakeholders who have an interest in the river. This study used AHP method because this is useful in structuring the river restoration policy and identifying important criteria, sub-criteria for restoring the river, and alternatives; the method easy for stakeholders to compare each criterion, sub-criterion using the number of scales; the result tested by consistency test; low-cost investigations, and this method didn't require a lot of data. The AHP is a mathematical method for analyzing complex determination problems under multiple criteria [23].

The model consists of five phases: (1) structuring a problem into a hierarchy with objectives, criteria, sub criteria and alternatives, (2) extracting a stakeholder's opinions using criteria, sub-criteria and alternatives, representing those opinions with numbers, (3) using these numbers to estimate the priorities of the criteria's and alternatives in the hierarchy, (4) checking the consistency of judgments (5) comparing the synthesis of priority in order to determine the best choice [24].

In this study, to draw up important criteria and sub-criteria in the structure of the AHP using study literature as follows: the restoration of the river influenced by: (1) habitat for species in the rivers and others, (2) species in the river and catchment area, and (3) the characteristics of the river are water and sediment quality, and flow regimes [1]; the criteria's for habitat restoration are: significance of the habitat and cost, degree of connectivity/area, and special status of species, these are followed by the sub-criteria of construction costs, cost for duration of benefits, and operation and maintenance cost [25]; the degradation caused by the silt of river erosion, settlement of river banks, riparian land use changes, and decreased river water quality due to domestic, agricultural, and industrial waste [26]; the impact of human activities on river systems can affect their flow regime, habitat structure, water quality, food source, and biotic interactions [12].

The types of restoration that will be used in this study are: (1) restoration of species (RS), (2) restoration of ecosystems of landscapes (REL), and (3) restoration ecosystem services (RES) [11]. The restoration of species focuses on creating the conditions necessary to sustainably reintroduce and maintain species native to the river, for example, productive fishery. The focus of landscape restoration is restoring the river and the landscape: for example, river oriented community development and the creation of multipurpose spaces for local residents. The restoration of ecosystem services describes the multiple beneficial services derived by society from ecosystems for example, flood control, raw water, and hydroelectric power plant.

The river stakeholders range starts from the public and private sector, including policy makers, practitioners, scientists and non-governmental organizations, as well as groups of citizens that can affect or be affected by the achievement of river systems in the watershed. The identification of stakeholders relevant to this research considered two points: first, the most appropriate groups or individuals from which objectives and preference weights to be derived and second, the issue of sample size and sample selection methodologies. The stakeholders used in this research are the local community from the Sugutamu Watershed, the government who manages and protects the Sugutamu River, and various experts in the fields of economy, environments, river systems, and spatial planning. The conflicts of stakeholders interests are as follows: the community (C) needs the fulfillment of water requirements in term of quality and river usage for fishing and recreation; the government (G) must provide the public with adequate water supply, hydropower, and protection for water; and the experts (E) want of water sustainable usage and the environment for the ecosystem.

This model is expected to be used in other watersheds by first reviewing existing condition of watersheds, rivers, and related stakeholders. The more stakeholders involved will be representing the interests of all.

3-3-2 Methods

Selection of the preferred river restoration alternative consists of problem identification, mapping, structuring, selection process and result. Identification of river restoration problems and mapping are based on a literature review. The problem is then structured into criteria, sub-criteria, and alternatives for river restoration. The selection process essentially involves selecting an appropriate alternative (**Figure 10**).

The AHP model in this research consists of four levels, with 29 nodes, and total of 100 pair wise comparisons. Level 1 defines the goal of the decision problem, i.e. selecting river restoration priorities. Level 2 breaks down the goal into five criteria for selecting river restoration priority, which are river water, habitat, cost, land use, and action. Level 3 divides each criterion into sub-criteria that are meaningful to the various stakeholder groups. Level 4 represents the alternatives options (**Figure 11**). This research consists of questionnaires with 100 pair wise comparisons from this hierarchical structure of selecting river restoration priority, divided into 3 sections. The questions in section 1 are regarding preferences towards the five criteria: river water, habitat, cost, land use, and action. In each question, the respondents were asked to compare each criterion with the other criteria with respect to the goal. Section 2 consists of questions designed to elicit preferences towards various river water sub-criteria and the respondents were asked to compare each river water sub-criteria with other river water sub-criteria; the same process was used for the habitat, cost, land use, and action sub-criteria. Section 3 consists of questions to elicit preferences of the stakeholder groups for prioritizing the alternative options with respect to each sub-criteria's of the five major criteria. The stakeholders gave their opinions regarding the relative importance of the criteria and preferences among the alternatives by making pair wise comparisons based on the nine point scale standard rating system used for the AHP adapted from Saaty, 2000 see **Table 10** [27].

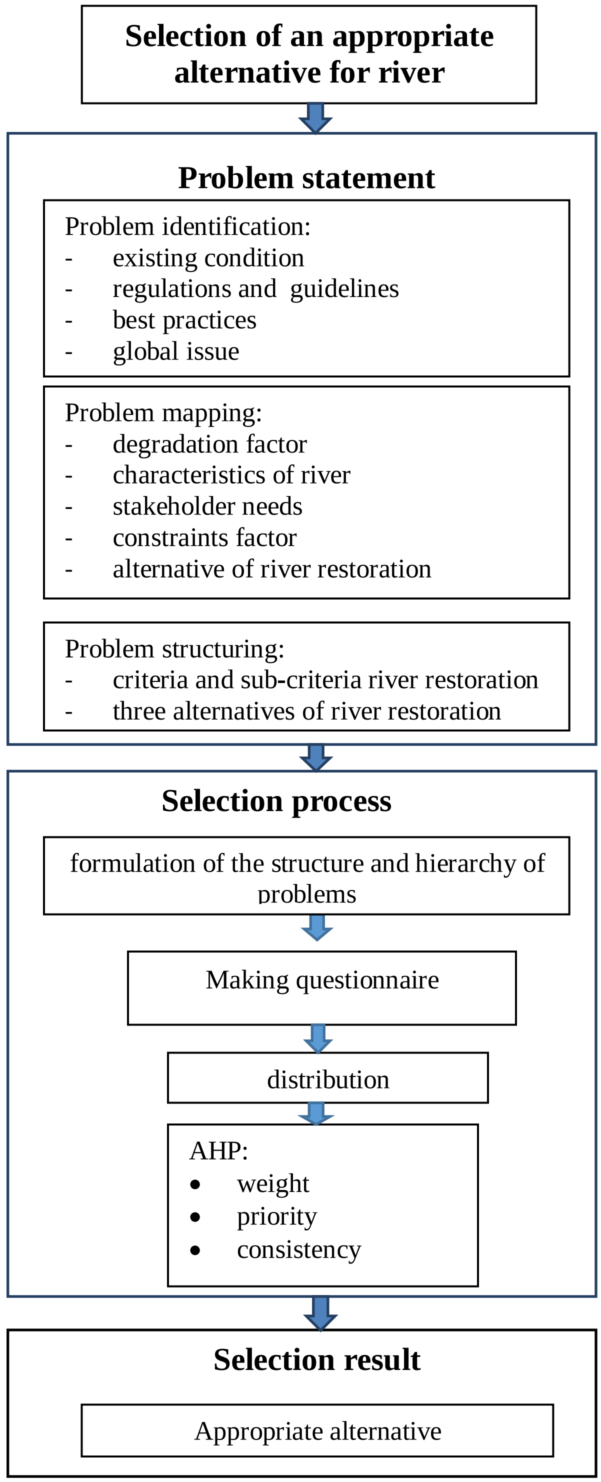

Fig. 10 Flowchart showing the process for selection of an appropriate policy for river restoration

Expert Choice (EC) 11 software was used to estimate the importance weighting of the five major criteria and their sub-criteria, and to select the preferred river restoration alternative. Stages of analysis using the EC are as follows, the first stage is the storage of hierarchical structures files, the second gives weights to each criterion to get the most important criteria, the third gives weights to each sub criteria to get the most important sub-criteria, the fourth stage provides alternatives respective weighting of the criteria, and the fifth phase is the global synthesis.

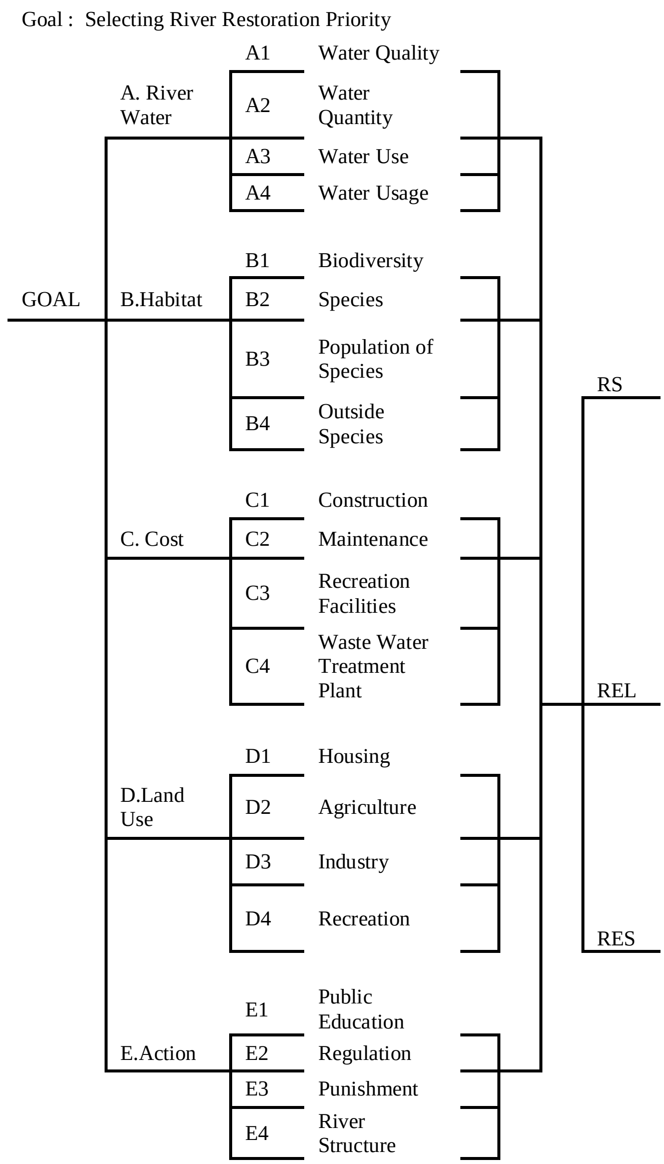

Fig. 11 Hierarchical structure for selecting river restoration priority

Table 10 Weight explanations for the standard nine-point preference scoring system used for the AHP

Weight	Explanation
1	Two attributes preferred equally
2	Judgement indicates weak favoring of one attribute over another
3	Judgement slightly favored one element over the another
4	Judgement moderately favored one element over the another
5	Judgement strongly favored one element over the another
6	Judgement slightly more than strongly favored one element over the another
7	Judgement very strongly favored one element over the another
8	Judgement very, very strongly favored one element over the another
9	Extreme preference of one attribute over the another

Case Study: The Sugutamu River

The Sugutamu River is located between the following latitudes and longitudes: 06º22'30" South Latitude-106º50'20" East Longitude and 06º28'35 " South Latitude-106º50'50" East Longitude. The total area of the Sugutamu Watershed is 13.21 km², with the length of the river being 13.74 km, and a total population of 507, 026 people.

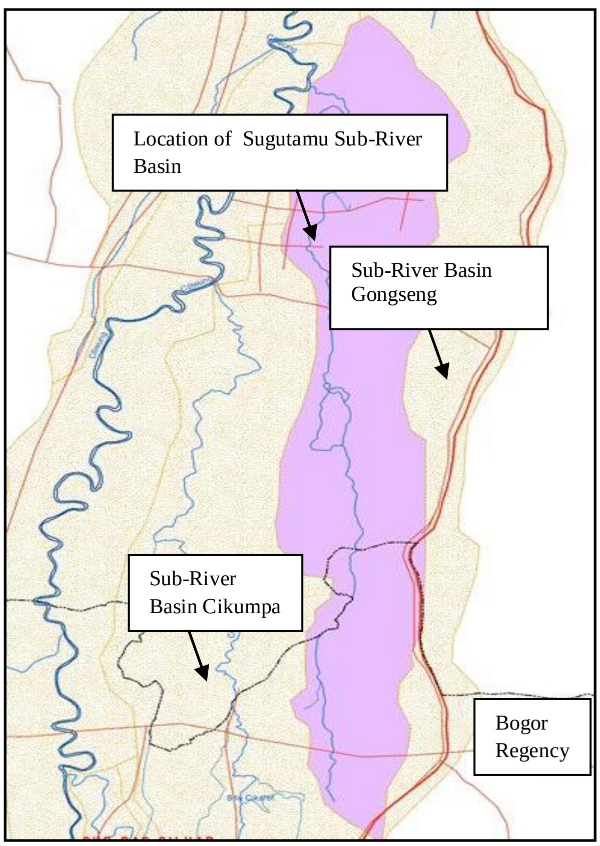

Fig. 12 Map of Sugutamu Watershed

The Sugutamu Watershed is included in the administrative area of Cilodong, Sukmajaya Sub district, Depok City, and also partly in the District of Cibinong, Bogor, West Java. In the Sukmajaya Sub district, lies Sidomukti Lake with an area of 7.5 hectares, and in the District of Cilodong lies Cilodong Lake with an area of 1 ha and a volume of 3,000 m^3 (**Figure 12**). The water quality of the Sugutamu River has declined due to the pollution from domestic sewage and garbage.

3-3-3 Results and discussion

In this research, stakeholders are community (C), government (G), and experts (E). Total of 62 respondents: 25 community, 26 government, and 11 experts questionnaires were analyzed and there were 15 respondents (5 community, 5 government, and 5 experts) representing experts who can use the results of the analysis. The analysis used is the result of analysis with a consistency ratio rate of below 0.15. The results of the questionnaires were processed using Expert Choice 11 software.

Table 11. Specific information on experts

	Study experience	Interest towards river	Function for river
C	Bachelor (economic,others)	Water use	User
G	Bachelor, Master (environment, river engineering)	Management of river	Policy makers
E	Doctor (environment, river engineering)	Sustainability of river	Observer

Analysis of criteria for selecting river restoration policy

Table 12. Criteria for selection of river restoration

Criteria	Description
River water (RW)	Consider to water quality, water quantity, water use, and water usage.
Habitat (H)	Consider to biodiversity, aquatic species, biota population, and terrestrial species.
Cost (C)	Consider to a financial need for river construction, routine maintenance, recreation facility development, waste water treatment plant (construction and operation).
Land use (L)	Consider to the residential area, agriculture, industrial area, recreation places.
Action (A)	Consider activities in community education, law and regulation enforcement, sanction and penalty, improvement of river construction.

Here is an example of the weighting of the criteria for participant purpose of government (G1) as follows: compare the relative importance with respect to goal: policy river restoration.

Table 13. Example pairwise comparison

	RW	H	C	L	A
RW	X	2	1	**2**	2
H		X	**2**	**3**	1
C			X	1	2
L				X	2
A	incon 0.01				X

The results: RW = 0.214; H = 0.112; C = 0.244; L = 0.308; A = 0.122 with inconsistency = 0.01. The calculation result for all stakeholders can be seen in the following **Table 14**.

Table 14. Criteria for selecting river restoration priority

Criteria	E (%)	C (%)	G (%)	Total (%)
River water	**25.90**	20.00	20.80	**34.50**
Habitat	24.60	21.30	20.60	29.50
Cost	11.70	**21.40**	15.70	6.70
Land use	23.00	17.70	**23.00**	13.40
Action	14.80	19.70	19.90	16.20

The most important criteria for river restoration policy selection are river water according to 34.5 % of the total stakeholders. However, each stakeholder group had different top on criteria with the most important criteria for the community is being cost, at 21.4%; for government, it was land use at 23%; and for the experts it was river water at 25.9% (see **Table 14**). The differences between stakeholder analysis results are due to the differences in education and work experience (**Table 11**). AHP method result depends on people who have the knowledge and experience dealing with the matter will be selected by using AHP. To determine the ability of stakeholders used for AHP methods can be combined by assessing the ability of stakeholders. The AHP method is a decision making method through consensus by calculating the geometric mean of the individual pair wise comparisons. This result doesn't require the existence of a consensus, but combining the results of different assessments [28].

The Geometric equations are:

$$GM = \sqrt[n]{(X1)(X2)\,\ldots.(Xn)} \quad (1)$$

Where: GM = Geometric Mean, X1 = Expert-1, X2 = Expert-2, and Xn = Expert-n

Weighting of Priority Sub-Criteria

The weighting of policy sub-criteria aims to get a local weight (lw) and global weight (gw). The local weight is the weighting of sub-criteria to select most important sub-criteria for the criteria. The global weight is the weighting of sub-criteria to select most important sub-criteria for the goal. These results are in **Table 15**.

Based on **Table 15**, total stakeholder's judge water quality sub-criteria is the best priority for river water criteria. They also judge agriculture sub-criteria the best priority for land use criteria.

According to the experts and government, the most important sub-criteria for habitat are biodiversity. The government and the expert with educational background in environmental gave biodiversity assessment. The community judge population because people was used the river for fishing and thus require a lot of fish populations.

Sub-criteria that is most policy to the criteria of cost, according to the expert stakeholder is maintenance while according to the community and the government, it is the waste water treatment plant. Based on **Table 15** for the total stakeholders, the most important sub-criteria for the river water criteria is water quality with 54.1 %; for the habitat criteria, it is biodiversity with 48.7 %; for the cost criteria, it is maintenance with 31.80 %; for the land use criteria, it is agriculture with 56.10 %; and for the action criteria, it is public education with 43.40 %.

According to the government, sub-criteria that are the most important to the criteria of action are regulations. It is accordance with the duties and functions of government as a policy maker. The experts and community judge public education are the most priority sub-criteria. In all stakeholders, the following sub-criteria do not become an important part to realize the goal, such as sub-criteria species outside, recreation facilities, industry, and punishment.

In **Table 16**, the global weight shows the percentage of the most important sub-criteria for river restoration policy selection, which are water quality, water quantity, biodiversity, species, agriculture, and public education, total in about 62.90 %.

Table 15 Weighting of priority sub-criteria

Criteria/Sub-criteria	E		C		G		Total	
	lw (%)	gw (%)	lw (%)	gw (%)	lw (%)	gw (%)	lw (%)	gw (%)
River water								
Water quality	**43.5**	11.3	**35.0**	7.0	**36.2**	7.5	**54.1**	18.7
Water quantity	20.2	5.2	11.9	2.4	24.7	5.1	25.4	8.8
Water use	17.2	4.5	22.0	4.4	15.6	3.2	11.7	4.0
Water usage	19.1	4.9	31.1	6.2	23.6	4.9	8.8	3.0
Habitat								
Biodiversity	**35.2**	8.7	27.4	5.8	**35.8**	7.4	**48.7**	14.4
Species	27.4	6.7	23.9	5.1	27.7	5.7	21.9	6.5
Population	21.7	5.3	**30.3**	6.4	23.8	4.9	20.1	5.9
Outside species	15.7	3.9	18.5	3.9	12.7	2.6	9.2	2.7
Cost								
Construction	23.3	2.7	23.9	5.1	22.2	3.5	29.5	1.9
Maintenance	**36.7**	4.3	25.4	5.4	30.1	4.7	**31.8**	2.1
Recreation Facilities	10.7	1.3	17.2	3.7	9.9	1.6	9.2	0.6
Waste water treatment plant	29.3	3.4	**33.6**	7.2	**37.9**	5.9	29.5	1.9
Land use								
Housing	21.4	4.9	22.0	3.9	28.7	6.6	20.8	2.8
Agriculture	**44.7**	10.2	**44.4**	7.9	**32.2**	7.4	**56.1**	7.5
Industry	13.0	2.9	10.5	1.9	17.3	3.9	8.00	1.1
Recreation	20.9	4.8	23.1	4.1	21.8	5.0	15.1	2.0
Action								
Public education	**41.6**	6.2	**36.3**	7.2	26.2	5.2	**43.4**	7.0
Regulation	18.6	2.8	22.7	4.5	**28.1**	5.6	16.4	2.6
Punishment	18.1	2.7	16.5	3.3	19.9	3.9	9.3	1.5
River structure	21.7	3.2	24.5	4.8	25.8	5.1	30.9	5.0

Table 16 Sub-criteria for selecting river restoration priority

Criteria/Sub Criteria	E		C		G		Total	
	gw (%)	rank	gw (%)	rank	gw (%)	rank	gw (%)	rank
A1. Water Quality	11.3	1	7.0	4	7.5	1	**18.7**	**1**
A2. Water Quantity	5.2	7	2.4	19	5.1	10	**8.8**	**3**
A3. Water Use	4.5	11	4.4	13	3.2	18	4.0	9
A4. Water usage	4.9	8	6.2	6	4.9	12	3.0	10
B1. Biodiversity	8.7	3	5.8	7	7.4	3	**14.4**	**2**
B2. Species	6.7	4	5.1	10	5.7	6	**6.5**	**6**
B3. Population	5.3	6	6.4	5	4.9	13	5.9	7
B4. Outside species	3.9	13	3.9	15	2.6	19	2.7	12
C1. Construction	2.7	18	5.1	9	3.5	17	1.9	17
C2. Maintenance	4.3	12	5.4	8	4.7	14	2.1	14
C3. Recreation Facilities	1.3	20	3.7	17	1.6	20	0.6	20
C4. Water Treatment Plant	3.4	14	7.2	2	5.9	5	1.9	16
D1. Housing	4.9	9	3.9	16	6.6	4	2.8	11
D2. Agriculture	10.2	2	7.9	1	7.4	2	**7.5**	**4**
D3. Industry	2.9	16	1.9	20	3.9	15	1.1	19
D4. Recreation	4.8	10	4.1	14	5.0	11	2.0	15
E1. Public Education	6.2	5	7.2	3	5.2	8	**7.0**	**5**
E2. Regulation	2.8	17	4.5	12	5.6	7	2.6	13
E3. Punishment	2.7	19	3.3	18	3.9	16	1.5	18
E4. River Structure	3.2	15	4.8	11	5.1	9	5.0	8

Comparative analysis of alternatives

The results of the analysis of the various choices for river restoration alternative for each stakeholder show that the experts and community judge the ecosystems services restoration alternative, while the government judges the restoration of ecosystems of landscape. Overall, the stakeholders judge the ecosystems services restoration alternative (see **Table 17**).

Table 17 Priority weighting of alternatives

Alternative	E	C	G	Total
RS	0.294	0.215	0.311	0.275
REL	0.332	0.354	**0.352**	0.360
RES	**0.374**	**0.431**	0.336	**0.365**

The most preferred alternative for river restoration is ecosystems services restoration with a weighting of 0.365, the second one is restoration of ecosystems of landscapes with a weighting of 0.360, and the least preferred alternative is species restoration with a weighting of 0.275.

3-3-4 Conclusion

In this study, the AHP method was introduced to select the important policy criteria, sub-criteria, and the preferred alternatives for river restoration. Based on the results, it can be concluded that the most important criteria for stakeholders are river water with 34.50 %, the second is habitat with 29.50 %, the third is action with 16.20 %, the fourth is land use with 13.4 % and the lowest ranking is criterion costs with 6.7 %. The results of the sub-criteria weighting showed that the important sub-criteria for selecting the preferred river restoration alternative are water quality, water quantity, biodiversity, species, agriculture, and public education with a total of 62.80 %. The preferred alternative for river restoration is ecosystems services restoration with a weighting of 0.365, the second is the restoration of ecosystems or landscapes with a weighting of 0.360, and the least preferred alternative is species restoration with a weighting of 0.275.

One of the weaknesses of the method of AHP is that the result of the analysis is highly dependent on the knowledge and understanding of the participant. Therefore, before the participants fill out questionnaires, they were conducted a brief explanation on how to fill out questionnaires, the notion of the material to be studied.

Furthermore, the ability of the experts is also evaluated in the model because the weakness AHP method is that the result depends on people who have the knowledge or a lot of experience dealing with things that will be selected by using AHP.

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CHAPTER FOUR: APPLICATION OF HYDROLOGICAL METHOD FOR SUSTAINABLE WATER MANAGEMENT IN THE UPPER-MIDDLE CILIWUNG (UMC) RIVER BASIN, INDONESIA

4-1 Introduction

The current and future challenges of water resources management vary widely because of the population growth, changes in land use, intensive socio-economic development, and warming climate [1]. Sustainable water resource management has become a very important issue because of the lack of good quality water resources due to environmental damage caused by the pressure of human activities.

This affects the balance between the supply and demand for water resources. The evaluation of the water supply capacity and water demand in a river basin can contribute to decision-making and strategy of sustainable water resources management. The evaluation of the water supply demand capacity aims to determine the balance between water supply and demand in a basin, in a certain period, using the IWSD method.

The water supply is calculated by a hydrological method whereas the water requirement is calculated based on each sector's water needs and environmental water demand. There are several common hydrological models: Soil and Water Assessment Tool (SWAT) [2], Genie Rural four parameters Journal (GR4J) [3], Tank model [4], Rain run [4], National Rural Electric Cooperative Association (NRECA) [5], and FJ. Mock [6-7]. The SWAT model uses parameters such as land use change, global change, and land conservation techniques [2]. The GR4J model uses daily input data of rainfall and evapotranspiration, the maximum capacity of the production store, the water exchange coefficient, the maximum capacity of the routing store, and the time base of a unit hydrograph [3]. The Tank model describes the several combination tanks for each soil layer in the catchment area [4]. The Rain run model takes into account the average weighted runaway components of the forest and non-forest catchment fraction [4]. The NRECA uses an index of the soil moisture storage-capacity, the rate of discharge from groundwater storage to a stream, daily rainfall data, and potential evapotranspiration data [5]. The FJ. Mock model uses daily rainfall data, evapotranspiration, and hydrologic watershed characteristics. This model provides a good alternative tool for rapid watershed assessment using hydrological parameters as part of monitoring and evaluation, particularly in the regions with limited hydrological data [6-7].

The selection of a hydrological model is based on the watershed characteristics, data availability, and expected output.

In this study, two models were used: the FJ. Mock and NRECA. The model accuracy is evaluated by calibration and validation between the simulation results and observation data using two indicators: the r and the VE.

The objectives of this study are:

(1) to select a hydrological model in order to estimate the water supply in a river basin based on limited data and an accuracy model.

(2) to evaluate and analyze the water supply demand capacity with several scenarios for contributing to sustainable water resources management.

The methods were applied to the UMC river basin in Indonesia with a coverage area of 264.35 km^2 [8]. This basin has a high population growth. The population served by piped water is still low. Known issues in this river basin are the degradation of the water's quantity and quality and the high rate of the land use change [2, 8].

River restoration activities are dredging sediment and garbage from the river and utilization of domestic and industrial wastewater treatment technologies will increase the quantity and quality of the river water. The application of the hydrological method to evaluate the water supply demand capacity is useful for consideration in the framework of future water resource development. By using various scenarios of water supply and demand, it can be found whether the river can supply water for economic, social, and environmental needs within a certain period.

4-2 Concept and Method

4-2-1 Concept of application of hydrological method for sustainable water resources management in the river basin

The method is composed of the supply and demand modules. The supply module is based on a regional rainfall, evapotranspiration, and hydrological model. The demand module based on water needs for each sector (domestic, industrial, and agricultural) and the environmental water demand. The structure of the method is shown in **Figure 1**. The evaluation of the water supply and demand capacity took place with scenarios of increasing water demand, due to population growth and economic development, and water supply reduction due to climate change. IWSD's calculation results will recommend solutions towards the sustainability of water resources management. A value > 0, means that the river can supply the water for the economy, society, and environment while a value < 0, means that it is necessary to find a solution for a more sustainable water resources management.

4-2-2 Methodology

The methodology used in this study is comprised of the following:

1) Establishment of NRECA and FJ. Mock hydrological models with an analysis of rainfall and climate data into regional rainfall and evapotranspiration categories
2) Calibration and validation of the models
3) Method selection by comparing the method deviation values
4) Demand model analysis
5) Comparison between water supply and demand for several scenarios with the IWSD formula
6) Making recommendations regarding the water supply and demand in the catchment area.

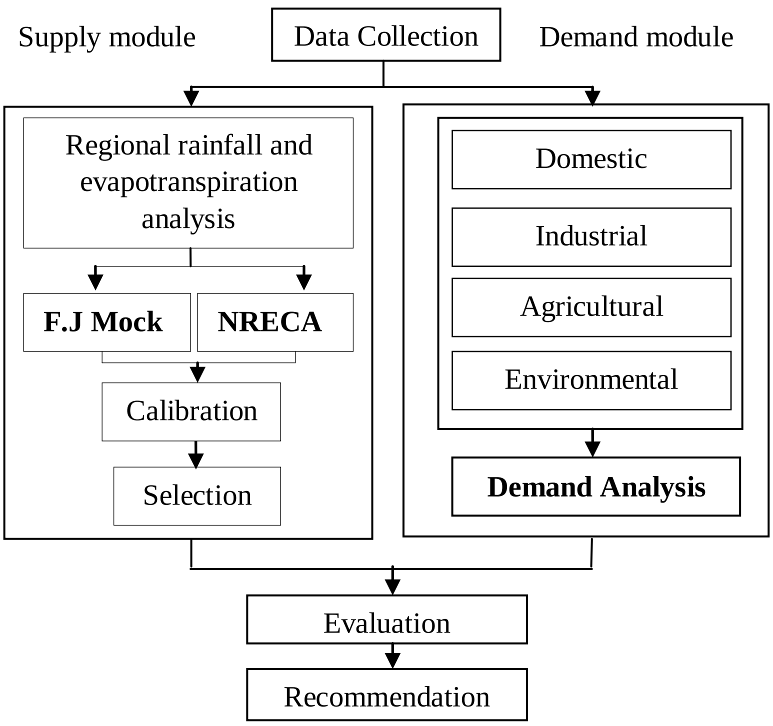

Fig. 1 Structure of the method.

The scenario used in this study was organized by consideration of parameters in the river's region: population growth, economic growth, land use change, and climate change. Based on population census from 1998 until 2008, the population growth rate in UMC river basin was 2.74%, the higher population growth rate from 2004 until 2006 was around 5.28% until

6.52% [3]. The economic growth rate from 1960 until 2010 showed varieties which tend to be stable between 5% and 6% a year so moderate economic growth scenario can be used with 5-6% economic growth rate [8]. Land use change in the UMC river basin is an average of 7.45% [8]. Climate change prepares for the worst condition (increasing and/or decreasing of rainfall ± 0.3 mm/day) [8].

In this study, the following scenarios were developed:

1. Reference or BAU
2. Scenario one: 5% population growth rate
3. Scenario two: 5% reduction of water availability
4. Mix scenario

The equation of the hydrological balance in the catchment area is as follows:

$$\text{In} = \text{Out} \pm \Delta S \quad (1)$$

In: inflow of water to the hydrological unit.

Out: outflow of the hydrological unit.

ΔS: change in storage within the selected hydrological unit (e.g. catchment).

Regional rainfall and evapotranspiration analysis

The regional rainfall is transformed from monthly rainfall data. An algebraic method was used because the catchment area is between 250 and 50,000 ha. The formula of the algebraic method is as follows:

$$R_H = \frac{H_1 + \cdots + H_n}{n} \quad (2)$$

R_H: average regional rainfall (mm),

H: monthly rainfall data from gauge station 1, 2,…n,

N: number of gauge stations.

Evapotranspiration is the total volume of evaporation from the surface of the soil, ground surfaces, wetlands, natural water bodies, and transpiration of plants [9, 10]. The Penman's equation is:

$$ETp = F_1.R(1 - r) - F_2(0.1 + 09\,S) + F_3\,(k + 0.01\,w) \quad (3)$$

$$F_1 = A\frac{0.18 + 0.55S}{(A + 0.27)} \quad (4)$$

$$F_2 = AB\frac{0.56 - 0.092\,ed^{0.5}}{(A + 0.27)} \quad (5)$$

$$F_3 = \frac{(0.27)(0.35)(ea - ed)}{(A + 0.27)} \quad (6)$$

A: slope of the vapor pressure curve (Hg/°F),

B: black body radiation based on the value of temperature (Hg/°F), *ea*: saturation vapor pressure for the measured air temperature (mm Hg),

ed: actual vapor pressure of the air (mm Hg) = ea x relative humidity (%),

S: average percentage of monthly of sun-shine,

R: solar radiation (mm/day),

r: reflection coefficient,

k: evaporation surface roughness coefficient = (1,0), and

w: wind velocity (mile/day).

The actual evapotranspiration is described as follows:

$$\Delta E = ETp.\left(\frac{m}{20}\right).(18-h) \quad (7)$$

$$ETa = ETp - \Delta E \quad (8)$$

ET_p: potential evapotranspiration (mm/day),

ΔE: difference between potential evapotranspiration and limited evapotranspiration,

ETp: potential evapotranspiration,

ETa: actual evapotranspiration,

h: number of rainy days in a month, and

m: percentage of land covered vegetation (m = 0% dense forest, m = (10 – 40%) eroded land, and m = (30 – 50%) agricultural land).

Description of NRECA model

The NRECA model was developed by Norman H. Crawford (USA) in 1985. This model is a simplification of the Standard Watershed Model IV (SWM).

NRECA model is developed in the USA which is a subtropical country while Indonesia has a tropical climate so the rainfall conditions are different. Besides, the kind of soil and land covering vegetation are also different.

NRECA model has five parameters to count the water debit in a river basin where each parameter has its own certain value regarding the rainfall condition, kind of soil, and the land covering vegetation. To count the water discharge, trials and errors are done towards the value of the parameter mentioned so the water discharge result is counted with the tolerance limit at ≤ 10% if validated towards the measurement result. Those five parameters of the NRECA model are:

- NOM or Nominal: an index of the soil moisture storage capacity in the watershed, with values NOM = 100 + C × average annual rainfall, where C is approximately 0.2 in watersheds with precipitation throughout the year and 0.25 in watersheds with seasonal rainfall;
- GWF: an index to the rate of discharge from the groundwater storage to the stream, with values ranging from 0.2-0.9;
- PSUB: the fraction of runoff that moves out of the watershed as base flow or groundwater flow, with values ranging from 0.3-0.8;
- SMSSTOR: the initial moisture storage, with values ranging from 500-760;
- GWSTOR: the initial groundwater storage, with values ranging from 200-330.

A diagram of the calculations is shown in **Figure 2**. The water balance equation is:

$$run\ off = precipitation - actual\ evapotranspiration + storage \quad (9)$$

The total river discharge was analyzed with the following formula [5, 11]:

$$Q = (direct\ flow + groundwater\ flow) \times A \quad (10)$$

A: number area (km^2),

Direct flow: excess moist minus the recharge to groundwater,

Excess moist: excess moist ratio × water balance,

Water balance: precipitation minus the AET,

AET: PET × (AET/PET) ratio from **Figure 3**,

The excess moist ratio = 0 if the water balance is negative. If the water balance is positive, the moist ratio is obtained by the soil moisture storage ratio, **Figure 4**.

Storage ratio: moisture storage/nominal,

NOM: given by 100 + 0.2 × average annual rainfall,

NOMINAL: an index of the soil moisture storage capacity in the watershed,

Recharge to groundwater: given by PSUB × excess moist,

PSUB: fraction of runoff that moves out of the watershed as base flow or groundwater flow, with values ranging from 0.3-0.8,

Groundwater flow: given by GWF × (recharge to groundwater + BEGIN STOR GW),

PET: potential evapotranspiration,

GWF: an index to the rate of discharge from the groundwater storage to the stream, with values ranging from 0.2-0.9

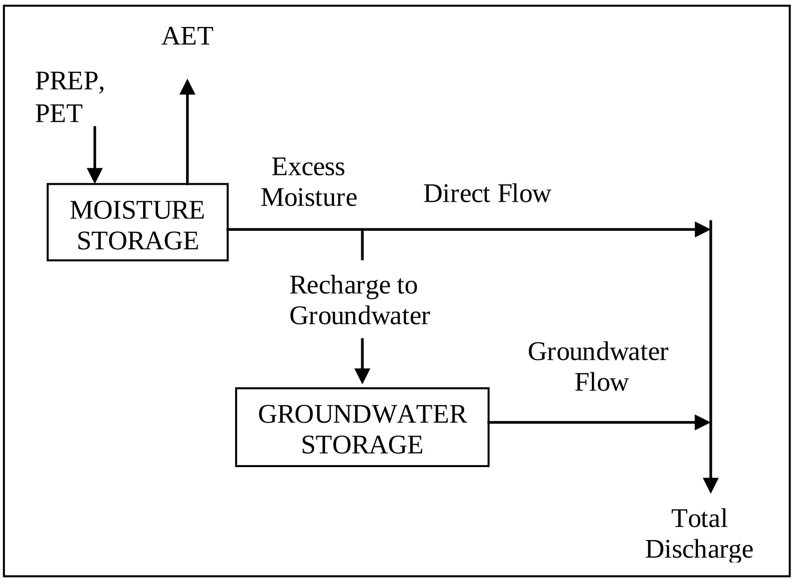

Fig. 2 Schematic of monthly runoff calculations from rainfall and potential evapotranspiration data [5].

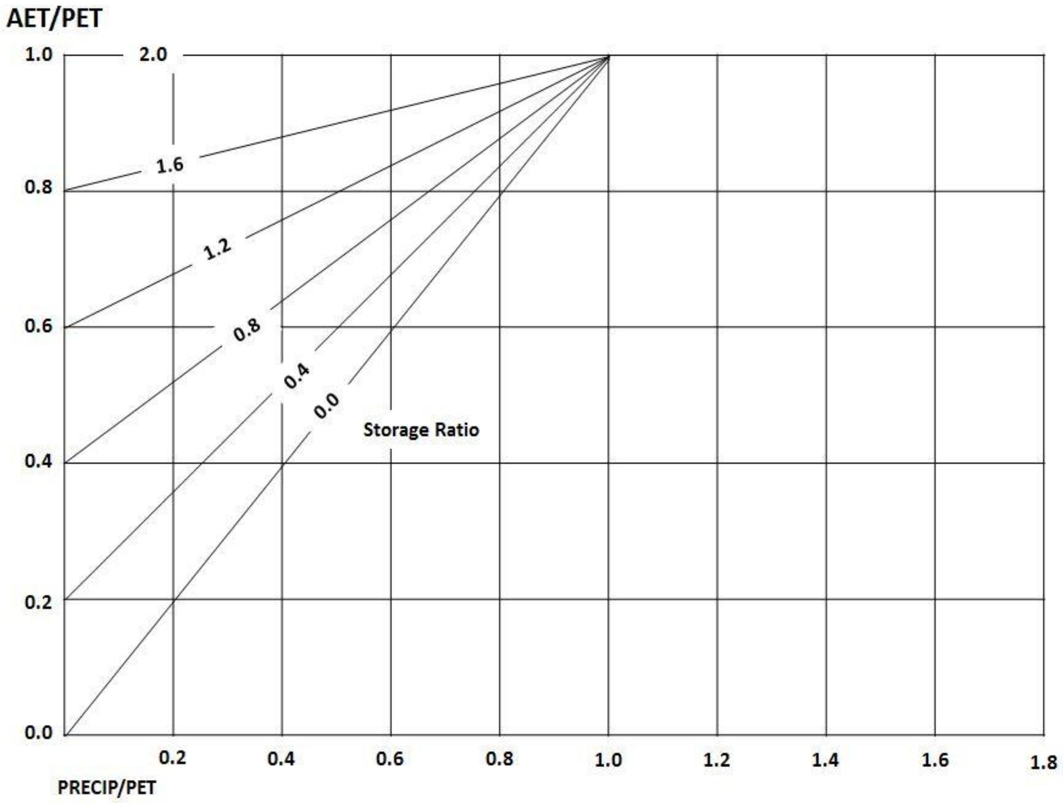

Fig. 3 AET/PET ratio as a function of PRECIP/PET and soil moisture ratio.

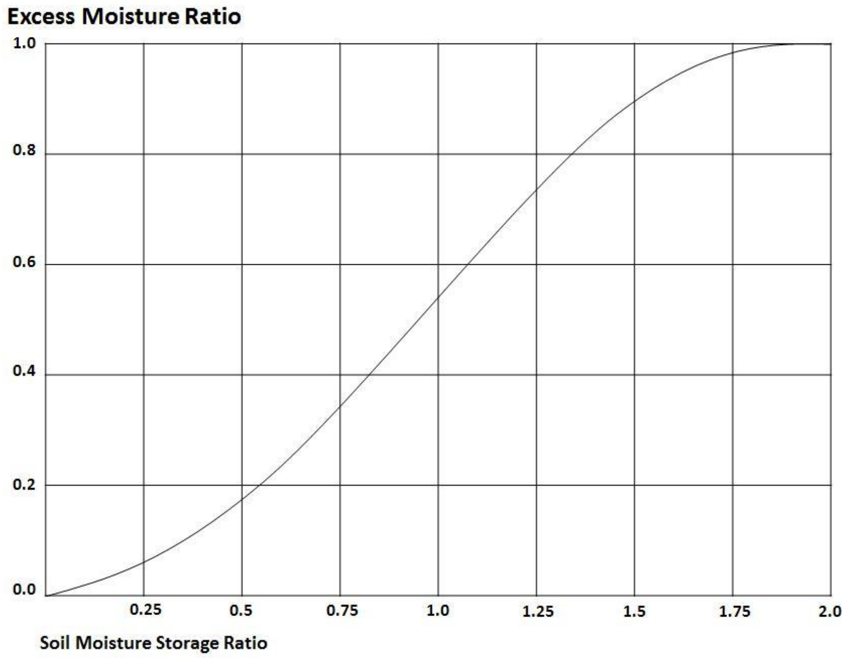

Fig. 4 Soil moisture storage ratio.

Description of FJ. Mock model

A flowchart of the calculations is shown in **Figure 5**.

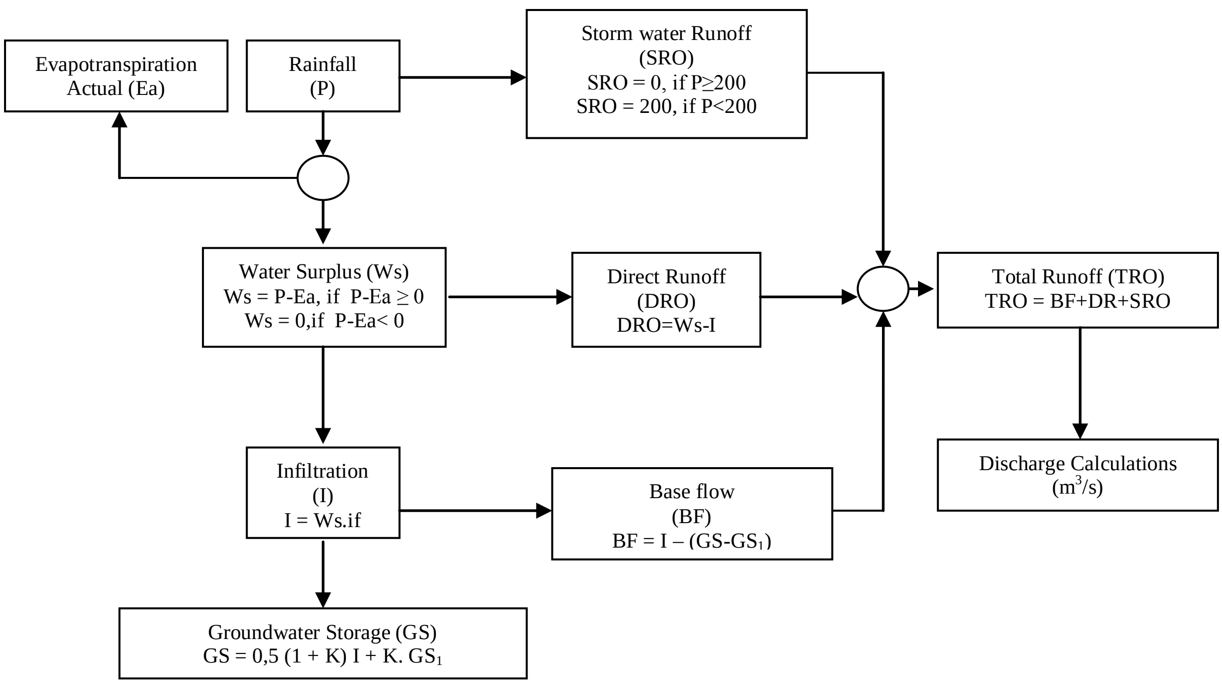

Fig. 5 Flowchart of Mock calculation [12].

Method performance evaluation

The model accuracy was evaluated by calibration and validation using the r and VE indicators. The formula can be seen in equations 11 and 12. The model is rated as having a high associate degree if the value of r is 0.7 <r <1. Calibration refers to the adjustment of model parameters to reproduce observations within acceptable levels of agreement. A validation test was conducted by applying the calibrated model to a second period of data not used in the calibration [13].

$$r = \frac{n\sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{(n\sum x_i^2 - (\sum x_i)^2)(n\sum y_i^2 - (\sum y_i)^2)}} \quad (11)$$

$$VE = \frac{\sum_i^n X_i - \sum_i^n Y_i}{\sum_i^n X_i} * 100\% \quad (12)$$

r: correlation coefficient,

VE: volume error,

x_i: simulated daily discharge (m^3/sec),

y_i: observed daily discharge (m^3/sec),

n: total step calibration.

Water demand model

The water demand model consists of the domestic, industrial, agricultural, and environmental water demand [12]. The formula for calculating water requirements is as follows:

Water requirement = water demand unit x standard (13)

The standard can be seen in **Table 1** [14]. Domestic water requirements are calculated based on the projected population according to the geometric method:

$$Pn = Po\ (1+r)^n \quad (14)$$

Pn: projected population in the future,

Po: initial population,

r: annual population growth rate, and

n: time or period.

Dependable flow

The dependable flow is the amount of available discharge to meet water needs, taking into account the risk of failure (**Table 2**). The level of reliability of discharge may occur under probability of occurrence, following the Weibull formula [15]:

$$P\ \% = \frac{m_2}{(n_2+1)}\, x\ 100\% \quad (15)$$

P %: probability percentage (%),

m_2: serial number of the data, and

n_2: amount of data.

Water supply and demand capacity evaluation method

The formula of water supply and demand capacity evaluation is as follows:

$$IWSD = 1 - (water\ demand/water\ supply) \quad (16)$$

If IWSD < 0, the volume of usable water is not sufficient to support the economy, society, and environment [16].

Table 1. Standard water demand for unit water demand.

No.	Unit water demand	Standard
1	Domestic	160 L/people/day
2	Big Industrial process	65000 L/day/unit
3	Small Industrial process	1000 L/day/unit
4	Industrial worker	60 L/people/day
5	Agriculture	1.2 L/ha/sec
6	Environmental	300 L/people/day

Table 2. Dependable flow for water planning.

Planning water demand	Probability
Drinking water	P 90%
Hydropower	P (85 – 90)%
Irrigation	P (70 – 85)%

4-3 Descripton of field and data

The UMC river basin is located between 106°50′20″ to 106°50′50″ East Longitude and 6°22′30″ to 06°28′35″ South Latitude, comprising a total area of 264.35 km^2 (**Figure 6**). Two main urban centers (the cities of Bogor and Depok) and Bogor regency are within the basin with a total permanent population of 3.79 million people (2014 census). The main river in this basin is Ciliwung with a length of 119 km, an average rainfall of 1586 to 2486 mm/year, a maximum temperature of 30°C, and a humidity of between 65% and 70% [18].

The data collected for this study can be classified into five different categories, i.e., hydrology data (daily rainfall data and discharge river actual data), land use and soil characteristics, meteorological data (precipitation, relative humidity, sunshine hours, average temperature, and wind speed), population data, and water usage data (irrigation and industry). The data were collected from the Statistical District Data and Ciliwung Cisadane River Basin Agency. Daily rainfall data were used from Gandog, Cibinong, UI-Depok, and Gunung Mas stations for the years between 2008 and 2012. The observed data were taken from Katulampa weir.

4-4 Results and discussion

Regional rainfall and evapotranspiration

The hydrology method built for this study is a rainfall-runoff model that uses daily rainfall and climate data. The result of the average rainfall regional analysis, using algebraic methods, shows the highest rainfall value of 457.9 mm and the lowest of 21.09 mm. The average monthly rainfall ranges from 91.36 mm to 369.34 mm. The use of daily rainfall data for five years can still provide accurate calculation results. The influence of global climate is not significant. The results can be seen in **Figures 7 and 8**. The evapotranspiration results obtained by the Penman's method can be seen in **Figure 9**.

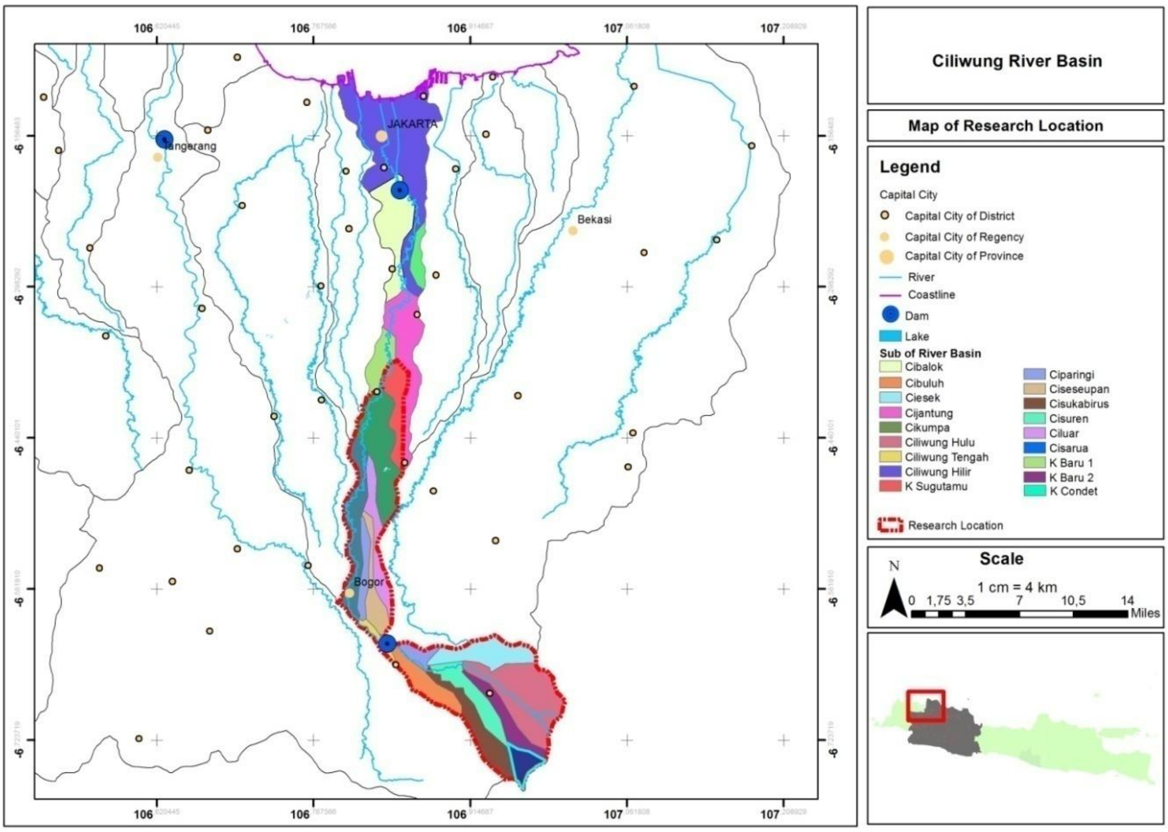

Fig. 6 Research location.

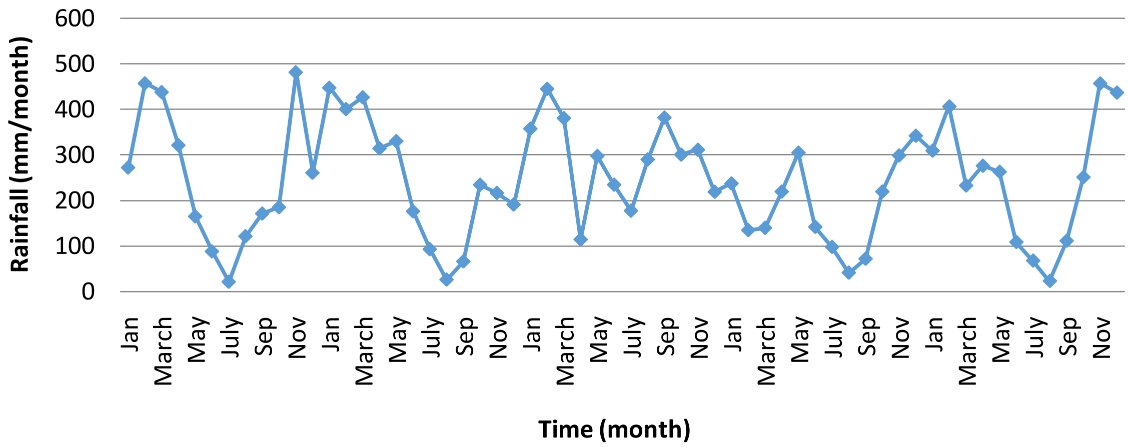

Fig. 7 Monthly regional rainfall from 2008 to 2012.

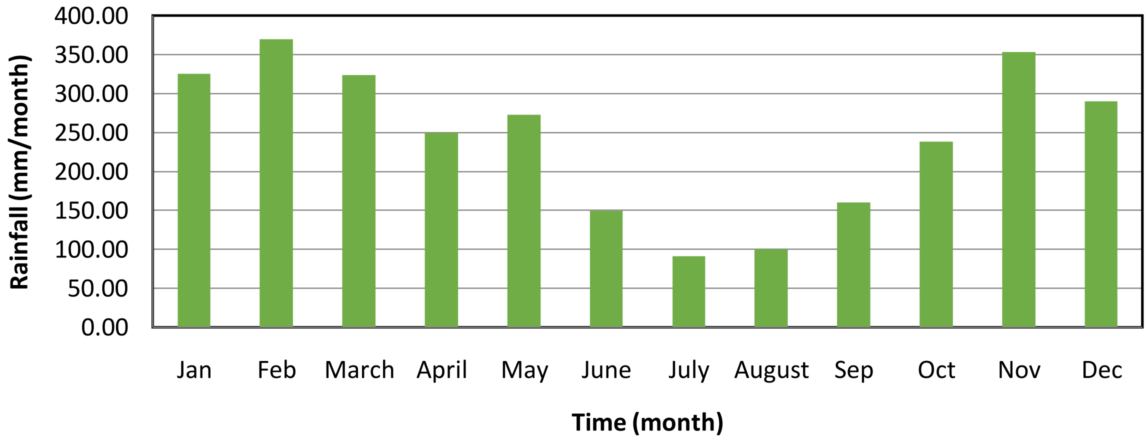

Fig. 8 Monthly average regional rainfall in the UMC river basin.

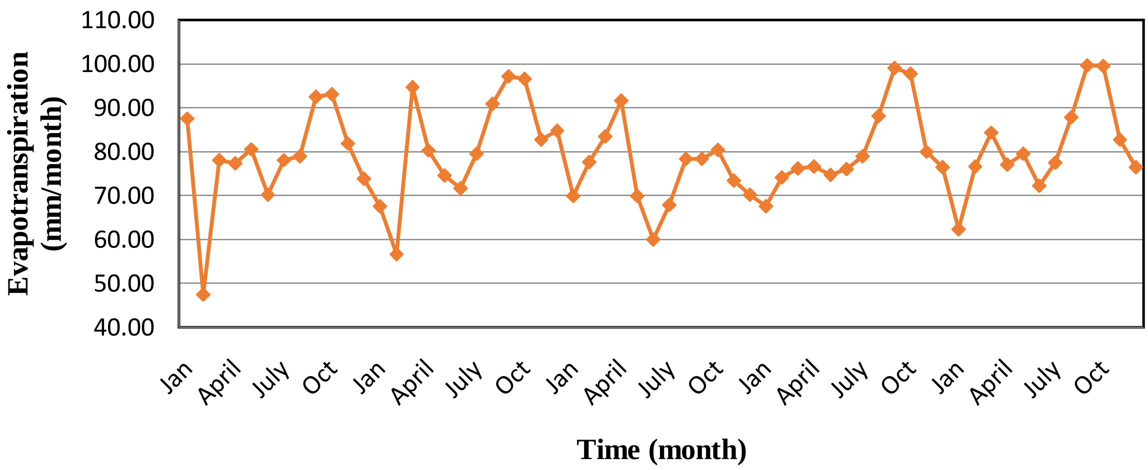

Fig. 9 Monthly evapotranspiration using Penman's method from 2008-2012.

Model calibration and validation

The model calibration is a process of obtaining the best fit between the observed and simulated results by adjusting the input parameter values, whereas model validation is the process of comparing a set of observed data with the simulation results without adjusting any input parameter values [17]. A 12-month test run from January to December 2011 was carried out in order to calibrate the model parameters. The model validation was carried out from January to December 2012.

Table 3 shows the parameters and values of the calibration results for the NRECA model. The NRECA model performance for the calibration and validation periods can be seen in **Table 4**. Based on the calibration and validation values obtained, model NRECA is chosen to count the water discharge in UMC river basin with the most optimal parameters used: NOM 400 mm, PSUB 0.5 mm, GWF 0.27 mm, SMSSTOR 700 mm, and GWSTOR 330 mm.

Table 5 shows the parameters and values of the calibration results for the FJ. Mock model. The FJ. Mock model performance for the calibration and validation periods can be seen in **Table 6**.

Table 3. Final calibrated flow parameter values for NRECA model.

Discharge parameters	Units	Symbol	Low and upper bounds	Fitted values
Initial nominal	mm	Nom	200-400	400
The fraction of runoff that moves out of the watershed as base flow or groundwater flow	mm	PSUB	0.3-0.8	0.50
An index to the rate of discharge from the groundwater storage to the stream	mm	GWF	0.2-0.9	0.27
Initial moisture storage	mm	SMSSTOR	500-760	700
Initial groundwater storage	mm	GWSTOR	200-330	330

Table 4. Summary of model performance for calibration and validation periods for NRECA model.

Period	Mean annual water yield (mm)		Monthly method efficiency	
	Observed	Simulated	r	VE
Calibration	157.58	118.2	0.90	0.25
Validation	172.83	166.2	0.97	0.03

Table 5. Final calibrated flow parameter values for FJ. Mock model.

Discharge parameters	Units	Symbol	Low and upper bounds	Fitted values
Reflection coefficient	-	r	0.4	0.4
Exposed surface	mm	m	(30-50) %	40
Coefficient of infiltration	mm	if	0.3-0.35	0.35
Groundwater recession constant	-	K	0.5-0.95	0.8
Percentage of rainfall into runoff	mm	Pf	0.05-0.1	0.1

Table 6. Summary of model performance for calibration and validation periods for FJ. Mock model.

Period	Mean annual water yield (mm)		Monthly method efficiency	
	Observed	Simulated	r	VE
Calibration	157.58	119.4	0.81	0.24
Validation	172.83	178.22	0.95	0.03

The hydrological method used to estimate the water availability in the UMC river basin was the NRECA model because the calibrated values of r and VE were 0.90 and 0.25, respectively, while the values obtained from the FJ. Mock model were 0.81 and 0.24, respectively. **Fig. 10a** show a comparison of simulated NRECA method and observed monthly river discharge for the calibration period Jan-Dec 2011 and **Fig. 10b** show a comparison of simulated NRECA method and observed monthly river discharge for the validation period Jan-Dec 2012. **Fig. 11a** show a comparison of simulated FJ. Mock method and observed monthly river discharge for the calibration period Jan-Dec 2011 and **Fig. 11b** show a **c**omparison of simulated FJ. Mock method and observed monthly river discharge for the validation period Jan-Dec 2012. **Figure 12** shows the comparison graph between simulated (the NRECA and FJ. Mock) and observed for period Jan-Dec 2011.

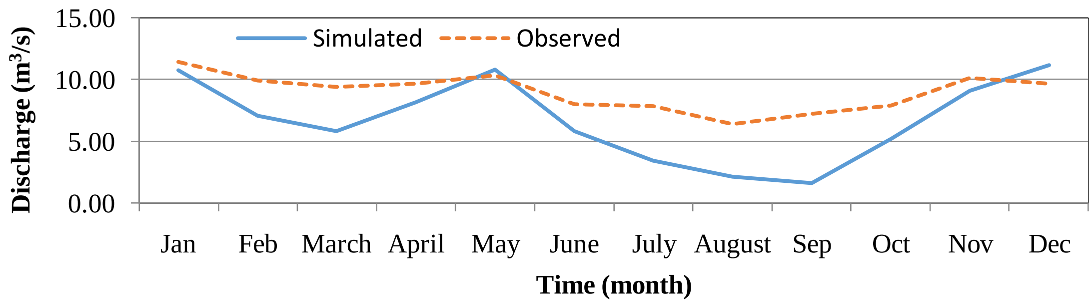

Fig. 10a Comparison of simulated NRECA method and observed monthly river discharge for the calibration period Jan-Dec 2011.

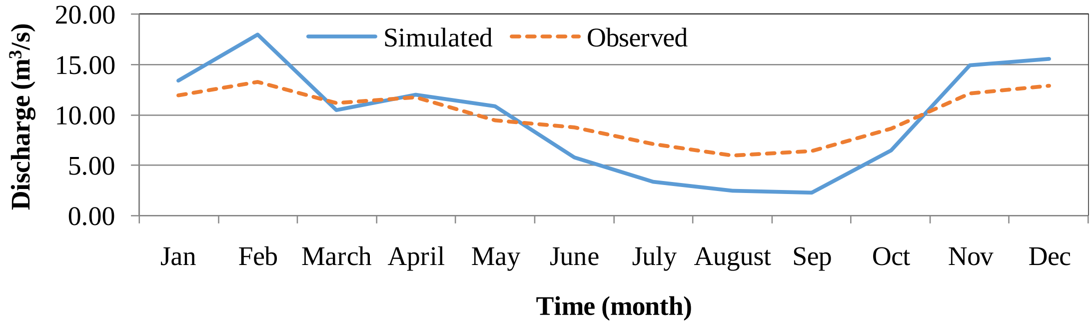

Fig. 10b Comparison of simulated NRECA method and observed monthly river discharge for the validation period Jan-Dec 2012.

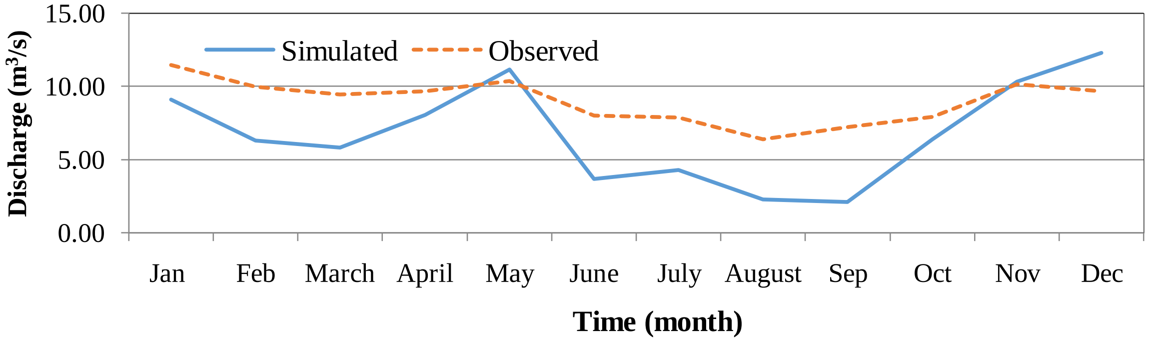

Fig. 11a Comparison of simulated FJ. Mock method and observed monthly river discharge for the calibration period Jan-Dec 2011

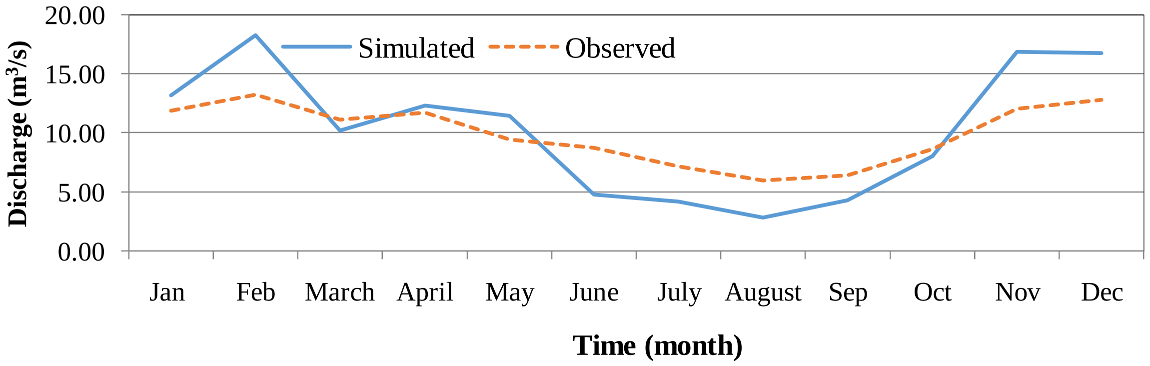

Fig. 11b Comparison of simulated FJ. Mock method and observed monthly river discharge for the validation period Jan-Dec 2012.

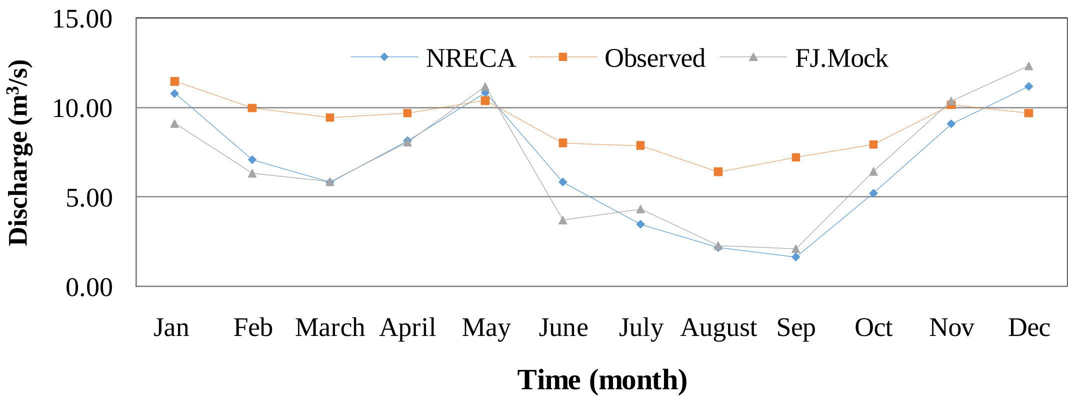

Figure 12 shows the comparison graph between simulated (the NRECA and FJ. Mock) and observed for period Jan-Dec 2011.

Application of the hydrologic method for estimating water availability in the UMC river basin

Water availability at the UMC river basin was estimated using the NRECA hydrology model. The model input data is the catchment area of264.4 km^2, the rainfall and evapotranspiration of the calculation results (**Figures7 to 9**), and the optimal model parameters of the calibration process: NOM 400, PSUB 0.5, GWF 0.27, SMSTOR 700, and GWSTOR 330.

The results of water availability and dependable discharge calculations can be seen in **Table 7**.

Based on the calculations of water availability in Table 8, the calculated dependable flow for each water planning is 90% probability for drinking water, 85% probability for hydropower, and 80% probability for irrigation, **Figure 13**.

Table 7. Water availability in the UMC river basin.

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2008	19.76	34.85	31.41	26.08	15.05	9.42	6.04	6.92	8.57	8.84	28.12	17.38
2009	29.18	32.11	29.39	24.93	25.04	16.21	8.58	5.80	4.37	11.27	11.87	10.15
2010	21.00	30.51	25.40	9.88	20.04	17.88	13.19	18.71	25.62	20.92	22.84	16.87
2011	17.50	11.22	9.43	13.87	18.91	10.04	5.92	3.66	2.76	9.30	16.34	20.06
2012	20.41	29.20	16.76	19.84	18.25	9.38	5.35	3.91	3.68	11.29	26.38	27.50
Average	21.57	27.58	22.48	18.92	19.46	12.58	7.82	7.80	9.00	12.32	21.11	18.39

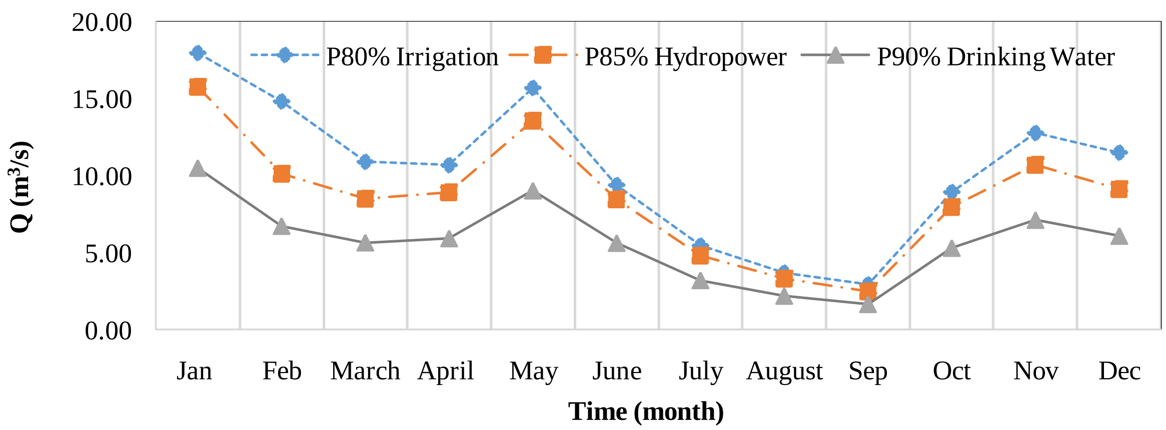

Fig. 13 Comparison of monthly dependable discharge in the UMC river basin.

Water demand in the UMC river basin

The total water requirement in the UMC river basin was calculated based on the water users in **Table 8** [18, 19-21].

Future water requirements are estimated by projections according to the planning time. Based on the existing data on the population number, from 2005 to 2014, **Table 9**, the population growth is 3.34%.

The projected population according to the geometric method:

$Pn = Po\ (1+r)^n$

Pn: projected population in the future,

Po: initial population,

r: annual population growth rate, and

n: time or period.

The value of r is calculated as follows:

$r = (Pn/Po)^{(1/n)} – 1$

$r = (3.79/2.82^{)(1/9)} – 1$

r = 0.0334 or r = 3.34%

The projected population for the next 50 years based on BAU with a population growth rate of 3.34%, and scenario 1 with a population growth rate of 5%, can be seen in **Table 10**.

Table 8. Water users in the UMC river basin year of 2014.

No.	Water use	Unit	Amount
1	Population	million people	3.79
2	Big industry	unit	1,158
3	Small industry	unit	4,416
4	Industry worker	people	144,679
5	Irrigation area	ha	1,199
6	Environmental	million people	3.79

Table 9. Existing number of residents of UMC river basin (million people).

Year									
2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2.82	3.07	3.15	3.21	3.13	3.15	3.20	3.59	3.65	3.79

Table 10. Number of residents of UMC river basin (million people).

Scenario	Year			
	2014	2024	2034	2064
BAU	3.79	5.26	7.31	19.59
One	3.79	6.17	10.06	43.46

The results of the calculations for the water requirements for each scenario can be seen in **Tables 11** and **12**. Volume of WS and WD for evaluation of two scenarios can be seen in **Table 13**.

Table 11. Water demand projection based on BAU scenario.

No.	Water Use	Water Demand (10^6 m^3/year)			
		2014	2024	2034	2064
1	Domestic	221.34	307.71	426.99	1,144.13
2	Industrial	32.25	44.80	62.22	166.73
3	Agriculture	45.37	63.02	87.53	234.55
4	Environmental	415.01	576.42	800.61	2,145.24
	Total	713.97	991.66	1,377.36	3,690.64

Table 12. Water demand projection based on scenario 1.

No.	Water Use	Water Demand (10^6 m^3/year)			
		2014	2024	2034	2064
1	Domestic	221.34	360.53	587.27	2,538.15
2	Industrial	32.25	52.54	85.58	369.87
3	Agriculture	45.37	73.91	120.39	520.32
4	Environmental	415.01	676.00	1,101.13	4,759.03
	Total	713.97	1,162.98	1,894.37	8,187.37

Table 13. Volume of WS and WD for evaluation of different scenarios.

Year	BAU		Scenario 1	Scenario 2
	Volume WS 10^6 m^3	Volume WD 10^6 m^3	Volume WD 10^6 m^3	Volume WS 10^6 m^3
2014	6276.42	713.97	713.97	5962.60
2024	6276.42	991.66	1162.98	5962.60
2034	6276.42	1377.36	1894.37	5962.60
2064	6276.42	3690.64	8187.37	5962.60

Evaluation of water supply demand capacity of the UMC river basin

The development and the application of hydrological methods have been a cornerstone of hydrological research for many decades. The purpose of the development of these methods is to improve the understanding of hydrological processes involved in the rainfall and runoff transformations and to provide practical solutions for water resources management problems [22].

In this study, a hydrological method is used to evaluate whether the availability of water in the river basin can still meet the needs of its users. The evaluation was done with two scenarios. The first scenario assumed an economic growth of 5% and a population growth of

5%. The second scenario assumed a 5% reduction in water availability due to changes in the forest area, which decreases every year by an average of 7.45% and the existence of global climate change.

Based on the IWSD formula, an evaluation of the water supply demand capacity for each scenario can be seen in **Table 14**.

Based on IWSD analysis, the river can carry and support the economy, society, and environment from the year 2014 until the year 2064, as the IWSD values were all greater than zero for the BAU and scenario 2. In scenario 1 and the mix scenario, the IWSD value is smaller than zero. The utilization of water resources for the planning year 2064 needs to consider other aspects such as recycling of water, water use efficiency, and search for new water sources.

Table 14. IWSD values for evaluation of water supply demand capacity of different scenarios.

IWSD				
Year	BAU	Scenario 1	Scenario 2	Mix scenario
2014	0.89	0.89	0.88	0.88
2024	0.84	0.81	0.83	0.80
2034	0.78	0.70	0.77	0.68
2064	0.41	-0.30	0.38	-0.37

4-5 Conclusions

Hydrological method was used to calculate the availability of water in a watershed based on the results of a comparison between simulated and measured discharge.In this study, we used the FJ. Mock and NRECA models because of the availability of data and the ease of calculation methods. Data included daily rainfall data, potential evapotranspiration data, and hydrologic watershed characteristics. The model accuracy was evaluated by calibration and validation between the simulation results and observation data using two indicators: the r and the VE. The model used was the model that has the greatest r and the smallest VE.

The NRECA model gave an r of 0.90 and VE of 0.25. The FJ. Mock model had an r of 0.81 and VE of 0.24.Based on these calibrated results, the hydrological model used in this study was the NRECA model. This model can be used to calculate the water availability and analyze the dependable flow for multiple water needs (P90% for drinking water, P85% hydropower, and P80% for irrigation).

Based on the IWSD, the river can carry and support the economy, society, and environment from the year 2014 until the year 2064, as the IWSD values were all greater than zero for BAU scenarios and scenario 2.

This hydrological method application can be used to evaluate the water supply demand capacity with the assumption value approach adapted to current conditions and future predictions for the water resources development plan along with the development strategy that needs to be done. Future research should further improve the accuracy of the results using more detailed data and refined assumptions.For example, time series data used for calculations and debit data for river measurements are more than or equal to 10 years.

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CHAPTER FIVE: SYSTEM DYNAMICS FOR WATER RESOURCE SUSTAINABILITY ISSUES: ASSESSING THE IMPACT OF RIVER RESTORATION PLANS IN THE UPSTREAM-MIDDLE CILIWUNG (UMC) RIVER BASIN, INDONESIA

5-1 Introduction

The current and future challenges of water resources management vary widely because of the population growth, changes in land use, intensive socio-economic development, and warming climate [1]. Sustainable water resource management has become a very important issue because of the lack of good quality water resources due to environmental damage caused by the pressure of human activities. River water may suffer from pollution due to increase in population and urbanization, industrials developments, deforestation, and intensified agriculture [2].

Water resources management paradigm in the world are changing from paradigm of searching new sources of water be an emphasis on integrating ecological values into water policy, emphasis on meeting water services to meet basic human needs, and approach for all user of waters river from the river basin. This new paradigm's improve efficiency and reduce the gap between users of waters [3].

River restoration aims to (1) restore the natural conditions of the river, (2) restore river function to support biodiversity, recreation, flood management and landscape development, (3) improve the resilience of the river system, and (4) create the framework for utilization of the river in a sustainable, multifunctional manner [4]. There are some failures of the restoration project because of the gap between the restoration plans and the expected results of a restoration project. Water resource decision makers need to assess the efficiency and effectiveness of the restoration plans for a long period of time.

SD uses feedback as an elementary unit to describe a system, a causal relationship to show the connections among system elements, flow graphs to represent the structure and nature of system elements, and difference equations to quantitatively describe the system. SD is a decision support tool for sustainable water resources management.

The objective of some SD model applications in the field of water resources are: (1) to compare the potential effects of water infrastructure, cropland expansion, and dry conditions on communities [5], (2) to investigate water resource management strategies that minimize water losses from evaporation and groundwater depletion through aquifer storage and recovery (ASR) [6], (3) to improve our understanding of both the short- and long-term effects of flooding and irrigation [7], (4) to assess agricultural efficiency, as well as the impacts of climate change, artificial recharge, and changes in the allocation of water supplies [8], (5) to assess the effectiveness of water resource management practices relative to economics and environmental development by combining a dynamic input-output model, economy model, water resource cycle model, and a water pollutant flow model [9], (6) to assess restoration plans for a drying lake, it is found that increasing irrigation efficiency by 4% annually and controlling irrigated lands would have around 60% effect in revitalizing the lake to its ecological level, among those considered restoration plans [10].

This study aims to develop a system dynamics (SD) model for assessing the impact of river restoration plans on the sustainability of water resources using the relative water stress indicator (RWSI). The river restoration scenarios were used to compare the impact of proposed river restoration activities, specifically: the use of processed wastewater (reclaimed water), increased agricultural water demand efficiency, reduction of agricultural land, and inter basin water transfer.

Study Area

The UMC river basin is located between 106°50′20″E to 106°50′50″E longitude and 6°22′30″S to 06°28′35″S latitude, comprising a total area of 264.35 km^2 (**Figure 1 -2**). Two main urban centers (the cities of Bogor and Depok) and Bogor Regency are within the basin, which has a total permanent population of ~ 3.79 million people (2014 census). The main river is the Ciliwung with a length of 119 km, annual rainfall ranges between 1586 to 2486 mm/year, a maximum temperature of 30°C, and a local humidity of 65% to 70% [2].

The utilization of Ciliwung river water as a source of raw water is 0.94 m^3/s while the discharge potential varies between 0.54 - 7.80 m^3/s [11].

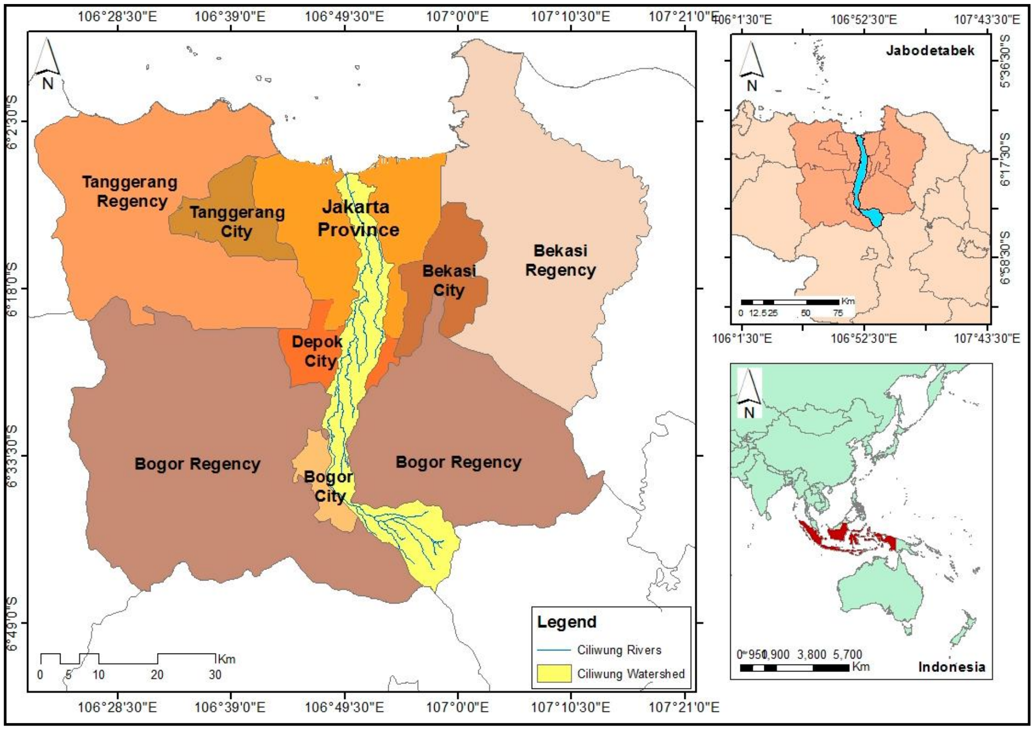

Figure 1. Location of the Ciliwung River Basin (Kumar, P., *et al*. 2017)

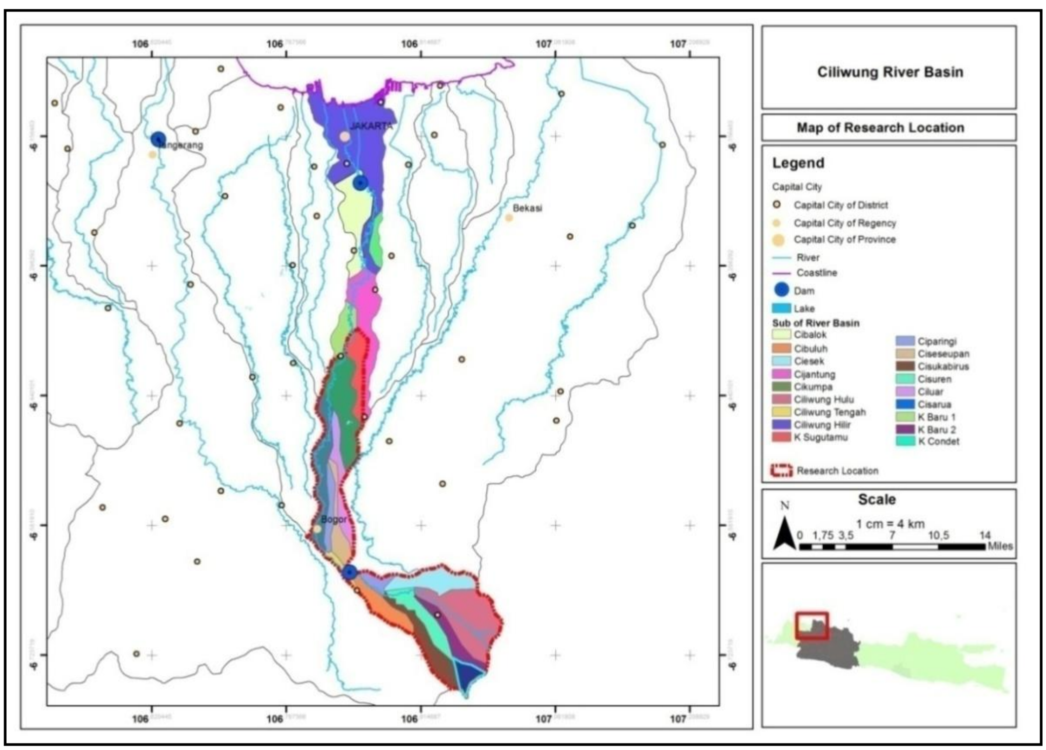

Figure 2. Research location

This basin is characterized by high population growth, declining waters availability, and limited capabilities of biodegradation and self-purification [2].

Several issue in this basin are: gap between water need and water supply from regional drinking water company (PDAM) of Jakarta, raw water crisis, river water quality polluted [12], land use changes for housing from 1990 until 1996 increase until 67,88 % [13], and degraded forest in the upstream [12].

5-2 Method and Concept

Methodology

The structure of the method is shown in **Fig.3.** The methodology used in this study is comprised of the following:

1) Establishment of models with an analysis of system include problem definition, conceptualization, and model formulation
2) System simulation process include calibration and selection of the models
3) Method selection by comparing the method deviation values
4) Policy analysis
5) Comparison between water supply and demand for several scenarios with the RWSI formula
6) Making recommendations regarding the water supply and demand in the catchment area.

The system dynamic modelling process consists of 5 steps: (1) problem definition, (2) system conceptualization, (3) model formulation, (4) simulation, and (5) policy analysis [14].

The SD model simulates a 50-year period, equal to a time horizon of 2008-2058. A time step of 0.25 years was selected. The Euler method was selected for numerical integration purposes. Calibration of key model parameters carried out from 2008 to 2012 for available surface water and 2008-2014 for population.

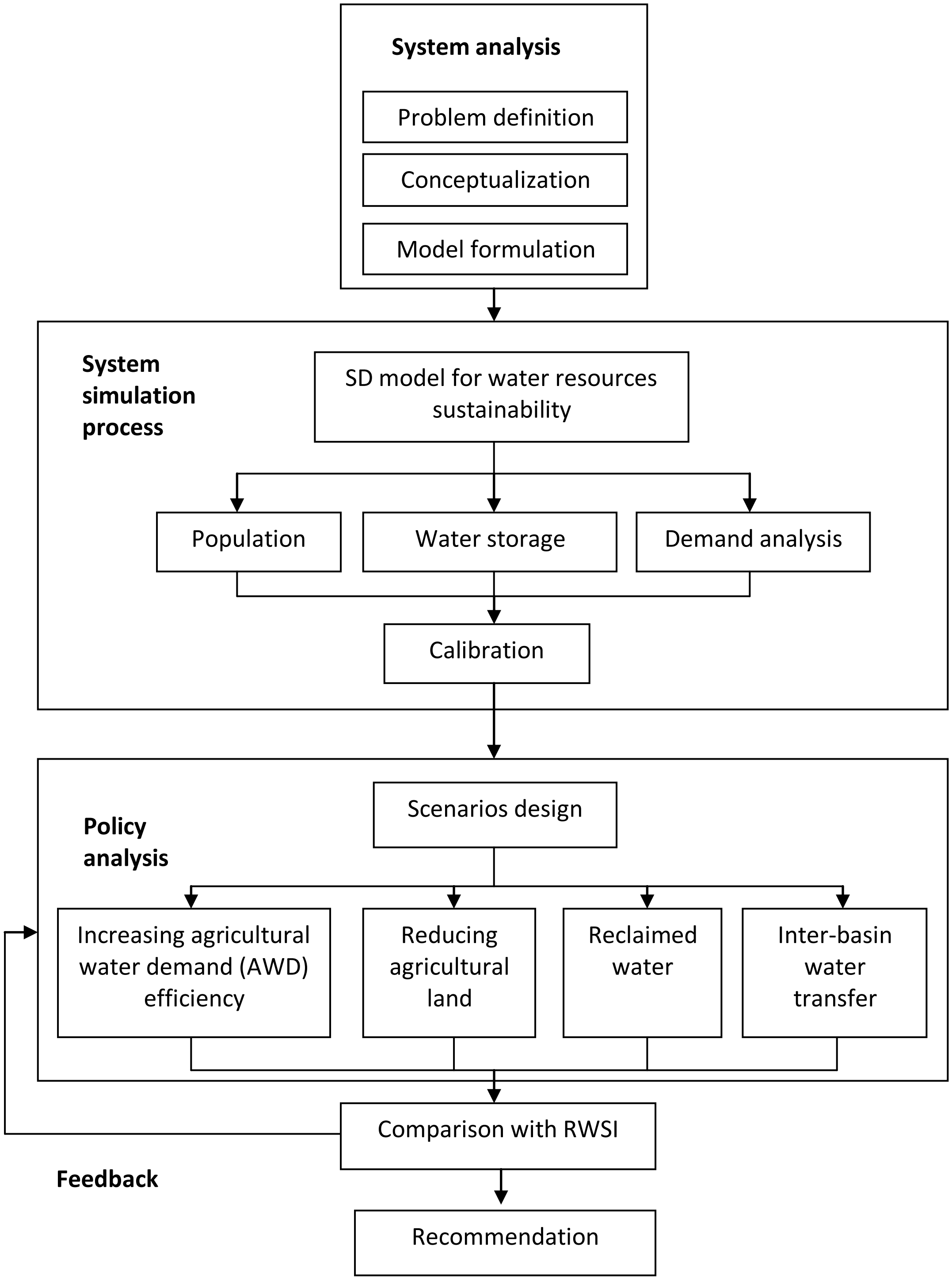

Figure 3. Structure of the method

The SD model uses Powersim Studio 10. The visual layer of a Powersim model for example: 1) level: state variables representing reservoirs of material, populations, etc., 2) flows with rate: movements between stocks, and 3) auxilary: auxilary variables representing algebraic relationships, additional parameters, constants, etc., which typically modify how levels/flows interact.

System Conceptualization and Model Formulation

The system dynamic models are designed to understand dynamic interactions occurring within the hydrologic system in order to establish the sustainability of water resources and to assess the impact of river restoration action. The model is composed of the hydrological cycle and human elements. The hydrological elements: such as direct runoff, base flow, and stream flow. The human elements: such as municipal and agricultural withdrawals, and wastewater and storm water discharges. The UMC river basin SD model consists of sub models population, water demand, and available surface water.

An SD-UMC model was used to assess the effect of each restoration plan using the Relative Water Stress Indicator (RWSI) value. The formula is as follows:

$$RWSI = DIA/Q \quad (1)$$

where: DIA is total water demand (in m^3) in a basin and Q is water storage (in m^3). RWSI > 0.4 for a basin indicates a highly stressed and critical condition [10].

A CLD-SD model is built based on a continuous sustainability process that considers the functionality of dynamic feedback relationships among hydrology, social and economic demands, and environmental conditions [15]. The conceptual and causal diagram for the UMC river basin model is shown in **Figure 4.**

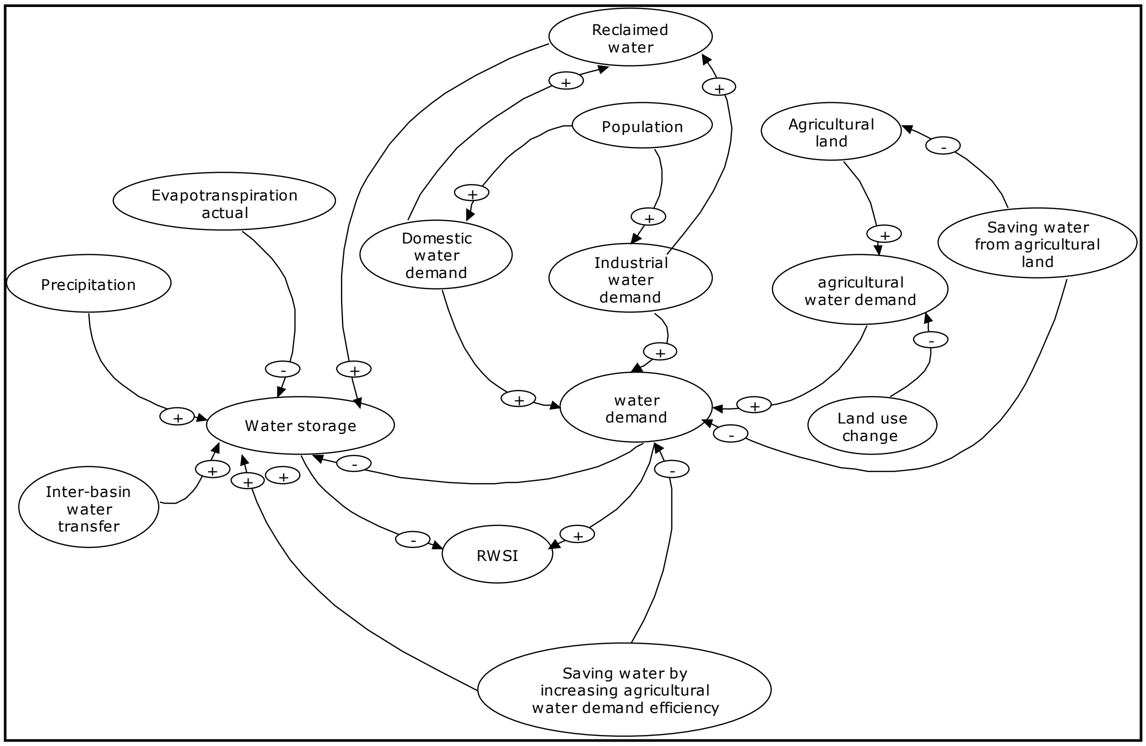

Figure 4. The Conceptual (CLD) UMC SD model

Population

The population sub-model represents the population of the UMC river basin. It is a simplified one consisting of one level 'population' (P), which is increased by births (br) and decreased by deaths (dr). The number of deaths calculated based on 68 years life expectancy.

The population at time t is mathematically represented as:

$$P(t) = P(0) + \int_{t0}^{t} P\,[br - dr]\ \ dt \qquad (2)$$

where: P = population, br = births, dr = deaths, t = time (year).

Water Demand

In our model, water demand is the domestic, industrial and agricultural water demand. The industrial water demand assumed to be approximately 10% from domestic water demand. The total water demand can be calculated as:

$$W = D + I + A \qquad (3)$$

where: W = total water demand (in m^3/year), D = domestic water demand (in m^3/year), I = industrial water demand (in m^3/year), A = agricultural water demand (in m^3/year).

The formula for calculating water requirement is as follows:

$$Qd = Qdu \times standard \quad (4)$$

where: Qd is the water requirement; Qdu is the water demand unit; the standard water demand are shown in **Table 1.**

Water Storage

The equation of the hydrological balance in the catchment area is as follows:

$$\mathrm{In} = \mathrm{Out} \pm \Delta S \quad (5)$$

where: In = inflow of water to the hydrological unit, Out = outflow of the hydrological unit, $\Delta S =$ change in storage within the selected hydrological unit (e.g. catchment).

The available surface water or water storage in this SD model can be calculated as:

$$S(t) = S(0) + \int_{t0}^{t}[(P(t) - Ea(t) - W(t)]\, dt \quad (6)$$

where: S(t) = volume of water storage at time t (in m^3), S(0) = volume of water storage at time 0, P(t) = precipitation at time t (in m^3), Ea(t) = evaporation actual at time t (in m^3), W(t) = water demand at time t (in m^3).

Based on the above equations a model structure is formed as shown in **Figure 5.**

Input Data

The input data were obtained from multiple governmental agencies including, the Ciliwung Cisadane River Basin Agency, the Central Bureau of Statistics, and based on secondary data from research results. Some key parameters used in the model and their corresponding values are described in **Table 2**.

Calibration Model

Model calibration is the process of obtaining the best fit between the observed and simulated results by adjusting the input parameter values, whereas model validation is the process of comparing a set of observed data with the simulation results without adjusting any input parameter values [15]. Behavioral replication was used as a verification method to test whether the model can reproduce, both qualitatively and quantitatively, the behavior of key parameters [16]. Model accuracy was evaluated by calibration and validation using Mean Absolute Percentage Error (MAPE), the formula for which is shown in equation 7.

Table 1. Standard water demand for unit water demand.

No.	Unit water demand	Standard
1	Domestic	160 L/people/day
2	Agriculture	1.2 L/ha/sec

Table 2. Details of some important parameter values used in the UMC river basin SD model

Variable	Initial values used (unit)	Source of Data
Population sub-model		
Total population	3211450 (people)	Central Bureau of Statistic
Birth rate	3.34 % (year)	This work
Life Expectancy	68 (year)	Central Bureau of Statistic
Water demand		
Domestic water demand standard	58.4 (m^3/people/year)	Ministry of Public Works
Industrial water demand	10% from domestic	Assumption
Agricultural water demand standard	37843.20 (m3/ha/year)	Ministry of Public Works
Initial Agricultural land	1190 (ha)	Ciliwung Cisadane River Agency
Land use change rate	0.2 %/year	Assumption
Land rate	3.34 %/year	Assumption
Water storage		
Precipitation annual	773027651 (m^3/year)	Secondary data
Evapotranspiration actual annual	218806779 (m^3/year)	Secondary data
Initial water storage	554220872 (m^3)	Secondary data

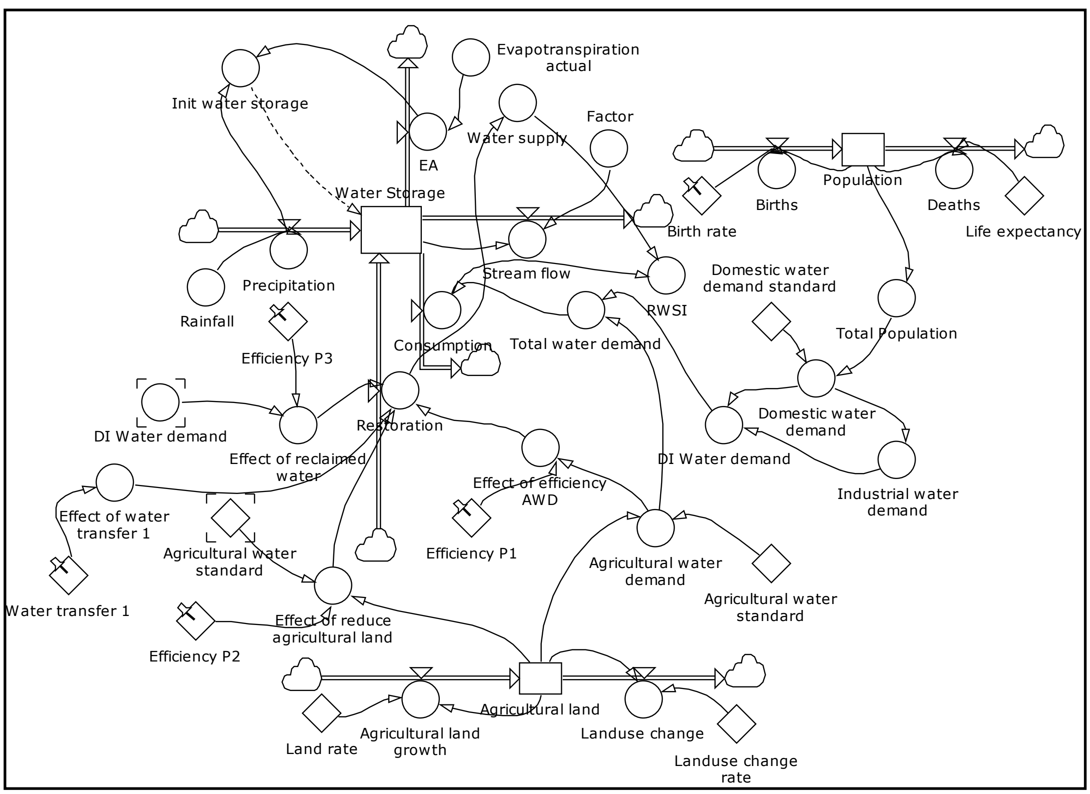

Figure 5. The UMC-SD model

Calibration refers to the adjustment of model parameters to reproduce observations within acceptable levels of agreement. A validation test was conducted by applying the calibrated model to a second period of data not used in the calibration [16].

$$\text{MAPE} = \frac{1}{n}\sum\frac{|X_m - X_d|}{X_d} \text{ x } 100\% \qquad (7)$$

where, Xm = simulated data, Xd = observed data, n = total step calibration. MAPE < 5% indicates that the model is arranged according to the actual conditions; 5% < MAPE< 10% indicates that the model is arranged close to the actual conditions; MAPE > 10% indicates that the model is arranged differently than the actual conditions.

Restoration Plans

The scenario used in this study is to assessment the impact of river restoration action. River restoration plans are implemented to increase the availability and quality of river water. Examples of river restoration plans include: increasing irrigation efficiency, reducing irrigated land, and wastewater (reuse of refined domestic and industrial wastewater), inter basin water transfers, and cloud seeding [10]. The modeled plans are explained as below and also summarized in **Table 3**.

Plan 1 - Increasing agricultural water demand (AWD) efficiency

Some studies related to the efficient use of water for irrigation include using sluice gates and sprinklers.

Plan 2 - Reducing agricultural land

Many experts argue that water for agriculture poses a problem in the availability of water because the need for water for agriculture is quite large [10].

Plan 3 - Reclaimed water

The use of wastewater for agricultural water has been widely used in several countries.

Plan 4 – Inter-basin water transfer

The other way of adding water to a basin is via inter-basin water transfer projects [10].

Table 3. Name of restoration plans and their characteristics

Plans	Aim	Scenario
P.1	Increasing agricultural water demand efficiency	20%, 50%, and 100%
P.2	Reducing agricultural land	20%, 50%, and 100%
P.3	Reclaimed water	20%, 50%, and 100%
P.4	Inter-basin water transfers	1300 MCM

5-3 Results and Discussion

It is the results of the simulation model for 2008 to 2058. This study used 3 sub-models, namely sub-model population, water storage, and water demand.

Calibration of population and water storage sub-models do in the year of 2008 to 2012.

The water demand sub model is not calibrated because there is no data.

Simulation is used to assess the adequacy of water storage or water supply in the river basin for its users. The simulation results are used to assess the effect efficiency of the restoration plan on river water supply-demand. The effects of each restoration plan and the combination of the restoration plan are analyzed and compared using the RWSI indicator. In this study the RWSI < 0.4 value was used.

Calibration Model and Behavior of Selected Parameters

The model parameters calibrated are parameters that have a considerable influence on the model. In this study, the parameters calibrated were population and water availability. Whereas water needs not carried out because the water requirements in the study location do not have sufficient data, so only the calculation data is used using the standard water requirements for each user. Test behavior for population growth from 2008 to 2014 is shown in **Figure 6.** Based on the MAPE test score obtained (4.13%), the model closely reproduces the actual conditions.

Test behavior for volume of available surface water in the river from 2008 to 2012 is shown in **Figure 7**. Based on the MAPE test score obtained (8.89%), the model closely reproduces the actual conditions.

Figure 8 to 9 show model simulation results for the period 2008 to 2058 consist of the population, water demand, available surface water, water storage, and water balance.

Based on the simulation results it is known that water storage in the river basin will continue to decrease due to water demand > water supply. **Figure 10** shows that water storage has decreased to zero in year of 2046. A river restoration plan is needed to increase water supply. A comparison between water availability and water requirements is shown in **Table 4**. As shown in these tables, storage tends to decrease and even become negative. A river restoration plan is needed to increase water supply.

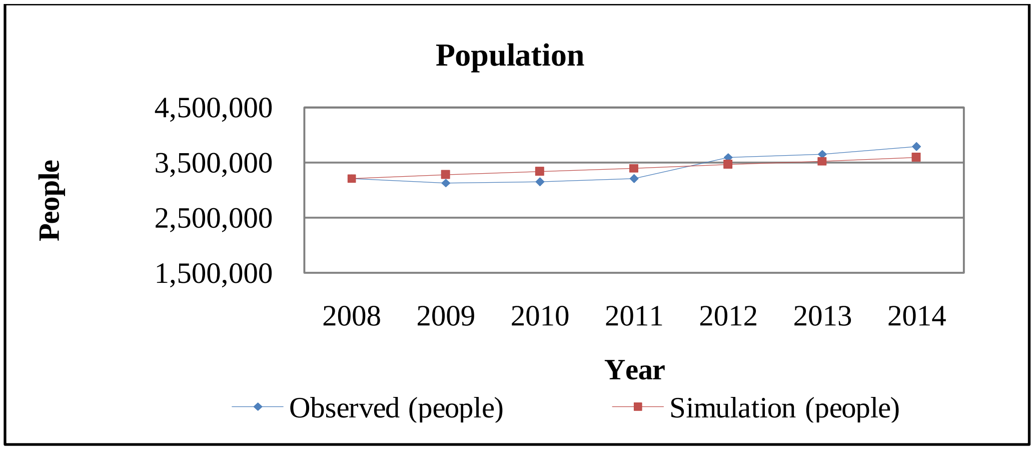

Figure 6. The comparison between observed and simulated results for population

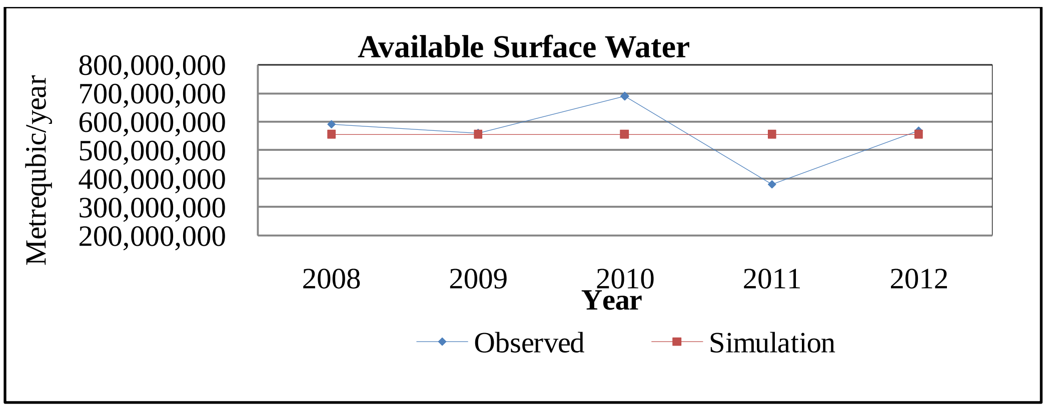

Figure 7. The comparison between observed and simulated results for available surface water

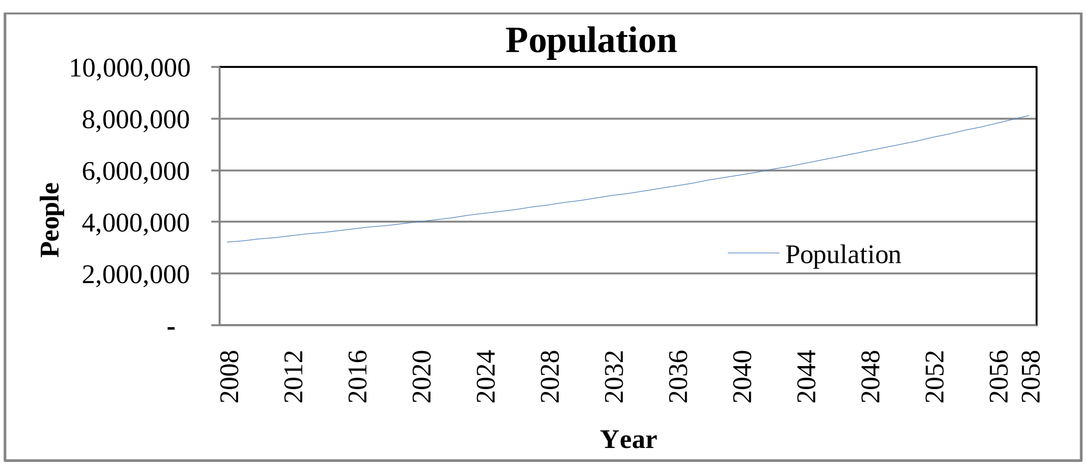

Figure 8. The chart of population growth behavior simulation results

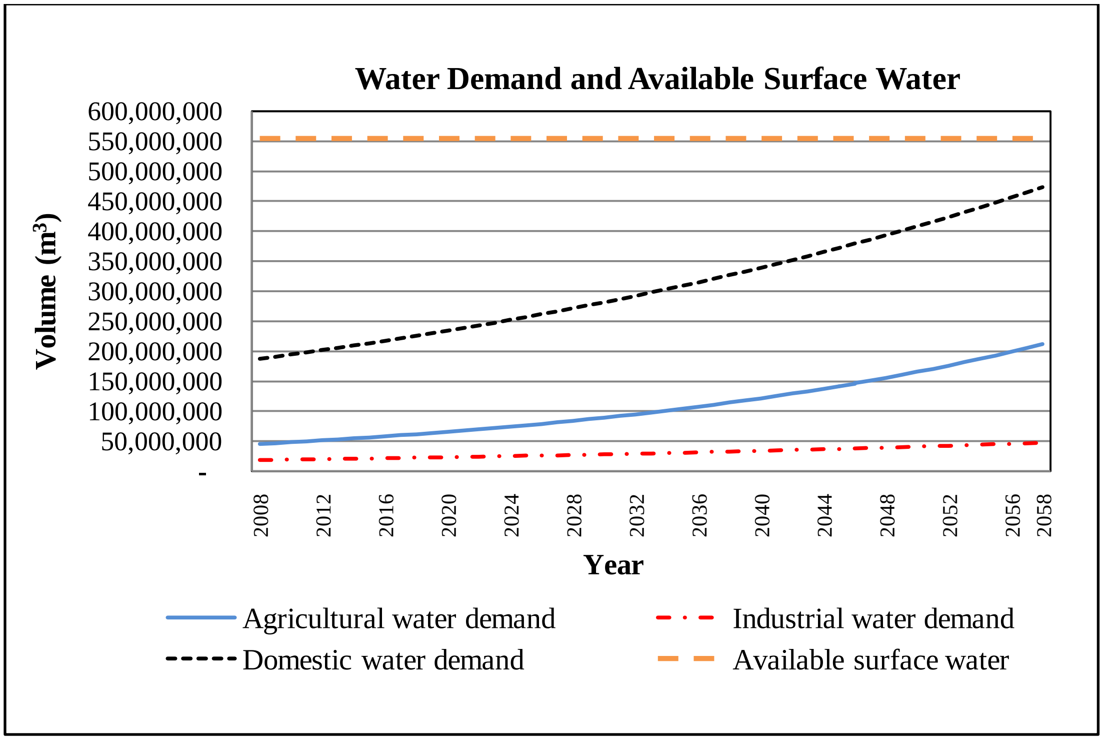

Figure 9. Water demand and available surface water

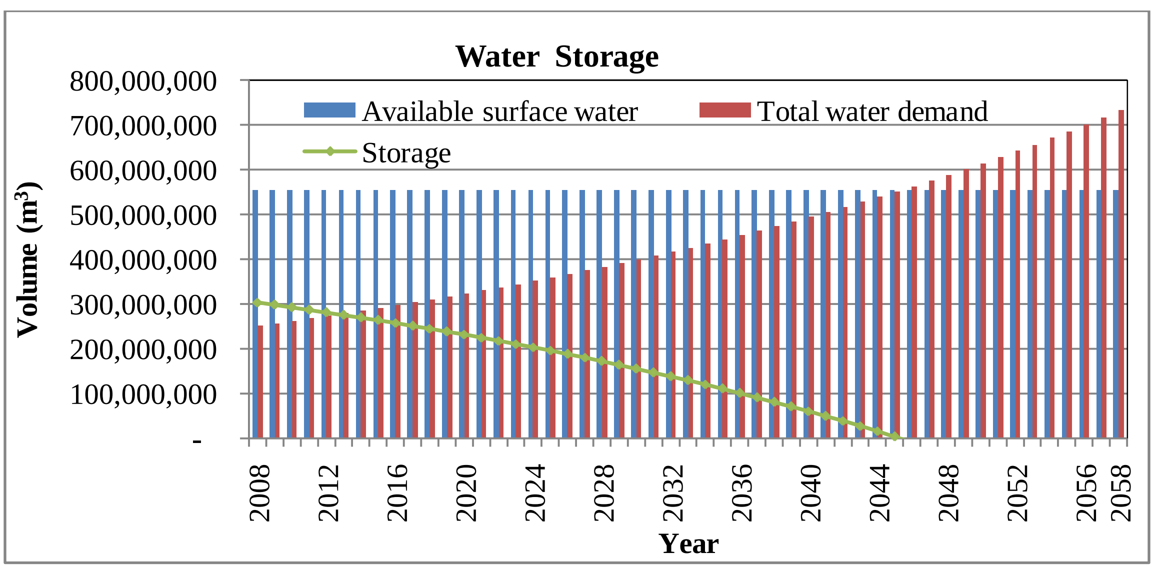

Figure 10. The charth of the water storage

Table 4. Water storage business as usual condition

Volume (m3)	Year					
	2008	2018	2028	2038	2048	2058
Available Surface Water	554,220,872	554,220,872	554,220,872	554,220,872	554,220,872	554,220,872
Total Water Demand	251,336,956	309,630,485	382,376,612	473,454,886	587,874,373	732,126,696
Storage	302,883,916	244,590,387	171,844,260	80,765,986	(33,653,501)	(177,905,824)

Effect of Restoration Plans

Individual Effect of Restoration Plans

Fig. 11 shows a chart of water supply with the restoration plans. **Table 5** shows the RWSI values for each individual restoration plan. **Table 6** shows the storage simulation results for each individual restoration plan. Based on the simulation results for each restoration plan, an RWSI > 0.4 indicates a highly stressed and critical condition in the basin for the P1, P2, and P3 restoration plans. The P4 restoration plan has an RWSI< 0.4 indicating that the restoration plan can meet water needs while maintaining water resources sustainability in the basin.

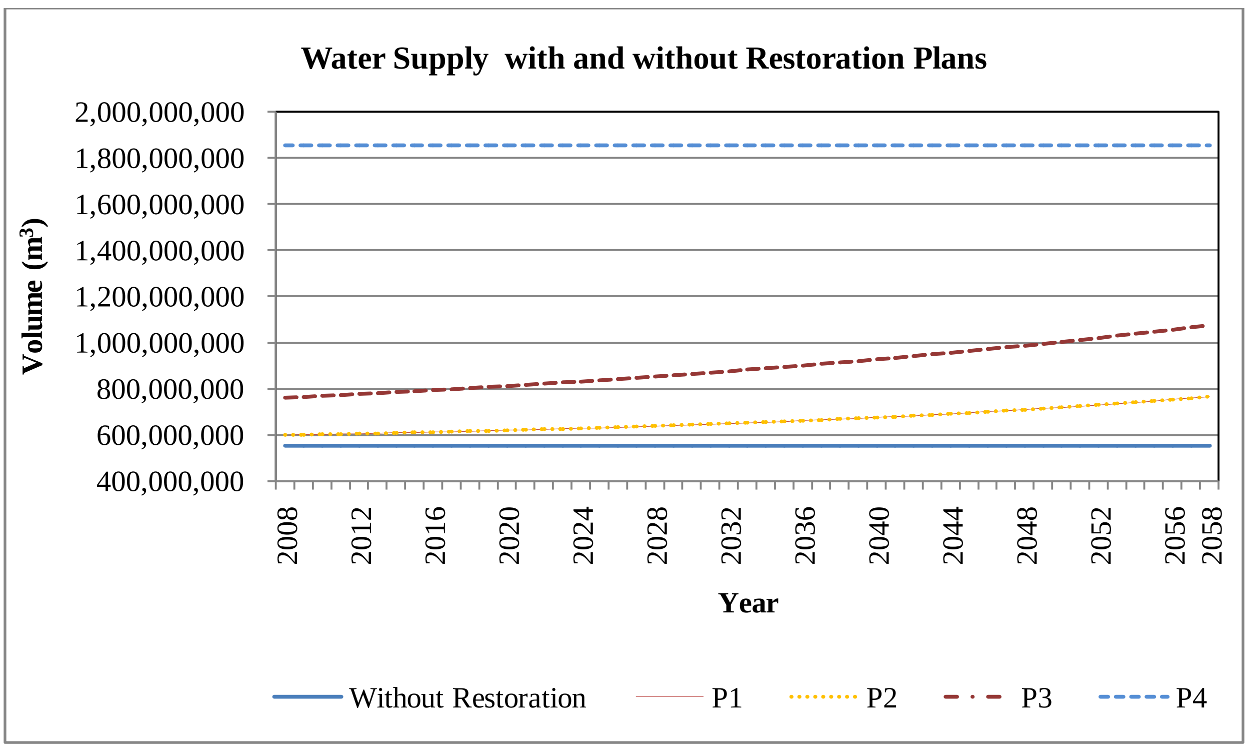

Figure 11. The Water supply with and without individual restorations plans

Table 5. RWSI indicator value for each individual restoration plans

Restoration Plans	**Value**	**RWSI**
P1	20%;50%;100%	0.42 to 1.23
P2	20%;50%;100%	0.42 to 1.23
P3	20%;50%;100%	0.33 to 1.11
P4	1300 millions qubic metre (MCM)	0.14 to 0.39

Table 6 . Simulation result of water storage for each individual restoration plans (m^3)

Scenario		Year					
		2008	2018	2028	2038	2048	2058
P1 (%)	20	311,890,598	256,860,147	188,559,297	103,536,803	(2,632,922)	(135,646,634)
	50	325,400,620	275,264,788	213,631,853	137,693,030	43,897,945	(72,257,850)
	100	347,917,324	305,939,189	255,419,447	194,620,073	121,449,392	33,390,124
P2 (%)	20	311,890,598	256,860,147	188,559,297	103,536,803	(2,632,922)	(135,646,634)
	50	325,400,620	275,264,788	213,631,853	137,693,030	43,897,945	(72,257,850)
	100	347,917,324	305,939,189	255,419,447	194,620,073	121,449,392	33,390,124
P3 (%)	20	344,144,626	294,246,724	231,604,545	152,686,146	52,900,795	(73,739,674)
	50	406,035,690	368,731,229	321,244,973	260,566,386	182,732,239	82,509,550
	100	509,187,464	492,872,070	470,645,685	440,366,785	399,117,978	342,924,924
P4 (MCM)	750	1,052,883,916	994,590,387	921,844,260	830,765,986	716,346,499	572,094,176
	1000	1,302,883,916	1,244,590,387	1,171,844,260	1,080,765,986	966,346,499	822,094,176
	1300	1,602,883,916	1,544,590,387	1,471,844,260	1,380,765,986	1,266,346,499	1,122,094,176

Effect of a Combination of Restoration Plans

Because the results of the simulation of individual scenarios P1 to P3 show the RWSI value > 0.4 and the value of water storage scenarios of P1 to P3 tend to decrease to negative, then try scenario simulations by combining P1 to P4 to obtain RWSI indicator values <0.4. Table 7 shows the combination scenarios and the value of RWSI.

The best scenarios can be able to select used the value of water storage. **Table 8** shows the storage simulation results for combination of restoration plan. **Fig. 12** showed the charts of water supply for each combination of restoration plans, respectively.

Table 7. The RWSI indicator value for each scenario

Scenario	Restoration Plans	RWSI
PC1	P1 = 50% and P4 = 1.200 MCM	0.14 to 0.39
PC2	P1 = 100% and P4 = 1.100 MCM	0.15 to 0.39
PC3	P2 = 50% and P4 = 1.200 MCM	0.14 to 0.39
PC4	P2 = 100% and P4 = 1.100 MCM	0.15 to 0.39
PC5	P3 = 20% and P4 = 1.200 MCM	0.14 to 0.39
PC6	P3 = 50% and P4 = 1.100 MCM	0.14 to 0.38
PC7	P1= 20%, and P3 = 20%, and P4 = 1.200 MCM	0.14 to 0.39
PC8	P1 = 50%;P3 = 50%;P4 = 1.000 MCM	0.15 to 0.38
PC9	P2 = 20%, and P3 = 20%, and P4 = 1.200 MCM	0.14 to 0.39
PC10	P2 = 50%;P3 = 50%;P4 = 1.100 MCM	0.14 to 0.38

Table 8. Simulation result of water storage for each combination of restoration plans (m^3)

Scenario	Year					
	2008	2018	2028	2038	2048	2058
PC1	1,447,917,324	1,405,939,189	1,355,419,447	1,294,620,073	1,221,449,392	1,133,390,124
PC2	1,525,400,620	1,475,264,788	1,413,631,853	1,337,693,030	1,243,897,945	1,127,742,150
PC3	1,447,917,324	1,405,939,189	1,355,419,447	1,294,620,073	1,221,449,392	1,133,390,124
PC4	1,525,400,620	1,475,264,788	1,413,631,853	1,337,693,030	1,243,897,945	1,127,742,150
PC5	1,506,035,690	1,468,731,229	1,421,244,973	1,360,566,386	1,282,732,239	1,182,509,550
PC6	1,544,144,626	1,494,246,724	1,431,604,545	1,352,686,146	1,252,900,795	1,126,260,326
PC7	1,553,151,308	1,506,516,484	1,448,319,582	1,375,456,963	1,283,921,374	1,168,519,516
PC8	1,428,552,394	1,399,405,630	1,363,032,566	1,317,493,430	1,260,283,685	1,188,157,524
PC9	1,553,151,308	1,506,516,484	1,448,319,582	1,375,456,963	1,283,921,374	1,168,519,516
PC10	1,428,552,394	1,399,405,630	1,363,032,566	1,317,493,430	1,260,283,685	1,188,157,524

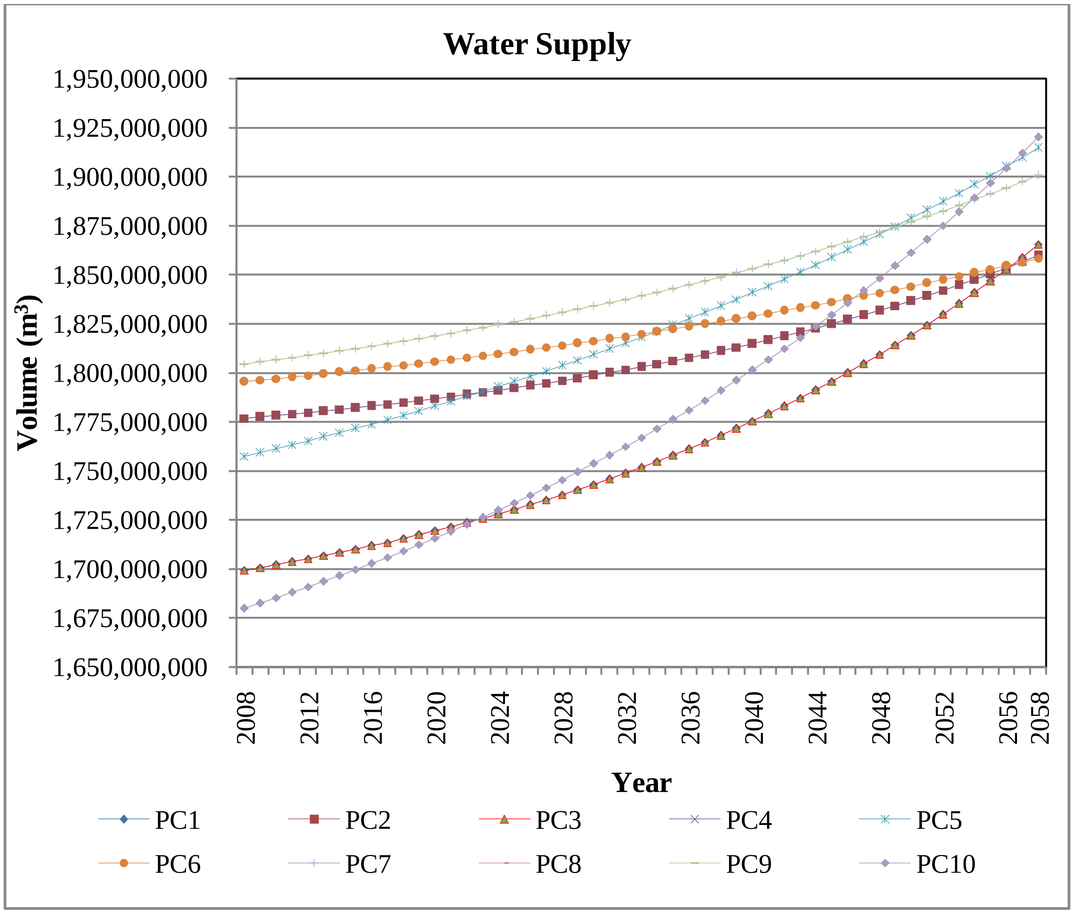

Figure 12. Water supply with combination of restoration plans.

The best scenario selection uses material flow analysis (MFA).

MFA is a systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner and Rechberger, 2004). Material Flow Analysis (MFA) is the assessment of water which going to the city during a defined period.

MFA has four mains steps:

- System analysis
- Quantification of water and indicator flow
- Identification of the current situation weak points
- Development and assessment of the technology scenario

River basin system can be seen in Fig.13. The red arrow is a waste water flow and black arrow is a water flow.

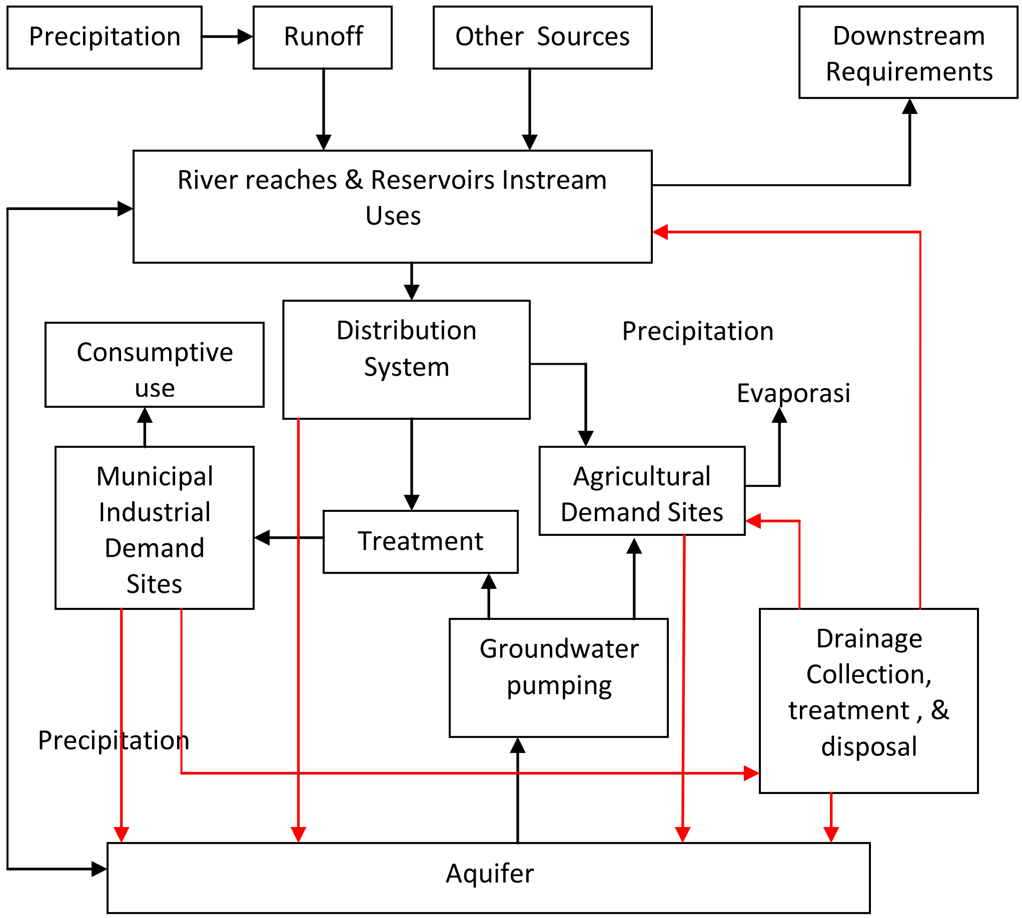

Figure.13 River Basin System

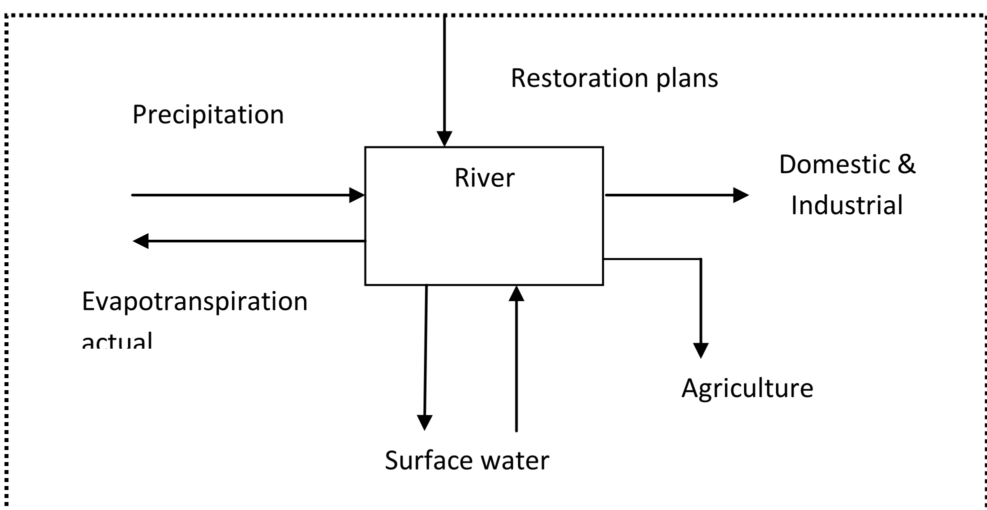

Figure.14 Boundary system water flows in river basin

In this study, the selection of restoration scenarios used is the maximum amount of water storage in the river. Table 8 shows the water storage data for each scenario.

PC8 and PC 10 give the bigger of water availability storage in the basin. PC 8 is the best scenario because of the combination from P1 (50%); P3 (50%); P4 (1.000 MCM) compare with PC 10 combination from P2 (50%); P3 (50%); P4 (1.100 MCM). PC 8 more efficient than PC 10. The selection of the most effective alternative restoration plan was conducted using a cost–benefit method.

5-4 Conclusions

An SD model was developed for understanding and analyzing the complex dynamics to assess the impact of river restoration plans in the UMC river basin in Indonesia. The simulation results show that with the individual effects of restoration plans, namely increased agricultural water demand efficiency, agricultural land reduction, and reclaimed water use, an RWSI > 0.4 indicates a highly stressed and critical condition in the basin. The effect of the inter-basin water transfer plan results in an RWSI < 0.4 meaning that the restoration plans can meet water needs while maintaining water resources sustainability.

However, based on the combination of restoration plans, there are several alternatives to the most efficient restoration plan that can restore river water such that it can meet the increasing water needs with an RWSI < 0.4.

In this study, the selection of restoration scenarios used is the maximum amount of water storage in the river. PC8 and PC 10 give the bigger of water availability storage in the basin. PC 8 is the best scenario because of the combination from P1 (50%); P3 (50%); P4 (1.000 MCM) compare with PC 10 combination from P2 (50%); P3 (50%); P4 (1.100 MCM). PC 8 more efficient than PC 10.

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CHAPTER SIX: CONCLUSIONS AND FUTURE RESEARCH

6-1 Needs for assessment river restoration policy

Clean water needs are increasing as population and economic growth are increasing in a region. In a river basin, rivers are used as a source of water for various needs of users such as water for domestic, industrial, agricultural, and industrial. River water may suffer from pollution due to increasing in population and urbanization, industrials developments, deforestation, and intensified agriculture. River restoration aims to restore the natural conditions of the river, restore river function to support biodiversity, recreation, flood management and landscape development, improve the resilience of the river system and create the framework for utilization of the river in a sustainable, multifunctional manner. Based on the experience of countries that have been a project of restoration, not every restoration project provides benefits to the expectations of river users. There are some failures of the restoration project which can only be recognized after the restoration project is completed. The gap between the plan and the expected results of a restoration project makes the choice of selecting priority river restoration very important. The success of a project is affected by the accuracy in selecting the method of restoration in accordance with the needs of users of the river. There are various alternative ways to restore the river, and conflicting interests of stakeholders require a method of making the right decision in choosing a river restoration.

This study aims to build an instrument of river restoration policy for sustainable management of water resources. In this research, AHP method is used to find out the focus of river restoration for river stakeholders, the water balance method is used to find out the sustainable water, and the system dynamics model to find out the efficient river restoration impact.

This study used AHP method because this is useful in structuring the river restoration policy and identifying important criteria, sub-criteria for restoring the river, and alternatives; the method easy for stakeholders to compare each criterion, sub-criterion using the number of scales; the result tested by consistency test; low-cost investigations, and this method didn't require a lot of data. The AHP consists of questionnaires with 100 pair wise comparisons from this hierarchical structure of selecting river restoration priority, divided into 3 sections. The questions in section 1 are regarding preferences towards the five criteria: river water, habitat, cost, land use, and action.

In each question, the respondents were asked to compare each criterion with the other criteria with respect to the goal. Section 2 consists of questions designed to elicit preferences towards various river water sub-criteria and the respondents were asked to compare each river water sub-criteria with other river water sub-criteria; the same process was used for the habitat, cost, land use, and action sub-criteria. Section 3 consists of questions to elicit preferences of the stakeholder groups for prioritizing the alternative options with respect to each sub-criteria's of the five major criteria. The types of restoration that will be used in this study are: (1) restoration of species (RS), (2) restoration of ecosystems or landscapes (REL), and (3) restoration of ecosystem services (RES). The stakeholders gave their opinions regarding the relative importance of the criteria and preferences among the alternatives by making pair wise comparisons based on the nine point scale standard rating system used for the AHP.

Data used to select the restoration of the river is the primary data from river stakeholders:

1) Experts of economists, environmental, river engineer and urban planner (from outside local community).
2) The local community from the Sugutamu Watershed, the government who manages and protects the Sugutamu River, and various experts in the fields of economy, environments, river systems and spatial planning.

Data from the questionnaire was analyzed to obtain the percentage of each stakeholders in prioritizing the criteria and aspects.

Based on the first stakeholders: the most important criteria for each expert is river water except planner expert (land use priority). Important sub criteria component for river restoration are: water quality, water quantity, water use, water usage, biodiversity, species, maintenance, agriculture, recreation, and public education.

The river restoration alternatives for each expert are based on their interests but with this calculation for total from expert is restoration ecosystems services, except environment engineer and urban planning choose restoration of ecosystems of landscapes (REL).

Public awareness of the importance of the restoration is 95%. Communities around expecting rivers and lakes can be used for recreation, tourism, and fishing.

Based on the second stakeholders results, total stakeholders choose RES except government choose REL. The most important criteria for total stakeholders is river water except community choose cost and government choose land use.

The next stage a water balance analysis is carried out in a river basin. The river is used as a source of raw water so that river restoration is carried out to maintain the sustainability of water resources. Calculation of water requirements is calculated based on water requirements for users in a river basin. Calculation of water availability uses 2 hydrological models namely NRECA and FJ. Mock models. In this study, we used the FJ. Mock and NRECA models because of the availability of data and the ease of calculation methods. The model accuracy was evaluated by calibration and validation between the simulation results and observation data using two indicators: the r and the VE. The model used was the model that has the greatest r and the smallest VE.

The NRECA model gave an r of 0.90 and VE of 0.25. The FJ. Mock model had an r of 0.81 and VE of 0.24. Based on these calibrated results, the hydrological model used in this study was the NRECA model. Based on the IWSD, the river can carry and support the economy, society, and environment from the year 2014 until the year 2064, as the IWSD values were all greater than zero for BAU scenarios and scenario 2.

This hydrological method application can be used to evaluate the water supply demand capacity with the assumption value approach adapted to current conditions and future predictions for the water resources development plan along with the development strategy that needs to be done.

The third stage an assessment of the efficiency of river restoration is carried out on river water availability or the sustainability of water resources. The model used is a system dynamic model consisting of several sub-models which are interrelated in a continuous water supply system.

SD uses feedback as an elementary unit to describe a system, a causal relationship to show the connections among system elements, flow graphs to represent the structure and nature of system elements, and difference equations to quantitatively describe the system. SD is a decision support tool for sustainable water resources management.

This study aims to develop a system dynamics (SD) model for assessing the impact of river restoration plans on the sustainability of water resources using the relative water stress indicator (RWSI). The river restoration scenarios were used to compare the impact of proposed river restoration activities, specifically: the use of processed wastewater (reclaimed water), increased agricultural water demand efficiency, reduction of agricultural land, and inter basin water transfer.

SD model was used to assess the impact of river restoration plans in the river basin using the RWSI value. The RWSI > 0.4 which means for a basin indicates a highly stressed and critical condition. In this study, we used 3 sub-models, namely sub-model population, water storage, and water demand.

Based on the individual effect of restoration plans namely increased agricultural water demand efficiency, reduction of agricultural land, and reclaimed water, the value of RWSI > 0.4 which means for a basin indicates a highly stressed and critical condition. The effect of inter basin water transfer plan, the RWSI value < 0.4 means that the restoration plans can meet water needs while maintaining the sustainability of water resources.

Based on the combination of restoration plans, there are several alternatives to the most efficient restoration plan that can restore river water so that it can meet the increasing water needs the value of RWSI < 0.4.

The SD model can be used to assess the efficiency of restoration plans for the water resources development plan along with the development strategy that needs to be done.

This research produces novelty as follows:

1) This research presents the novelty of research to design a river restoration policy that combines two methodological approaches: soft system (AHP) with hard system (SD)
2) This research produces a model of river restoration policy for sustainable management of water resources
3) This research produces an instrument to select the best river restoration policy.

6-2 Future research

One of the weaknesses of the method of AHP is that the result of the analysis is highly dependent on the knowledge and understanding of the participant. Therefore, before the participants fill out questionnaires, they were conducted a brief explanation on how to fill out questionnaires, the notion of the material to be studied.

Furthermore, the ability of the experts is also evaluated in the model because the weakness AHP method is that the result depends on people who have knowledge or a lot of experience dealing with things that will be selected by using AHP.

Future research should further improve the accuracy of the results using more detailed data and refined assumptions. For example, time series data used for calculations water demand.

The selection of the most effective alternative restoration plan is carried out using the Cost-Benefit method.

Future research to built SD for restoration of species and restoration of ecosystems of landscapes.