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RESEARCH ARTICLE

The Sustainability Aspect Affecting the Urban Rainwater Harvesting System in Balikpapan City: A Water Supply Adaption Strategies for The Capital City of Nusantara

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ABSTRACT

Water conservation efforts are needed to meet increasing water demand (e.g., rainwater harvesting) to help maintain water and environmental sustainability in the present and future. The interdependence of the five components, which comprised 31 factors, was examined in a quick assessment of urban rainwater harvesting. This study aimed to evaluate the sustainability aspect that affects rainwater harvesting based on five sustainability factors. Stages of the research methodology; 1) Preparation of the research area and respondents, 2) Collecting data through survey methods using interview techniques to obtain related data, 3) Conducting data analysis and characterizing the sustainability of rainwater harvesting, using multi-aspect analysis based on developed factors and attributes, and 4) Using two scenarios reasonably sustainable circumstances urban rainwater harvesting variables, adapting management strategies should be developed based on the urban rainwater harvesting sustainability research, which is in a reasonably sustainable environment. The results show that the sustainability status of urban rainwater harvesting in the City of Balikpapan is relatively consistent, with an indicator of 44.77%. Institutional and technological infrastructure are aspects of low sustainability. To raise sustainability status to 'sustainable,' then choose scenario number 1, that is a realistic scenario in which the 10 sensitive factors are upgraded, thereby raising the sustainability indicator to 65.52%. The most sensitive attributes to be improved are poor groundwater quality, availability of funding for rainwater harvesting, need for roof cleaning, need for collaboration between stakeholders, and reduction of conflict over taking water sources.

Introduction

In 2019, the Indonesian government announced plans for the relocation of the capital city to a new capital city, Nusantara, in the east of Kalimantan. Programmes that incorporate the concept of sustainable development will support Nusantara as the capital. This is evidenced by plans to develop extensive green open spaces, balanced land use, a green economy, and liveable and intelligent residential areas. However, there still appear to be shortcomings in terms of disaster risk reduction. This is particularly the case with regard to the need for clean water supplies and social aspects. This needs to be addressed in the future through additional programmes.

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To measure the urgency of clean water supply issues in the City of Balikpapan as the headquarters of the Capital City of Nusantara (the future capital of Indonesia), it is necessary to describe in detail the potential losses that will be faced today and, in the future, if the problems faced are not soon found a concrete solution [1]. The clean water needs of Balikpapan City in 2021 are expected to reach 1,420.59 L/s. If projected in 2032 without the Capital City of Nusantara, the need for clean water will be 1,805.59 L/s (up 27.1%). When projected with the Capital City of Nusantara, the need will rise to 3,074.53 L/s (up 116.4%). This is a very high increase, while the capacity of the *Perusahaan Daerah Air Minum* (PDAM) of Balikpapan City was only 1,426 L/s.

The construction of the Sepaku Semoi Dam to support clean water supply to Nusantara is currently a settlement process. From a capacity of 2,500 L/s, as much as 500 L/s of water from this dam will be connected to Balikpapan City. As for 2,000 L/s, it was transferred to the Capital City of Nusantara [2]. It has not yet been able to meet such enormous demand. Efforts have been made to meet the demand for clean water through rainwater harvesting. The purpose of this study is to conduct a rapid assessment of rainwater harvesting in the city of Balikpapan as an initial strategy in water conservation efforts in response to increasing water demand. Therefore, this research will contribute to policymakers regarding the sustainable aspects and factors of rainwater harvesting in Balikpapan City.

Materials and Methods

Study Area

This study was conducted from August to October 2023 in the City of Balikpapan (Figure 1), the province of East Kalimantan. The primary and secondary data were used in this study. Primary data were collected from completed questionnaires through direct interviews with community groups in the Southern Balikpapan District and key stakeholders, such as related service leaders. The respondents in this research were 55 people, who were purposefully based on respondents living in the southern district for at least 10 years and agency government leaders related to the environment, weather, and community development. Secondary data related to rainwater harvesting in Balikpapan City were obtained through a search of literature and reports from various agencies.

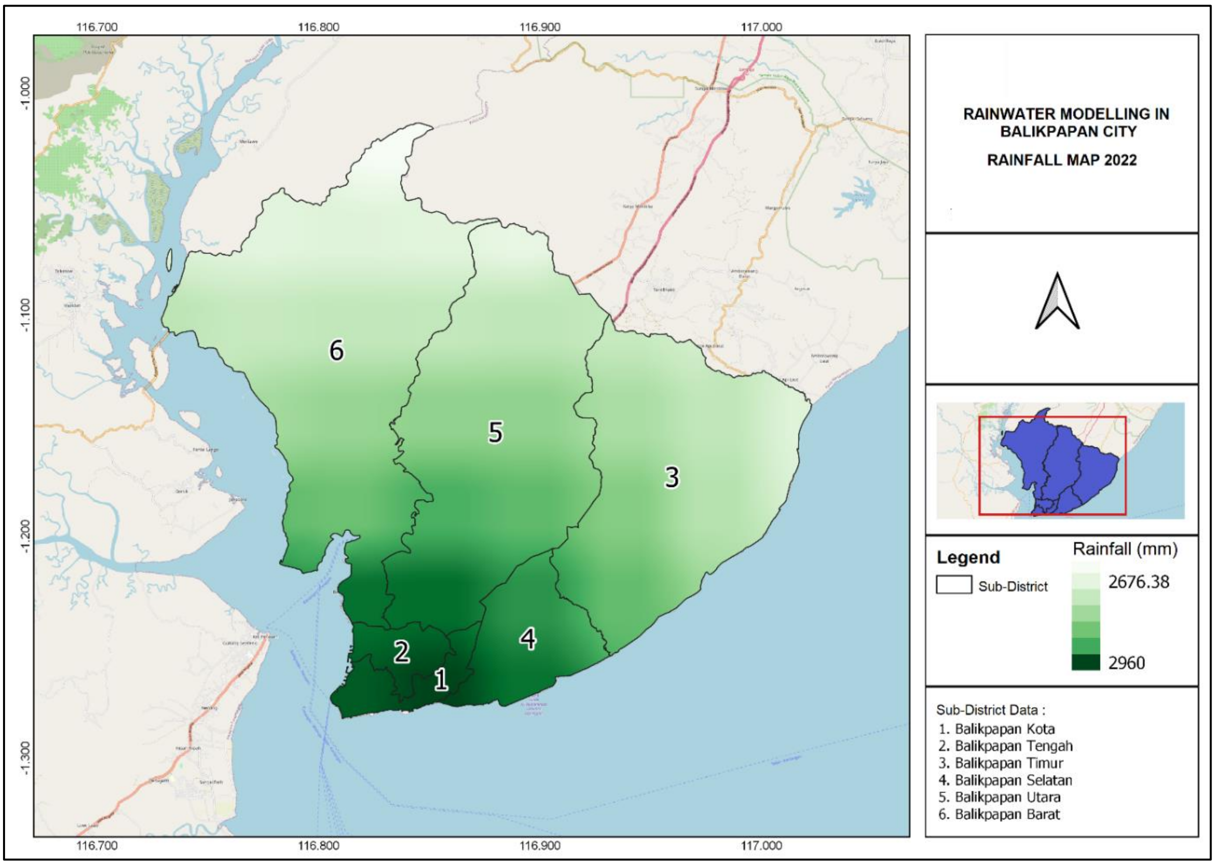


Figure 1. Ranfall map 2022 of Balikpapan City.

Data Collection and Analysis

To obtain the sustainability status of rainwater harvesting in Balikpapan city, multi-aspect sustainability analysis (MSA) using Exsimpro software is a further development of an earlier tool called Rapid Appraisal for Fisheries (RAPFISH) [3]. This assessment is also known as a quick (rapid) assessment because it uses an existing database submitted by experts or chosen respondents who fulfil that criterion. This assessment can then be improved over time with new data and circumstances, without requiring reanalysis using updated formulations or creating new models. This database used in MSA is data derived from a desk study, the evaluation of experts who are responsible or competent in the field of research or research being undertaken, and may also come from experts in an Forum Group Discussion [4]. Figure 2 illustrates the conceptual framework of the MSA approach.

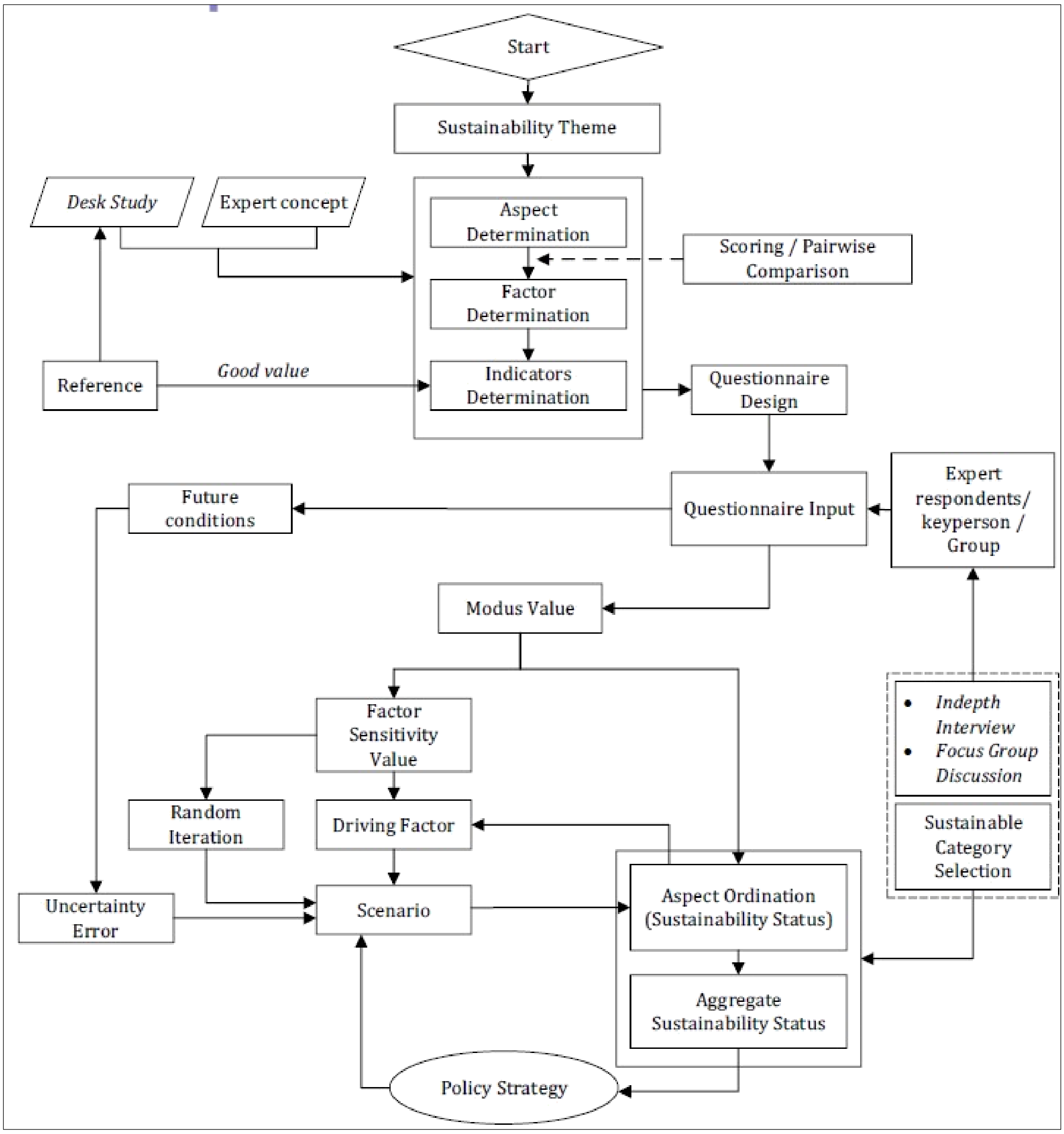


Figure 2. Conceptual framework of the multi-aspect sustainability (MSA) analysis approach [3].

Results and Discussion

The performance sustainability index refers to the sustainability indicators of five SDGs [5],[6]: ecology, economy, social, infrastructure, technology, and institutional aspects that influence the sustainability of rainwater and harvesting in Balikpapan City. The results of the MSA Rainwater Harvesting City Balikpapan (MSA-RWH), This following is an explanation of the analysis for each aspect.

Analysis of Rainwater Harvesting City Balikpapan (MSA-RWH)

Ecology Aspect

The sustainability index for rainwater harvesting in Balikpapan City for ecological aspects is 47.17% in the less sustainable classification; in the future, this value is unlikely to upgrade and is not very significant because future conditions have a mark of 37.5%. However, when compared with the multi-aspect sustainability index value of rainwater harvesters, the ecological sustainability index value was greater than the multi-aspect sustainability index value. From Figure 3 which shown about the results of the ecological aspect leverage, it is known that from 6 analyzed factors there are 2 factors that are the most sensitive affecting, the sustainability of urban rainwater harvesting, namely; 1) Availability of other water sources, 2) drought events frequency, 3) quality of groundwater, 4) rainfall and rainy days, and 5) quality of rainwater.

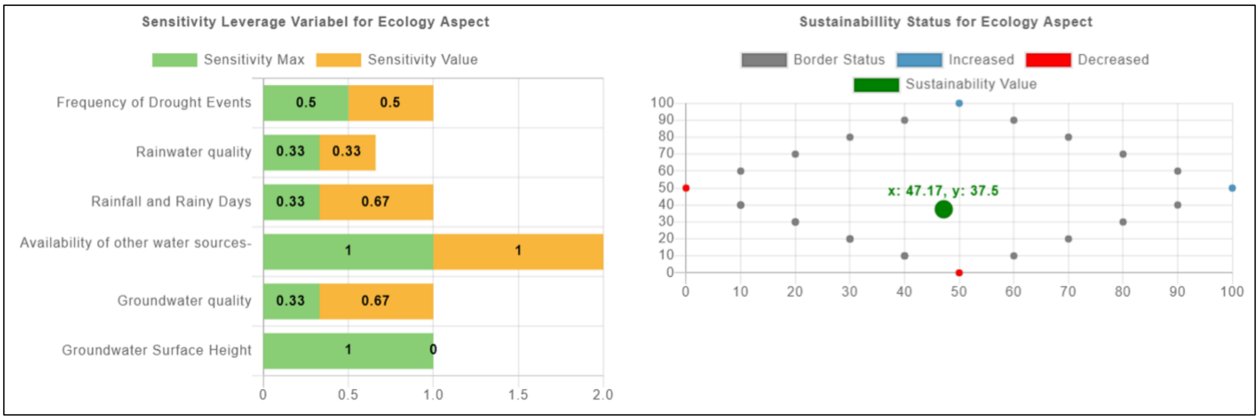


Figure 3. The sensitivity leverage variable, and sustainability status for the ecology aspect.

Similar to other areas in Indonesia, the city of Balikpapan has a tropical climate with year-round rainfall. Figure 4 shows a graph of the maximum monthly rainfall for the 2013 to 2022 period. The highest monthly rainfall was recorded in June (198 mm), and the lowest was in January (75.3 mm). With low rainfall, it is important to store rainwater as water reserves [7,8]. RWH systems are a possible solution for addressing the alarming issue of water scarcity [9].

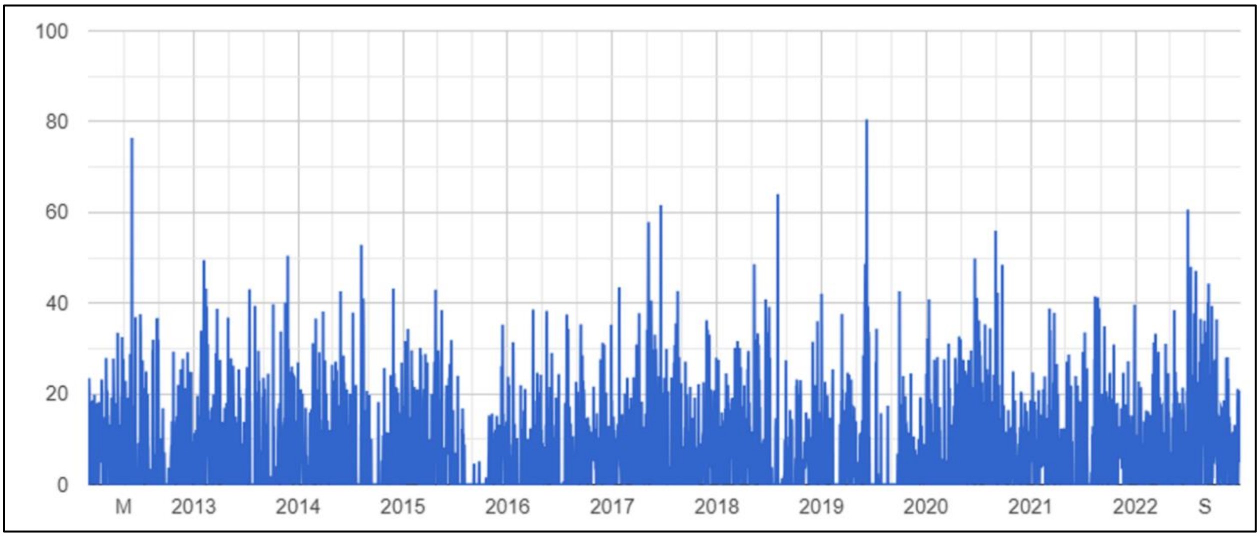


Figure 4. Maximum monthly rainfall in 2013–2022.

The sustained sensitivity factor of the ecological aspect is the availability of the water sources. This is consistent with [10–12] in that the availability of other water sources can improve the availability of clean water. The concept of harvesting rainwater could be a solution for supplying clean water to Balikpapan City. Another sensitive attribute is the groundwater quality. As a result of interviews with community groups in the Southern Balikpapan district, 62.5 % of residents had shallow wells as other water sources, and 78.6%

stated that the surface elevation of the wells fluctuated significantly. When the rain falls, the height decreases, and when the rain is high, the water increases. This was the same as that used in Ayele [13]. Rainwater harvesting can be drained into wells to increase the elevation of the groundwater surface. Well water quality in both categories (30.4% and 52.6%) indicated that their water quality was poor. One of the initial MD respondents said that "the well water was clear but high in heavy metals, especially during the rainy season". This is proven by the conditions of the bathroom floor and walls, which are black and yellow, respectively. The well water contained high levels of Fe and Mn. During the rainy season, the well water tends to be dull and smelly.

Economy Aspect

The attributes that influence the scale of sustainability in the economic aspect consist of six elements. The economic aspect of the MSA-RWH was 61% (sustainable), as shown in Figure 5. The future condition value was 50%, which could increase but not significantly. Compared to the sustainability indicator values of multi-aspect rainwater harvesting, the sustainability indicator values of the economic aspect of rainwater harvesting were above the sustainability indicator value of multi-aspect rainwater harvesting.

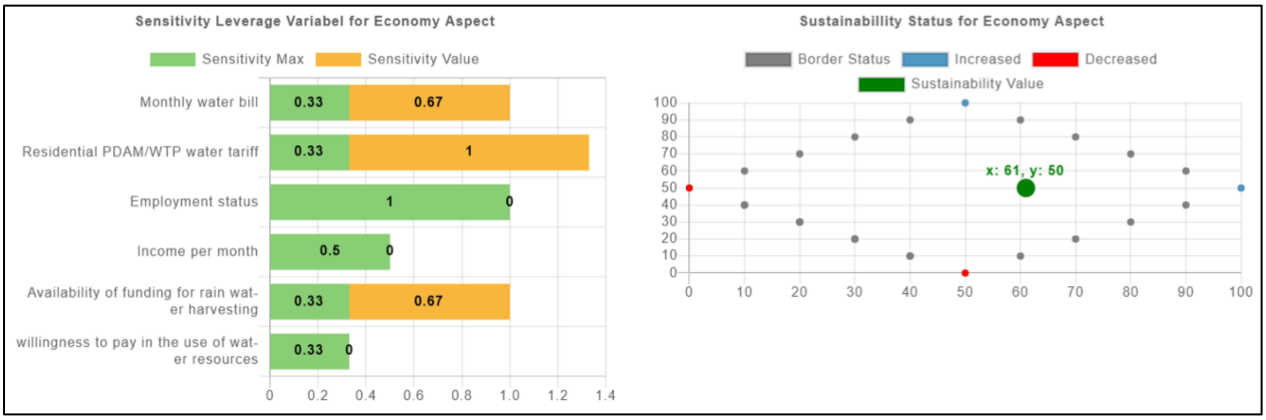


Figure 5. The sensitivity leverage variable and sustainability status for the economy aspect.

Employment status and monthly income showed good values; therefore, there is no need for improvement. 52.6% of respondents are still working, while 47.4% were not working (retired) but still received their monthly pensions. Budgetary availability is essential to the construction of rainwater harvesting facilities. This is consistent with Jiang [14], who found that elderly people, full-time housewives or husbands, and unemployed people have relatively more time to get involved in harvesting rainwater and show more interest in activities that require time and employment. Men and single-family homeowners have higher annual incomes and thus a greater willingness to pay for harvesting rainwater.

Pipe water is a water source obtained from water that had previously undergone a process of purification and sanitation before being distributed to consumers through the installation of water pipes. In some interviews, 3.6 % of respondents stated that the PDAM Balikpapan water tariff was very high and intimidating. In contrast, 19.6% of the respondents declared the PDAM Balikpapan tariff to be in the high category. For respondents who were not served by the PDAM Balikpapan, 30.4% had no cost for building rainwater installations. Under these conditions, the water sector has an inefficient tariff structure and incomplete/incoherent regulatory framework that hinders good governance [15]. The water demand of the system was improved using the RWH Method through volume and frequency analyses [16]. Additionally, most surface and groundwater sources in most regions of the country are polluted or unprotected.

Social Aspect

The attributes that influence the social aspect include six attributes at the sustainability level. The social aspect of MSA-RWH was 51.5% (sustainable), as shown in Figure 6. The future condition value is 50%, and the value could soon increase, but not significantly. Compared with the multi-aspect sustainability indicator values for rainwater harvesting, the sustainability indicator value of the social aspect of rainwater harvesting was above the multi-aspect sustainability indicator values for rainwater harvesting. The sustainability of rainwater harvesting from a social perspective is affected by many sensitive factors; 1) the preservation of water resources requires understanding and concern, 2) understanding and perception of rainwater quality, and 3) overtaking water source conflicts. Therefore, it is crucial to help people understand the importance of rainwater collection. This is consistent with [17–20], who state that the government needs to provide incentives to residents to build rainwater harvesting systems in their own homes owing to budgetary restrictions. According to the interview findings, respondents with initial IW and 64.9% of the other respondents were open to installing rainwater collection systems. This was done to reduce complaints to the PDAM Balikpapan. The Manggar and Teritip Reservoirs, both of which are mostly reliant on rainfall, are Balikpapan raw water sources [21].

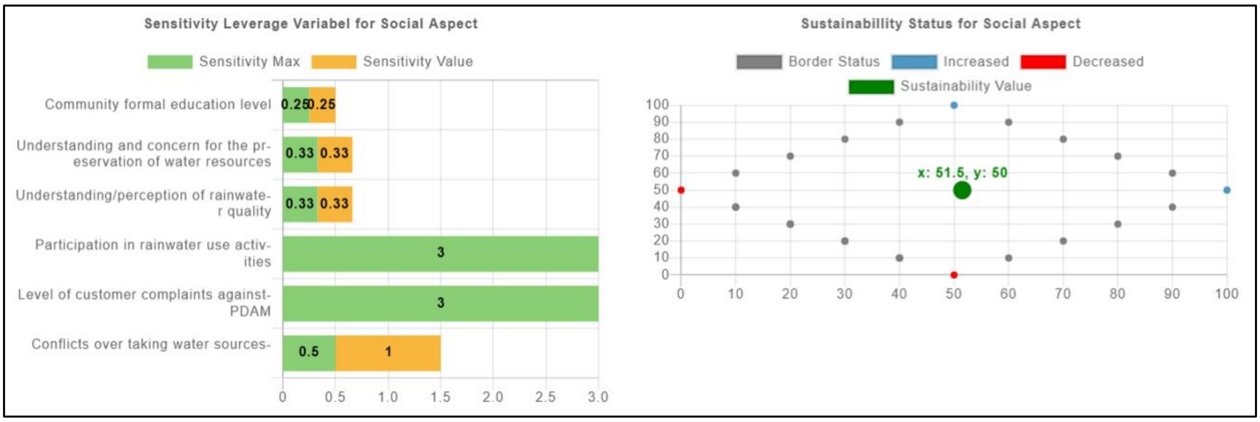


Figure 6. The sensitivity leverage variable and sustainability status for the social aspect.

Institutional Aspect

Seven attributes influenced the level of sustainability in the institutional context. Based on the MSA-RWH, the institutional aspect achieved 30.86% (low sustainability), as shown in Figure 7. The future condition value is 50%, and the value could soon increase, but not significantly. Comparison with multi-aspect sustainability indicator values rainwater harvesting, the sustainability indicator value of the institutional aspect of rainwater harvesting, is below the sustainability indicator value of multi-aspect rainwater harvesting.

The availability of water management units in housing complexes, the existing monitoring quality of water units, and the existence of social institutions that provide access to clean water are three sensitive factors that impact the sustainability of urban rainwater harvesting according to the conclusion of the leverage analysis of institutional aspects, as shown in Figure 7. Water management units are essential, particularly for households with water treatment systems. The unit is tasked with regularly checking the water quality produced by the the Water Treatment Plant (WTP) and reporting it to relevant services. Regular monitoring and control can ensure that the water produced is consistent with water quality standards. Based on the results of the interviews, 70% of respondents stated that their residential area did not have a centralized water treatment system, and only 18.2% said that water quality monitoring was going well.

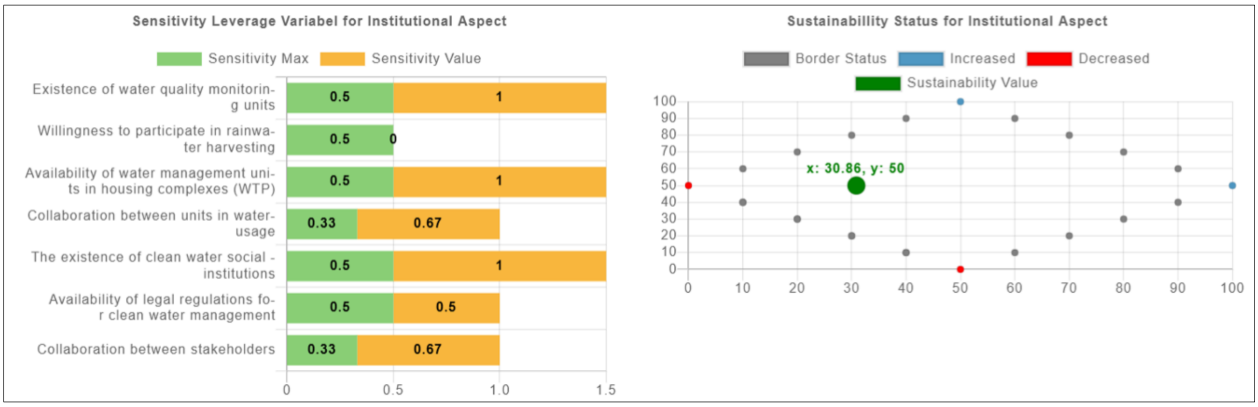


Figure 7. The sensitivity leverage variable and sustainability status for the institutional aspect.

The presence of social institutions that have access to clean water is important. Social institutions serve as a glue that holds various social groupings together, making them one of the most crucial elements in the formation of society. According to Hoffman et al. [22], community institutions are uniquely positioned to benefit from RWH; their large roofs provide significant rainfall capture areas. This is consistent with [23–25] in the implementation process, which facilitates issues such as the ownership and management of rainwater systems, which play an important role. The social institutions discussed here are norms or regulations that account for the citizens who make up society and regulate patterns of behavior among its members, as well as components of networking and trust between members of the community.

Technology and Infrastructure Aspects

The attributes that influence the sustainability level of technology and infrastructure comprise six attributes. Based on the MSA-RWH, the technology and infrastructure aspects obtained were 13.83% (low sustainability), as shown in Figure 8. The future condition value was 66.67%, and the value could increase, but not so significantly soon. Compared with the multi-aspect sustainability indicator values for rainwater harvesting, the sustainability indicator values of the technology and infrastructure aspects of rainwater harvesting were below the multi-aspect sustainability indicator values for rainwater harvesting.

Leveraging the analysis of technology and infrastructure aspects shown in Figure 8, known on six factors of analyzed, there is one sensitive factor affecting the sustainability of urban rainwater harvesting: 1) roof cleaning and 2) rainwater harvesting infrastructure.

The Rainwater harvesting system consists of rainwater padding construction, which is incredibly straightforward and quick to create [26]. The roof of the house, gutter, tap, filters for removing leaves and other debris that carry water, and rainwater storage tanks are the major components of rainwater harvester construction. These faucets can be utilized as alternative solutions because of the scarcity of clean water resources, reduction in surface rainwater depletion, and refilling of groundwater, particularly in urban areas. Clearing, cleaning, and refinement of the catchment area substantially increases runoff efficiency and water quality [27].

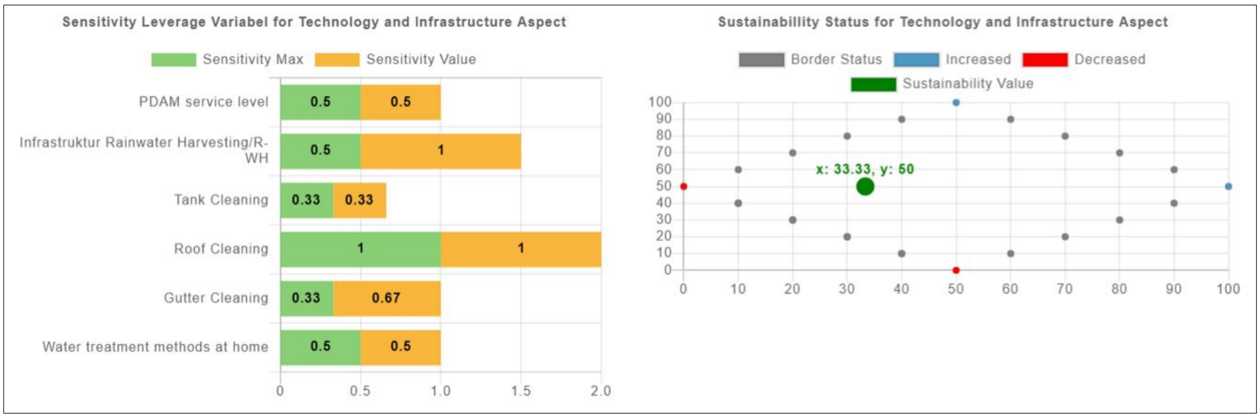


Figure 8. The sensitivity leverage variable and sustainability status for the technology and infrastructure aspect.

Clean rainwater harvesting facilities were rare. Interviews showed that only 9.1% of the respondents cleaned their water tanks twice a year, 46.8% never cleaned their gutter, and 79.9% did not clean their roofs. Even 61% did not have a water treatment system; therefore, they only used water as it was. Because these conditions make the water consumed unhygienic, the public should be aware of the importance of keeping rainwater harvesting systems clean. This has increased the quality of water and the health of waterways. This decreases the cost of infrastructure to manage rainwater, the amount of land required for wetlands, and the cost of flooding [28]. In a dry situation, rainwater harvesting continues to provide water long after all runoff into dams ceases. Therefore, rainwater harvesting is climate change-resilient for both dry and intense rain events [29,30].

Sensitivity Leverage Variable

The variable leverage sensitivity value indicates the difference between the actual state (based on the value of the mode) and the state value obtained from random iterations (based on the opinion of the average); the difference between the two is no more than 5%. The respondent's estimated error value represents the confidence interval between the factors; the closer the actual status value and the random iteration-based status value, the smaller or better the error rate value. In contrast, the larger the range between the two values (or greater than 0.5), the higher is the error rate. Therefore, it is necessary to check the opinions of the respondents to check for differences in their opinions [3].

Ecology Aspect

Figure 9 shows the sensitivity leverage variable values for the ecological aspect. It can be clearly seen that good status values were obtained because the range between the actual status and random iterations was 0.83% or less than 5%. The actual status was 47.17% and the random repeat status was 48%. By contrast, the error value estimated by the respondents was 0.23%, indicating a very low error rate. This also shows that the consistency of the respondents' answers is very good, at less than 5%.

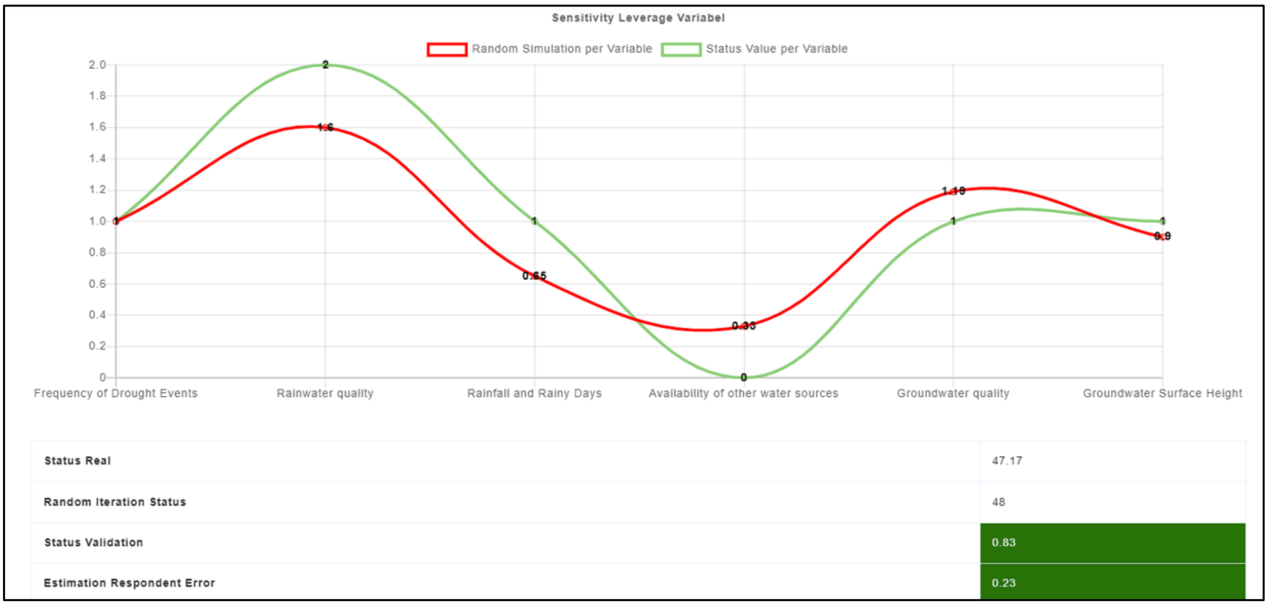


Figure 9. Sensitivity leverage variable of the ecological aspect.

Economy Aspect

Based on the sensitivity leverage variable value, as Figure 10 shows, the economic aspect has a good status value. This is because the range between the actual state and random iteration was 1% or less than 5%, with the actual state and 61% of the random iteration being 60%. However, the estimated error value for the respondents was 0.34%, indicating a very low error rate. This also shows that the consistency of the respondents' answers is still very good, at less than 5%.

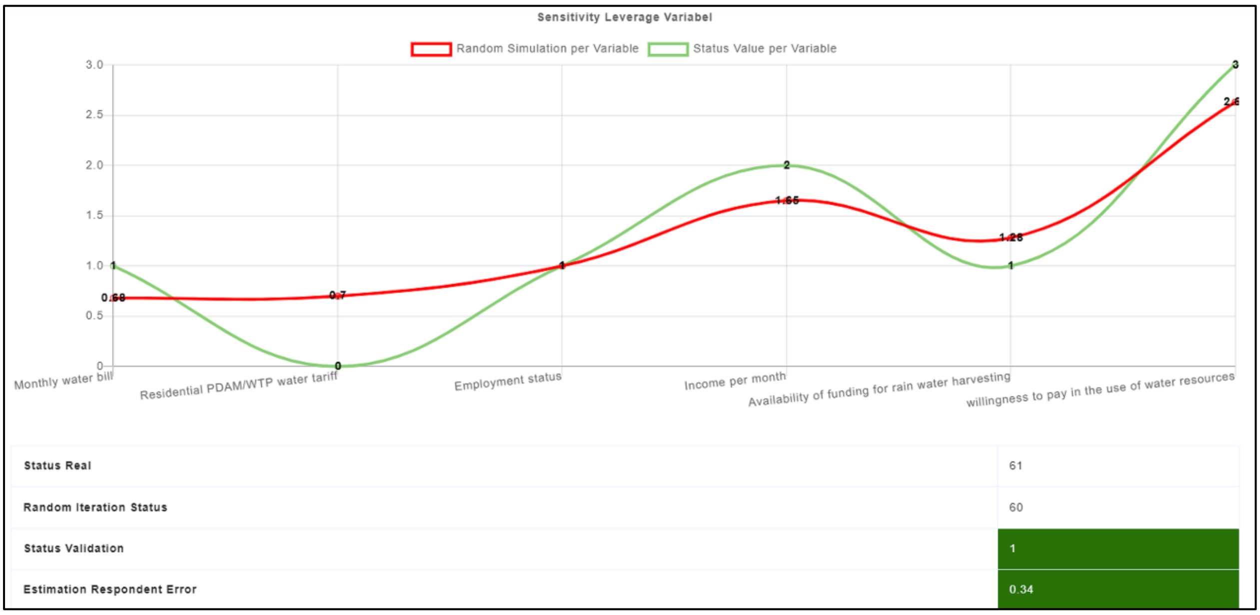
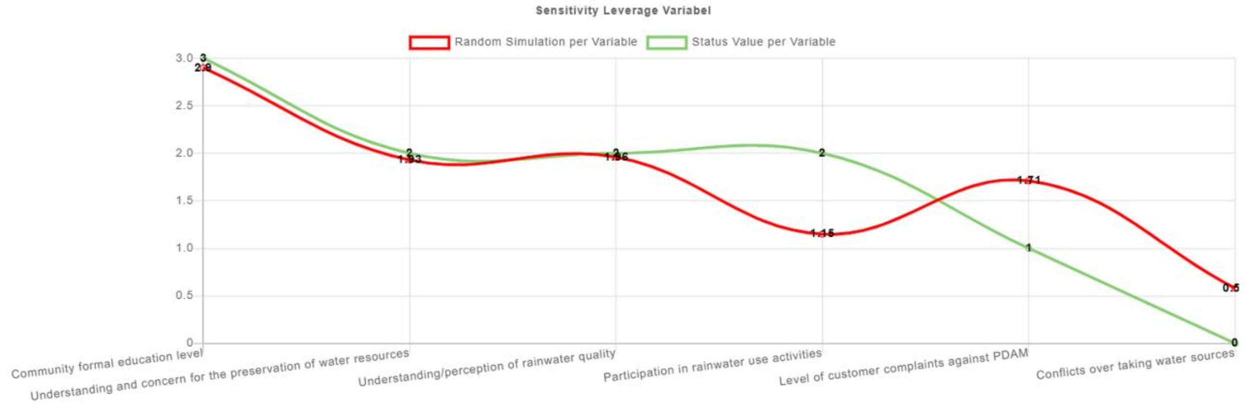


Figure 10. Sensitivity leverage variable of the economic aspect.

Social Aspect

Figure 11 illustrates the sensitivity leverage variable value for the social aspect, where the social aspect of cultivation good status values is obtained, because the range between the actual status and random iteration is 2.5% or 5%. The actual status was 51.5% and the random repeat status was 54%. By contrast, the error value estimated by the respondents was 0.39%, indicating a very low error rate. This also shows that the consistency of respondent answers is still very good at less than 5%.

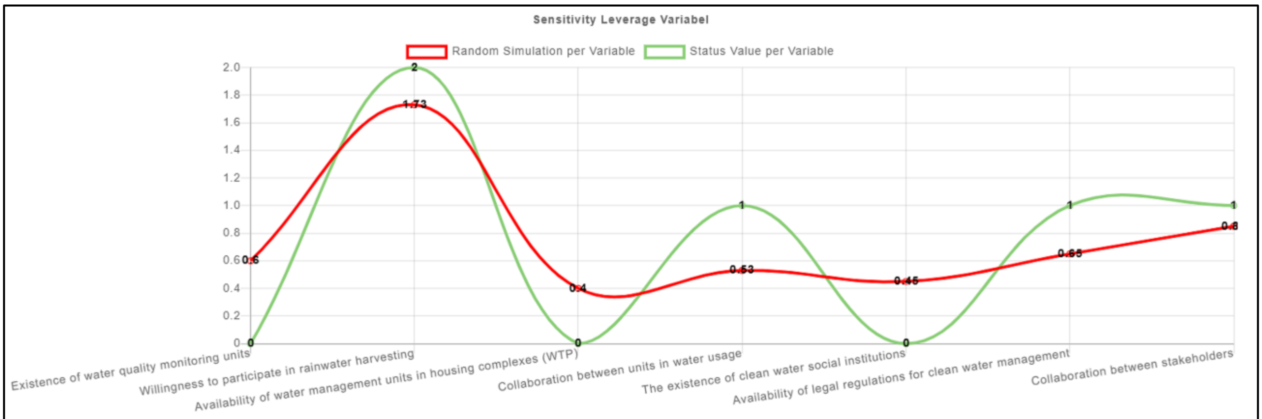


Status Real	51.5
Random Iteration Status	54
Status Validation	2.5
Estimation Respondent Error	0.39

Figure 11. Sensitivity leverage variable of the social aspect.

Institutional Aspect

As shown in Figure 12, the range between the actual status and random iteration was 3.14% or less than 5%, where the actual status was 30.86%, and the random iteration status was 34%. Therefore, this institution has a good status value. Meanwhile, the error estimate for respondents was 0.38%, indicating a very low margin of error; however, this also means that the level of consistency in respondents' answers was still less than 5%. It also showed that the level of consistency of the responses was very good.



Status Real	30.86
Random Iteration Status	34
Status Validation	3.14
Estimation Respondent Error	0.38

Figure 12. Sensitivity leverage variable of the institutional.

Technology and Infrastructure Aspect

The data in Figure 13 show that the infrastructure and technology aspects have a good status because the range between the actual status and random iteration is 3.57% or less than 5% because the actual status is 33.33% and the random iteration status is 37%. However, the estimated error value for the respondents was 0.35%, indicating a very low error rate. This also shows that the level of consistency of respondents' answers was very good, at less than 5%.

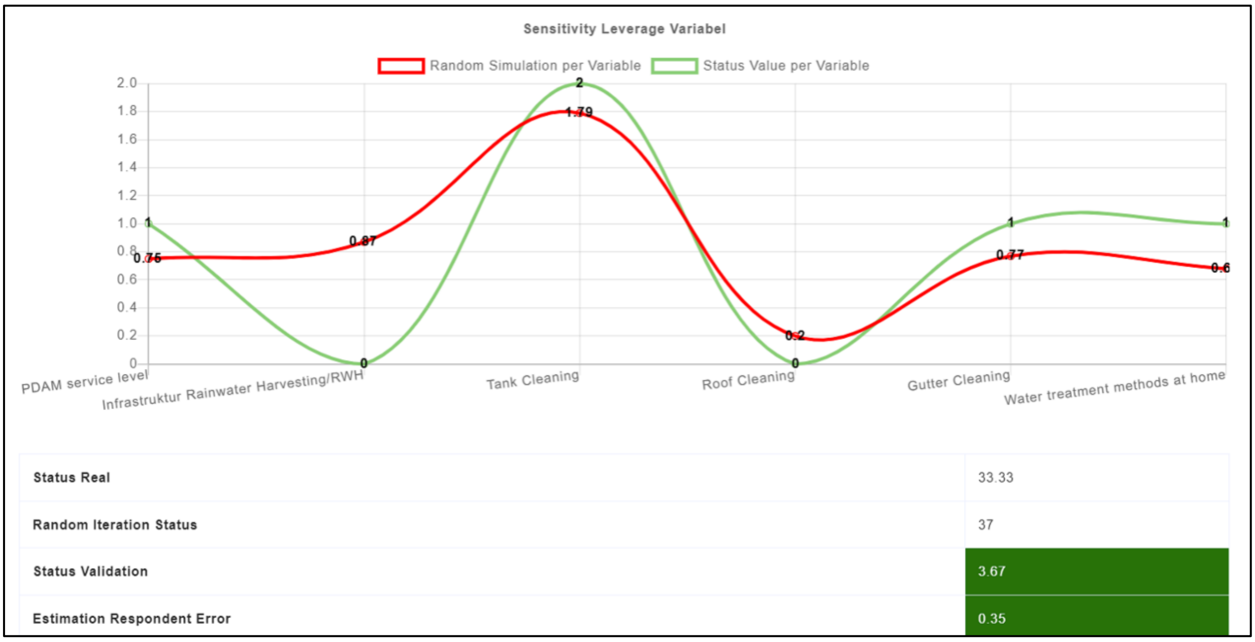


Figure 13. Sensitivity leverage variable of the infrastructure and technology aspects.

The Index and Sustainability Status of Rainwater Harvesting

The total uncertainty error was 1.94 %. This indicates that the agreement rate for respondents' answers was still very good, at less than 5%. The total value of sustainability in existing conditions is 44.77 in the low sustainability category, but the economic aspect is the highest, with a value of 61 (sustainable). Lever factors were performed in scenario simulations, with one lever factor for each aspect, increasing the aggregate total sustainability score for Scenario 1 (realistic) to 65.52 (Sustainable). In the second scenario (idealistic), we simulated the leverage factor by adding one factor to each aspect, which increased the total sustainability score to 80.29 (very sustainable). Detailed changes in status values between the scenarios are presented in Table 1.

Table 1. Status and sustainability value of existing conditions & scenarios.

No	Aspect	Uncertainty error	Existing	Realistic	Idealistic
1	Ecology	7.44	47.17	63.83	63.83
2	Economy	0.67	61	77.83	94.5
3	Social	0.67	51.5	59.83	79.17
4	Technology & infrastructure	0.33	33.33	66.67	80.67
5	Institutional	0.57	30.86	59.43	83.29
Total average		1.94	44.77	65.52	80.29
Status		Very good	Low sustainable	Sustainable	Very sustainable

The values of the multidimensional sustainability indicators for urban rainwater harvesting are shown in Figure 14. Based on the analysis results using MSA, the current sustainability indicator of the existing conditions is indicated by the red line. After making some improvements through Scenario 1 (realistic), significant changes occurred, as shown by the orange line. The blue line indicates the improvements in Scenario 2 (idealistic).

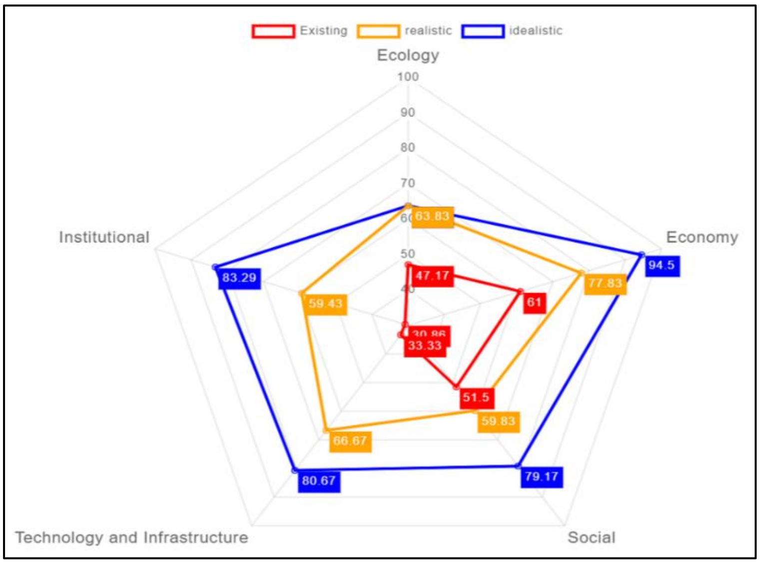


Figure 14. The kite diagram of indicator and sustainability status rainwater harvesting in Balikpapan City.

The Sustainability Value and Scenario Priority

In the selection of scenarios, this can be done on the basis of the status value in the scenario results. The leverage factor is also a basis for the analysis of the emerging scenarios, in addition to the scenario value. In this research, there are two scenarios: Realistic scenarios, which are based on the region's current ability to make real changes to existing policies; and Idealistic scenarios, which are based on conditions that would be desirable if they could be achieved. The realistic scenario has 15 factors to be addressed in each aspect; while the idealistic scenario has 17 factors to be addressed in each aspect towards the existing condition of rainwater harvesting in Balikpapan City. The increase in sustainability factor values for each scenario is presented in Table 2.

Table 2. Exisiting condition and scenarios.

Aspects	Factors/Attributes	Existing	Scenarios	
			Realistic	Idealistic
Ecology	Frequency of drought events	Frequently	-	Frequently
	Rainwater quality	Pretty good	-	-
	Rainfall and rainy days	Moderate	Moderate	Moderate
	Availability of other water sources	Not available	Available	Available
	Groundwater quality	Bad	Bad	Bad
	Groundwater surface height	Does not fluctuate excessively	-	-
Economy	Monthly water bill	High	Average	Low
	Residential PDAM/WTP water tariff	Very high	High	Average
	Employment status	Work	-	-
	Income per month	> regional minimum wage	-	-
	Availability of funding for rainwater harvesting	Less available	Available	Highly available
	Willingness to pay when using water resources	Very high	-	-
Social	Community formal education level	College/university	-	-
	Understanding and concern for the preservation of water resources	High	High	Very high
	Understanding/perception of rainwater quality	High	High	Very high
	Participation in rainwater use activities	Less than optimal	-	-
	Level of customer complaints against PDAM	Moderate	-	-
	Conflicts over taking water sources	All sub-districts	Certain	None

Aspects	Factors/Attributes	Existing	Scenarios	
			Realistic	Idealistic
			districts only	
Infrastructure and Technology	PDAM service level	Moderate	High	-
	Infrastructure Rainwater Harvesting/RWH	None	Available without filter	Available with filter
	Tank Cleaning	2 times/year	-	-
	Roof Cleaning	Never	1 time/year	-
	Gutter Cleaning	1 time/year	-	2 times/year
	Water treatment methods at home	Sand/ active carbon filter	-	Membrane filter
Institutional	Existence of water quality monitoring units	Not available	Up and running	-
	Willingness to participate in rainwater harvesting	Very willing	-	-
	Availability of water management units in housing complexes (WTP)	Not available	Not available	Up and running
	Collaboration between units in water usage	Quite in line	-	-
	Existence of social institutions for clean water	Not available	Up and running	-
	Availability of legal regulations, for clean water management	Available but not running	-	Available and running
	Collaboration between stakeholders	Quite in line	-	Very much in line

Table 3 lists the situations chosen and illustrates how simple it is to improve the underlying causes of each component. The choice of scenarios can be seen in the differences between Scenario 1 and the current situation, in which the second scenario must have a minimum value of two or twice that of Scenario 1, which demonstrates the simplicity of altering the driving factors to increase the status value [3]. The findings of the scenario simulation show that Scenario 2 has a value of 1.91 compared to Scenario 1, making preference for Scenario one: Policy options that are more responsive to policy changes than Scenario two. From the analyses that have been simulated, it can be seen that scenario 1 is capable of providing sufficient and realistic water supply to support a sustainable clean water supply plan in Balikpapan City. The policy developed from Scenario 1 is to make significant changes in the effort to provide clean water to the community by making improvements in 15 aspects of rainwater harvesting sustainability that are consistent with the actual capacity of the region. Scenario 1 has the potential for improvement in the responsiveness, effectiveness and efficiency of rainwater harvesting services and systems.

Table 3. Priority scenario for rainwater harvesting.

No	Aspect	ΔS1S	ΔS2S	ΔS2S/ΔS1S
1	Ecology	16.66	16.66	1
2	Economy	16.83	33.5	1.99
3	Social	8.33	27.67	3.32
4	Technology & Infrastructure	33.34	47.34	1.42
5	Institutional	28.57	52.43	1.84
Average scenario priority				1.91

Conclusions

Rainwater harvesting in Balikpapan City is less sustainable, whereas institutional and technological infrastructure have the lowest sustainability values. The social and economic aspects are well-preserved and sustainable. Future conditions can be made more sustainable by improving certain attributes. Factors that are very sensitive to influencing the sustainability of urban rainwater harvesting in Balikpapan City are poor groundwater quality, availability of funding for rainwater harvesting, need for roof cleaning, need for collaboration between stakeholders, and reduction of conflict over taking water sources.

Author Contributions

EA, HH: conceived and design the studies (aspects/factors of sustainability); **SMD, MK, AWA**: collected the data and interviews; **EA, CAP, SMD**: performed data analysis and interpretation; **CAP**: contributed to analysis tools (MSA Eximpro); **EA, TYR**: wrote the manuscript. All authors critically reviewed and approved the final manuscript.

Conflicts of Interest

There are no conflicts to declare.

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