GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 18 • Number 2 • 2024

https://doi.org/10.7494/geom.2024.18.2.5

Lili Mulyatna[1], Chay Asdak[2], Budhi Gunawan[3], Yonik Meilawati Yustiani[4]

Sustainability Analysis of Domestic Raw Water Supply in Bandung City of Indonesia

Abstract: The availability and sustainability of good quantities and qualities of water supplies for human needs and support development should be warranted; therefore, existing water resources should be managed sustainably. A multidisciplinary rapid appraisal method called multidimensional scaling (MDS) is an approach for a comprehensive analysis of the sustainability statuses of domestic water supplies. This study aims to analyze the index and sustainability status of raw water management from three dimensions of sustainability. The results that were obtained from a specific multidimensional scaling analysis method called Rapid Appraisal for Air Baku (Rapaku) are expressed in the form of indices and sustainability statuses. Based on different dimensions of the sustainability status review, the analysis results showed that Bandung's domestic raw water was "less sustainable" (42.34%). Of the 35 attributes that were analyzed, there were 13 sensitive attributes that affected the index and sustainability status with a very small error at a 95% confidence level.

Keywords: multidimensional scaling, Rapaku, sustainability, water supply

Received: June 26, 2023; accepted: January 17, 2024

[1] Universitas Pasundan, Faculty of Engineering, Indonesia, email: lili.mulyatna@gmail.com
[2] Padjadjaran University, Faculty of Agricultural Industrial Engineering, Bandung, Indonesia, email: c_asdak@yahoo.com, https://orcid.org/0009-0003-9117-4400
[3] Padjadjaran University, Faculty of Social and Political Sciences, Bandung, Indonesia, email: budhi.gunawan@unpad.ac.id, https://orcid.org/0000-0001-8183-0839
[4] Universitas Pasundan, Faculty of Engineering, Indonesia, email: yonik@unpas.ac.id (corresponding author), https://orcid.org/0000-0001-6963-0295

1. Introduction

The availability and sustainability of good quantities and qualities of water supplies for human needs and support development should be warranted; therefore, existing water resources should be managed sustainably. Sustainable water resource management is a system that manages water resources that can fully contribute to current and future community goals (social and economic) while maintaining the sustainability of its ecological aspects [1–4].

Land-use alterations due to development are considered to have resulted in increases in maximum discharges and decreases in minimum discharges [5–8]. The land-use changes in Bandung Basin during the period of 1983–2002 impacted vegetation areas such as forests and rice fields (which were reduced by 54%). Additionally, these changes have resulted in a 223% increase in built-up areas [9, 10]. Watershed impairment is indicated by an increase in the runoff coefficient (from 0.3 in 1950 to 0.55 in 1998). There was also a change in the flow regime, which was indicated by an increase of the maximum extreme discharge (from 217.6 m^3/s in 1951 to 285.8 m^3/s in 1998) and a decrease in the minimum extreme discharge (from 6.35 m^3/s in 1951 to 5.70 m^3/s in 1998). Furthermore, the groundwater productivity index continued to decline (from 0.1 million m^3/unit in 1900 to 0.0188 million m^3/unit in 2002) [9, 10].

The provision of sustainable drinking water is one of the 17 sustainable development goals (SDGs); these are listed under Goal 6 of the Clean Water and Proper Sanitation Sector. One of the points in the SDG goal within the environmental sector is to ensure that people achieve universal access to clean water and sanitation [11, 12]. This SDG target can be obtained by assessing the sustainability status of the water sources that can be used as a basis in formulating a strategy for the development of the clean water sector [13, 14].

A multidimensional scaling assessment (MDS) is a multidisciplinary rapid-appraisal method that can be used as an approach in assessing sustainability statuses. An MDS assessment calculation using Rapfish (Rapid Appraisal for Fisheries) software was developed by the Rapfish Group Fisheries Center of the University of British Columbia, Canada [15, 16]. In this study, five different dimensions were studied, including ecological, economic, social, infrastructural, and technological dimensions as well as legal and institutional aspects.

The purpose of this study is to analyze the sustainability status of natural resource management for the provision of domestic water supplies based on a mixed raw water source in Bandung City of Indonesia.

2. Methodology

The primary data was obtained through field surveys, interviews, and questionnaires, while the secondary data was obtained through a literature review of research results, reports, and documents from various agencies that were related to the field of this research.

2.1. Data-Collection Techniques

The primary data-collection was carried out by conducting interviews and field observations in the research area. The interviews were conducted with stakeholders from government agencies, Perusahaan Daerah Air Minum (PDAM), or Water Supply Company officers, academics, practitioners, and non-governmental organizations (NGOs). This target audience is considered to have a good understanding of the exploitation and those problems that are related to the provision of raw water for drinking purposes.

The number of respondents totaled 19 people; the basis for selecting the experts to be used as respondents was their willingness, reputation, and knowledge/experience in the field of water resource management.

2.2. Data-Analysis Methods

In this study, the analysis methods that were used consisted of the following: (1) multidimensional scaling (MDS) using the Rapid Appraisal for Air Baku (Rapaku) software (which was the innovational development of the Rapfish method – Rapid Appraisal for Fisheries), (2) leverage analysis (which was used to determine any sensitive attributes), and (3) Monte Carlo analysis (which was used to determine the effect of the errors on 95% confidence intervals. In addition to the Monte Carlo index, the stress value (S) and the coefficient of determination (R^2) were calculated to measure the mismatch of the method that was used with an actual situation; the higher the stress value, the less-suitable it was [17, 18]. A model that belongs to the good category is when the value of stress (S) is below 25% and R^2 is close to 1 (100%) [15–19].

The multidimensional scaling method is a statistical-analysis method based on similarity or dissimilarity; whereas the rapid appraisal technique uses a multidimensional aspect based on ordination. The Rapaku ordination technique was carried out along with the MDS method through several stages, including the following:

1. Determining the attributes in each dimension of sustainability and defining them through a literature review and field observations. This study included 35 attributes on 5 different dimensions that were comprised of 11 attributes of the ecological dimension, 6 attributes of the economic dimension, 6 attributes of the social dimension, 6 attributes of the technological infrastructure dimension, and 6 attributes of the legal and institutional dimensions.
2. Assessing each attribute on an ordinal scale (scoring) based on the results of the field surveys.
3. Utilizing ordination analysis with MDS for determining the position of the sustainability status on each dimension in the sustainability index scale.
4. Assessing the sustainability indices and their statuses on each dimension.
5. Conducting a sensitivity analysis (leverage analysis) for determining any variables that are sensitive for affecting sustainability.
6. Performing a Monte Carlo analysis to account for the uncertainty dimension [15, 17, 19].

Table 1 describes the sustainability index value of each dimension using a score value; each index value represents a certain sustainability condition. The category can conclude each dimension on its level of sustainability.

Table 1. Sustainability category based on Rapfish analysis index value

Index value [%]	Category
00.00–25.00	Bad (unsustainable)
25.01–50.00	Less (less sustainable)
50.01–75.00	Sufficient (moderately sustainable)
75.01–100.00	Good (very sustainable)

Source: [16, 19]

3. Results and Discussion

3.1. Sustainability Status of Ecological Dimension

The attributes that were predicted to influence sustainability amounted to 11. These ecological dimension attributes were based on the discussion outcomes with experts and from previous studies, including the following: (1) water-protected areas, (2) frequency of drought events, (3) quantity of groundwater, (4) quality of groundwater, (5) quantity of springs, (6) quantity of rainwater, (7) quantity of water that was recycled from domestic wastewater, (8) development of raw water sources, (9) land-use on quality of domestic water supply, (10) groundwater level height, and (11) level of river pollution. The simulation results using the Rapfish/Rapaku software on the 11 attributes resulted in a 40.08% sustainability index value for the ecological dimension; this was considered to be “less sustainable,” as the index was located between 25.01 and 50.00% [17, 20]. Based on the results of the leverage analysis, four attributes that were sensitive to the sustainability of the ecological dimension were obtained (Fig. 1), namely: (1) development of raw water sources, (2) land-use of water quality, (3) groundwater level, and (4) level of river pollution.

3.2. Sustainability Status of Economic Dimension

The attributes that were predicted to affect sustainability from the economic dimension consisted of six items, namely: (1) the cost of public water expenditure each month, (2) the presentation of low-income communities, (3) the willingness to pay, (4) the contribution of the raw water source utilization sector to the GRDP, (5) the availability of funds for the development of the drinking water supply systems, and (6) the availability of funds for preserving the raw water sources of drinking water. The simulation results on the six attributes using the Rapaku software resulted in a sustainability index value of 45.77% for the economic dimension of the domestic raw water supply (with the status of “less sustainable”).

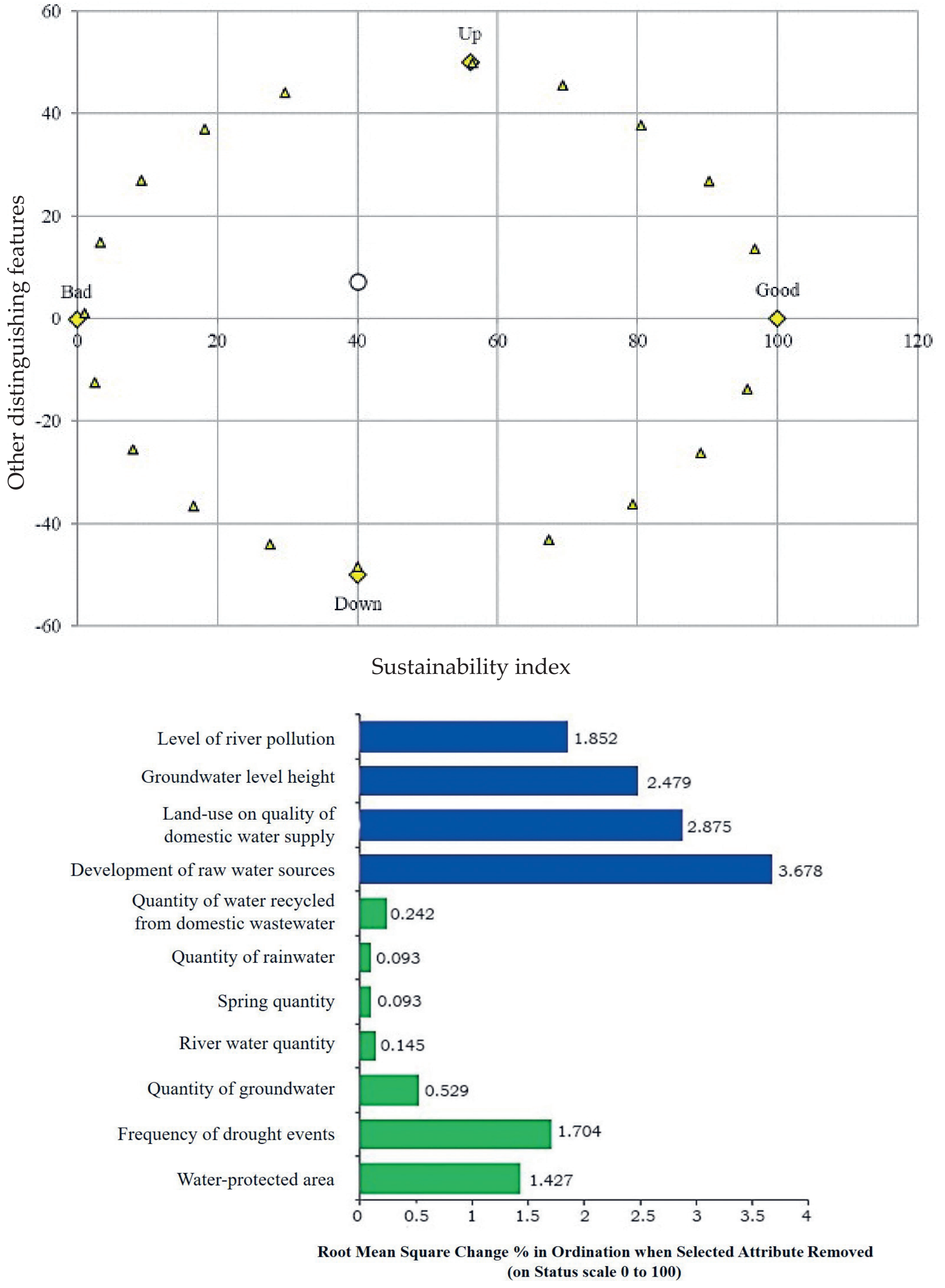


Fig. 1. Sustainability status index [%] and sensitive attributes of ecological dimensions

Source: data-processing results (2022)

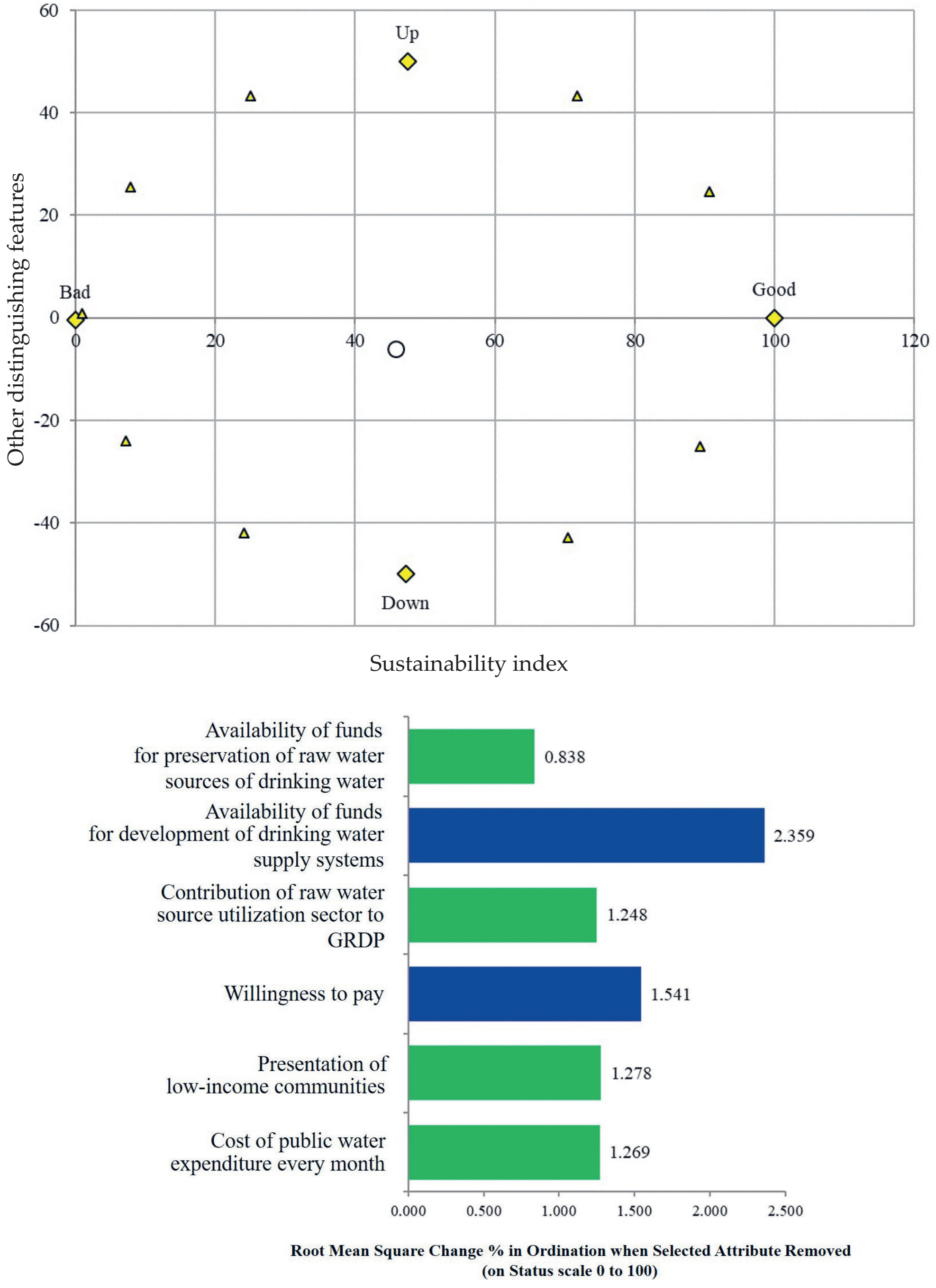


Fig. 2. Sustainability status index [%] and sensitive attributes of economic dimensions

Source: data-processing results (2022)

Based on the leverage analysis, it is known that the root mean square (RMS) value of the six analyzed attributes resulted in two attributes that were sensitive to the sustainability of the economic dimension of the domestic raw water supply (Fig. 2), i.e.: (1) the availability of funds for the development of the drinking water supply systems, and (2) the ability for the communities to pay for the use of their drinking water.

3.3. Sustainability Status of Social Dimension

The attributes that were predicted to influence the sustainability of the social dimension consisted of six items, i.e.: (1) the level of the formal education of the community, (2) the community's understanding and concern for the preservation of their drinking water raw water sources, (3) the community's empowerment in drinking water-utilization activities for domestic activities, (4) the level of the public complaints against PDAM's drinking water services, (5) the conflicts over the use of raw water resources, and (6) the role of religious leaders/traditional leaders and communities in managing raw water sources. The results of the simulation on the six attributes using the Rapaku software resulted in a 42.83% sustainability index value for the social dimension of domestic raw water supply sources (with the status of "less sustainable").

Based on the leverage analysis, it is known that the RMS value of the six analyzed attributes resulted in three attributes that were sensitive to the sustainability of the social dimension of domestic raw water supply sources (Fig. 3), i.e.: (1) the public understanding and concern for the sustainability of drinking water raw water sources, (2) the level of public complaints against drinking water services, and (3) the community's empowerment in the use of drinking water for domestic activities.

3.4. Sustainability Status of Infrastructure and Technology Dimensions

The attributes that were predicted to influence the sustainability of the infrastructure and technology dimensions consisted of six items, i.e.: (1) the level of community accessibility to the provision of drinking water, (2) the domestic wastewater infrastructure, (3) an environmentally sound drainage infrastructure (eco-drainage), (4) rainwater-harvesting technology, (5) non-latrine domestic wastewater-recycling technology, and (6) the performance of existing drinking water-treatment plants. The simulation results on the six attributes using Rapaku software resulted in a 43.62% sustainability index value for the infrastructure and technology dimension (with a status of "less sustainable").

Based on the leverage analysis, it is known that the RMS value of the six analyzed attributes resulted in two attributes that were sensitive to the sustainability of the dimensions of infrastructure and technology of domestic raw water supply sources (Fig. 4), namely: (1) domestic wastewater-recycling technology, and (2) environmentally sound drainage infrastructure.

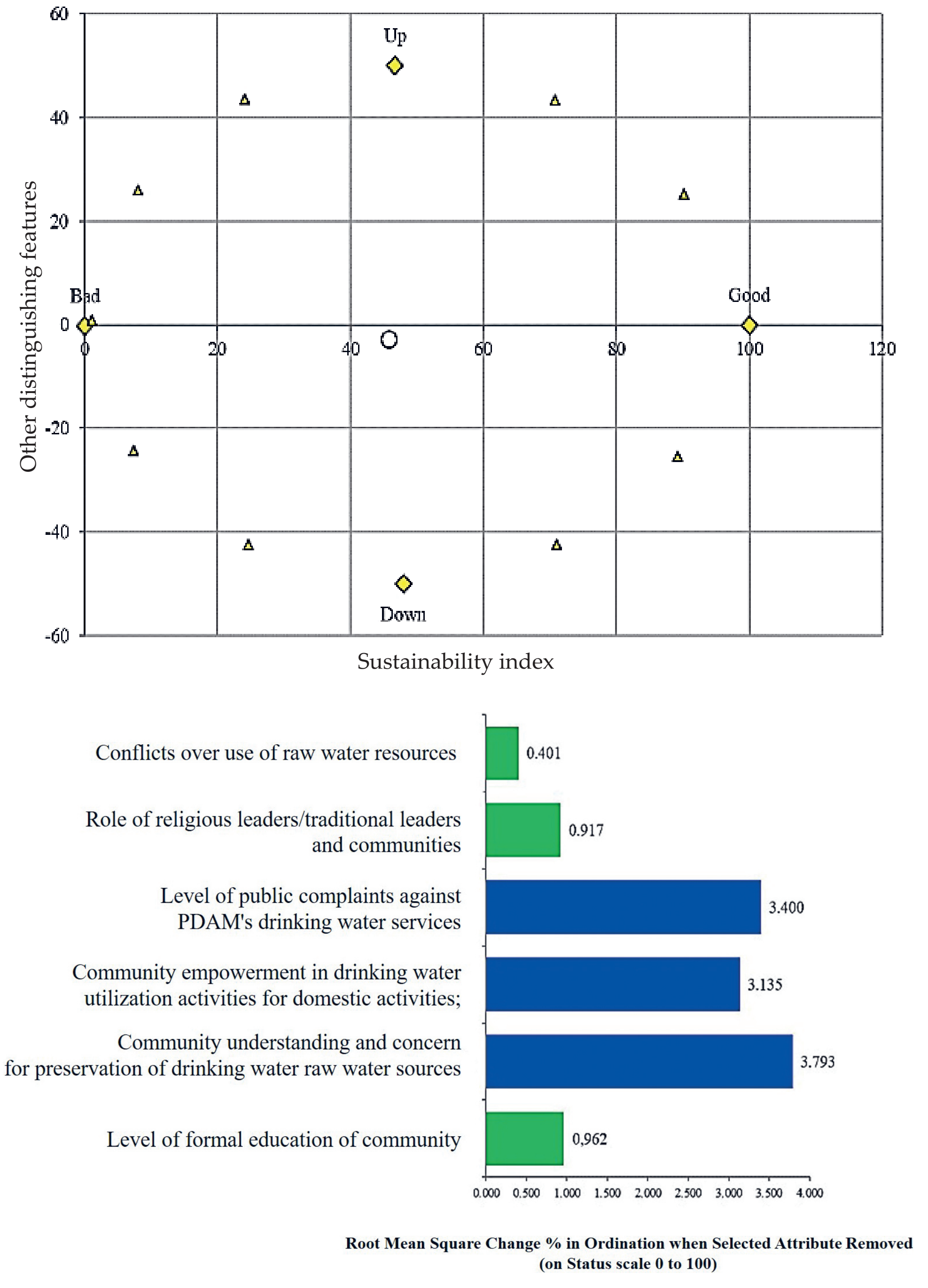


Fig. 3. Sustainability status index [%] and sensitive attributes of social dimensions

Source: data-processing results (2022)

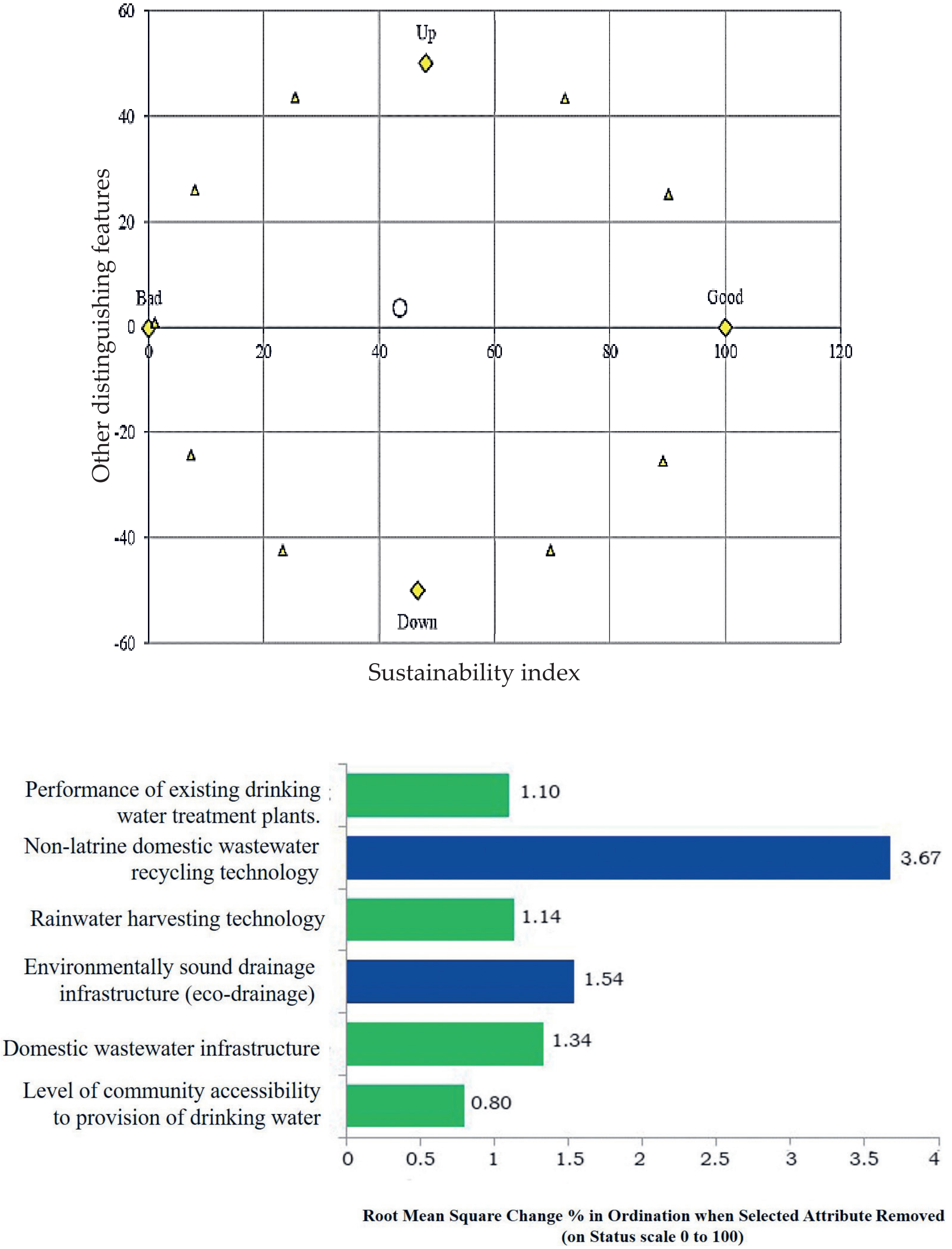
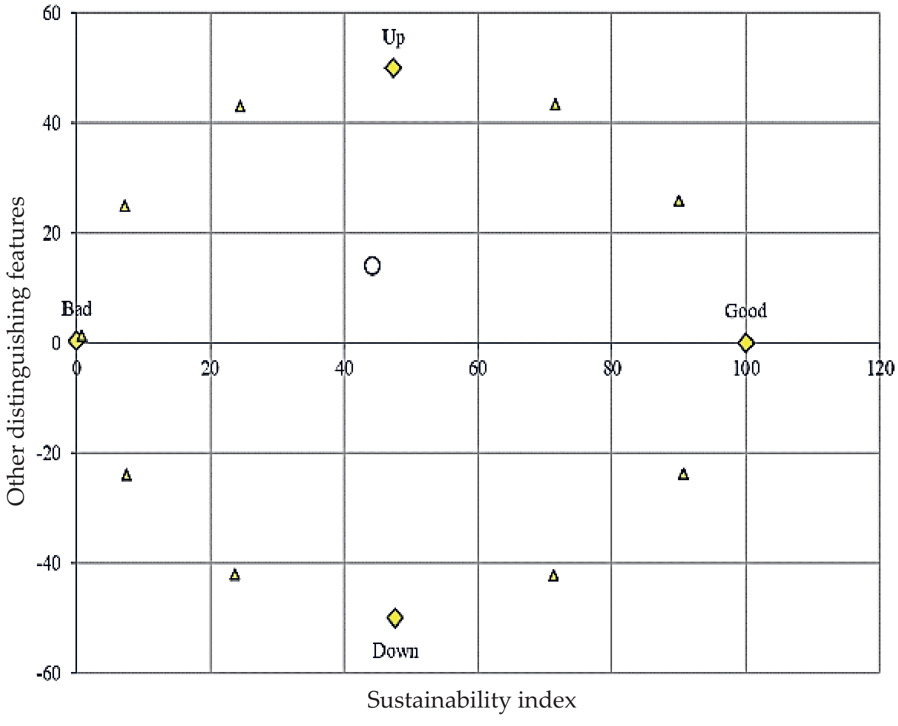


Fig. 4. Sustainability status index [%] and sensitive attributes of infrastructure and technology dimensions

Source: data-processing results (2022)



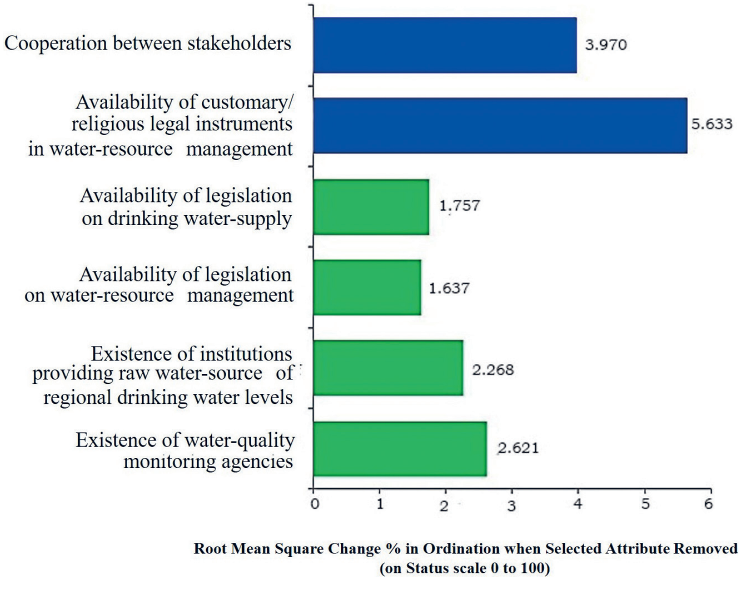


Fig. 5. Sustainability status index [%] and sensitive attributes of legal and institutional dimensions

Source: data-processing results (2022)

3.5. Sustainability Status of Legal and Institutional Dimensions

The attributes that were predicted to influence sustainability from the legal and institutional dimensions consisted of six attributes, namely: (1) the existence of water quality-monitoring agencies, (2) the existence of institutions that provide the raw water sources of regional drinking water levels, (3) the availability of legislation on water-resource management, (4) the availability of legislation on drinking water-supply systems, (5) the availability of customary/religious legal instruments in water-resource management, (6) cooperation among stakeholders. The results of the analysis on the six attributes using Rapaku software resulted in a 42.72% sustainability index value for the legal and institutional dimensions (good governance) (with a status of "less sustainable").

Based on the leverage analysis, it is known that the RMS value of the six analyzed attributes resulted in two attributes that were sensitive to the sustainability of the legal and institutional dimensions of the domestic mixed raw water supply (Fig. 5); namely, (1) the availability of customary/religious legal tools in water-resource management, and (2) the cooperation among stakeholders.

3.6. Sustainability Status of Bandung City's Domestic Water Raw Water Supply (Viewed from all Dimensions)

The results of the ordinance using Rapaku software showed that the index value and sustainability status for each dimension were as are illustrated in Table 2.

Table 2. Multidimensional sustainability index value of domestic raw water supply in Bandung City

Sustainability dimension	Sustainability index value [%]	Sustainability status
Ecology	40.08	less sustainable
Economics	45.77	less sustainable
Social	42.83	less sustainable
Infrastructure and technology	43.62	less sustainable
Legal and institutional	42.72	less sustainable
Sum	43.00	less sustainable

Source: data-processing results (2022)

Based on the respondents' opinions (summarized in Table 2 and Figure 6), the condition of the domestic raw water supply in Bandung City is in a poor condition, thus potentially threatening its sustainability. Therefore, it is necessary to intervene policies that overcome the issue.

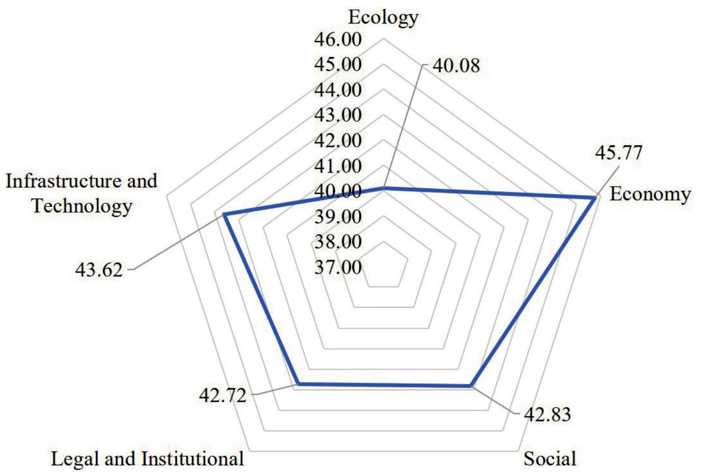


Fig. 6. Sustainability index [%] of domestic water supply sources based on mixed raw water source in Bandung City

Source: data-processing results (2022)

3.7. Monte Carlo Analysis

Table 3 describes the results of the Monte Carlo and MDS analyses at a 95% confidence level. The difference in the value of the sustainability index was achieved with a value of less than 1 (<1). Therefore, the resulting MDS simulation was adequate for being used in estimating the value of the sustainability index of the domestic raw water supply in Bandung City.

Table 3. Differences in sustainability index between Rapaku/Rapfish (MDS) and Monte Carlo

Sustainability dimension	Sustainability index value [%]		Difference MDS – MC
	MDS	Monte Carlo (MC)	
Ecology	40.08	40.07	0.01
Economics	45.77	44.96	0.81
Social	42.83	43.62	0.79
Infrastructure and technology	43.62	43.49	0.13
Legal and institutional	42.72	43.15	0.43

Source: data-processing results (2022)

This relatively small difference in the values indicates that the errors in the analysis process could have been minimized or avoided. The errors that were caused by scoring each attribute and the multidimensional scoring variations that were caused by the different opinions were relatively small, the process of the data analysis that was repeatedly carried out was relatively stable, and the errors in inputting the data and missing data could have been avoided [15, 17, 19].

3.8. Goodness of Fit (Analysis Accuracy Test)

From the results of the Rapaku analysis (Table 4), a coefficient of determination (R^2) that was between 94 and 95% was achieved. This shows that the sustainability index estimation model was in the category of good and adequate to be used [14–19]. The stress value was between 0.14–0.17 (or below 25%), so the obtained MDS analysis model had a high accuracy (goodness of fit) for assessing the sustainability index [14–19].

Table 4. Values of stress and coefficient of determination (R^2) of Rapaku analysis results

Parameters	Dimension				
	Ecology	Economy	Social	Infrastructure and technology	Legal and institutional
S value	0.139	0.170	0.151	0.163	0.150
R^2 value	0.951	0.937	0.942	0.946	0.946

Source: data-processing results (2022)

4. Conclusion

Based on the results of this study, there are two important messages that can be summarized.

1) The sustainability status of the domestic raw water supply in Bandung City is currently less sustainable, as it has a sustainability index of 43.0%. The status is less sustainable due to the following:
   a) The ecological dimension of Bandung City that is experiencing a raw water crisis that has been caused by a lot of land-use changes and groundwater level subsidence, thereby reducing the quantity of the available raw water (additionally, river pollution has resulted in decreases in the raw water's quality).
   b) The economic dimension (due to the limited availability of funds for the development of domestic water-supply systems) and the low economic value of water in the eyes of the public (as it is still considered to be a social object).
   c) The social dimension (due to the low public understanding of water-resource conservation, while advocacy to increase community capacity toward drinking water use is rarely carried out). On the other hand, public complaints against the drinking water services that are managed by PDAMs are still relatively high.

   d) The infrastructure and technology dimensions (because the use of raw water sources still relies on natural sources that have decreased in quantity and quality). The utilization of alternative raw water sources that require new infrastructures and technologies has not been implemented.
   e) The legal and institutional dimensions (due to the fading of community obedience to religious and customary-based legal rules as informal legal sources so that they do not support the applications of formal laws). Meanwhile, cooperation between stakeholders has not been going well, sectoral egos and overlapping rules and policies are still the main obstacles in water-resource management.
2) Efforts made to improve the sustainability status of the domestic raw water supply in Bandung City are by intervening in sensitive attributes from the leverage analysis, which include controlling river pollution, groundwater use, and land use change. Another thing that needs to be done is to allocate more drinking water-development funds so that they are adequate to carry out development, while level adjustment is an unavoidable choice in order to improve drinking water services. On the community side, it is necessary to conduct frequent advocacy and training on water management for the community and improve drinking water services for the community. Meanwhile, to increase the availability of raw water sources, it is necessary to apply the use of alternative raw water sources by applying the appropriate technology. Another very important thing to realize is establishing excellent relationships among organizations (institutions) to build the synergy of the programs and activities that are related to water-resource management.

Acknowledgements

This study was academically and financially supported by the Faculty of Engineering of Universitas Pasundan and Padjadjaran University.

References

[1] Loucks D.P.: *Quantifying trends in system sustainability*. Hydrological Sciences Journal, vol. 42(4), 1997, pp. 513–530. https://doi.org/10.1080/02626669709492051.

[2] Supramoko M.: *Ekonomi Sumber Daya Alam dan Lingkungan: Suatu Pendekatan Teoritis*. BPFE UGM, Yogyakarta 2018.

[3] Mays L.W. (ed.): *Water Resources Sustainability*. McGraw-Hill Education, New York 2007.

[4] Russo T., Alfredo K., Fisher J.: *Sustainable water management in urban, agricultural, and natural system*. Water, vol. 6(12), 2014, pp. 3934–3956. https://doi.org/10.3390/w6123934.

[5] Asdak C.: *Hidrologi dan Pengelolaan Daerah Aliran Sungai*. Gadjah Mada University Press, Yogyakarta 2014.

[6] Du J., Qian L., Rui H., Zuo T., Zheng D., Xu Y., Xu C.-Y.: *Assessing the effects of urbanization on annual runoff and flood events using an integrated hydrological modeling system for Qinhuai River basin, China*. Journal of Hydrology, vol. 464–465, 2012, pp. 127–139. https://doi.org/10.1016/j.jhydrol.2012.06.057.

[7] UNEP: *A Snapshot of the World's Water Quality: Towards a Global Assessment*. United Nations Environment Programme, Nairobi, Kenya. 2016. https://www.unep.org/resources/publication/snapshot-report-worlds-water-quality [access: 30.05.2023].

[8] Suriya S., Mudgal B.V.: *Impact of urbanization on flooding: The Thirusoolam sub watershed – A case study*. Journal of Hydrology, vol. 412–413, 2012, pp. 210–219. https://doi.org/10.1016/j.jhydrol.2011.05.008.

[9] Wangsaatmaja S.: *Dampak Konversi Lahan Terhadap Rezim Aliran Air Permukaan Serta Kesehatan Lingkungan (Suatu Analisis Kasus DAS Citarum Hulu)*. Department of Environmental Engineering, Institute of Technology, Bandung 2004 [PhD thesis].

[10] Wangsaatmaja S., Sabar A., Prasetiati M.A.N.: *Permasalahan dan Strategi Pembangunan Lingkungan Berkelanjutan. Studi Kasus: Cekungan Bandung*. Jurnal Geologi Indonesia, vol. 1(3), 2006, pp. 163–171.

[11] Weststrate J., Dijkstra G., Eshuis J., Gianoli A., Rusca M: *The sustainable development goal on water and sanitation: Learning from the Millenium Development Goals*. Social Indicator Research, vol. 143, 2018, pp. 795–810. https://doi.org/10.1007/s11205-018-1965-5.

[12] Gallopín C.G.: *A system approach to sustainability and sustainable development.* Serie Medio ambiente y desarrollo, vol. 64, Sustainable Development and Human Settletments Division, CEPAL, Naciones Unidas, Santiago, Chile 2003.

[13] Bass S., Dalay-Clayton B.: *Sustainable Development Strategies: A Resource Book.* Routledge, London 2002. https://doi.org/10.4324/9781849772761.

[14] Munasinghe M.: *Environmental Economics and Sustainable Development*. World Bank Environment Paper, no. 3, The World Bank, Washington 1993. https://doi.org/10.1596/0-8213-2352-0.

[15] Kavanagh P., Pitcher T.J.: *Implementing Microsoft Excel software for Rapfish: A technique for the rapid appraisal of fisheries status*. Fisheries Centre Research Reports, vol. 12(2), Fisheries Centre, University of British Columbia, Vancouver 2004. https://doi.org/10.14288/1.0074801.

[16] Fauzi A.: *Ekonomi Sumber Daya Alam dan Lingkungan: Teori dan Aplikasi*. Gramedia Pustaka Utama, Jakarta 2006.

[17] Pitcher T.J., Preikshot D., Bonfil R.: *Rapid Appraisal of Distant Water Fleet Fisheries Relative to Home Fleets Using the Rapfish Technique*. [in:] Bonfil R., Munro G., Sumaila U.R., Valtysson H., Wright M., Pitcher T., Preikshot D., Haggan N., Pauly D. (eds.), *Distant Water Fleets: An Ecological, Economic and Social Assessment* [Chapter 5: *Status of West African Fleets*], Fisheries Centre Research Reports, vol. 6(6), Fisheries Centre, University of British Columbia, Vancouver 1998, pp. 90–93. https://doi.org/10.14288/1.0074783.

[18] Fauzi A., Anna S.: *Pemodelan Sumber Daya Perikanan dan Lautan untuk Analisis Kebijakan*. Gramedia Pustaka Utama, Jakarta 2005.

[19] Eka S., Setiawan D., Mubarok R., Ernawati, Otok B.W.: *Analisis Multi Dimensional Scaling pada Kabupaten di Papua Berdasarkan Faktor-Faktor yang Memperngaruhi Indeks Pembangunan Manusia (IPM) Tahun 2013*. 2017. https://www.academia.edu/33049183/Analisis_Multi_Dimensional_Scaling_pada_Kabupaten_di_Papua_Berdasarkan_Faktor_Faktor_yang_Mempengaruhi_Indeks_Pembangunan_Manusia_IPM_Tahun_2013 [access: 30.05.2023].

[20] Rembet U.N.W.J., Boer M., Bengen D.G., Fahrudin A.: *Struktur Komunitas Ikan Target di Terumbu Karang Pulau Hogow dan Putus-Putus Sulawesi Utara*. Jurnal Perikanan dan Kelautan Tropis, vol. 7(2), 2011, pp. 60–65. https://doi.org/10.35800/jpkt.7.2.2011.179.