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Sustainability Status of Konaweha River Management for Raw Water Supply in Kendari City, Southeast Sulawesi Province, Indonesia

Darwin Ismail[1,2*], Muhammad Zamrun Firihu[3], La Ode Safuan[3] and Armid[2]

[1]Doctoral Student of Agricultural Sciences, Postgraduate Program, Universitas Halu Oleo, Kendari, Indonesia; [2]Department of Chemistry, Faculty of Science, Halu Oleo University, Anduonohu Kendari, Indonesia; [3]Department of Physics, Faculty of Science, Halu Oleo University, Anduonohu Kendari, Indonesia
[*]Corresponding author's e-mail: darwin.ismail@uho.ac.id

The aim of this study is to assess the level of sustainability of natural resource management for raw water supply in Kendari City, as well as to identify critical elements influencing the sustainability of natural resource management for raw water supply in Kendari City. The method used is RAPFISH MDS, which includes 41 attributes on five dimensions analyzed, namely 12 attributes of the ecological dimension, 7 attributes of the economic dimension, 7 attributes of the social dimension, 8 attributes of the technological dimension, and 7 attributes of the institutional dimension; (2) assessment of each attribute on an ordinal scale (scoring) based on field survey results. According to the findings, the ecological dimension has a sustainability index of 53.33% (moderately sustainable), the economic dimension has a sustainability index of 40.48% (less sustainable), the social dimension has a sustainability index of 41.64% (less sustainable), the technological dimension has a sustainability index of 33.85% (less sustainable), and the institutional dimension has a sustainability index of 54.48%. Overall, the sustainability rating of raw water management is 44.76, indicating a less sustainable position. The technology dimension is an important factor influencing sustainability. Important characteristics include the state of PDAM's piped distribution network, drainage systems in residential areas, and waste treatment technologies. The lack of contemporary infrastructure and technology is a key impediment to sustainable water management, compromising service reliability and pollution control. In conclusion, while the ecological and institutional factors demonstrate modest sustainability, economic, social, and technological concerns remain. Improving technological infrastructure and addressing other major leverage factors are critical for improving the overall sustainability of raw water management in Kendari City.
Keywords: Kendari city**,** river management, raw water supply, sustainability status water management.

INTRODUCTION

Water supply to support the development and various human needs to be guaranteed, especially in quantity and quality as required. Therefore, existing water resources need to be managed sustainably. A sustainable water resources management system is a water resources management system that is designed and managed to fully contribute to the current and future goals of society (social and economic) while maintaining the sustainability of its ecological aspects (Loucks, 2021). Clean water is essential to human existence and significantly impacts various aspects of life including household needs, social, economic, and public facilities, and population growth (Yani 2020). Groundwater is the main source of clean water for the community (Kete, 2021). It is sourced from rainwater, is fresh, and undergoes natural filtration through infiltration into the soil, making it safe for use in daily life. About 70% of community clean water needs and 90% of industrial water needs are met by groundwater (Bregasnia *et al.,* 2020). The government's efforts in fulfilling the need for clean water for the community, minimizing the clean water crisis, and ensuring equitable access, are carried out through the establishment of Tirta Anoa Regional Drinking Water Company (PDAM) in Kendari. The organization of this PDAM is regulated in Regional Regulation No. 3/2010 and Regional Regulation No. 7/2010 on Drinking Water Services. PDAM Tirta Anoa treats raw water from five main areas, with the largest contribution coming from the Konaweha River (75%). This river is one of the largest in Sulawesi, crossing three regencies with a watershed area of 6,978.41 km² (Adiyanto *et al.,* 2021). Recently, the Konaweha watershed has experienced problems

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both in terms of quantity and quality. In terms of water quantity, river water in the Konaweha watershed has decreased. This is caused by climate change which has an impact on changes in rainfall patterns and water availability. This condition is in line with research conducted by Irawan *et al* (2022), changes in rainfall cause a decrease in water availability. In terms of water quality, the level of pollution due to community activities around the watershed has increased (Setiawan *et al*., 2023). This hurts the raw water quality of the PDAM. Therefore, to prevent a water resource crisis, it is necessary to manage raw water sustainably. This study seeks to directly address these ongoing concerns by assessing the sustainability of water resource management in Kendari City, with a focus on climate change, water quality degradation, and community consequences. The research focuses on identifying important components of sustainability, with a particular emphasis on ecological, economic, social, technical, and institutional concerns.

Despite growing understanding of water sustainability challenges, gaps in the literature exist regarding the integration of these factors within the specific context of water management in Kendari City. Previous research, such as that conducted by Irawan *et al*. (2022); Setiawan *et al*. (2023), has focused on individual issues such as water supply and pollution, but few have adopted a complete multi-dimensional approach to assessing sustainability. This study extends on previous research by evaluating raw water management in Kendari City using the Multi-Dimensional Scaling (MDS) method, which has been shown to be effective in measuring sustainability across many sectors (Fahmi *et al*., 2023). By addressing these gaps, this study hopes to provide useful insights into long-term water resource management plans, providing a comprehensive view that includes technological, social, and institutional aspects as well as ecological and economic factors.

MATERIALS AND METHODS

Data type and source**:** Data sources used were primary data and secondary data. Primary data was obtained through field survey activities, expert interviews (in-depth interviews), and filling out questionnaires. Meanwhile, secondary data was obtained through literature searches of research results, literature studies, reports and documents from various agencies related to the research field

Data collection**:** Primary data was acquired in the research region through interviews and field observations. Interviews with local government officials and specialists gave in-depth insights into water resource management, a qualitative research method frequently used to explore difficult issues (Kvale and Brinkmann, 2015; Yin, 2018). This technique provides for a thorough examination of stakeholders' viewpoints and experience in water resource concerns. Field observations supplemented interviews by providing real-time verification of environmental and infrastructure conditions, hence increasing data dependability (Creswell and Poth, 2018). These combined methodologies are critical for maintaining the validity of findings in environmental management research (Silverman, 2020). Secondary data was gathered through document inspections and electronic media, enabling for triangulation and cross-referencing of material from diverse sources to provide a thorough grasp of the research topic (Johnston, 2017). The study's robustness is enhanced by the use of both primary and secondary data sources.

Data analysis**:** The analytical methods used are (1) software development of the Rapfish (Rapid appraisal for fisheries) method named Rapid Appraisal for Kendari Raw Water (RAPS-Kendari Raw Water) through the Multi-Dimensional Scaling (MDS) method to assess the index and status of sustainability of natural resource management for raw water supply in Kendari City, (2) leverage analysis to determine sensitive attributes that affect the sustainability index in each dimension, (3) Monte Carlo analysis is used to estimate the effect of errors at a 95 percent confidence interval. The Monte Carlo index value was compared with the MDS index value. The determination of the stress value and the coefficient of determination (R^2) serve to determine whether or not additional attributes are needed and reflect the accuracy of the dimensions studied with the actual situation. The RAPS-Kendari Raw Water ordination technique using the MDS method is carried out through several stages, namely: (1) determining attributes in each dimension of sustainability and defining them through literature review and field observations. In this study, 41 attributes in 5 dimensions were analyzed, namely 12 attributes of the ecological dimension, 7 attributes of the economic dimension, 7 attributes of the social dimension, 8 attributes of the technological dimension, and attributes of the institutional dimension; (2) Assessment of each attribute on an ordinal scale(scoring) based on the results of field surveys;(3) Ordination analysis with MDS to determine the position of sustainability status in each dimension on the sustainability index scale; (4) Assessing the index and sustainability status in each dimension; (5) Conducting sensitivity analysis (leverage analysis) to determine sensitive variables affecting sustainability; (6) Monte Carlo analysis to take into account the uncertainty dimension (Kavanagh, 2001; Pitcher and David, 2001). In the analysis with MDS, leverage analysis, Monte Carlo analysis, determination of Stress value, and coefficient of determination were also conducted (R^2). The scale of the sustainability index of the system studied has a range of 0 percent - 100 percent, as shown in Table 1.

Leverage analysis in MDS is performed to determine sensitive attributes and interventions or improvements that need to be made. Sensitive attributes are obtained based on the results of the leverage analysis seen in the change in Root Mean Square (RMS) ordination on the x-axis. The greater the change in RMS, the more sensitive the role of the attribute is to improving sustainability status. Monte Carlo analysis was used to estimate the effect of errors at a 95 percent confidence interval. The Monte Carlo index value is compared with the MDS index. The Stress value and the coefficient of determination (R^2) serve to determine whether additional attributes are needed and reflect the accuracy of the dimensions studied with the actual situation. Furthermore, Fauzi and Anna (2021) added that a low S-Stress value indicates a good fit, while a high S-Stress value indicates the opposite. According to Kavanagh and Pitcher (2004), a good model is if the S-Stress value is less than 0.25 (S <0.25), and R^2 is close to 1 (100%).

Table 1. Index categories and sustainability status.

Index Value	Category
0,00 - 25	Poor (Unsustainable)
25,01 - 50	Less (Less Sustainable)
50,01 - 75	Enough (Sustainable Enough)
75,01 - 100	Good (Sustainable)

RESULTS

Ecological dimension sustainability status**:** The results of the analysis using RAPS-Kendari Raw Water on 12 attributes, obtained a sustainability index value for the ecological dimension of 53.33 means that it is quite sustainable (the index lies between the values of 50.00 - 74.99). This sustainability index value shows that the ecological conditions in Konawe Regency are quite good. This shows that the ecological ability of the region to support activities in the region is quite sustainable.

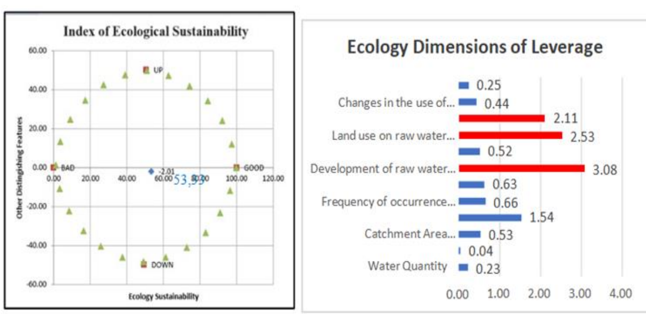

Figure 1. Sustainability Status index and leverage attributes ecological dimension.

Economic dimension sustainability status**:** The results of the analysis using RAPS-Kendari Raw Water on seven attributes obtained a sustainability index value for the economy of 40.48 means less sustainable (the index is located between values 25.00 - 49.99). Based on the leverage analysis of economic attributes obtained 3 (three) attributes that are considered sensitive to the level of sustainability of the economic dimension, namely: 1). PDAM profit level (RMS = 3.24), 2). Labor absorption (RMS = 2.43), and 3). Percentage of poor population (RMS = 2.16). Changes to these three leverage factors will easily affect the increase or decrease in the value of the economic dimension sustainability index. The results of the leverage analysis are presented in Figure 2.

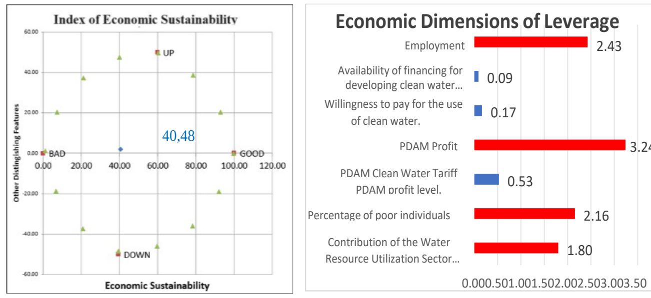

Figure 2. Sustainability status index and leverage attributes economic dimension.

PDAM Tirta Anoa Kendari, as a regional company, must be able to finance its operations and support the Regional Original Revenue (PAD), although it is not fully profit-oriented. The PDAM manages water from five sources, with the Konaweha River as the largest contributor (75%) of the supply. In 2023, the PDAM served 15,378 customers and sold 2,043,180 m³ of water, with the majority used by households (77.71%) (BPS Kota Kendari, 2023). However, the PDAM's profitability is still low, with a significant effect on the economic sustainability of 3.24, indicating the need for improved operational efficiency (Adiyanto *et al.*, 2021). A major challenge for the PDAM is the distribution of water over a large and dispersed area, which requires substantial investment. Labor absorption in PDAM management is also not optimal, with a moderate impact on economic sustainability (score of 2.43). In addition, although only 4% of Kendari residents are categorized as poor, access to clean water is still limited, and the PDAM's services are not considered fully pro-poor (Nur *et al.*, 2018). The PDAM's efforts to improve clean water access should be strengthened with more inclusive management strategies and improved water treatment technologies (Scanlon *et al.*, 2023).

Social dimension sustainability status**:** The results of the analysis using RAPS-Kendari on 7 attributes, obtained a sustainability index value for the social dimension of 41.64 means less sustainable (the index lies between the value of 25.00-49.99). Based on the leverage analysis social attributes obtained 1 (one) attribute that is considered sensitive to the level of sustainability of the social dimension, namely: 1). Community motivation and concern for environmental improvement efforts, forest and land rehabilitation for the preservation of raw water sources (RMS = 4.31). Changes to this leverage factor will easily affect the increase or decrease in the value of the social dimension sustainability index. The results of the leverage analysis are presented in Figure 3.

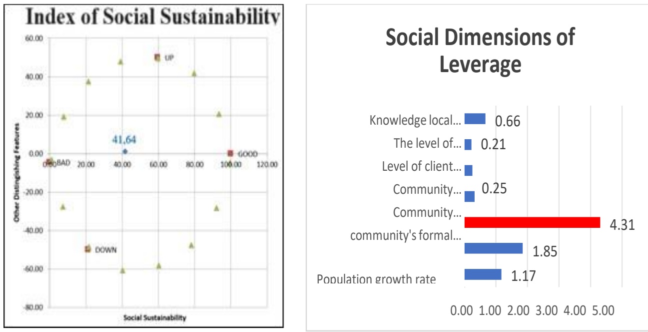

Figure 3. Sustainability status index and leverage attributes social dimension.

Community motivation and concern for forest rehabilitation and preservation of raw water sources are rated low, with a score of 4.31 on the social dimension, indicating that community efforts in preserving water resources are still insignificant. In addition, water pollution in the watershed due to pesticide waste, domestic waste, and illegal mining and logging activities have worsened the condition of the watershed. These activities trigger erosion, landslides, and flooding in the upstream area of the Kanawha River to Kendari City. The level of public concern for environmental improvement and water resources management is still low, exacerbating ecological damage and threatening the sustainability of clean water supply (Scanlon *et al.*, 2023). Therefore, increasing public awareness and land rehabilitation is essential to maintain the sustainability of water sources

***Technology dimension sustainability status*:** The results of the analysis using RAPS-Kendari Raw Water on eight attributes obtained a sustainability index value for the technology dimension of 33.85 means less sustainable (the index is located between values 25.00 and 49.99). Based on the leverage analysis of technological attributes, 5 (five) attributes are considered sensitive to the level of sustainability of the technological dimension, namely: 1). The level of PDAM clean water service (RMS = 4.78), and 2). Drainage conditions in residential areas (RMS = 4.49), 3). Condition of PDAM piping distribution network (RMS = 3.84), 4). Support for clean water supply facilities and infrastructure (RMS = 3.78), and 5). Changes to the 5 leverage factors will easily affect the increase or decrease in the sustainability index value of the technology dimension. The results of the leverage analysis are presented in Figure 4. The level of PDAM clean water services greatly affects the sustainability of water supply in various regions. The analysis shows that PDAM services, particularly PDAM Tirta Anoa in Kendari, are still not optimal, with a technology dimension sustainability score of 4.78. Frequent problems include low water pressure, frequent water jams, and dirty and smelly water quality, which results in customer complaints not being addressed immediately (Adiyanto *et al.*, 2021). Other challenges include high water leakage rates in the pipeline system as well as uneven water flow in different areas. Some PDAMs in other regions show variations in service levels. For example, PDAM Tirta Sejuk in Aceh provides better service with a focus on empathy and responsiveness, while the PDAM in Cirebon is projected to be able to meet only 62.17% of water demand by 2040, despite increasing demand (Ali *et al.*, 2024; Abdurrafiq and Widjajati, 2024). PDAM Lematang Enim in Sumatera reported a customer satisfaction index of 66.14%, although there are still issues related to water quality (Ningsih *et al.*, 2023). The condition of PDAM Tirta Anoa's piping network also has a significant impact on uneven water distribution, with a score of 3.84 for the sustainability dimension of technology. Facilities and infrastructure support are also considered not optimal (score 3.78), which affects the utilization of raw water sources for sustainable water supply (Lestari, 2022). The waste handling technology currently used is not sufficient to overcome pollution in the Konaweha River, which is categorized as lightly polluted based on the Pollution Index (Suriadikusumah *et al.*, 2021). Improving clean water services requires stronger collaboration between local governments, communities, and the private sector, with a focus on improving water treatment infrastructure and technology and real-time monitoring of water quality (Vidyashankar *et al.*, 2024). This is essential to ensure more equitable access to clean water and quality.

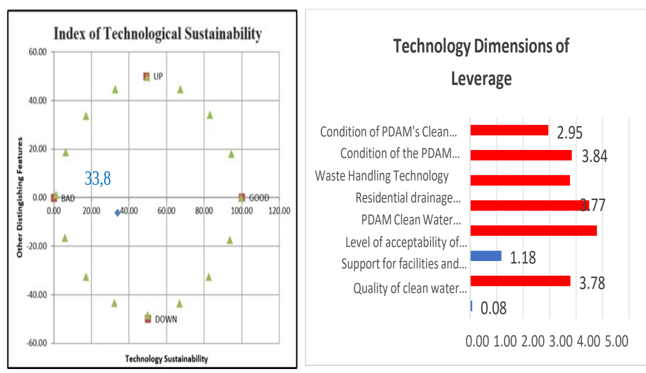

Figure 4. Sustainability status index and leverage attributes technology dimension.

***Institutional Dimension Sustainability Status*:** The results of the analysis using RAPS-Kendari Raw Water on seven attributes, obtained a sustainability index value for the institutional dimension of54.48, meaning that it is quite sustainable (the index lies between the values of 50.00 - 74.99). Based on the leverage analysis of institutional attributes, 2 (two) attributes are considered sensitive to the level of sustainability of the institutional dimension, namely: 1). Clean water management regime (RMS = 10.23), and 2). Availability of laws and regulations on water resources management, especially at the district/city level (RMS = 5.88). Changes to these two leverage factors will easily affect the increase or decrease in the sustainability index value of the institutional dimension. The results of the leverage analysis are presented in Figure 5.

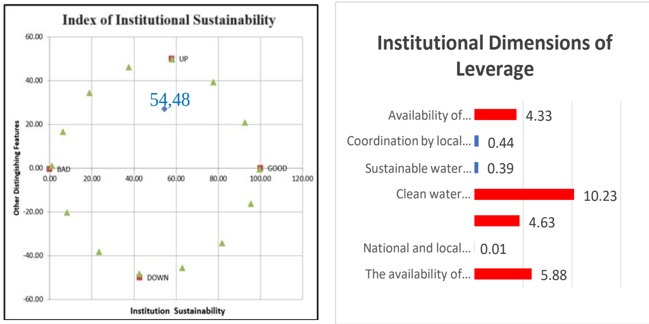

Figure 5. Sustainability status index and leverage attributes institutional dimension.

The water management regime of PDAMs, such as PDAM Tirta Anoa in Kendari City plays an important role in social and economic functions. On the social side, PDAMs are responsible for providing drinking water to the community to improve quality of life and health. On the economic side, the PDAM contributes to local revenue and local economic growth, with a service coverage target of 80%in Kendari City (BPS Kendari City, 2022). However, the analysis shows that the water management regime is not optimal, with a score of 10.23 on the institutional dimension, indicating that the utilization of raw water sources and service quality still need to be improved (Adiyanto *et al.*, 2021). The availability of laws and regulations is also an important factor in water management. PDAM Tirta Anoa is regulated by Regional Regulations No. 3 and No. 7 of 2010, but these regulations have not fully addressed the main water management issues in Kendari City. A score of 5.88 on the institutional dimension indicates that policies need to be adjusted to meet current challenges, including more sustainable water management (Putuhena, 2022). The sustainability of water supply requires a stronger strategy in terms of regulation and implementation at the district level.

***Sustainability status of raw water management in Kendari City*:** Based on the weighting results of the five dimensions of sustainable raw water management, the sustainability index value of sustainable raw water management in Kendari City is 44.76 (located between 25.00 and 49.99), which means that the status of sustainable raw water management in Kendari City is currently in a less sustainable status. The less sustainable status in the research area is caused by the low value of the sustainability index of the five dimensions assessed. Where the ecological dimension and institutional dimension have moderately sustainable performance, while the other three dimensions, the economic dimension, social dimension, and technological dimension, show less sustainable performance. The weighted index values of the five dimensions are presented in Table 2.

Table 2. Raw water management multidimensional sustainability index values sustainability.

No.	Dimension	Index value Sustainability	Weight value (%)	Value weighted
1	Ecology	53,33	20	10,67
2	Economy	40,48	20	8,10
3	Social	41,64	20	8,33
4	Technology	33,85	20	6,77
5	Institutional	54,48	20	10,90
	Total			44,76

This sustainability index value is the largest obtained from the ecological dimension of 10.67 and then the institutional dimension of 10.90, while the other dimensions are smaller. The ecological dimension is expected to have the ability to provide greater performance so that it can provide greater environmental services in sustainable raw water management in the Konawe District.

***Monte Carlo analysis*:** Considering the results of the Monte Carlo analysis and MDS analysis at the 95% confidence level, it was found that the value of the Sustainability Index for Sustainable Raw Water Management in Kendari City showed a very small difference in the values of the two analyses (0.30%). This means that the resulting MDS analysis model is adequate for estimating the value of the Sustainable Raw Water Management index in the Konawe District. This very small difference in value indicates that errors in the analysis process can be minimized or avoided. Errors caused by scoring each attribute, multidimensional scoring variations due to different opinions are relatively small, the data analysis process that is carried out repeatedly is relatively stable, and errors in inputting data and missing data can be avoided (Fauzi and Anna, 2021). Monte Carlo analysis can also be used as a simulation method to evaluate the impact of random errors in statistical analysis conducted on all dimensions (Kavanagh and Pitcher 2004). The results of the MDS and Monte Carlo analysis are presented in Table 3.

Table 3. Differences in sustainability index between RAPS Kendari (MDS) with Monte Carlo.

No.	Dimensions	Sustainability Index Value (%)		
		MDS	Monte Carlo	(MDS - MC)
1	Ecology	53.33	53.56	0.23
2	Economy	40.48	42.00	1.52
3	Social	41.64	40.97	0.67
4	Technology	33.85	34.08	0.23
5	Institutional	54.48	48.77	5.71

***MDS analysis accuracy test (goodness of fit)*:** From the results of the RAPS-Kendari Raw Water analysis, the coefficient of determination (R^2) is between 92.56% - 95.15% or greater than 80% or close to 100%, meaning that the sustainability index estimation model is good and adequate to

Table 6. Stress Value and Coefficient of Determination (R^2).

No.	Parameters	Ecology	Economy	Social	Technology	Institution
1	Stress Value	0,14	0,15	0,15	0,15	0,14
2	R-value^2	95,15	94,24	94,39	94,70	92,56

use (Kavanagh 2001). The stress value is between 0.14 - 0.15. The coefficient of determination is close to the value of 95-100%, and the stress value is smaller than 25% so that the MDS analysis model obtained has a high accuracy (goodness of fit) to assess the sustainability index of sustainable raw water management in Kendari City/The stress value and coefficient of determination of the RAPS-Kendari Raw Water analysis results are presented in Table 4.

DISCUSSION

The investigation employing the RAPS-Kendari Raw Water model yielded a variety of sustainability indices across multiple domains. The ecological dimension has a sustainability value of 53.33%, which indicates that it is fairly sustainable. This shows that while there are ecological measures in place to promote sustainability, further changes are required to ensure long-term sustainability. Ecological interventions should focus on maintaining water resources and minimizing the consequences of climate change to ensure water availability (Kavanagh 2001).

The economic dimension, with a score of 40.48%, is classified as less sustainable. This reflects economic issues such as insufficient investment in water infrastructure and limited capacity for water services to fulfill rising demand. To overcome this, additional financial support and better resource allocation are required to improve the economic viability of water resource management practices. Similarly, the social dimension scored 41.64%, showing that community involvement and awareness remain low. Improving community participation and public education on water conservation may lead to increased engagement in sustainable water practices. Thus, efforts to raise awareness and increase social participation are critical to ensuring the social dimension's long-term viability (Adiyanto *et al.*, 2021). The technological factor had the lowest rating at 33.85%, indicating major technological gaps in water management, such as old infrastructure and a slow adoption of innovative technology. To make water management more effective, there is an obvious need to modernize technology and increase the use of current instruments in water treatment and distribution (Putuhena, 2022).

Finally, the institutional dimension's sustainability index was 54.48%, suggesting modest sustainability. While institutional frameworks exist, strengthening policies and governance for water resource management is critical for improving stakeholder coordination and guaranteeing equitable access to clean water. The kite diagram (Figure 6) depicts the sustainability of each dimension, highlighting the regions where changes are most needed. These findings highlight the importance of focused interventions across all dimensions to improve the overall sustainability of water resource management in Kendari.

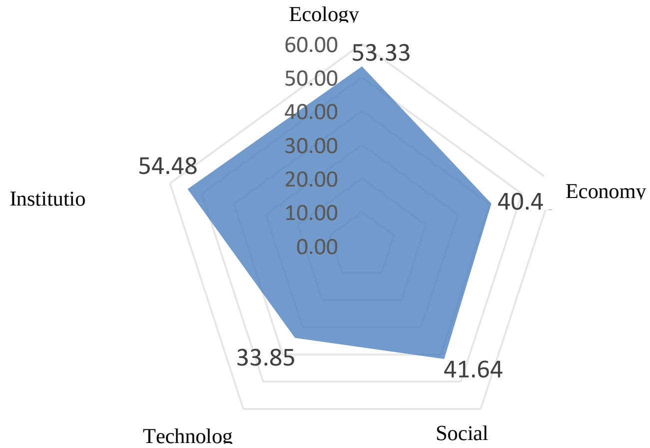

Figure 6. Kite diagram of sustainability index of Konaweha River management for sustainable raw water supply.

***Conclusion*:** Based on the assessment of 41 attributes from five dimensions (ecological, economic, social, institutional, and technological) of raw water management in Kendari City, the sustainability index is 44.76, indicating a "less sustainable" status. The ecological and institutional dimensions show moderately sustainable performance, while the economic, social, and technological dimensions are less sustainable. Leverage factors show that 14 leverage attributes affect sustainability, including attributes in the ecological dimension such as raw water source development and land use change. Attributes in the economic dimension include the PDAM's profitability and employment, while only one attribute in the social dimension relates to community motivation. In the technological dimension, attributes such as the condition of the pipeline network and waste technology play an important role. The water management regime and the availability of regulations are key to the institutional dimension. To improve the sustainability index, policy interventions and improved performance of leverage attributes are required. Further research should look into climate change adaptation measures that can make water management systems more adaptable to changing weather patterns, particularly in regions like Kendari. Investigating technological improvements, such as smart water systems and enhanced waste treatment, may improve the technological dimension of sustainability. Furthermore, research into effective community involvement strategies could help boost public participation in water conservation, hence increasing the social dimension. Research on the performance of current policies and regulatory frameworks could help discover opportunities for improving institutional sustainability. Finally, assessing the economic viability of sustainable practices, particularly their impact on profitability and job creation, would provide useful insights into improving the economic aspects of water management.

***Authors' contributions*:** Darwin Ismail designed and prepared the draft, Muhammad Zamrun Firihu, La Ode Safuan, Armid reviewed and finalized the draft

***Conflict of Interest*:** The authors declare no conflict of interest.

***Ethical statement*:** This article does not contain any studies regarding human or

Animal.

***Availability of data and material*:** We declare that the submitted manuscript is our work,

which has not been published before and is not currently being considered for publication elsewhere?

***Code Availability*:** Not applicable

***Consent to participate*:** All authors participated in this research study.

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***SDGs addressed*:** Clean Water and Sanitation.

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