Comparative Performance Assessment of Urban Flood Pump Systems in Coastal Cities: A Statistical Evaluation from Indonesia

Dadang Yahya
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
yahya.2705@gmail.com

M. Bisri
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
mbisri@ub.ac.id

Lily Montarcih Limantara
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
lilymont@ub.ac.id (corresponding author)

Very Dermawan
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
perydera@ub.ac.id

Received: 20 January 2026 | Revised: 12 March 2026, 12 April 2026, and 20 April 2026 | Accepted: 21 April 2026

 DOI: https://doi.org/10.48084/etasr.17664

ABSTRACT

Urban flooding in low-lying coastal cities has been mitigated using pump-based flood control systems. Despite the latter's widespread implementation, systematic and quantitative evaluation of pump system performance integrating technical, operational, maintenance, and institutional dimensions remains limited. This study evaluates and compares the performance of urban flood pump systems in Semarang and Pekalongan, two highly flood-prone coastal cities in Indonesia. A statistical Performance Index (PI) framework was developed by integrating four dimensions of system performance: technical condition, operational management, maintenance practice, and institutional capacity. Data were collected from 20 pump stations through field inspections, structured surveys, and institutional assessments. The results indicate that the average PI reached 0.902 in Semarang and 0.996 in Pekalongan, suggesting higher operational reliability of the pump system in Pekalongan. Correlation analysis shows that the technical dimension exhibits the strongest relationship with the PI (r = 0.925), followed by institutional (r = 0.850) and maintenance aspects (r = 0.778), while operational factors show relatively weaker influence (r = 0.628). Variance contribution analysis further indicates that technical factors account for 38.82% and 79.30% of the performance variability in Semarang and Pekalongan, respectively. These findings highlight the significant role of infrastructure condition and institutional capacity in determining the effectiveness of urban flood pump systems. The proposed statistical evaluation framework provides a practical tool for performance assessment and supports evidence-based decision-making for improving urban flood management in coastal cities.

Keywords-flood control pump; performance index; urban flood management; statistical analysis; coastal cities; infrastructure resilience

I. INTRODUCTION

Urban flooding has become one of the most significant environmental and infrastructure challenges faced by modern cities. Rapid urbanization, land-use change, and increasing rainfall intensity associated with climate change have significantly increased flood risk in many urban areas worldwide [1, 2]. The expansion of impervious surfaces reduces natural infiltration and increases surface runoff, resulting in higher peak discharge and greater pressure on urban drainage systems [3, 4]. As a consequence, many urban drainage networks frequently experience capacity limitations, leading to recurring inundation and disruption of socio-economic activities.

In low-lying and coastal cities, gravity-based drainage systems are often insufficient to discharge excess runoff because downstream water levels in rivers or coastal waters may exceed the elevation of urban drainage outlets [5]. Under these conditions, pumping stations are significant components of urban flood control infrastructure. Pumping systems function to transfer excess water from urban catchments to receiving water bodies when gravitational flow is no longer effective, thereby reducing flood risk and improving drainage system performance [6, 7]. Thus, the operational reliability and performance of pumping stations contribute to maintaining the functionality of urban flood mitigation systems. [8, 9]

Methods for improving the operational efficiency of urban pumping stations have been investigated. Operational strategies that consider downstream water levels have been shown to significantly reduce flooding in urban drainage systems [9]. Similarly, intelligent real-time control systems have been proposed to optimize pump operation and enhance system responsiveness during extreme rainfall events [10]. Optimization-based approaches for pump operation and river diversion systems have been introduced to improve stormwater management and reduce flood impacts in urban environments [11, 12]. These approaches highlight the growing importance of advanced operational strategies in improving the effectiveness of urban flood control infrastructure.

In addition to operational optimization, evaluating the overall performance of flood control-infrastructure has become increasingly important for sustainable urban water management. Infrastructure performance assessment enables decision-makers to systematically evaluate the effectiveness of flood mitigation systems based on multiple criteria, including technical performance, operational reliability, maintenance conditions, and institutional management capacity [13]. Performance Index (PI) models have also been applied to evaluate water infrastructure systems because they allow the integration of multiple indicators into a comprehensive assessment framework, enabling more systematic and objective evaluation of system effectiveness [14].

Multi-Criteria Decision-Making (MCDM) approaches have been widely applied in engineering and infrastructure management to support complex decision processes involving multiple indicators. MCDM methods allow the integration of technical, environmental, and managerial factors into a unified evaluation framework, enabling more systematic performance assessment and decision support [15]. Advanced hybrid approaches that combine optimization techniques with MCDM methods have been introduced to improve ranking stability and decision accuracy in engineering applications [16-18]. These developments demonstrate the substantial role of analytical decision-support frameworks in infrastructure evaluation and planning.

Despite these advances, the selection of weighting methods remains a significant methodological issue in multi-criteria evaluation. Expert-based weighting techniques, such as the Analytic Hierarchy Process (AHP), may introduce subjectivity due to reliance on expert judgment, while data-driven approaches, such as entropy weighting, require large and consistent datasets. In contrast, equal weighting provides a transparent and reproducible baseline aggregation method for aggregating multiple indicators. This approach minimizes potential bias in the weighting process and ensures reproducibility of results. Furthermore, equal weighting can serve as a reference benchmark that enables comparison with more advanced MCDM weighting methods in future research.

In the Indonesian context, pumping stations have been widely used as part of urban flood control systems in several flood-prone cities [19, 20] such as Semarang, Pekalongan, Palembang, and Dumai. The role of pumping systems in mitigating urban flooding and improving drainage system performance has been examined [21, 22]. Government reports also indicate that the effectiveness of pumping infrastructure depends not only on pump capacity but also on operational management, maintenance practices, and institutional coordination among responsible agencies. [23] However, systematic frameworks that integrate these multiple dimensions into a comprehensive performance evaluation model are limited.

Furthermore, the impacts of climate change and extreme rainfall events highlight the importance of strengthening urban infrastructure resilience. Flood control infrastructure, such as pumping stations, plays a crucial role in supporting climate adaptation strategies and improving the reliability of urban drainage systems [1, 2]. A structured performance evaluation framework can therefore support decision-makers in identifying system weaknesses, prioritizing infrastructure improvements, and enhancing the long-term sustainability of urban flood management systems.

Although many studies have focused on hydraulic modeling, operational optimization, and intelligent control systems for pumping stations, limited research has addressed integrated performance assessment frameworks that integrate technical, operational, maintenance, and institutional dimensions simultaneously, particularly in the context of urban flood control systems in developing countries. In addition, many existing evaluation approaches rely on complex weighting techniques that may introduce subjectivity or require extensive datasets. Therefore, there is a need for a transparent and reproducible baseline framework that can evaluate pumping system performance while allowing future integration with more advanced decision-support methods.

Based on the identified research gap, this study develops and applies a comprehensive performance assessment framework for urban flood control pumping systems by integrating technical, operational, maintenance, and institutional indicators. The study adopts an equal-weighting aggregation method as a transparent baseline approach for multi-criteria performance evaluation. The main contributions of this research are: (i) developing a multi-dimensional performance assessment framework for urban flood control pumping systems, (ii) applying a transparent equal-weighting aggregation approach as a baseline method for infrastructure performance evaluation, and (iii) providing empirical insights into the performance of urban pumping systems in Indonesian cities. In addition, the results of this study will support decision-makers in improving the reliability, sustainability, and climate resilience of urban flood management infrastructure.

II. MATERIALS AND METHODS

A. Study Area and Pump Station Characteristics

This study was conducted in two coastal cities in Central Java, Indonesia: Semarang and Pekalongan. Both cities are located in low-lying coastal zones and are highly vulnerable to flooding caused by tidal inundation, extreme rainfall events, and land subsidence. Semarang has experienced significant land subsidence and increasing flood frequency over the past two decades, while Pekalongan frequently experiences tidal flooding due to its proximity to the coastline and limited gravity drainage capacity. Consequently, both cities rely heavily on pump-based flood control systems as a primary flood mitigation measure.

A total of 20 flood control pump stations were evaluated in this study, consisting of 10 stations in Semarang and 10 stations in Pekalongan. These stations represent the main operational pumping infrastructure used for urban flood mitigation. Instead of selecting a statistical sample, this study evaluated the entire population of operational pump stations in the study areas to ensure comprehensive system representation. The pump stations vary in pump capacity, operational age, physical condition, and management structure. The systems include both electric and fuel-powered pumps with capacities ranging from 250 L/s to 5000 L/s, serving significant urban areas, including residential, industrial, and commercial zones. The geographical locations of the evaluated pump stations are presented in Figures 1 and 2, while the technical characteristics of the pump stations are summarized in Table I.

B. Data Collection Procedure

Data collection was conducted between May and August 2024 across 20 pumping stations. At each station, 2-3 operators and maintenance staff were interviewed, resulting in 45 respondents in total, through a combination of field surveys, technical inspections, structured interviews, and document review. Field observation indicated sediment accumulation ranging between 15 and 35 cm in intake channels, reducing the hydraulic efficiency of several pumping stations in Semarang. Field surveys were carried out to assess the physical condition, operational readiness, and maintenance status of each pump station. Technical inspections included evaluation of pump functionality, mechanical components, electrical systems, inlet–outlet structures, and supporting infrastructure.

Structured interviews were conducted with 40 respondents, consisting of pump operators, maintenance personnel, and technical supervisors responsible for daily pump operation and management. Each pump station was represented by two technical respondents (operator and supervisor), ensuring adequate representation of operational knowledge. Additional technical and institutional data were obtained from operational logs, maintenance records, and infrastructure management reports provided by the Public Works and Housing Departments of Semarang and Pekalongan. These data were used to validate field observations and ensure assessment reliability.

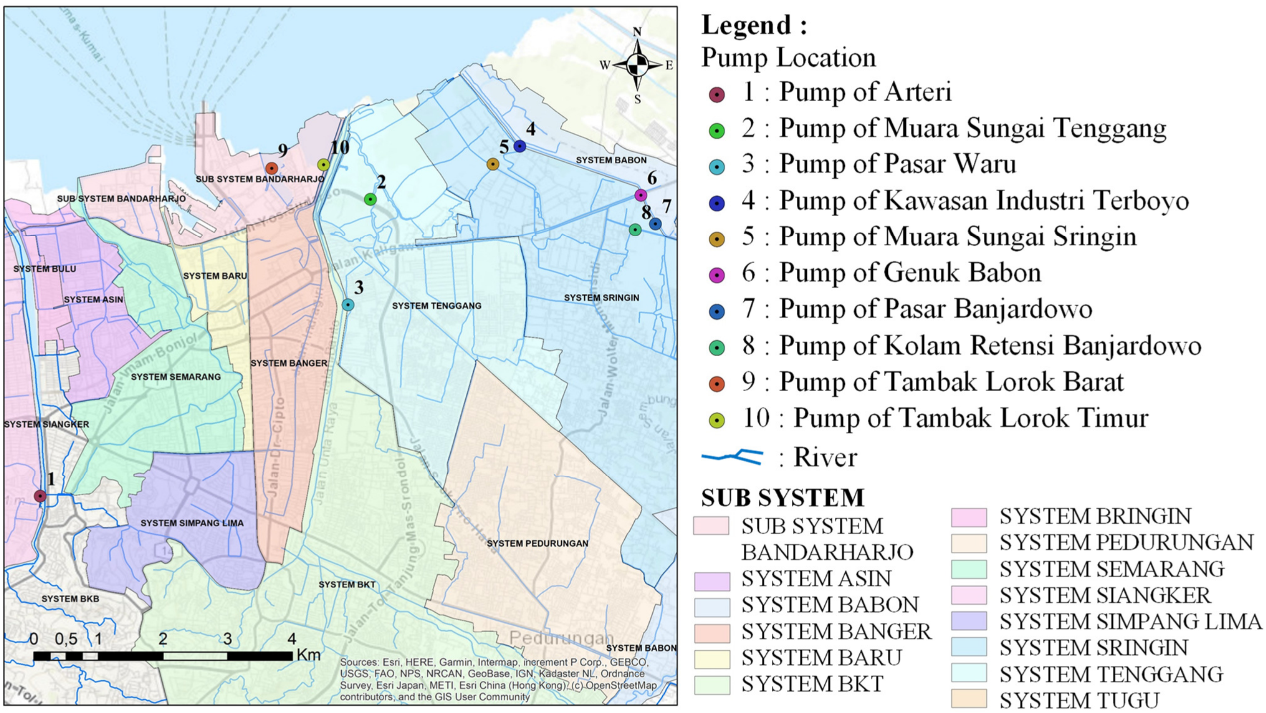

Fig. 1. Pumping station location in Semarang City.

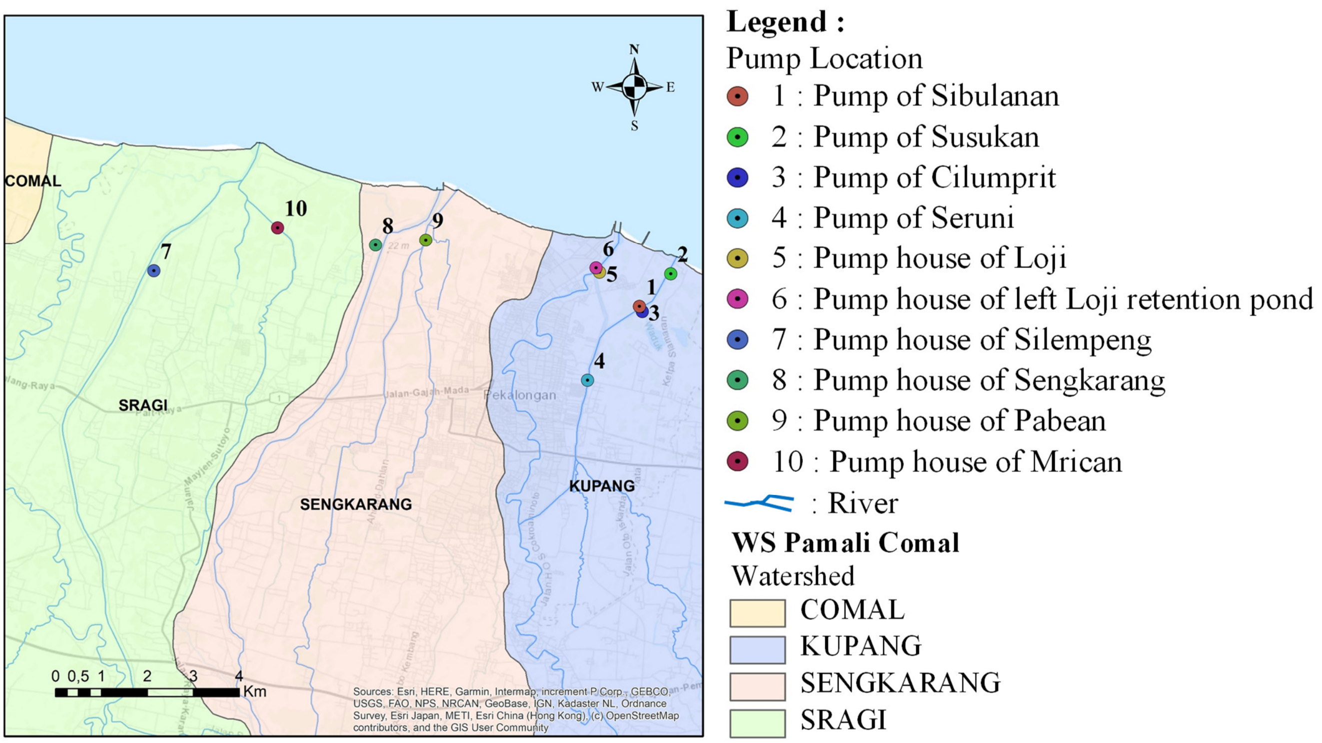

Fig. 2. Pumping station location in Pekalongan City and district.

TABLE I. SUMMARY OF PUMP STATION CHARACTERISTICS IN SEMARANG AND PEKALONGAN

City	Pump station	Units	Capacity (L/s)	Energy	Backup
Semarang	Arteri Kanal Banjir Barat	2	2000	Electric	Yes
Semarang	Muara Sungai Tenggang	6	12000	Fuel	No
Semarang	Pasar Waru	2	4000	Electric	Yes
Semarang	Kawasan Industri Terboyo	2	1000	Electric	Yes
Semarang	Muara Sungai Sringin	5	10000	Fuel	No
Semarang	Genuk–Babon	2	7000	Electric	Yes
Semarang	Pasar Banjardowo	3	3000	Electric	Yes
Semarang	Kolam Retensi Banjardowo	2	500	Electric	Yes
Semarang	Tambak Lorok Barat	3	1500	Electric	Yes
Semarang	Tambak Lorok Timur	3	1500	Electric	Yes
Pekalongan	Sibulanan	3	3500	Electric	Yes
Pekalongan	Susukan	4	5000	Electric	Yes
Pekalongan	Clumprit	4	5000	Electric	Yes
Pekalongan	Seruni	2	1000	Electric	Yes
Pekalongan	Loji	5	18000	Electric	Yes
Pekalongan	Loji Kiri retention pool	2	600	Electric	Yes
Kab. Pekalongan	Silempeng	2	4000	Fuel	No
Kab. Pekalongan	Sengkarang	3	6000	Fuel	No
Kab. Pekalongan	Pabean	2	4000	Fuel	No
Kab. Pekalongan	Mrican	3	6000	Electric	Yes

C. Performance Assessment Framework

The performance of flood control pump systems was evaluated using a multidimensional PI framework integrating four key aspects: (i) technical aspect, (ii) operational aspect, (iii) maintenance aspect, and (iv) institutional aspect. Each aspect consists of several indicators evaluated using a standardized 1–5 scoring scale, as presented in Table II. The scoring criteria were based on infrastructure inspection standards, operational performance indicators, maintenance records, and institutional management characteristics. The assessment was conducted by qualified engineers and verified through field observation and technical documentation to ensure consistency and objectivity. Multidimensional infrastructure performance evaluation frameworks have been widely applied in flood management and urban infrastructure studies to integrate technical and institutional components into a single evaluation index [15, 24, 25].

TABLE II. SCORING SCALE

Score	Description
1	Very poor – non-functional
2	Poor – significant operational issues
3	Fair – functional with limitations
4	Good – minor issues
5	Excellent – fully operational

D. Weighting Method and Equal Weight Justification

To calculate the overall PI, this study applied an equal-weight aggregation approach, where each performance aspect was assigned an identical weight of 0.25. The equal weighting method was selected for several methodological reasons. First, equal weighting provides a neutral baseline assumption when empirical evidence is insufficient to justify differential weighting among performance dimensions. This approach avoids subjective prioritization and ensures methodological transparency. Second, equal weighting is widely used in infrastructure performance evaluation as a reference framework before applying more advanced MCDM techniques. Advanced weighting approaches such as the AHP, entropy weighting, and hybrid optimization models may provide refined weighting structures but often require extensive expert judgment or large datasets [15]. Third, equal weighting ensures comparability and reproducibility of the PI across multiple infrastructure systems. This baseline approach enables future studies to compare results with alternative weighting schemes or optimization-based frameworks.

Therefore, equal weighting in this study serves as a transparent and scientifically valid baseline method for evaluating multidimensional pump system performance.

E. Performance Index Calculation

The overall PI was calculated using a weighted aggregation of the four performance aspects:

$$PI = \sum_{i=1}^{4} w_i\, S_i$$

where w_i is the weight of aspect i (0.25 for each aspect), and S_i is the score of aspect *i*. The resulting index was normalized to allow comparison across pump stations and between cities.

F. Statistical Analysis

To strengthen the analytical rigor of the evaluation and identify dominant performance factors, statistical analysis was conducted using three approaches: Descriptive statistical analysis, Correlation analysis, and Variance contribution analysis. Descriptive statistics were used to determine the mean values and standard deviations of each performance dimension and the overall PI. Correlation analysis was performed using the Pearson correlation coefficient to evaluate the relationship between individual performance aspects and the overall PI. This analysis provides insights into the relative influence of each dimension on system performance. Variance contribution analysis was conducted to quantify the proportion of performance variability explained by each dimension. This method enables the identification of dominant performance drivers and provides quantitative insights into system behavior.

The use of statistical evaluation methods enhances the methodological robustness of infrastructure performance assessment by moving beyond descriptive evaluation toward quantitative performance analysis [26, 27].

III. RESULTS AND DISCUSSION

A. Comparative Performance of Flood Control Pump Systems

The comparative evaluation of flood control pumping systems in Semarang and Pekalongan shows measurable differences in overall infrastructure performance. The comparison of the average performance scores across the four evaluated dimensions is displayed in Tables III and IV. The results indicate that Pekalongan demonstrates higher overall system performance compared with Semarang. The higher average score reflects stronger technical reliability, more consistent maintenance practices, and better institutional coordination. Although Semarang operates a larger number of pump stations, infrastructure capacity alone does not necessarily guarantee higher performance.

Urban flood control infrastructure is a socio-technical system, where engineering infrastructure interacts with operational management and governance structures. The effectiveness of flood mitigation systems depends not only on technical infrastructure but also on institutional coordination and maintenance management [19, 20].

B. Descriptive Statistical Analysis

Descriptive statistical analysis was conducted to evaluate the distribution and variability of performance indicators across pump stations. Pekalongan shows consistently higher mean values in most performance indicators.

TABLE III. PERFORMANCE COMPARISON ACROSS THE FOUR EVALUATED DIMENSIONS

City	Number of pumps	Technical	Operational	Maintenance	Institutional	Average score
Semarang	10	0.998	0.988	0.839	0.782	3.65
Pekalongan	10	1.171	1.065	0.887	0.860	4.00

TABLE IV. DESCRIPTIVE STATISTICS BY CITY

City	Technical (mean)	Technical (Std)	Operational (mean)	Maintenance (mean)	Institutional (mean)	PI (mean)	PI (Std)
Semarang	0.998	0.152	0.988	0.839	0.782	0.902	0.07
Pekalongan	1.171	0.074	1.065	0.887	0.860	0.996	0.02

The technical dimension, which reflects pump condition and mechanical reliability, is significantly higher in Pekalongan. Institutional performance also demonstrates noticeable differences, suggesting stronger coordination among infrastructure management agencies. Another important observation is the variability of performance. The standard deviation of the PI in Semarang is higher than in Pekalongan, indicating greater heterogeneity among pump stations. This variability may be associated with differences in infrastructure age, maintenance practices, and operational management.

Infrastructure asset management studies highlight that inconsistent maintenance regimes often lead to performance disparities across infrastructure systems [26, 27]. The relatively low variability observed in Pekalongan suggests more standardized operational and maintenance practices.

C. Correlation Analysis of Performance Dimensions

To identify the dominant factors influencing overall performance, correlation analysis was conducted between each performance dimension and the PI. The results of the correlation analysis are outlined in Table V.

TABLE V. CORRELATION WITH PI

Performance dimension	Correlation coefficient
Technical	0.925
Operational	0.628
Maintenance	0.778
Institutional	0.850

The analysis indicates that the technical dimension has the strongest correlation with the overall PI, highlighting the importance of pump reliability, mechanical condition, and hydraulic capacity in determining flood control effectiveness. Institutional performance also shows a strong positive correlation with the overall index. This finding emphasizes the role of governance capacity, coordination among operational personnel, and effective resource allocation in maintaining infrastructure functionality. Maintenance performance demonstrates a strong relationship with system performance. Preventive maintenance practices are essential strategies for maintaining infrastructure reliability and extending asset service life [27]. Finally, the operational dimension shows a moderate correlation with system performance. This may indicate that operational procedures are relatively standardized across the evaluated pump stations.

D. Performance Structure and Infrastructure Management Implications

Variance contribution analysis was conducted to quantify the relative influence of each dimension on the variability of the PI. The results are illustrated in Table VI.

TABLE VI. VARIANCE CONTRIBUTION TO PI (%)

Dimension	Semarang	Pekalongan
Technical	38.82	79.30
Operational	2.620	0.000
Maintenance	36.02	20.70
Institutional	22.54	0.000

The results reveal different performance structures between the two cities. In Pekalongan, technical factors dominate system performance, indicating that infrastructure reliability is the primary determinant of flood control effectiveness. In contrast, Semarang shows a more balanced contribution between technical, maintenance, and institutional factors. This suggests that system improvements in Semarang should focus on integrated strategies combining infrastructure rehabilitation, improved maintenance practices, and stronger institutional coordination.

The equal-weight aggregation approach used in this study provides a transparent baseline for evaluating multidimensional infrastructure performance. Since each dimension contributes meaningfully to the overall index, equal weighting minimizes subjective bias that may arise from expert-based weighting methods. Baseline approaches such as this are commonly used before applying more advanced MCDM methods [15]. From a broader perspective, the proposed evaluation framework can support decision-makers in improving the reliability and adaptive capacity of urban flood management systems, particularly in coastal cities experiencing increasing flood risks due to climate change and rapid urbanization [3].

Figure 3 depicts the comparative structure of pump system performance in Semarang and Pekalongan. The radar diagram shows that Pekalongan consistently achieves higher scores across all performance dimensions, particularly in the technical and institutional aspects. In contrast, Semarang demonstrates a more balanced distribution between technical and maintenance factors. This visual representation supports the statistical results presented in Tables III–V and highlights the multidimensional nature of flood pump system performance.

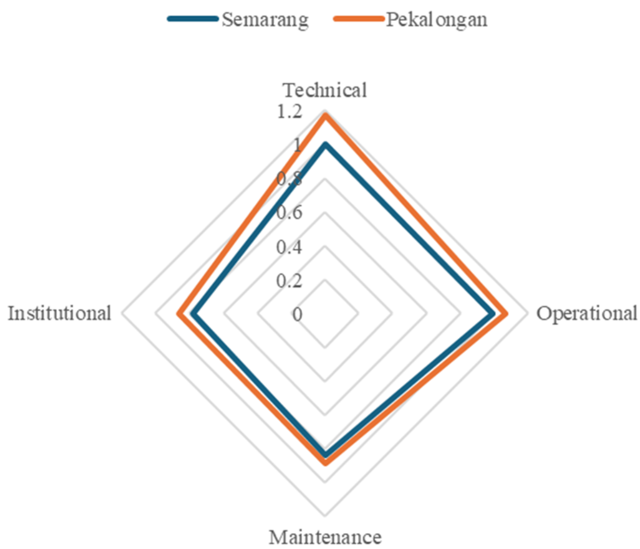

Fig. 3. Radar comparison of flood pump system performance dimensions in Semarang and Pekalongan.

IV. CONCLUSION

This study developed and applied a multidimensional performance evaluation framework for assessing flood control pumping systems in coastal urban areas. The framework integrates four key dimensions—technical, operational, maintenance, and institutional aspects—into a single Performance Index (PI) using an equal-weight aggregation approach. The results show that the overall performance of flood pump systems in Pekalongan is slightly higher than in Semarang, indicating stronger system reliability and more consistent operational management.

Statistical analysis revealed that the technical dimension is the dominant factor influencing overall system performance, followed by institutional and maintenance factors. Correlation and variance contribution analyses demonstrate that infrastructure reliability and effective governance structures play important roles in maintaining flood control system functionality. The higher variability observed in Semarang suggests that system performance is influenced not only by infrastructure condition but also by maintenance practices and institutional coordination. The equal-weight aggregation method adopted in this study provides a transparent and reproducible baseline framework for multidimensional infrastructure performance evaluation. While more advanced Multi-Criteria Decision-Making (MCDM) approaches may offer refined weighting structures, the baseline framework enables consistent comparison across infrastructure systems while minimizing subjective bias.

The proposed evaluation framework provides practical insights for improving the reliability and adaptive capacity of urban flood control infrastructure. As coastal cities face flood risks due to climate change, land subsidence, and rapid urbanization, systematic performance assessment of pumping systems can support more effective infrastructure management and contribute to sustainable urban flood resilience strategies [14].

Future research may extend this framework by integrating optimization-based MCDM methods and incorporating energy efficiency and operational cost analysis to further enhance decision support for urban flood infrastructure management.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflicts of interest.

ACKNOWLEDGMENT

Not applicable to this work

DATA AVAILABILITY

The considered and acquired data are described within the paper.

REFERENCES

[1] J. D. Miller and M. Hutchins, "The Impacts of Urbanisation and Climate Change on Urban Flooding and Urban Water Quality: A Review of the Evidence Concerning the United Kingdom," *Journal of Hydrology: Regional Studies*, vol. 12, pp. 345–362, Aug. 2017, https://doi.org/10.1016/j.ejrh.2017.06.006.

[2] Z. W. Kundzewicz *et al.*, "Flood Risk and Climate Change: Global and Regional Perspectives," *Hydrological Sciences Journal*, vol. 59, no. 1, pp. 1–28, Jan. 2014, https://doi.org/10.1080/02626667.2013.857411.

[3] T. D. Fletcher, H. Andrieu, and P. Hamel, "Understanding, Management, and Modelling of Urban Hydrology and Its Consequences for Receiving Waters: A State of the Art," *Advances in Water Resources*, vol. 51, pp. 261–279, Jan. 2013, https://doi.org/10.1016/j.advwatres.2012.09.001.

[4] Z. Ling, Y. Jing, M. Aqeel, F. Siddiqa, L. Yan, and M. Wenlong, "Urban Flood Modeling and Mitigation Strategies Using Remote Sensing and GIS," *Scholars Journal of Engineering and Technology*, vol. 13, no. 07, pp. 535–551, Jul. 2025, https://doi.org/10.36347/sjet.2025.v13i07.007.

[5] F. Bakhtiar and S. I. Wahyudi, "Studi Kasus Pemodelan Operasi Pompa Banjir Kawasan Jl. Madukoro Kota Semarang," *Pondasi*, vol. 29, no. 2, Dec. 2024, https://doi.org/10.30659/pondasi.v29i2.39821.

[6] C. Zevenbergen, A. Cashman, N. Evelpidou, E. Pasche, S. Garvin, and R. Ashley, *Urban Flood Management*, Boca Raton, FL, USA: CRC Press, 2010.

[7] D. Butler and J. W. Davies, *Urban Drainage*, 2nd ed. London, UK: Spon Press, 2004.

[8] K. Kuno and T. Suzuki, "Availability of CSO Control and Flood Control of Real-Time Control System in Urban Pumping Station," *Proceedings of the Water Environment Federation*, vol. 2009, no. 13, pp. 3347–3364, Jan. 2009, https://doi.org/10.2175/193864709793953160.

[9] N.-S. Hsu, C.-L. Huang, and C.-C. Wei, "Intelligent Real-time Operation of a Pumping Station for an Urban Drainage System," *Journal of Hydrology*, vol. 489, pp. 85–97, May 2013, https://doi.org/10.1016/j.jhydrol.2013.02.047.

[10] C.-C. Wei, N.-S. Hsu, and C.-L. Huang, "Two-Stage Pumping Control Model for Flood Mitigation in Inundated Urban Drainage Basins," *Water Resources Management*, vol. 28, no. 2, pp. 425–444, Jan. 2014, https://doi.org/10.1007/s11269-013-0491-0.

[11] J. Yazdi and J. H. Kim, "Intelligent Pump Operation and River Diversion Systems for Urban Storm Management," *Journal of Hydrologic Engineering*, vol. 20, no. 11, Nov. 2015, Art. no. 04015031, https://doi.org/10.1061/(ASCE)HE.1943-5584.0001226.

[12] J. Yazdi, H. S. Choi, and J. H. Kim, "A Methodology for Optimal Operation of Pumping Stations in Urban Drainage Systems," *Journal of Hydro-environment Research*, vol. 11, pp. 101–112, Jun. 2016, https://doi.org/10.1016/j.jher.2015.09.001.

[13] J. M. Andrić and J. Wang, "Measuring the sustainability performance of infrastructure projects under the Belt and Road Initiative," *KSCE Journal of Civil Engineering*, vol. 30, no. 1, Jan. 2026, Art. no. 100294, https://doi.org/10.1016/j.kscej.2025.100294.

[14] A. D. Trimartinni, L. M. Limantara, P. T. Juwono, and H. Siswoyo, "Development of Performance Index Model for Assessing the Multipurpose Reservoir Storage Capacity," *Civil Engineering and Architecture*, vol. 13, no. 1, pp. 105–117, Jan. 2025, https://doi.org/10.13189/cea.2025.130106.

[15] N. T. Mai, "Hybrid Multi-Criteria Decision-Making Methods: Combination of Preference Selection Index Method with Faire Un Choix Adèquat, Root Assessment Method, and Proximity Indexed Value," *Engineering, Technology & Applied Science Research*, vol. 15, no. 1, pp. 19086–19090, Feb. 2025, https://doi.org/10.48084/etasr.9235.

[16] B. T. T. Trang, D. D. Trung, and R. Turmanidze, "A Novel Approach for Criteria Weighting to Enhance Ranking Stability of Alternatives for Industrial Equipment and Material Selection," *Advanced Engineering Letters*, vol. 4, no. 3, pp. 118–133, 2025, https://doi.org/10.46793/adeletters.2025.4.3.2.

[17] D. Duc Trung, H. T. Dung, N. C. Bao, and D. Van Duc, "A Novel Approach for Determining Criteria Weights: Application in Ranking Materials for Mechanical Manufacturing Processes," *Manufacturing Review*, vol. 12, 2025, Art. no. 16, https://doi.org/10.1051/mfreview/2025014.

[18] D. D. Trung, M. Özçalıcı, N. Ersoy, D. V. Duc, N. C. Bao, and N. H. Son, "SIWEC-R: A Rank-Sensitive Improvement to SIWEC Methodology," *Teknomekanik*, vol. 8, no. 2, pp. 183–210, Dec. 2025, https://doi.org/10.24036/teknomekanik.v8i2.40172.

[19] *Performance Evaluation Document for the Northern and Eastern Pump Houses*. Pekalongan City, Indonesia: Public Works and Public Housing Agency of Pekalongan City, 2023.

[20] Operation and Maintenance Report of the Semarang City Flood Control Pump System. Jakarta, Indonesia: Ministry of Public Works, 2023.

[21] R. Fauziah, S. Siswanto, and M. Fauzi, "Pengendalian banjir menggunakan pompa (Studi kasus: drainase Jl Simpang Tetap Kota Dumai)," *JOM FTEKNIK UNRI*, vol. 2, 2015.

[22] H. Gunawan, A. Saggaf, and. Sarino., "Kajian Penanganan Banjir Dengan Sistem Pompa di Sungai Bendung, Kota Palembang," *Jurnal Sumber Daya Air*, vol. 17, no. 1, pp. 49–58, May 2021, https://doi.org/10.32679/jsda.v17i1.684.

[23] "Circular Letter of the Director General," Ministry of Public Works and Housing, Jakarta, Indonesia, Technical Report 05/SE/D/2016, Jun. 2016.

[24] F. W. Geels, "From Sectoral Systems of Innovation to Socio-Technical Systems," *Research Policy*, vol. 33, no. 6–7, pp. 897–920, Sep. 2004, https://doi.org/10.1016/j.respol.2004.01.015.

[25] J. Markard, R. Raven, and B. Truffer, "Sustainability Transitions: An Emerging Field of Research and Its Prospects," *Research Policy*, vol. 41, no. 6, pp. 955–967, Jul. 2012, https://doi.org/10.1016/j.respol.2012.02.013.

[26] G. Kabir, S. Tesfamariam, A. Francisque, and R. Sadiq, "Evaluating Risk of Water Mains Failure Using a Bayesian Belief Network Model," *European Journal of Operational Research*, vol. 240, no. 1, pp. 220–234, Jan. 2015, https://doi.org/10.1016/j.ejor.2014.06.033.

[27] P. Ferrans, M. N. Torres, J. Temprano, and J. P. Rodríguez Sánchez, "Sustainable Urban Drainage System (SUDS) Modeling Supporting Decision-Making: A Systematic Quantitative Review," *Science of The Total Environment*, vol. 806, Feb. 2022, Art. no. 150447, https://doi.org/10.1016/j.scitotenv.2021.150447.