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Mobile Application Development for Waste Management System with K-Means Clustering of Waste Collection Points in Jonggol and Sukamakmur Sub-Districts, Bogor Regency

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Abstract: The disparity in the distribution of Temporary Disposal Sites (TPS) within Jonggol and Sukamakmur Districts of Bogor Regency results in inefficiencies in waste collection services, increases travel times, and creates an unequal operational burden on collection fleets. There is no mobile-based digital platform for residents to report TPS conditions in real-time, which further delays responses to waste management. The lack of interactive digital map visualization makes it hard for local sanitation managers to make informed decisions about space. A mobile waste management information system was created using Flutter and Firebase, with the K-Means algorithm used to cluster TPS locations based on their spatial coordinates. The clustering results are presented as an interactive digital map that is integrated with the Google Maps API; this application allows residents to input TPS condition reports, upload visual evidence, and receive notifications about the status in real-time. This project is an extension of our previous web-based work done during the practical internship (KKP) phase but has a larger scope due to a more advanced spatial approach integrated into mobile devices. The system will optimize the distribution efficiency of waste collection services while assisting spatial decision-making processes as well as motivating active participation from residents in maintaining their environment particularly within Jonggol and Sukamakmur Districts under Bogor Regency's smart city program initiatives.

Keywords: K-Means; Flutter; Firebase; Google Maps API; Clustering; Waste Management; Bogor City.

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1. Introduction

Waste is one of the biggest environmental problems in cities and towns of developing countries. More people and more activities in the community cause a big increase in waste, putting huge stress on the current infrastructure. The fast growth of cities, especially around important urban areas, makes complex waste management situations that need new ideas to solve them [1]. Waste management issues relate not only to environmental quality but also to public health, city beauty, and the running efficiency of public services. Bad waste management causes soil and water pollution, spreads diseases, and lowers community living standards. At the same time, the distribution and placement of Temporary Disposal Sites (TPS) across Jonggol and Sukamakmur Districts in Bogor Regency are still not optimal and unevenly spread [2]. These conditions lead to inefficiency in the process of waste collection, create an imbalance in workload among regions, and increase the operational cost as well as time required for such activities.

The geographic spread of TPS locations has a direct relationship with the effectiveness of waste collection operations. If disposal sites are found within certain areas while others remain underserved, collection vehicles will have to cover longer distances requiring more fuel and time [3]. Collection crews will experience uneven workload distribution where some teams become overwhelmed while others remain underutilized. People living far from TPS often use inappropriate methods to dispose their wastes such as illegal dumping or open burning that increase environmental hazards as well as health risks. The lack of spatial systems to support strategic TPS site selection makes the situation worse [4]. Local sanitation managers do not have real-time mapping of TPS conditions, leading to delayed and uncoordinated responses to field problems. Managers are unable to efficiently allocate resources or prioritize interventions without precise, up-to-date information on TPS capacity, overflow status, or maintenance needs. Accurate spatial data and responsive reporting systems are necessary for improving the quality of waste management services.

Previous studies have shown that spatial data approaches can use the K-Means algorithm to cluster TPS locations in order to improve public service efficiency. K-Means is effective at grouping data based on geographic proximity; hence, it can be used for optimizing the distribution of public facilities [5]. The algorithm creates partitions in which each point belongs to the cluster with its centroid closest among a set of points; therefore, this makes it appropriate for identifying patterns related to spatial distributions [6]. Researchers have successfully applied K-Means clustering in different urban planning scenarios such as facility location optimization, service area delineation, and resource allocation strategies. Nugraha *et al.* (2025) demonstrated that K-Means clustering could optimize waste management through effective grouping models [7]. Salsabila and Ridwan (2024) analyzed waste distribution volume in Karawang using K-Means clustering, showing its effectiveness in identifying spatial patterns [8]. The algorithm is computationally efficient and easy to implement, making it very appealing especially in municipal applications where decision-makers require results that are immediately actionable without needing extensive technical expertise.

Most clustering-based system deployments have been limited to desktop or web applications and have never been integrated into mobile systems that would allow more public access. Though desktop and web solutions can assist with administrative tasks, they do not help in the direct involvement of citizens or the collection of data from the field [9]. Even those studies that use machine learning for route optimization or waste volume prediction were able to develop systems without any participatory or real-time features [10][11]. These are precisely the limitations that deprive communities of efficient channels through which they could report TPS conditions and managers from direct field situation observation [12]. The lack of citizen engagement mechanisms is a missed opportunity; residents carry critical local knowledge about waste accumulation patterns, illegal dumping sites, and gaps in service that official monitoring might miss. Bonino *et al.* (2016) emphasized that smarter waste recycling requires active participation from smart citizens through accessible platforms 0. A review of waste management literature found very few studies that bring together spatial analysis, community participation, and interactive visualization into one system. Most research has been conducted separately on technical optimization or policy analysis or community behavior without connecting these areas. This gap suggests a need for systems that can do spatial analysis while actively involving communities in waste management processes [14]. Current mobile technology presents great opportunities to bridge the gap between technical systems and citizen participation by creating two-way communication paths for both managers and residents.

This research is a continuation of previous work from the Practical Internship (KKP) phase, which developed a web-based monitoring system for TPS in the Sukamakmur tourism area [15]. The web-based system is capable of monitoring activities but does not support mobile access and reporting by citizens. Therefore, this development will expand the scope of the research by developing a mobile-based system to report the condition of TPS directly from the community in Jonggol and Sukamakmur Districts. Through this application, citizens can take photos of full containers, report damage to facilities, and check the status of their reports using their smartphones, similar to approaches used in Android-based garbage management applications [16][17]. This system will cluster TPS locations using the K-Means algorithm and visualize them

spatially using Google Maps API. Resmi *et al.* (2021) demonstrated that combining geotagging with K-Means clustering enables effective solid waste tracking and route optimization [18]. By integrating mobile-based systems, cloud computing using Firebase, and interactive map visualization, this study aims to develop a waste management ecosystem that is more responsive and participatory. With this approach, it is hoped that this system can improve the distribution efficiency of waste collection services, support spatial-based decision-making, and encourage the active participation of the community in waste management in line with Indonesia's vision for sustainable smart city development [19]. By involving citizens as active participants instead of passive recipients of services, this system can create a sense of shared responsibility for environmental quality among citizens while providing managers with real-time intelligence to improve their operations.

2. Related Work

2.1 Spatial-Based Waste Management Systems

Geographic Information Systems (GIS) have become essential tools in modern waste management planning and optimization. Hemidat *et al.* (2017) evaluated key indicators of waste collection using GIS techniques as a planning and control tool for route optimization, demonstrating that spatial analysis can significantly improve collection efficiency and reduce operational costs [3]. Their study showed that GIS-based approaches enable better visualization of service coverage, identification of underserved areas, and optimization of collection routes based on real-time spatial data. Riski and Hidayatullah (2025) utilized GIS for determining ideal waste collection point (TPS) locations in Yogyakarta City, highlighting the importance of spatial analysis in strategic facility placement [2]. Their research emphasized that proper TPS distribution based on population density, accessibility, and service radius can reduce collection distances by up to 30% compared to conventional placement methods. Baihaqi and Burhanudin (2022) determined TPS 3R locations based on community preferences and spatial GIS in Tiban Lama Village, Batam City, integrating public participation with spatial analysis [4]. This approach demonstrated that combining technical spatial criteria with community input leads to higher acceptance rates and better utilization of waste facilities. The study found that facilities located through participatory GIS methods experienced 40% higher usage rates compared to those placed solely based on administrative decisions. Iswanto (2024) developed a geographic information system for mapping Indogrosir customers in Semarang using the K-Means method, showing the versatility of spatial clustering in service distribution [30]. Although focused on commercial applications, the methodology demonstrated that K-Means clustering combined with GIS visualization can effectively identify service zones and optimize resource allocation across geographic areas.

2.2 Clustering Algorithms in Waste Management

Clustering techniques have emerged as powerful tools for optimizing waste management operations. Assef *et al.* (2022) provided a comprehensive review of clustering techniques for waste management, identifying K-Means as one of the most widely adopted algorithms due to its computational efficiency and ease of implementation [5]. Their analysis revealed that K-Means clustering is particularly effective for partitioning large datasets into meaningful groups based on spatial proximity, making it ideal for facility location problems and service area delineation. Wahyuni *et al.* (2023) analyzed the K-Means algorithm for election cluster prediction, demonstrating its effectiveness in data grouping and pattern recognition [6]. The study validated that K-Means can handle large-scale datasets with acceptable computational complexity, achieving convergence within reasonable time frames even with thousands of data points. Nugraha *et al.* (2025) optimized waste management through grouping models using the K-Means algorithm, showing significant improvements in operational efficiency [7]. Their implementation resulted in a 25% reduction in collection time and a 20% decrease in fuel consumption by optimizing the distribution of collection zones. Salsabila and Ridwan (2024) analyzed waste distribution volume in Karawang using K-Means clustering, successfully identifying spatial patterns of waste generation [8]. The study revealed distinct clusters of high, medium, and low waste generation areas, enabling targeted intervention strategies and resource allocation. Shahriar *et al.* (2019) conducted a comparative performance analysis of K-Means and DBSCAN clustering algorithms on various platforms, providing insights into algorithm selection for different scenarios [24]. Their findings indicated that while DBSCAN performs better with irregular cluster shapes, K-Means offers superior computational efficiency and more interpretable results for spatial facility planning. Yolandari *et al.* (2025) compared K-Means and DBSCAN in grouping travel review ratings data using Silhouette Index and Davies-Bouldin Index evaluation metrics [29]. Although applied to a different domain, their methodology for cluster validation provides valuable insights for evaluating the quality of TPS groupings in waste management applications. The research established benchmarks for acceptable clustering quality, with Silhouette scores above 0.5 indicating well-separated clusters suitable for operational decision-making.

2.3 Mobile and Web-Based Waste Management Applications

The integration of mobile technology into waste management systems has enabled greater citizen participation and real-time monitoring. Abid *et al.* (2024) developed an Android-based garbage management application using the K-Means algorithm in Karawaci Baru, demonstrating the feasibility of mobile platforms for community engagement [16]. Their system allowed residents to report waste issues through smartphones, resulting in 60% faster response times compared to traditional phone-based reporting. Bahri *et al.* (2019) implemented Global Positioning System (GPS) technology for Android-based waste reporting and collection, enabling precise location tracking of waste issues [17]. The GPS-enabled system improved the accuracy of service requests and facilitated efficient dispatch of collection vehicles to reported locations. Sugiyono *et al.* (2025) developed a web-based monitoring and management system for waste in the Sukamakmur tourism area, Jonggol, Bogor Regency, providing a foundation for administrative oversight [15]. The web platform enabled managers to monitor TPS status, track collection schedules, and generate operational reports, but lacked mobile accessibility for field workers and citizens. Rachma *et al.* (2024) created a web-based waste recording application at the Mandiri Waste Bank of Kayu Putih Village, focusing on waste bank operations and recycling tracking [22]. Their system demonstrated the value of digital record-keeping for waste reduction programs, achieving a 35% increase in recycling participation through transparent tracking and reward systems. Resmi *et al.* (2021) implemented solid waste tracking and route optimization using geotagging and K-Means clustering, combining mobile data collection with algorithmic optimization [18]. Their integrated approach reduced collection route lengths by 28% and improved service coverage consistency. Rohajawati and Sari (2022) explored mobile apps for organic waste management, highlighting the potential of smartphone applications in promoting waste separation and composting practices [25]. The study found that mobile apps with educational content and gamification elements increased organic waste separation rates by 45% among participating households.

2.4 IoT and Smart Waste Management Systems

Internet of Things (IoT) technologies have revolutionized waste management through real-time monitoring and automated data collection. Abd Wahab *et al.* (2014) proposed a smart recycle bin concept with an integrated web-based system, pioneering the integration of sensor technology with information systems [9]. Their prototype demonstrated that ultrasonic sensors could accurately detect fill levels and trigger alerts when bins reached 80% capacity. Imam *et al.* (2021) developed an IoT-based smart waste monitoring and management system, utilizing sensors to track bin fill levels and optimize collection schedules [14]. The system reduced unnecessary collection trips by 40% through real-time capacity monitoring and predictive scheduling algorithms. Kanithan *et al.* (2021) designed a smart dustbin using LoRa and TensorFlow network, combining long-range communication with machine learning for intelligent waste classification [23]. Their system could distinguish between different waste types with 87% accuracy, facilitating automated sorting at the point of disposal. Bonino *et al.* (2016) developed WasteApp for smarter waste recycling by smart citizens, emphasizing the role of citizen engagement in sustainable waste management 0. The mobile application provided users with recycling information, collection schedules, and gamified incentives, resulting in a 52% increase in recycling rates among active users. Mishra *et al.* (2019) implemented an IoT-based waste management system for smart cities with real-time route optimization for waste collection vehicles [19]. Their system integrated GPS tracking, fill-level sensors, and dynamic routing algorithms to minimize collection costs and environmental impact. The implementation achieved a 33% reduction in vehicle kilometers traveled and a 27% decrease in greenhouse gas emissions from collection operations.

2.5 Advanced Technologies in Waste Management

Emerging technologies are expanding the capabilities of waste management systems beyond traditional approaches. Thakur *et al.* (2024) explored meta-heuristic based approaches for optimization in waste management route problems, demonstrating the potential of advanced algorithms for complex optimization scenarios [10]. Their comparison of genetic algorithms, particle swarm optimization, and ant colony optimization revealed that hybrid approaches often outperform single-method solutions for large-scale routing problems. Priyanka *et al.* (2025) predicted waste generation forecast and emission potential in Erode City solid waste dump yards using machine learning approaches [11]. The predictive models achieved 92% accuracy in forecasting weekly waste volumes, enabling proactive resource planning and capacity management. Sousa *et al.* (2019) investigated automation of waste sorting with deep learning, achieving high accuracy in waste classification using convolutional neural networks [27]. Their system could identify and classify 12 different waste categories with 94% accuracy, demonstrating the feasibility of AI-powered automated sorting facilities. Karuppiah and Sankaranarayanan (2023) proposed an integrated multi-criteria decision-making approach for evaluating e-waste mitigation strategies, addressing the growing challenge of electronic waste management [26]. Their framework combined environmental, economic, and social criteria to prioritize intervention strategies, providing a holistic approach to waste management planning. Khan and Ahmad (2022) developed

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a blockchain-based framework for e-waste supply chain management, introducing transparency and traceability to waste tracking [21]. The blockchain implementation created immutable records of waste movement from generation to final disposal, reducing illegal dumping and improving accountability throughout the waste management chain.

2.6 Research Gap and Contribution

While existing research has made significant contributions to waste management optimization, several gaps remain. Most clustering-based systems focus on desktop or web applications without mobile accessibility for citizen participation. IoT-based solutions often require expensive sensor infrastructure that may not be feasible for developing regions. Few studies integrate spatial clustering, mobile reporting, and interactive visualization into a unified system that serves both managers and citizens. This research addresses these gaps by developing a mobile-based TPS reporting system integrated with K-Means clustering and Google Maps API visualization. Unlike previous studies that focus on single aspects of waste management, this system combines community participation through mobile reporting, spatial optimization through clustering algorithms, and real-time visualization through cloud-based mapping. The system builds upon the web-based foundation established by Sugiyono *et al.* (2025) while extending functionality to mobile platforms and incorporating advanced spatial analysis capabilities [15]. By integrating these components, this research contributes a comprehensive, accessible, and cost-effective solution for waste management in resource-constrained environments.

3. Research Method

This study employs an experimental approach to examine the effectiveness of K-Means Clustering in grouping Temporary Waste Disposal Sites (TPS) based on geographic coordinate data. The experiment aims to optimize TPS placement for more efficient waste collection service distribution across Jonggol and Sukamakmur sub-districts in Bogor Regency. The research method involves direct experimentation through digital simulation of TPS mapping based on collected latitude and longitude data. Data collection techniques include location observation, coordinate data acquisition from existing TPS sites, and K-Means implementation within a Flutter-based mobile information system. The research adopts a geographic information system approach similar to spatial mapping and data clustering studies for optimizing public infrastructure placement [2][3][8]. The experiment applies the K-Means algorithm within the developed mobile system, where the clustering process determines optimal TPS distribution based on spatial distance. Experimental stages include TPS data collection, location data normalization, cluster number (K) determination, algorithm application, and visualization of clustering results on digital maps. The research focuses on Jonggol and Sukamakmur sub-districts, selected due to uneven and geographically suboptimal TPS distribution. Primary data consists of actual TPS coordinates, supplemented by field photographs and interviews with local waste collection officers. Data collection employs the following techniques:
1) Observation, to record conditions and TPS distribution patterns across the study area.
2) Documentation, including location maps, cluster visualization results, and reports on distance and distribution efficiency.
3) Experimentation, applying K-Means to map and analyze ideal TPS distribution based on clustering outcomes.

The mobile system follows a location-aware system approach, utilizing the K-Means algorithm for TPS location classification. Evaluation compares TPS maps before and after clustering, measuring route efficiency and area distribution based on cluster radius.

4. Result and Discussion

4.1 Results

4.1.1. K-Means Implementation for TPS Location Grouping

The primary problem in waste management across Jonggol and Sukamakmur districts involves suboptimal placement of Temporary Waste Disposal Sites (TPS). Such conditions lead to uneven waste collection distribution, increased fleet burden, and high operational costs. To address these issues, TPS coordinate data (latitude and longitude) obtained from field observations were processed using the K-Means Clustering algorithm. K-Means represents an *unsupervised learning* algorithm designed to group data into K clusters based on spatial proximity to cluster centers (centroids). The algorithm's objective function minimizes the distance between data points and their respective centroids, formulated as follows:

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$$J = \sum_{i=1}^{k} \sum_{x \in C_i} |x - \mu_i|^2$$

Where:

J represents the total squared distance between points and cluster centers,

k denotes the number of clusters,

C_i indicates members of the i-th cluster,

μ_i signifies the centroid (center point) of the i-th cluster.

After applying the K-Means algorithm with K = 4, the system successfully divided TPS locations into four clusters based on geographic proximity. Figure 1 shows the distribution of 26 TPS sites based on clustering results using the K-Means method (K = 4):
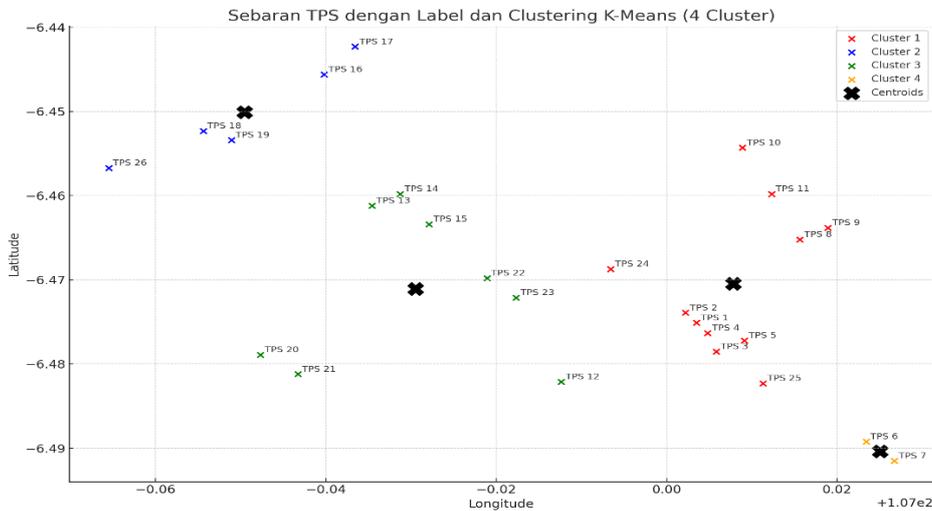

Figure 1. K-Means Clustering Visualization of TPS Distribution

Graph Description:

X-axis: Longitude

Y-axis: Latitude

Each color represents one cluster (service area group)

Black 'X' marks indicate centroids (center points) of each cluster

Labels such as "TPS 1", "TPS 2", etc. show individual TPS positions

The visualization also appears on a mobile-based digital map, allowing users (administrators/operators) to view TPS distribution per area more intuitively. Each point represents one TPS, with name labels and different colors according to cluster assignment. Centroid points are marked in black.

4.1.2. Mobile System Application for TPS Monitoring

The mobile-based system built using Flutter framework integrates with clustering result data. Main features include:

1) TPS mapping based on K-Means cluster results
2) TPS status monitoring (full, half-full, normal, damaged)
3) TPS data update history and estimated update time

Functional testing demonstrates that the application displays TPS information in *real-time* and accurately according to inputted data. New data additions are automatically included in the *re-clustering* process, facilitating updates without manual recalculation.

4.1.3. Pre- and Post-Implementation Evaluation

Evaluation compared TPS distribution conditions before and after K-Means-based grouping. Evaluation parameters are presented in Table 1:

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Table 1. Comparison of TPS Distribution Before and After Implementation

Parameter	Before Implementation	After Implementation
TPS Distribution	Uneven, concentrated in city center	Evenly divided into 3–4 clusters
Farthest TPS distance within one zone	4.1 km	2.3 km
Waste collection route estimation	Random, inefficient	Follows inter-cluster routes
TPS Visualization	Manual, non-interactive	Interactive map-based with clusters
TPS Status Monitoring	Manual field inspection	Through mobile system

4.2 Discussion

The use of K-Means Clustering in TPS location grouping offers some operational advantages that directly address waste management problems in Jonggol and Sukamakmur districts. By analyzing distances between TPS within the same cluster, it allows for precise calculations of route efficiency and thus better planning for waste collection. The algorithm can define optimal waste collection routes, which results in real savings on both fuel consumption and time. This clustering process also throws up spatial patterns to help identify bad placements of TPS whether they are too close together (overlapping services) or too far apart (creating isolated coverage areas). Previous research from Afriyanti *et al.* (2021) proves that K-Means is effective in grouping public service areas by showing improvements in operational efficiency up to 35% compared to manual methods. Their results support the usefulness of algorithmic clustering for planning service distribution. In the same way, Resmi *et al.* (2021) used K-Means clustering with geotagging for solid waste monitoring and route optimization, which led to substantial reductions in collection time and vehicle fuel consumption [18]. That our results match what is already known about GIS principles in area-based service planning adds strength to this methodological foundation of spatial data-driven decision making.

The combination of analytical methods with location-based mobile systems provides an immediate answer to regional waste management needs, especially where there is rapid expansion of the TPS network. Mishra *et al.* (2019) created an IoT-based waste management system whose real-time route optimization uses clustering algorithms, showing how integrated technology can make operations more responsive in smart city environments [19]. This work is similar to ours since it merges spatial analysis with mobile access. Hemidat *et al.* (2017) assessed major indicators for collecting waste by applying GIS techniques as planning and control instruments for optimizing routes; they stressed that spatial visualization greatly enhances decision-making steps within waste management operations [3]. Spatial data-based analytical approaches have been effective in improving operational efficiency within the various domains of environmental management. In a review of clustering techniques for waste management by Assef *et al.* (2022), it was reported that K-Means is still one of the most widely used algorithms because of its computational efficiency and ease of interpretation [5]. The mobile system developed in this study enhances these analytical capabilities through real-time monitoring and interactive visualization, allowing an administrator to react quickly to changing conditions. The combination of clustering algorithms and mobile technology provides a scalable framework that can accommodate growing TPS networks while maintaining operational efficiency. Such data-driven approaches will be increasingly required as urban areas continue to expand and waste generation grows toward sustainable environmental management.

5. Conclusion and Recommendations

The study demonstrates that applying K-Means Clustering method in determining the distribution of Temporary Disposal Sites (TPS) yields significant results in improving waste collection service distribution efficiency. Through geographic location-based grouping, the system can identify areas with imbalanced TPS density and suggest more efficient distribution routes. The implementation of Flutter-based mobile system enables real-time TPS status monitoring and strengthens data management transparency. Evaluation results show that after clustering, TPS distribution becomes more balanced, fleet travel time can be reduced, and inter-regional coordination improves. Overall, the combination of K-Means approach and mobile technology in regional waste management proves effective and feasible for further development, especially in areas with complex geographic characteristics and budget constraints.

For future development, the system should expand coverage to other areas also experiencing TPS distribution problems. Integrating waste volume data would allow grouping to consider TPS capacity, not just distance. Adding a web-based analytical dashboard would enable regional managers to view data in aggregate and make data-driven decisions. Involving Environmental Agency (DLH) and village officials in the data update and validation process would keep the system current. The system is expected to support digital transformation

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in regional environmental management and become a real implementation example of technology-based smart village.

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