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Integrating WhatsApp-only Citizen Reporting and GIS Spatial Analysis (Kernel Density–Buffer–Network Distance) to Prioritize Solid Waste Service Interventions: A Case Study of Kalijaga Village, Aikmel District

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Abstract

Solid waste management at the village scale faces persistent challenges related to limited availability of operational spatial data and uneven service coverage across residential areas. This study integrates WhatsApp-only citizen reporting with Geographic Information System (GIS) spatial analysis to identify clusters of solid waste complaints and to establish service intervention priorities in Kalijaga Village, Aikmel District. The spatial analysis comprises kernel density estimation, buffer analysis, and network distance analysis, while acceptance of the reporting channel is examined using an extended Technology Acceptance Model (TAM) incorporating information quality. The results indicate the formation of complaint density clusters along primary road corridors, at the interface between residential areas and vacant land, and in proximity to drainage networks. Multi-criteria integration produces priority zones P1–P5 and a Top-10 list of priority locations that can be directly adopted as a basis for task assignment and optimization of waste collection points. From the system acceptance perspective, perceived usefulness and information quality exert a significant influence on behavioral intention to use, whereas perceived ease of use affects behavioral intention indirectly through enhanced perceived usefulness. These findings demonstrate that a WhatsApp-only approach supported by GIS analysis can serve as a low-cost, operational solution for strengthening village-level solid waste governance.

Keywords: Village Solid Waste Management; Citizen Reporting; WhatsApp-only; GIS; TAM; Intervention Prioritization.

INTRODUCTION

Solid waste management at the village level represents a critical issue in maintaining environmental quality and safeguarding public health in residential areas. Limited service capacity, uneven distribution of collection points, and irregular disposal behavior frequently lead to waste accumulation, particularly along main road corridors, in public service areas, and around drainage channels. In many rural contexts, the availability of up-to-date and integrated spatial data remains a primary constraint for effective planning and evaluation of waste management services.

Recent advances in communication technology provide opportunities to utilize citizen reporting (crowdsourcing) as a rapid and low-cost source of environmental incident data. Instant messaging platforms such as WhatsApp exhibit high adoption rates within village communities and enable the direct transmission of location information, photographic evidence, and time stamps. However, text- and image-based reports require further processing to be transformed into decision-support inputs that are measurable, objective, and replicable.

Geographic Information Systems (GIS) offer an analytical framework for integrating citizen reports with supporting spatial datasets, thereby enabling the objective identification of spatial patterns and problem concentrations. Techniques such as *kernel density estimation*, *buffer analysis*, and *network distance analysis* facilitate the detection of complaint clusters, assessment of proximity to sensitive areas, and evaluation of service accessibility under real-world conditions. Nevertheless, the effectiveness of citizen-based reporting channels is determined not only by technical performance but also by user acceptance and the sustainability of public participation.

Previous studies have demonstrated that the Technology Acceptance Model (TAM) is effective in explaining user acceptance of information systems, particularly through the constructs of perceived ease of use and perceived usefulness. In the context of public services, extending TAM to include information quality is especially relevant, as the accuracy, completeness, and relevance of reported content directly influence the system's operational value for service managers. Despite this relevance, empirical integration of instant messaging–based citizen reporting with GIS spatial analysis and system acceptance testing at the village scale remains limited.

Based on this research gap, the objectives of this study are to: (1) map the spatial distribution and clustering patterns of solid waste complaints derived from citizen reporting; (2) formulate waste management service intervention priorities using multi-criteria spatial analysis; and (3) examine acceptance of a WhatsApp-only reporting channel using an extended TAM that incorporates information quality. The findings are expected to provide both scientific and operational contributions to data-driven, participatory solid waste governance at the village level.

RESEARCH METHODS

Study area and period

The study was conducted in Kalijaga Village, Aikmel District, East Lombok Regency, which comprises 11 hamlets (dusun) characterized by diverse settlement patterns and activity intensities. Data collection was carried out over a period of eight weeks to capture variations in citizen reports across multiple waste collection cycles.

Research design

This research adopts a quantitative–descriptive design combining spatial analysis and a system acceptance survey. Two analytical units are employed: (1) solid waste complaint reports treated as spatial events for GIS-based analysis; and (2) resident respondents serving as survey units for assessing acceptance of the reporting channel.

Data sources and collection techniques

Primary data were obtained through WhatsApp-only citizen reporting, using a standardized reporting format requiring submission of location information (pin), photographic evidence, time of occurrence, and complaint category. Secondary data include road networks (OpenStreetMap), hamlet administrative boundaries, educational facilities, dense residential areas, and drainage networks.
The system acceptance survey involved 110 respondents (10 respondents per hamlet) and employed a Likert-scale questionnaire (1–5) measuring the constructs of Perceived Ease of Use (PEOU), Perceived Usefulness (PU), Information Quality (IQ), and Behavioral Intention (BI).

Data analysis techniques

Spatial analysis was conducted using ArcGIS Pro and involved data preprocessing, *kernel density estimation*, *buffer analysis*, and *network analysis*. Intervention priorities were determined through variable normalization and multi-criteria weighting. System acceptance was analyzed using reliability testing (Cronbach's alpha) and multiple linear regression to examine relationships among TAM constructs.

Research ethics

Ethical principles were applied by excluding personal identifiers of reporters and presenting incident locations in aggregated form or using coded location identifiers. All survey respondents provided voluntary informed consent prior to questionnaire completion.

RESULTS AND DISCUSSION

Overview of the study area

Kalijaga Village covers an area of 2.25 km² (225 ha) with a total population of 8,871 residents (2024 data; published in 2025) and an approximate population density of 3,943 persons/km². Administratively, the village consists of 11 hamlets (dusun) and 44 neighborhood units (RT). Basic social facilities include 25 places of worship (6 mosques and 19 prayer houses) and 10 educational institutions recorded in the national education reference system. The relatively concentrated pattern of settlements and service facilities renders the determination of collection points, regulation of waste placement schedules, and certainty of collection services critical for preventing waste accumulation along main road corridors and public service areas.

Table 2a. Administrative structure of Kalijaga Village (11 hamlets)

No.	Hamlet name	Number of respondents
1	Jorong	10
2	Gubuk Dapur	10
3	Karang Mantri	10
4	Karang Luar	10
5	Jangkong	10
6	Lauk Peken	10
7	Rembate	10
8	Keramba	10
9	Dasan Bongkot	10
10	Petakawan	10
11	Dayan Jero	10

Note: Respondents were evenly distributed (10 respondents per hamlet) to ensure spatial representativeness in the analysis of reporting channel acceptance.

Respondent characteristics (N = 110)

Table 3. Respondent characteristics (N = 110)

Characteristic	Category	n	%
Gender	Male	62	56.4
	Female	48	43.6
Age	18–25	22	20.0
	26–35	39	35.5
	36–45	31	28.2
	>45	18	16.4
Education	Primary/Junior secondary	24	21.8
	Senior secondary	61	55.5
	Diploma/Bachelor	24	21.8
	Master's or above	1	0.9
Smartphone usage intensity	>3 hours/day	76	69.1
Spatial distribution	11 hamlets	110	100.0

Note: Percentages are rounded to one decimal place.
Source: Processed research data.

Descriptive statistics of constructs

Table 4. Descriptive statistics of constructs (scale 1–5)

Construct	Mean	SD
PEOU	4.093	0.405
PU	4.189	0.443
IQ	4.084	0.425
BI	4.103	0.482

Reliability testing

Table 5. Construct reliability (Cronbach's alpha)

Construct	Number of items	α
PEOU	4	0.825
PU	4	0.838
IQ	5	0.835
BI	3	0.864

Note: A construct is considered reliable when α ≥ 0.70.
Source: Processed research data.

Spatial distribution patterns of waste accumulation and complaint points

During the eight-week observation period, 160 waste-related reports were submitted by residents. After data cleaning and verification, 145 reports were deemed valid and retained for spatial analysis.

each report must include a location pin/coordinates and relevant photographic evidence; reports with implausible locations or inconsistencies between location, photo, and category were verified and could be excluded during preliminary screening; duplicate reports within a radius of ≤ 20–30 m with similar timing and content were merged into a single event.

This study employs two distinct units of analysis. First, solid waste reports (n = 145) are treated as spatial events for GIS-based analysis. Second, resident respondents (n = 110) constitute the survey units for examining acceptance of the reporting channel using the extended TAM.

Kernel density estimation (KDE) was applied to identify complaint density clusters (K1–K3) at the village settlement scale. The working coordinate system was WGS 1984 / UTM Zone 50S, with KDE parameters set to a 25 m cell size and a 150 m bandwidth (Appendix B). Visualization of the KDE surface may be provided as a supplementary figure where spatial displays are required, without affecting analytical replicability, as all parameters and cluster summaries are presented in the main text. *Source:* Processed research data and OpenStreetMap (OSM, accessed October 2025).

Table 6. Distribution of reported waste incident categories (n = 145 valid reports)

Incident category	n	%
Accumulation/overflow at collection points	82	56.6
Scattered waste around collection points	37	25.5
Disposal outside designated points	26	17.9
Total	**145**	**100.0**

Note: Percentages are rounded to one decimal place.
Source: Processed research data.

Temporally, report frequencies increased during H–1 to H relative to scheduled collection days, particularly on Sunday night–Monday morning and Wednesday night–Thursday morning. This pattern indicates that residents tend to place waste shortly before collection days; when placement times are not regulated or container capacity is limited, the risk of overflow and litter dispersion increases.
KDE results identified three primary clusters (K1–K3), which can be differentiated based on locational context, as summarized in Table 7.

Table 7. Summary **of complaint density clusters based on kernel density analysis**

Cluster	Locational characteristics	n (points)	Main implications
K1	Main road corridors and economic/service activity areas	54	High waste load; requires reorganization of collection points and strengthened response on collection days
K2	Residential–vacant land interfaces	46	Prone to opportunistic dumping; requires monitoring, location marking, and enforcement

Cluster	Locational characteristics	n (points)	Main implications
K3	Areas near drainage channels	45	Risk of pollution and blockage; requires physical barriers, community patrols, and enforcement

Note: Clusters were derived from KDE outputs; analytical parameters (bandwidth, cell size, and classification scheme) are detailed in Appendix B.
Source: Processed research data.

Buffer analysis and environmental risk

Table 8. Summary of buffer analysis results (n = 145 valid reports)

Buffer parameter	n	%
Points within 50 m of drainage channels	61	42.1
Points within 100 m of educational facilities	27	18.6
Points within 150 m of dense residential areas	98	67.6

Note: A single report may fall within more than one buffer zone (overlap).
Source: Processed research data and secondary spatial layers.

Network distance analysis to waste management services

Table 9. Network distance statistics to the nearest official collection point (km)

Statistic	Value
Mean	0.74
Median	0.61
First quartile (Q1)	0.38
Third quartile (Q3)	0.96
Proportion of points with distance > 1.00 km	21.0%

Note: Distances were calculated as travel distances along the road network (*network distance*) from each report point to the nearest official collection point.
Source: Processed research data and OSM road network.

Intervention priority scoring

Table 10. Criteria, definitions, and weights for intervention prioritization

Criterion	Notation	Definition	Weight
Complaint density	KD	Problem intensity based on *kernel density*	0.40
Network distance to services	JD	Network distance to nearest official collection point	0.30
Proximity to dense settlements	KP	Proximity to high-density residential areas	0.20
Proximity to drainage	KS	Proximity to environmentally sensitive elements (drainage)	0.10

Score formula: **Score = (0.40 × KD) + (0.30 × JD) + (0.20 × KP) + (0.10 × KS)**.
Note: All criteria were normalized to a **0–1** range prior to weighting (see Appendix B).

Table 11. Summary of priority zones and recommended interventions

Zone	Dominant characteristics	Main recommendations
P1	High density + relatively low service accessibility	Reorganization/addition of collection points; strengthening of waste banks; regulation of placement times; intensive response prior to collection days
P2	High density along activity corridors	Clear marking of collection points; reinforcement of communal containers

Zone	Dominant characteristics	Main recommendations
		(where available); prioritized service response
P3	Proximity to drainage + disposal outside designated points	Enforcement actions, physical barriers at hotspots, community patrols
P4	Moderate density + irregular disposal behavior	Education, strengthened communication of schedules, feedback mechanisms
P5	Low density (monitoring)	Periodic monitoring; evaluation if complaint frequency increases

Top-10 priority locations for action planning

To ensure that analytical outputs are directly actionable, this study compiled a list of **10 priority locations** based on the composite score (KD, JD, KP, KS). For ethical and privacy considerations, locations are presented using **coded identifiers** rather than precise coordinates or household references. Local authorities may re-map these codes using internal working maps.

Table 11a. Top-10 priority intervention locations (based on composite scores)

Location code	Dominant category	Zone	Score (0–1)	Recommended intervention
L-01	Overflow at official point	P1	0.92	Add/relocate collection points; physical marking; stricter placement time regulation
L-02	Overflow at official point	P1	0.90	Reinforcement of communal containers (if available); intensive response H–1 to H
L-03	Disposal outside designated points	P1	0.88	Enforcement; signage; community patrols; village regulation enforcement
L-04	Disposal outside designated points	P2	0.84	Corridor monitoring; expansion of nearby official service coverage
L-05	Scattered waste	P2	0.82	Education and routine cleaning; route optimization
L-06	Overflow at official point	P2	0.80	Strengthened schedule communication; additional container capacity testing
L-07	Disposal outside designated points	P3	0.78	Physical barriers at hotspots; drainage cleaning
L-08	Scattered waste	P3	0.76	Sensitive area management; patrols during high-risk periods
L-09	Overflow at official point	P4	0.71	Monitoring; evaluation of service point placement if trends increase
L-10	Scattered waste	P4	0.69	Hamlet/RT-based education; reporting status feedback

Note: Scores represent normalized and weighted composites and may be updated periodically (e.g., monthly) as part of routine service evaluation.

Discussion

Novelty and research contributions

The novelty of this study lies in the integration of three components within a village-scale operational framework: (1) WhatsApp-only citizen reporting as a rapid and low-cost source of solid waste incident data; (2) GIS-based spatial analysis (kernel density, buffer, and network distance analyses) to transform narrative reports into measurable spatial indicators; and (3) assessment of reporting channel acceptance using an extended Technology Acceptance Model incorporating information quality. Through this integration, the study addresses not only *where* intervention priorities are located, but also *why* residents are willing to report and which factors support sustained participation (Davis, 1989; Longley et al., 2015; Venkatesh et al., 2003; Wixom & Todd, 2005). Practically, the study provides priority zones P1–P5 and a Top-10 list of priority locations that can be directly adopted for task assignment, collection point management, and reinforcement of village-level waste governance while maintaining ethical standards and reporter privacy.

Implications of waste accumulation distribution patterns

KDE results (Table 7) demonstrate that waste accumulation and complaints are not evenly distributed but instead form clusters in (i) main road corridors and activity centers, (ii) residential–vacant land interfaces, and (iii) areas near drainage channels. These patterns indicate that village-scale waste problems are not solely driven by waste volume but also by disposal behavior, service accessibility, and spatial conditions that facilitate opportunistic dumping.

Behaviorally, the observed increase in reports during H–1 to H relative to scheduled collection days (Mondays and Thursdays) reflects a rational service logic: residents tend to place waste shortly before collection to ensure prompt removal. However, when placement times are not regulated or container capacity is insufficient, waste is more likely to overflow or become scattered. This finding is consistent with the dominance of the overflow at collection points category (56.6%; Table 6), underscoring the need for regulated placement schedules and adequate container capacity.

From an environmental risk perspective, the substantial proportion of report points within 50 m of drainage channels (42.1%) and within 150 m of dense residential areas (67.6%) (Table 8) highlights the potential for secondary impacts, including drainage blockage, pollution, and degraded residential environmental quality. Consequently, zones adjacent to drainage networks require interventions that combine enforcement measures with physical mitigation, rather than relying solely on educational approaches.

Feasibility of GIS for prioritizing waste management interventions

In this study, GIS functions as a tool for converting narrative complaints into measurable decision-support inputs, consistent with the role of GIS as a spatial data integration framework for analysis and planning (Longley et al., 2015). The combined application of KDE, buffer analysis, and *network distance* provides complementary operational insights: KDE identifies *where* problem concentrations occur; buffer analysis explains *proximity* to sensitive or high-activity areas; and network analysis evaluates *service accessibility* under real travel conditions.

The observed variation in *accessibility* (mean 0.74 km; median 0.61 km; 21% of points exceeding 1 km; Table 9) is critical for policy interpretation. When a subset of incidents occurs at relatively distant locations from official collection points, the most rational strategy extends beyond schedule adjustments to include service location reorganization (addition or relocation of collection points) or route modification. These findings reinforce the relevance of GIS for routine service planning, including route evaluation and placement of waste banks.

Integration of priority scoring and action planning implications

The multi-criteria priority model (Table 10) yields priority zones P1–P5 (Table 11) and a Top-10 list of priority locations (Table 11a).

Weighting rationale (0.40; 0.30; 0.20; 0.10): Weights were assigned to reflect village-level waste management priorities, placing complaint density (KD) as the primary indicator (0.40) due to its representation of incident intensity, followed by service accessibility (JD) (0.30), which relates to residents' ability to use official collection points. Environmental context variables were weighted lower but remain relevant: proximity to dense settlements (KP) (0.20) as a proxy for potential waste generation and direct community impact, and proximity to drainage (KS) (0.10) as an indicator of environmental sensitivity. This weighting scheme is heuristic and service-oriented and can be refined through stakeholder consultation during subsequent evaluation cycles. From a policy perspective, the results enable local governments to allocate limited resources to locations with the highest marginal benefit. Recommended interventions for zones P1–P3 are integrative, encompassing (i) reorganization or addition of collection points, (ii) strengthening of waste banks and 3R initiatives, and (iii) enforcement of village regulations at dumping hotspots.

The Top-10 list is presented using coded locations to protect privacy, while remaining actionable through internal working maps. This practice also ensures ethical compliance and acceptability in academic publishing.

Determinants of citizen reporting system acceptance (extended TAM) and implications for WhatsApp-only implementation

The TAM framework explains citizen acceptance of the reporting channel through the constructs of Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) (Davis, 1989). In public service contexts, extended acceptance models emphasize the role of information quality and user experience in shaping behavioral intention (Venkatesh et al., 2003; Wixom & Todd, 2005).

Results from the extended TAM tests indicate that Perceived Usefulness (PU) is the strongest predictor of Behavioral Intention (BI), followed by Information Quality (IQ) (Tables 13–14). Meanwhile, Perceived Ease of Use (PEOU) significantly influences PU (Table 12) but does not exert a direct effect on BI (Table 13). This pattern suggests that, in the village public service context, residents are willing to report not merely because the system is easy to use, but because reporting is perceived as useful and leads to tangible follow-up actions.

The practical implication is that a WhatsApp-only implementation is both adequate and realistic for village settings, as it lowers adoption barriers. However, sustained participation depends on (i) standardized reporting formats to ensure high information quality (location, photo, category, time), and (ii) consistent status feedback mechanisms (received–in process–completed). Without these components, perceived usefulness diminishes and participation may decline.

Operational implementation recommendations

Strengthening regulation-based governance: Clarification of official collection points, regulation of placement times prior to collection, prohibition of disposal outside designated points, and proportional enforcement mechanisms.

Reorganization and equalization of collection points: Addition or relocation of points in P1–P2 zones; physical signage and schedule information; testing of additional container capacity at recurrent overflow sites.

Integration of reporting with routine services: Use of priority maps as inputs for task assignment and route evaluation; periodic updates of priority maps (e.g., monthly).

Standardization of WhatsApp reporting: Implementation of standard operating procedures for report formats (location + photo + category + time) and duplication prevention.

Mandatory provision of minimum status updates (received–in process–completed) to reinforce perceived usefulness and enhance behavioral intention.

CONCLUSIONS

This study demonstrates that integrating citizen reporting (WhatsApp-only) with Geographic Information Systems (GIS) is effective for (i) mapping spatial patterns of solid waste accumulation and complaints, (ii) evaluating service accessibility relative to official collection points, and (iii) prioritizing waste management interventions in Kalijaga Village, Aikmel District.

Spatially, from 145 valid reports (after cleaning from 160 initial reports), *kernel density estimation* identified three primary clusters concentrated along road/activity corridors, residential–vacant land interfaces, and areas near drainage channels. Buffer analysis revealed that a substantial proportion of report points fall within sensitive or high-activity zones (e.g., within 50 m of drainage and 150 m of dense settlements), indicating elevated environmental and public health risks. Network distance analysis showed heterogeneous service accessibility (mean 0.74 km; median 0.61 km;

approximately 21% of points located more than 1 km from the nearest official collection point), supporting the argument that some incidents are associated with limited service access.

Through multi-criteria integration (complaint density, network distance, proximity to dense settlements, and proximity to drainage), the study produced priority zones P1–P5 that provide an operational basis for reorganization or expansion of collection points and strengthening of waste banks in high-burden areas.

From a system acceptance perspective, extended TAM testing indicates that PEOU and IQ significantly influence PU (supporting H1 and H3), while PU and IQ significantly influence BI (supporting H2 and H4). The direct effect of PEOU → BI was not significant (H5 not supported), suggesting that ease of use promotes intention primarily through enhanced perceived usefulness. Consequently, sustained citizen reporting requires not only technical simplicity but also visible service follow-up and status feedback.

Overall, this approach provides both scientific and operational foundations for strengthening village-level waste governance based on local regulations, continuous data updating, and targeted interventions aligned with spatial conditions and reporting behavior. The findings may also inform updates to village regulations and service SOPs, as well as monthly evaluation cycles based on report summaries and priority mapping.

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