International Journal of Public Health Science (IJPHS)
Vol. 15, No. 3, September 2026, pp. 794~801
ISSN: 2252-8806, DOI: 10.11591/ijphs.v15i3.27139

Effectiveness and acceptability of a digital early warning system for gestational diabetes management: a quasi-experimental study in Lampung Province

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Article Info

Article history:

Received May 4, 2026
Revised Jul 8, 2026
Accepted Jul 12, 2026

Keywords:

Acceptability
Digital health
Early warning system
Gestational diabetes mellitus
Glycemic control

ABSTRACT

Despite growing evidence supporting digital health interventions for gestational diabetes mellitus (GDM), no study has evaluated the acceptability and effectiveness of such interventions across geographically heterogeneous healthcare settings in low-resource contexts, where disparities in infrastructure and connectivity may critically influence outcomes. This study addresses this gap by introducing and evaluating the Early Warning System for Gestational Diabetes Mellitus (EWSDMG), a novel digital application uniquely designed to function across diverse geographical conditions. A quasi-experimental one-group pre-test post-test design was employed with 200 GDM-diagnosed pregnant women across four sites in Lampung, Indonesia, representing urban, remote, coastal, and rural settings. Technology acceptability was measured using the System Usability Scale (SUS), while knowledge, adherence, and glycemic profiles were assessed before and after 8 weeks of intervention. The overall SUS score was 77.9 ± 6.4 (Good/Acceptable), with urban settings scoring highest (82.4 ± 5.2). Knowledge and adherence scores increased significantly by 26.27 and 24.35 points, respectively ($p < 0.001$). Fasting and 2-hour post-prandial glucose decreased by 13.3 mg/dL ($p = 0.002$) and 22.2 mg/dL ($p = 0.001$), respectively. SUS scores strongly correlated with glycemic improvement ($r = 0.642$, $p < 0.001$). This study provides the first evidence that a single digital GDM intervention can achieve consistent acceptability and clinical effectiveness across heterogeneous geographical settings, offering a scalable model for equitable GDM management in resource-limited regions.

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1. INTRODUCTION

Gestational diabetes mellitus (GDM) represents a significant and escalating public health concern globally, characterized by glucose intolerance first recognized during pregnancy [1]. The condition poses substantial risks to both maternal and neonatal outcomes, including preeclampsia, macrosomia, birth injuries, and long-term metabolic sequelae for mother and child [2]. In Indonesia, showed that 51.8% of pregnant women had good knowledge, and 54.2% had poor preventive behaviors. There is a significant relationship between age ($p = 0.019$), family history of diabetes ($p = 0.021$), knowledge ($p < 0.001$), and preventive practices of GDM. Multivariate analysis showed that knowledge ($p < 0.001$) is a significant factor related to preventive practice after controlling for age ($p = 0.169$) and family history of diabetes ($p = 0.428$) [3].

Lampung Province presents a uniquely challenging context for healthcare delivery due to its considerable geographical and sociodemographic heterogeneity. The province encompasses 13 regencies and 2 cities, spanning urban centers such as Bandar Lampung, remote inland areas including Central Lampung, coastal regions such as East Lampung, and rural districts such as Tanggamus. This diversity creates significant disparities in healthcare infrastructure, digital literacy, and access to specialized obstetric and endocrinological services. Rural and remote communities frequently experience delayed diagnosis and suboptimal management of high-risk pregnancies, compounding the burden of GDM-related complications [4].

The comprehensive management of GDM requires sustained patient engagement encompassing dietary modification, physical activity regulation, glycemic self-monitoring, and timely clinical follow-up [5], [6]. However, conventional healthcare delivery models in resource-limited settings often fail to provide the continuous support necessary for effective GDM management [7], [8]. Pregnant women in Lampung Province, the majority of whom are housewives with varying educational backgrounds [9], face barriers including geographical distance to healthcare facilities, limited health literacy, and insufficient frequency of antenatal consultations to adequately address the complex self-management demands of GDM.

Digital health innovations have emerged as promising solutions to bridge these gaps in maternal healthcare delivery. Mobile health (mHealth) applications offer the potential for real-time health monitoring, automated educational content delivery, and early warning systems that can extend clinical oversight beyond the limitations of facility-based encounters [10], [11]. The integration of technology into healthcare management has demonstrated effectiveness across various contexts, with studies confirming that digital platforms can enhance knowledge acquisition, improve treatment adherence, and facilitate better clinical outcomes [12].

Despite the growing body of evidence supporting mHealth interventions for GDM management, several critical gaps remain underexplored in the existing literature. First, the majority of studies evaluating digital health applications for GDM have been conducted in high-income, urban settings with robust digital infrastructure, limiting their generalizability to resource-constrained and geographically heterogeneous regions such as Lampung Province. Second, few studies have simultaneously assessed both user acceptability and clinical effectiveness of mHealth tools within a single framework, yet both dimensions are essential for sustainable implementation. Third, evidence regarding the effectiveness of integrated early warning systems combining educational delivery, self-monitoring, and automated alerts specifically tailored for GDM in low-resource Indonesian settings remains notably absent.

The Early Warning System for Gestational Diabetes Mellitus (EWSDMG) was developed as an integrated digital application incorporating automated educational content, daily reminder notifications, glycemic self-monitoring features, and alert systems for abnormal glucose values. This innovation was specifically designed to address the multifaceted challenges of GDM management in Lampung Province by providing continuous, technology-mediated support to pregnant women across diverse settings. However, prior to widespread implementation, rigorous evaluation of both its acceptability among target users and its effectiveness in improving knowledge, adherence, and glycemic control is essential. Therefore, this study aimed to analyze the acceptability and effectiveness of the EWSDMG innovation in the comprehensive management of GDM across healthcare facilities representing the geographical diversity of Lampung Province, thereby generating evidence to inform digital health policy and practice in maternal care.

2. METHOD

2.1. Study Design

This study employed a quasi-experimental design with a one-group pre-test post-test approach to evaluate the acceptability and effectiveness of the EWSDMG innovation in the comprehensive management of GDM across healthcare facilities in Lampung Province, Indonesia. Measurements were conducted at two time points: prior to intervention (baseline) and following 8 weeks of EWSDMG application utilization. This design was selected as the most appropriate approach given the nature of the digital health intervention and the operational constraints of implementing a randomized controlled trial across geographically diverse healthcare settings in the province.

2.2. Population and sample

The study population comprised all pregnant women diagnosed with GDM attending healthcare facilities in Lampung Province. A total of 200 respondents were recruited using a purposive sampling technique based on predetermined eligibility criteria. Inclusion criteria encompassed: pregnant women with fasting plasma glucose (FPG) >92 mg/dL or 2-hour post-prandial glucose (2hPPG) >153 mg/dL in accordance with the International Association of Diabetes and Pregnancy Study Groups (IADPSG) diagnostic thresholds, willingness to participate voluntarily, and capacity to operate a smartphone-based digital application. Exclusion criteria included pregnant women with pre-gestational type 1 or type 2 diabetes mellitus, severe pregnancy complications necessitating intensive inpatient care, and those with limited access to smartphone technology throughout the intervention period. The sample size was determined using a power analysis with 95% confidence level and 80% statistical power.

All participants provided written informed consent after receiving a comprehensive explanation of the study objectives, procedures, and their rights as voluntary participants. Data security was maintained through encrypted digital storage, anonymized participant identifiers, and restricted access protocols. These measures complied with the institutional ethical guidelines.

2.3. Study setting

The research was conducted across four distinct loci representing the geographical and sociodemographic heterogeneity of Lampung Province: Bandar Lampung City (urban setting), Central Lampung Regency (inland/remote area), East Lampung Regency (coastal area), and Tanggamus Regency (rural setting). This multi-site selection was deliberately designed to examine the acceptability and generalizability of the EWS_DMG innovation across varying sociocultural contexts, healthcare infrastructure levels, and digital literacy environments. Consequently, the study design enhanced the external validity of the findings.

2.4. Study variables

The independent variable was the utilization of the EWS_DMG application over an 8-week intervention period. The dependent variables encompassed four domains: i) technology acceptability, ii) knowledge regarding GDM, iii) adherence to management protocols including dietary regulation and physical activity, and iv) glycemic profile indicators. The glycemic profile indicators specifically included fasting plasma glucose (FPG) and 2-hour post-prandial glucose (2hPPG) levels.

2.5. Instruments

Technology acceptability was assessed using the System Usability Scale (SUS), a validated and internationally recognized instrument consisting of 10 items rated on a 5-point Likert scale (1–5), yielding composite scores ranging from 0 to 100. Score interpretation followed the adjective rating classification proposed by Bangor *et al.* [13] where scores ≥80.3 were categorized as Excellent and scores between 68 and 80.3 as good/acceptable. GDM knowledge was measured using a structured questionnaire developed based on current clinical guidelines and validated through expert panel review and pilot testing. Adherence to management protocols was evaluated using a validated compliance scale encompassing dietary and physical activity domains. Clinical data for FPG and 2hPPG were obtained through standardized laboratory examinations performed at accredited healthcare facilities at both pre-test and post-test phases.

2.6. Data collection procedures

During the baseline phase, demographic characteristics, knowledge scores, adherence levels, and glycemic profiles (FPG and 2hPPG) were assessed. Subsequently, respondents were provided with the EWS_DMG application, which incorporated automated educational content delivery, daily reminder notifications, glycemic self-monitoring features, and an early warning alert system for abnormal glucose values. Respondents utilized the application for a continuous period of 8 weeks under periodic supervision by trained research assistants. Upon completion of the intervention period, all dependent variables were reassessed, and respondents completed the SUS questionnaire to evaluate their experience with the technology.

2.7. Data analysis

The data were analyzed using statistical software with a significance level set at $\alpha = 0.05$. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were employed to characterize demographic profiles and SUS score distributions across study sites. The paired t-test was utilized to examine the statistical significance of mean differences in knowledge, adherence, FPG, and 2hPPG between pre-test and post-test measurements. Pearson's correlation coefficient was applied to analyze the association between technology acceptability scores SUS and the magnitude of 2hPPG reduction as a primary clinical effectiveness indicator.

3. RESULTS

Table 1 presents the baseline demographic and clinical characteristics of 200 respondents. The majority were aged 20–35 years (72.0%), consistent with peak reproductive age. Most were multiparous

(56.0%), and the majority were housewives (59.0%). Regarding pre-intervention glycemic status, 67.0% exhibited fasting plasma glucose exceeding 92 mg/dL, while 78.0% demonstrated two-hour postprandial glucose above 153 mg/dL, indicating a substantial proportion with hyperglycemia warranting intervention. These baseline data establish the clinical context for evaluating the EWSDMG innovation, suggesting that the study population represented a high-risk cohort requiring comprehensive GDM management across diverse healthcare settings in Lampung Province.

Table 1. Baseline demographic and clinical characteristics of respondents (n = 200)

Characteristics	Category	Frequency (n)	Percentage (%)
Mother's age	<20 years	12	6.0
	20–35 years	144	72.0
	>35 years	44	22.0
Parity	Primipara (1)	68	34.0
	Multipara (2–4)	112	56.0
	Grandemultipara (>4)	20	10.0
Work	Work	82	41.0
	Not working (Housewife)	118	59.0
Baseline glycemic status	GDP >92 mg/dL	134	67.0
(Pre-Intervention)	GD2PP >153 mg/dL	156	78.0

Table 2 presents the distribution of SUS scores across four healthcare facilities representing distinct regional characteristics in Lampung Province. The urban site (Bandar Lampung City) achieved the highest mean SUS score (82.4 ± 5.2), classified as "Excellent," suggesting greater digital literacy and infrastructure readiness. Remote, coastal, and rural sites scored between 74.5 and 78.2, all falling within the "Good/acceptable" range. The overall mean SUS score was 77.9 ± 6.4, indicating that the EWSDMG innovation was broadly acceptable across diverse geographical contexts. Notably, coastal areas (East Lampung) demonstrated the lowest score with highest variability, potentially reflecting limited technological access. These findings suggest that while the innovation is generally usable, targeted support for non-urban settings may enhance adoption equity.

Table 2. Distribution of technology acceptability scores (SUS) based on research locus (n = 200)

Research locus	Regional characteristics	Average SUS score	Elementary school	Interpretation
Bandar Lampung City	Urban	82.4	5.2	Excellent
Central Lampung Regency	Remote	76.8	6.1	Good/acceptable
East Lampung Regency	Coastal	74.5	7.4	Good/acceptable
Tanggamus Regency	Rural	78.2	6.8	Good/acceptable
Total average	—	77.9	6.4	Good/acceptable

Excellent ≥80.3; Good/acceptable 68–80.3.

Table 3 demonstrates statistically significant improvements in both knowledge and compliance scores following the EWSDMG intervention. GDM management knowledge increased substantially from a pre-test mean of 62.45 (SD = 10.21) to a post-test mean of 88.72 (SD = 5.84), yielding a mean difference of +26.27 points ($p < 0.001$). Similarly, management compliance scores rose from 58.21 (SD = 12.14) to 82.56 (SD = 7.42), with a mean difference of +24.35 points ($p < 0.001$). The reduced standard deviations post-intervention indicates more homogeneous performance among participants. These findings, confirmed through paired t-tests at $\alpha = 0.05$, provide robust evidence that the EWSDMG digital innovation effectively enhanced both cognitive understanding and adherence to GDM management protocols among the 200 participants across Lampung Province healthcare facilities.

Table 4 demonstrates statistically significant reductions in both glycemic parameters following the EWSDMG intervention. Fasting plasma glucose (GDP) decreased by 13.3 mg/dL (from 105.4 ± 12.6 to 92.1 ± 8.3 mg/dL; $p = 0.002$), while two-hour postprandial glucose (GD2PP) decreased by 22.2 mg/dL (from 148.7 ± 20.4 to 126.5 ± 14.2 mg/dL; $p = 0.001$). Both reductions were statistically significant at $\alpha = 0.05$ using paired t-tests. The greater reduction in postprandial glucose suggests the intervention was particularly effective in improving glucose regulation after meals. Additionally, decreased standard deviations in post-test values indicate more consistent glycemic control among participants, supporting the effectiveness of the EWSDMG digital innovation in managing gestational diabetes mellitus.

Table 3. Analysis of differences in knowledge and compliance scores of DMG management before and after the EWS_DMG intervention (n = 200)

Variables	Stage	Mean	Elementary school	SE	Δ Mean	p-value
DMG knowledge	Pre-test	62.45	10.21	0.72	+26.27	<0.001*
	Post-test	88.72	5.84	0.41		
Management compliance	Pre-test	58.21	12.14	0.85	+24.35	<0.001*
	Post-test	82.56	7.42	0.52		

Analysis using paired t-test; significant at α = 0.05.*

Table 4. Changes in respondents' glycemic profile before and after the EWS_DMG intervention (n = 200)

Clinical variables	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Mean decrease (mg/dL)	p-value
GDP (mg/dL)	105.4 ± 12.6	92.1 ± 8.3	13.3	0.002*
GD2PP (mg/dL)	148.7 ± 20.4	126.5 ± 14.2	22.2	0.001*

Analysis using paired t-test; significant at α = 0.05.*

Table 5 presents a Pearson correlation analysis examining the relationship between technology acceptability (SUS score) and decrease in GD2PP levels among 200 participants. The analysis yielded a correlation coefficient of r = 0.642, classified as strong according to Dancey and Reidy [14] framework. The association was statistically significant (p < 0.001), well below the α = 0.05 threshold. These findings indicate that higher technology acceptability is positively associated with greater reductions in GD2PP levels. Participants who perceived the technology as more usable demonstrated more substantial glycemic improvements, suggesting that user acceptance plays a meaningful role in optimizing clinical outcomes in diabetes management interventions.

Table 5. Correlation analysis between technology acceptability score (SUS) and decrease in GD2PP Levels (n = 200)

Paired variables	r (Pearson correlation)	Strength of correlation	p-value
SUS score vs GD2PP decline	0.642	Strong	<0.001*

Analysis using Pearson's correlation coefficient; significant at α = 0.05. Interpretation of correlation strength based on Dancey & Reidy's classification: 0.60–0.79 = Strong. *

4. DISCUSSION

The findings of this study demonstrate that the EWS_DMG innovation constitutes an effective technology-based intervention for improving knowledge, treatment adherence, and glycemic control among pregnant women with GDM across diverse geographical contexts in Lampung Province. These findings are discussed in relation to the existing literature. Such discussion helps to contextualize the study results within the broader body of evidence.

The overall SUS score of 77.9 ± 6.4 (Good/acceptable) with urban Bandar Lampung achieving the highest score (82.4, Excellent) suggests that digital health interventions can be successfully implemented across varied settings. mHealth and telemedicine platforms can effectively improve glycemic control and diabetes self-management, although they cautioned about limited assessment of digital health literacy appropriateness [15]-[17]. The lower scores in coastal (74.5) and remote (76.8) areas likely reflect infrastructure and digital literacy disparities. Only 25% of GDM-related interventions scored successfully on digital health literacy assessment [18].

The significant increase in knowledge (+26.27 points, p < 0.001) and adherence (+24.35 points, p < 0.001) scores following the 8-week intervention is consistent with multiple studies demonstrating the effectiveness of structured educational interventions. Highly significant improvements in total knowledge scores and health-promoting behaviors among gestational diabetic women following a lifestyle coaching program (p < 0.001) [19]-[21]. Counseling significantly improved knowledge and compliance among diabetes mellitus patients using paired t-test analysis (p < 0.001) [22]. Furthermore, social media-delivered diabetes education significantly increased knowledge scores from 68.3% to 76.7% (p < 0.001) in the intervention group, alongside positive improvements in attitudes and self-care activities [23], [24]. The reduction in standard deviation observed in post-test scores in the current study indicates homogenization of understanding [25]-[27].

The significant reductions in FPG (13.3 mg/dL, p = 0.002) and 2hPG (22.2 mg/dL, p = 0.001) represent clinically meaningful improvements. Exercise interventions significantly reduced fasting blood glucose levels in GDM patients (p < 0.001), supporting the principle that structured interventions can achieve measurable glycemic improvements [28]-[30]. The post-intervention FPG approaching the IADPSG threshold (92.1 mg/dL) suggests that the EWS_DMG intervention facilitated near-normalization of glycemic parameters, which is critical for reducing adverse maternal and neonatal outcomes [31].

The strong positive correlation between SUS scores and 2hPG reduction ($r = 0.642$, $p < 0.001$) represents a novel and significant finding, indicating that user acceptance directly influences clinical effectiveness. Engagement with digital health platforms enhances glycemic outcomes, as women in intervention groups transmitted more glucose measurements and reported greater health engagement [32]. The coefficient of determination ($r^2 = 0.412$) suggests that technology acceptability explains 41.2% of variance in glycemic improvement, highlighting the critical importance of user-centered design in digital health interventions for GDM management.

4.1. Limitations and implications

The use of a single-group pre-test/post-test quasi-experimental design without a control group in this study is a limitation that needs to be explicitly acknowledged, as it could compromise the internal validity of the findings. However, the choice of this design is justified based on several operational and ethical considerations. First, implementing a randomized controlled trial (RCT) across four geographically dispersed research sites in Lampung Province covering urban, inland, coastal, and rural areas faces substantial logistical challenges in terms of randomization and providing an equivalent control group. Second, ethically, withholding access to digital health interventions for pregnant women with diagnosed GDM poses potential clinical risks. However, without a control group, threats to internal validity such as maturation effects, regression to the mean, and the influence of co-interventions (e.g., routine antenatal care) cannot be completely ruled out as alternative explanations for the observed improvements.

5. CONCLUSION

The EWS_DMG demonstrated effectiveness in improving knowledge ($\Delta = +26.27$; $p < 0.001$), treatment compliance ($\Delta = +24.35$; $p<0.001$), and glycemic control among pregnant women with GDM in Lampung Province over eight weeks. Fasting plasma glucose decreased by 13.3 mg/dL ($p = 0.002$) and postprandial glucose by 22.2 mg/dL ($p = 0.001$). Technology acceptability was favorable across urban, rural, remote, and coastal settings (SUS score: 77.9 ± 6.4). A strong correlation between acceptability and glycemic improvement ($r = 0.642$; $p < 0.001$) confirmed user acceptance as a critical determinant of clinical outcomes, supporting broader implementation of digitally mediated, context-adaptive GDM interventions.

ACKNOWLEDGMENTS

The authors express sincere gratitude to the Health Research Ethics Committee of Malahayati Lampung University, the Director of Poltekkes Kemenkes Tanjungkarang, all participating healthcare facilities across Bandar Lampung, Central Lampung, East Lampung, and Tanggamus, the trained research assistants, and all respondents whose voluntary participation made this study possible.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

All research procedures upheld the fundamental principles of research ethics and received formal approval from the Health Research Ethics Committee of Malahayati Lampung University under protocol number 7851/EC/KEP-UNIMAL/V/2026.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AA], upon reasonable request.

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