International Journal of Evaluation and Research in Education (IJERE)
Vol. 15, No. 2, April 2026, pp. 1426~1434
ISSN: 2252-8822, DOI: 10.11591/ijere.v15i2.38353

Impact of competency-based teacher education on mathematical conceptual understanding in Kenyan teacher training colleges

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Article Info

Article history:

Received Dec 20, 2025
Revised Mar 12, 2026
Accepted Apr 2, 2026

Keywords:

Competency-based teacher education
Conceptual understanding
Instructional approaches
Learner-centered pedagogy
Mathematics instruction
Pre-service teachers

ABSTRACT

Pre-service teachers of mathematics must be systematically prepared as effective teachers through structured instruction that targets conceptual understanding and enables them to develop the competencies needed to address real-world problems. This paper reports the findings from a study aimed at assessing the impact of competency-based teacher education (CBTE) on mathematical conceptual understanding among pre-service teachers in Kenyan teacher training colleges (TTCs). The study was guided by scientific management and constructivist theories, emphasizing structured instructional planning and learner-centered facilitation. A mixed-methods research design was employed to collect data from 371 pre-service teachers using questionnaires and interviews. Quantitative data were analyzed using descriptive and inferential statistics, while qualitative data were analyzed thematically. The study revealed a significant positive association between CBTE variables and pre-service teachers' mathematics conceptual understanding (Spearman's $rho_{(371)}=0.198$, $p<0.05$). Further, regression analysis indicated that CBTE instructional practices significantly predicted pre-service teachers' conceptual understanding ($F_{(7,363)}=7.791$, $p<0.05$), accounting for 13.1% of the variance. Qualitative findings corroborated these results, showing that learner-centered and technology-supported instruction enhances conceptual understanding. The findings suggest that holistic and coherent CBTE implementation can enhance trainees' understanding of mathematics concepts.

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1. INTRODUCTION

Competency-based teacher education (CBTE) is a training framework used by educators to guide pre-service teachers to acquire and demonstrate competencies essential for their future teaching careers [1]. The relevance of CBTE in fostering mastery of explicitly defined competencies by trainees has led to its widespread recognition in training institutes worldwide [2]. The need to balance procedural fluency and conceptual understanding has long driven reforms in mathematics education, with conceptual comprehension reflecting a coherent grasp of concepts to support reasoning, transfer, and justification of processes [3]. In Kenya, the goal of competency-based education (CBE), which is accomplished through competency-based curriculum (CBC), is to foster transferable skills across different grades, though various studies point to potential implementation issues based on teacher preparation, assessment alignment, and resource sufficiency [4], [5]. The need for systemic reforms in teacher professional development and evidence-based assessment practices highlights how teaching methods shape learning outcomes, reinforcing the importance of deliberate, topic-specific instructional planning for conceptual understanding in mathematics [6]. CBTE instruction that explicitly focuses on mathematical subject matter and encourages reflection on key concepts has been recognized as effective for learning, with students' conceptual understanding demonstrated through formative assessment practices that elicit their ideas and provide meaningful feedback [7]. Under CBTE, concepts should be explicitly addressed, with teaching revealing not just processes but also underlying concepts, while performance and reality-based tasks should allow students to demonstrate proficiency to solve real-world problems [8]. A systematic review on problem-and project-based learning indicates that such environments can support critical and higher-order thinking, while also revealing persistent conceptual ambiguity, inconsistent measurement, and methodological weaknesses [9], thereby justifying the need to investigate conceptual understanding of mathematics among pre-service teachers.

The mismatch between teacher training and the instructional needs of mathematics classrooms has prompted curriculum reforms, also underscoring the need for further research on CBTE, to guide policy and address concerns about the quality of mathematics teacher graduates [10]. CBTE supports the development of 21st century skills in pre-service teachers, enabling them to create detailed lesson plans and implement diverse instructional and assessment strategies that promote sustainable mathematics learning [11]. CBTE is useful for a customizable pace, allowing students to progress at varying speeds, and requires formative assessment for learning to occur proximally to instruction to modify teaching in real time and support conceptual change [12]. CBTE performance tasks can also generate safe spaces for productive struggle, enabling structured engagement with desirable challenges to improve competency attainment.

Several studies report improvements in teachers' ability to plan for conceptual targets and suggest ways to enhance mathematics teaching aligned to competencies and assessment rubrics for conceptual reasoning [13], with links between teacher professional competence, instructional quality, and student outcomes [14]. However, when curriculum implementation approaches are not closely matched with competency-based principles, there are risks of superficial adoption in Kenya. Even though CBTE has the potential to revolutionize mathematics education, teacher candidates' capacity to grasp mathematical concepts deeply is still lacking, and there is limited research on CBTE implementation amid challenges such as insufficient training, lack of resources, poor government support, and misalignment between intended competencies and assessment practices [15], [16]. Therefore, this study explored the implementation of CBTE instructional approaches in mathematics, focusing on their impact on pre-service teachers' conceptual understanding. Ncube and Luneta [17] demonstrate that concept-based instruction fosters deep understanding, critical thinking, and transferable skills, supporting CBTE in teacher preparation by showing that structured, concept-focused teaching can enable pre-service teachers to develop strategies that address learners' conceptual gaps. There are still concerns about how well CBTE-aligned approaches support student trainees' mathematical conceptual comprehension in Kenya, and if this issue is not intentionally addressed, mathematics teachers may continue to prioritize procedural fluency over conceptual understanding, contrary to the CBC's mission. This article emphasizes the need to strengthen teacher preparation, ongoing professional development, and institutional support to ensure effective implementation of learner-centered mathematics instruction, which is essential for building teachers' competence and confidence in promoting conceptual understanding.

2. THEORETICAL UNDERPINNING

The study integrates theories of scientific management and constructivism to provide a balanced framework for developing competent teachers. Scientific management operates subtly in higher education, driving professional preparation, growth, and maturity [18]. These principles align with CBTE through structured learning pathways, measurable competencies, and systematic monitoring of trainee progress [19], though their mechanistic tendencies may constrain creativity and teacher autonomy within CBE contexts [20]. Constructivism views learning as active and socially mediated [21], emphasizing engagement and knowledge co-construction that enhance mathematical understanding. Although constructivism faces challenges such as time, assessment, and resource constraints, these can be mitigated by integrating it with the efficiency-focused tenets of scientific management [22]. Figure 1 shows the conceptual framework where students' conceptual understanding in mathematics is shaped by instructional practices enhanced through CBTE implementation.

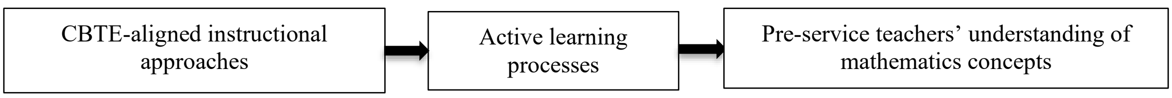

Figure 1. Conceptual framework

3. METHOD
3.1. Participants and procedure
The study adopted a mixed methods research design to enabled the collection and analysis of information obtained to address the research question holistically. The study purposively [23] selected public teacher training colleges (TTCs) implementing CBTE to ensure relevance, excluding private colleges for consistency, which may limit generalizability. Third-year student teachers were selected because their advanced pedagogical content knowledge and sustained engagement in practicum and mentored microteaching [24] enable them to meaningfully reflect on CBTE instructional practices in mathematics. The sample size was determined using the Yamane model [25], resulting in 371 student teachers drawn from a population of 5,074 across the selected colleges. Data were collected using both quantitative and qualitative approaches, and in this paper, qualitative findings complementing the quantitative results.

3.2. Instruments
Primary data were collected using a structured questionnaire and a semi-structured interview guide. The questionnaire comprised both closed-ended and open-ended items to capture participants' perceptions of CBTE in mathematics instruction. Closed-ended items generated quantitative data, while open-ended items yielded qualitative insights to complement the numerical findings. A pilot study was conducted in one TTC outside the study region to establish the validity and reliability of the instruments. Content and construct validity were ensured through expert consultation and alignment with CBE theory, while reliability was confirmed using Cronbach's alpha, which yielded a coefficient of 0.749, indicating strong internal consistency [26]. Feedback from the pilot was used to refine the instruments for the main study.

3.3. Data analysis
Quantitative data were analyzed through descriptive and inferential statistics using SPSS version 25. Trainees' perceptions were rated as 5=strongly agree, 4=agree, 3=not sure, 2=disagree, and 1=strongly disagree. Inferential analysis utilized multiple regression and correlation to determine whether statistically significant relationships exist among the variables. Qualitative data obtained through interviews and open-ended questionnaire responses were analyzed thematically through an inductive approach, involving multiple readings to generate initial codes, which were systematically organized into a coding framework, reviewed by a second independent coder to establish inter-rater agreement, and then grouped into broader categories and synthesized into overarching themes [27], that directly complemented the quantitative results presented in different sections. The model equation for analysis:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \varepsilon$$

Where, Y=understanding of mathematical concepts under CBTE, refers to the extent to which pre-service teachers can accurately explain, apply, and connect key mathematical concepts in problem-solving and instructional contexts, reflecting both their own conceptual comprehension and their ability to design and deliver lessons that foster conceptual understanding in learners. X1=support to struggling learners, X2=use of technology and real-life problems, X3=use of instructional materials, X4=learner participation, X5=alignment of assessments with CBE, X6= specific CBTE approach, X7=general teaching methods. In the model, β_0 represents the baseline level of conceptual understanding when all CBTE instructional practices are absent. The regression coefficients $\beta_1\ to\ \beta_7$ indicate the unique contribution of each instructional practice to understanding. The error term ε captures unexplained variance attributable to other factors not included in the model. Correlation utilized Spearman's rank formula:

$$rho(p) = 1 - \frac{6\sum di^2}{n(n^2-1)}$$

Where, p is the Spearman correlation coefficient, di is the difference between the paired ranks of the variables for participant i, and n=371.

4. RESULTS AND DISCUSSION
4.1. Descriptive statistics and normality assessment
The assumptions of Spearman's rank-order correlation were assessed. CBTE-aligned instructional approaches had a mean score of 24.53, with negative skewness (-1.028) and kurtosis (1.692). Understanding of mathematical concepts had a mean of 3.81, with negative skewness (-1.077) and kurtosis (0.476). These

values indicated a deviation from normality, supporting the use of Spearman's correlation for subsequent analyses [28].

4.2. Correlation analysis between CBTE approaches and conceptual understanding

The rank correlation, as shown in Table 1 (monotonic relationship), indicates a statistically significant, positive correlation between CBTE approaches in mathematics and pre-service teachers' understanding of mathematical concepts (rho=0.198, $p<0.01$). This confirms that teaching using CBTE approaches improves trainees' understanding of mathematical concepts. The analysis, as seen in Table 2, applied two significance thresholds: $p<0.05$ indicates acceptable evidence of a meaningful association, $p<0.01$ provides stronger evidence with a reduced likelihood that the observed relationships occurred by chance, which is appropriate for studies where distinguishing varying levels of significance enhances the interpretive clarity and robustness of statistical findings [29]. The correlation strengths ranged from rho≃0.1 to rho≃0.4; the widespread interrelationships, particularly among Items (1, 2, 4, 5, 6, and 7) having strong interconnections, suggest that these elements reinforce one another to enhance learners' conceptual understanding. The need for improvement is strongly linked across different methods (items 6 and 7, rho=0.423**, $p<0.01$). The strong interrelationships among these items indicate that trainees perceive CBTE approaches as interconnected, underscoring the need for high-quality, holistic pedagogical implementation. These significant correlations suggest that CBTE strategies should be integrated rather than applied in isolation to generate a synergistic effect on learner engagement and academic outcomes. The findings indicate that the CBTE framework is most effective when diverse instructional strategies are implemented synergistically to enhance student outcomes [30], particularly when modern tools and authentic learning contexts are integrated into mathematics instruction [31]. This interpretation is consistent with previous studies that emphasize teaching for understanding and the use of explicit problem-solving strategies as the foundation of effective competency-based pedagogy in mathematics [32].

Table 1. Overall Spearman rank correlation between CBTE approaches and pre-service teachers' mathematical conceptual understanding (N=371)

Variables	Statistics	CBTE approaches	Conceptual understanding of mathematics.
CBTE-aligned instructional approaches	Correlation coefficient	1.000	0.198**
	Sig. (2-tailed)		0.000
Conceptual understanding of mathematics.	Correlation coefficient	0.198**	1.000
	Sig. (2-tailed)	0.000	

**Correlation is significant at the 0.01 level (2-tailed)

Table 2. Spearman's rank correlations between CBTE approaches and pre-service teachers' mathematics conceptual understanding (N=371)

Variables	Statistics	1	2	3	4	5	6	7
1	rho	1.000	0.277**	0.152**	0.212**	0.134**	0.115*	0.165**
	Sig.	.	0.000	0.003	0.000	0.010	0.027	0.001
2	rho	0.277**	1.000	0.175**	0.205**	0.221**	0.223**	0.206**
	Sig.	0.000	.	0.001	0.000	0.000	0.000	0.000
3	rho	0.152**	0.175**	1.000	0.147**	0.105*	0.081	0.085
	Sig.	0.003	0.001	.	0.005	0.042	0.121	0.100
4	rho	0.212**	0.205**	0.147**	1.000	0.129*	0.232**	0.152**
	Sig.	0.000	0.000	0.005	.	0.013	0.000	0.003
5	rho	0.134**	0.221**	0.105*	0.129*	1.000	0.065	0.159**
	Sig.	0.010	0.000	0.042	0.013	.	0.211	0.002
6	rho	0.115*	0.223**	0.081	0.232**	0.065	1.000	0.423**
	Sig.	0.027	0.000	0.121	0.000	0.211	.	0.000
7	rho	0.165**	0.206**	0.085	0.152**	0.159**	0.423**	1.000
	Sig.	0.001	0.000	0.100	0.003	0.002	0.000	.

**Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).
1=support to struggling learners, 2=use of technology and real-life problems, 3=understanding of mathematics concepts, 4=use of instructional materials, 5=alignment of assessment with CBE, 6=specific CBTE instructional approach, 7=general teaching methods.

Collectively, the results reinforce existing evidence that experiential, inquiry-driven, and context-based pedagogies enable learners to actively engage with, manipulate, and reason through mathematical ideas, thereby supporting the development of competencies grounded in authentic conceptual understanding rather than procedural recall [33]. The analysis also revealed some positive but non-significant relationships that, while not meeting the established alpha thresholds, offer important pedagogical insights into CBTE implementation. For instance, the association between items 3 and 7 (rho=0.085, $p>0.05$; items 5 and 6, rho=0.065, $p>0.05$) suggest that although current instructional approaches may support basic conceptual comprehension, tutors need to explicitly align instructional strategies with competency outcomes rather than assuming understanding alone equates to competence. The findings indicate that existing practice opportunities may be insufficiently structured or aligned with instructional goals, reinforcing evidence from the literature that effective mathematics instruction must be authentic, reflective, and closely aligned with competency-based principles to enhance learning outcomes [34].

4.3. Regression analysis of CBTE approaches and conceptual understanding

All key assumptions of multiple linear regression were tested and satisfied, as in Tables 3 and 4, with variance inflation factor (VIF) values ranging from 1.084 to 1.454, indicating low multicollinearity among the predictors. These values are well below accepted thresholds, confirming that intercorrelations among CBTE instructional practices did not adversely affect the stability or interpretation of the regression results. The regression results indicate a modest explanatory power of 13.1% of pre-service teachers' conceptual understanding, as seen in Table 3, to be accounted for by the analyzed CBTE approaches ($R=0.361$; $R^2=0.131$; adjusted $R^2=0.114$). The overall regression, as shown in Table 5, was statistically significant ($F(7, 363)=7.791$, $p<0.05$), suggesting that while CBTE instructional practices make a meaningful contribution, a substantial proportion of variance in conceptual understanding is likely attributable to contextual, learner-level, and institutional factors not captured in the present model. The results show that current practices exhibit substantive gaps in translating competency-based instruction into measurable conceptual understanding.

Table 3. Model summary for regression analysis between CBTE approaches and pre-service teachers' conceptual understanding of mathematics

Model	R	R square	Adjusted R square	Std. Error of the estimate	Durbin-Watson
1	0.361	0.131	0.114	1.075	1.932

Table 4. Regression coefficients of CBTE approaches predicting pre-service teachers' understanding of mathematical concepts

Model 1	Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
(Constant)	1.198	0.433		2.765	0.006		
Support to struggling learners	0.227	0.063	0.189	3.598	0.000	0.864	1.157
Use of technology and real-life problems	0.242	0.068	0.187	3.535	0.000	0.855	1.169
Use of instructional materials	0.122	0.071	0.090	1.717	0.087	0.879	1.138
Learner participation	-0.059	0.057	-0.056	1.047	0.296	0.822	1.216
Alignment of assessments with CBE	0.144	0.054	0.137	2.683	0.008	0.922	1.084
Specific CBTE approach	-0.064	0.057	-0.062	1.112	0.267	0.758	1.319
General teaching methods	0.001	0.066	0.001	0.015	0.988	0.688	1.454

Table 5. Analysis of variance (ANOVA) for the effect of CBTE approaches on pre-service teachers' conceptual understanding of mathematics

Model	Source of variations	Sum of squares	df	Mean square	F	Sig.
1	Regression	62.980	7	8.997	7.791	0.000
	Residual	419.187	363	1.155		
	Total	482.167	370			

In Table 4, targeted instructional supports significantly predicted pre-service teachers' conceptual understanding, strategies for struggling learners ($\beta=0.189$, $p<0.05$), integration of technology and real-life problems ($\beta=0.187$, $p<0.05$), and alignment of assessments with CBE expectations ($\beta=0.137$, $p<0.05$). This suggests that supportive pedagogy, contextualized learning, and assessment alignment meaningfully enhance conceptual understanding. The study also found that CBTE instructional practices such as use of instructional materials ($\beta=0.090$, $p>0.05$), learner participation ($\beta=-0.056$, $p>0.05$), general teaching methods ($\beta=0.001$, $p>0.05$), and overall CBTE instructional approach ($\beta=-0.062$, $p>0.05$) did not yield significant effects, indicating that participatory learning and pedagogical shifts remain insufficient without targeted scaffolding, contextualization, and assessment coherence. These findings indicate that CBTE instructional practices like learner participation and general teaching methods only enhance conceptual understanding when deliberately structured, scaffolded, and aligned with learning goals, as evidenced by CBE outcomes showing improved problem-solving, critical thinking, and reflective learning when supported by feedback, collaborative tasks, and effective use of resources [35]; challenges such as limited teacher preparation and inadequate resources explain why participatory elements alone may not yield significant gains, highlighting the need for coherent instructional design and sustained professional development.

4.4. CBTE approaches for promoting conceptual understanding and learner engagement in mathematics

Participants' interview accounts highlighted that CBTE instructional approaches enhance learners' conceptual understanding through collaboration and application of mathematics knowledge to real-life contexts. Conceptual understanding is further strengthened when learners are grouped according to ability levels to tailor support and ensure instruction meets diverse competency needs. They further noted that such approaches cultivate positive attitudes toward mathematics. For example, beginning lessons with songs can reduce anxiety, build interest, and create an emotionally supportive learning environment.

> "*Learner-centered approaches help learners to apply the knowledge learnt in mathematics to the immediate environment and the community.*" (Informant 31, 2025)
> "*We group learners according to their abilities to understand concepts.*" (Informant 23, 2025)
> "*We have to instill positive attitudes in learners. Sometimes you can introduce your lesson with a song to help learners get into the right mindset to learn mathematics.*" (Informant 30, 2025)

These findings suggest that mathematics educators should prepare future teachers to differentiate instruction based on competency levels to strengthen their ability to deliver inclusive, engaging, and contextually meaningful lessons.

4.5. CBTE approaches role in enhancing conceptual understanding through technology and real-world applications

Pre-service teachers reported that CBTE approaches significantly support their understanding of mathematics instruction. One trainee described using digital tools, such as YouTube videos, to provide visual demonstrations of operations like addition, illustrating how technology can clarify complex concepts. Others highlighted the importance of facilitating learning accurately by using supplementary resources strategically.

> "*When teaching addition, you can search for videos for learners to watch to improve their understanding.*" (Informant 22, 2025)
> "*I will use group work and peer demonstration. I can make the classroom shop in the class, then we can demonstrate the selling for better understanding.*" (Informant 35, 2025)
> "*In the strand about numbers, we have learnt to use real objects: sticks and bottle tops. They make learning numbers very easy. I would love to use them during teaching.*" (Informant 24, 2025)

The findings indicate that CBTE's focus on competency development, rather than rote content transmission, equips pre-service teachers with practical pedagogical skills for translating abstract mathematical concepts into meaningful learning experiences. To enhance pre-service teachers' understanding and satisfaction, CBTE instructional approaches should be strengthened by embedding skill-based practice as a visible and integral component of every lesson, ensuring that such activities are clearly perceived as directly supporting learning outcomes [36].

4.6. Summary of the findings

CBTE approaches demonstrated a statistically significant but modest contribution to pre-service teachers' conceptual understanding of mathematics, accounting for 13.1% of the variance, consistent with evidence that learner-centered instructional strategies promote deeper conceptual understanding [37]. Only targeted instructional supports, such as scaffolding for struggling learners, integration of technology and real-life contexts, and alignment of assessment with CBE expectations, significantly predicted conceptual understanding, underscoring the importance of structured support, contextualization, and assessment coherence in deep learning [17]. Broad CBTE practices, such as teaching methods, learner participation, and use of instructional materials, were not significant predictors of conceptual understanding, indicating that competence-based reforms may remain superficial without pedagogical coherence and targeted teacher training in learner-centered mathematics instruction [38]. The findings suggest that CBTE functions as an integrated system in which the synergistic use of technology, authentic tasks, differentiated instruction, positive learning environments, and formative assessment enhances conceptual understanding, reinforcing evidence on the importance of structured teacher training for effective CBE in Kenya [4].

5. CONCLUSION

This study concludes that CBTE-aligned instructional practices significantly contribute to students' conceptual understanding of mathematics, though their impact remains modest due to inconsistent and fragmented implementation. Conclusive evidence indicates that conceptual understanding alone is insufficient to ensure competence unless instruction explicitly promotes application, reasoning, and demonstration of mathematical principles. Isolated use of CBTE strategies limits their collective effectiveness, underscoring the necessity of a holistic and systematic pedagogical approach. Mathematics educators and TTCs should prioritize structured professional development, targeted instructional supports, integration of technology and real-life problem-solving, and alignment of assessments with competence-based curricula. Policymakers are encouraged to provide supportive frameworks, allocate resources, and offer clear guidance, while communities of practice, including curriculum developers, teacher mentors, and professional networks, should collaborate to share best practices, monitor implementation, and promote continuous improvement. Remaining gaps related to institutional, contextual, and learner-level factors highlight the need for longitudinal and implementation-focused research, making this study both a practical and theoretical guide for enhancing mathematics teacher education and for informing scalable, context-sensitive CBTE strategies in future investigations.

ACKNOWLEDGEMENTS

We acknowledge the support of institutions and authorities that authorized this study, the pre-service teachers from selected public TTCs in the Eastern Region for their participation, and academic supervisors and colleagues for their guidance, constructive feedback, and encouragement.

FUNDING INFORMATION

The 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

The authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all participants included in this study.

ETHICAL APPROVAL

This study received approval from the Board of Postgraduate Studies at the University of Embu, after which ethical clearance was obtained from Chuka University (NACOSTI/NBC/AC-0812). These documents were used to obtain an authorization with research license no (NACOSTI/P/25/4177932) from the National Commission for Science, Technology and Innovation (NACOSTI) in Kenya.

DATA AVAILABILITY

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

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