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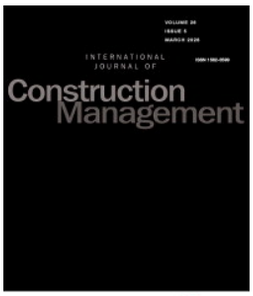

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Critical strategies for building urban community resilience through public-private partnerships: a system dynamics modelling

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ABSTRACT

Public–private partnerships (PPPs) are frequently recommended for strengthening urban community resilience; however, empirical evidence on how PPPs achieve this goal is limited. This study identifies and evaluates practical strategies through which PPPs can enhance the economic, social, and environmental resilience of urban communities. An international questionnaire survey was conducted among experts with experience in resilience and PPP practices. Forty-three valid responses were analysed using the Kendall coefficient of concordance and an ANOVA to assess consensus on the importance of strategy. A system dynamics model was then used to examine the impact of the strategies on PPP's success in building urban community resilience. Employing highly skilled and competent workmanship in in-service operations emerged as the most influential strategy. Other critical strategies include the development of efficient communication and coordination policies, developing strong governance and institutional capacity, practising and simulating any preparedness actions and policies, and developing a practical business continuity plan for disaster-prone areas. The study translates broad recommendations into an evidence-based roadmap that governments and private operators can adopt when structuring PPPs for urban resilience. This is the first empirical study to link specific PPP strategies with measurable contributions to urban community resilience, providing actionable guidance for policy and practice.

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Public-private partnership; urban community; resilience; partnerships; system dynamics; disaster management

Introduction

Currently, more people live in urban areas than ever before (Lewis and Mioch 2005). Urban communities rely on critical infrastructure services, including transportation, electricity, telecommunications, and water supply. These infrastructures are essential lifelines for cities, including municipal public engineering systems (Zhou et al. 2021). Rapid urban growth and climate change affect the economic and social aspects of urban communities, increasing their vulnerability to disasters (Feofilovs and Romagnoli 2021). The concentration of people in hazardous areas makes urban communities susceptible to environmental, natural, and technological risks (Lewis and Mioch 2005).

Recently, the public-private partnership (PPP) approach has gained traction in disaster management, especially in enhancing urban community resilience (UCR) (Osei-Kyei et al. 2024). This approach enables collaboration between government or local authorities and the private sector, facilitating the sharing of resources and information to build resilience in urban communities (Osei-Kyei et al. 2023). In PPP arrangements for urban community resilience, the private sector contributes technical knowledge, finance, and specialised expertise, while the government provides policy support and a framework for building resilience (Osei-Kyei et al. 2023). Such collaboration enables countries to work effectively with the private sector in providing adequate response and recovery for urban communities following unexpected events. Thus, the PPP concept has become crucial in addressing the challenges related to financial resources and expertise required for building resilient cities (Ampratwum et al. 2024).

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For practitioners to successfully build urban community resilience through collaboration between the public and private sectors, effective strategies must be explored and empirically tested. The public and private sectors often have different goals and expectations when engaging in contractual arrangements. Hence, if proper measures and strategies are not established, the partnership will likely fail, resulting in negative consequences (Ampratwum et al. 2024). Having comprehensive information on resilience strategies will enable both government and private sectors to implement practical measures that enhance the success of PPPs in building urban community resilience (Osei-Kyei et al. 2024).

While a significant body of literature (e.g. Babatunde et al. 2012; Cheung et al. 2012) discusses success factors and strategies for adopting PPPs, many focus on infrastructure projects without addressing the resilience-building aspect. Additionally, previous studies have treated PPP as a procurement tool rather than a mechanism for resilience building in urban communities and disaster management (Ampratwum et al. 2024; Osei-Kyei et al. 2024). As the demand for governments to adopt practical approaches for addressing urban disaster crises increases, a comprehensive investigation is necessary to identify effective strategies for utilising PPPs in building stronger urban community resilience (Osei-Kyei et al. 2024).

Against this background, two research questions are formulated:

1. How can urban community resilience be developed using the PPP approach? Specifically, what are the strategies?
2. How do these resilience strategies relate to each other to inform practice?

This paper addresses the above stipulated questions by examining the critical strategies within PPP frameworks for enhancing urban community resilience. Based on data from a global survey, it thoroughly examines the impact of these strategies on the success of partnerships for UCR using system dynamics modelling. The results of this study will provide government authorities, non-governmental organisations, and private developers with practical measures and approaches to ensure the effective recovery of urban communities after unexpected incidents.

Literature review of strategies for building urban community resilience through PPPs

Urban communities face unique problems in recovery efforts from disruptive events. Urban resilience implies the management of infrastructure and governance systems in the long term, where communities continuously learn and adapt to rebuild after a disruptive event (Yabe et al. 2021). The long-term planning of UCR necessitates developing strategies to guide the implementation of PPPs over the long term. Although the concept of PPP in UCR is relatively new, some studies have explored resilience strategies that could be useful for adopting PPP in community resilience building.

For example, Saja et al. (2021) assessed social resilience in disaster management in Sri Lanka. Their data analysis revealed six potential surrogates for measuring social resilience. Hung et al. (2016) researched community participation in the integrated assessment of resilience to climate-related hazards in metropolitan land-use management. Xu et al. (2020) developed a network structuring model for community resilience in Nanning. Using neighbourhood, college, and village communities as case studies, the study found that neighbourhood communities were the most resilient to urban flooding, followed by college and village communities.

Others focused on the analytical measures to enhance UCR in PPPs. Johansen et al. (2017) studied metrics for evaluating and improving community resilience. They grouped their metrics into community-level, sector-specific, or sociological categories. Podesta et al. (2021) quantified community resilience based on fluctuations in visits to points of interest derived from digital trace data in Houston. They found that certain buildings exhibited higher resilience metrics, whereas others, such as medical facilities and entertainment venues, exhibited lower ones. Asmamaw et al. (2019) explored households' resilience to climate change-induced shocks in Ethiopia and developed a climate resilience index based on absorptive, adaptive, and transformative capacities. Moradi et al. (2021) developed effective environment indicators for improving the resilience of Mashhad neighbourhoods. DasGupta and Shaw (2015) developed an indicator-based approach to assess coastal communities' resilience against climate-related

Table 1. List of resilience strategies.

Strategies for building urban community resilience through PPP	References
Proper and efficient community needs assessment	Chi et al. (2015)
Practice preparedness actions	Scott and Coleman (2016); Osei-Kyei et al. (2024)
Vulnerability assessment	Auguste (2018)
Provide homes in risk-prone areas with seals of approval or risk scores based on their susceptibility to different hazards.	(Kousky and Kunreuther (2018)
Develop community maps delineating current and future risk	Osei-Kyei et al. (2024)
Information accessibility	Chandra et al. (2013)
Knowledge co-production	Bixler et al. (2021)
Efforts to locally contextualise disaster management information, including a greater understanding of local vulnerability and resilience	Chen et al. (2020)
Develop a community risk awareness program	Bajracharya et al. (2012)
Publishing/disseminating the objectives, benefits and implications of resilience strategies to all urban community	Osei-Kyei et al. (2024)
Building information sharing platform and resource database	Hahn (2010)
Documentation and formalisation of community-level disaster management planning, processes and coordination within existing disaster management arrangements	Bajracharya et al. (2012)
Enablement of community feedback and contribution to the development of disaster management initiatives	Bixler et al. (2021)
Reasonable legal framework	Osei-Kyei and Chan (2017); Zhang (2005)
Stable political system	Babatunde et al. (2016); Wang et al. (2018)
Credibility of government policies	Ullah et al. (2018)
Governance and institutional capacity	Rodriquez et al. (2018)
Well-structured legal dispute resolution mechanism	Wang et al. (2018)
Policy/strategy formulation	Budhiati (2017)
Well-structured PPP urban community resilience policy	Osei Kyei and Chan (2017)
Clarity of roles and responsibilities among parties in public-private partnership	Dithebe et al. (2023)
Monitoring and controlling institutions for any public-private partnership formed for urban community resilience	Osei-Kyei et al. (2024)
Employment of highly skilled and competent workmanship in service operations	Alteneiji et al. (2019)
Strengthening partnerships with non-governmental organization	Chandra et al. (2013)
Efficient communication and coordination	Cui and Li (2020)
Establish mechanisms for community input	Chi et al. (2015); Osei-Kyei et al. (2024)
Financial support for disaster-prone communities	Scott and Coleman (2016); Osei-Kyei et al. (2024)
Business continuity plan within disaster-prone communities	Hahn (2010)

disasters in the Indian Sundarbans. The community resilience of 19 coastal blocks was assessed, and only one block was classified as having high resilience.

In summary, the review shows that UCR is a long-term process that requires continuous adaptation to rebuild after disruptive events. Existing studies are primarily grouped into two categories: those that provide assessments and metrics, and those that analyse specific cases/countries.

The existing literature lacks empirical evidence and analytical depth regarding how PPPs can improve UCR. As mentioned earlier, from the perspective of PPP in building UCR, there have been few studies; the only study is by Osei-Kyei et al. (2024). In their study, the authors conducted a systematic review of success factors for the development of UCR through PPPs. Their study identified 35 critical resilience strategies that are yet to be empirically tested.

This current study further bridges the knowledge gap by conducting an empirical analysis of the strategies required to build UCR through PPPs using advanced techniques such as system dynamics modelling. The novelty of this analytical approach lies in its ability to reveal the interrelationships among these critical strategies throughout the partnership. In addition, this modelling approach allows to understand how these resilience strategies perform over the long-term partnership duration and evaluate their impact on overall success of UCR.

From a comprehensive review of the literature on UCR and PPP practices, 28 strategies for building UCR through PPP were identified. The list of strategies is presented in Table 1.

Research methodology

Pre-testingof the questionnaire

An agreement analysis was conducted to confirm the final list of strategies. This analysis includes agreements and disagreements from subject matter experts regarding the inclusion or exclusion of

research items under investigation (Narbaev et al. 2022). The list of strategies was sent to three experienced academics with PhDs and two industry PPP practitioners with over seven years of experience to assess the practicality and authenticity of the strategies. The five experts confirmed the relevance of the strategies and suggested some minor changes to the wording. The final list of strategies presented in Table 1 was used to develop the study questionnaire.

Questionnaire survey with global experts

An international online questionnaire was conducted with experienced experts in PPPs and urban community resilience. This global survey was conducted because urban community resilience has gained worldwide recognition as a crucial step toward achieving sustainable cities. Gathering international expert insights into the strategies required to use PPPs to enhance urban resilience is pertinent. A Likert-scale questionnaire was developed to elicit experts' opinions on the significance of strategies for developing urban community resilience through PPPs. A standard scale with five options ranged from 1 (for "least important") to 5 (for "extremely important").

Purposive sampling was used to select research participants who were most likely to yield appropriate and useful information (Kelly et al. 2010). The predefined criteria used in sampling respondents were (1) the respondent should have basic knowledge about PPP and/or urban community resilience, (2) the respondent should have at least one peer-reviewed journal article as lead author and/or one year of hands-on industry experience in PPP and/or urban community resilience/disaster management. Scopus was used to identify research works on urban community resilience. Scopus is an online database used to search for relevant literature, offering a wide-ranging coverage of academic journals across various disciplines. The email addresses of the prospective research participants were retrieved from the selected publications on Scopus. Some of the prospective respondents were also sourced from the websites of public institutions, reports and websites of international organisations, and industry blogs. Subsequently, a Qualtrics survey link was sent to prospective respondents to participate in the study. A total of 250 prospective respondents were identified, and questionnaires were sent *via* email. 43 valid responses were received for further analysis.

International online-based surveys have several limitations and challenges, including low response rates. The average response rate for online surveys is 17.2% lower than that for other methods, particularly face-to-face surveys. Nevertheless, the response rate for this study is considered adequate for further analysis. This is because studies with online-based surveys such as Chileshe et al. (2022) obtained 27 responses out of 50, Sachs et al. (2007) obtained 29 responses and Osei-Kyei et al. (2021) obtained 48 responses out of 320. Considering this, it is recognised that international questionnaire surveys always yield lower response rates. However, the lower response does not invalidate the authenticity and genuineness of the survey responses for further analysis (Sach et al. 2007; Osei-Kyei et al. 2023).

Analytical techniques adopted

The Statistical Package for the Social Sciences (SPSS) was used to perform statistical analyses, including Cronbach's alpha for reliability, Kendall's tau-b (W) for internal consistency, mean score ranking, and one-way analysis of variance (ANOVA). System dynamics (SD) analysis was conducted to examine the interrelationships among the strategies throughout the partnership period in building urban community resilience. To conduct the SD modelling, the Vensim software was used. The system dynamics model mimics the actual system of a situation by describing and establishing the relationships among the system and its subsystems (Li et al. 2019). Vensim was used to draw a causal loop diagram and a stock-and-flow diagram.

Results and discussions

Background of respondents

Table 2 presents the detailed background information of the respondents. 58% of the respondents are from the industry, whereas 42% are from academia. This demonstrates that a greater number of

Table 2. Respondents background.

		Frequency	Percentage
Sector of respondents	Public sector	7	16.2
	Private sector	18	41.9
	Academic	18	41.9
	Total	43	100
Years of research/industrial experience	0–10 years	24	55.9
	11–15 years	5	11.6
	16–20 years	5	11.6
	21 years or above	9	20.9
	Total	43	100
Region	Countries/Jurisdictions		No. of respondents
Developed	Australia		12
	U.K.		4
	U.S.A		4
	Belgium		2
	Sweden		3
	Spain		2
	Hong Kong		1
	Ireland		1
	New Zealand		1
Developing	Nigeria		2
	Ghana		2
	India		6
	Philippines		3
	Total		43

Table 3. Results of reliability and consistency tests.

Test Statistics	
N	43
Cronbach alpha	0.98
Kendall's W	0.59
df	27
Significance level	0.05

industry practitioners were interested in participating in this study, which signifies the practicality of the responses and outputs of this study. Further, 43% of respondents have more than 11 years of academic and/or industrial experience in PPP practice and/or urban community resilience management. This indicates that a substantial number of respondents had a very good experience with the subject matter. Therefore, their responses are rich and authentic, providing valuable material for further empirical analysis. As shown in the table, respondents are from 13 countries, i.e. nine developed economies and four developing economies. The highest response rate was from Australia, with 27.9%. The second-highest response rate was from India, at 14%. The United Kingdom and the United States of America were ranked third, with a 9.3% response rate. The Philippines and Sweden were ranked 4th with a 7% response rate. Belgium, Ghana, Nigeria, and Spain were ranked 5th with a 4.7% response rate. This demonstrates that the study captured diverse views from various practitioners, thereby enhancing the adoption of PPP for urban community resilience by different governments across different regions. Further, this shows that many countries are now interested in adopting PPP for disaster management and urban community resilience building.

Test on the reliability and consistency of survey results

Table 3 presents the results of both tests. A reliability test assessed the internal consistency of the 28 strategies for building UCR through PPP. This test yielded a Cronbach alpha of 0.98, indicating excellent reliability and suggesting that the responses of each expert across the strategies are dependable. Next, a test using Kendall's coefficient of concordance analysis was undertaken to further verify the validity of the survey responses. Various project stakeholders from different countries participated in this research, necessitating a test of the internal consistency of the respondents' rankings of the strategies. The Kendall's value is 0.59, accompanied by a p-value of 0.001. This value is below the recommended

Table 4. Mean score ranking for critical resilience strategies.

S/N	Strategies for building urban community resilience through PPPs	Mean	Std. Deviation
1	Efficient communication and coordination	4.77	0.480
2	Governance and institutional capacity	4.60	0.541
3	Employment of highly skilled and competent workmanship in service operations	4.28	0.549
4	Practice preparedness actions	4.21	0.600
5	Business continuity plan within disaster-prone communities	4.19	0.546
6	Proper and efficient community needs assessment	4.19	0.546
7	Financial support for disaster prone communities	4.12	0.731
8	Clarity of roles and responsibilities among parties in public-private partnership	4.00	0.787
9	Establish mechanisms for community input	3.47	0.984
10	Credibility of government policies	3.35	1.021
11	Well-structured legal dispute resolution mechanism	3.35	1.044
12	Stable political system	3.28	1.054
13	Information accessibility	3.26	1.002
14	Provide homes in risk-prone areas with seals of approval or risk scores based on their susceptibility to different hazards.	3.21	1.059
15	Vulnerability assessment	3.16	1.132
16	Strengthening partnership with non-governmental organization	3.05	1.214
17	Policy/strategy formulation	2.98	1.282
18	Develop community risk awareness program	2.81	1.220
19	Develop community maps delineating current and future risk	2.74	1.311
20	Monitoring and controlling institutions for any public-private partnership formed for urban community resilience	2.70	1.440
21	Building information sharing platform and resource database	2.58	1.314
22	Enablement of community feedback and contribution to the development of disaster management initiatives	2.51	1.298
23	Publishing/disseminating the objectives, benefits and implications of resilience strategies to all urban community	2.47	1.297
24	Well-structured PPP urban community resilience policy	2.37	1.381
25	Reasonable legal framework	2.30	1.389
26	Documentation and formalisation of community- level disaster management planning, processes and coordination within existing disaster management arrangements	2.19	1.350
27	Efforts to locally contextualise disaster management information, including greater understanding of local vulnerability and resilience	2.16	1.344
28	Knowledge co-production	2.09	1.377

significance level of 0.05, indicating an acceptable level of consistency in the rankings provided by the experts. These results reinforce the overall reliability of the survey responses for further analysis.

Mean ranking and one-way ANOVA results of strategies

A mean ranking analysis was conducted to determine the overall criticality of the 28 strategies for building urban community resilience through PPP. The results of the mean analysis are shown in Table 4. As presented in the table, the mean values range from 4.77 to 2.09, with the top three ranked strategies being "Efficient communication and coordination," "Governance and institutional capacity," and "Employment of highly skilled and competent workmanship in service operations." The standard deviation values range from 0.480 to 1.377.

Considering that three groups of respondents, namely the public, private, and academic sectors from different countries and industrial sectors, participated in the study, it was essential to investigate whether there were any significant differences in their perceptions. This analysis will help clarify the actions each project party should take in a PPP agreement to support the development of UCR. A one-way ANOVA was conducted, and the results are presented in Table 5.

As presented in the table, among the 28 strategies, three emerged as significant differences. These are "Develop community maps delineating current and future risk", "Develop community risk awareness program", and "Building information sharing platform and resource database" with values 0.044, 0.048 and 0.044. The significant differences in respondents' perceptions of the criticality of these strategies are not surprising. This is because these strategies may already exist; therefore, practitioners do not need to focus on implementing them to build urban community resilience through PPPs. Typically, government departments responsible for disaster management already have community maps and existing risk awareness programs in place. Therefore, the private sector or stakeholders may have to focus on other critical strategies, such as developing efficient communication and coordination among the urban residents and other stakeholders.

Table 5. One-way ANOVA results of the strategies for building UCR through PPP by the public, private and academic sectors.

Strategies for adopting PPP in urban community resilience		Sum of Squares	df	Mean Square	F	*p* value.
Proper and efficient community needs assessment	Between Groups	0.266	2	0.133	0.434	0.651
	Within Groups	12.246	40	0.306		
	Total	12.512	42			
Practice preparedness actions	Between Groups	0.148	2	0.074	0.198	0.821
	Within Groups	14.968	40	0.374		
	Total	15.116	42			
Vulnerability assessment	Between Groups	4.726	2	2.363	1.923	0.159
	Within Groups	49.135	40	1.228		
	Total	53.860	42			
Provide homes in risk-prone areas with seals of approval or risk scores based on their susceptibility to different hazards.	Between Groups	3.759	2	1.880	1.734	0.190
	Within Groups	43.357	40	1.084		
	Total	47.116	42			
Develop community maps delineating current and future risk	Between Groups	10.416	2	5.208	3.373	0.044
	Within Groups	61.770	40	1.544		
	Total	72.186	42			
information accessibility	Between Groups	3.535	2	1.768	1.829	0.174
	Within Groups	38.651	40	0.966		
	Total	42.186	42			
knowledge co-production	Between Groups	3.977	2	1.989	1.051	0.359
	Within Groups	75.651	40	1.891		
	Total	79.628	42			
efforts to locally contextualise disaster management information, including greater understanding of local vulnerability and resilience	Between Groups	6.226	2	3.113	1.788	0.180
	Within Groups	69.635	40	1.741		
	Total	75.860	42			
develop community risk awareness program	Between Groups	8.797	2	4.399	3.276	0.048
	Within Groups	53.714	40	1.343		
	Total	62.512	42			
Publishing/disseminating the objectives, benefits and implications of resilience strategies to all urban community	Between Groups	6.729	2	3.365	2.104	0.135
	Within Groups	63.968	40	1.599		
	Total	70.698	42			
Building information sharing platform and resource database	Between Groups	10.465	2	5.233	3.376	0.044
	Within Groups	62.000	40	1.550		
	Total	72.465	42			
documentation and formalisation of community- level disaster management planning, processes and coordination within existing disaster management arrangements	Between Groups	5.734	2	2.867	1.620	0.211
	Within Groups	70.778	40	1.769		
	Total	76.512	42			
enablement of community feedback and contribution to the development of disaster management initiatives	Between Groups	8.244	2	4.122	2.638	0.084
	Within Groups	62.500	40	1.563		
	Total	70.744	42			
reasonable legal framework	Between Groups	7.244	2	3.622	1.963	0.154
	Within Groups	73.825	40	1.846		
	Total	81.070	42			
Stable political system	Between Groups	3.238	2	1.619	1.492	0.237
	Within Groups	43.413	40	1.085		
	Total	46.651	42			
credibility of government policies	Between Groups	3.656	2	1.828	1.823	0.175
	Within Groups	40.111	40	1.003		
	Total	43.767	42			
governance and institutional capacity	Between Groups	0.009	2	0.005	0.015	0.985
	Within Groups	12.270	40	0.307		
	Total	12.279	42			
Well-structured legal dispute resolution mechanism	Between Groups	3.656	2	1.828	1.737	0.189
	Within Groups	42.111	40	1.053		
	Total	45.767	42			
Policy/strategy formulation	Between Groups	4.993	2	2.496	1.561	0.223
	Within Groups	63.984	40	1.600		
	Total	68.977	42			

(*continued*)

Table 5. Continued.

Strategies for adopting PPP in urban community resilience		Sum of Squares	df	Mean Square	F	*p* value.
Well-structured PPP urban community resilience policy	Between Groups	4.721	2	2.361	1.254	0.296
	Within Groups	75.325	40	1.883		
	Total	80.047	42			
Clarity of roles and responsibilities among parties in public-private partnership	Between Groups	0.865	2	0.433	0.688	0.508
	Within Groups	25.135	40	0.628		
	Total	26.000	42			
monitoring and controlling institutions for any public-private partnership formed for urban community resilience	Between Groups	8.467	2	4.233	2.154	0.129
	Within Groups	78.603	40	1.965		
	Total	87.070	42			
Employment of highly skilled and competent workmanship in service operations	Between Groups	0.651	2	0.326	1.085	0.348
	Within Groups	12.000	40	0.300		
	Total	12.651	42			
strengthening partnership with non-governmental organization	Between Groups	5.605	2	2.803	1.991	0.150
	Within Groups	56.302	40	1.408		
	Total	61.907	42			
efficient communication and coordination	Between Groups	0.762	2	0.381	1.709	0.194
	Within Groups	8.913	40	0.223		
	Total	9.674	42			
Establish mechanisms for community input	Between Groups	3.087	2	1.543	1.641	0.207
	Within Groups	37.611	40	0.940		
	Total	40.698	42			
financial support for disaster prone communities	Between Groups	1.006	2	0.503	0.940	0.399
	Within Groups	21.413	40	0.535		
	Total	22.419	42			
business continuity plan within disaster prone communities	Between Groups	0.401	2	0.200	0.661	0.522
	Within Groups	12.111	40	0.303		
	Total	12.512	42			

Results of the system dynamics modelling

System dynamics modelling has gained much popularity in the construction management discipline due to its ability to examine the dynamic behaviours of a system (Ma et al. 2023). This study employed this tool to examine the interactions between strategies over time in PPP arrangements for building urban community resilience. More importantly, it was adopted to enable practitioners to understand the long-term impact of these strategies on PPP arrangements for building urban community resilience (Mak et al. 2019). The stages and results of the SD modelling are discussed in subsequent sections.

Qualitative system dynamics: causal loop diagram

Causal loop diagrams (CLD) are used in system dynamics for connection purposes with the intention of simulation modelling (Ma et al. 2023). They are used before simulation to depict the cause-and-effect relationships that describe the behaviours of a system over time (Binder et al. 2004). CLD consist of relevant factors that document a causal relationship between them. A CLD maps the hypotheses of system structures by linking causal relationships between variables (Sterman 2002). It is a simple yet effective qualitative modelling approach that many scholars employ to analyse complex interactions (Purwanto et al. 2019). Emphatically, the strategies explored in this study exhibit a cause-and-effect relationship, where the occurrence of one strategy influences the occurrence of another.

Regarding selecting the strategies for the SD modelling, on the Likert scale, a score of 3 means "important" and 4 "very important". Therefore, strategies with mean values greater than 3.0 were considered critical and were used in this study. According to Table 4, only the first 16 strategies are eligible for inclusion. Figure 1 illustrates a CLD model designed for critical resilience strategies in UCR through PPP. All the plus signs (+) indicate a positive relationship between the strategies that form a cause-effect loop. Linkages show a relationship where the strategy at the arrow tail influences the occurrences of the strategy at the arrowhead. For instance, conducting a "vulnerability assessment" will influence the need to conduct a "proper and efficient community needs assessment", which would subsequently

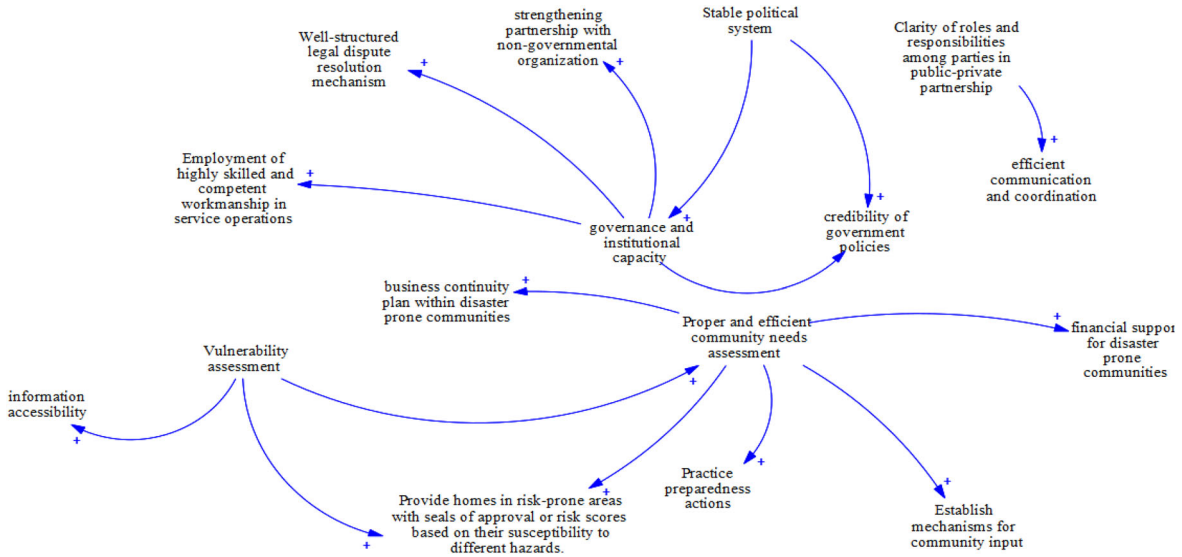

Figure 1. Causal loop diagram for critical resilience strategies.

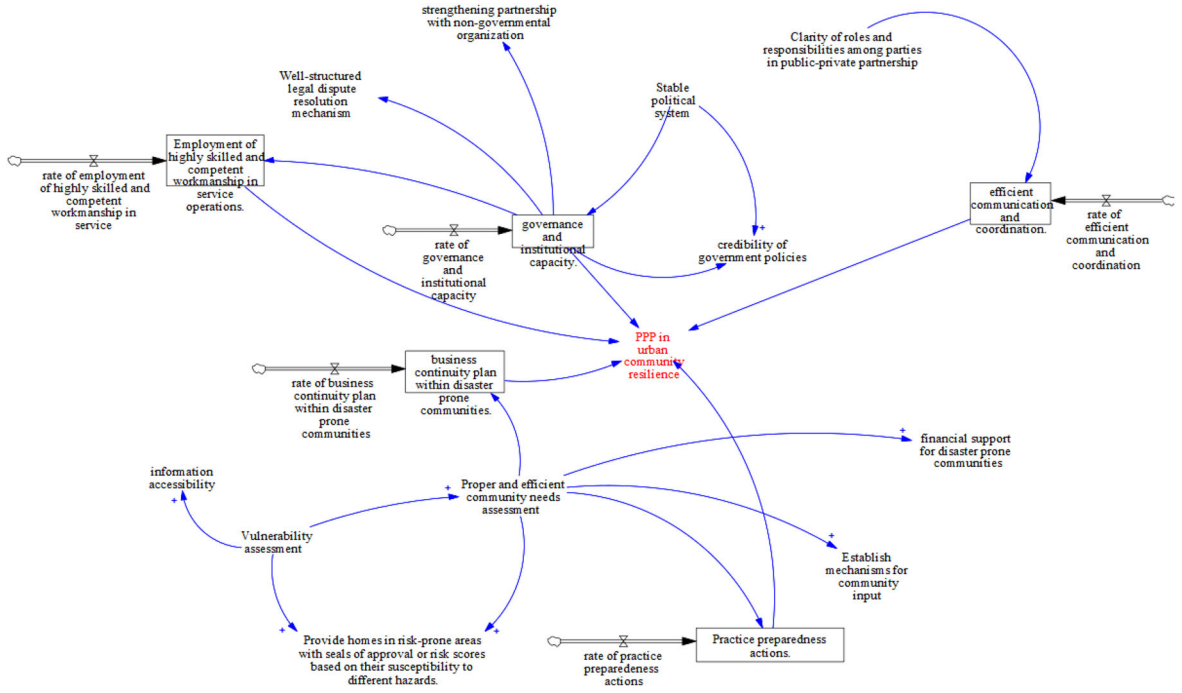

Figure 2. Stock and flow diagram.

lead to providing "financial support for disaster-prone communities" and a "business continuity plan within disaster-prone communities". It is worth noting that CLD was developed based on 16 variables, as reviewed in the literature, which explores how these strategies interact and influence one another.

Quantitative system dynamics: stock and flow

The quantitative model of system dynamics utilizes stocks (represented as boxes) and flows (rates), which illustrate the relationships between variables (Ma et al. 2023). The stock and flow diagram enables the simulation and quantitative analysis of processes. In this regard, the CLD must be translated into the stock and flow diagram for further analysis. Figure 2 illustrates the stock and flow diagram for the critical strategies, which collectively impact the use of PPP in urban community resilience. The first five top-ranked variables (very critical) were used as stock variables in the system. This is because of their high ranking, demonstrating their significant impact towards developing urban community

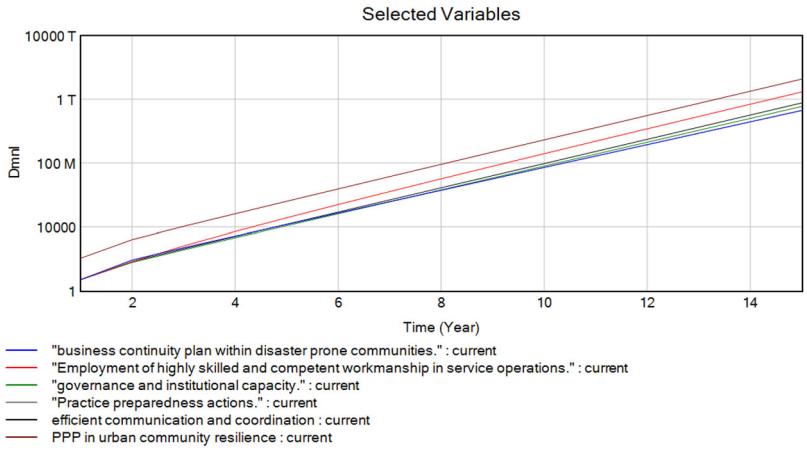

Figure 3. Simulation results for five (5) stock variables.

resilience through PPP. These five variables used as critical in the stock and flow diagram were further validated through an expert forum with the five experts who participated in the pilot study. The experts confirmed the overall structure and adequacy of the stocks and flows for this model.

For further clarification, below is a summary of the important SD tests conducted for this study:

1. Boundary adequacy: All variables, constructs and information on the composition and relation between the variables in CLD are founded on a comprehensive review of extant literature on strategies for building the resilience of urban communities.
2. Parameter verification: The variables used in the stock and flow diagram were tested empirically through a survey using mean score ranking. Further, an expert forum with five practitioners was conducted to validate the stock and flow model.
3. Behaviour sensitivity: This was performed by changing the constant values (mean values). This was to check whether other interdependent variables change reasonably while a variable is modified.
4. Extreme condition test: The extreme condition test was conducted to determine the model's behaviour when extreme values, such as zeros, are assigned to the strategies. The extreme values, such as zero, represent "no effort", which means when these recommended strategies are not implemented by practitioners, what will be the impact of this "no effort" on urban community resilience building?
5. Dimension consistency test: The variables used in this study are qualitative variables, which do not have defined units of measurement. Also, there are no existing mathematical equations available in the literature to support the relationship between the variables. The absence of structured units of measurement or equations for the model does not invalidate the parameters/variables, or affect the structure of the model for further analysis.

Simulation results (sensitivity analysis) and discussion

Figure 2 above was simulated using Venism. Venism software is used to simulate the model to provide predictive and suggestive support for building urban community resilience through PPP. The simulation was conducted to examine the behaviour of strategies towards using PPP to build urban community resilience over a period. The model provides a test bed to understand the extent to which strategies influence the use of PPP in building urban community resilience.

The mean values for these strategies were loaded onto the stock and flow model, and a sensitivity analysis was conducted. The model was simulated for 15 years. This is because a typical PPP arrangement typically spans an average of 15 years, from the design phase through to the operational phase of the project. More importantly, in building urban community resilience through PPPs, a 15-year arrangement is ideal so that the government can properly evaluate the performance of the private sector before any future contract extension period (Osei-Kyei et al. 2024). The sensitivity analysis and impact

Table 6. Simulation values for five (5) stock variables.

Time (Year)	PPP in urban community resilience: current	business continuity plan within disaster-prone communities:current	Employment of highly skilled and competent workmanship in service operations:current	governance and institutional capacity:current	Practice preparedness actions:current	efficient communication and coordination: current
1	110	5	5	5	5	5
2	1606	85	68	60	86	68
3	10758	502	651	367	506	429
4	66149	2667	5149	2090	2694	2513
5	398471	13899	36815	11734	14094	14539
6	2377720	72194	248380	65744	73491	83929
7	14093700	374746	1613890	368197	382946	484310
8	83084500	1944990	10215100	2061930	1995210	2794510
9	487528000	10094600	63420400	11546900	10395100	16124400
10	2849300000	52390800	387975000	64662500	54158500	93037600
11	16594300000	271908000	2345960000	362110000	282166000	536827000
12	96349100000	1411200000	14052400000	2027810000	1470080000	3097490000
13	557906000000	7324150000	83524400000	11355800000	7659140000	17872500000
14	3222790000000	38012300000	493245000000	63592300000	39904100000	103124000000
15	18576900000000	197284000000	2896860000000	356117000000	207900000000	595028000000

of the five high-ranking strategies on building urban community resilience through PPP over 15 years are presented in Figure 3, along with the corresponding indicative values in Table 6.

It should be noted that a dimensionless equation was derived for the system, as no mathematical calculations in the literature exist to express the qualitative relationship among variables in the stock and flow diagram of the system. Therefore, the units in the system are indicated as dimensionless (Dmnl). In this regard, the values presented in the graph and table are used solely for comparative purposes and analysis and do not represent absolute quantities. As indicated in Table 6, all the strategies have a significant impact on the success of PPP in building urban community resilience in the 12th year. It can be seen from the table that there is a huge increase in the dimensionless values in the 12th year. This is quite understandable, considering that strategies and policies produce results over the long term, and in this case, at the latter end of the partnership agreement.

From Figure 3, the graph for "employment of highly skilled and competent workmanship in service operations" rises higher than the other strategies. According to the results, this strategy has the greatest influence on building urban community resilience through PPP. It is ranked 3rd with a mean of 4.28. Private developers require a highly skilled and competent workforce to effectively operate infrastructure services for urban communities. It is crucial for competent staff to be able to respond to and manage disruptions, ensuring the continuity of essential services to urban communities (Osei-Kyei et al. 2024). It is, therefore, essential that all private developers of critical urban systems and infrastructures ensure the upskilling and reskilling of their staff on how to manage and mitigate disruptions. Further, staff of urban systems should have a thorough understanding of the impact of disruptions on urban communities and resident as part of their career development training.

Efficient communication and coordination have the second-highest influence on using PPP to build urban community resilience in the SD modelling. This strategy has a significant impact on the success of PPP in building urban community resilience. It is also ranked first, with a mean of 4.77. This outcome is unsurprising because, for any partnership to succeed, a well-established communication channel is necessary to ensure the smooth and unimpeded flow of information (Osei-Kyei et al. 2024). For PPP to be successful in building urban community resilience, both the local government and the private sector must develop mechanisms, such as regular meetings and community forums, to foster coordination among residents and project parties. This will help ensure that proper and strong bonds are established between projects and the residents or public. In addition, communities must be informed about economic recovery plans and support available for disaster-affected individuals and businesses (Mannakkara and Wilkinson 2013). Access to information impacts the community's awareness of their vulnerability and their understanding of what help is available in the aftermath of a disaster (Kaźmierczak and Cavan 2011).

Governance and institutional capacity have the third highest influence on using PPP to build urban community resilience in the SD modelling system. It is ranked 2nd with a mean of 4.60. Good governance reduces the vulnerability of urban communities and enables the development of mitigation and recovery methodologies through PPPs (Lewis and Mioch 2005). For a PPP policy to effectively support urban community resilience, the local government authority and other government disaster institutions should be well-resourced in terms of experienced staff and funding. This is crucial for enabling these institutions to effectively negotiate with the private sector in the development of urban communities. More importantly, with a well-resourced public institution, it will be easier for the government to engage with the residents in the areas where communities need more resources to withstand unexpected events. A well-resourced public institution will also be able to monitor the performance of the private sector in delivering urban infrastructure and disaster-related projects. Good governance is crucial for ensuring the satisfaction of all stakeholders in building urban community resilience (Almarri and Boussabaine 2017).

Practice preparedness actions have the fourth highest influence on using PPP to build urban community resilience. It is also ranked 4th with a mean of 4.21. For an urban community to be resilient against unexpected events through PPP, both the government and private sector must develop comprehensive resilient actions to demonstrate their preparedness for any disruptions. The roadmap or plan should be simulated in real-world scenarios to identify any gaps within the urban community. If there

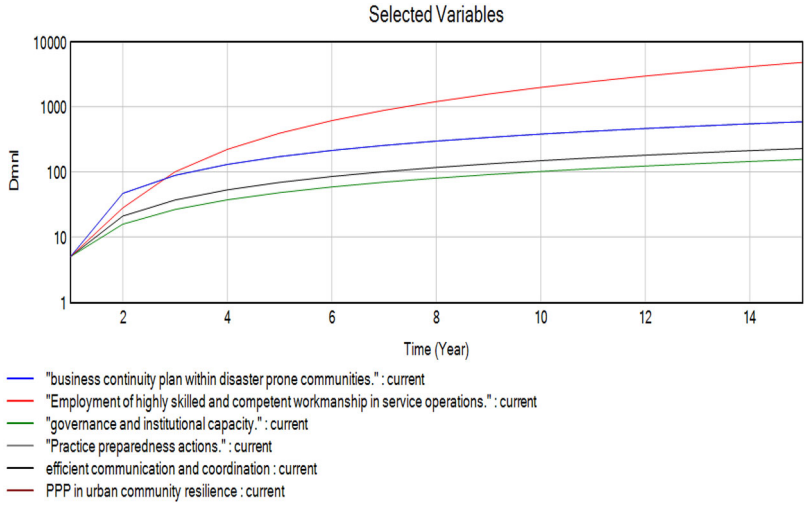

Figure 4. Extreme condition test.

are any gaps, these must be addressed by allocating or distributing tasks to the party in the PPP arrangement that can best manage the resilience gaps within the community (Osei-Kyei et al. 2024). These actions are required because a community's vulnerability is influenced by the degree of their preparedness actions to combat and alleviate the effects of disruptive events. Developing a resilient plan should not exclude the residents; urban community leaders must be involved in the vulnerability reduction plan and simulations. Preparedness increases the learning capacity of communities through exchanging knowledge and sharing mutual experiences (Mehmood 2016). Practising preparedness actions by using pseudo-disruptive events increases the learning capacity of the communities, which helps prepare them for crisis situations (Mehmood 2016).

A business continuity plan within disaster-prone communities has the fifth-lowest influence on using PPP to build urban community resilience in the SD modelling. It is ranked 5th with a mean of 4.19. Business continuity plans are a recovery strategy for society to strengthen their resilience and reduce their vulnerabilities to disasters (Lewis and Mioch 2005). Therefore, it is crucial for local governments to ensure that private operators of urban systems and infrastructures develop a continuity plan that outlines the actions to be taken in the event of disasters. Business activities should continue uninterrupted after unexpected events, and this can only be achieved if a proper business continuity plan is developed and regularly updated to reflect current scenarios.

Extreme condition test

An extreme condition test evaluates the model's capability in extreme conditions (Ma et al. 2023). This test was conducted to further ascertain the impact of the top five strategies on building the resilience of urban communities through PPP. When the strategies are tested under extreme conditions, the extent of their impact can be determined. Figure 4 and Table 7 show the results of the extreme condition testing.

The outcome of the extreme condition test is best interpreted by comparing it to the sensitivity results. The strategies "efficient communication and coordination," "governance and institutional capacity, "employment of highly skilled and competent workmanship in service operations, "practice preparedness actions," and "business continuity plan within disaster-prone communities" are assigned a value of 0 in the Vensim software. This implies that in an extreme condition where stakeholders make no efforts to implement the above strategies, what impact will this have on the cumulative effect of PPP in building urban community resilience? As seen in Figure 4 and the dimensionless values in Table 7, reducing the five significant strategies to a value of zero (no effort) in the system results in a drastic reduction or no positive cumulative effect of using PPP in building urban community resilience. This clearly indicates and affirms the criticality and significance of the five strategies.

Table 7. Extreme condition test results for five (5) stock variables.

Time (Year)	PPP in urban community resilience:current	business continuity plan within disaster prone communities:current	Employment of highly skilled and competent workmanship in service operations:current	governance and institutional capacity:current	Practice preparedness actions:current	efficient communication and coordination:current
1	0	5	5	5	5	5
2	0	46.8397	28	15.7584	46.8397	21
3	0	88.6793	100.489	26.5168	88.6793	37
4	0	130.519	222.466	37.2752	130.519	53
5	0	172.359	393.932	48.0336	172.359	69
6	0	214.198	614.886	58.792	214.198	85
7	0	256.038	885.33	69.5504	256.038	101
8	0	297.878	1205.26	80.3088	297.878	117
9	0	339.717	1574.68	91.0672	339.717	133
10	0	381.557	1993.59	101.826	381.557	149
11	0	423.397	2461.99	112.584	423.397	165
12	0	465.236	2979.88	123.342	465.236	181
13	0	507.076	3547.25	134.101	507.076	197
14	0	548.916	4164.11	144.859	548.916	213
15	0	590.755	4830.47	155.618	590.755	229

In the simulation analysis, "efficient communication and coordination" had a dimensionless value of 595028000000 in year 15, as presented in Table 6. In contrast, the extreme condition test revealed this strategy's dimensionless value of 229, as detailed in Table 7. This significant disparity in values underscores that, if this strategy is not carefully considered and implemented, it can significantly undermine the effectiveness of PPP in enhancing urban community resilience. Similarly, "governance and institutional capacity" recorded a value of 356117000000 in year 15 (Table 6) during the simulation analysis, while the extreme condition test produced a value of 155.618 (Table 7). The resilience of urban areas to disasters is closely linked to the governance and institutional capacity of stakeholders. These figures once again indicate substantial declines. Therefore, it is essential that policies and decisions regarding urban resilience be tailored to the specific context of the community and other economic activities. Communities are more likely to recover from disruptive events when stable governance is in place to ensure the effective implementation of policies that guide the recovery process for affected populations.

"Employment of highly skilled and competent workmanship in service operations" had a value of 2896860000000 (Table 6), while the extreme condition test produced 4830.47 (Table 7). Employment of highly skilled and competent skilled personnel is an enabler of change and development (Kirby et al. 2025). "Practice preparedness actions" had a value of 207900000000 (Table 6) for the simulation analysis and 590.755 (Table 7) for the extreme condition test. Every community must have the capacity to withstand disruptive events (Zhong et al. 2020). This can be achieved by deploying resources that will build communities' capacity to withstand external shocks.

"Business continuity plan within disaster-prone communities" had a value of 197284000000 (Table 6) for simulation analysis, while the extreme condition test generated a value of 590.755 (Table 7). For PPP to be successful in building urban community resilience, it is important for private operators of urban systems to develop continuity plans and ensure they are reviewed periodically.

Implications and limitations

The outcomes of this paper provide practical implications that could enable the government and private sector to partner successfully in building urban community resilience. Based on the outputs of the system dynamics modelling, the key strategies that practitioners could consider include developing efficient communication and coordination policies, employing highly skilled and competent personnel in service operations, strengthening governance and institutional capacity, practising and simulating preparedness actions and policies, and creating a practical business continuity plan for disaster-prone areas.

Importantly, these strategies can be incorporated into PPP contractual frameworks, where the government can include clauses to ensure that competent and skilled personnel are employed by private operators of urban infrastructure. Further, governments could ensure that continuity plans are developed by private operators of urban systems, and more importantly, these plans should be periodically reviewed throughout the contractual process. When these findings are incorporated into PPP contracts/frameworks for urban infrastructure and systems, they will enable stronger actions by private operators to ensure the resilience of these infrastructure and systems.

Also, based on the research findings, the specific skills required by both the public and private sectors for developing UCR through PPPs could include proactive communication, stakeholder management (particularly for the private sector), risk management, service operations (particularly for private operators), and resource management. These skills are essential for implementing the identified strategies.

Indeed, the overall outcomes of this study set the tone for decisions on urban community resilience and how public-private partnerships (PPPs) can be used to achieve it. This study demonstrates firsthand how each critical resilience strategy impacts the development of urban community resilience through PPP. This demonstration will be useful for resource mobilisation and will provide a clear understanding of each party's responsibilities under a PPP arrangement for building urban community resilience.

1. Despite the impact of the findings, there are limitations that could affect the intepretation of the research findings:The model has not been validated against real-world data using case studies. To interpret the real-world scale of the "cumulative effect" on resilience, real-world results could be ascertained by implementing the model at a small scale through case studies.
2. The model uses a 15-year simulation which over the period of this timeframe, these strategies may evolve to reflect the changing vulnerabilities that urban communities face. In this instance, a systematic literature review and a new quantitative survey through case studies can be conducted to reflect these changes..
3. The generalisation of the results is also limited because of the small sample size. A larger sample would have yielded a more diverse set of responses from the experts. Nonetheless, the strength of this study is that the respondents are experts from 13 countries who have drawn on their years of experience to contribute. Hence, the results are relevant for future reference and further investigations.

Conclusions

PPP in building urban community resilience has gained attention in recent years due to the increasing number of unexpected disasters and the limited ability of urban communities to bounce back after such events. This paper explores the critical strategies for building urban community resilience through PPP through an international survey of experts. Kendall's concordance analysis shows high consistency in the rankings of the strategies by the experts. This affirmed the reliability and consistency in the rankings by respondents. System dynamic modelling was conducted over 15 years of a PPP arrangement to build urban community resilience. The simulation results show that the most impactful strategy in building urban community resilience is to employ highly skilled and competent workmanship in in-service operations. This important strategy is to be implemented by the private sector partner responsible for operating urban systems and infrastructure. Other critical strategies include developing efficient communication and coordination policies, strengthening governance and institutional capacity, practising and simulating preparedness actions and policies, and developing a practical business continuity plan for disaster-prone areas. The extreme condition test results on the system dynamic model showed that a decline in implementing these strategies leads to cumulative lower performance results in using PPP in building UCR. This implies that stakeholders in PPP arrangements for building urban community resilience should carefully observe the five critical strategies.

The outputs of this study significantly contribute to the existing body of knowledge by providing practical strategies that can be adopted by governments and private operators of urban systems to enhance urban community resilience. Further, the system dynamic model, i.e. stock and flow diagram, provides a solid foundation for further empirical studies using case studies from different countries.

Author contributions

CRediT: **Robert Osei-Kyei**: Conceptualization, Data curation, Funding acquisition, Project administration, Resources, Software, Supervision, Writing – review & editing; **Timur Narbaev**: Funding acquisition, Methodology, Project administration, Supervision, Visualization; **Godslove Ampratwum**: Formal analysis, Investigation, Methodology, Writing – original draft; **Yongjian Ke**: Project administration, Resources, Software, Validation, Writing – review & editing.

Disclosure statement

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary material

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