Points of entry dynamics: understanding the cross-border threats for Ebola virus disease and COVID-19 in Ghana using a logic model approach

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Abstract

Background. The influx of people across the national borders of Ghana has been of interest and concern in the public health and national security community in recent times due to the low capacity for the prevention and management of epidemics and other public health risks. Although the international health regulations (IHR) stipulate core public health capacities for designated border facilities such as international airports, seaports, and ground crossings, contextual factors that influence the attainment of effective public health measures and response capabilities remain understudied.

Objective. This study aims to assess the relationship between contextual factors and COVID-19 procurement to help strengthen infrastructure resources for points of entry (PoE) public health surveillance functions, thereby eliminating gaps in the design, implementation, monitoring, and evaluation of pandemic-related interventions in Ghana.

Methods. This study employed a mixed-methods design, where quantitative variables were examined for relationships and effect size interactions using multiple linear regression techniques and the wild bootstrap technique. Country-level data was sourced from multiple publicly available sources using the social-ecological framework, logic model, and IHR capacity monitoring framework. The qualitative portion included triangulation with an expert panel to determine areas of convergence and divergence.

Results. The most general findings were that laboratory capacity and Kotoka International Airport testing center positively predicted COVID-19 procurement, and public health response and airline boarding rule negatively predicted COVID-19 procurement.

Conclusion. Contextual understanding of the COVID-19 pandemic and Ebola epidemic is vital for strengthening PoE mitigation measures and preventing disease importation.

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Introduction

Emerging infectious diseases like the Ebola virus disease (EVD) and COVID-19 continue to pose health security threats in places like Ghana and the West African sub-region due to gaps in public health systems and the capacity to detect, prevent, and respond to epidemics and pandemics.[1] Even though public health surveillance systems have been vital in communicating health risks and promoting disease mitigation measures in epidemic and pandemic settings, resource challenges like the inadequate supply of goggles or face shields, hand gloves, laboratory test kits, gowns, N95 respirators, hand-washing stations, isolation sites, and the low capacity for infection prevention and control at several designated points of entry (PoE) facilities in Ghana undermines the ability to effectively disrupt the spread of infectious diseases along the borders of the country.[2]

Further, without enhanced monitoring systems at the PoE, measuring progress on the international health regulations (IHR) public health core capacities and capabilities and developing corrective action could be adversely affected.[3] Ideally, containing the international spread of infectious diseases like EVD and COVID-19 in places like Ghana and the West-African sub-region should be a collective priority for the Government of Ghana and other countries in the region and the international community as no nation alone can do it all.[4] Importantly, lack of political action and insufficient funds to strengthen the public health infrastructure, especially the laboratory facilities, disease early warning systems, competent workforce, and the procurement of adequate medical supplies and equipment, can lead to poor response to health emergencies, increased disease burden, mass suffering, and preventable deaths.[5,6]

Interestingly, existing literature on the 2014-2016 Ebola epidemic identified multiple system challenges that must be addressed to enhance the public health preparedness and response capacities and capabilities in Ghana and the West Africa sub-region. Examples of the challenges and issues highlighted were inconsistent messaging by leadership, especially crisis, and emergency risk communication, gaps in information sharing, weak surveillance systems, workforce shortages, poor handling of laboratory specimens, and fear of contracting an infection at the workplace.[7-12] All these challenges present complex dynamics, requiring the adoption and application of system thinking tools and methodologies. In their scholarly work, Johnson *et al*. observed that the systems approach offers opportunities to examine and understand multiple interactions and linkages.[13]

Despite past recommendations and the call to action for improved quality outcomes in the West African sub-region, significant gaps remain in prioritizing resources for effective response at the local, district, national, and regional levels.[14] Ghana must overcome these systemic resource challenges before another epidemic and pandemic strike. Often, the inputs or available resources determine the outputs or activities undertaken. Consequently, the outputs lead to the purpose, and the purpose or objective provides opportunities for managers and program leaders to set realistic outcome goals. As a framework, the logic model can be portrayed as a set of interlocking concepts critical for designing, implementing, monitoring, and evaluating interventions and strategies. Figure 1 illustrates how the Ripple model can affect project outcomes based on the development of IHR core capacities. Arguably, the Ripple model is a simplified version of a logic model.[3]

Furthermore, understanding why some interventions work well in different countries and settings is vital for addressing implementation gaps and enhancing quality outcomes.[15] Epidemics and pandemics present several complexities, requiring a need for critical appraisal of facts, situational leadership, cooperation, and resource mobilization. Utilizing the social-ecological model, IHR capacity monitoring framework, and the logic model in this study would enhance understanding of the multiple levels of influence and linkages that can facilitate or impede PoE pandemic-related interventions in resource-constraints environments like in Ghana. In their scholarly work, Spiegel *et al*. found the social-ecological model resourceful in capturing, understanding, and protecting human populations from diseases like dengue fever.[16] Similarly, Phillips *et al*. demonstrated that undertaking global disease surveillance presents a critically important challenge with political, social, and economic overtones for the US and the international community.[17]

Importantly, even though supplies and materials for undertaking surveillance functions have been critical in disease outbreak response and addressing other health risks, years of inadequate funding make resource mobilization during public health emergencies in Ghana difficult.[4,18] In addition, the IHR also recognizes and highlights multiple factors essential for building requisite capabilities to meet the threats posed by infectious diseases and other public health risks.[6] Likewise, the social-ecological model considers relationships and influences at the individual, interpersonal, community, and societal levels,[19] as shown in Figure 2, making the in-depth examination of these complexities during pandemics worthwhile. To prevent the total collapse of the fragile health care system in places like Ghana and the West African sub-region during pandemics, constant vigilance and timely application of PoE screening mitigation measures must be a top priority.[20] Although the literature does suggest that increased progress for the IHR is necessary for effectuating the global health security agenda, not enough studies have assessed the association between contextual factors and COVID-19 procurement in Ghana. Besides, there is insufficient information on how the free mobility of citizens protocol enacted by the 15 Member States in West Africa facilitates PoE surveillance and monitoring activities during epidemics and pandemics. This mixed-methods study will contribute to existing research by offering context-specific actionable measures critical for strengthening PoE functions during international health emergencies. Assessing and recognizing the multiple influences, interrelationships, and linkages in epidemic-prone settings using multiple linear regression statistical analysis is appropriate, timely, and noteworthy. It is worthy of note because increased insights regarding the association between COVID-19 procurement and the contextual factors and their relative contributions can lead to the judicious allocation of infrastructure resources for mission-specific preparedness, response, and recovery efforts during public health emergencies.

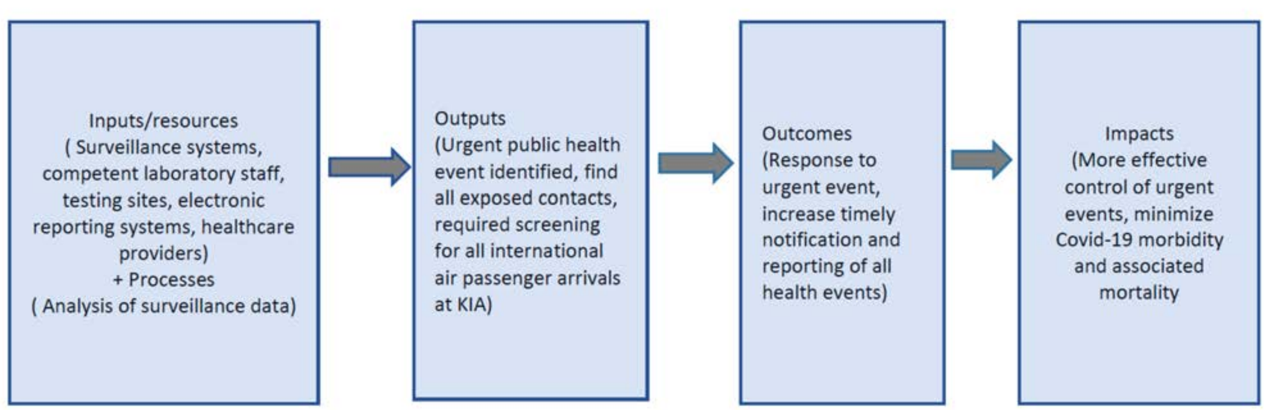

Figure 1. Application of the Ripple concept adapted to illustrate the interrelationships between inputs, outputs, and outcomes during the process of achieving results.[3] Adapted from WHO (2011), IHR Core Capacity Framework: checklist and indicators for monitoring progress in the development of IHR core capacities in state parties, with permission of the World Health Organization.

Materials and Methods

This study assessed the relationship between COVID-19 procurement and contextual factors derived from the IHR capacity monitoring framework, social-ecological framework, and logic model/Ripple concept to help address resource and implementation gaps and enhance surveillance and monitoring systems for designated PoE in Ghana. The requisite contextual domains assessed were clinical, social, economic, and environmental, reflecting the complexities and levels of awareness and analysis critical to understanding a human phenomenon like an epidemic or pandemic and applying innovative strategies to improve quality outcomes.

Ethical considerations

This study was approved by the Central Michigan University Institutional Review Board on November 29, 2021, with protocol number 2021-1395. The study received an Expedited Review with minimal risk or discomfort of disclosure of participants' information.

Study participants and sample size

A select group of subject matter experts (SMEs) was recruited for the qualitative portion of the interview. Participation in the panel interview was contingent on familiarity with the public health cross-border issues in Ghana and West Africa, availability for the interview, and years of professional experience. Considering the scope of this research, five SMEs participated in the panel interview. Moreover, significant attention was on supplies and materials procured for containing the spread of COVID-19 in Ghana, especially at the Kotoka International Airport (KIA), as other designated PoE like the Aflao and Elubo borders have been closed since the start of the COVID-19 pandemic in March 2020.[21] Also, the Tema and Takoradi Ports were excluded from the study because the two seaports traditionally receive container vessels, general cargo vessels, tankers, and sometimes cruise vessels.[22] Field asserts that the general rule for sample size in regression models is a minimum of 15 cases of data per predictor,[23] and this study has 23 cases per predictor variable and meets the requirement. A fundamental understanding of this rule is that the bigger the sample size, the better.[23]

Methodology

Country-level data on Ghana IHR capacity progress report, COVID-19 associated morbidity and mortality data, air passenger traffic statistics, presidential address time, and COVID-19 procurement data were retrieved from multiple publicly available data sources. These include the World Health Organization Electronic State Party Annual Reporting database/platform, World Health Organization (WHO) COVID-19 Dashboard, Ghana Airports Company Limited Traffic Statistics, Presidency.gov.gh, YouTube, and Ghana Health Service website.

The IHR capacity monitoring framework, social-ecological framework, and the logic model approach/Ripple concept were employed to construct contextual factors in the clinical, social, economic, and environmental systems, with indicators identified in the data sources mentioned above.

Due to administrative and logistical constraints regarding data availability, there was no annual IHR capacity progress report for Ghana for the calendar years 2015 and 2021. The total number of contextual factors was 13, and they are clinical (4), social (3), economic (2), and environmental (4). Excel worksheet was used in gathering and collating the multiple data sources extracted. The

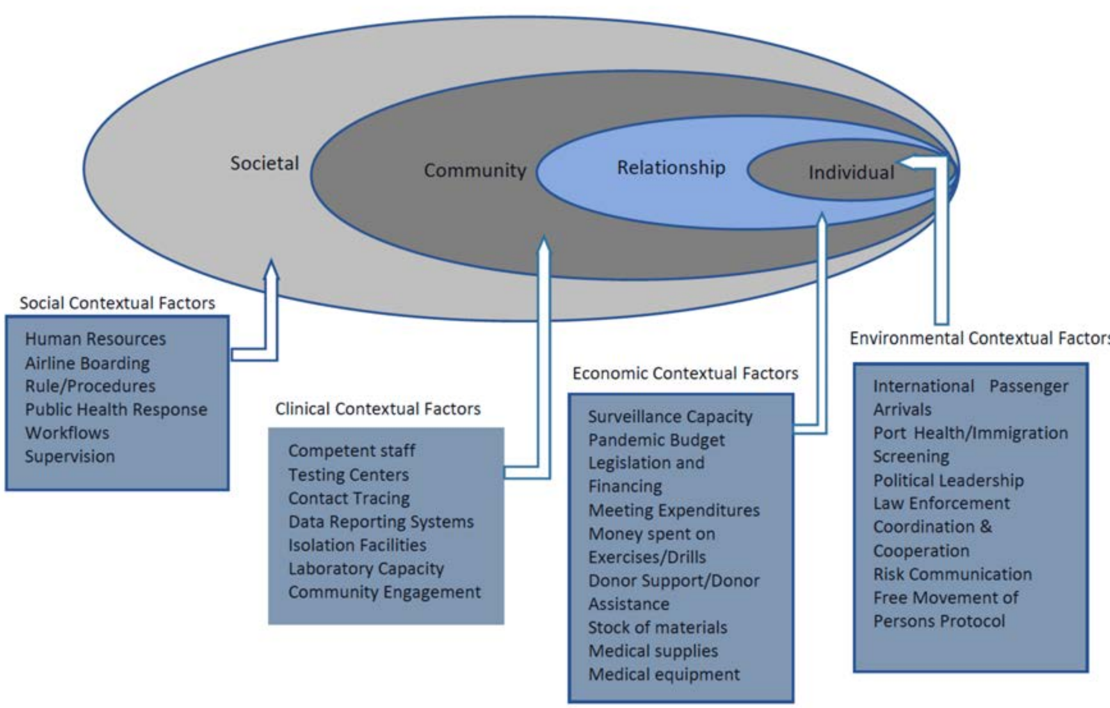

Figure 2. Social-ecological model adapted for the association between contextual factors and Covid-19 procurement.[19] Adapted from Krug *et al.* (2002), World Report on Violence And Health, with permission of the World Health Organization.

contextual factors, which comprise 3 categorical variables, 9 discrete level variables, and 1 continuous level variable, were then created in IBM SPSS statistical platform for analysis to answer the research questions and assess the hypotheses posed by this study.

Overarching research questions

What is the relationship between COVID-19 procurement and contextual factors using the social-ecological framework? How can an understanding of this association help improve the effectiveness, planning, and implementation of pandemic-related strategies at PoE in Ghana and the West African sub-region? Four investigative research questions were posted to reflect the contextual domains identified in the social-ecological framework.

The first investigative research question is: is there a relationship between clinical contextual features (COVID-19 cases, cumulative monthly total number of positive COVID-19 cases recorded), Kotoka International Airport (KIA) Testing Center, whether KIA has a COVID-19 testing center, laboratory capacity (average % score of attributes for laboratory using the WHO monitoring questionnaire), COVID-19 deaths, the cumulative monthly total number of COVID-19 deaths, and COVID-19 Procurement (the amount of money in US dollars spent on buying supplies for the COVID-19 pandemic in Ghana for the calendar year 2020)?

The second investigative research question is: is there a relationship between social contextual features (human resources, average % score of attributes for human resources using the WHO monitoring questionnaire), airline boarding rule, whether there is a boarding polymerase chain reaction (PCR) testing rule for international airline passengers arriving at the KIA, public health response (average % score per annum at all times for designated PoE using the WHO monitoring questionnaire), and COVID-19 procurement (the amount of money in US dollars spent on buying supplies for the COVID-19 pandemic in Ghana for the calendar year 2020)?

The third investigative research question is: is there a relationship between economic contextual features (surveillance capacity, average % score of attributes for surveillance using the WHO monitoring questionnaire), legislation and financing (average % score of legislation, laws, policies, administrative requirements, and other government instruments using the WHO monitoring questionnaire), and COVID-19 procurement (the amount of money in US dollars spent on buying supplies for the COVID-19 pandemic in Ghana for the calendar year 2020)?

The fourth investigative research question is: is there a relationship between environmental contextual features (international arrivals, cumulative total number of international airline passengers that arrived at the KIA), health workers cases (cumulative total number of health workers who tested positive for COVID-19), PoE designation (type of PoE assessed), PrezCOVID19 (presidential address time in minutes), and COVID-19 procurement (the amount of money in US dollars spent on buying supplies for the COVID-19 pandemic in Ghana for the calendar year 2020)?

In determining the status and progress made on the IHR core capacities for PoE in Ghana, the average percentage score of attributes *per annum* was calculated using the standardized WHO monitoring questionnaire established for all State Parties.[3] Cumulative monthly counts were used to evaluate the COVID-19-associated morbidity and mortality data and air passenger traffic data. Given that COVID-19 procurement addresses essential lifesaving items like medical supplies, equipment, ventilators, N95 masks, vaccines, and therapeutics, the researchers made the response/outcome variable in this study. As noted in the IHR monitoring framework, the attainment of the required core capacities for PoE is vital to preventing the international spread of diseases.[3] Interestingly,

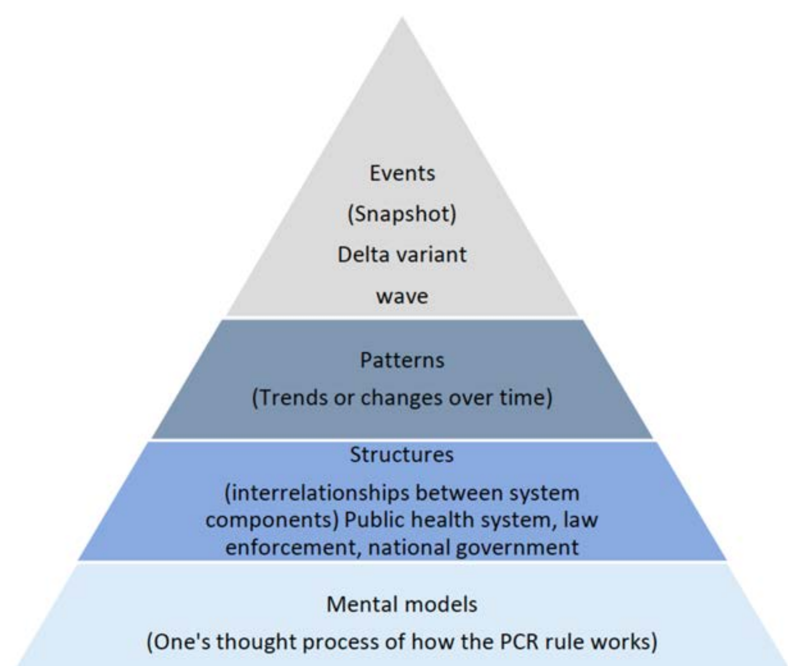

Figure 3. Application of systems thinking in the airline polymerase chain reaction boarding rule adapted from Johnson *et al.* Health systems thinking: a primer.[13] Adapted from Johnson JA and Rossow C (2017), Health Organizations (2nd ed.), with permission of the authors.

Cohen and Rogers also argue that a lack of proper access to personal protective equipment for healthcare workers can predispose them to illness.[24]

Generally, the capacity for early event detection, risk assessment, and prompt notification must be guided by robust and scalable real-time public health surveillance systems,[3] further highlighting the complexities and levels of awareness needed to influence disease outcomes. As has been the case in past outbreaks, Curran *et al*. found genomic surveillance capabilities resourceful in addressing the origin and transmission patterns associated with infectious diseases.[25] In the context of the Ebola epidemic in West Africa, Gire *et al*. used sequencing techniques to identify 99 Ebola virus genomes in several patients in Sierra Leone, one of the epicenters of the outbreak at the time,[26] making the realignment of public health mitigation measures in the country possible. Importantly, Boddington *et al*. also demonstrated the value of collecting and analyzing PoE Ebola virus disease screening data in resource decision-making.[27] Given the pathophysiology of infectious diseases and the influence of medical supplies on patient outcomes, the researchers postulated these hypotheses: i) there is a relationship between COVID-19 cases, KIA Testing Center, laboratory capacity, COVID-19 Deaths, and COVID-19 procurement; ii) there is a relationship between human resources, airline boarding rule, public health response, and COVID-19 procurement; iii) there is a relationship between surveillance capacity, legislation and financing, and COVID-19 procurement; iv) there is a relationship between international arrivals, health workers cases, PoE designation, PrezCOVID19, and COVID-19 procurement.

Data analysis

The research hypotheses were evaluated utilizing a multiple regression model that was unweighted, where each observation was considered as an equal unit. The regression equation is represented as:

COVID-19 procurement=β0+β*COVID-19 cases+β2*KIA testing center+β3*laboratory capacity+β4*COVID-19 deaths+β5*human resources+β6*airline boarding rule+β7*public health response+β8*surveillance capacity+β9*legislation and financing+β10*international arrivals+β11*health workers cases+β12*PoE designation+β13*PrezCOVID-19.

The wild bootstrap regression technique was employed after key asymptotic assumptions were violated and additional unsuccessful transformation attempts. Several scholars assert that this method is not sensitive to asymptotic regression assumptions, and it can be used to address non-constant variance of residuals and more.[28,29] Likewise, Roodman *et al*. noted that the wild bootstrap is especially useful in circumstances where the conventional inference methods are unreliable because large-sample assumptions do not hold.[30] As mentioned earlier, examining the contextual factors can enhance understanding regarding what works in different settings and finding a comprehensive solution, as well as making a prudent allocation of critical resources during epidemics and pandemics.

Results

The first regression model conducted was an unweighted analysis. COVID-19 procurement was approximately normally distributed with a few outliers. Pearson correlation between COVID-19 procurement and human resources was statistically significant *r*=.412, P=.025, legislation and financing, *r*=.449, P=.016, surveillance capacity, *r*=.404, P=.028, COVID-19 cases, *r*=.426, P=.021, and laboratory capacity, *r*=.483, P=.010. Due to a few asymptotic violations, the model parameters cannot be relied on. The wild bootstrap technique was utilized to address this concern. Table 1 shows the Bootstrap for coefficients.

Assumptions checks for first regression model

The appropriateness of the multiple linear regression model was evaluated as follows:

Independent errors

The Durbin-Watson test value was 3.298, which indicates a negative correlation or serial correlation of errors.[23]

Table 1. Bootstrap for coefficients

Model		Bootstrap[a]				
					BCa 95% confidence interval	
	B	Bias	Std. error	Sig. (2-tailed)	Lower	Upper
(Constant)	-205033.243	345.236	148145.036	.405	-484943.082	82578.457
Health workers who tested positive COVID-19	-120.320	-8.886	49.265	.178	-207.823	-52.785
Human resource capacity indicator score for Ghana in percentages	-7109.930	-424.667	4918.354	.394	-15678.842	1264.205
Airline passenger boarding PCR testing rule	-3298111.623	2216.956	222306.183	.001	-3726984.456	-2896557.309
KIA has a COVID-19 testing center	3061160.560	-382.168	166064.263	.001	2737525.781	3388233.916
Type of points of entry	272026.307	-5823.062	159649.171	.296	2213.604	562728.523
Points of entry capacity indicator score in percentages	-25981.461	-265.812	6844.018	.026	-37919.441	-14457.173
Legislation and capacity indicator score for Ghana in percentages	-24228.561	-355.654	7367.702	.078	-36730.715	-12354.868
Ghana surveillance capacity indicator score in percentages	23038.463	473.435	7973.981	.161	8801.360	36924.784
Cumulative monthly COVID-19 deaths in Ghana	1186.504	-16.206	1014.893	.463	-806.878	3107.927
Cumulative monthly COVID-19 cases in Ghana	-25.040	.063	15.793	.275	-54.720	3.418
Laboratory capacity indicator score for Ghana in percentages	9619.229	117.171	2457.346	.026	4918.270	14928.893
Annual total number of international air passenger arrivals in Ghana	-.009	.001	.190	.967	-.355	.370
Presidential address time in minutes	19891.941	299.151	9362.580	.218	3167.709	36343.031

[a]Unless otherwise noted, bootstrap results are based on 1000 wild bootstrap samples. Std. error, standard error; Sig, significance; BCa, bias-corrected and accelerated; PCR, polymerase chain reaction; KIA, Kotoka International Airport.

Multicollinearity

The variance inflation factor (VIF) was used to check the multicollinearity assumption, and a few predictor variables had VIF values greater than 10, indicating a violation of the rule.

Homoscedasticity

Examination of the regression studentized residual against regression standardized predicted value appears to show evidence of non-constant variance, indicating heteroscedasticity.

As previously mentioned, several attempts were made to transform a few predictor variables, but the problem persisted. Moreover, removing these predictors altogether would be detrimental as well. Importantly, several scholars found the wild bootstrap technique valuable as an inferential method or robustness check in simulations and computational applications and is not sensitive to asymptotic regression assumptions.[28-30]

Based on the wild bootstrap analysis conducted, as shown in Table 1, we can be 95% confident that the coefficient for the predictor variable, airline boarding rule, was between -3726984.456 and -2896557.309, KIA testing center, 2737525.781 and 3388233.916, public health response, -37919.441 and -14457.173, and laboratory capacity, 4918.270 and 14928.893. Also, the results further indicate that airline boarding rule and public health response negatively predicted COVID-19 procurement, while the KIA testing center and laboratory capacity positively predicted COVID-19 procurement.

The researchers validated the study by integrating quantitative and qualitative data approaches via a sequential mixed-methods design. During the SME panel interview, the experts noted disparities in infrastructure resources for PoE functions in Ghana and West Africa, with the KIA having relatively better infrastructure resources and frontline staff compared to ground crossing facilities and the seaports. They also observed gaps in risk communication and community engagement in the border communities. Concerning the free movement of person protocol, they noted it presents additional logistical and administrative challenges for border and port health authorities during health screenings due to language barriers and travelers carrying fake documents. There were no divergent views among the SMEs.

Discussion

The wild bootstrap regression analysis showed there is a strong association between COVID-19 procurement, the predictor variables KIA testing center, laboratory capacity, airline boarding rule, and public health response. The only exception was the surveillance capacity predictor variable. The initial coefficients showed surveillance capacity as a statistically significant predictor, β=23038.463, P=.038, but it turned out to be an insignificant predictor when the wild bootstrap technique was employed. The public health implications of the findings are significant.

First, the policy by the Ghana government requiring all international airlines that fly to the KIA to have negative COVID-19 test results for arriving passengers is consistent with past epidemiological public health measures implemented to prevent disease importation during epidemics and pandemics.[11,15,20] Second, implementing the airline boarding rule alongside other screening and quarantine health measures at the PoE allowed for time to assess additional resource and capability needs as the pandemic evolved. As past literature shows, several factors affect the transmission of infectious diseases,[4,16,24] and PoE facilities vary in complexity and public health needs, making this contextual factor worthwhile. Figure 3 provides a mental model of how systems thinking can enhance situational awareness concerning Ghana's airline PCR boarding rule at the KIA. The findings from the analysis showing the predictor variable public health response as a significant contextual factor imply that IHR PoE capacities and capabilities are essential for strengthening disease surveillance and monitoring systems during periods of public health emergencies of international concern.[6]

Limitations

This study analyzed quantitative data gleaned from multiple publicly available data sources, followed by an interview with a panel of experts. While we recognize that this approach adds rigor to the study findings, the process has a few limitations. The first limitation of this study pertains to the unavailability of the IHR state parties self-assessment annual report on Ghana for the calendar years 2015 and 2021. Overall, while the gap in data did not adversely impact the study findings, access to the 2015 and 2021 calendar years report could have enriched the analysis. Second, a lack of control over secondary data accuracy and quality may be an issue, given the inherent biases and motivations in primary data collection. Third, we wanted to include other PoE, but the closure of these facilities made it impossible. Future research will expand on the findings, including utilizing other quantitative data collection methods.

Conclusions

As this research demonstrates, improving public health mitigation measures at PoE in Ghana requires an in-depth examination of many influencing factors and their linkages in the larger environment. Laboratory capacity and KIA testing center positively predicted COVID-19 procurement, confirming two of the contextual factors evaluated in hypothesis one. Likewise, public health response and airline boarding rule negatively predicted COVID-19 procurement, confirming two of the contextual factors assessed in hypothesis two. Collectively, the study findings validate the IHR.[6] Furthermore, the research findings also highlight the significance of enhancing infrastructure resources to help mitigate the health security threats posed by infectious diseases like EVD and COVID-19 in resource-challenged environments like Ghana.[7-9] Ghana must enhance readiness in proactive planning, inventory management, and public health workforce capacity for emerging infectious diseases. As more border communities become vulnerable to EVD and COVID-19, risk communication and community engagement activities in Ghana must receive urgent attention. Finally, the logic model highlights how available resources can affect program outputs and outcomes, providing opportunities for effective resource mobilization, prioritization, and evaluation.

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