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Letter from the Editors

Dear Reader,

Through our Fall 2021 issue, we aim to continue contributing to global and public health conversations through the publication of original research from members around the world. With a combination of virtual meetings and a gradual return to normalcy this fall, the journal has continued to engage with community members through the launch of our new issue and online events with featured guests. The pandemic underscored the importance of scientific research and continued engagement in these dialogues, and we have strived to continue maintaining this journal as an open space and platform for these conversations to occur.

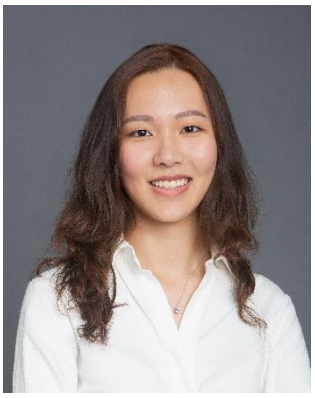
Our most recent event titled "Battling Pandemic Burnout" sought to shed light on mental health resources and outreach following the enduring long-term effects of the pandemic. We welcomed two guests – Kelly Gorman from Alice! Health Promotion and Kausik from Columbia The Art of Living – and the event featured conversations surrounding mindfulness and the practice of yoga.

In addition, we have continued to work closely in partnership with Columbia University Libraries and this semester marked a new milestone for our online board, as the team transitioned our podcast and blog to a new website. We are excited for the online board's upcoming productions with their new online home.

In this Fall 2021 issue, you'll find articles that deal with timely issues regarding the ongoing COVID-19 pandemic such as factors that contribute to COVID-19 vaccine acceptance in Sub-Saharan Africa and global trends in vaccine hesitancy and acceptance. You will also find articles that explore ongoing public health concerns such as incorporating community engagement to optimize rainwater harvesting systems and centering community acceptance of water sanitation and hygiene initiatives to reduce the burden of soil-transmitted helminth infections in low and middle income countries. We are very fortunate to be able to work with our authors in publishing articles on these topics.

We continue to be so grateful for the contributions of our wonderful staff, advisers, and peer reviewers, with special thanks to Digital Publishing Librarian Michelle Wilson and faculty advisor Professor James Colgrove, without which this journal would not be what it is today.

Sincerely,
Scarlet Au & Sophia Spiegel
Co-Editors-in-Chief,
The Columbia University Journal of Global Health



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Covid-19 in Africa: Exploring the Factors that Predict Public Acceptance & Intended Use of the Covid-19 Vaccine in Sub-Saharan Africa

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ABSTRACT The Covid-19 pandemic has resulted in many unprecedented mortality and fatalities globally. To address the negative effects of the pandemic on the general public and nations, the Covid-19 vaccine was developed and rolled out around the world. However, historical evidence suggests that Africans initially struggle to accept and use vaccines because of misconceptions and unfamiliarity about vaccine safety and administration. The Covid-19 vaccine might not be an exception. This study identifies the various factors that correlate with the intention of citizens to acceptance and use of the Covid-19 vaccine in Sub-Saharan Africa, using a chi-square analysis of 3000 respondents from six countries in the region. Results from our analysis suggest that vaccine-specific issues such as safety, effectiveness, availability, delivery methods, and other factors strongly correlate with acceptance and intended use of the Covid-19 vaccine in Sub-Saharan Africa. The findings of this study have serious implications for both theory and practice vaccine administration in Africa and globally.

KEY WORDS Covid-19, Sub-Saharan Africa, vaccination & African

INTRODUCTION

Globally, the Covid-19 virus that started in Wuhan, China in 2019 has been devastating for many individuals and nations. Among the notable effects of the virus are the collapse of world economies and businesses, the pressure on healthcare systems and professionals, a decline in the emotional and physical wellbeing of individuals, unemployment, and the death of hundreds of thousands of people (Nkengasong et al., 2020; Afolabi & Ilesanmi, 2021). In Africa, especially Sub-Saharan Africa, the impact of Covid-19 on the lives of the citizens has been more devastating for several reasons, such as poor healthcare systems, the lack of health professionals, etcetera. (Hotez & Bottazzi, 2020; Dinga, Sinda & Titanji, 2021). Efforts to find a vaccine has yielded results, however, there are questions regarding the safety and public perception of the vaccine (Dinga, Sinda & Titanji, 2021). Few studies currently attempt to examine the factors that correlate or influence Covid-

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19 vaccine us (Lancet, 2020; Singh, 2020; Murphy et al., 2021). The present study augments the existing literature and also address the gap in the literature pertaining to Africa.

LITERATURE REVIEW

The importance of vaccines in global health promotion is well documented in the literature. In Africa, vaccine programs have been highly effective in reducing illness such as smallpox, measles, diphtheria tetanus, poliomyelitis, and death, especially among children (Dubé et al., 2016; Cooper et al., 2018; Olson, Berry & Kumar, 2020; Afolabi & Ilesanmi, 2021). Another important effect of vaccine programs in Africa is the reduction in hospital cost incurred by families to treat several illnesses (Cooper et al., 2018). The success of vaccine programs in Africa has led to calls for the creation of a malaria vaccine to help curtail the disease, which is endemic to the continent (Ojakaa et al., 2011; Dzordzormenyoh, Asafo, & Domeh, 2020). Beside the malaria vaccine, there are currently trials in some parts of Africa with the Ebola virus vaccine with hopes of reducing Ebola outbreaks (Huo et al., 2016). Nevertheless, there are still challenges with vaccine programs on the continent and even across the world. Empirical evidence from previous studies and the World Health Organization (WHO) suggest that the administration of vaccines in Africa is usually delayed because of public misconception and unfamiliarity (Fine, Eames & Heymann, 2011; Febir et al., 2013; Marti et al., 2017; Patel et. al., 2019). It has been observed that misconceptions and unfamiliarity about the polio vaccine in Africa led to delays in acceptance and intended use of the vaccine. These delays led to an increase in polio infection across the continent. Additionally, religious beliefs have been attributed to the high levels of misconceptions and unfamiliarity surrounding vaccines in Africa (Jegede, 2007; Afolabi & Ilesanmi, 2021). In essence, vaccine rejection by the public in Africa is rooted in fear, unfamiliarity, misconceptions, and religious beliefs.

In regard to the challenges of acceptance and intended use of the Covid-19 vaccine in Africa, government mistrust has also been proposed as an explanatory factor (Amadasun, 2020; Afolabi & Ilesanmi, 2021). The inadequate response by African governments has weakened citizens' trust in their leaders and governments, reducing citizens' willingness to accept the Covid-19 vaccine (Afolabi & Ilesanmi, 2021). Most African countries and governments adopted an authoritarian approach, using security agencies instead of healthcare professionals to implement and monitor several Covid-19 control measures like the use of face masks, social distancing, hand hygiene, and stay-at-home orders (Amadasun, 2020; Bowman, 2020). This led to the abuse of citizens by security agencies and further weakening of public trust in their governments on the continent (Bowman, 2020). In addition to these challenges faced in Africa that can hinder acceptance and intended use of the vaccine, other studies have also identified specific concerns the general public have about the Covid-19 vaccine. Among these concerns are safety of the vaccine (Makoni, 2020; Singh, 2020), effectiveness of the vaccine (Madhi et. al., 2021; Wiysonge et al., 2021), availability of the vaccine, and delivery method (Nachega et al., 2021) of the vaccine to all citizens.

METHOD

Data source

The data for this study was obtained from the Inter-university Consortium for Political and Social Research (ICPSR) at the University of Michigan, Ann Arbor. The data was initially collected by the research firm GeoPoll from six African countries – Côte D'Ivoire, the Democratic Republic of Congo, Kenya, Mozambique, Nigeria, and South Africa. The survey was conducted via SMS from November 10th to 24th, 2020, and it contains data on the impact of Covid-19 on citizens' daily routines, finances, and consumer spending. Additional questions were asked about vaccine safety and effectiveness and the public's willingness to take a Covid-19 vaccine if available. The sample size for this data was 3000 respondents. GeoPoll used a simple random sampling technique from GeoPoll's respondent database. While SMS surveys are criticized for over sampling the rich and more educated, the sample used by GeoPoll was nationally representative. [1]

MEASURES

Outcome variable

The dependent variable for this study is *Covid-19 vaccine acceptance and intended use*. Respondents were asked if they would get the vaccine if it was free and available at the time of the interview. Respondents were given five

[1] Geopoll. 2020 Year End Report. https://f.hubspotusercontent30.net/hubfs/325431/GeoPoll%20Year%20End%20Report%202020.pdf?__hstc=242131037.14a7e8d5d637d04133d74d047bb72384.1637611423169.1637611423169.1637611423169.1&__hssc=242131037.1.1637611423169&__hsfp=999455785&hsCtaTracking=3867c49b-55bc-4e71-a9a4-5d1e0aeffec6%7Cb471350b-9319-4ed7-9891-3993ac319d8c. Accessed: November 22, 2021.

options – 1 as definitely yes, 2 as probably yes, 3 as probably not, 4 as definitely not and 5 as unsure.

Predictor variables

Since this study adopted a bivariate and exploratory approach in understanding the factors that correlate with Covid-19 vaccine acceptance and intended use, all the variables were treated as predictors. Over 20 variables were used as predictors of the outcome variable and they are: *the country of respondents* coded as 1 = Côte D'Ivoire, 2 = the Democratic Republic of Congo, 3 = Kenya, Mozambique, 4 = Nigeria, and 5 = South Africa. The *gender* of respondents was coded as male and female, and the *age* of respondents measured in actual years was coded as 1 = 15 – 25 years, 2 = 26 – 35 years, and 3 = 36+ years. Respondents were also asked *how covid affected their daily routines* and if the respondent's *life had returned to normal at the time of the interview*. For both questions respondents had five options: 1 = not at all, 2 = very little, 3 = somewhat, 4 = quite a bit and 5 = a great deal. Respondents were also asked *when Covid would end* and had the choices: 1 = already, 2 = first half of 2021, 3 = second half of 2021, 4 = 2020 or later and 5 = never. Also, respondents were asked about *the impact of Covid on their physical and emotional health* with the options: 1 = much worse, 2 = a little worse, 3 = about the same, 4 = a little better and 5 = much better. Respondents were also asked about *the biggest challenge they experienced because of Covid* and had the following options: 1 = finances, 2 = staying at home, 3 = emotional wellbeing, 4 = physical health, 5 = illness of loved ones and 6 = others. Respondents were asked if they *trust the information on Covid from their government* with options: 1 = strongly disagree and 5 = strongly agree.

Furthermore, *the impact of Covid on the income of respondents* was assessed with 1 = decreased a lot, 2 = decreased a little, 3 = no change, 4 = increased a little and 5 = increased a lot. Respondents were asked about *the concerns they have had in paying their monthly bills since Covid started* and the options were 1 = more concerned, 2 = less concerned, and 3 = no change. Respondents were also surveyed about *their spending habits on essential and non-essential items during the pandemic* and both questions had these options: 1 = more, 2 = less and 3 = about the same. *Shopping online and using mobile money instead of physical cash* was another question the respondent had to answer with the options 1 = more frequently, 2 = less frequently and 3 = about the same.

The survey also had questions directly related to the vaccine. Respondents were asked if they think the *vaccine is safe to use* and had these options: 1 = strongly agree, 2 = somewhat agree, 3 = neither agree or disagree, 4 = somewhat disagree and 5 =strongly disagree. For *the effectiveness of the vaccine*, respondents had these options: 1 = strongly agree, 2 = somewhat agree, 3 = neither agree or disagree, 4 = somewhat disagree and 5 = strongly disagree. Respondents were also asked about the *concerns they have about the vaccine* with the options, 1 = vaccine safety, 2 = ability to get the vaccine myself, 3 = ability for everyone to get the vaccine, 4 = cost, 5 = no concern/nothing and 6 = others. Respondents' views regarding *when the vaccine would be available were also collected,* and the answer choices were 1 = Nov. – Dec. 2020, 2 = Jan. – Jun. 2021, 3 = July – Dec. 2021, 4 = 2022 or later and 5 = unsure. Respondents were also asked *who should get the vaccine* and the options were: 1 = everybody at once, 2 = vulnerable/poor people, 3 = healthcare workers, 4 = those who can pay for the vaccine, 5 = poorest populations and 6 = others.

ANALYTICAL STRATEGY

To achieve the primary objective of this study – what are the factors that correlate with Covid-19 vaccine acceptance and intended use in Sub-Saharan Africa? We assessed how each of the predictor variables separately correlates with the outcome variable – acceptance and intended use of the vaccine. Furthermore, we calculated descriptive statistics and conducted chi-square analysis. The descriptive statistics were used to show the distribution of scores across various variables used in the present study (see Table 1 below). In addition to the descriptive statistics, chi-square analysis was conducted between each predictor variable and the outcome variable to determine the correlation between both variables. The chi-square results are presented in Table 2 below.

RESULTS

Descriptive statistics

Table 1 below shows the distribution of scores for the variables included in this study. Overall, a total of 3000 respondents were interviewed from six African countries – Cote D'Ivoire (16.7%), Democratic Republic of Congo (16.7%), Kenya (16.7%), Mozambique (16.7%), Nigeria (16.7%) and South Africa (16.7%). Women were slightly oversampled (50.4%) compared to men at 49.6%. The age distribution of respondents was 38.4% for respondents aged 15 – 25 years, 28.3% for respondents aged 26 – 35 years, and finally 33.4% for respondents aged 36 years and above. Regarding respondents' acceptance and intended use of the Covid-19

vaccine, the answers were as follows: definitely yes (41.9%), probably yes (19.8%), definitely not (9.5%), probably not (9.9%), and unsure (18.9%). Again, most of the respondents (87.1%) suggest Covid has changed their daily routine compared to 12.9% who experienced no change. Similarly, most of the respondents (84.7%) suggest their lives have returned to normal since Covid started compared to 15.3% whose lives have not returned to normal. Finally, most of the respondents (40.1%) believed that Covid would end the first half of 2021 compared to 23.7% that believed Covid had already ended.

TABLE 1. SUMMARY STATISTICS FOR THE VARIABLES USED IN THIS STUDY (N = 3000)

Variables	N	Valid %
Get the Covid vaccine		
Definitely	1,256	41.9
Definitely not	286	9.5
Probably	594	19.8
Probably not	296	9.9
Unsure	568	18.9
Country		
Cote D'Ivoire	500	16.7
DRC	500	16.7
Kenya	500	16.7
Mozambique	500	16.7
Nigeria	500	16.7
South Africa	500	16.7
Age		
15 – 25	1,151	38.4
26 – 35	848	28.3
36+	1,001	33.4
Gender		
Female	1,512	50.4
Male	1,488	49.6
Covid changed my daily routine		
A lot	846	28.2
Somewhat	382	12.7
Quite a bit	651	21.7
Very little	734	24.5
Not at all	387	12.9
Life return to normal since Covid		
A lot	273	9.1
Somewhat	480	16.0
Quite a bit	511	17.0
Very little	1,277	42.6
Not at all	459	15.3
When will Covid end		
Already	710	23.7
First half of 2021	1,225	40.8
Second half of 2021	516	17.2
2022 or later	284	9.5
Never	265	8.8
Impact of Covid on physical health		
A little better	673	22.4
Much better	487	16.2
About the same	1,079	35.9
A little worse	495	16.5
Much worse	266	8.9
Impact of Covid on emotional health		
A little better	604	20.1
Much better	344	11.5
About the same	759	25.3

A little worse	787	26.2
Much worse	506	16.9
Biggest challenge because of Covid		
Emotional wellbeing	229	7.6
Finances	1,658	55.3
Illness of loved one	191	6.37
Other	82	2.7
Physical health	148	4.9
Staying home	692	23.1
Trust Covid information from government		
Strongly agree	735	24.5
Agree	151	5.0
Undecided	225	7.5
Disagree	176	5.9
Strongly disagree	1,713	57.1
Changes in income due to Covid		
Decreased a little	796	26.5
Decreased a lot	1,566	52.2
No change	371	12.4
Increased a little	167	5.6
Increased a lot	100	3.3
Concerned about paying expense due to Covid		
Less concerned	662	22.1
No change	389	12.9
More concerned	1,949	64.9
Spending on essential items		
Less	702	23.4
About the same	484	16.1
More	1,814	60.5
Spending on non-essential items		
Less	1,702	56.7
About the same	546	18.2
More	752	25.1
Use of online shopping		
Less	1,756	58.5
About the same	688	22.9
More	556	18.5
Use of mobile money		
Less	1,340	44.7
About the same	615	20.5
More	1,045	34.8
Covid Vaccine is safe		
Strongly agree	986	32.9
Agree	642	21.4
Undecided	867	28.9
Disagree	243	8.1
Strongly disagree	262	8.7
Covid vaccine effectiveness		
Strongly agree	983	32.8
Agree	720	24.0
Undecided	828	27.6
Disagree	221	7.4
Strongly disagree	248	8.3
Concerns about the Covid vaccine		
Everyone can get the vaccine	814	27.1
Ability to get the vaccine myself	306	10.2
Cost	359	11.9

Nothing	331	11.0
Vaccine safety	1,061	35.4
Other	129	4.3
When will the vaccine be available		
November - December 2020	441	14.7
January-June 2021	942	31.4
July-December 2021	313	10.4
2022 or later	147	4.9
Unsure	1,157	38.6
How should be vaccine be delivered		
Everybody at once	562	18.7
Healthcare workers	858	28.6
Poorest populations	180	6.0
Those who can pay	700	23.3
Vulnerable people	551	18.4
Other	149	4.9

N represents number of respondents & **Valid %** represents percentage of respondents based on the number of respondents for each question.

Furthermore, the responses regarding the impact of Covid on the physical health of respondents were: the same (35.9%), either better or much better (38.6%), worse or much worse (25.4%). The impact of Covid on the emotional health of respondents, the responses were: better (31.6%), the same (25.3%), and worse (43.1%). Respondents suggested that finance (55.3%) and staying at home (23.1%) are the two major challenges that came with Covid. Additionally, with the quality of Covid-19 information most respondents (63%) either agree or strongly disagree with the quality of information on Covid compared to 29.5% who agree with the quality of Covid-19 information they receive. This shows support to public mistrust towards African governments by the citizens discussed in the literature review. Regarding the impact of Covid on income, responses include decreased income (78.7%), and unchanged/same income (12.4%).

Moreover, most of the respondents (64.9%) are more concerned about paying for expenses during Covid, compared to 22.1% who are less concerned and 12.9% who argue there is no change.

Again, about 61% of the respondents spend on essential items compared to 23% that do not spend on essential items during the pandemic. In contrast to essential items, 67% of respondents spend less on non-essential items compared to 25% that spend more on non-essential items during the pandemic. The use of online shopping among respondents was less at about 59% compared to 19% that used online shopping during the pandemic. With the use of non-physical cash (mobile money) during the pandemic, 45% of the respondents used it less compared to 35% that used it more.

Finally, with specific questions related to the vaccine the distributions were as follows. With regards to the safety of the vaccine, about 54% of the respondents believe the vaccine is safe. However, about 29% of the respondents were undecided. Regarding the effectiveness of the vaccine, 57% of the respondents believe the vaccine is effective against the virus but 28% of the respondents were undecided. With concerns that people have about the vaccine, 11% of the respondents had no concern about the vaccine, 23% were concerned if the vaccine will be made available for everyone, 35% were concerned about the safety of the vaccine and about 12% were concerned about the cost of the vaccine. With questions regarding vaccine availability, 39% of the respondents were unsure; however, 31% of respondents believe the vaccine will be available in the first half of 2021. About 29% of respondents believe healthcare workers should be the first to have the vaccine, followed by 23% of respondents who believe individuals who can pay for the vaccine should have it. Access to the vaccine by everybody and vulnerable people was about 19% and 18% respectively.

Correlates of acceptance & intended use of Covid-19 vaccine

Table 2 below shows the estimates for the association of several variables with the acceptance and intended use of Covid-19 vaccine. From the results presented in Table 2, several interesting and intriguing revelations about the factors that correlate with intended Covid-19 vaccine use, can be observed. Overall, three variables were found not to correlate with the public's acceptance and intended use of Covid-19 vaccine in Sub-Saharan Africa. First, the age of respondents was not significant, with the estimate ($X^2 = 10.54$) and a p-value of 0.229.

Second, gender was not significant, with the estimate (X^2 = 9.05) and a p-value of 0.060. Finally, the biggest challenge that respondents experienced because of Covid-19 was also not significant with the estimate (X^2 = 27.38) and a p-value of 0.125. These results are consistent with empirical studies from some previous studies examining the factors that correlates with vaccine acceptance and intended use (El-Gendy et. al., 2020; Freeman et. al., 2020).

TABLE 2. PREDICTORS OF ACCEPTANCE AND USE OF VACCINE (N=300)

Variables	Definitely	Definitely Not	Probably	Probably Not	Unsure	Chi-square Test (p-value)
Age						
15 – 25	451(35.9)	116(40.6)	227(38.2)	128(43.2)	229(40.3)	$X^2(8)$ =10.54
26 – 35	370(29.5)	85(29.7)	172(28.9)	69(23.3)	152(26.8)	(0.222)
36+	435(34.6)	85(29.7)	195(32.8)	99(33.5)	187(32.9)	
Gender						
Female	611(48.6)	150(52.5)	286(48.2)	150(50.7)	315(55.5)	$X^2(4)$ = 9.05
Male	645(51.4)	136(47.5)	308(51.9)	146(49.3)	253(44.5)	(0.060)
Country						
Cote D'Ivoire	149(11.9)	41(14.3)	105(17.7)	50(16.9)	155(27.3)	$X^2(20)$ = 196.44
DRC	132(10.5)	78(27.2)	98(16.5)	67(22.6)	125(22.0)	(0.000***)
Kenya	237(18.9)	35(12.2)	103(17.3)	60(20.2)	65(11.4)	
Mozambique	244(19.4)	31(10.8)	97(16.3)	35(11.8)	65(16.4	
Nigeria	234(18.6)	57(19.9)	106(17.9)	40(13.5)	63(11.1)	
South Africa	260(20.7)	44(15.4)	85(14.3)	44(14.9)	67(11.8)	
Change daily routine						
A lot	345(27.5)	83(29.0)	154(25.9)	86(29.1)	178(31.3)	$X^2(16)$ = 47.76
Somewhat	130(10.4)	33(11.5)	95(15.9)	47(15.9)	77(13.6)	(0.000***)
Quite a bit	302(24.0)	51(17.8)	136(22.9)	62(20.9)	100(17.6)	
Very little	322(25.6)	68(23.8)	153(25.8)	70(23.7)	121(21.3)	
Not at all	157(12.5)	51(17.8)	56(9.4)	31(10.5)	92(16.0)	
Life return to normal						
A lot	125(9.9)	26(9.1)	39(6.6)	27(9.1)	56(9.9)	$X^2(16)$ = 68.13
Somewhat	152(12.1)	38(13.3)	134(22.6)	64(21.6)	92(16.2)	(0.000***)
Quite a bit	209(16.6)	48(16.8)	103(17.3)	53(17.9)	98(17.3)	
Very little	569(45.3)	121(42.3)	260(43.8)	113(38.2)	214(37.7)	
Not at all	201(26.0)	53(18.5)	58(9.8)	39(13.2)	108(19.0)	
When will Covid end						
Already	300(23.9)	73(25.5)	133(22.4)	65(21.9)	139(24.5)	$X^2(16)$ = 27.17
First half of 2021	515(41.0)	112(39.2)	272(45.8)	118(39.9)	208(36.6)	(0.040*)
Second half of 2021	217(17.3)	51(17.8)	103(17.3)	59(19.9)	86(15.1)	
2022 or later	123(9.8)	22(7.7)	45(7.6)	26(8.8)	68(11.9)	
Never	28(9.8)	101(8.0)	41(6.9)	28(9.5)	67(11.8)	
Impact of Covid on physical health						
A little better	298(23.7)	64(22.4)	129(21.7)	56(18.9)	126(22.2)	$X^2(16)$ = 46.08
Much better	225(17.9)	56(19.6)	74(12.5)	36(12.2)	96(16.9)	(0.000***)
About the same	389(30.9)	110(38.5)	243(40.9)	124(41.9)	213(37.5)	
A little worse	215(17.1)	32(11.2)	106(17.9)	58(19.6)	84(14.8)	
Much worse	129(10.3)	24(8.4)	42(7.1)	22(7.4)	49(8.6)	
Impact of Covid on emotional health						
A little better	275(21.9)	55(19.2)	116(19.5)	44(14.9)	114(20.1)	$X^2(16)$ = 62.76
Much better	164(13.1)	48(16.8)	45(7.6)	23(7.7)	64(11.3)	(0.000***)
About the same	277(22.1)	69(24.1)	156(26.3)	88(29.7)	169(29.8)	
A little worse	294(23.4)	72(25.2)	185(31.1)	90(30.4)	146(25.7)	
Much worse	246(19.6)	42(14.7)	92(15.5)	51(17.2)	75(13.2)	
Covid challenges						
Emotional wellbeing	93(7.4)	20(6.9)	49(8.3)	29(9.8)	38(6.7)	$X^2(20)$ = 27.38

Finances	697(55.5)	161(56.3)	341(57.4)	157(53.0)	302(53.2)	(0.125)
Illness of loved one	81(6.5)	12(4.2)	37(6.2)	18(6.1)	43(7.6)	
Other	24(1.9)	14(4.9)	12(2.0)	7(2.4)	25(4.4)	
Physical health	72(5.7)	10(3.5)	28(4.7)	13(4.4)	25(4.4)	
Staying home	289(23.1)	69(24.1)	127(21.4)	72(24.3)	135(23.8)	
Trust information on covid						
Strongly agree	252(20.1)	101(35.3)	140(23.6)	101(34.1)	141(24.8)	$X^2(16) = 126.64$
Agree	48(3.8)	22(7.7)	40(6.7)	21(7.1)	20(3.5)	(0.000***)
Undecided	67(5.3)	26(9.1)	64(10.8)	34(11.5)	34(5.9)	
Disagree	66(5.3)	19(6.6)	42(7.1)	20(6.8)	29(5.1)	
Strongly disagree	823(65.5)	118(41.3)	308(51.9)	120(40.5)	344(60.6)	
Changes in income						
Decreased a little	306(24.4)	76(26.6)	206(34.7)	61(20.6)	147(25.9)	$X^2(16) = 46.90$
Decreased a lot	688(54.8)	145(50.7)	266(44.8)	160(54.1)	307(54.1)	(0.000***)
No change	140(11.2)	41(14.3)	79(13.3)	38(12.8)	73(12.9)	
Increased a little	76(6.1)	13(4.6)	31(5.2)	19(6.4)	28(4.9)	
Increased a lot	46(3.7)	11(3.9)	12(2.0)	18(6.1)	13(2.3)	
Concerned expenses						
Less concerned	272(26.7)	67(23.4)	137(23.1)	63(21.3)	123(21.7)	$X^2(8) = 20.76$
No change	140(11.2)	42(14.7)	65(10.9)	40(13.5)	102(17.9)	(0.008**)
More concerned	844(67.2)	177(61.9)	392(65.9)	193(65.2)	343(60.4)	
Spending on essential items						
Less	279(22.2)	79(27.6)	144(24.2)	79(26.7)	121(21.3)	$X^2(8) = 30.49$
About the same	165(13.1)	48(16.8)	97(16.3)	51(17.2)	123(21.7)	(0.000***)
More	812(64.7)	159(55.6)	353(59.4)	166(56.1)	324(57.0)	
Spending on non-essential items						
Less	701(55.8)	160(55.9)	341(57.4)	50(16.9)	317(55.8)	$X^2(8) = 24.42$
About the same	200(15.9)	51(17.8)	114(19.2)	183(61.8)	131(23.1)	(0.002**)
More	355(28.3)	75(26.2)	139(23.4)	63(21.3)	120(21.1)	
Use of online shopping						
Less	734(58.4)	175(61.2)	358(60.3)	171(57.8)	318(55.9)	$X^2(8) = 32.65$
About the same	251(19.9)	67(23.4)	132(22.2)	68(22.9)	170(29.9)	(0.000***)
More	271(21.6)	44(15.4)	104(17.5)	57(19.3)	80(14.1)	
Use of mobile money						
Less	569(45.3)	127(44.4)	260(43.8)	132(44.6)	252(44.4)	$X^2(8) = 36.57$
About the same	213(16.9)	69(24.1)	115(19.4)	61(20.6)	157(27.6)	(0.000***)
More	474(37.7)	90(31.5)	219(36.9)	103(34.8)	159(27.9)	
Covid vaccine is safe						
Strongly agree	697(55.5)	37(12.9)	123(20.7)	43(14.5)	86(15.1)	$X^2(16) = 936.02$
Agree	255(20.3)	21(7.3)	217(36.5)	60(20.3)	89(15.7)	(0.000***)
Undecided	219(17.4)	80(27.9)	197(33.2)	106(35.8)	265(46.7)	
Disagree	48(3.8)	57(19.9)	34(5.7)	50(16.9)	54(9.5)	
Strongly disagree	37(2.9)	91(31.8)	23(3.9)	37(12.5)	74(13.0)	
Covid Vaccine effectiveness						
Strongly agree	672(53.5)	39(13.6)	128(21.6)	39(13.2)	105(18.5)	$X^2(16) = 774.33$
Agree	279(22.2)	36(12.6)	238(40.1)	73(24.7)	94(16.6)	(0.000***)
Undecided	208(16.6)	83(29.0)	175(29.5)	106(35.8)	256(45.1)	
Disagree	48(3.8)	50(17.5)	33(5.6)	39(13.2)	51(8.9)	
Strongly disagree	49(3.9)	78(27.3)	20(3.4)	39(13.2)	62(10.9)	
Vaccine concerns						
Everyone can get the Vaccine	518(41.2)	26(9.1)	151(25.4)	42(14.2)	77(13.6)	$X^2(20) = 556.47$
Ability to get the vaccine Myself	149(11.9)	17(5.9)	63(10.6)	39(13.2)	38(6.7)	(0.000***)
Cost	183(14.6)	14(4.9)	70(11.8)	26(8.8)	66(11.6)	
Nothing	53(4.2)	63(22.0)	38(6.4)	43(14.5)	134(23.6)	
Vaccine safety	334(26.6)	129(45.1)	260(43.8)	131(44.3)	207(36.4)	
Other	19(1.5)	37(12.9)	12(2.0)	15(5.1)	46(8.1)	

Availability of vaccine						
Nov - Dec 2020	281(22.4)	20(6.9)	69(11.6)	25(8.5)	46(8.1)	$X^2(16) = 344.54$
Jan - June 2021	471(37.5)	54(18.9)	228(38.4)	85(28.7)	104(18.3)	(0.000***)
July-Dec 2021	116(9.2)	25(8.7)	77(12.9)	46(15.5)	49(8.6)	
2022 or later	53(4.2)	21(7.3)	28(4.7)	24(8.1)	21(3.7)	
Unsure	335(26.7)	166(58.0)	192(32.3)	116(39.2)	348(61.3)	
Vaccine delivery						
Everybody at once	280(22.3)	30(10.5)	106(17.9)	33(11.2)	113(19.9)	$X^2(20) = 143.86$
Healthcare workers	405(32.3)	78(27.3)	160(26.9)	84(28.4)	131(23.1)	(0.000***)
Poorest populations	65(5.2)	27(9.4)	33(5.6)	28(9.5)	27(4.8)	
Those who can pay	265(21.1)	62(21.7)	148(24.9)	85(28.7)	140(24.7)	
Vulnerable people	217(17.3)	55(19.2)	125(21.0)	51(17.2)	103(18.1)	
Other	24(1.9)	34(11.9)	22(3.70)	15(5.1)	54(9.5)	

Column percentages in parenthesis beside number of respondents; chi-square degree of freedom in parenthesis followed by chi-square statistic number.
* p<0.05, ** p<0.01, *** p<0.001

In contrast to these variables that had no correlation with public acceptance and intended use of the Covid-19 vaccine, several other variables were observed to be significant. First, the country of respondents was significant with the estimate ($X^2 = 196.44$; $p<0.001$). Country variations in vaccine acceptance and intended use in Africa is well documented in the literature and further supports this result (Afolabi, & Ilesanmi, 2021). For example, Seychelles, Mauritius, Morocco, Tunisia, Brazzaville, Comoros, and Cape Verde have vaccines between 20% to 60% of their population with the Covid-19 vaccine compared to the other countries on the continent yet to reach the 10% global Covid-19 vaccination goal (WHO, 2021). Second, the effect of Covid on the daily routine of respondents was significant with the estimate ($X^2 = 47.76$; $p<0.001$). Covid-19 preventive measures such as stay-at-home orders, the use of security agencies to enforce these measures etcetera created new daily challenges for citizens in Africa to overcome. Third, respondents' view of their life returning to normal since the start of Covid was highly significant with the estimate ($X^2 = 68.13$; $p<0.001$). Fourth, respondents' view of when Covid will end was very significant with the estimate ($X^2 = 27.17$; $p< 0.05$). Fifth, the impact of Covid on the physical and emotional health of respondents was highly significant with the estimates ($X^2 = 46.08$; $p< 0.001$) and ($X^2 = 62.76$; $p<0.001$) respectively. These results are consistent with empirical evidence from previous studies (Oliver et. al., 2020; Mellet & Pepper, 2021).

Furthermore, the trust respondents had in the quality of information about Covid from their government was also significant with the estimate ($X^2 = 126.64$; $p<0.001$). Again, change in income due to Covid was significant with the estimate ($X^2 = 46.90$; $p<0.001$). Also, respondents' concern about paying for their expenses during Covid was significant with the estimate ($X^2 = 20.76$; $p<0.01$). Respondents spending on essential and non-essential items during Covid was significant at ($X^2 = 30.49$; $p<0.001$) and ($X^2 = 24.42$; $p<0.01$) respectively. Also, respondents' use of online shopping instead of face-to-face shopping was significant at ($X^2 = 32.65$; $p<0.001$). Finally, the use of mobile money instead of physical exchange of cash during Covid was also significant ($X^2 = 36.57$; $p<0.001$). The literature on vaccine acceptance and intended use is replete with similar empirical evidence (Matrajt et. al., 2020; Mellet & Pepper, 2021).

Moreover, the correlation of specific Covid-19 vaccine questions such as safety of the vaccine, effectiveness of the vaccine, availability, delivery, and concerns about the vaccine with Covid-19 vaccine acceptance and intended use were examined. The results reveal the following – the safety of Covid vaccine use was significant with the estimate ($X^2 = 936.02$; $p<0.001$); effectiveness of the Covid vaccine was significant with the estimate ($X^2 = 774.33$; $p < 0.001$); other concerns and questions about the vaccine was significant with the estimate ($X^2 = 556.47$; $p<0.001$), and finally, the availability and delivery method of the vaccine was significant with the estimate ($X^2 = 344.54$; $p<0.001$) and ($X^2 = 143.86$; $p<0.001$) respectively. The current findings are consistent with some most recent findings about predictors of Covid-19 vaccine acceptance and intended use (Oliver et. al., 2020; Mellet & Pepper, 2021).

DISCUSSION & CONCLUSION

The Covid-19 pandemic has challenged many aspects of human life, especially regarding healthcare and vaccine delivery across the globe. The race to find a vaccine has not been void of public concerns about vaccine safety and effectiveness (Mellet & Pepper, 2021; Afolabi & Ilesanmi, 2021). Some scholars argue that public misconceptions, fear, and unfamiliarity about the Covid-19 vaccine can negatively affect the public's acceptance

and intended use, especially in Africa (Grech, Gauci, & Agius, 2020; Afolabi & Ilesanmi, 2021). Although few seminal studies have been done regarding vaccine use in Africa, there are still some gaps in the literature worth investigating (Grech, Gauci, & Agius, 2020; Mellet & Pepper, 2021; Afolabi & Ilesanmi, 2021). The present study seeks to address this gap in the literature by examining the factors that correlates with public acceptance and intended use of the Covid-19 vaccine in Africa, specifically Sub-Saharan Africa.

Several important revelations and observations made from the results of this current study are discussed below. One interesting revelation worth discussing is the correlation between perceive vaccine safety and effectiveness with public acceptance and intended use of the Covid-19 vaccine. Globally, various stakeholders and the general public continue to express concerns about the safety and effectiveness of Covid-19 vaccine (Singh, 2020; Madhi et. al., 2021). Concerns about whether enough clinical testing has been done to ensure the safety and effectiveness of the vaccine continues to make headlines in major media outlets globally (Makoni, 2020; Wiysonge et al., 2021). It was therefore unsurprising to observe that Covid-19 vaccine safety and effectiveness strongly correlates with public acceptance and intended use of the vaccine. Additionally, it was also revealed that availability and delivery of the vaccine correlates with public acceptance and intended use of the vaccine. Debates about whether the vaccine would be free for all citizens and who should be vaccinated first were contentious among various stakeholders (Makoni, 2020; Nachega et al., 2021). The current study suggests that vaccine availability and delivery strongly correlate with public acceptance and intended use of the Covid-19 vaccine.

Another important observation worth discussing is the association between factors such as country of respondents, effect of Covid on the physical and emotional health of respondents and public acceptance and intended use of the Covid-19 vaccine. The literature review above suggested the existence of different rate of vaccination among countries in Africa because of fear of vaccines, misinformation, religious beliefs etcetera (Nkengasong et al., 2020; Mbow et al., 2020). The present study shows a strong correlation between country (varying geographic, sociocultural, and economic beliefs) and vaccine administration in Africa. This further supports existing empirical evidence in the literature. Future study can further investigate the country specific variables that accounts for the different rate of vaccination in Africa.

Moreover, like most empirical studies, the current study is not without limitations. First, we acknowledge the possibility of desirability bias that is likely to influence the results. Since we utilized survey data collected from the public, there is the likelihood that respondents may alter their answers to appear good and credible during the interviewing process. This limitation can be addressed by using systematic social observations in future studies to further examine this issue. Furthermore, we acknowledge that this study is an exploratory study that serves as the foundation of future studies seeking to understand the factors that predict public acceptance and intended use of the Covid-19 vaccine in Africa, specifically sub-Saharan Africa. Therefore, the methodology utilized in this study only measures the association of each predictor variable separately with the outcome variable without controlling for other variables. In essence, this study shows a correlation but not causation. Future studies can focus on developing a more robust analysis that accounts for the effect of all the variables simultaneously instead of separately. In essence, the present study provides a correlation between the outcome variable and the predictors and not a causal effect. Finally, using SMS surveys in Africa can lead to the oversampling of wealthier and educated respondents. Therefore, we caution readers against further interpretation of the present results based on this factor. Despite these limitations, we argue the revelations from this study are important for theory building and for practice. Theoretically, the present study and its findings adds to the existing knowledge on vaccine administration in Africa by exploring the factors that correlates with intended Covid-19 use. Specifically, the present study explores a broad range of factors that correlates with vaccine use Practically, the current study and its findings have serious policy implications for developing policies that can help improve public acceptance and intended use of the Covid-19 vaccine in Africa.

In conclusion, globally, the Covid-19 virus that started in Wuhan, China in 2019 has been devastating for many individuals and nations. Among the notable effects of the virus are the collapse of world economies and businesses, the pressure on healthcare systems and professionals, a decline in the emotional and physical wellbeing of individuals, unemployment, and the death of hundreds of thousands of people (Nkengasong et al., 2020; Afolabi & Ilesanmi, 2021). In attempts to find a solution to the negative consequences of the pandemic, the Covid-19 vaccine was developed. However, stakeholders continue to ponder whether the general public will accept and use the vaccine (Afolabi & Ilesanmi, 2021). In Africa, historical and empirical evidence suggest that vaccine acceptance and intended use is a challenge on the continent because of public fear, misconception,

and religious beliefs (Ojakaa et al., 2011). The empirical evidence from the present study reveals several important and intriguing associations between the predictor variables and the outcome variable – Covid-19 vaccine acceptance and intended use. Based on the empirical evidence of the current study we make the following recommendations. We recommend prioritizing community involvement and collaboration involving various stakeholders. African governments must work collaboratively with local stakeholders like the traditional, religious leaders, and public healthcare professionals to conscientize the public. Failure to adopt a community involvement and collaborative approach by African governments could further add on to the unfamiliarity and misconception about vaccines among the public.

REFERENCES

1. Amadasun, S. (2020). COVID-19 palaver: Ending rights violations of vulnerable groups in Africa. *World Development*, *134*, 105054–105054. https://doi.org/10.1016/j.worlddev.2020.105054
2. Afolabi, A. A., & Ilesanmi, O. S. (2021). Dealing with vaccine hesitancy in Africa: the prospective COVID-19 vaccine context. *The Pan African Medical Journal*, *38*, 3–3. https://doi.org/10.11604/pamj.2021.38.3.27401
3. Bowman, B. (2020). On the biopolitics of breathing: race, protests, and state violence under the global threat of COVID-19. *South African Journal of Psychology*, *50*(3), 312–315. https://doi.org/10.1177/0081246320947856
4. Cooper, S., Betsch, C., Sambala, E. Z., Mchiza, N., & Wiysonge, C. S. (2018). Vaccine hesitancy - a potential threat to the achievements of vaccination programmes in Africa. *Human Vaccines & Immunotherapeutics*, *14*(10), 2355–2357. https://doi.org/10.1080/21645515.2018.1460987
5. Dinga, J. N., Sinda, L. K., & Titanji, V. P. K. (2021). Assessment of Vaccine Hesitancy to a COVID-19 Vaccine in Cameroonian Adults and Its Global Implication. *Vaccines (Basel)*, *9*(2), 175–. https://doi.org/10.3390/vaccines9020175
6. Dubé, E., Gagnon, D., Ouakki, M., Bettinger, J. A., Guay, M., Halperin, S., Wilson, K., Graham, J., Witteman, H. O., MacDonald, S., Fisher, W., Monnais, L., Tran, D., Gagneur, A., Guichon, J., Saini, V., Heffernan, J. M., Meyer, S., Driedger, S. M., … MacDougall, H. (2016). Understanding Vaccine Hesitancy in Canada: Results of a Consultation Study by the Canadian Immunization Research Network. *PloS One*, *11*(6), e0156118–e0156118. https://doi.org/10.1371/journal.pone.0156118
7. Dzordzormenyoh, M., Asafo, D. M., & Domeh, T. (2021). Place, People & Diseases: The Association Between Geography & Diseases in Ghana. *The Columbia University Journal of Global Health*, *10*(2). https://doi.org/10.52214/thecujgh.v10i2.7111
8. Febir, L. G., Asante, K. P., Dzorgbo, D.-B. S., Senah, K. A., Letsa, T. S., & Owusu-Agyei, S. (2013). Community perceptions of a malaria vaccine in the Kintampo districts of Ghana. *Malaria Journal*, *12*(1), 156–156. https://doi.org/10.1186/1475-2875-12-156
9. Fine, P., Eames, K., & Heymann, D. L. (2011). "Herd Immunity": A Rough Guide. *Clinical Infectious Diseases*, *52*(7), 911–916. https://doi.org/10.1093/cid/cir007
10. Freeman, D., Loe, B. S., Chadwick, A., Vaccari, C., Waite, F., Rosebrock, L., Jenner, L., Petit, A., Lewandowsky, S., Vanderslott, S., Innocenti, S., Larkin, M., Giubilini, A., Yu, L.-M., McShane, H., Pollard, A. J., & Lambe, S. (2020). COVID-19 vaccine hesitancy in the UK: the Oxford coronavirus explanations, attitudes, and narratives survey (Oceans) II. *Psychological Medicine*, 1–15. https://doi.org/10.1017/S0033291720005188
11. Huo, X., Shi, G., Li, X., Lai, X., Deng, L., Xu, F., Chen, M., Wei, Q., Samba, T., & Liang, X. (2016). Knowledge and attitudes about Ebola vaccine among the general population in Sierra Leone. *Vaccine*, *34*(15), 1767–1772. https://doi.org/10.1016/j.vaccine.2016.02.046
12. Hotez, P. J., & Bottazzi, M. E. (2020). Developing a low-cost and accessible COVID-19 vaccine for global health. *PLoS Neglected Tropical Diseases*, *14*(7), e0008548–. https://doi.org/10.1371/journal.pntd.0008548
13. Jegede, A. S. (2007). What led to the Nigerian boycott of the polio vaccination campaign? *PLoS Medicine*, *4*(3), e73–e73. https://doi.org/10.1371/journal.pmed.0040073
14. The Lancet. (2020). An African plan to control COVID-19 is urgently needed. *The Lancet (British Edition)*, *396*(10265), 1777–1777. https://doi.org/10.1016/S0140-6736(20)32580-0
15. Madhi, S. A., Baillie, V., Cutland, C. L., Voysey, M., Koen, A. L., Fairlie, L., ... & Izu, A. (2021). Safety and efficacy of the ChAdOx1 nCoV-19 (AZD1222) Covid-19 vaccine against the B. 1.351 variant in South Africa. *MedRxiv*.
16. Makoni, M. (2020). COVID-19 vaccine trials in Africa. *The Lancet Respiratory Medicine*, *8*(11), e79-e80. https://doi.org/10.1016/S2213-2600(20)30401-X
17. Marti, M., de Cola, M., MacDonald, N. E., Dumolard, L., & Duclos, P. (2017). Assessments of global drivers of vaccine hesitancy in 2014-Looking beyond safety concerns. *PloS One*, *12*(3), e0172310–e0172310. https://doi.org/10.1371/journal.pone.0172310
18. Matrajt, L., Eaton, J., Leung, T., & Brown, E. R. (2020). Vaccine optimization for COVID-19: Who to vaccinate first? *Science Advances*, *7*(6), eabf1374–. https://doi.org/10.1126/sciadv.abf1374
19. Mbow, M., Lell, B., Jochems, S. P., Cisse, B., Mboup, S., Dewals, B. G., Jaye, A., Dieye, A., & Yazdanbakhsh, M. (2020). COVID-19 in Africa: Dampening the storm? *Science (American Association for the Advancement of Science)*, *369*(6504), 624–626. https://doi.org/10.1126/science.abd3902
20. Mellet, J., & Pepper, M. S. (2021). A COVID-19 Vaccine: Big Strides Come with Big Challenges. *Vaccines (Basel)*, *9*(1), 39–. https://doi.org/10.3390/vaccines9010039
21. Murphy, J., Vallières, F., Bentall, R. P., Shevlin, M., McBride, O., Hartman, T. K., McKay, R., Bennett, K., Mason, L., Gibson-Miller, J., Levita, L., Martinez, A. P., Stocks, T. V. A., Karatzias, T., & Hyland, P. (2021). Psychological characteristics associated with COVID-19 vaccine hesitancy and resistance in Ireland and the United Kingdom. *Nature Communications*, *12*(1), 29–29. https://doi.org/10.1038/s41467-020-20226-9
22. Nachega, J. B., Sam-Agudu, N. A., Mellors, J. W., Zumla, A., & Mofenson, L. M. (2021). Scaling Up Covid-19 Vaccination in Africa — Lessons from the HIV Pandemic. *The New England Journal of Medicine*, *385*(3), 196–198. https://doi.org/10.1056/NEJMp2103313
23. Nkengasong, J. N., Ndembi, N., Tshangela, A., & Raji, T. (2020). COVID-19 vaccines: how to ensure Africa has access. *Nature (London)*, *586*(7828), 197–199. https://doi.org/10.1038/d41586-020-02774-8
24. Ojakaa, D. I., Ofware, P., Machira, Y. W., Yamo, E., Collymore, Y., Ba-Nguz, A., Vansadia, P., & Bingham, A. (2011).

Community perceptions of malaria and vaccines in the South Coast and Busia regions of Kenya. *Malaria Journal*, *10*(1), 147–147. https://doi.org/10.1186/1475-2875-10-147

25. Oliver, S. E., Gargano, J. W., Marin, M., Wallace, M., Curran, K. G., Chamberland, M., McClung, N., Campos-Outcalt, D., Morgan, R. L., Mbaeyi, S., Romero, J. R., Talbot, H. K., Lee, G. M., Bell, B. P., & Dooling, K. (2020). The Advisory Committee on Immunization Practices' Interim Recommendation for Use of Pfizer-BioNTech COVID-19 Vaccine - United States, December 2020. *MMWR. Morbidity and Mortality Weekly Report*, *69*(50), 1922–1924. https://doi.org/10.15585/MMWR.MM6950E2
26. Olson, O., Berry, C., & Kumar, N. (2020). Addressing parental vaccine hesitancy towards childhood vaccines in the United States: A systematic literature review of communication interventions and strategies. *Vaccines (Basel)*, *8*(4), 1–25. https://doi.org/10.3390/vaccines8040590
27. Osama El-Gendy, A., Saeed, H., Ali, A. M.., Zawbaa, H. M., Gomaa, D., Harb, H. S., Madney, Y. M., Osama, H., Abdelrahman, M. A., & Abdelrahim, M. E. (2020). Bacillus Calmette–Guérin vaccine, antimalarial, age and gender relation to COVID-19 spread and mortality. *Vaccine*, *38*(35), 5564–5568. https://doi.org/10.1016/j.vaccine.2020.06.083
28. Patel, M., Lee, A. D., Redd, S. B., Clemmons, N. S., McNall, R. J., Cohn, A. C., & Gastañaduy, P. A. (2019). Increase in Measles Cases - United States, January 1-April 26, 2019. *MMWR. Morbidity and Mortality Weekly Report*, *68*(17), 402–404. https://doi.org/10.15585/mmwr.mm6817e1
29. Rosenthal, P. J., Breman, J. G., Djimde, A. A., John, C. C., Kamya, M. R., Leke, R. G., Moeti, M. R., Nkengasong, J., & Bausch, D. G. (2020). COVID-19: Shining the light on Africa. *The American Journal of Tropical Medicine and Hygiene*, *102*(6), 1145–1148. https://doi.org/10.4269/ajtmh.20-0380
30. Singh, J. A. (2020). The Case for Why Africa Should Host COVID-19 Candidate Vaccine Trials. *The Journal of Infectious Diseases*, *222*(3), 351–355. https://doi.org/10.1093/infdis/jiaa303
31. Wiysonge, C. S., Ndwandwe, D., Ryan, J., Jaca, A., Batouré, O., Anya, B.-P. M., & Cooper, S. (n.d.). Vaccine hesitancy in the era of COVID-19: could lessons from the past help in divining the future? *Human Vaccines & Immunotherapeutics*, *ahead-of-print*(ahead-of-print), 1–3. https://doi.org/10.1080/21645515.2021.1893062
32. World Health Organization. (September 10, 2021). Fifteen African Countries hit the 10% Covid-19 Vaccination Goal. https://www.afro.who.int/news/fifteen-african-countries-hit-10-covid-19-vaccination-goal. Accessed: December 19, 2021.

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COVID-19 Vaccine Hesitancy and Acceptance in the Global Context: A Systematic Review and Meta-Analysis

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ABSTRACT Large-scale vaccination is the only hope to end the COVID-19 pandemic. Previous studies show that many people are hesitant to get vaccinated and COVID-19 vaccine hesitancy varies between countries and minoritized groups. Our study aims to shed light on the latest trends in vaccine hesitancy and acceptance across countries and identify the predictors driving these trends in the global context. We used a meta-analysis of proportion to analyse the trends in vaccine hesitancy and acceptance and systematically reviewed their predictors in the global context. We found that, across all studies, the acceptance and hesitancy rates for taking the vaccine are 64% and 21% respectively. The acceptance rates among healthcare workers was found to be higher than the general adult population (70% vs 61%). Being a female, concerns about vaccine side effects, and perceiving the vaccine unsafe were the most reported predictors of hesitancy. Older age, higher educational level, flu vaccine history, and low perceived risks were found to predict COVID-19 vaccine acceptance. Many nations face huge challenges to get their significant proportion of populations immune to COVID-19. It is important to disseminate accurate information through trusted channels, and policymakers should address predictors of hesitancy when designing vaccination policies.

KEY WORDS COVID-19, vaccination, hesitancy, acceptance, predictors, vaccination policy

INTRODUCTION

Almost two years into the pandemic, the world's defensive measures against COVID-19 were upgraded from handwashing, social distancing, and masking to vaccination. As large-scale vaccination is suggestive to obtaining herd immunity, governments are racing to get their citizens vaccinated. Will this fast advancement in technology and government policies be enough to get 70% of the population – required for herd immunity – vaccinated so our communities are safe from this virus and its variants? Research indicates that a serious portion of many societies are found to be hesitant to receive doses of the vaccine. The hesitancy may slow the progression back to normalcy.

Developing a safe and effective vaccine within a short time period is a major step to stopping the coronavirus. While access to the vaccines to millions of people is an endeavour itself, the world faces an even bigger challenge: inadequate uptake of the vaccine. Since the first shot was administered in December 2020 to December 2021, about 8.21 billion doses of the COVID-19 vaccine were distributed globally, meaning about 55% of the world

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population received at least one dose. However, there are huge gaps between countries in the vaccination numbers. In low-income countries, only 6.2% of the population have received at least one dose of a COVID-19 vaccine [1].

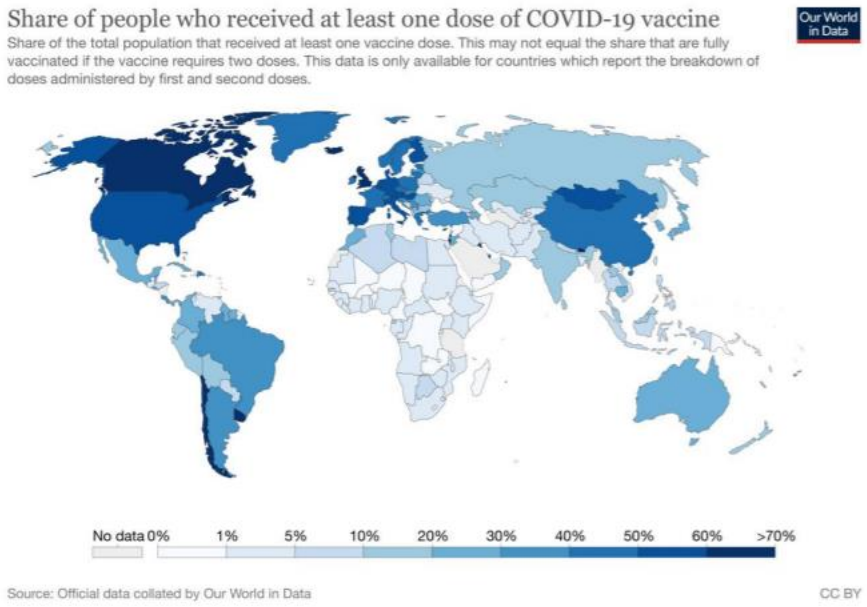

FIGURE 1. SHARE OF PEOPLE WHO RECEIVED AT LEAST ONE DOES OF COVID-19 VACCINE, JUNE 27, 2021

Even when vaccines are available, hesitancy towards receiving the vaccines raises another issue. The World Health Organization (WHO) defines vaccine hesitancy as "the behavior - refusal or delay in taking the vaccine despite their availability - that results from the decision-making process and reflects the factors influencing the process," emphasizing its variability between and within countries [2]. Fast growing literature on this issue has evidence. For example, while survey results indicated that 35.2% of respondents were hesitant to get vaccinated for COVID-19 in France [3], in Australia only 4.8% were hesitant to be vaccinated [4] and in Japan the hesitancy rate was 12.8% [5]. The numbers vary for different populations within the countries as well. Among US-based studies, one study found that 54.1% nonelderly were hesitant in a Tennessee survey, other separate studies concluded that 75% of Ohio Amish, 68.9% of the underserved communities of North Carolina [6], and 10.8% across a nationally representative survey would not accept the shot [7]. Pointing at the ethnic differences, in Israel, 7.7% of Jewish men and 29.9% of Arab men responding to a survey that they would refuse to get vaccinated [8].

Surveys, polls, and systematic reviews show changing trends in COVID-19 vaccine hesitancy and acceptance rates. In a systematic review, Sallam et al. (2021) found in the US, the vaccine receptivity intent showed an upward trend from 56.9 % in April to 75.4% in June 2020 [9]. On the contrary, the same study found that despite the high level of intentions for the uptake of the vaccine in China, the acceptance rates continued to fall about 2.7% between three time points. A big drop in acceptance rates was reported in Italy from April to September 2020 with a rate of 23.6% (62.0% to 58.9%). Sampling different countries in their meta-analysis, Robinson et al. (2021) found 18 studies reported an increase in vaccination hesitancy from 12% to 20% among the Western countries [10]. Furthermore, there is evidence that the big declines in vaccine acceptance (20% drop from March to October 2020) displayed demographic, socioeconomic, and political view variability [11].

There are many factors that influence people's intentions to receive the COVID-19 vaccine. Previously, separate studies focused on different populations from several countries including Australia, the U.K., France, Greece, Saudi Arabia, and the United States to investigate the factors that are associated with vaccine hesitancy. They found that factors of vaccine hesitancy included concerns about the safety, side effects and efficacy of the vaccine; demographic characteristics such as minority ethnic groups, females, and lower institutional educational backgrounds; being against vaccines in general; low perceived risk of disease; believing in conspiracy theories; and far left-wing political partisanship [4, 12–15]. In contrast, being older and male along with having a high educational level, higher income, high perceived risk of disease, past flu vaccination history, and democratic

ideology were found to be predictors of COVID-19 vaccine acceptance [7, 16–20].

This evidence suggests the importance of understanding how hesitancy and acceptance rates vary by country and minoritized groups as well as the factors determining this variability. However, further research is required as many countries are not included in the literature. The first aim of this study is to shed light to differences in vaccine hesitancy and acceptance globally. In doing so, we intend to contribute to the literature by synthesizing information from more countries as more variation will help better understand the predictors of hesitancy. Secondly, we seek to identify the factors for the hesitancy and acceptance of the vaccine in the global context. The goal of this study is to synthesize research findings in this topic and provide evidence to the policymakers and global efforts to make the right policy decisions to improve public health.

MATERIALS AND METHODS

This study aims to answer two research questions: (1) What are the COVID-19 vaccine hesitancy and acceptance rates across countries? (2) What are the factors that determine the COVID-19 vaccine hesitancy and acceptance in the global context? The first question will be answered by a meta-analysis of proportion approach while we will employ a systematic review methodology to answer the second.

Study Selection

We searched for studies about COVID-19 vaccine hesitancy on the PubMed database in March 2021. The terms searched were "COVID-19, vaccine hesitancy, survey," "COVID-19, vaccine hesitancy, race, survey," and "COVID-19, vaccine hesitancy, culture, survey." As the number of studies increased each day, we completed a total of three different searches at three different times, March 12, 2021, March 13, 2021, and March 31, 2021. Two researchers screened articles for inclusion in the study. In total 81 studies were screened for title review and 64 studies were screened for full-text review as illustrated in Figure 2. These 15 studies were excluded due to being the wrong study design or being in a language other than English. A total of 49 studies that met the selection criteria were included in this study.

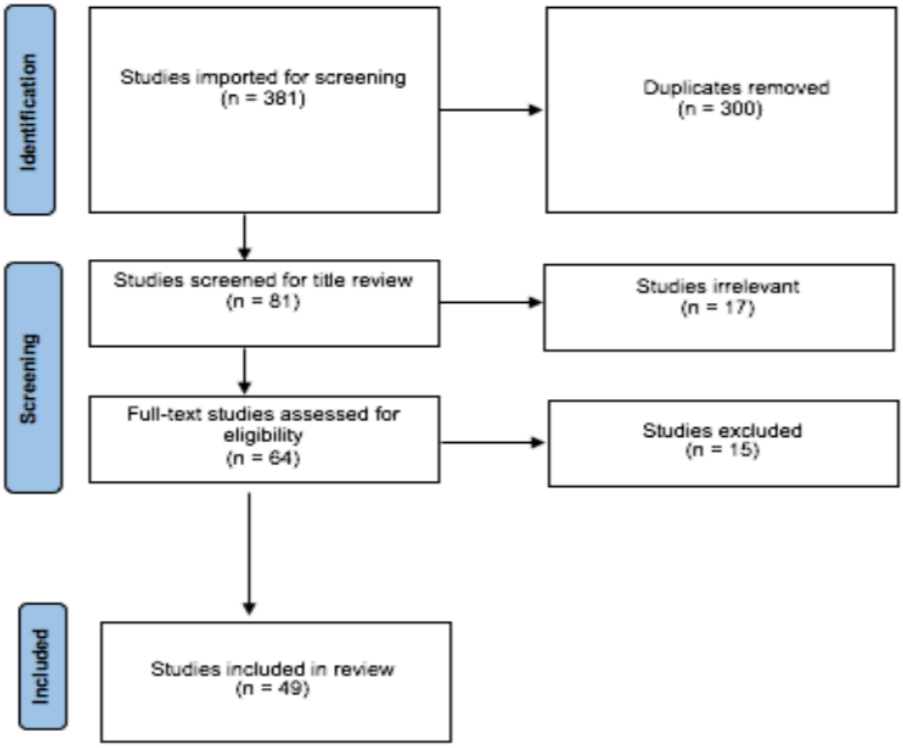

FIGURE 2. PRISMA STUDY SELECTION CHART

Our inclusion criteria consisted of four factors: (1) quantitative studies, (2) studies must have used a survey-based design (i.e., online questionnaires), (3) studies must have reported COVID-19 vaccine hesitancy and/or acceptance rate, (4) Data about COVID-19 vaccine hesitancy, beliefs and/or attitudes must be reported in English, (5) studies had to focus on an adult or health care worker (HCW) population and (6) be peer-reviewed

and published. We made no temporal or geographic restrictions. We excluded the studies that used (1) meta-analyses approach, (2) systematic review method, (3) qualitative method, and focused on (4) children, adolescents and (5) student populations.

Methodological Quality (Risk of Bias) Assessment

JBI (Joanna Briggs Institute) critical appraisal tool for cross-sectional studies was used to assess the risk of bias in each study [21]. This checklist has 8 categories which constitutes 8 points. We used "Yes = 1", "No = 0" and "Unclear = 0" as the values for the assessment of each category. We included the studies that scored 4 and above in our systematic review. Two researchers (author 1 and author 2) conducted the quality assessment together to ensure a strong interrater-reliability. All 49 studies that we assessed for risk of bias scored above 4 points. The quality assessment of the studies can be found in the Supplementary File 1.

Effect Size Data

The effect size of interest is a proportion statistic. Specifically, it is the proportion of vaccine hesitancy and acceptance reported in the sample. These two rates are treated in separate analyses. The effect size data used in this study is then a univariate statistic. This is different from most meta-analyses, which synthesize evidence for bivariate statistics. In most cases, the standard error was unreported for these proportion statistics. We therefore imputed the standard error (SE) in every case using the formula: SE= p(1-p)n. The SE is needed to use as inverse variance weights.

Data Coding

Two researchers extracted the data to be used in the analysis. Data was coded into excel using data validation settings to ensure data inputting accuracy. We coded information for the following between-study variables: study authors, country, year, survey population, study design (e.g. cross-sectional, longitudinal, etc.), sample size, information on mean demographic characteristics (percent female, educational level, income, and age), hesitancy rates, acceptance rates, quantitative results for predictors associated with hesitancy and predictors associated with acceptance, health behavior model used and reasons for hesitancy or acceptance. We met and coded a series of studies together so as a training exercise. Since most of our study-level used unambiguous definitions and required low-inference judgments, there were almost no coding disagreements as we worked together. We coded data separately and felt assured that our data would meet the high-quality standards that are necessary for conducting a systematic review and meta-analysis.

Data Analysis

We conducted proportional meta-analyses using R software to analyze COVID-19 vaccine hesitancy and acceptance trends. Meta-analysis of proportion is used to compare and combine effect sizes across different studies. Meta-analysis of proportion in this study helps us pool COVID-19 vaccine hesitancy and acceptance rates based on the included study weights [54]. The statistical significance and the level of study heterogeneity were assessed based on Q statistic and I^2 statistic. A higher percentage of between-study heterogeneity suggested that a random effects approach would be suitable [54, 55, 56].

The two effect size metrics of interest in the current study are the proportion of individuals who expressed either hesitancy or acceptance of getting a COVID-19 vaccination. Note that many studies provided estimates for both hesitancy and acceptance separately. Two proportional meta-analyses were used to synthesize the evidence about COVID-19 vaccine acceptance and reluctance.

First, the evidence base is summarized by reporting a random-effects model. The random-effects model of meta-analysis is the most widely used model for integrating estimates from different studies into a single summary estimate [22]. Both the meta-analyses of COVID-19 vaccine hesitancy and acceptance had significant statistical heterogeneity. Specifically, we found that there was a significantly higher degree of heterogeneity in our overall effect size for COVID-19 vaccine acceptance with Q (53) = 20946.9205, $\tau 2 = 0.0479$, $p<.0001$), I2 = 99.81%, $p<.0001$). Our analysis of the overall effect size for COVID-19 vaccine hesitancy also showed a significantly higher degree of heterogeneity, with Q (41) = 10659.3129, $\tau 2 = 0.0288$, $p<.0001$), I2 = 99.83%, $p<.0001$) So, random-effects models were applied in our overall effect size analyses. Secondly, we also displayed forest plots. Forest plots are a visual device that focus on comparing different estimates of the same statistical parameter across different studies. In this study, the statistical parameters are acceptance and hesitancy proportion.

RESULTS

Characteristics of Studies

Our inquiry included 49 studies with a total sample size of 86,822. The studies included covered COVID-19 vaccine hesitancy and/or acceptance survey results in 23 countries. The most studied countries were France (n=5), UK (n=4), China (n=4), Turkey (n=4) and the United States with the US being the most studied country for vaccine hesitancy (n=17)]. The sample sizes ranged from 47 (Bhutan) to 12,035 (UK). The mean percentage of females in the samples ranged from 39% (Saudi Arabia) to 89% (China). All studies were conducted before COVID-19 vaccines became available and were published between March 2020 and March 2021. Table 1 shows descriptive statistics for all studies located for this systematic review.

TABLE 1. STUDY CHARACTERISTICS

Study ID	First author & Year	Country	Design	N
Studies with effect sizes for adults				
1	Dror 2020	Israeli	Cross-sectional	1112
2	Fisher 2020	US	Cross-sectional	991
4	Detoc 2020	France	Cross-sectional	3259
5	Pogue 2020	US	Cross-sectional	316
6	Ward 2020	France	Cross-sectional	5018
7	Salali 2020	Turkey	Cross-sectional	3936
7	Salali 2020	UK	Cross-sectional	1088
8	Kreps 2020	US	Cross-sectional	1971
9	Olagoke 2021	US	Cross-sectional	502
11	Al-Mohaithef 2020	Saudi Arabia	Cross-sectional	992
12	Freeman 2020	UK	Cross-sectional	5114
14	Lin 2020	China	Cross-sectional	3541
15	Borriello 2021	Australia	Cross-sectional	2136
17	Murphy 2021	UK	Cross-sectional	2025
17	Murphy 2021	Ireland	Cross-sectional	1041
18	Williams 2021	Scotland	Cross-sectional	3436
19	Yigit 2021	Turkey	Cross-sectional	428
20	Motta 2021	US	Cross-sectional	990
21	Mercadante 2020	US	Cross-sectional	525
22	Sallam 2021	Saudi Arabia	Cross-sectional	154
22	Sallam 2021	Jordan	Cross-sectional	2173

22	Sallam 2021	Kuwait	Cross-sectional	771
23	Ruiz 2021	US	Cross-sectional	804
24	Yoda 2021	Japan	Cross-sectional	1100
25	Alley 2021	Australia	Cross-sectional	575
27	Scott 2021	US	Cross-sectional	391
28	Kourlaba 2021	Greece	Cross-sectional	1004
29	Schwarzinger 2021	France	Cross-sectional	1942
30	Latkin 2021	US	Cross-sectional	1043
31	Alabdulla 2021	Qatar	Cross-sectional	7821
32	Kaplan 2021	US	Cross-sectional	1000
36	Wang 2021	China	Cross-sectional	791
37	Khubchandani 2021	US	Cross-sectional	1878
38	Papagiannis 2021	Greece	Cross-sectional	340
39	Edwards 2021	Australia	Longitudinal	3061
40	Al-Qerem 2021	Jordan	Cross-sectional	1144
41	Qattan 2021	Saudi Arabia	Cross-sectional	673
42	Salmon 2021	US	Longitudinal	2525
43	Gatwood 2021	US	Cross-sectional	1000
44	Robertson 2021	UK	Cross-sectional	12035
45	Latkin 2021	US	Longitudinal	592
46	Green 2021	Israel	Cross-sectional	606
46	Green 2021	Israel	Cross-sectional	351
47	Vallis 2021	Canada	Cross-sectional	2078
48	Yurttas 2021	Turkey	Cross-sectional	763
Studies with effect sizes of HCW				
1	Dror 2020	Israeli	Cross-sectional	338
1	Dror 2020	Israeli	Cross-sectional	211
3	Wang 2020	China	Cross-sectional	806
10	Gagneux-Brunon 2021	France	Cross-sectional	431
10	Gagneux-Brunon 2021	France	Cross-sectional	371

13	Kwok 2021	China	Cross-sectional	1205
16	Unroe 2021	US	Cross-sectional	2372
26	Verger 2021	France	Cross-sectional	1209
26	Verger 2021	Belgium	Cross-sectional	414
26	Verger 2021	Canada	Cross-sectional	1055
33	Kuter 2021	US	Cross-sectional	12034
34	Di Gennaro 2021	Italy	Cross-sectional	1723
35	Doherty 2021	US	Cross-sectional	984
48	Yurttas 2021	Turkey	Cross-sectional	320
49	Chew 2021	China	Cross-sectional	303
49	Chew 2021	India	Cross-sectional	406
49	Chew 2021	Indonesia	Cross-sectional	430
49	Chew 2021	Singapore	Cross-sectional	61
49	Chew 2021	Vietnam	Cross-sectional	472
49	Chew 2021	Bhutan	Cross-sectional	47

Vaccine Acceptance and Hesitancy Rates

Figures 3 and 4 show forest plots for acceptance and hesitancy rates across studies. By focusing on the random-effects summary estimate of vaccine acceptance (Figure 3), we found across all studies, the acceptance rate for taking the COVID vaccine was approximately 64% (95% CI: [0.58, 0.70]). However, as the forest plot makes clear, there is a lot of variability around this 64%. The results are visibly sorted into two main groups. Some studies used samples from a general adult population, while others focused on medical professionals. As can be observed, the acceptance rate among medical professionals seems slightly higher than the acceptance rate among the general adult population. Subgroup summary effects for adults only or health care workers (HCWs) only are also shown. Among HCWs, the average acceptance rate is 70%, with a 95% CI of [0.59, 0.81]. As expected, this is much higher than the acceptance rate in the general adult population – which is 61% (95% CI: 0.54, 0.67). It is, however, not possible to conclude that the mean proportion of acceptance between adults and health care workers is statistically significant ($p < .0001$) since the confidence intervals overlap.

The hesitancy rates in Figure 3 reveal similar patterns – the difference between adults and HCWs is not statistically significant although the summary effect for HCWs is lower (16% vs 23%). Pooling across all studies, the average hesitancy rate is 21% (95% CI: 0.16, 0.26).

Predictors of Vaccine Hesitancy

A total of 49 studies were included in the systematic review and were analyzed qualitatively to identify the predictors of vaccine hesitancy. The most reported predictors of COVID-19 vaccine reluctance fall into three main categories; (1) *demographic characteristics* such as being female (n=10), Black people (n=10), and young age (n=7), (2) *vaccine characteristics* including side effects (n=17), vaccine efficacy (n=6), and origin of vaccine (n=3), (3) *perceptions and beliefs* including beliefs (n=13) and perceived risks (n=10).

Demographic Characteristics

Of the 49 studies, 19 reported demographics-related (sex, age, ethnicity) predictors which are associated with vaccine hesitancy. 10 of 19 studies saw sex as a differentiating factor, as females were more likely to be hesitant

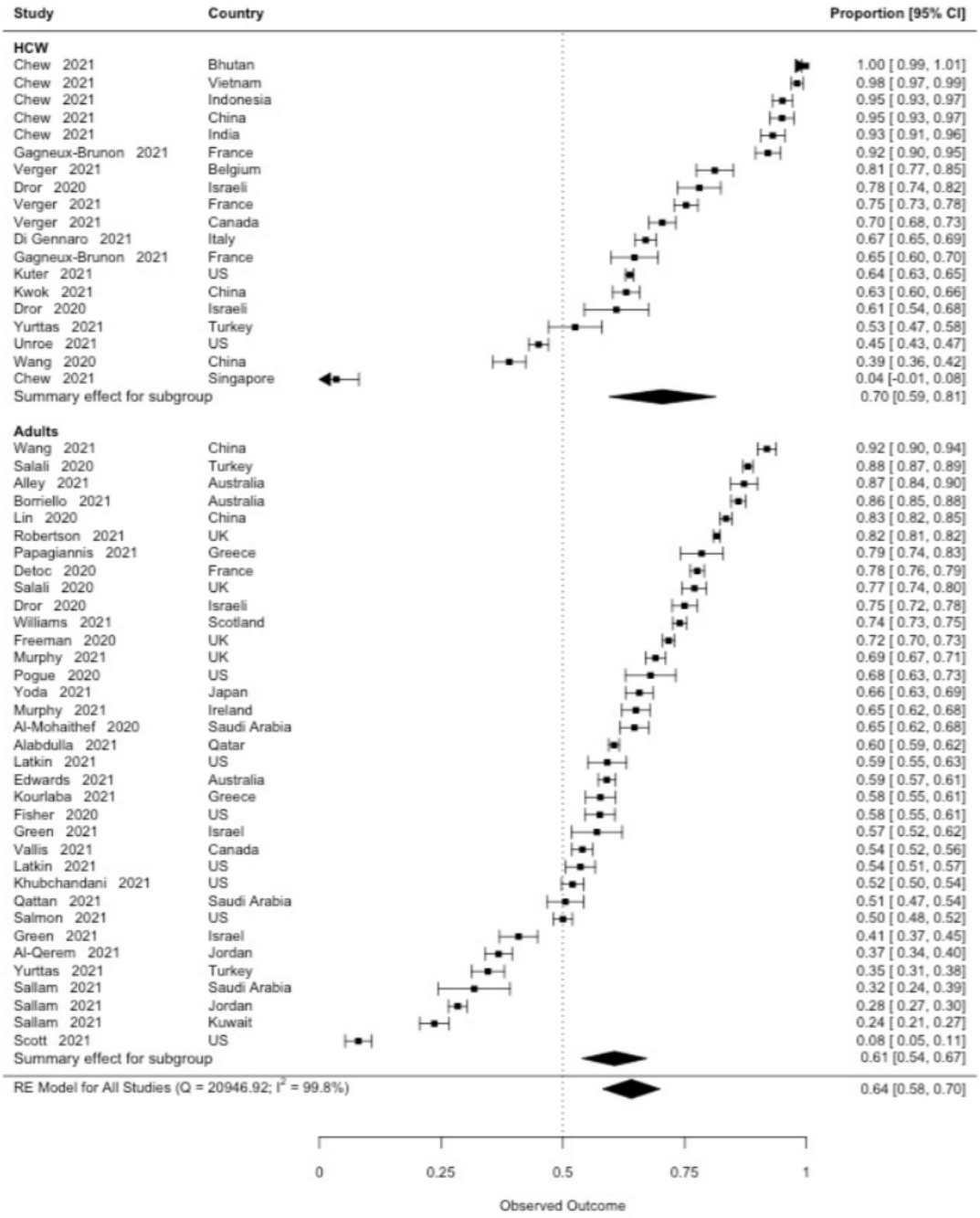

FIGURE 3. FOREST PLOT OF ACCEPTANCE RATES FOUND ACROSS STUDIES

compared to males. Among the nine studies that used a nationally representative sample of the US population, four found significant sex-based differences; females had higher odds of reporting they would not get vaccinated if a vaccine were available compared to males [7, 15, 23, 24]. One study investigated vaccine hesitancy in the under-resourced communities of North Carolina and found that females were 1.90 times more likely to report negative COVID-19 vaccination intentions [6]. These results are consistent with the findings of the European studies (n=3). Results of one UK study showed that 21% of female respondents were hesitant compared to 14.7% males due to concerns of vaccine side effects and distrust in the safety of vaccines [12]. Two French studies reported strong associations between hesitancy and being female [13, 25], the latter noted that women were more likely to refuse the vaccine compared to men and were against vaccines generally [13]. Consistent with these results, Alley et al. (2021) found Australian women were 1.89 times more likely to report being unsure

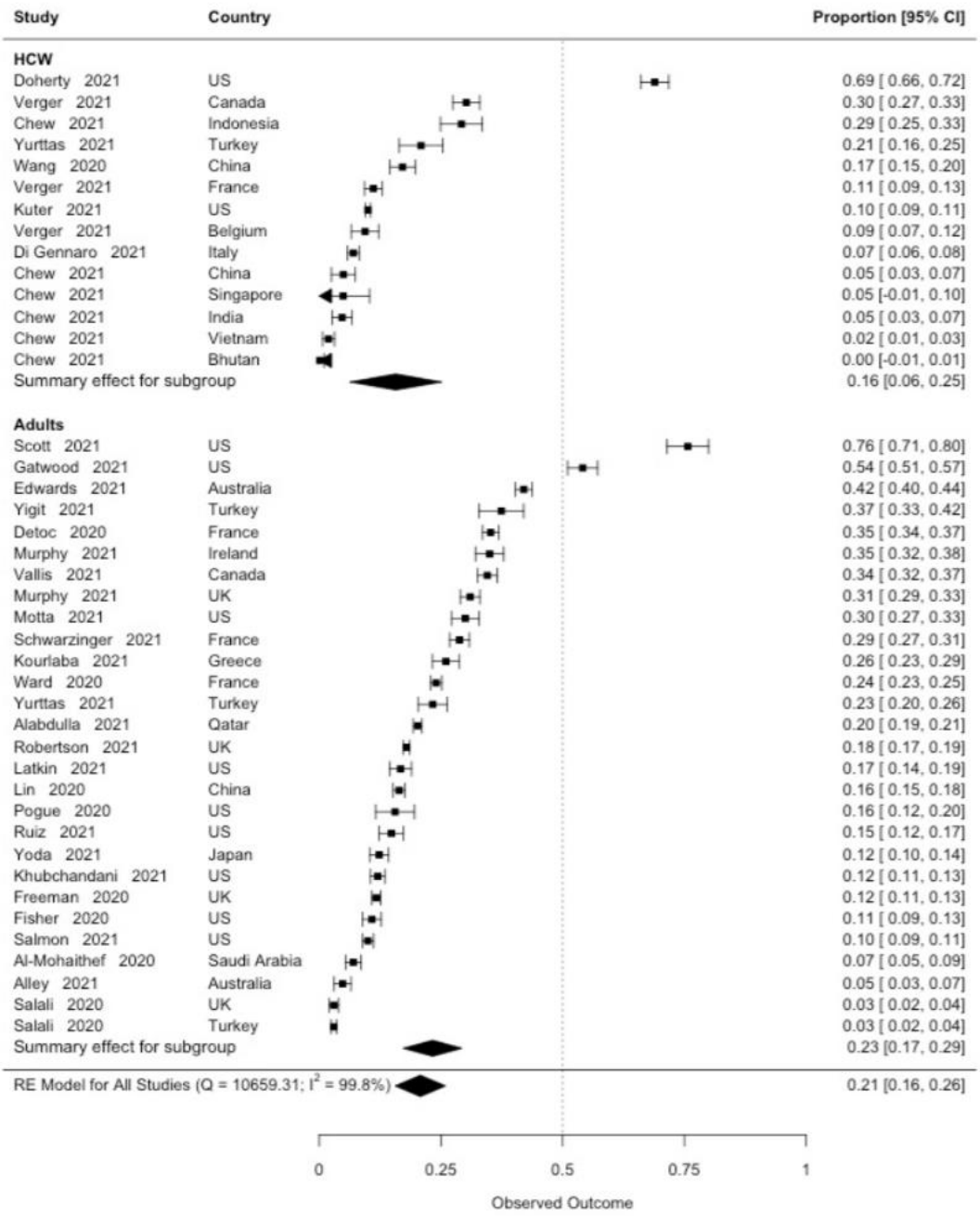

FIGURE 4. FOREST PLOT OF HESITANCY RATES FOUND ACROSS STUDIES

to get vaccinated compared to men [4]. Al-Qerem and Jarab (2021) also stated that Jordanian females have 3-fold higher relative likelihood of refusing to receive the vaccine and 1.5-fold higher relative likelihood of being unsure [26]. Finally, Turkish women were found to be less likely to be receptive to either domestic or foreign vaccines than men [27].

Age is found to be another predictor of COVID-19 vaccine hesitancy as seven of 18 studies showed that younger adults are more hesitant to get the vaccine [5, 12–14, 24, 25, 28]. Gatwood et al. (2021) reported that US adults less than 55 years have a greater likelihood of being reluctant [14]. Similarly, in the UK and Ireland, Murphy et al. (2021) found that adults between the ages of 35-44 years were 3.33 times more likely to have no intention of getting vaccinated [28]. Robertson et al. (2021) also demonstrated evidence in a UK survey that the likelihood of rejecting vaccination is 1.48 times higher for adults between the 16-24-year-old category [12]. Finally, in Japan,

Yoda and Katsuyama (2021) found that the 20-29-year-old age group expressed uncertain intentions towards the vaccine [5]. In contrast, Dror et al. (2020) and Al-Qerem and Jarab (2021) did not find significant associations between age and hesitancy [29].

The results show that vaccine hesitancy in western countries is higher among Black people. The results of 10 of 49 studies indicated that Black people are more likely to be reluctant to get vaccinated [6, 7, 14–16, 23, 24, 30–32]. Fisher et al. (2021) found that Black people are 6-fold more likely to refuse to be vaccinated compared to white people [7]. One study reported that Black and Latinx people refuse to take the vaccine due to time constraints in accessing the vaccine [15]. Two other studies point to distrust in vaccines [12], and mistrust in the government [6] as the reasons for Black peoples's hesitancy towards a COVID-19 vaccine. The results are consistent for general the population and medical professionals. In a study conducted in two Philadelphia hospitals, Black hospital employees expressed negative intentions to get COVID-19 inoculations [16]. Doherty et al. (2021) also noted that vaccine hesitancy showed a lower decline over time among Black people compared to white people in a U.S. sample [6].

Vaccine Characteristics

Vaccine safety is found to be the top concern reported by hesitant individuals including the HCWs. Seventeen of forty-nine studies reported potential side effects or future unknown effects as the main reason for vaccine reluctance [5, 6, 11, 12, 26, 29, 33–43]. In the U.S., Doherty et al. (2021) found a strong association between safety concerns and vaccine hesitancy [6], and in Israel, Dror et al. (2020) showed that 70% of both the general adult and HCW populations reported safety concerns as their reason for being unwilling to receive the vaccine [29]. Three studies concluded that HCWs and the general population reported side effects as a reason for hesitancy in Turkey and in Greece [34–36]. Five studies conducted in other Western and Asian countries stated fear of adverse effects and worries about contracting COVID-19 from the vaccine as common concerns (US: [38, 39]Australia: [40]; China, Indonesia, Bhutan, Singapore, Vietnam, India: [33]; China: [42]. It is important to note that HCWs in the Asian-based studies also reflected similar concerns [33, 42].

On the other hand, six studies showed that low vaccine efficacy is associated with hesitancy [5, 24–26, 29, 44]. One study demonstrated that the decrease in the probability of efficacy of the vaccine (50% compared to 70%, or 90%) was associated with higher probability of refusing vaccination [44]. The results of a survey experiment conducted in France indicated that the respondents were more hesitant towards a hypothetical vaccine with 50% efficacy compared to one with 90% [25]. The results of a conjoint experiment also indicated that a 20% to 40% increase in the efficacy of a hypothetical vaccine and longer protection duration were associated with an increase in the probability of receiving the COVID-19 vaccine [24].

Vaccine origin is another important feature that led to hesitancy in five of 49 studies. Four studies indicated that respondents are more likely to be reluctant towards the vaccines manufactured in China [24, 25, 38] or in Russia [38], and in one study, 80.4% Turkish respondents reported distrust in a foreign vaccine [35].

Perceptions and Beliefs

Beliefs and perceived risks were found to play an important role for hesitancy for both the general population and the HCWs. Beliefs refer to one's accepting something to be true, and perceptions refer to an individual's interpretation and understanding of something through their senses. While perceptions are a common construct found to be a predictor for hesitancy in 10 of the 49 studies, beliefs were identified as influencing hesitancy in 13 studies. Across five studies, respondents were not reassured by the fast development of the vaccine and perceived it to be dangerous [13, 26, 36–38]. One study emphasized that respondents with perceived risk of contracting infection from the vaccine are more likely to refuse being vaccinated [42]. Four studies reported that perceiving COVID-19 as harmless [13, 18, 25, 29] increased the odds of being against vaccination and one study found that hesitant individuals were at greater probability of believing that vaccines don't work due to the mild nature of the disease [6].

In four Middle Eastern and European studies, the authors found that believing in conspiracy theories or believing that the coronavirus was developed by humans in laboratories are influencing factors for unwillingness to receive the vaccine [9, 17, 26, 28]. Other studies demonstrated that hesitancy manifested in higher levels of COVID-19 related anxiety or low confidence in vaccines [35, 37]. Higher levels of religiosity [28, 32], being against vaccines in general [7, 13, 32], higher levels of scepticism [31], lack of trust in government, health authorities or scientists [6, 7, 18, 28, 31, 45], receiving little or conflicting information about vaccines [41], relying on social media [20,

41] were all associated with vaccine hesitancy across the different countries. Ideologies also mattered for Covid-19 vaccination hesitancy. Five studies indicated that respondents supporting far left-wing, conservative, Republican, or moderate parties were more likely to reject getting Covid-19 vaccination [13–15, 28, 31].

TABLE 2. PREDICTORS OF VACCINE HESITANCY AND ACCEPTANCE ACROSS COUNTRIES

Country ID	Country	Predictors of Vaccine Hesitancy	Predictors of Vaccine Acceptance
1	Australia	• Being a female • Side effects	• Older age • Higher educated
2	Belgium	• Beliefs	
3	Bhutan	• Side effects	• High perceived risk of getting the disease
4	Canada	• Side effects • Beliefs	
5	China	• Side effects	• Being a male • Older age • High perceived risk of getting the disease • Vaccine history
6	France	• Being a female • Vaccine efficacy • Side effects • Origin of vaccine • Beliefs	• Being a male • High perceived risk of getting the disease • Vaccine history
7	Greece	• Side effects • Beliefs	• Being a male • Older age • Vaccine history
8	India	• Side effects	• High perceived risk of getting the disease
9	Indonesia	• Side effects	• High perceived risk of getting the disease
10	Ireland	• Beliefs	
11	Israeli	• Side effects	• Higher educated • Vaccine history
12	Italy	• Beliefs	• Being a male • Older age
13	Japan	• Young age	• Being a male • Older age

14	Jordan	• Being a female • Beliefs	
15	Kuwait	• Beliefs	
16	Qatar		• Older age • Vaccine history
17	Saudi Arabia	• Side effects • Beliefs	• Being a male • High perceived risk of getting the disease
18	Scotland		• Higher educated
19	Singapore	• Side effects	• High perceived risk of getting the disease
20	Turkey	• Being a female • Side effects • Origin of vaccine • Beliefs	• Being a male • Higher educated
21	UK	• Being a female • Young age • Being Black • Beliefs	• High perceived risk of getting the disease
22	US	• Being a female • Being Black • Young age • Side effects • Vaccine efficacy • Origin of vaccine • Beliefs	• Being a male • Older age • Higher educated • High perceived risk of getting the disease • Vaccine History
23	Vietnam	• Side effects	• High perceived risk of getting the disease

Predictors of Vaccine Acceptance

Across 49 studies, vaccine acceptance is found to be mostly associated with certain (1) demographic characteristics including male (n= 9), higher education level (n=6), higher income levels (n=18), (2) perceived risks and severity of disease (n=12), and (3) vaccine history (n=12).

Demographic Characteristics

In terms of demographic characteristics that influence the reception of the COVID-19 vaccine, nine studies (across most countries studied) found that being male is associated with vaccine acceptance [5, 16, 20, 35, 36, 41, 42, 46, 47]. While in France Gagneux-Brunon et al. (2021) and, in Japan, Yoda et al. (2021) reported that male HCWs were more likely to get COVID-19 vaccination, in Saudi Arabia and the US, the likelihood was double for men compared to women [16, 46].

We also found that older age is an important factor for vaccination receptivity across 11 studies. [5, 15–17, 30, 36, 41–43, 48, 49].Three studies reported the elderly >70 are more likely to accept vaccination compared to people at younger age brackets [5, 49]. In Australia, Edwards et al. (2021) [48] reported positive intentions towards vaccination among individuals >55 and other studies report similar findings with individuals 65 and over [16, 17]. In the Unroe et al. (2020) [30] study, HCWs older than 60 years old were found to be more inclined to get the vaccine.

Finally, in six studies, individuals holding a university degree or a higher level of education were reported to have greater odds of being unopposed to the vaccine [4, 8, 16, 35, 38, 50].

Perceived Risks

We found individuals willing to accept the vaccine have similar perceptions and beliefs among HCWs and general adult populations across countries. High perceived risk of acquiring COVID-19 infection was associated with vaccine acceptance in seven of the 49 studies [3, 7, 19, 33, 46, 47, 51]. Saudi Arabian, Asian, and French HCWs who perceived a high risk of getting coronavirus had greater chances to accept the COVID-19 vaccine [33, 46, 47]. In a Middle Eastern survey, Qattan et al. (2021) reported that HCWs with high perception of getting COVID-19 had a 1.8 times greater likelihood of accepting the vaccine [46] while Gagneux-Brunon et al. (2021) reported similar evidence for French HCWs [47], and Chew et al. (2021) showed similar findings for HCWs in Asia including India, Indonesia, Bhutan, Vietnam, Singapore, and China [33].

Two studies, Salali and Uysal (2020) and Yigit et al. (2021) showed that among Turkish or British samples, higher levels of fear and anxiety scores are associated with vaccine acceptance [51]. Kwok et al. (2021) noted that work stress associated with unfavorable attitudes towards infection control policies acts as a mediator for the intentions for obtaining the COVID-19 vaccine among Chinese HCWs [52]. Four studies reported that people who perceived COVID-19 as a severe disease or its monumental impact on society have higher odds of receptivity [18, 20, 25, 53]. Three studies also reported that respondents who believe that vaccination will help to avoid getting COVID-19 are more likely to report willingness [11, 18, 49]. Moreover, two of the studies that examined the predictors of COVID-19 vaccine acceptance using a Health Belief Model, reported that under the perceived benefit construct, being unconcerned about the new vaccine's side effects as well as its efficacy increased the intentions to get vaccinated significantly [11, 49].

Vaccine History

Finally, a very important predictor for vaccine uptake is found to be an individual's vaccine history. 12 of 49 studies showed that positive attitudes towards influenza vaccines is a predictor of COVID-19 vaccine acceptance. Nine studies concluded that individuals who had flu vaccinations in the past are found to be more likely to vaccinate [7, 17, 18, 20, 29, 42, 43, 47, 53]. This is also the main predictor of vaccine uptake among French HCWs [47]. Furthermore, one U.S. study stated being up-to-date with vaccines is an indicator of receptivity [16].

DISCUSSION

In this study, COVID-19 vaccine hesitancy and acceptance trends across countries and their predictors were investigated. Across all studies, the COVID-19 vaccine hesitancy and acceptance rates were found to be 21% and 64% respectively. The results indicate a huge variability in the vaccine acceptance and hesitancy rates across countries and minoritized populations. Concerns about vaccine side effects and perception of the fast development of the vaccine to be unsafe by certain demographics, such as being female, young age, and race, were found to be the main drivers for vaccine refusal. On the other hand, being male, older age, having a high level of education, perceived risk of COVID-19, and receiving the flu vaccine in the past predicted the willingness to uptake the COVID-19 vaccine.

The results of this study indicate the current vaccine acceptance rate is found to be less than needed for reaching herd immunity. Scientists state that at least 70%-80% of the population needs to get vaccinated to halt the spread of COVID-19. Existing evidence for skepticism of vaccination across countries and minoritized groups, show that nations face huge challenges to get an adequate percentage of populations immune to COVID-19. This impedes the efforts to stop the pandemic and improve public and global health. Policymakers should consider the context and hesitancy of different minoritized demographics when designing vaccination policies.

The findings on the predictors of hesitancy and acceptance reveal evidence for causes of health disparities. People with certain demographic characteristics differ in their intentions to get vaccinated. Females [6, 7, 13, 15, 23, 24],

people with low schooling levels [7, 12, 13, 23, 38], and young people [5, 12–14, 24, 25, 28] are more hesitant to get the vaccine. Consistent with the results of previous studies, Black people reported less willingness to get vaccinated compared to Latinx or white people [6, 7, 14–16, 23, 24, 30–32]. Their hesitancy stems from both lacking resources, and the valid distrust in vaccines, government, or healthcare authorities which have historically abused marginalized communities in the U.S. and Puerto Rico, such as the unethical Tuskegee experiment and sterilization of Boricua women. The hesitancy is especially alarming because it is well known that culturally oppressed populations are disproportionately vulnerable to the COVID-19 pandemic, as they lack access to basic healthcare. Ultimately, these populations have higher rates of pre-existing conditions that make them more susceptible to COVID-19.

Ethics and evidence matter. Firstly, there is a tremendous need for transparency of information from trusted authorities. This study shows people have different perceptions and beliefs of the COVID-19 disease and the vaccination based on the channels of information they have. Stopping the virus might begin with changing the perceptions and the behaviors of the community. Within the Health Belief Model framework, a person's perception of the risks for getting the virus, the severity of the disease, the effectiveness of getting vaccinated, and the stimulus from others to get vaccinated determines the effectiveness of the COVID-19 vaccine. Therefore, it is crucial to organize the spread of accurate information to these communities. Granted, health care systems need to build trust with their communities first. This effort relies on the partnership of the community, educational organizations, health institutions, political leaders, the media, among other stakeholders.

Public advocacy of the vaccine is also key to improving our collective health. It lays the groundwork for the spread of accurate information which should be instated at the community level in order to boost vaccination at the local level. Additionally, community activism will create the opportunity for communicating the needs of communities to political leaders. As this study demonstrates, some people's vaccination intentions are influenced by political ideologies. It is vital for the political leaders to keep the entire society's interests in mind when giving vaccination messages to the public. Vaccine policies and interventions should be centered on addressing the needs of all, beginning with most vulnerable populations.

Our study revealed some gaps in the literature. For one, there are not enough studies to provide evidence for the causes of hesitancy for many groups across the globe, which prevents the creation of evidence-based policies. Additionally, evidence is scarce for how vaccination policies are implemented across countries including whether they are government-mandated or voluntary. It is critical to know who has access to available vaccines and what types and to what degrees investments are allocated for vaccination objectives. Additionally, what are the vaccine brands available to whom and what are the variances across vaccine intents and behaviors ultimately affect public health.

There are some limitations to this study. First, only PubMed database was used to search for literature. Other databases may have had other published articles that could enhance this review. In addition, we used only the studies that are written in English, which may limit our understanding of the COVID-19 vaccine hesitancy and acceptance globally. Secondly, results of this study show evidence for several countries, and some samples were not representative of the populations of the respective countries. For this reason, the results of this current systematic review cannot be generalized to all countries or all people within their respective countries. Thirdly, the studies included the use of different study designs, survey questions, or data analysis methods. Therefore, the predictors that were found are only associations and causality cannot be claimed. Finally, the studies in this project conducted surveys before the COVID-19 vaccines were developed. The trends in acceptance might have changed after the vaccination programs were put in place. Future research may examine the latest trends across countries and compare before and after trends in order to understand which policies work best. To have solid evidence on the causes of COVID -19 vaccine hesitancy and acceptance, future research may analyze the predictors of hesitancy quantitatively.

CONCLUSION

The results of this study show that large proportions of the population in many countries are still hesitant to get vaccinated even though vaccination is an important tool for our communities to be safe from COVID-19. Large variability in COVID-19 vaccine hesitancy across countries and minoritized groups were found. The predictors of hesitancy and acceptance show similar trends across some subpopulations. These results point to the importance of disseminating accurate information through trusted channels, as well as through political support. Findings from the current systematic review can be used by policymakers as general evidence when proposing

policies that target vaccination behaviors of specific populations.

SUPPLEMENTARY FILE 1

JBI Quality (Risk of Bias) Assessment

Study	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Score
Detoc et al. (2020)	Y	Y	U	Y	U	U	Y	Y	5
Alley et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Yoda et al. (2021)	Y	Y	Y	Y	Y	N	Y	Y	7
Doherty et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Fisher et al. (2020)	Y	Y	Y	Y	Y	Y	Y	Y	8
Green et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Sallam et al. (2021)	Y	Y	N	N	U	U	Y	Y	4
Lin et al. (2020)	Y	Y	U	U	Y	N	Y	Y	5
Robertson et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Ward et al. (2020)	Y	Y	U	Y	Y	U	Y	Y	6
Gatwood et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Latkin et al. (2021) - *MASK USAGE*	Y	Y	U	Y	Y	Y	Y	Y	7
Kuter et al. (2021)	Y	Y	Y	Y	Y	U	Y	Y	7
Kourlaba et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Salmon et al. (2021)	Y	Y	Y	Y	Y	U	Y	Y	7
Al-Mohaithef et al. (2020)	Y	Y	Y	Y	U	U	Y	Y	6
Ruiz et al. (2021)	Y	Y	U	Y	Y	U	Y	Y	6
Khubchandani et al. (2021)	Y	Y	Y	Y	Y	U	Y	Y	7
Kreps et al. (2020)	Y	Y	Y	Y	Y	Y	Y	Y	8
Schwarzinger et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Al-Qerem et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Yigit et al. (2021)	Y	Y	Y	Y	N	N	Y	Y	6
Murphy et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Dror et al. (2020)	Y	Y	Y	Y	Y	Y	Y	Y	8
Unroe et al. (2021)	Y	Y	U	U	Y	U	Y	Y	5
Latkin et al. (2021) - *COVID-19 VACCINE INTENTIONS*	Y	Y	Y	Y	Y	U	Y	Y	7
Olagoke et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Chew et al. (2021)	Y	Y	Y	U	U	U	Y	Y	5
Freeman et al. (2020)	Y	Y	Y	Y	Y	Y	Y	Y	8

Yurttas et al. (2021)	Y	Y	Y	Y	Y	N	Y	Y	6
Papagiannis et al. (2021)	Y	Y	U	Y	N	N	Y	Y	5
Vallis et al. (2021)	Y	Y	Y	Y	Y	N	Y	Y	7
Motta et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Scott et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Borriello et al. (2021)	Y	Y	Y	Y	Y	N	Y	Y	7
di Gennaro et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Wang et al. (2021)	Y	Y	U	U	Y	U	Y	Y	5
Alabdulla et al. (2021)	Y	Y	U	Y	Y	Y	Y	Y	7
Kaplan et al. (2021)	Y	Y	Y	Y	U	U	Y	Y	6
Verger et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Qattan et al. (2021)	Y	Y	Y	Y	Y	U	Y	Y	7
Gagneux-Brunon et al. (2021)	Y	Y	U	U	Y	N	Y	Y	5
Edwards et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Mercadante et al. (2020)	Y	Y	Y	Y	Y	N	Y	Y	7
Williams et al. (2021)	Y	Y	Y	Y	Y	N	Y	Y	7
Salali et al. (2020)	Y	Y	N	N	U	U	Y	Y	4
Kwok et al. (2021)	Y	Y	Y	Y	Y	Y	Y	Y	8
Pogue et al. (2020)	Y	Y	Y	Y	Y	U	Y	Y	7
Wang et al. (2020)	Y	Y	U	U	U	N	Y	Y	4

REFERENCES

1. Our World in Data: "Coronavirus Vaccinations". Available online: https://ourworldindata.org/covid-vaccinations (accessed on 27 June 2021).
2. WHO: "Report of the Sage Working Group on Vaccine Hesitancy". Available online: https://www.who.int/immunization/sage/meetings/2014/october/SAGE_working_group_revised_report_vaccine_hesitancy.pdf?ua=1#:~:text=Vaccine%20hesitancy%20refers%20to%20delay,as%20complacency%2C%20convenience%20and%20confidence. (accessed on 17 April 2021).
3. Detoc, M., Bruel, S., Frappe, P., Tardy, B., Botelho-Nevers, E., Gagneux-Brunon, A.: "Intention to participate in a COVID-19 vaccine clinical trial and to get vaccinated against COVID-19 in France during the pandemic" *Vaccine*, 2020, **38**, (45), pp. 7002–7006.
4. Alley, S.J., Stanton, R., Browne, M., *et al.*: "As the Pandemic Progresses, How Does Willingness to Vaccinate against COVID-19 Evolve?" *International Journal of Environmental Research and Public Health*, 2021, **18**, (2).
5. Yoda, T., Katsuyama, H.: "Willingness to Receive COVID-19 Vaccination in Japan" *Vaccines*, 2021, **9**, (1).
6. Doherty, I.A., Pilkington, W., Brown, L., *et al.*: "COVID-19 Vaccine Hesitancy in Underserved Communities of North Carolina" *medRxiv: The Preprint Server for Health Sciences*, 2021.
7. Fisher, K.A., Bloomstone, S.J., Walder, J., Crawford, S., Fouayzi, H., Mazor, K.M.: "Attitudes Toward a Potential SARS-CoV-2 Vaccine: A Survey of U.S. Adults" *Annals of Internal Medicine*, 2020, **173**, (12), pp. 964–973.
8. Green, M.S., Abdullah, R., Vered, S., Nitzan, D.: "A study of ethnic, gender and educational differences in attitudes toward COVID-19 vaccines in Israel - implications for vaccination implementation policies" *Israel Journal of Health Policy Research*, 2021, **10**, (1), p. 26.
9. Sallam, M., Dababseh, D., Eid, H., *et al.*: "High Rates of COVID-19 Vaccine Hesitancy and Its Association with Conspiracy Beliefs: A Study in Jordan and Kuwait among Other Arab Countries" *Vaccines*, 2021, **9**, (1).
10. Robinson, E., Jones, A., Lesser, I., Daly, M.: "International estimates of intended uptake and refusal of COVID-19 vaccines: A rapid systematic review and meta-analysis of large nationally representative samples" *Vaccine*, 2021, **39**, (15).
11. Lin, Y., Hu, Z., Zhao, Q., Alias, H., Danaee, M., Wong, L.P.: "Understanding COVID-19 vaccine demand and hesitancy: A nationwide online survey in China" *PLoS neglected tropical diseases*, 2020, **14**, (12), pp. e0008961–e0008961.
12. Robertson, E., Reeve, K.S., Niedzwiedz, C.L., *et al.*: "Predictors of COVID-19 vaccine hesitancy in the UK household longitudinal study" *Brain, Behavior, and Immunity*, 2021.
13. Ward, J.K., Alleaume, C., Peretti-Watel, P., *et al.*: "The French public's attitudes to a future COVID-19 vaccine: The politicization of a public health issue" *Social Science & Medicine*, 2020, **265**.
14. Gatwood, J., McKnight, M., Fiscus, M., Hohmeier, K.C., Chisholm-Burns, M.: "Factors influencing likelihood of COVID-19 vaccination: A survey of Tennessee adults" *American journal of health-system pharmacy: AJHP: official journal of the American Society of Health-*

System Pharmacists, 2021.
15. Latkin, C.A., Dayton, L., Yi, G., Colon, B., Kong, X.: "Mask usage, social distancing, racial, and gender correlates of COVID-19 vaccine intentions among adults in the US" *PloS One*, 2021, **16**, (2), pp. e0246970–e0246970.
16. Kuter, B.J., Browne, S., Momplaisir, F.M., *et al.*: "Perspectives on the receipt of a COVID-19 vaccine: A survey of employees in two large hospitals in Philadelphia" *Vaccine*, 2021.
17. Kourlaba, G., Kourkouni, E., Maistreli, S., *et al.*: "Willingness of Greek general population to get a COVID-19 vaccine" *Global Health Research and Policy*, 2021, **6**, (1), p. 3.
18. Salmon, D.A., Dudley, M.Z., Brewer, J., *et al.*: "COVID-19 vaccination attitudes, values and intentions among United States adults prior to emergency use authorization" *Vaccine*, 2021.
19. Al-Mohaithef, M., Padhi, B.K.: "Determinants of COVID-19 Vaccine Acceptance in Saudi Arabia: A Web-Based National Survey" *Journal of Multidisciplinary Healthcare*, 2020, **13**, pp. 1657–1663.
20. Ruiz, J.B., Bell, R.A.: "Predictors of intention to vaccinate against COVID-19: Results of a nationwide survey" *Vaccine*, 2021, **39**, (7), pp. 1080–1086.
21. Joanna Briggs Institute: "Critical Appraisal Checklist for analytical cross-sectional studies."2020. Available from https://jbi.global/critical-appraisal-tools. Accessed on April 5, 2021
22. Borenstein, M., Hedges, L. v., Higgins, J.P.T., Rothstein, H.R.: "Introduction to Meta-Analysis" (John Wiley & Sons, Ltd, 2009)
23. Khubchandani, J., Sharma, S., Price, J.H., Wiblishauser, M.J., Sharma, M., Webb, F.J.: "COVID-19 Vaccination Hesitancy in the United States: A Rapid National Assessment" *Journal of Community Health*, 2021, **46**, (2), pp. 270–277.
24. Kreps, S., Prasad, S., Brownstein, J.S., *et al.*: "Factors Associated With US Adults' Likelihood of Accepting COVID-19 Vaccination" *JAMA network open*, 2020, **3**, (10), pp. e2025594–e2025594.
25. Schwarzinger, M., Watson, V., Arwidson, P., Alla, F., Luchini, S.: "COVID-19 vaccine hesitancy in a representative working-age population in France: a survey experiment based on vaccine characteristics" *The Lancet. Public Health*, 2021.
26. Al-Qerem, W.A., Jarab, A.S.: "COVID-19 Vaccination Acceptance and Its Associated Factors Among a Middle Eastern Population" *Frontiers in Public Health*, 2021, **9**, p. 632914.
27. Yigit, M., Ozkaya-Parlakay, A., Senel, E.: "Evaluation of COVID-19 Vaccine Refusal in Parents" *The Pediatric Infectious Disease Journal*, 2021, **Publish Ah**.
28. Murphy, J., Vallières, F., Bentall, R.P., *et al.*: "Psychological characteristics associated with COVID-19 vaccine hesitancy and resistance in Ireland and the United Kingdom" *Nature Communications*, 2021, **12**, (1), p. 29.
29. Dror, A.A., Eisenbach, N., Taiber, S., *et al.*: "Vaccine hesitancy: the next challenge in the fight against COVID-19" *European Journal of Epidemiology*, 2020, **35**, (8), pp. 775–779.
30. Unroe, K.T., Evans, R., Weaver, L., Rusyniak, D., Blackburn, J.: "Willingness of Long-Term Care Staff to Receive a COVID-19 Vaccine: A Single State Survey" *Journal of the American Geriatrics Society*, 2020.
31. Latkin, C., Dayton, L.A., Yi, G., *et al.*: "COVID-19 vaccine intentions in the United States, a social-ecological framework" *Vaccine*, 2021.
32. Olagoke, A.A., Olagoke, O.O., Hughes, A.M.: "Intention to Vaccinate Against the Novel 2019 Coronavirus Disease: The Role of Health Locus of Control and Religiosity" *Journal of Religion and Health*, 2021, **60**, (1), pp. 65–80.
33. Chew, N.W.S., Cheong, C., Kong, G., *et al.*: "An Asia-Pacific study on healthcare worker's perception and willingness to receive COVID-19 vaccination" *International journal of infectious diseases: IJID: official publication of the International Society for Infectious Diseases*, 2021.
34. Freeman, D., Loe, B.S., Chadwick, A., *et al.*: "COVID-19 vaccine hesitancy in the UK: the Oxford coronavirus explanations, attitudes, and narratives survey (Oceans) II" *Psychological Medicine*, 2020, pp. 1–15.
35. Yurttas, B., Poyraz, B.C., Sut, N., *et al.*: "Willingness to get the COVID-19 vaccine among patients with rheumatic diseases, healthcare workers and general population in Turkey: a web-based survey" *Rheumatology International*, 2021.
36. Papagiannis, D., Rachiotis, G., Malli, F., *et al.*: "Acceptability of COVID-19 Vaccination among Greek Health Professionals" *Vaccines*, 2021, **9**, (3).
37. Vallis, M., Glazer, S.: "Protecting Individuals Living with Overweight and Obesity: Attitudes and Concerns Towards COVID-19 Vaccination in Canada" *Obesity (Silver Spring, Md.)*, 2021.
38. Motta, M.: "Can a COVID-19 vaccine live up to Americans' expectations? A conjoint analysis of how vaccine characteristics influence vaccination intentions" *Social Science & Medicine (1982)*, 2021, **272**, p. 113642.
39. Scott, E.M., Stein, R., Brown, M.F., Hershberger, J., Scott, E.M., Wenger, O.K.: "Vaccination patterns of the northeast Ohio Amish revisited" *Vaccine*, 2021, **39**, (7), pp. 1058–1063.
40. Borriello, A., Master, D., Pellegrini, A., Rose, J.M.: "Preferences for a COVID-19 vaccine in Australia" *Vaccine*, 2021, **39**, (3), pp. 473–479.
41. di Gennaro, F., Murri, R., Segala, F.V., *et al.*: "Attitudes towards Anti-SARS-CoV2 Vaccination among Healthcare Workers: Results from a National Survey in Italy" *Viruses*, 2021, **13**, (3).
42. Wang, K., Wong, E.L.Y., Ho, K.F., *et al.*: "Intention of nurses to accept coronavirus disease 2019 vaccination and change of intention to accept seasonal influenza vaccination during the coronavirus disease 2019 pandemic: A cross-sectional survey" *Vaccine*, 2020, **38**, (45), pp. 7049–7056.
43. Alabdulla, M., Reagu, S.M., Al-Khal, A., Elzain, M., Jones, R.M.: "COVID-19 vaccine hesitancy and attitudes in Qatar: A national cross-sectional survey of a migrant-majority population" *Influenza and Other Respiratory Viruses*, 2021.
44. Kaplan, R.M., Milstein, A.: "Influence of a COVID-19 vaccine's effectiveness and safety profile on vaccination acceptance" *Proceedings of the National Academy of Sciences of the United States of America*, 2021, **118**, (10).
45. Verger, P., Scronias, D., Dauby, N., *et al.*: "Attitudes of healthcare workers towards COVID-19 vaccination: a survey in France and French-speaking parts of Belgium and Canada, 2020"*Euro Surveillance: Bulletin Europeen Sur Les Maladies Transmissibles = European Communicable Disease Bulletin*, 2021, **26**, (3).
46. Qattan, A.M.N., Alshareef, N., Alsharqi, O., al Rahahleh, N., Chirwa, G.C., Al-Hanawi, M.K.: "Acceptability of a COVID-19 Vaccine Among Healthcare Workers in the Kingdom of Saudi Arabia" *Frontiers in Medicine*, 2021, **8**, p. 644300.
47. Gagneux-Brunon, A., Detoc, M., Bruel, S., *et al.*: "Intention to get vaccinations against COVID-19 in French healthcare workers during the first pandemic wave: a cross-sectional survey" *The Journal of Hospital Infection*, 2021, **108**, pp. 168–173.
48. Edwards, B., Biddle, N., Gray, M., Sollis, K.: "COVID-19 vaccine hesitancy and resistance: Correlates in a nationally representative longitudinal survey of the Australian population" *PloS One*, 2021, **16**, (3), pp. e0248892–e0248892.
49. Mercadante, A.R., Law, A. v: "Will they, or Won't they? Examining patients' vaccine intention for flu and COVID-19 using the Health Belief Model" *Research in social & administrative pharmacy: RSAP*, 2020.
50. Williams, L., Flowers, P., McLeod, J., Young, D., Rollins, L., The Catalyst Project Team, null: "Social Patterning and Stability of Intention to Accept a COVID-19 Vaccine in Scotland: Will Those Most at Risk Accept a Vaccine?" *Vaccines*, 2021, **9**, (1).
51. Salali, G.D., Uysal, M.S.: "COVID-19 vaccine hesitancy is associated with beliefs on the origin of the novel coronavirus in the UK and Turkey" *Psychological Medicine*, 2020, pp. 1–3.
52. Kwok, K.O., Li, K.-K., Wei, W.I., Tang, A., Wong, S.Y.S., Lee, S.S.: "Editor's Choice: Influenza vaccine uptake, COVID-19 vaccination

intention and vaccine hesitancy among nurses: A survey" *International Journal of Nursing Studies*, 2021, **114**, p. 103854.
53. Pogue, K., Jensen, J.L., Stancil, C.K., *et al.*: "Influences on Attitudes Regarding Potential COVID-19 Vaccination in the United States" *Vaccines*, 2020, **8**, (4).
54. Ioannidis, J. P. (2008). Interpretation of tests of heterogeneity and bias in meta-analysis. *Journal of evaluation in clinical practice*, *14*(5), 951-957.
55. Engels, E. A., Schmid, C. H., Terrin, N., Olkin, I., & Lau, J. (2000). Heterogeneity and statistical significance in meta-analysis: an empirical study of 125 meta-analyses. *Statistics in medicine*, *19*(13), 1707-1728.
56. Barker, T. H., Migliavaca, C. B., Stein, C., Colpani, V., Falavigna, M., Aromataris, E., & Munn, Z. (2021). Conducting proportional meta-analysis in different types of systematic reviews: a guide for synthesisers of evidence. *BMC Medical Research Methodology*, *21*(1), 1-9.

REVIEW

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Moving Beyond MDA to Control STH Infections through WASH, Hygiene Education, and Community Engagement

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ABSTRACT The main types of soil-transmitted helminths (*Ascaris lumbricoides*, *Ancylostoma duodenale*, *Necator americanus*, and *Trichuris trichiura*) infected approximately 1.45 billion people in 2010, making them collectively the most common parasitic disease that infects humans. Children residing in low and middle income countries without adequate water, sanitation, and hygiene bear the majority of the burden of morbidity and mortality from these infections. School-based mass drug administrations of oral anthelmintic treatments is recognized as the primary means of infection control; however, these treatments alone are not solely capable of eliminating infections and breaking the cycle of disease transmission. Other approaches, such as improvements to water sanitation infrastructure and increasing hygiene education, are also promising, although these approaches have too fallen short in their ability to eliminate infections on their own. The inclusion of community engagement in the development and implementation of interventional infrastructure is a concept that has been moving towards the forefront of community health research for some time. Research shows that the centering of host communities in the design, implementation and evaluation of mass drug administration, water sanitation and hygiene education programs produces sustainable reductions in infection and transmission rates, maximizes intervention success and ensures long-term deliveries of maximal program benefits. For the purposes of this paper, we elected to focus especially on the benefits of incorporating community engagement into water sanitation-based interventions. We reviewed thirty articles that discussed the benefits of intervention implementation in communities across South America, Asia, and Africa. While limiting factors included the short time frames of some of the studies and a lack of attention to potential confounding variables, we found a promising relationship between the integration of community engagement into intervention development, and the resulting success of the integrated interventions.

KEY WORDS Soil-Transmitted Helminth Infections, Mass Drug Administration, Water Sanitation,

Introduction

Over 1.5 billion people worldwide are afflicted by soil-transmitted helminth (STH) infections: *Ascaris lumbricoides*, *Ancylostoma duodenale*, *Necator americanus*, and *Trichuris trichiura* (Ercumen et al., 2019). The disease burden mainly affects low and middle-income countries (LMICs) that lack adequate water, sanitation, and hygiene (WASH), since transmission mainly occurs via contact with soil contaminated with infected human feces (Khan et al., 2019). STH infections cause iron-deficiency anemia, malnutrition, and adverse outcomes in growth and cognitive development of children (Echazú et al., 2015). Infection control has relied on annual school-based mass drug

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administration (MDA) of oral anthelminthic treatments, most commonly albendazole or mebendazole; however, MDA is not solely capable of eliminating STH infections because it does not interrupt the environmental transmission of infection, and therefore presents a high risk of re-infection (Khan et al., 2019; Vaz Nery et al., 2019, Ziegelbauer et al., 2012).

While improvements in WASH infrastructure - such as increased access to safely managed water sources and latrines, and adequate fecal management - are critical in the fight to reduce environmental transmission of STH infections, these infrastructures must be accepted by the host community and coupled with behavior changes in order to achieve long-term, sustainable reductions in infection and transmission rates (Ecrumen et al., 2019; Worrell et al., 2016; Al-Delaimy et al., 2014; Parker et al., 2008; Watson et al., 2017).

The centering of host communities in the design, implementation and evaluation of WASH and MDA interventions increases intervention acceptance within the host community, which in turn maximizes the efficiency and beneficial outcomes of the programs (Clarke et al., 2018; Gyorkos et al., 2013; Muluneh et al., 2020).

Existing Interventions Combatting Soil Transmitted Helminth Infections

Interventions to control STH infections include MDA, WASH infrastructure improvements, and health education. Many health education and deworming programs are school-based, since children are most impacted by STH infections (Al-Delaimy et al., 2014; Gyorkos et al., 2013). Other interventions are community-based, focusing on improving hygiene behaviors within households (Dumba et al., 2013; Ercumen et al., 2019). A critical, but often forgotten, factor of any intervention is community engagement (Al-Delaimy et al., 2014; Clarke et al., 2013; Dumba et al., 2013). Peer-reviewed literature advocates for community-led integrated interventions, which combine MDA campaigns, WASH infrastructure and health education (Anderson et al., 2014; Khan et al., 2019).

Mass Drug Administration

School-based MDA campaigns have historically been the most common, and oftentimes only, intervention used to combat STH infections (Campbell et al., 2018). While MDA reduces STH infections substantially, it does not address reinfection and potential parasite reestablishment and drug resistance (Benjamin-Chung et al., 2015; Campbell et al., 2016; Khan et al., 2019). Mathematical modeling shows that MDA with school-aged children alone is insufficient in eliminating STH transmission without also including adults and preschool-aged children in MDA efforts (Anderson et al., 2014). Additionally, MDA campaigns in LMICs have been plagued with funding and delivery issues, making treatment inconsistent and eradication impossible (Campbell et al, 2018). MDA also does not address the environmental and structural root causes of STH infections (Benjamin-Chung et al., 2015; Khan et al., 2019).

WASH Infrastructure Interventions

Risk factors for high transmission rates in children include open defecation and a lack of handwashing (Nasr et al., 2013). The odds of contracting STH infections is shown to decrease with piped water and latrines (Campbell et al., 2016). Therefore, WASH infrastructure improvements are expected to interrupt the environmental transmission of STH infections and supplement the reductions in STH burden achieved by MDA (Anderson et al., 2014; Campbell et al., 2017).

However, there is significant inconsistency in the demonstrated impact of WASH intervention on reductions in STH infections (Vaz Nery et al., 2019). Freeman et al. (2013) found little impact of school-based WASH interventions on STH infections in Nyanza Province, Kenya in their cluster-randomized trial. Ercumen et al. (2019) studied the effects of WASH infrastructure improvements (water treatment, latrines, hand washing stations) in a cluster-randomized trial in rural Bangladesh. The water treatment and sanitation interventions reduced prevalence of some, but not all, STHs, and handwashing promotion had no effect on any of the STH infections (Ercumen et al., 2019). The lack of efficacy of handwashing promotion alone is also supported by a systematic review of school-based handwashing interventions in LMICs by Watson et al. (2017).

Health Education Interventions

School-based health education interventions alongside MDA have shown some success in reducing STH infections (Gizaw et al., 2019; Vaz Nery et al., 2019). Al-Delaimy et al. (2014) developed the STH Health Education Learning Package (HELP) for indigenous children in a highly endemic region of Malaysia. HELP improved the STH knowledge, attitudes, and practices of children, parents, and teachers. Additionally, stool

samples showed significantly lower incidence and intensity of infection among children in the intervention schools (Al-Delaimy et al., 2014). Similarly, in the Peruvian Amazon, Gyorkos et al. (2013) employed a school-based health education intervention. The children who received the intervention demonstrated increased knowledge of STH infections and reported improved hygiene behavior. However, there were no significant differences in the prevalence of STH infections between the intervention and control groups, though there was a significant reduction in *A. lumbricoides* intensity (Gyorkos et al., 2013). The inconsistencies of school-based interventions' success in reducing STH infections prevalence and intensity is indicative of an overlooked piece of STH and global health intervention efforts in general: community engagement.

Community Engagement

There are various ways to incorporate community input into the design, delivery, and decision-making processes of both school and community-based STH interventions. It is also important to note that while crucial, the incorporation of community engagement into an intervention does not automatically guarantee the intervention's success. Factors such as the amount and type of input, as well as the duration of the program design and implementation can lead to variety in efficacy across programs.

Extensive research into community engagement efforts and their effect on STH infections is lacking, but available research points to its utility and benefits if performed well. For example, Al-Delaimy et al. (2014) relied on the popular PRECEDE-PROCEED model to design their school-based health education intervention in Malaysia. This involved extensive communication with academic experts, community leaders and their members to understand all the factors that could influence infection control efforts. School teachers were employed as messengers of health promotion and children received the necessary products to improve hygienic behaviors. Results showed reduced infection rates and intensity of STH infections, as well as improved knowledge, attitudes, and practices regarding STH infections and WASH best practices among the teachers, students, and parents (Al-Delaimy et al., 2014). Gyorkos et al. (2013) suggests that the inclusion of family members as audiences for school-based health interventions is a a critical engagement method to expand the intervention's benefits to the wider community.

Clarke et al. (2018) implemented an intervention in six villages in Timor-Leste. Six villages received the intervention, three of which received additional CLTS to encourage the construction of latrines. The CLTS villages saw 18.1% less children reporting open defecation compared to the school-based interventions (Clarke et al., 2018). There is evidence, therefore, that the most significant reductions in STH infections can be achieved through interventions in communities rather than in schools.

The effect of community-centered interventions on STH infections varies. Dumba et al. (2013) employed a community engagement-based education intervention in Uganda using the Participatory Hygiene and Sanitation Transformation (PHAST) method. Families who participated in the program identified the problem of poor sanitation, decided what aspects of sanitation needed improvement, and planned solutions via new facilities and behavior change. There was a notable change in hygienic behaviors among intervention participants; however, the reductions in STH infections were not significantly different between intervention and control communities. The researchers suggested that this was due to a short follow-up period, which did not give sufficient time for the reductions in environmental transmission that follow behavior change to become detectable in the communities (Dumba et al., 2013).

Hürlimann et al. (2018) used the participatory approach of community-led total sanitation (CLTS), which aims to sustain open-defecation free (ODF) communities. One year post-intervention, they did not find significant differences in STH reinfection rates between intervention and control communities (Hürlimann et al., 2018). On the other hand, CLTS was found to reduce STH infections in kebeles in Ethiopia by 49% in ODF communities (Muluneh et al., 2020). In ODP kebeles, children who used latrines had a 2.15 times lower risk of STH infections than those who did not (Muluneh et al., 2020).

Shortcomings of Current Studies

A short follow up period is often cited as a limitation in intervention studies (Ercumen et al., 2019; Gyorkos et al., 2013; Hürlimann et al., 2018). Each STH responds to WASH interventions differently, due to differences in lifespan, ova and other biological factors (Coffeng et al., 2018; Vaz Nery et al., 2019). Interventions need to be studied over substantial periods of time in order to understand their true impact on disease burden and behavior change.

Additionally, variations in intervention effect stem from variances in baseline prevalence (Vaz Nery et al., 2019). Significant infection reductions are easier to detect in highly endemic places, such as the region in Malaysia studied by Al-Delaimy et al. (2014), versus communities with a low baseline prevalence. A more appropriate gauge of intervention impact in low endemic areas is to measure intensity rather than prevalence of STH infections (Anderson et al., 2014; Baker et al., 2018; Vaz Nery et al., 2019), as was done by Gyorkos et al. (2013).

Even a household with improved WASH infrastructure and demonstrated hygienic knowledge is at risk of infection if its members continue with certain behaviors such as walking barefoot, geophagy, or poor maintenance of sanitation facilities (Freeman et al., 2013; Mather et al., 2020; Vaz Nery et al., 2019; Worrell et al., 2016)). Failing to consider behavioral variables as targets and outcomes of interventions can moderate and negatively impact the effect of WASH interventions (Mather et al., 2020; Vaz Nery et al., 2019).

Limitations and Future Research Recommendations

Given only 30 articles are examined out of a wider literature, the scope of this article is limited. Articles were selected to investigate the breadth of interventions that intend to control STH infections both alone and in combination: MDA, WASH, education programs, and community engagement. The studies chosen for analysis are recent (within the last 15 years) and all take place in LMICs. Each study compares additional WASH, education, or community engagement interventions with the standard treatment of MDA with dewormers.

STH interventions need to be tailored to the study site's endemic context and population behaviors through community engagement (Clarke et al., 2018; Sacolo-Gwbu et al., 2019). The Geshiyaro Project offers a guideline for designing such studies, aiming to determine the effects of community-based MDA, WASH, and health education on 1.9 million people in Ethiopia (Mekete et al., 2019). The forthcoming results of the project will be vital in informing the role of community engagement in working towards the eradication of STH infections through intervention methods that go beyond MDA programs (Mekete et al., 2019).

Conclusion

MDA, while effective, runs the risk of re-infection and future drug resistance, among other problems (Clarke et al., 2018; Parker et al., 2011). Total elimination of STH infections, therefore, requires interventions that interrupt environmental transmission, such as improved WASH infrastructure and hygiene education (Echazú et al., 2015; Mascarini-Serra 2011). The studies reviewed demonstrate that the reduction of STH risk factors can reduce the morbidity of STH infections (Nasr et al., 2013), though results do vary depending on setting and intervention. Studies that incorporate community engagement demonstrated that the impact of WASH infrastructure and hygiene education interventions can be maximized when the community is given a role in the intervention (Clarke et al., 2018; Muluneh et al., 2020). This includes expanding school-based interventions to reach adults in the larger community who can aid children in changing their health behaviors (Clarke et al., 2018). MDA programs must be supplemented by WASH interventions and health education that engage the community in order to achieve the eradication of STH infections.

References

1. Al-Delaimy, A. K., Al-Mekhlafi, H. M., Lim, Y. A., Nasr, N. A., Sady, H., Atroosh, W. M.,
2. & Mahmud, R. (2014). Developing and evaluating health education learning
3. package (HELP) to control soil-transmitted helminth infections among Orang Asli
4. children in Malaysia. *Parasites & Vectors*, *7*(1), 416.
5. https://doi.org/10.1186/1756-3305-7-416
6. Anderson, R., Truscott, J., & Hollingsworth, T. D. (2014). The coverage and frequency of mass drug administration required to eliminate persistent transmission of soil-transmitted helminths. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *369*(1645), 2. https://doi.org/10.1098/rstb.2013.0435
7. Baker, J. M., Trinies, V., Bronzan, R. N., Dorkenoo, A. M., Garn, J. V., Sognikin, S., & Freeman, M. C. (2018). The associations between water and sanitation and hookworm infection using cross-sectional data from Togo's national deworming program. *PLOS Neglected Tropical Diseases*, *12*(3), e0006374. https://doi.org/10.1371/journal.pntd.0006374
8. Benjamin-Chung, J., Nazneen, A., Halder, A. K., Haque, R., Siddique, A., Uddin, M. S., Koporc, K., Arnold, B. F., Hubbard, A. E., Unicomb, L., Luby, S. P., Addiss, D. G., & Colford, J. M. (2015). The Interaction of Deworming, Improved Sanitation, and Household Flooring with Soil-Transmitted Helminth Infection in Rural Bangladesh. *PLOS Neglected Tropical Diseases*, *9*(12), e0004256. https://doi.org/10.1371/journal.pntd.0004256
9. Campbell, S.J., Biritwum, N.K., Woods, G., Velleman, Y., Fleming, F., & Russell Stothard, J. (2018). Tailoring Water, Sanitation, and Hygiene (WASH) Targets for Soil-Transmitted Helminthiasis and Schistosomiasis Control. *Trends in Parasitology*, *34*(1), 53–63. https://doi.org/10.1016/j.pt.2017.09.004 (accessed 15 September 2020).
10. Campbell, S.J., Nery, S.V., McCarthy, J.S., Gray, D.J., Soares M., Ricardo J., & C. A. Clements, A. (2016). A Critical Appraisal of Control Strategies for Soil-Transmitted Helminths. *Trends in Parasitology*, *32*(2), 97–107. https://doi.org/10.1016/j.pt.2015.10.006

11. Campbell, S. J., Nery, S. V., Wardell, R., D'Este, C. A., Gray, D. J., McCarthy, J. S., Traub, R. J., Andrews, R. M., Llewellyn, S., Vallely, A. J., Williams, G. M., & Clements, A. C. A. (2017). Water, Sanitation and Hygiene (WASH) and environmental risk factors for soil-transmitted helminth intensity of infection in Timor-Leste, using real time PCR. *PLOS Neglected Tropical Diseases*, *11*(3), e0005393. https://doi.org/10.1371/journal.pntd.0005393
12. Clarke, N. E., Clements, A. C. A., Amaral, S., Richardson, A., McCarthy, J. S., McGown, J., Bryan, S., Gray, D. J., & Nery, S. V. (2018). (S)WASH-D for Worms: A pilot study investigating the differential impact of school- versus community-based integrated control programs for soil-transmitted helminths. *PLOS Neglected Tropical Diseases*, 12(5), e0006389.https://doi.org/10.1371/journal.pntd.0006389
13. Coffeng, L. E., Vaz Nery, S., Gray, D. J., Bakker, R., de Vlas, S. J., & Clements, A. C. A. (2018). Predicted short and long-term impact of deworming and water, hygiene, and sanitation on transmission of soil-transmitted helminths. *PLOS Neglected Tropical Diseases*, *12*(12), e0006758. https://doi.org/10.1371/journal.pntd.0006758
14. Dumba, R., Kaddu, J., & Wabwire-Mangen, F. (2013). Design and implementation of participatory hygiene and sanitation transformation (PHAST) as a strategy to control soil-transmitted helminth infections in Luweero, Uganda. *African Health Sciences*, *13*(2), 512–517. https://doi.org/10.4314/ahs.v13i2.44
15. Echazú, A., Bonanno, D., Juarez, M., Cajal, S. P., Heredia, V., Caropresi, S., Cimino, R. O.,
16. Caro, N., Vargas, P. A., Paredes, G., & Krolewiecki, A. J. (2015). Effect of Poor Access to Water and Sanitation As Risk Factors for Soil-Transmitted Helminth Infection: Selectiveness by the Infective Route. *PLOS Neglected Tropical Diseases*, *9*(9), e0004111. https://doi.org/10.1371/journal.pntd.0004111
17. Ercumen, A., Benjamin-Chung, J., Arnold, B. F., Lin, A., Hubbard, A. E., Stewart, C.,
18. Rahman, Z., Parvez, S. M., Unicomb, L., Rahman M., Haque, R., Colford, J. M., &
19. Luby, S. P. (2019). Effects of water, sanitation, handwashing and nutritional interventions on soil-transmitted helminth infections in young children: A cluster-randomized controlled trial in rural Bangladesh. *PLOS Neglected Tropical Diseases 13*(5), e0007323. https://doi.org/10.1371/journal.pntd.0007323
20. Freeman, M. C., Clasen, T., Brooker, S. J., Akoko, D. O., & Rheingans, R. (2013). The impact of a school-based hygiene, water quality and sanitation intervention on soil-transmitted helminth reinfection: a cluster-randomized trial. *The American journal of tropical medicine and hygiene, 89*(5), 875–883. https://doi.org/10.4269/ajtmh.13-0237
21. Gizaw, Z., Addisu, A., & Dagne, H. (2019). Effects of water, sanitation and hygiene (WASH) education on childhood intestinal parasitic infections in rural Dembiya, northwest Ethiopia: An uncontrolled before-and-after intervention study. *Environmental Health and Preventive Medicine*, *24*(1), 16. https://doi.org/10.1186/s12199-019-0774-z
22. Gyorkos, T. W., Maheu-Giroux, M., Blouin, B., & Casapia, M. (2013). Impact of Health Education on Soil-Transmitted Helminth Infections in Schoolchildren of the Peruvian Amazon: A Cluster-Randomized Controlled Trial. *PLOS Neglected Tropical Diseases*, *7*(9), e2397. https://doi.org/10.1371/journal.pntd.0002397
23. Han, K.T., Wai, K.T., Aye, K.H., Kyaw, K.W., Maung, W.P., & Oo, T. (2019) Emerging neglected helminthiasis and determinants of multiple helminth infections in flood-prone township in Myanmar. *Tropical Medicine and Health*, *47*(1), 1-10. https://doi.org/10.1186/s41182-018-0133-6
24. Hürlimann, E., Silué, K. D., Zouzou, F., Ouattara, M., Schmidlin, T., Yapi, R. B., Houngbedji, C. A., Dongo, K., Kouadio, B. A., Koné, S., Bonfoh, B., N'Goran, E. K., Utzinger, J., Acka-Douabélé, C. A., & Raso, G. (2018). Effect of an integrated intervention package of preventive chemotherapy, community-led total sanitation and health education on the prevalence of helminth and intestinal protozoa infections in Côte d'Ivoire. *Parasites & vectors, 11*(1), 115. https://doi.org/10.1186/s13071-018-2642-x
25. Khan, M. S., Pullan, R., Okello, G., Nyikuri, M., McKee, M., & Balabanova, D. (2019). "For how long are we going to take the tablets?" Kenyan stakeholders' views on priority investments to sustainably tackle soil-transmitted helminths. *Social science & medicine* (1982), *228*, 51–59. https://doi.org/10.1016/j.socscimed.2019.02.050
26. Mascarini-Serra L. (2011). Prevention of Soil-transmitted Helminth Infection. *Journal of global infectious diseases*, *3*(2), 175–182. https://doi.org/10.4103/0974-777X.81696
27. Mather, W., Hutchings, P., Budge, S., & Jeffrey, P. (2020). Association between water and sanitation service levels and soil-transmitted helminth infection risk factors: A cross-sectional study in rural Rwanda. *Transactions of The Royal Society of Tropical Medicine and Hygiene*, 114(5), 332–338. https://doi.org/10.1093/trstmh/trz119
28. Mekete, K., Ower, A., Dunn, J., Sime, H., Tadesse, G., Abate, E., Nigussu, N., Seife, F., McNaughton, E., Anderson, R. M., & Phillips, A. E. (2019). The Geshiyaro Project: a study protocol for developing a scalable model of interventions for moving towards the interruption of the transmission of soil-transmitted helminths and schistosome infections in the Wolaita zone of Ethiopia. *Parasites & vectors, 12*(1), 503. https://doi.org/10.1186/s13071-019-3757-4
29. Muluneh, C., Hailu, T., & Alemu, G. (2020). Prevalence and Associated Factors of Soil-Transmitted Helminth Infections among Children Living with and without Open Defecation Practices in Northwest Ethiopia: A Comparative Cross-Sectional Study. *The American Journal of Tropical Medicine and Hygiene*, *103*(1), 266–272. https://doi.org/10.4269/ajtmh.19-0704
30. Nasr, N.A., Al-Mekhlafi, H.M., Ahmed, A., Roslan, M.A., & Bulgiba, A. (2013). Towards an effective control programme of soil-transmitted helminth infections among Orang Asli in rural Malaysia. Part 1: Prevalence and associated key factors. *Parasites and Vectors*, 1–12. https://doi.org/doi:10.1186/1756-3305-6-27
31. Parker, M., Allen, T. (2011). Does mass drug administration for the integrated treatment of neglected tropical diseases really work? Assessing evidence for the control of schistosomiasis and soil-transmitted helminths in Uganda. *Health Res Policy Sys* 9(3), 1-20. https://doi.org/10.1186/1478-4505-9-3
32. Parker, M., Allen, T., & Hastings, J. (2008). Resisting Control of Neglected Tropical Diseases: Dilemmas in the Mass Treatment of Schistosomiasis and Soil-Transmitted Helminths in North West Uganda. *Journal of Biosocial Science*, 40(2), 161-181. https://doi.org/10.1017/S0021932007002301
33. Sacolo-Gwebu, H., Kabuyaya, M. & Chimbari, M. (2019). Knowledge, attitudes and practices on schistosomiasis and soil-transmitted helminths among caregivers in Ingwavuma area in uMkhanyakude district, South Africa. *BMC Infectious Diseases*, 19, 734. https://doi.org/10.1186/s12879-019-4253-3
34. Vaz Nery, S., Pickering, A. J., Abate, E., Asmare, A., Barrett, L., Benjamin-Chung, J., Bundy, D., Clasen, T., Clements, A., Colford, J. M., Jr, Ercumen, A., Crowley, S., Cumming, O., Freeman, M. C., Haque, R., Mengistu, B., Oswald, W. E., Pullan, R. L., Oliveira, R. G., Einterz Owen, K., … Brooker, S. J. (2019). The role of water, sanitation and hygiene interventions in reducing soil-transmitted helminths: interpreting the evidence and identifying next steps. *Parasites & vectors*, 12(1), 273. https://doi.org/10.1186/s13071-019-3532-6
35. Watson, J. A., Ensink, J. H. J., Ramos, M., Benelli, P., Holdsworth, E., Dreibelbis, R., & Cumming, O. (2017). Does targeting children with hygiene promotion messages work? The effect of handwashing promotion targeted at children, on diarrhoea, soil-transmitted helminth infections and behaviour change, in low- and middle-income countries. *Tropical Medicine & International Health*, *22*(5), 526–538. https://doi.org/10.1111/tmi.12861

36. Worrell, C. M., Wiegand, R. E., Davis, S. M., Odero, K. O., Blackstock, A., Cuéllar, V. M., Njenga, S. M., Montgomery, J. M., Roy, S. L., & Fox, L. M. (2016). A Cross-Sectional Study of Water, Sanitation, and Hygiene-Related Risk Factors for Soil-Transmitted Helminth Infection in Urban School- and Preschool-Aged Children in Kibera, Nairobi. *PLOS ONE*, 11(3), e0150744. https://doi.org/10.1371/journal.pone.0150744
37. Ziegelbauer K, Speich B, Mausezahl D, Bos R, Keiser J., & Utzinger, J. (2012) Effect of Sanitation on Soil-Transmitted Helminth Infection: Systematic Review and Meta-Analysis. *PLoS Med* 9(1), e1001162. https://doi:10.1371/journal.pmed.1001162

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Rainwater Harvesting Systems in Urban Areas and the Potential Value of Incorporating Community Engagement

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ABSTRACT Rainwater harvesting (RWH) is a water catchment technique used in urban areas globally. RWH has a deep history rooted in indigenous practices and has recently become more accepted in urban areas. The quality and quantity of harvested water depends both on the geographical location of the system with respect to nearby land-use, seasonality, and rainfall intensity, as well as the material of the catchment surface. The economic viability of RWH systems is dependent on initial expenses, operation and maintenance costs, and water fees. Furthermore, government subsidies and clear, concise policy may improve water tank installation, usage, and maintenance. Policy may also help the general public install and use RWH systems through the promotion of education that improves RWH-specific knowledge. While community engagement (CE), stakeholder participation, and increased community knowledge of RWH may potentially yield increases in system use and sustainability, there is a general paucity of this research in peer-reviewed literature. Future studies should explore community engagement within the context of rainwater harvesting systems in urban areas.

INTRODUCTION

Water insecurity is a global issue (Hanasaki et al., 2013). As of 2000, over 1.1 billion people lack access to improved water sources (Zhu et al., 2015). Rainwater harvesting (RWH) is a sustainable and inexpensive method of water collection that reduces unnecessary water use and labor (Campisano et al., 2017; Staddon et al., 2018). RWH is viable for potable and non-potable purposes in urban areas, especially when supported by policy, proper construction materials, and tank maintenance, and may be encouraged through community engagement (CE). However, further research is required to understand the relationship between CE and RWH. This paper explores indigenous RWH practices, community engagement, factors that affect rainwater quality, and barriers and facilitators to RWH.

INDIGENOUS RWH PRACTICES

Historically, the practice of RWH was performed within indigenous communities (Oweis, 2017). As RWH is adopted globally, implementation of RWH should recognize these roots and credit these communities (Rahman et al., 2012). RWH's relevance in many indigenous communities has motivated other water-insecure indigenous populations to implement RWH, leading to reductions in disease and water costs (Gonzalez-Padron et al., 2019). We describe two examples of RWH within indigenous communities below.

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The *Rod Kohi* System

Zia and Hasnain (2000) review RWH methods used by indigenous, Pakistani communities to combat water insecurity. *Rod kohi* water harvesting, the most common regional technique, involves hill torrents that bring water through a network of dams and tunnels and into terraced fields; landowners can use this water for agricultural and domestic purposes. The system is governed by a set of centuries-old regulations detailing water distribution guidelines (Zia & Hasnain, 2000).

The Black Tickle-Domino Inuit Community

Many indigenous communities adopt RWH even if it is not traditional to their roots (Mbilinyi et al., 2005). Using a CE framework, Mercer and Hanrahan (2017) worked with the Black Tickle-Domino Inuit community in Canada to understand RWH and water accessibility. Results show a 17% increase in water consumption and a 41% decrease in water retrieval efforts indicating that CE benefits the implementation of RWH (Mercer & Hanrahan, 2017).

As RWH is further adopted, acknowledging its historical roots is essential (Rahman et al., 2012). Although there is limited research on CE and RWH, understanding the roots of RWH may improve future research on incorporating CE.

COMMUNITY ENGAGEMENT

While research on the value of CE when considering RWH is limited, preliminary findings show promise. Through stakeholder participation and capacity building, CE can improve RWH acceptance and sustainability by allowing system adaptation to specific contexts (Zimmermann et al., 2012). CE can also facilitate collective learning and knowledge generation to promote RWH sustainability (Suleiman et al., 2019).

Educational workshops, focus group discussions, stakeholder participation, and capacity building in RWH design and construction are CE methods that can promote RWH sustainability and increase water access (Mercer & Hanrahan, 2017; Zimmermann et al., 2012; Mwamila et al., 2016; Kim et al., 2016). Educational workshops can improve community member knowledge of RWH and allow individuals to make informed decisions (Zimmermann et al., 2012). Focus groups allow communities to outline water access barriers and their RWH needs and wants (Mercer & Hanrahan, 2017; Zimmermann et al., 2012). To promote CE, RWH systems should be designed in collaboration with local government and community partners, members, and stakeholders (Zimmermann et al., 2012). In a study conducted in Namibia, community members chose the specific system, location, and people tasked with construction, and the community had final say in all aspects of construction, operation, and maintenance (Zimmermann et al., 2012). Studies that explore the effects of CE on RWH have found there is greater ownership, more regular usage, and improvements in long-term sustainability (Mercer & Hanrahan, 2017; Zimmermann et al., 2012) and show that CE is an innovative way to increase access to water (Kim et al., 2016).

RAINWATER QUALITY

Land Use and Spatial Effects

Rainwater microbial and physicochemical quality depends on nearby land use and pollutants (Gwenzi et al., 2015). Rainwater pollution can occur during collection, treatment, storage, and consumption (Meera & Ahammed, 2006). Gwenzi et al. (2015) outline how land uses and geographical differences affect rainwater quality. Rainwater from industrial areas may contain more dangerous contaminants than rainwater from rural areas, likely because rural areas are farther from machine exhaust and industrial waste. Industrialization, traffic emissions, and fossil fuel combustion have deleterious effects on water quality; in Brisbane, Australia, 21% of the incidence of high lead levels in water was attributed to human activity (Gwenzi et al., 2015). However, other studies reveal similar levels of contamination among water samples, regardless of proximity to traffic and industry emissions (Mendez et al., 2010; Farreny et al., 2011), suggesting the effect of land-use activities on rainwater quality depends on the level of nearby pollution (Gwenzi et al., 2015). Using CE principles, such as educational workshops and focus group discussions, may educate community members and policymakers on how to improve, and maintain, rainwater quality.

Seasonality and Rainfall Intensity

There can be seasonal variations in the microbial and physicochemical quality of water from RWH (Meera & Ahammed, 2006; Gwenzi et al., 2015). Seasonal variability in quality can be attributed to length of dry season, rainfall intensity, and wind strength (Meera & Ahammed, 2006; Gwenzi et al., 2015). Areas that have well-

defined wet and dry seasons can experience high variability in water quality as the length of dry periods is positively associated with contamination (Meera & Ahammed, 2006). The seasonal "first-flush" has greater levels of contamination than later rainfall events because longer dry periods allow for increased build-up of contamination on RWH surfaces resulting in a high contaminant load once rainfall occurs (Meera & Ahammed, 2006). "First-flush" also refers to the change in quality from the start of rainfall compared to later during that same event; typically, the contaminant concentration is highest at the onset of rainfall (Gwenzi et al., 2015). Winds can also transfer pollutants into catchment areas on a seasonal basis and affect water quality (Gwenzi et al., 2015).

While CE cannot change seasonal weather patterns, Zimmermann et al. (2012) discuss ways that CE can aid capacity development in the form of education, which can improve the process of collective learning and promote the adaptation of systems to a community's context. If capacity development and knowledge generation included information on seasonal variations in quality, community members may be able to make improved decisions about water use and strategies to mitigate water contamination. While there are optimistic preliminary findings, we advocate for the intentional incorporation of CE into RWH practices.

Roof Characteristics and Water Quality

Roof characteristics like material, weatherability, and age can affect water quality (Meera & Ahammed, 2006; Chapa et al., 2020; Nasif & Roslan, 2015; Bae et al., 2019). Water from metal rooftops is generally of better microbial quality than water collected from other roof materials, likely because the heat produced can destroy bacteria (Meera & Ahammed, 2006). However, water collected from metal rooftops has been associated with hazardous metal levels, likely due to material disintegration (Meera & Ahammed, 2006; Gwenzi et al., 2015). However, other studies do not show these increased metal concentrations (Gwenzi et al., 2015). Roofs with wooden shingles and concrete have also been associated with increased levels of zinc and copper (Gwenzi et al., 2015). Collectively, these studies indicate that unknown confounding variables may affect the concentration of metals in rainwater (Gwenzi et al., 2015).

Roof material can affect water quality, and regular water testing is recommended to ensure potability; when treatment is infeasible, water should be considered non-potable (Rahman et al., 2014). While there is insufficient research on CE in regard to RWH materials, CE may offer value by facilitating material-specific knowledge, capacity development, and opportunities for community members to make informed, locally-appropriate decisions.

Runoff Quantity

Urbanization increases the water stress on cities; implementing RWH can reduce this stress, allow aquifers to recharge, and reduce use of contaminated water (Barthwal et al., 2014). Angrill et al. (2017) analyzed the quantity of rainwater collected from pedestrian areas, traffic roads, and parking lots made from asphalt, concrete, and precast concrete slabs in Spain and found that 89% of rainwater falling on concrete surfaces may be captured for domestic use. Abdulla and Al-Shareef (2008) studied the effects of RWH in Jordan and found that widespread RWH could supply 5.6% of Jordan's total water in 2005. We argue that CE strategies may improve community knowledge on which surfaces are best for rainwater collection and encourage installation of high-yielding, sanitary surfaces in urban areas globally. Further, encouraging community-led projects may result in RWH tailored to specific communities, rather than systems that do not align with local circumstances.

BARRIERS AND FACILITATORS TO RWH

Economic Barriers

Despite limited research on CE specific to RWH financing, the findings of Mercer and Hanrahan (2017) indicate that CE promotes sustainability. Based on review of the literature, we believe that CE geared towards education and capacity development could inform community members of practical investment plans and government financing options.

Economic viability impacts the potential for global implementation of RWH (Farreny et al., 2011; Ward et al., 2013). High initial construction and installation costs can discourage RWH implementation (Temesgen et al., 2016; Sousa et al., 2018; Campisano et al., 2017). Operation, maintenance, and treatment also influence affordability (Roebuck et al., 2011). RWH system design prior to implementation can maximize benefits and minimize costs; for instance, gravity-based, instead of pump-based, systems can reduce expenses (Hafizi Md Lani et al., 2018). Governments can also provide subsidies, low interest rates, and rebates to reduce costs

(Sheikh, 2020; Barthwal et al., 2014).

Despite the barriers, RWH is economically feasible. Gomez & Teixeira (2017) determined that economic feasibility is highest in households with higher water demand, regardless of the size of the system. RWH can also be cost-efficient when implemented in large-scale settings (Morales-Pinzón et al., 2012; Parsons et al., 2010). As water production costs increase, RWH will become more appealing, particularly when coupled with subsidized implementation costs that center the community's financial situation (Gomez & Teixeira, 2017; Farreny et al., 2011).

Tank Maintenance Facilitators

RWH tank maintenance helps ensure clean water. During long-term storage, bacteria concentrations can increase, and tanks can harbor mosquito breeding (Mankad & Greenhill, 2014; Moglia et al., 2016). Mankad and Greenhill (2014) analyzed the tank-cleaning motivations of system owners and found that those who were not intrinsically motivated could benefit from extrinsic motivation like government subsidies. Encouraging stakeholder participation and mutual accountability may also encourage the tank maintenance necessary for safe water.

Political Factors

Political support through public policy legitimizes RWH and increases the likelihood of a project's success, highlighting the need for RWH-specific public policy (Suleiman et al., 2019; Campisano et al., 2017; Ndeketeya & Dundu, 2019). Temesgen et al. (2016) found that clear policy may aid the establishment of RWH as a legitimate practice. Zia and Hasnain (2000) found that subsidies for machinery, like *Rod Kohi*, increase RWH success; the authors encourage federal subsidies and complementary localized policy to promote RWH. While there is limited research, the findings of Zimmerman et al. (2012) and Elder and Gerlak (2019) indicate that intentional incorporation of CE may be able to promote RWH through policy.

CONCLUSION

This literature review highlights the dearth of information regarding the benefits of CE on successful implementation of urban RWH. As RWH becomes more prominent in urban areas (Mankad & Greenhill, 2017; Suleiman et al., 2019), it is wise to model the indigenous CE practices that yield increased water consumption and decreased retrieval efforts (Mercer & Hanrahan, 2017), as well as incorporate knowledge of RWH catchment locations, surfaces, and maintenance to capture high quality water. Focus group discussions, stakeholder participation, and increased ownership via community-led projects are CE principles that will allow for the sustainable implementation of successful RWH catchment systems. The literature shows that CE may foster successful RWH, but further research is required to specifically determine the best methods to employ. In this way, future research should study how best to incorporate CE in RWH in urban areas and the resulting benefits of centering the community's needs, values, and knowledge on rainwater harvesting.

TABLES

TABLE 1. RAINWATER HARVESTING POTENTIAL QUANTITY AND QUALITY FOR VARIOUS SURFACES AND POTENTIAL RATIONALES FOR POLLUTANT LEVELS

Surface	*Quality Rank*[1]	*Quality Rank*[1]	*Potential Quality Rational*
Concrete parking lot	1	2	○ Smooth surface prevents particle deposition[1] ○ Nearby traffic emissions associated with higher pollution[2]
Asphalt road	2	3	○ Cracked asphalt accumulates particulate matter[2] ○ Nearby traffic emissions associated with higher pollution[2]
Pedestrian concrete slabs	3	1	○ Smooth surface prevents particle deposition[1] ○ Lower traffic emissions associated with lower pollution[2]

Angril et al. (2017) 1 ; Gwenzi et al. (2015)[2]

REFERENCES

1. Abdulla, F. A., & Al-Shareef, A. W. (2009). Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, *243*(1–3), 195–207. https://doi.org/10.1016/j.desal.2008.05.013
2. Angrill, S., Petit-Boix, A., Morales-Pinzón, T., Josa, A., Rieradevall, J., & Gabarrell, X. (2017). Urban rainwater runoff quantity and quality – A potential endogenous resource in cities? *Journal of Environmental Management*, *189*, 14–21. https://doi.org/10.1016/j.jenvman.2016.12.027
3. Bae, S., Maestre, J. P., Kinney, K. A., & Kirisits, M. J. (2019). An examination of the microbial community and occurrence of potential human pathogens in rainwater harvested from different roofing materials. *Water Research*, *159*, 406–413. https://doi.org/10.1016/j.watres.2019.05.029
4. Barthwal, S., Chandola-Barthwal, S., Goyal, H., Nirmani, B., & Awasthi, B. (2014). Socio-economic acceptance of rooftop rainwater harvesting – A case study. *Urban Water Journal*, *11*(3), 231–239. https://doi.org/10.1080/1573062X.2013.765489
5. Campisano, A., Butler, D., Ward, S., Burns, M. J., Friedler, E., DeBusk, K., Fisher-Jeffes, L. N., Ghisi, E., Rahman, A., Furumai, H., & Han, M. (2017). Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water Research*, *115*, 195–209. https://doi.org/10.1016/j.watres.2017.02.056
6. Chapa, F., Krauss, M., & Hack, J. (2020). A multi-parameter method to quantify the potential of roof rainwater harvesting at regional levels in areas with limited rainfall data. *Resources, Conservation and Recycling*, *161*, 104959. https://doi.org/10.1016/j.resconrec.2020.104959
7. Dumit Gómez, Y., & Teixeira, L. G. (2017). Residential rainwater harvesting: Effects of incentive policies and water consumption over economic feasibility. *Resources, Conservation and Recycling*, *127*, 56–67. https://doi.org/10.1016/j.resconrec.2017.08.015
8. Elder, A. D., & Gerlak, A. K. (2019). Interrogating rainwater harvesting as Do-It-Yourself (DIY) Urbanism. *Geoforum*, *104*, 46–54. https://doi.org/10.1016/j.geoforum.2019.06.007
9. Farreny, R., Gabarrell, X., & Rieradevall, J. (2011). Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. *Resources, Conservation and Recycling*, *55*(7), 686–694. https://doi.org/10.1016/j.resconrec.2011.01.008
10. Farreny, Ramon, Morales-Pinzón, T., Guisasola, A., Tayà, C., Rieradevall, J., & Gabarrell, X. (2011). Roof selection for rainwater harvesting: Quantity and quality assessments in Spain. *Water Research*, *45*(10), 3245–3254. https://doi.org/10.1016/j.watres.2011.03.036
11. González-Padrón, S. K., Lerner, A. M., & Mazari-Hiriart, M. (2019). Improving Water Access and Health through Rainwater Harvesting: Perceptions of an Indigenous Community in Jalisco, Mexico. *Sustainability*, *11*(18), 4884. https://doi.org/10.3390/su11184884
12. Gwenzi, W., Dunjana, N., Pisa, C., Tauro, T., & Nyamadzawo, G. (2015). Water quality and public health risks associated with roof rainwater harvesting systems for potable supply: Review and perspectives. *Sustainability of Water Quality and Ecology*, *6*, 107–118. https://doi.org/10.1016/j.swaqe.2015.01.006
13. Hafizi Md Lani, N., Yusop, Z., & Syafiuddin, A. (2018). A Review of Rainwater Harvesting in Malaysia: Prospects and Challenges. *Water*, *10*(4), 506. https://doi.org/10.3390/w10040506
14. Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., Kainuma, M., Kanamori, Y., Masui, T., Takahashi, K., & Kanae, S. (2013). A global water scarcity assessment under Shared Socio-economic Pathways – Part 2: Water availability and scarcity. *Hydrology and Earth System Sciences*, *17*(7), 2393–2413. https://doi.org/10.5194/hess-17-2393-2013
15. Imteaz, M. A., & Moniruzzaman, M. (2018). Spatial variability of reasonable government rebates for rainwater tank installations: A case study for Sydney. *Resources, Conservation and Recycling*, *133*, 112–119. https://doi.org/10.1016/j.resconrec.2018.02.010
16. Islam, M. M., Chou, F. N.-F., & Kabir, M. R. (2011). Feasibility and acceptability study of rainwater use to the acute water shortage areas in Dhaka City, Bangladesh. *Natural Hazards*, *56*(1), 93–111. https://doi.org/10.1007/s11069-010-9551-4
17. Mankad, A., & Greenhill, M. (2014). Motivational indictors predicting the engagement, frequency and adequacy of rainwater tank maintenance: MOTIVATION FOR RAINWATER TANK MAINTENANCE. *Water Resources Research*, *50*(1), 29–38. https://doi.org/10.1002/2013WR014338
18. Mbilinyi, B. P., Tumbo, S. D., Mahoo, H. F., Senkondo, E. M., & Hatibu, N. (2005). Indigenous knowledge as decision support tool in rainwater harvesting. *Physics and Chemistry of the Earth, Parts A/B/C*, *30*(11–16), 792–798. https://doi.org/10.1016/j.pce.2005.08.022
19. Meera, V., & Ahammed, M. M. (2006). Water quality of rooftop rainwater harvesting systems: A review. *Journal of Water Supply: Research and Technology-Aqua*, *55*(4), 257–268. https://doi.org/10.2166/aqua.2006.0010
20. Mendez, C., Afshar, B., Kinney, K., Barrett, M., & Kiristis, M. J. (2010). *Effect of Roof Material on Water Quality for Rainwater Harvesting System* (No. 0804830855; pp. 1–36). Texas Water Development Board. https://www.twdb.texas.gov/publications/reports/contracted_reports/doc/0804830855_RainwaterHarvestingV1.pdf
21. Mercer, N., & Hanrahan, M. (2017). "Straight from the heavens into your bucket": Domestic rainwater harvesting as a measure to improve water security in a subarctic indigenous community. *International Journal of Circumpolar Health*, *76*(1), 1312223. https://doi.org/10.1080/22423982.2017.1312223
22. Moglia, M., Gan, K., & Delbridge, N. (2016). Exploring methods to minimize the risk of mosquitoes in rainwater harvesting systems. *Journal of Hydrology*, *543*, 324–329. https://doi.org/10.1016/j.jhydrol.2016.10.010
23. Morales-Pinzón, T., Lurueña, R., Rieradevall, J., Gasol, C. M., & Gabarrell, X. (2012). Financial feasibility and environmental analysis of potential rainwater harvesting systems: A case study in Spain. *Resources, Conservation and Recycling*, *69*, 130–140. https://doi.org/10.1016/j.resconrec.2012.09.014
24. Mwamila, T. B., Han, M. Y., & Kum, S. (2016). Sustainability evaluation of a primary school rainwater demonstration project in Tanzania. *Journal of Water, Sanitation and Hygiene for Development*, *6*(3), 447–455. https://doi.org/10.2166/washdev.2016.186
25. Nasif, M. S., & Roslan, R. (2015). Effect of Utilizing Different Building's Roof Material on Rainwater Harvesting System's Payback Period, Water and Energy Savings, and Carbon Dioxide Emission Reduction. *Applied Mechanics and Materials*, *802*, 593–598. https://doi.org/10.4028/www.scientific.net/AMM.802.593
26. Ndeketeya, A., & Dundu, M. (2019). Maximising the benefits of rainwater harvesting technology towards sustainability in urban areas of South Africa: A case study. *Urban Water Journal*, *16*(2), 163–169. https://doi.org/10.1080/1573062X.2019.1637907
27. Oweis, T. Y. (2017). Rainwater harvesting for restoring degraded dry agro-pastoral ecosystems: A conceptual review of opportunities and constraints in a changing climate. *Environmental Reviews*, *25*(2), 135–149. https://doi.org/10.1139/er-2016-0069
28. Parsons, D., Goodhew, S., Fewkes, A., & De Wilde, P. (2010). The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. *Urban Water Journal*, *7*(4), 257–265. https://doi.org/10.1080/1573062X.2010.500331
29. Rahman, A., Keane, J., & Imteaz, M. A. (2012a). Rainwater harvesting in Greater Sydney: Water savings, reliability and economic benefits. *Resources, Conservation and Recycling*, *61*, 16–21. https://doi.org/10.1016/j.resconrec.2011.12.002
30. Rahman, A., Keane, J., & Imteaz, M. A. (2012b). Rainwater harvesting in Greater Sydney: Water savings, reliability and economic benefits. *Resources, Conservation and Recycling*, *61*, 16–21. https://doi.org/10.1016/j.resconrec.2011.12.002
31. Rahman, S., Khan, M. T. R., Akib, S., Din, N. B. C., Biswas, S. K., & Shirazi, S. M. (2014). Sustainability of Rainwater Harvesting System in terms of Water Quality. *The Scientific World Journal*, *2014*, 1–10. https://doi.org/10.1155/2014/721357

32. Roebuck, R. M., Oltean-Dumbrava, C., & Tait, S. (2011). Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom: Cost performance of domestic rainwater harvesting systems. *Water and Environment Journal*, *25*(3), 355–365. https://doi.org/10.1111/j.1747-6593.2010.00230.x
33. Sheikh, V. (2020). Perception of domestic rainwater harvesting by Iranian citizens. *Sustainable Cities and Society*, *60*, 102278. https://doi.org/10.1016/j.scs.2020.102278
34. Sousa, V., Silva, C. M., & Meireles, I. C. (2018). Technical-financial evaluation of rainwater harvesting systems in commercial buildings–case ase studies from Sonae Sierra in Portugal and Brazil. *Environmental Science and Pollution Research*, *25*(20), 19283–19297. https://doi.org/10.1007/s11356-017-0648-0
35. Staddon, C., Rogers, J., Warriner, C., Ward, S., & Powell, W. (2018). Why doesn't every family practice rainwater harvesting? Factors that affect the decision to adopt rainwater harvesting as a household water security strategy in central Uganda. *Water International*, *43*(8), 1114–1135. https://doi.org/10.1080/02508060.2018.1535417
36. Suleiman, L., Olofsson, B., Saurí, D., Palau-Rof, L., García Soler, N., Papasozomenou, O., & Moss, T. (2020). Diverse pathways—common phenomena: Comparing transitions of urban rainwater harvesting systems in Stockholm, Berlin and Barcelona. *Journal of Environmental Planning and Management*, *63*(2), 369–388. https://doi.org/10.1080/09640568.2019.1589432
37. Temesgen, T., Han, M., Park, H., & Kim, T. (2016). Policies and Strategies to Overcome Barriers to Rainwater Harvesting for Urban Use in Ethiopia. *Water Resources Management*, *30*(14), 5205–5215. https://doi.org/10.1007/s11269-016-1479-3
38. Ward, S., Barr, S., Memon, F., & Butler, D. (2013). Rainwater harvesting in the UK: Exploring water-user perceptions. *Urban Water Journal*, *10*(2), 112–126. https://doi.org/10.1080/1573062X.2012.709256
39. Zhu, Q., Li, Y., & Tang, X. (2015). Why Harvesting Rainwater—China's Experiences. In Q. Zhu, J. Gould, Y. Li, & C. Ma (Eds.), *Rainwater Harvesting for Agriculture and Water Supply* (pp. 3–42). Springer Singapore. https://doi.org/10.1007/978-981-287-964-6_1
40. Zia, S. M., & Hasnain, T. (2000). *Water Harvesting in Mountain Areas of Pakistan:* Sustainable Development Policy Institute. https://www.jstor.org/stable/resrep00602.3
41. Zimmermann, M., Jokisch, A., Deffner, J., Brenda, M., & Urban, W. (2012). Stakeholder participation and capacity development during the implementation of rainwater harvesting pilot plants in central northern Namibia. *Water Supply*, *12*(4), 540–548. https://doi.org/10.2166/ws.2012.024