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Comparative Analysis of Pre- and Post-COVID-19 Determinants of Basic Handwashing Facility in Bangladesh: A GLMM Study Using BDHS 2017-18 and 2022 Data

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Abstract

This study sought to identify key determinants of basic handwashing facility in Bangladesh before and after COVID-19. Data from the Bangladesh Demographic and Health Surveys (BDHS) for 2017–18 and 2022 were analyzed using a Generalized Linear Mixed Model (GLMM) that accounted for fixed effects and cluster-level variations. The prevalence of basic handwashing facility increased from 41.3% to 59.7%. Before COVID-19, significant determinants included division, place of residence, the sex and age of the household head, household size, partner's education, working status, media exposure, and the age and education of mothers with children under five. After the pandemic, critical factors shifted to the household head's age, partner's education, media exposure, women empowerment, wealth index, and the age and education of mothers. These findings suggest that the pandemic accelerated improvements in hand hygiene, emphasizing the need for targeted public health interventions informed by socio-demographic factors.

Keywords*:* Handwashing facility, COVID-19, GLMM, BDHS

I. Introduction

COVID-19, also known as the coronavirus disease 2019, is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). First identified in December 2019 in Wuhan, China, it rapidly spread across the globe, leading to a worldwide pandemic. The COVID-19 pandemic significantly impacted low- and middle-income countries, and Bangladesh is one of them. In Bangladesh, the first cases were confirmed on March 8, 2020[1]. The COVID-19 pandemic underscored the critical importance of hand hygiene in preventing the spread of the virus. Regular handwashing with soap and water or using alcohol-based hand sanitizers became one of the primary recommendations from health authorities worldwide. Studies have shown that proper hand hygiene can significantly reduce the transmission of COVID-19[2]. The pandemic also highlighted disparities in access to hand hygiene facilities, especially in low- and middle-income countries. Many people lacked basic handwashing facility at home, contributing to the virus's spread. In response, there was a global push to improve hand hygiene practices and infrastructure, including installing handwashing stations in public places, healthcare facilities, and promoting hand hygiene education campaigns. These efforts were crucial in controlling the spread of COVID-19[3].

Studying handwashing facilities before and after COVID-19 in Bangladesh is necessary to understand public health dynamics and improve future health outcomes. It provides insights into the effectiveness of hygiene interventions during the pandemic and reveals shifts in behavior that can guide future campaigns. Highlighting access disparities ensures resources and infrastructure improvements are allocated where they are most needed. The findings can inform policymakers in developing targeted interventions and policies for long-term hand hygiene improvements, ultimately leading to a healthier community and better-prepared health systems for future challenges.

Despite the recognized importance of hand hygiene, there is limited research comparing the determinants of access to basic handwashing facility in Bangladesh before and after the pandemic. Reflecting conditions before the pandemic, Sarker et al. documented disparities in the prevalence of handwashing with antimicrobial agents and identified potential factors driving socio-economic inequalities in this practice[4]. Hasan et al. examined the relationship between water, sanitation, handwashing facilities, and child undernutrition, while also providing essential insights into infrastructural factors such as facility availability and quality that establish a baseline for understanding pre-pandemic access levels[5]. Ahmed and Yunus evaluated the prevalence and determinants of household handwashing practices in Bangladesh by integrating MICS 2019 data with confirmed COVID-19 case reports, thereby comparing national handwashing behaviors with emerging trends in the virus's spread[6]. Potential factors affecting handwashing facility were also pinpointed in a work of Endalew et al[7]. Binary logistic regression model was used by Ahmed et al. to investigate the situation of water, sanitation and handwashing facilities for households in Bangladesh[8]. Gaffan et al. also used binary logistic regression model to identify potential determinants of water, sanitation, and handwashing facilities[9].

Most studies have examined either the pre-pandemic or pandemic phase independently, leaving a gap in understanding how these factors have evolved over time[4-7]. Moreover, existing analyses often fail to account for the correlated nature of survey data from two-stage stratified cluster sampling designs and rarely use advanced methods

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like GLMM to incorporate both fixed socio-demographic influences and random cluster effects[8-9]. This study has addressed these gaps by analyzing BDHS data from 2017–18 and 2022 using a GLMM approach. The BDHS provides nationally representative data on various aspects of population health and demographics in Bangladesh. Given its two-stage stratified cluster sampling approach, responses within the same cluster tend to be correlated. To ensure consistent and efficient parameter estimates, this shady has used GLMM to incorporate both random effect and fixed effects[10]. It aimed to provide robust insights into the evolving determinants of handwashing facility availability in Bangladesh, thereby informing the development of targeted public health interventions.

II. Data and Methods

Data sources

Secondary data from BDHS 2017-18 (before COVID-19) and 2022 (after COVID-19) have been used in this study. Both surveys employed two-stage stratified sampling. In 2017-18, 675 clusters were selected, with 30 households per cluster, totaling 20,250 households; three clusters were eliminated due to natural calamities, resulting in a reduced sample size of 20,160 households. After removing missing data, there were 13,392 usable observations from the BDHS 2017-18 dataset.

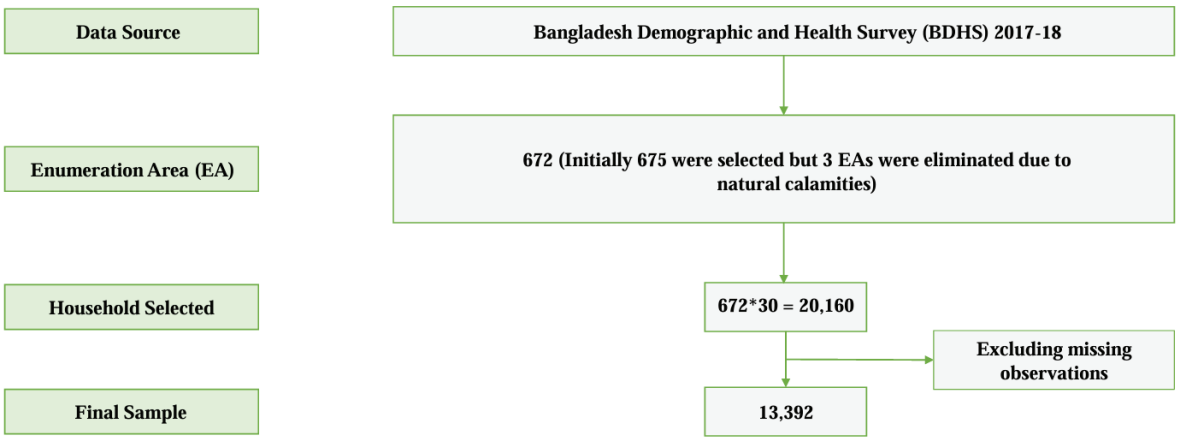

Fig. 1. Flowchart of sample selection from the BDHS 2017-18 dataset.

In 2022, the survey was carried out initially in 675 clusters, each consisting of 45 households. One rural cluster in Cox's Bazar, Chittagong, was excluded due to security concerns. As a result, a total of 30,330 residential households were selected. After excluding missing data, 15,610 valid observations remained from the BDHS 2022 dataset. The survey focused on ever-married women aged 15-49 years[11-12].

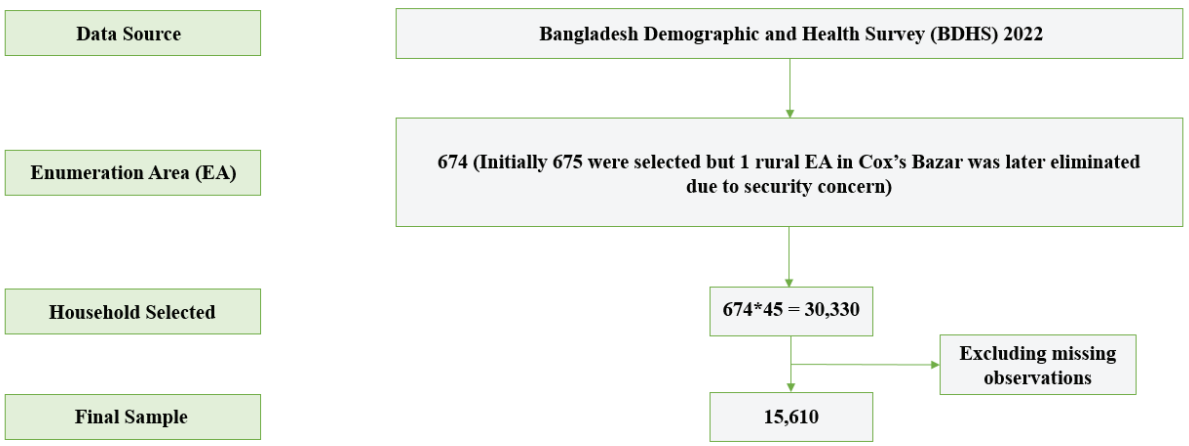

Fig. 2. Flowchart of sample selection from the BDHS 2022 dataset.

Dependent variable

The study has focused on household access to basic handwashing facility pre- and post-COVID-19. According to the WHO/UNICEF Joint Monitoring Programme (JMP) guidelines, handwashing facility is determined as basic level if handwashing facility is available on premises with soap and water[13]. To create the dependent variable (basic handwashing facility), a dichotomization has been performed: if the service level was basic, it has been labeled as "yes"; otherwise, it has been labeled as "no".

Covariates

Based on literature reviews[4-9,14-19], this study considers several covariates, including geographic division (Barisal, Chittagong, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur, and Sylhet), place of residence (urban or rural), and household head characteristics such as sex (male or female) and age (< 30, $30-39$, $40-49$, $50-59$, and ≥ 60). Other factors include household size (≤ 5 or > 5), partner's education level (no education, primary, secondary, or higher), working status (yes or no), media exposure (exposed or non-exposed), migration status (migrant or non-migrant), and women's empowerment (yes or no). Additionally, wealth index (poor, middle, or rich), presence of children aged 5 and under (yes or no), mother's age of under 5 children (≤ 30 or > 30), and mother's education level of under 5 children (no education, primary, secondary, or higher) have been analyzed. Media exposure is defined as reading magazines or newspapers, listening to the radio, or watching television at least once a week. Migration is determined by whether individuals have lived in their current home for less than two years. Women empowerment is classified based on involvement in decisions regarding healthcare, major household purchases, visiting relatives, and control over their husband's earnings—participation in any of these places them in the "yes" category. The original five-category wealth index has been consolidated into three: poor (poorest and poorer), middle, and rich (richer and richest).

Regression model

To account for the correlation among the observations within each cluster, the Generalized Linear Mixed Model (GLMM) for binary response has been utilized in this investigation. Unlike the Generalized Linear Model (GLM), random effects have been incorporated alongside fixed effects to obtain more accurate estimates of the regression parameters. GLMMs extend GLMs to handle correlated responses within the same group, which violates the independence assumption. GLMM is considered a superior method for analyzing data that exhibits clustering effect[20].

Let, y_{ip} be the binary response collected from the p^{th} individual in the i^{th} cluster; $p = 1, 2, ..., n_i$ and $i = 1, 2, \dots, q$. Also, let, $x_{ip} = (x_{ip1}, x_{ip2}, \dots, x_{ipk})'$ is the $k \times 1$ vector of covariates for the p^{th} individual in the i^{th} cluster, and $\beta = (\beta_1, \beta_2, \dots, \beta_k)'$ be the $k \times 1$ vector of coefficients for the corresponding k covariates. The random effect term for the i^{th} cluster, u_i, is assumed to be normally distributed with zero mean and variance σ_u^2. The GLMM for binary response for the p^{th} individual in the i^{th} cluster can be written as, $g(\mu_{ip}) = x_{ip}'\beta + u_i = \eta_{ip}$, where $\mu_{ip} = E(y_{ip} \mid u_i)$.The intra-cluster correlation (ICC) for binary response denoted by ρ is defined as[21], $\rho = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\pi^2}{3}}$. Detailed information about the regression model is provided in the Appendix.

III. Results

Univariate findings

Table 1 shows that in 2017-18 (before COVID-19), 41.3% of the 13,392 observations had access to basic handwashing facility, increasing to 59.7% in 2022 (after COVID-19) among 15,610 observations. The highest number of respondents was from Dhaka (16.2% in 2017-18 and 15.7% in 2022), and the lowest from Sylhet (9.4% and 10.2%, respectively). A larger proportion resided in rural areas (61.9% in 2017-18 and 64.6% in 2022). Most household heads were male (88.5% in 2017-18 and 88.6% in 2022) and aged 40-49 years (26.5% and 28.9%, respectively). The majority had a household size of 5 or fewer (70.9% in 2017-18 and 74.7% in 2022). Among partners of respondents 31.0% had secondary education in 2017-18 (highest) and 16.6% had higher education (lowest), while in 2022, 32.2% had primary education (highest) and 16.8% had higher education (lowest). Additionally, in 2017-18 and 2022, 50.3% and 33.2% of respondents were working, 65.3% and 58.4% had media exposure, 89.2% and 90.6% were non-migrants. Women empowerment was 92.7% in 2017-18 and 89.1% in 2022. Respondents from poor families were 33.9% in 2017-18 and 37.9% in 2022, middle-class were 20.0% and 19.8%, and rich were 46.0% and 42.3%, respectively. Nearly half had prior aged 5 or under (46.6% in 2017-18 and 47.9% in 2022). Among these mothers, 56.9% in 2017-18 and 60.0% in 2022 were older than 30. Educational levels among these mothers were: illiterate (14.3% in 2017-18 and 16.3% in 2022), primary (33.2% and 28.4%), secondary (37.6% and 34.1%), and higher education (12.9% and 23.2%).

Table 1. Univariate analysis of dependent and independent variables.

Variable	Before COVID-19 (2017-18) (n=13392) Frequency (%)	After COVID-19 (2022) (n=15610) Frequency (%)
Basic Handwashing Facility		
Yes	5525 (41.3)	9324 (59.7)
No	7867 (58.7)	6286 (40.3)
Division		
Barishal	1534 (10.1)	1662 (10.6)
Chattogram	1909 (14.3)	2239 (14.3)
Dhaka	2171 (16.2)	2450 (15.7)
Khulna	1829 (13.7)	2060 (13.2)
Mymensingh	1502 (11.2)	1690 (10.8)
Rajshahi	1762 (13.2)	2056 (13.2)
Rangpur	1603 (12.0)	1860 (11.9)
Sylhet	1262 (9.4)	1593 (10.2)
Place of Residence		
Urban	5099 (38.1)	5528 (35.4)
Rural	8293 (61.9)	10082 (64.6)
Sex of Household Head		
Male	11858 (88.5)	13827 (88.6)
Female	1534 (11.5)	1783 (11.4)
Age of Household Head		
<30	2311 (17.3)	2115 (13.5)
30-39	3052 (22.8)	3710 (23.8)
40-49	3543 (26.5)	4506 (28.9)
50-59	2412 (18.0)	3002 (19.2)
≥60	2074 (15.5)	2277 (14.6)
Household Size		
≤5	9501 (70.9)	11653 (74.7)
>5	3891 (29.1)	3957 (25.3)
Partner's Education Level		
No Education	3035 (22.7)	3594 (23.0)
Primary	4312 (32.2)	4583 (29.4)
Secondary	3791 (28.3)	4836 (31.0)
Higher	2254 (16.8)	2597 (16.6)
Working Status		
Yes	6737 (50.3)	5177 (33.2)
No	6655 (49.7)	10433 (66.8)
Media Exposure		
Exposed	8751 (65.3)	9112 (58.4)
Non-exposed	4641 (34.7)	6498 (41.6)
Migration		
Migrant	1449 (10.8)	1464 (9.4)
Non-migrant	11943 (89.2)	14146 (90.6)
Woman Empowerment		
Yes	12413 (92.7)	13912 (89.1)
No	979 (7.3)	1698 (10.9)
Wealth Index		
Poor	4545 (33.9)	5912 (37.9)
Middle	2681 (20.0)	3089 (19.8)
Rich	6166 (46.0)	6609 (42.3)
Children Aged 5 and Under in Household		
Yes	6241 (46.6)	7483 (47.9)
No	7151 (53.4)	8127 (52.1)

Mother's Age of Under 5 Children		
≤30	5774 (43.1)	6250 (40.0)
>30	7618 (56.9)	9360 (60.0)
Mother's Education of Under 5 Children		
No Education	2187 (16.3)	2233 (14.3)
Primary	4447 (33.2)	4430 (28.4)
Secondary	5036 (37.6)	5327 (34.1)
Higher	1722 (12.9)	3620 (23.2)

Bivariate findings

Bivariate analysis is a fundamental quantitative method used to identify the empirical relationship between two distinct variables. Cross-tabulation, a key technique in bivariate analysis, organizes data in a tabular format to explore connections between variables. The results of the bivariate analysis for basic handwashing facility are provided in Table 2.

Table 2. Bivariate frequency distribution of basic handwashing facility among the different categories of selected covariates, along with p-value.

Explanatory Variables	Handwashing Facility Before COVID-19 (2017-18)			Handwashing Facility After COVID-19 (2022)		
	Yes, n (%)	No, n (%)	p-value	Yes, n (%)	No, n (%)	p-value
Division			0.001			0.153
Barisal	331 (24.4)	1023 (75.6)		861 (51.8)	801 (48.2)	
Chittagong	865 (45.3)	1044 (54.7)		1417 (63.3)	822 (36.7)	
Dhaka	1126 (51.9)	1045 (48.1)		1536 (62.7)	914 (37.3)	
Khulna	717 (39.2)	1112 (60.8)		1275 (61.9)	785 (38.1)	
Mymensingh	452 (30.1)	1050 (69.9)		862 (51.0)	828 (49.0)	
Rajshahi	791 (44.9)	971 (55.1)		1258 (61.2)	798 (38.8)	
Rangpur	743 (46.4)	860 (53.6)		1203 (64.7)	657 (35.3)	
Sylhet	500 (39.6)	762 (60.4)		912 (57.3)	681 (42.7)	
Place of Residence			< 0.001			< 0.001
Urban	2923 (57.3)	2176 (42.7)		3934 (71.2)	1594 (28.8)	
Rural	2602 (31.4)	5691 (68.6)		5390 (53.5)	4692 (46.5)	
Sex of Household Head			0.027			0.005
Male	4852 (40.9)	7006 (59.1)		8204 (59.3)	5623 (40.7)	
Female	673 (43.9)	861 (56.1)		1120 (62.8)	663 (37.2)	
Age of Household Head			< 0.001			< 0.001
<30	730 (31.6)	1581 (68.4)		1085 (51.3)	1030 (48.7)	
30-39	1525 (43.0)	2018 (57.0)		2179 (58.7)	1531 (41.3)	
40-49	1085 (45.0)	1327 (55.0)		2744 (60.9)	1762 (39.1)	
50-59	911	1163		1905	1097	

	(43.9)	(56.1)		(63.5)	(36.5)	
≥60	5525	7867		1411	866	
	(41.3)	(58.7)		(62.0)	(38.0)	
Household Size			0.007			0.021
≤5	3850	5651		6899	4754	
	(40.5)	(59.5)		(59.2)	(40.8)	
>5	1675	2216		2425	1532	
	(43.0)	(57.0)		(61.3)	(38.7)	
Partner's Education Level			< 0.001			< 0.001
No Education	711	2324		1696	1898	
	(23.4)	(76.6)		(47.2)	(52.8)	
Primary	1298	3014		2331	2252	
	(30.1)	(69.9)		(50.9)	(49.1)	
Secondary	1861	1930		3100	1736	
	(49.1)	(50.9)		(64.1)	(35.9)	
Higher	1655	599		2197	400	
	(73.4)	(26.6)		(84.6)	(15.4)	
Working Status			< 0.001			< 0.001
Yes	2250	4487		2916	2261	
	(33.4)	(66.6)		(56.3)	(43.7)	
No	3275	3380		6408	4025	
	(49.2)	(50.8)		(61.4)	(38.6)	
Media Exposure			< 0.001			< 0.001
Exposed	4462	4289		6096	3016	
	(51.0)	(49.0)		(66.9)	(33.1)	
Non-exposed	1063	3578		3228	3270	
	(22.9)	(77.1)		(49.7)	(50.3)	
Migration			< 0.001			0.001
Migrant	712	737		932	532	
	(49.1)	(50.9)		(63.7)	(36.3)	
Non-migrant	4813	7130		8392	5754	
	(40.3)	(59.7)		(59.3)	(40.7)	
Woman Empowerment			0.249			< 0.001
Yes	5104	7309		8398	5514	
	(41.1)	(58.9)		(60.4)	(39.6)	
No	421	558		926	772	
	(43.0)	(57.0)		(54.5)	(45.5)	
Wealth Index			0.001			< 0.001
Poor	1827	2718		2171	3741	
	(40.2)	(59.8)		(36.7)	(63.3)	
Middle	1028	1653		1722	1367	
	(38.3)	(61.7)		(55.7)	(44.3)	
Rich	2670	3496		5431	1178	
	(43.3)	(56.7)		(82.2)	(17.8)	
Children Aged 5 and Under in Household			< 0.001			< 0.001
Yes	2448	3793		4399	3084	
	(39.2)	(60.8)		(58.8)	(41.2)	
No	3077	4074		4925	3202	
	(43.0)	(57.0)		(60.6)	(39.4)	
Mother's Age of Under 5 Children			< 0.001			< 0.001
≤30	2184	3590		3551	2699	
	(37.8)	(62.2)		(56.8)	(43.2)	
>30	3341	4277		5773	3587	
	(43.9)	(56.1)		(61.7)	(38.3)	
Mother's Education of Under 5 Children			< 0.001			< 0.001
No Education	542	1645		1045	1188	

	(24.8)	(75.2)	(46.8)	(53.2)
Primary	1343	3104	2172	2258
	(30.2)	(69.8)	(49.0)	(51.0)
Secondary	2346	2690	3192	2135
	(46.6)	(53.4)	(59.9)	(40.1)
Higher	1294	428	2915	705
	(75.1)	(24.9)	(80.5)	(19.5)

Table 2 reveals that, before COVID-19(2017-18), division, place of residence, sex and age of household head, household size, partner's education level, respondent's working status, media exposure, migration status, wealth index, presence of children aged 5 and under, and the mother's age and education of these children had significant association with basic handwashing facility while after COVID-19(2022), basic handwashing facility was significantly associated with the place of residence, household head's sex and age, household size, partner's education level, respondent's working status, media exposure, migration status, women empowerment, wealth index, presence of children aged 5 and under, and the mother's age and education of these children. All of these associations are found significant as the corresponding p-values are less than $\alpha=0.05$.

Regression findings

To account for clustering effects, a mixed-effect logistic regression model within the GLMM framework has been applied. This model includes a random effect for each cluster, assuming uniform baseline odds of the event within a cluster while allowing variation between clusters. Significant explanatory variables identified in the bivariate analysis have been incorporated into the GLMMs. Table 3 presents the odds ratios (OR), 95% confidence intervals (CI), and p-values derived from the mixed-effect logistic regression analysis of basic handwashing facility.

Table 3. Odds ratios (OR), 95% confidence intervals (CI), and p-values obtained from mixed-effect logistic regression for analyzing basic handwashing facility.

Covariates	Handwashing Facility Before COVID-19 (2017-18)			Handwashing Facility After COVID-19 (2022)		
	OR	p-value	95% CI	OR	p-value	95% CI
Intercept	0.047	<0.001	(0.034, 0.066)	0.324	<0.001	(0.256, 0.409)
Division						
Barisal	-	-	-	-	-	-
Chittagong	3.193	<0.001	(2.333, 4.369)	-	-	-
Dhaka	3.383	<0.001	(2.482, 4.611)	-	-	-
Khulna	2.316	0.002	(1.693, 3.169)	-	-	-
Mymensingh	1.982	0.033	(1.426, 2.755)	-	-	-
Rajshahi	3.811	<0.001	(2.780, 5.225)	-	-	-
Rangpur	5.058	<0.001	(3.675, 6.962)	-	-	-
Sylhet	2.989	<0.001	(2.134, 4.187)	-	-	-
Place of Residence						
Urban	-	-	-	-	-	-
Rural	0.433	<0.001	(0.375, 0.500)	0.892	0.111	(0.776, 1.025)
Sex of Household Head						
Male	-	-	-	-	-	-
Female	1.336	0.016	(1.167, 1.529)	1.050	0.450	(0.925, 1.193)
Age of Household Head						
<30	-	-	-	-	-	-
30-39	1.262	0.001	(1.094, 1.456)	1.108	0.133	(0.972, 1.264)
40-49	1.502	0.009	(1.276, 1.767)	1.230	0.008	(1.056, 1.433)
50-59	1.917	<0.001	(1.607, 2.287)	1.452	0.020	(1.232, 1.712)
≥60	1.654	<0.001	(1.400, 1.954)	1.169	0.054	(0.997, 1.370)
Household Size						
≤5	-	-	-	-	-	-
>5	1.323	0.001	(1.197, 1.462)	1.080	0.115	(0.981, 1.189)
Partner's Education Level						
No Education	-	-	-	-	-	-

Primary	1.254	<0.001	(1.108, 1.419)	0.969	0.573	(0.870, 1.080)
Secondary	2.303	<0.001	(2.020, 2.626)	1.077	0.212	(0.957, 1.211)
Higher	1.670	<0.001	(3.218, 4.561)	1.670	<0.001	(1.406, 1.985)
Working Status						
No	-	-	-	-	-	-
Yes	0.679	<0.001	(0.619, 0.745)	0.967	0.311	(0.878, 1.043)
Media Exposure						
Non-exposed	-	-	-	-	-	-
Exposed	1.811	<0.001	(1.639, 2.001)	1.147	0.001	(1.054, 1.248)
Migration						
Non-migrant	-	-	-	-	-	-
Migrant	0.968	0.648	(0.839, 1.117)	0.901	0.151	(0.783, 1.038)
Woman Empowerment						
No	-	-	-	-	-	-
Yes	-	-	-	1.165	0.014	(1.032, 1.316)
Wealth Index						
Poor	-	-	-	-	-	-
Middle	0.904	0.107	(0.799, 1.029)	1.952	<0.001	(1.763, 2.162)
Rich	1.009	0.868	(0.902, 1.128)	5.888	<0.001	(5.276, 6.572)
Children Aged 5 and Under in Household						
No	-	-	-	-	-	-
Yes	0.963	0.426	(0.877, 1.058)	1.061	0.184	(0.973, 1.156)
Mother's Age of Under 5 Children						
≤30	-	-	-	-	-	-
>30	1.689	<0.001	(1.505, 1.896)	1.182	0.002	(1.061, 1.316)
Mother's Education of Under 5 Children						
No Education	-	-	-	-	-	-
Primary	1.404	0.003	(1.224, 1.610)	1.051	0.427	(0.929, 1.189)
Secondary	2.232	<0.001	(1.923, 2.591)	1.288	<0.001	(1.127, 1.471)
Higher	4.108	<0.001	(3.331, 5.067)	1.990	<0.001	(1.681, 2.355)
Variance Component		**0.3856**			**0.4357**	
ICC		**0.105**			**0.117**	

Table 3 illustrates that various factors, including division, place of residence, sex, and age of the household head, household size, partner's education level, employment status, media exposure, along with the mother's age and education of under-5 children, were significantly associated with the presence of basic handwashing facility before COVID-19. Households in Rangpur had 405.8% higher odds of having basic handwashing facility compared to those in Barisal. Similarly, households in Chittagong, Dhaka, Khulna, Mymensingh, Rajshahi, and Sylhet exhibited increased odds by 219.3%, 238.3%, 131.6%, 98.2%, 281.1%, and 198.9%, respectively, compared to Barisal. Rural households faced a 56.7% reduction in odds compared to urban households. Female-headed households had 33.6% greater odds than those headed by males. The likelihood of having basic handwashing facility rose with the age of the household head, with households led by individuals aged 30-39, 40-49, 50-59, and 60 years or older exhibiting 26.2%, 50.2%, 91.7%, and 65.4% greater odds, respectively, compared to households with heads younger than 30 years. Larger households, with more than five members, showed 32.3% increased odds compared to smaller households with five or fewer members. The education level of the partner played a crucial role, with primary, secondary, and higher education levels contributing to 25.4%, 130.3%, and 283.1% increased odds, respectively, compared to no education. Working individuals had 32.1% lower odds, while media exposure improved the odds by 81.1%. Mothers of under-5 children aged above 30 years were 68.9% more likely to have basic handwashing facility, and those with primary, secondary, and higher education levels showed 40.4%, 123.2%, and 310.8% increased odds, respectively, compared to mothers without education. The ICC value of 0.105 suggests that 10.5% of the variance in handwashing facility availability stemmed from inter-cluster differences, while the remaining 89.5% was attributable to individual differences within clusters. Figure 3 shows the forest plot of odds ratios for the determinants of handwashing facility before COVID-19. The plot emphasizes the factors that exhibit significant association.

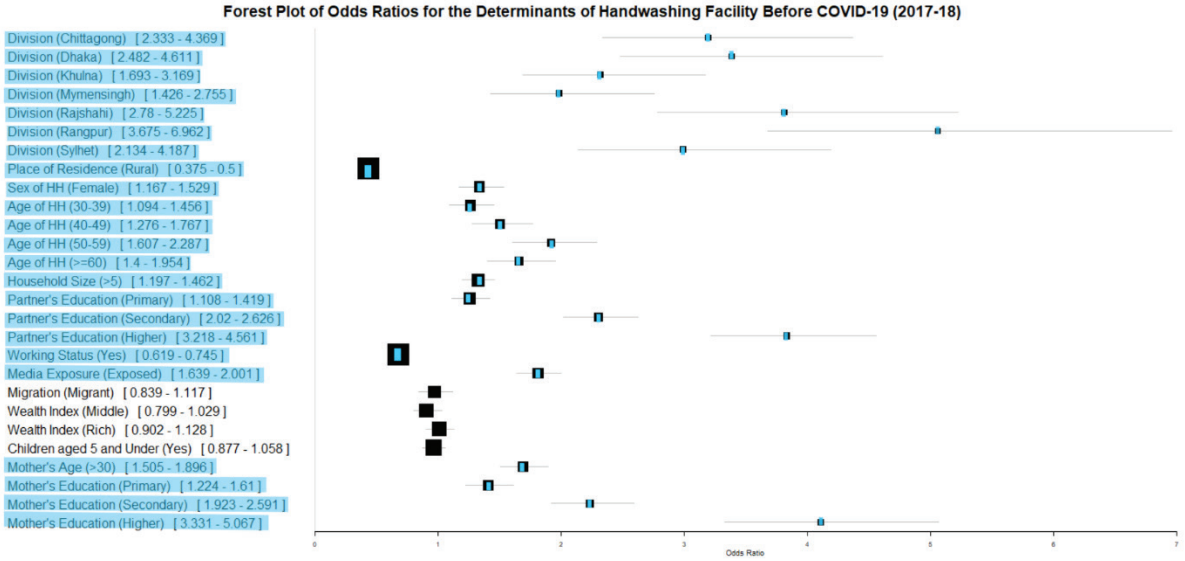

Fig. 3. Forest Plot of Odds Ratios for the Determinants of Handwashing Facility Before COVID-19.

After COVID-19, significant associations with basic handwashing facility were observed for factors such as the age of the household head, partner's education level, media exposure, women empowerment, wealth index, mother's age, and education of under-5 children. Households with heads aged 40-49 and 50-59 years demonstrated 23.0% and 45.2% greater odds, respectively, compared to households with heads younger than 30 years. Households where the partner attained higher education levels exhibited 67.0% improved odds compared to no education. Media exposure led to a 14.7% increase in odds, and empowered women had 16.5% higher odds of accessing basic handwashing facility. Middle-class households experienced a 95.2% increase in odds compared to poor households, while wealthy households had 488.8% higher odds. Mothers of under-5 children aged above 30 years exhibited 18.2% greater odds of having basic handwashing facility, while mothers with secondary and higher education levels demonstrated 28.8% and 99.0% greater odds, respectively, compared to those without education. The ICC value of 0.117 indicates that 11.7% of the variation in handwashing facility availability was due to inter-cluster differences, with the remaining 88.3% arising from individual differences within clusters. Figure 4 shows the forest plot of odds ratios for the determinants of handwashing facility after COVID-19. The plot highlights the factors demonstrating significant association.

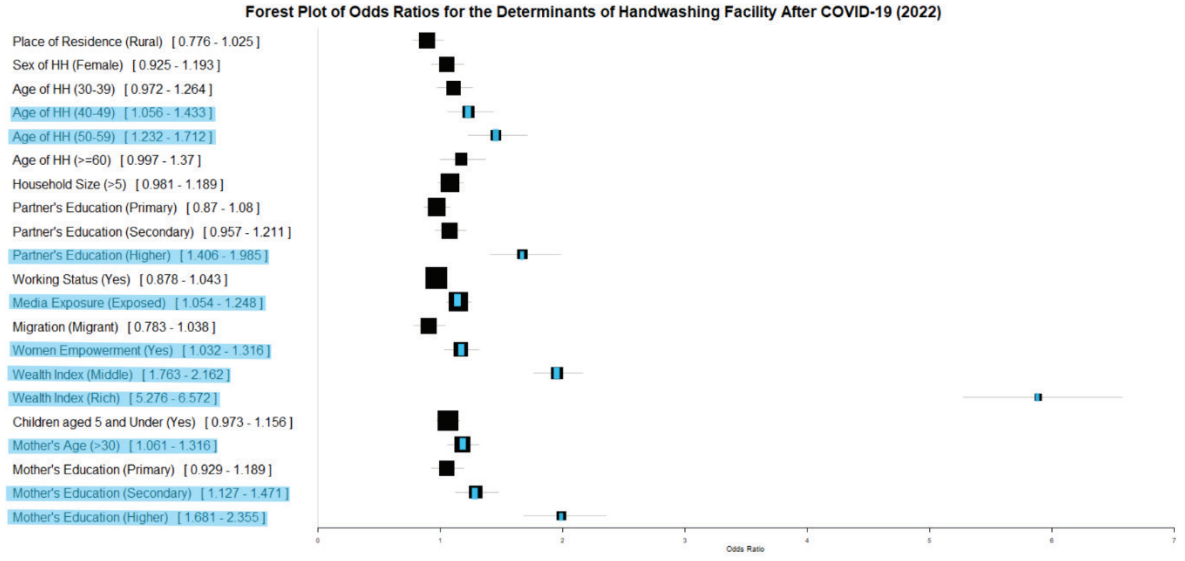

Fig. 4. Forest Plot of Odds Ratios for the Determinants of Handwashing Facility After COVID-19.

Validation of the mixed-effect logistic regression model was achieved through comparison with the fixed-effect model using AIC values and likelihood ratio tests (LRT). Before COVID-19, the mixed-effect model had a lower AIC (14355.3) compared to the fixed-effect model (14717.0), with an LRT p-value of less than 0.001, confirming the mixed-effect model's superior performance. Similarly, after COVID-19, the mixed-effect model demonstrated better performance

with a lower AIC (17373.3) compared to the fixed-effect model (17844.0), and an LRT p-value of less than 0.001.

IV. Discussion

The findings reveal notable advancements in the availability of basic handwashing facility in Bangladesh across various socio-demographic groups before and after COVID-19. The analysis highlights the pivotal role of socio-economic factors such as education, wealth, and media exposure in enhancing access to handwashing facility. Higher education levels among partners and mothers of under-5 children consistently contributed to improved odds of having basic handwashing facility, underscoring the importance of educational attainment in promoting hygiene practices. The results also expose significant rural-urban disparities, with rural households continuing to encounter considerable obstacles. This underscores the need for targeted initiatives to address these inequities, particularly in regions with lower odds of access, such as Barisal. The role of women empowerment emerged as a crucial factor after COVID-19, aligning with global efforts that emphasize the importance of women's agency in making household health and sanitation decisions. Furthermore, the wealth index underlines stark inequalities, revealing that middle and rich households are substantially better positioned compared to poor households. The variations attributed to cluster-level differences, as indicated by ICC values, highlight the importance of community and contextual influences. However, the majority of the variation arises from individual-level differences, pointing to the necessity of combining community-wide strategies with household-specific interventions. Finally, the validation of the mixed-effect logistic regression model confirms its reliability and suitability for this analysis, as evidenced by its superior performance over the fixed-effect model.

V. Strength and Limitations

This research stands out for addressing a crucial public health challenge and for leveraging robust, nationally representative BDHS data from two distinct time points to enhance the credibility of its findings. Moreover, the use of GLMM, which adeptly accounts for both cluster and fixed effects, offers nuanced insights into the determinants of handwashing facility before and after COVID-19. However, a key limitation of this study is its reliance on cross-sectional data, which may introduce selection and information biases and restrict the capacity to thoroughly examine trends and establish causal relationships over time. Future research would benefit from adopting a longitudinal design, as well as exploring additional factors including informal social accountability mechanisms and behavior change interventions to further enrich the insights gained.

VI. Conclusion

This study identifies key determinants of handwashing facility before and after COVID-19 in Bangladesh. The findings show that, before COVID-19 in 2017-18, improving handwashing facility required prioritizing infrastructural improvements and resource allocation in areas with lower odds of having basic handwashing facility like Barisal, intensifying efforts in rural areas, engaging male household heads in promoting hand hygiene, creating awareness among the younger household heads and younger mothers of under-5 children. Also, tailoring interventions to larger households and improving workplace handwashing facility, prioritizing partner's education as well as mother's education ofunder-5 children, enhancing media exposure were crucial for improving access to basic handwashing facility. After COVID-19 in 2022, improving handwashing facility required prioritizing partner's education and mother's education ofunder-5 children, increasing media exposure and economic support, empowering women and creating awareness among the younger mothers of under-5 children. This study has found that, access to basic handwashing facility in Bangladesh has been improved after COVID-19 compared to before COVID-19. Yet, some key factors such as – partner's education of partner and mother's education of under-5 children, exposure to media, age of mothers of under-5 children needed to be considered pre-and post COVID-19 for improving hand hygiene facilities. Moreover, after COVID-19, the positive significant association of women empowerment and wealth index with basic handwashing facility, has demonstrated the importance of empowering women and improving economic status.

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Appendix

Regression model

Let, y_{ip} be the p^{th} individual from the i^{th} cluster where $i = 1, 2, \dots, q$ and, $p = 1, 2, ..., n_i$. Let, x_{ip} be a vector of covariates for p^{th} individual from i^{th} cluster related with fixed effect parameter denoted by β as variation may exist in the number of subjects per cluster. Also, let, u be a $(q \times 1)$ vector of random effects associated with q clusters and z_{ip} be a unique vector of dimensions $(q \times 1)$, which is composed entirely of zeros except for a single entry of 1 at the i^{th} position where, $i = 1, 2, \dots, q$. One may write, $\mu_{ip} = E(y_{ip} \mid u_i)$, where, u_i is the random effect of i^{th} cluster. The linear predictor in GLMM has the form: $g(\mu_{ip}) = x_{ip}{}'\beta + z_{ip}{}'u$. For a continuous response variable, $y_{ip} = x_{ip}{}'\beta + z_{ip}{}'u + e_{ip}$. It can be written in matrix notation as, $Y = X\beta + Zu + e$, where, Y denotes $n \times 1$ column vector, X denotes $n \times k$ matrix of covariates, β is $k \times 1$ vector of coefficients of fixed effects, Z is $n \times q$ design matrix of q random effects, u denotes $q \times 1$ vector of random effects associated with q clusters and the $n \times 1$ vector of residuals is denoted by e where, $n = \sum_{i=1}^{q} n_i$. u follows normal distribution with mean 0 and covariance matrix, Σ. In this study, only random intercept term has been considered which turned Σ into a scalar. In this case, the variance-covariance matrix of residuals is, $Var(e_{ip}) = \sigma_e^2$. In this structure, it is assumed that the variance of residual is homogeneous for all observations and also they are independent of each other. The between-group (or cluster) variance is denoted by σ_u^2 and the within group variance is denoted by σ_e^2. The likelihood function for the individuals associated with i^{th} cluster is, $L_i\left((\beta, \sigma_u^2) \mid x_{ip}, u_i\right) = f(y_i \mid x_{ip}, u_i) = \prod_{p=1}^{n_i} f(y_i \mid x_{ip}, u_i)$. The marginal likelihood function is, $L\left((\beta, \sigma_u^2) \mid x_{ip}\right) = \int_{-\infty}^{\infty} \left[\prod_{i=1}^{q} L_i\left((\beta, \sigma_u^2) \mid u_i\right)\right] g(u_i)\, du_i$.It is quite impossible to have an explicit solution from this expression. For this reason, some techniques such as Gauss-Hermite quadrature, Laplace approximation, Penalized quasi-likelihood method have been utilized for approximation to obtain the maximum likelihood estimates.

When the response variable is binary, employing a mixed-effect logistic regression within the Generalized Linear Mixed Models (GLMM) framework is suitable for analyzing such data. The link function under this model is, $g(\mu_{ip}) = log\left(\frac{\mu_{ip}}{1-\mu_{ip}}\right) = x_{ip}{}'\beta + z_{ip}{}'u$, where, $u_i \sim N(0, \Sigma)$. Because of considering only random intercept term in this study, Σ can be replaced by σ_u^2. The conditional probability of p^{th} observation from i^{th} cluster given the value of covariate of that observation and the random cluster effect is provided by, $\mu_{ip} = E[Y_{ip} \mid x_{ip}, u_i] = Pr[Y_{ip} = 1 \mid x_{ip}, u_i] = \frac{e^{\beta' x_{ip} + u_i}}{1 + e^{\beta' x_{ip} + u_i}}$.The intra-cluster correlation (ICC) for binary response denoted by ρ is defined as, $\rho = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\pi^2}{3}}$.