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Investigating the causal relationship between wealth index and ICT skills: a mediation analysis approach

Tarikul Islam & Nabil Ahmed Uthso

This study examines the relationship between the wealth index (WI) and Information and Communication Technology (ICT) skills among women aged 15–49 in Bangladesh. The research aims to establish a cause-and-effect relationship between WI and ICT skills, while also examining how education mediates this relationship. Using the data from the Bangladesh Multiple Indicator Cluster Survey (MICS) Program 2019, a two-stage stratified clustered sampling method yielded a sample of 64,378 women. The analysis employed inverse probability weighting (IPW) to assess the causal effect of WI on ICT skills while investigating the mediating role of education in this cause-and-effect relationship through causal mediation analysis. The findings demonstrate a significant relationship between higher economic status and increased ICT proficiency among women aged 15–49 in Bangladesh. Mediation analysis reveals education status as a significant mediator, indicating that educational attainment plays a vital role in linking wealth and ICT skills among women. Sensitivity analysis indicates the observed effect estimates are robust to unmeasured confounding. This research underscores the importance of economic empowerment and educational interventions in narrowing the digital divide and fostering ICT skills development among women, particularly in rural and economically disadvantaged communities.

Information and communication technologies (ICTs) have led to significant economic and social changes worldwide^{1–4}. However, Ullah⁵ argues that the benefits of ICTs are only fully realized once they are fully implemented. Unfortunately, women in rural areas often have limited access to technology and fewer rights than their urban counterparts⁶. Nevertheless, ICTs offer many opportunities to positively contribute to gender equality and women's development⁷. Women worldwide increasingly use ICT skills for various business-related tasks and enhance their knowledge of communication, marketing, and purchasing⁸. However, statistics show that individuals in developing countries own fewer computers, mobile phones, and phone lines than those in developed countries⁹. Empowering women is essential in reducing poverty and ensuring sustainable development¹⁰. Several studies have shown that the use of ICTs can be beneficial in empowering women economically in various countries¹¹.

A few academic studies have examined the factors that influence ICT skills in Bangladesh^{12–14}. However, these studies rely on traditional data analysis methods that cannot effectively balance covariates at the exposure level, making it difficult to prove causal relationships. This study seeks to determine the causal effect of the wealth index, a dichotomous variable, on the ICT skills of women aged 15–49 in Bangladesh. Once a cause-and-effect relationship has been established between WI and ICT skills, the next question is how this relationship can be explained¹⁵. To address this issue, researchers use causal mediation analysis (CMA). CMA was initially introduced by Wright¹⁶, and Baron and Kenny¹⁷ and is still an active area of research¹⁸. CMA aims to decompose the causal effect of an exposure on the outcome (total effect) into the effect of that exposure on the outcome through a mediator (mediating or indirect effect) and not through that mediator (direct effect)¹⁹. Mediation analysis enables a more in-depth understanding of causal pathways by breaking down the total effect into direct and indirect effects²⁰.

Our study aims to explore the causal connection between wealth index and ICT skills by employing a mediation approach. We posit that the wealth index is a causal factor influencing ICT skills since affluent households typically possess essential technological tools such as smartphones, computers, and internet access, which are

Institute of Statistical Research and Training (ISRT), University of Dhaka, Dhaka 1000, Bangladesh. ✉email: tislam2@isrt.ac.bd

prerequisites for developing ICT skills. We will identify a suitable mediator to elucidate the causal pathway between wealth index and ICT skills.

This study investigates the causal effect of WI on ICT skills using mediation and sensitivity analysis techniques to provide insight into how to effectively improve the ICT skills of women among different socioeconomic groups by applying mediation analysis techniques to the relationship between WI and ICT skills. The expected outcomes of this study include a more comprehensive understanding of the mediating role of potential factors in the association between wealth index and ICT skills, as well as information that can lead to targeted interventions for improving the ICT skills of women and helping achieve Sustainable Development Goal 5.

Methods

Data

The Bangladesh MICS provided the data for this study, which is part of the Multiple Indicator Cluster Survey Program 2019²¹. This program was created by UNICEF in 1990 to assist countries in collecting data on various indicators related to women and children. The study used a two-stage stratified clustered sampling method and selected 64,400 households and 3,220 clusters. After adjusting for missing values, the sample included 64,378 women. The MICS website offers the data for free, a complete data description, and a detailed sampling procedure in the MICS 2019 report: “*Progotir Pathay Bangladesh*”²¹.

Inverse probability weighting (IPW)

We used the inverse probability weighting (IPW) approach to obtain the causal effect of an exposure on the outcome²². Let Y be a binary outcome, W be a binary exposure, and C be a vector of confounders; then the IPW estimate of average treatment effect (ATE) is

$$\widehat{ATE} = \widehat{E}(Y^{w=1}) - \widehat{E}(Y^{w=0}) = \frac{1}{n} \sum_{i=1}^n \frac{W_i Y_i}{\widehat{e}_i} - \frac{1}{n} \sum_{i=1}^n \frac{(1 - W_i) Y_i}{(1 - \widehat{e}_i)}, \quad (1)$$

where \widehat{e}_i is the estimate of propensity score $e_i = Pr(W_i = 1 | C_i = c_i)$ for the i th individual. According to Lunceford and Davidian²³, $\sqrt{n}(\widehat{ATE} - ATE)$ has an asymptotic normal distribution, which is useful for obtaining the confidence interval of ATE.

Causal mediation analysis (CMA)

After establishing a cause-and-effect relationship between WI and ICT skills, CMA is conducted to explain this relationship. CMA can be a crucial substitute for conventional statistical models (regression-based) to ensure accurate inferences. CMA yields three distinct effects, namely total, direct, and indirect effects. These effects can be visually represented in Figs. 1 and 2, where the total effect can be further broken down into direct and indirect effects. The CMA approach is actually based on the counterfactual framework. In the counterfactual framework, $Y^{w,m}$ represents the counterfactual outcome of ICT skills under exposure level w and mediator level m , e.g., $Y^{w=1,m=1}$ represents the responses on ICT skills if all individuals in the population are rich and have an education level higher than secondary. M^w represents the counterfactual value of the mediator education status under treatment level w , e.g., $M^{w=1}$ represents the responses on the education status of all individuals if all individuals in the population are rich. In this framework, the direct and indirect effects are called natural direct effect (NDE) and natural indirect effect (NIE), respectively. The NDE is obtained as the difference between the joint counterfactual outcomes where we fixed the mediator at the control level and changed the exposure, and the NIE is obtained as the difference between the joint counterfactual outcomes where we fixed the exposure and changed the mediator at different exposure level. That is, $NDE = Y^{w=1,M^{w=0}} - Y^{w=0,M^{w=0}}$, and $NIE = Y^{w=1,M^{w=1}} - Y^{w=1,M^{w=0}}$. The total effect (TE) is obtained as the sum of these two effects, i.e., $TE = Y^{w=1} - Y^{w=0} = NDE + NIE$. Suppose C represent a vector of potential confounders. A very popular approach to estimating these effects from observed data is the imputation approach introduced by Vansteelandt et al.²⁴ that is shown in the Table 1. This approach constructs a new dataset by repeating each observation in the original data set twice. Then creates a new variable W^* , which is equal to the original exposure in the first dataset and opposite to the original exposure in the second dataset. Then fit a regression model $\mathbb{E}(Y | w, m, c)$ using the first dataset and use the coefficients of that model to impute the counterfactual outcome Y^{w^*,M^w} from $\mathbb{E}(Y | w^*, m, c)$. After that, the natural effects are obtained by regressing the counterfactual outcome Y^{w^*,M^w} on w, w^* , and C on the basis of the expanded data set. Standard error of these effects can be obtained using the bootstrap method.

Sensitivity analysis Unmeasured confounding poses a significant challenge to the reliability of causal effect estimates in observational studies. The method proposed by Kasza et al.²⁵ (KWS) addresses this concern by assessing the impact of unmeasured confounding in binary exposure and outcome settings. Their approach involves

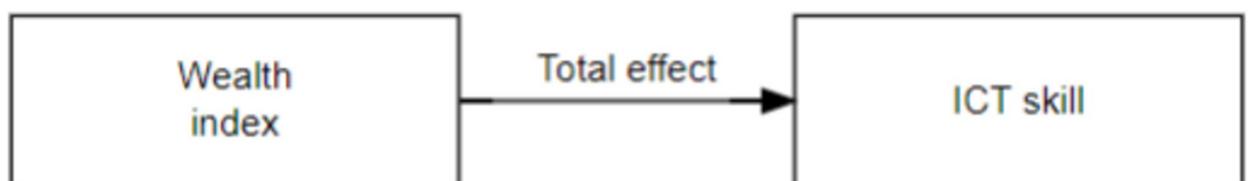


Figure 1. Effect of wealth index on ICT skill.

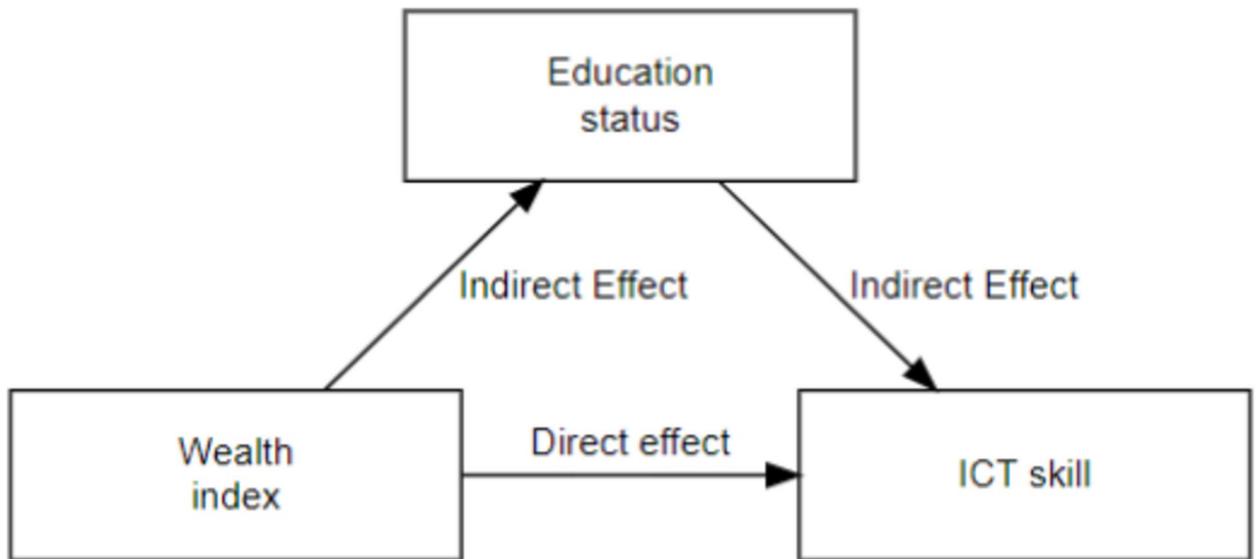


Figure 2. Total effect has been broken down into direct and indirect effects.

	W	W*	M ^{w*}	Y ^{w*,M^{w*}}	
1st dataset	w ₁	w ₁	M ^{w₁}	Y ^{w₁,M^{w₁}} = Y ₁	Fit $\mathbb{E}(Y w, m, \epsilon)$ using first dataset
	w ₂	w ₂	M ^{w₂}	Y ^{w₂,M^{w₂}} = Y ₂	
	⋮	⋮	⋮	⋮	
	w _n	w _n	M ^{w_n}	Y ^{w_n,M^{w_n}} = Y _n	
2nd dataset	w ₁	w ₁ [*]	M ^{w₁[*]}	Y ^{w₁[*],M^{w₁[*]}} = $\mathbb{E}(Y_1 w_1^*, M_1, \epsilon)$	Predict counterfactual outcome using the fitted model
	w ₂	w ₂ [*]	M ^{w₂[*]}	Y ^{w₂[*],M^{w₂[*]}} = $\mathbb{E}(Y_2 w_2^*, M_2, \epsilon)$	
	⋮	⋮	⋮	⋮	
	w _n	w _n [*]	M ^{w_n[*]}	Y ^{w_n[*],M^{w_n[*]}} = $\mathbb{E}(Y_n w_n^*, M_n, \epsilon)$	

Table 1. Imputation based approach of mediation analysis.

defining sensitivity analysis parameters to establish plausible ranges for causal effects. However, it is crucial to recognize that the causal quantity in the original population may differ from that in the weighted population, potentially leading to inaccurate characterization of the original population when following KWS’s method. To address these limitations, Ciocănea-Teodorescu and Sjölander²⁶ proposed modifications to KWS’s framework for assessing unmeasured confounding in binary outcomes. In our study, we applied the framework developed by Ciocănea-Teodorescu and Sjölander²⁶ to conduct a sensitivity analysis for unmeasured confounding. According to this framework, we first identified the range of the sensitivity parameter K_w as follows:

$$\max_{C_i} \widehat{Pr}(W = w | C_i) \leq K_w \leq \min_{C_i} \left(\widehat{Pr}(W = w | C_i) + \frac{\widehat{Pr}(W = 1 - w | C_i)}{\widehat{Pr}(Y = 1 | W = w, M = m, C_i)} \right),$$

for $w \in \{0, 1\}$ as suggested by Ciocănea-Teodorescu and Sjölander²⁶. Using this range, we then identified the ranges for the average counterfactual outcomes (e.g., $E(Y^{w=1, M^{w=1}})$, $E(Y^{w=1, M^{w=0}})$, $E(Y^{w=0, M^{w=0}})$) and, consequently, determined the ranges for natural effect estimates to assess the sensitivity of our observed results to unmeasured confounding.

Outcome variable. ICT skills (Y) is the only dependent variable in the dataset which is a binary variable with two levels: yes (1: Performed atleast one of the nine computer related activity (“Copied or moved a file or folder”; “Used a copy and paste tool to duplicate or move information within a document”; “Sent e-mail with attached file, such as a document, picture or video”; “Used a basic arithmetic formula in a spreadsheet”; “Connected and installed a new device, such as a modem, camera or printer”; “Found, downloaded, installed and configured software”; “Created an electronic presentation with presentation software, including text, images, sound, video or charts”; “Transferred file between a computer and other device”; “Wrote a computer program in any programming language”)) and no (0: Not perform any of these nine computer related activities).

Exposure variable. Wealth index (W) is the exposure variable in this study which is also a binary variable with two levels: rich ($w = 1$ (above 60th quantile)) and non-rich ($w = 0$ (upto 60th quantile)).

Mediator variable. Education status (M) is the only mediator variable in this study which is a binary variable with two levels: secondary+ ($m = 1$) and upto secondary ($m = 0$).

Covariates. Division (0: Barishal, 1: Chittagong, 2: Dhaka, 3: Khulna, 4: Mymensingh, 5: Rajshahi, 6: Rangpur, 7: Sylhet), residence (1: Urban, 0: Rural), age, ethnicity (1: Bengali, 0: Other).

Statistical analysis

We employ the IPW method to explore the causal relationship between WI and ICT skills. This technique entails computing the probability of receiving the treatment ($w = 1$) based on observed confounding variables for each individual. Subsequently, a pseudo-population is created where the inverse probability of receiving their observed treatment status determines each individual's weight. This process ensures a balanced distribution of covariates between the treatment and control groups within the pseudo-population. Consequently, applying any regression model within this pseudo-population can yield a causal effect. We employed the Poisson regression model with a log link function for modeling the outcome of interest ICT skills. After establishing a cause-and-effect relationship between WI and ICT skills, we employ a mediation analysis using the imputation technique to explore this causal relationship. In the imputation method, we impute the counterfactual outcome to obtain natural direct and indirect effects. Further, we conduct a sensitivity analysis to ratify the robustness of the observed effect estimates. The analyses were conducted using the R software (*version 4.2.0*) and Stata (*StataCorp version 14.0*) software.

Results

The findings in Table 2 indicate that a mere 1.09% of the participants possess ICT skills. On average, the age of the respondents is 29.96 years (with a standard deviation of 9.66 years). Out of all the female participants, around 20% come from the Dhaka division, while only 5.17% hail from Mymensingh. Furthermore, 83.45% of women have an education level that goes up to secondary school. Almost all (97.66%) of the women identified as Bengali. Regarding wealth, 38.03% of women are from rich households, while the remaining 61.97% come from non-rich households.

Table 3 displays the results of the standardized mean difference before and after implementing IPW. The findings suggest that following the application of IPW, there is a balance in the distributions of covariates such as age, ethnicity, division, and area of residence between the treatment (rich) and control (non-rich) groups. In this study, education status was selected as a mediator due to its pivotal role in mitigating socio-economic disparities related to technology access and proficiency. Previous research has consistently identified education as a fundamental driver in the acquisition of ICT skills, especially among economically disadvantaged populations. Furthermore, wealth status is closely linked to educational attainment, further justifying the selection of education as a mediator in this context^{12,27}. Although other potential mediators, such as the affordability of technology,

Variables	Frequency/ mean (SD)	Percentage (%)
ICT skills		
Yes	702	1.09
No	63,676	98.91
Age (in years)	29.96 (9.66)	
Area of residence		
Urban	13,033	20.24
Rural	51,345	79.76
Division		
Barishal	5500	8.54
Khulna	10,134	15.74
Chittagong	12,067	18.74
Rajshahi	7582	11.78
Mymensingh	3331	5.17
Rangpur	7840	12.18
Dhaka	12,994	20.18
Sylhet	4930	7.66
Highest education level		
Up to secondary	53,726	83.45
Secondary+	10,652	16.55
Ethnicity		
Bengali	62,869	97.66
Others	1509	2.34
Wealth index		
Rich	24,482	38.03
Non-rich	39,896	61.97
Total	64,378	100

Table 2. Background characteristics of respondents.

Variables	Before IPW	After IPW
Age	-0.034	0.013
Ethnicity		
Non-bengali (Reference)		
Bengali	0.163	-0.016
Division		
Barishal (Reference)		
Chittagong	0.145	-0.038
Dhaka	0.335	-0.076
Khulna	0.019	0.019
Mymensingh	-0.156	0.017
Rajshahi	-0.091	0.036
Rangpur	-0.297	0.029
Sylhet	0.083	0.029
Area of residence		
Rural (Reference)		
Urban	0.709	-0.074

Table 3. Standardized mean difference before and after IPW.

were considered, they were excluded due to data constraints²⁸. The emphasis on education is grounded in its strong theoretical and empirical connections to both wealth and ICT skills. As demonstrated in Table 4, the analysis using the Baron and Kenny¹⁷ approach confirms that education status is a significant mediator in the causal relationship between wealth index and ICT skills.

In the pseudo-population, a Poisson regression model is utilized to calculate the causal effect of WI on ICT skills using a risk ratio scale, resulting in a value of 10.149 for the causal effect (Table 5). Through bootstrapping, the confidence interval for the causal risk ratio (RR_{causal}) is determined to be between 8.562 and 12.004. Results show that the NDE of the wealth index in the risk ratio scale is 2.349 (CI 2.116–2.592), and the NIE is 4.320 (CI 3.948–4.704). The total effect is 10.149 (CI 8.562–12.004), which indicates that the probability of having ICT skills is 10.149 times higher if all individuals are rich than if all individuals are not rich. The proportion mediation is 85.252% (CI 84.290–86.305%) which indicates that the mediator education can explain 85.252% (by bootstrapping this proportion, mediation is significant) of the total effect of wealth index on ICT skills. The evidence suggests that mediator education is potent and could be considered a potential risk factor for ICT skills.

We further conducted a sensitivity analysis to evaluate whether our observed effect estimates are robust or sensitive to unmeasured confounding, using the framework proposed by Ciocănea-Teodorescu and Sjölander²⁶. Our analysis revealed the following ranges for the sensitivity parameters: $K_0 \in [0.941, 3.950]$ and $K_1 \in [0.964, 1.090]$. Within these ranges, the global bounds for the average counterfactual outcomes were as follows: for $E(Y^{w=1, M^{w=1}})$: [0.02068045, 0.0233835], for $E(Y^{w=0, M^{w=0}})$: [0.001992015, 0.008361806], and for $E(Y^{w=1, M^{w=0}})$: [0.004787142, 0.005412847]. The global lower and upper bounds for the NDE, NIE, and total effect (TE) on the risk ratio scale were found to be: NDE: [0.5725009, 2.717272], NIE: [3.820623, 4.884647], and TE: [2.473204, 11.73861]. Our results indicate that the causal effect of the wealth index on ICT skills (total effect) and the effect through education status (indirect effect) are robust to unmeasured confounding, as the

Steps	Statement	p-value	Comments
Step-1	Does the wealth index significantly predict ICT skills?	< 0.001	Yes
Step-2	Does the wealth index significantly predict education?	< 0.001	Yes
Step-3	Does education significantly predict ICT skills, controlling for wealth index?	< 0.001	Yes

Table 4. Steps to identify whether education status is a mediator in the causal pathway between wealth index and ICT skills.

Effect type	Risk Ratio	95% CI	Proportion mediation (95% CI)
Natural Direct Effect (NDE)	2.349	[2.116, 2.592]	$\frac{RR^{NDE} \times (RR^{NIE} - 1)}{(RR^{NDE} \times RR^{NIE}) - 1} \times 100 = 85.25\%$ (84.290%, 86.305%)
Natural Indirect Effect (NIE)	4.320	[3.948, 4.704]	
Total Effect (TE)	10.149	[8.562, 12.004]	

Table 5. Effect estimate of natural effects and its confidence interval.

ranges do not include 1. However, the direct effect is sensitive to unmeasured confounding. This suggests that if unmeasured confounders were included in the study, the mediating effect might be even stronger, as the direct effect would be attenuated.

Discussion

The present study aimed to examine the causal relationship between the wealth index (WI) and information and communication technology (ICT) skills in women aged 15–49 in Bangladesh. The results demonstrated a clear cause-and-effect relationship between the WI and ICT skills in this particular group. Furthermore, it was seen that people with higher incomes demonstrated greater proficiency in these skills. This relationship suggests that economic status plays a crucial role in determining access to and proficiency in ICT skills among women in Bangladesh.

These findings support previous studies that emphasize the impact of socioeconomic factors on technology adoption and skills acquisition. The observed disparities align with Ullah's⁵ argument that the full potential benefits of ICTs are only realized when they are fully accessible and implemented. This study highlights the ongoing disparity in technology access and proficiency, especially among rural and economically disadvantaged communities. It echoes the concerns voiced by Rashid et al.⁶ over the low availability of technology for women in rural areas, despite global efforts to promote digital inclusion.

A study conducted in Bangladesh found a high growth rate in the ownership of a phone, which is one of the key tools for developing ICT skills among poorer households²⁹. However, having ICT skills depends on ICT affordability. In a study, inequality is revealed to impact ICT affordability positively²⁸. Furthermore, several studies suggest that the diffusion of ICT skills depends on the affordability of ICT services, and a high level of affordability denotes a high diffusion of ICT skills^{30–32}. Since the diffusion of ICT skills depends on the affordability of ICT services, that is, on the wealth index, these results also support our results of the causal pathway between the wealth index and ICT skills. Hossain et al.³³ stated that Bangladesh's ICT sector's job market suffers from a huge workforce shortage due to a lack of ICT skills, demanding an immediate action of diffusion of ICT skills in Bangladesh.

A noteworthy finding is the mediating role of education in the WI–ICT skills pathway. Education status emerged as a significant mediator, indicating that women's educational attainment acts as a bridge between economic status and ICT skills. This mediation effect suggests that interventions targeting education enhancement, particularly among economically disadvantaged groups, could substantially improve ICT skills acquisition and mitigate the existing disparities. The findings of this study suggest the need for targeted policies that focus on increasing access to education and ICT training for women, particularly in economically disadvantaged and rural areas³⁴. By investing in these areas, policymakers can help bridge the digital divide and promote gender equality, contributing to broader development goals such as the Sustainable Development Goals (SDGs), specifically SDG 4 (Quality Education) and SDG 5 (Gender Equality). We recommend implementing the government's revised educational programs integrating ICT skills training from an early age, economic initiatives like microfinance to empower women financially, and gender-specific policies encouraging women's participation in the digital economy³⁵. Addressing educational gaps, especially among economically marginalized communities, should be a priority. By implementing initiatives that ensure fair and equal opportunities for education, vocational training, and ICT literacy, we can narrow the divide and promote a society that is more inclusive and technologically enabled. However, it's vital to note this study establishes a causal relationship using observational data, which typically has limitations due to the possibility of unmeasured confounders. To address this, a sensitivity analysis was conducted to assess the assumption of no unmeasured confounding variables, which confirmed the robustness of our methodological findings.

Although the data we used in our study includes only female participants, women have fewer opportunities than men to access ICT in developing countries³⁶. Cooper et al.³⁷ noted that a gender digital divide exists among people of all ages worldwide, deeply rooted in existing socialization patterns. Furthermore, several studies found that men have better computer and internet skills than their female counterparts^{38,39}. Hence, it is crucial to address the issue of the lack of ICT skills among developing countries like Bangladesh to move a step forward toward achieving the SDGs.

This study adds useful insights into the link between socioeconomic status, education, and ICT skills among women in Bangladesh. The findings underline the crucial role of economic empowerment and education in shaping technology uptake and proficiency. Future studies should go deeper into understanding these connections, embracing a larger range of confounding variables for a more comprehensive knowledge of the WI–ICT skills relationship. The insights taken from this study underline the necessity of focused interventions and legislative actions to reduce the digital divide, empower women via greater access to education and technology, and support inclusive economic and social growth.

Limitation

One of the limitations of this study is that due to the unavailability of multiple datasets, we have used only the latest MICS data to draw a causal relationship between wealth index and ICT skills. Hence, the Granger causality analysis couldn't be performed. Moreover, this study's generalizability may be limited to areas with similar geographic contexts, such as Bangladesh, most South Asian countries, and lower-and-middle-income countries (LMICs) in other parts of the world, like Ghana and South Africa. Furthermore, future studies should be conducted to consider ICT affordability as a mediator.

Conclusion

The study highlights the importance of economic and educational interventions in improving ICT skills among women in Bangladesh. By addressing the socio-economic and educational disparities, policymakers can help bridge the digital divide and promote gender equality in ICT access and proficiency. The findings underscore the need for targeted policies and programs that enhance economic opportunities and educational attainment for women, particularly in rural and underserved areas, to foster sustainable development and empower women through ICT skills. This study distinguishes itself by establishing a causal relationship between the exposure and outcome variables using a causal mediation analysis approach on data from an observational study, a method less common in public health research that typically focuses on association. Further in-depth studies are needed, focusing more on diverging confounders with respect to Bangladesh's context and considering panel data to establish a more robust causal relationship between the interested variables.

Data availability

The dataset used in this study is publicly available on the MICS website (<https://mics.unicef.org/surveys>).

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Author contributions

T.I. conceptualized the study, formulated the theoretical model, and conducted the formal analysis. T.I. and N.A.U. conducted the literature review and wrote the original manuscript. The final manuscript was read and approved by all the authors.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to T.I.

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