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Identifying the key attributes of fresh water crisis in Dhaka city: A structural equation modeling approach

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ABSTRACT

This paper aims to analyze how user behavior and climate change influence the freshwater demand in metropolitan areas. In total, 406 observations were obtained from different respondents in Dhaka city via an online survey. Our research demonstrates that the data are reliable and acceptable for factor analysis. Structural equation modeling (SEM) is adopted to show the relationships between the parameters. The model fit parameters (CFI, NFI, TLI, RMSEA, and so on) are used to choose the best structural equation (SE) model. Additionally, responses are analyzed by the relative importance index (RII) method and compared with the SEM results. This study shows that personal water waste and natural crises substantially impact the freshwater crisis. Excessive use of water during showering, washing clothing and dishes, washing vegetables, and pool refilling are the most common ways to wastewater. Furthermore, the ground layer in Dhaka city is gradually reducing due to the natural crisis, but the WASA pump's capacity is insufficient to pump up this water. This research aids policymakers in identifying the key attributes that are contributing to the urban freshwater crisis.

Key words: climate change, structural equation modeling, water crisis, water scarcity, water security

HIGHLIGHTS

- Evaluate water crisis scenario.
- Identifies influencing causes that aggravated water crisis problems.
- Inter-relationship among water misuse parameters.
- The relative importance index (RII) method is used to determine the relative importance of parameters involved in creating a water crisis.
- RII also used to compare the result with structural equation modeling.

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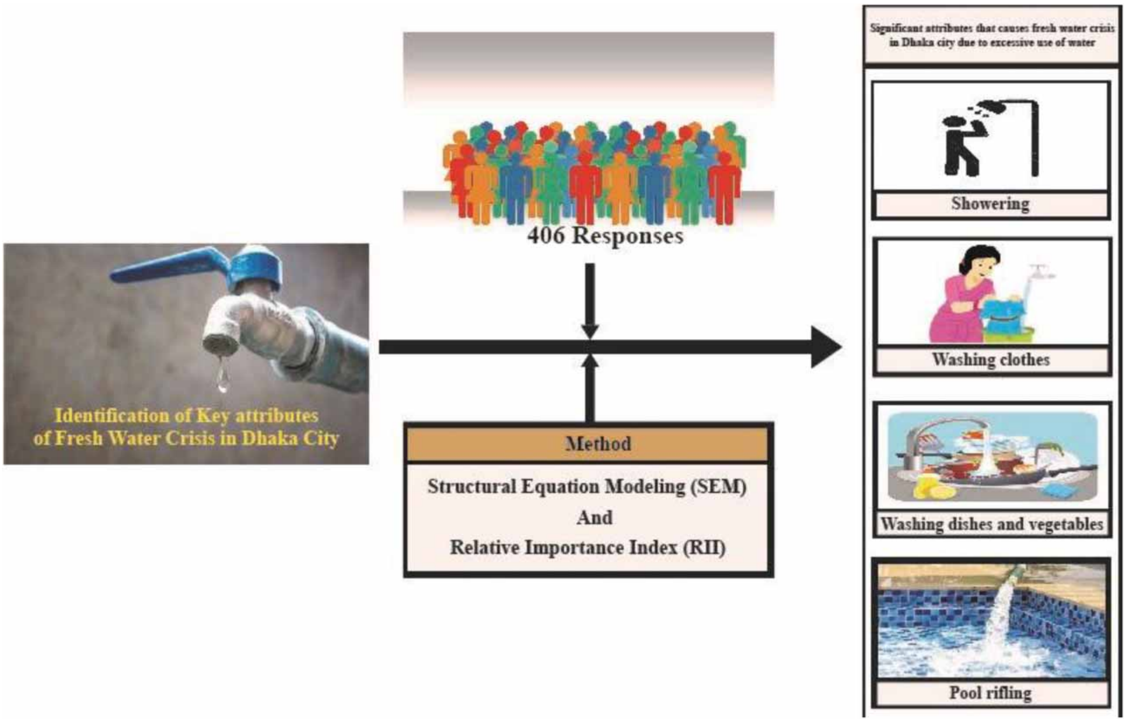
GRAPHICAL ABSTRACT



INTRODUCTION

Water scarcity poses a pervasive threat to us as it stifles economic progress, endangers public health, and jeopardizes ecosystems (Seckler *et al.* 1999; Rijsberman 2006; Liu *et al.* 2017). Municipalities and city corporations have concentrated on the immediate – tapping groundwater resources in and around cities – as water demand became more acute (Desbureaux & Rodella 2019). In Dhaka, the water table is falling by 2–3 m (6.6–9.8 ft) per year (*Bangladesh: Water for All in Dhaka* 2019). The most alarming forecast on future water availability comes from development officials, who claim that by 2030, under the current climate change scenario, 47% of people in the world will be living in places with severe water scarcity ('The OECD Environmental Outlook to 2030' n.d.). About 57% of the world's inhabitants will live in locations where water shortage occurs at least once a year by 2050 ('World Water Development Report 2018' n.d.). In Bangladesh, accessibility to potable water is denied to about 1.8 million people (*Bangladesh's Water Crisis – Bangladesh's Water* in 2021/*Water.Org* n.d.).

Bangladesh has enough water, with about 24,000 kilometres of rivers running across its rich terrain (*Annual Report 2018-2019 of Dhaka Water Supply & Sewerage Authority* 2019). However, supplying clean drinking water for everybody is a problematic national issue (Rasid & Paul 1987). Despite five rivers, several canals, lagoons, and lakes, Dhaka, Bangladesh's capital, is experiencing a significant water supply crisis (*Bangladesh: Water for All in Dhaka* 2019). The city's water supplies are under even more pressure because of the vast population and fast urbanization (*Bangladesh: Water for All in Dhaka* 2019). Water scarcity was unknown in Dhaka even in the 1960s, according to those who had lived there for a long time. In the 1980s, with the tremendous expansion in population and the establishment of further communities across the city, people began to realize how unpleasant life might be with home taps releasing just trickles of water (Islam *et al.* 2011). As the years passed, the situation deteriorated. Water supplied by WASA (Water Supply and Sewerage Authority) is the only source of water in large cities (Kamruzzaman & Huq 2020). The fact is that 78% of Dhaka WASA water comes from underground sources that contribute to the gradual reduction of groundwater (*Annual Report 2018-2019 of Dhaka Water Supply & Sewerage Authority* 2019). Pumping costs have risen due to the increased pumping capacity required to extract water due to groundwater depletion. In this situation, the only way forward is to reduce groundwater dependency and switch to surface water. However, surface water quality, degradation, and water resource shortage have become a global issue of concern with industrialization and climate change in Dhaka city (Sohel *et al.* 2003; Bhuiyan *et al.* 2011). The current situation in Bangladesh concerning the water problem

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is alarming (*Bangladesh: Water for All in Dhaka* 2019). The need for freshwater is growing with each passing day. Water demand for the home is increasing in tandem with population growth, as is water demand for agricultural purposes. At the same time, pollution of surface and groundwater makes it impossible for people to have access to safe drinking water (Abedin *et al.* 2014). The interplay between climatic fluctuations, water use, and local weather conditions is empirically concerning (Dwianika *et al.* 2020). Climate change also exacerbates the water shortage (Roshan & Kumar 2020). Temperature and precipitation account for 60% of water consumption (May & Lott 1992). This issue is severe in metropolitan areas. People's indifference has caused most water shortages in urban areas (Craig *et al.* 2019). Showers, toilet flushing, laundry, and dishwashing consume the most water in cities (Roshan & Kumar 2020). In our nation, individuals use 27.26 litres per day for bathing, 12.75 litres per day for toilet use, and 6.71 litres per day for cooking (Milton *et al.* 2006).

Various research has been carried out to reduce the problem of water scarcity in metropolitan areas. Various factors influence water scarcity in Dhaka city. Siddiquee & Ahamed (2020) used the instrumental variable regression (IVREG), and instrumental variable quantile regression (IVQREG) approaches for a better understanding of the water consumption of Dhaka city. Dwianika *et al.* (2020) analyzed water awareness, accountability, and governance to find a new measurement model. This paper has used structural equation modeling (SEM) to discover the essential factors that will assist policymakers in making urban environments more livable. SEM is a broad term for determining the validity of theoretical judgments based on empirical facts. SEM also aids in the identification of relationships between variables, both observed and latent. The primary goal of this lesson is to expose novice SEM researchers to the fundamentals of SEM modeling using simple covariance structural models (Lei & Wu 2007).

This study assesses how user behavior and climate change influence water demand in metropolitan areas. This study adopts SEM and RII to get the most contributing variables regarding the fresh water crisis in Dhaka city.

METHODS

Experimental context

A few phases of approach are used for this study. First, the water crisis factors were defined in accordance with the research goals. The questionnaire was then ready for the user's response. Data are gathered using an online survey and sorted in preparation for factor analysis. Simultaneously, the procedure for hypothesis testing is determined. The hypothesis tools were then chosen. Data are sent into the testing tools. The result of several trials and errors justifies the best structural equation (SE) model.

Data collection

The questionnaire was designed to collect data on the aspects contributing to the Dhaka city water crisis. Data are collected through an online questionnaire survey among the dwellers of Dhaka city. Both qualitative and quantitative scales are presented during data collection. There were no biases in data collection. The prime statistics of collected data are shown in Table 1. SEM is an enormous sample method with a sample size of over 200. The sample size to free parameter ratio can be as low as 5 to 1 or as high as 20 to 1 (Rahman *et al.* 2016). In total, of 406 data were collected through a questionnaire.

Among these respondents, 248 are female, and 158 are male; 116 respondents are less than 20 years old, whereas 232 respondents are in between 21–50 years, and the rest of the respondents are above 50 years. Again, 129 respondents are students/jobless, and the remaining 277 are job holders. Variations in respondents are shown in Figures 1–3.

Structural equation model

SEM is adopted to justify our research objectives. SEM allows users to justify the hypothesis model, whether satisfied or not, in qualitative and quantitative terms. Estimating SEM parameters is an iterative procedure that results in the best fit model after multiple trials and errors. By comparing the estimated variance–covariance matrix inferred by the model to the variance-covariance matrix of sample data, the model's overall fit can be justified. The path parameter is projected as a regression coefficient for direct relationships amongst the water crisis variables. Selecting the best method for SEM depends on probability distributions, the sample size, and the complication of SEM. In this study, for data tests, SPSS Statistics is used. SPSS Amos 26 is also used to test the hypothesis of the SE model. For proper justification of research objectives, various data tests and the model's fitness should be satisfied. The data test, Bartlett's, Kaiser–Meyer–Olkin (KMO), and Cronbach's alpha tests are

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Table 1 | Prime statistics

Item no.	Description	Numerical scale	Qualitative scale
1	Misuse of water during shower	1–5	Strongly Agree to Strongly Disagree
2	Misuse of water during laundry	1–5	Strongly Agree to Strongly Disagree
3	Misuse of water during cooking	1–5	Strongly Agree to Strongly Disagree
4	Misuse of water during washing dishes	1–5	Strongly Agree to Strongly Disagree
5	Misuse of water during toilet flushing	1–5	Strongly Agree to Strongly Disagree
6	Misuse of water during washing car	1–5	Strongly Agree to Strongly Disagree
7	Misuse of water during watering in the garden	1–5	Strongly Agree to Strongly Disagree
8	Misuse of water during cleaning food	1–5	Strongly Agree to Strongly Disagree
9	Misuse of water during pool refilling	1–5	Strongly Agree to Strongly Disagree
10	Misuse of water during tank refilling	1–5	Strongly Agree to Strongly Disagree
11	Leakage of water tap	1–5	Strongly Agree to Strongly Disagree
12	Ground water layer depletion	1–5	Strongly Agree to Strongly Disagree
13	Pump capacity	1–5	Strongly Disagree to Strongly Agree
14	Increase of salinity	1–5	Strongly Agree to Strongly Disagree
15	Drying of river bed	1–5	Strongly Agree to Strongly Disagree
16	Climate changing	1–5	Strongly Agree to Strongly Disagree
17	Overuse and misuse of water	1–5	Strongly Agree to Strongly Disagree
18	Mismanagement	1–5	Strongly Agree to Strongly Disagree
19	Unfair pricing	1–5	Strongly Agree to Strongly Disagree
20	Ecosystem loss	1–5	Strongly Agree to Strongly Disagree

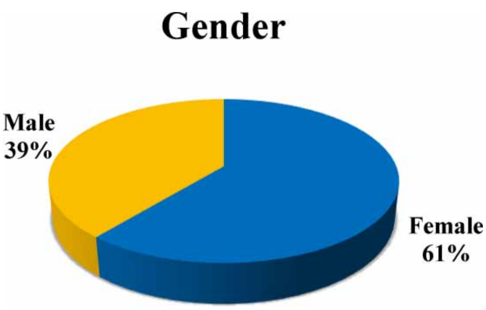

Figure 1 | Gender of respondents.

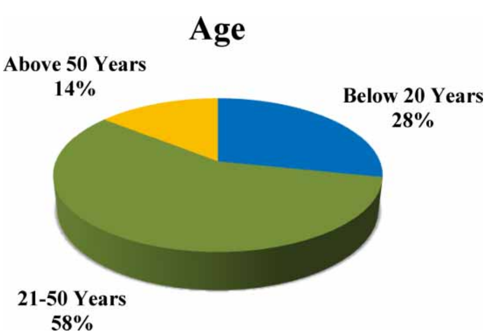

Figure 2 | Age difference of respondents.

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Figure 3 | Occupation of respondents.

conducted for data consistency and suitability. The higher value of KMO and Bartlett's value defines the suitability of data for factor analysis (Karim *et al.* 2020). A Cronbach's alpha value greater than 0.6 defines the data consistency for factor analysis. For incremental fit indices (IFI), comparative fit indices (CFI), normed fit index (NFI), Tucker–Lewis index (TLI), parsimonious normed fit index (PNFI), chi-squared value (χ^2), root mean square error of approximation (RMSEA) and degree of freedom (df) are widely used (Rahman *et al.* 2016). A χ^2/df value between 2.0 to 0.5, RMSEA value between 0.00 to 0.08, and CFI, NFI, TLI and PNFI values close to 1.00 are considered for the goodness of fit of the model (Bentler 1986).

Variables used in the structural equation model

In total, 23 water crisis variables are used for constructing an SE model. Amongst them, 20 variables are endogenous observed variables, two latent variables, and one dependent variable. These variables are selected from reviewing the water crisis, focusing on more profound variables that affect the crisis of water in Dhaka city. The variables are given in Table 2.

Table 2 | Water crisis variables and their role in the SE model

Item no.	Description	Variable type	Notation
1	Misuse of water during shower	Endogenous variable	y1
2	Misuse of water during laundry	Endogenous variable	y2
3	Misuse of water during cooking	Endogenous variable	y3
4	Misuse of water during washing dishes	Endogenous variable	y4
5	Misuse of water during toilet flushing	Endogenous variable	y5
6	Misuse of water during washing car	Endogenous variable	y6
7	Misuse of water during watering in the garden	Endogenous variable	y7
8	Misuse of water during cleaning food	Endogenous variable	y8
9	Misuse of water during pool refilling	Endogenous variable	y9
10	Misuse of water during tank refilling	Endogenous variable	y10
11	Leakage of water tap	Endogenous variable	y11
12	Ground water layer depletion	Endogenous variable	y12
13	Pump capacity	Endogenous variable	y13
14	Increase of salinity	Endogenous variable	y14
15	Drying of river bed	Endogenous variable	y15
16	Climate changing	Endogenous variable	y16
17	Overuse and misuse of water	Endogenous variable	y17
18	Mismanagement	Endogenous variable	y18
19	Unfair pricing	Endogenous variable	y19
20	Ecosystem loss	Endogenous variable	y20
21	Personal misuse	Latent variable	$\eta 1$
22	Natural crisis	Latent variable	$\eta 2$
23	Water crisis	Dependent variable	Z

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Conceptual framework

The above review provides a conceptual framework in Figure 4, which gives the idea of the hypothetical relationship among the variables.

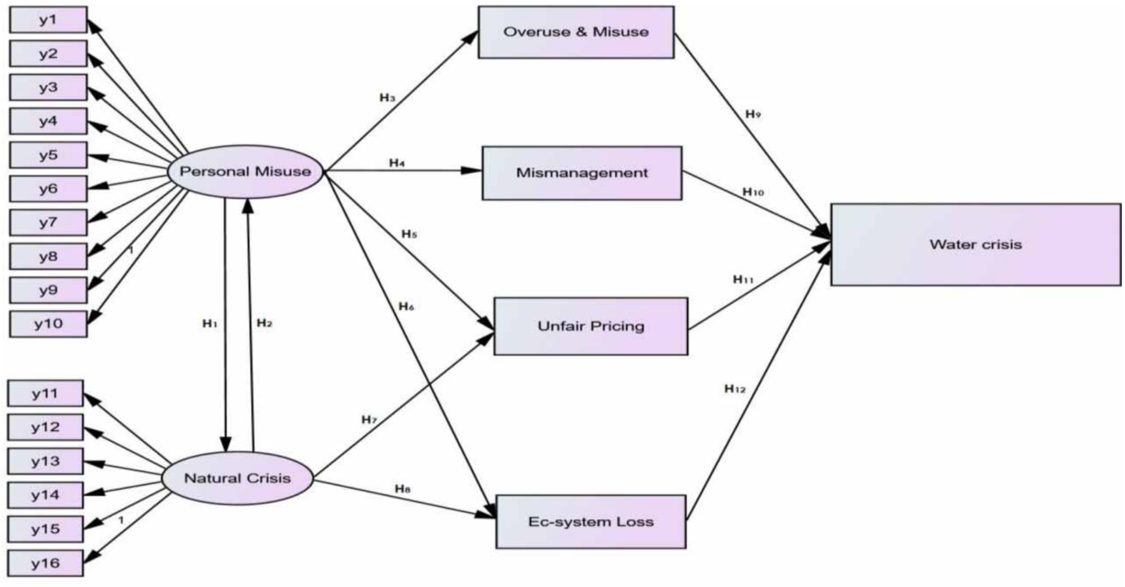

Figure 4 | Conceptual framework of SEM.

H1: Influence of personal misuse latent variable on the natural crisis latent variable.
H2: Influence of natural crisis latent variable on personal misuse latent variable.
H3: Influence of personal misuse latent variable on overuse and misuse endogenous observed variable.
H4: Influence of personal misuse latent variable on mismanagement endogenous observed variable.
H5: Influence of personal misuse latent variable on unfair water pricing endogenous observed variable.
H6: Influence of personal misuse latent variables on ecosystem loss endogenous observed variable.
H7: Influence of the natural crisis latent variable on unfair pricing is the endogenous observed variable.
H8: Influence of natural crisis latent variable on ecosystem loss is the endogenous observed variable.
H9: Influence of overuse and misuse variable on water crisis-dependent variable.
H10: Influence of mismanagement endogenous observe variable on water crisis-dependent variable.
H11: Influence of unfair pricing endogenous observe variable on water crisis-dependent variable.
H12: Influence of ecosystem loss endogenous observed variables on water crisis-dependent variable.

Structural equation model

An SE model is created with 20 endogenous observed variables and two latent variables to justify the water crisis parameters. Under personal misuse latent variables, there are 10 endogenous observed variables; under natural crisis latent variables, there are six endogenous observed variables. In this model, there is no exogenous variable. The SE model is shown in Figure 5.

The following equations can be written from the SE model (Rahman *et al.* 2016),

$$Z = \lambda_0 + \lambda Y + \delta \tag{1}$$

where, Y in Equation (1) represents the two endogenous variables (Y1 and Y2).

$$Y = \alpha\eta + \varepsilon \tag{2}$$

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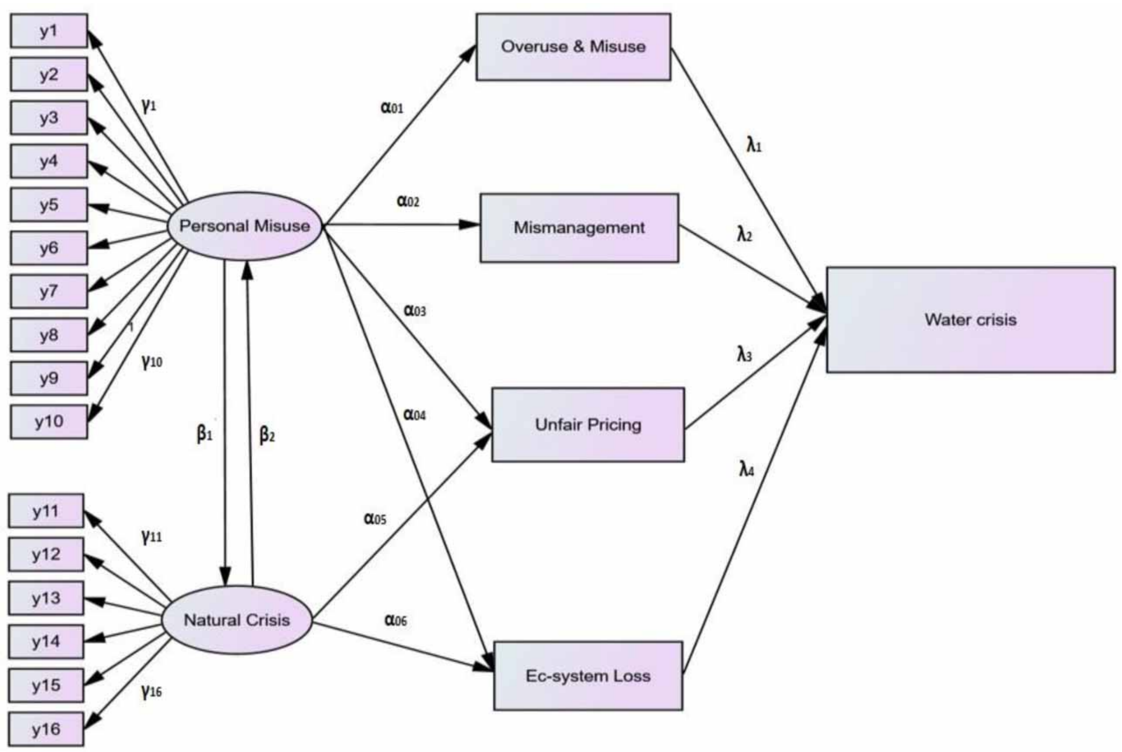

Figure 5 | Structural equation model.

In Equation (2), y represents the continuing eighteen endogenous variables:

$$Y = Y\eta + \rho \tag{3}$$

y or Y = Endogenous observed variables
Z = Dependent variables (water crisis)
λ_0 = Indicates constant value
λ = Co-efficient of endogenous observed variables
η = Latent variables
α = Co-efficient of the latent variables when influencing Y variables
δ = Error in Z-dependent variable
ζ = Error in latent variable
ε = Measurement error in Y
γ (gamma) = Co-efficient of the latent variable when influencing endogenous observed variables.
ρ = Error in endogenous observed variables

RESULTS AND DISCUSSION

KMO and Bartlett's tests define the suitability of the data. From this research, the KMO measure of sampling adequacy value is found to be 0.906 (Table 3), which satisfies the criteria (Karim *et al.* 2020). Cronbach's alpha value defines the data consistency for factor analysis. From this research, Cronbach's alpha value is 0.958, more than 0.6 (Table 4). So, it is observed that the data used in this research are both consistent and suitable for factor analysis (Rahman *et al.* 2016). Our model introduces two latent variables: personal misuse ($\eta 1$) and natural crisis ($\eta 2$). Ten endogenous observed variables are calibrated under the 'personal misuse' latent variable, and six endogenous observed variables are calibrated under the natural crisis latent variable. Initially, it is presumed that there is no direct relationship between the personal misuse and natural crisis latent variables.

Later, these two latent variables are linked using a path diagram, demonstrating a strong impact with a greater significant value on each other (0.85 and 0.21). Among 10 latent variables, water misuse during the shower (y1),

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Table 3 | Preliminary statistics

Kaiser–Meyer–Olkin measure of sampling adequacy	0.906
Bartlett's test of sphericity	
Approx. chi-squared	1,904.385
df	406
Sig.	0.000

Table 4 | Preliminary statistics

Cronbach's alpha	Cronbach alpha based on standardized item	No. of item
0.958	0.963	21

washing dishes (y4), toilet flushing (y5), cleaning food (y8), and water misuse during pool refilling (y9) variables are the most significant. That means that during a shower, washing dishes, toilet flushing, cleaning food and while refilling the pool, water is wasted, which causes the water crisis in Dhaka city. In addition, among six variables under the 'natural crisis' latent variable, the pump capacity (y13) variable is the most significant one. After connecting 'personal misuse' latent variables with overuse and misuse, the endogenous variables of mismanagement, unfair pricing, and ecosystem loss showed statistical significance. Again, the 'natural crisis' latent variable that connected with unfair pricing and ecosystem loss (endogenous variables) also showed higher statistical significance. All the path co-efficient values are shown in Table 5. This result represents the overall outcome of the hypothesis testing the water crisis using SEM. Table 6 displays the fit indices for the SEM.

Table 5 | Path co-efficient of the structural equation model

Item no.	Variable category	Description	Notation	Path co-efficient
1	Endogenous observed variables	Misuse of water during shower	y1	0.75
2		Misuse of water during laundry	y2	0.61
3		Misuse of water during cooking	y3	0.45
4		Misuse of water during washing dishes	y4	0.70
5		Misuse of water during toilet flushing	y5	0.75
6		Misuse of water during washing car	y6	0.32
7		Misuse of water during watering in the garden	y7	0.21
8		Misuse of water during cleaning food	y8	0.89
9		Misuse of water during pool refilling	y9	0.94
10		Misuse of water during tank refilling	y10	0.13
11		Leakage of water tap	y11	0.55
12		Ground water layer depletion	y12	0.42
13		Pump capacity	y13	1.23
14		Increase of salinity	y14	0.37
15		Drying of river bed	y15	0.21
16		Climate changing	y16	0.36
17		Overuse and misuse of water	y17	0.61
18		Mismanagement	y18	0.37
19		Unfair pricing	y19	0.09
20		Ecosystem loss	y20	0.74
21	Latent variables	Personal misuse	$\eta 1$	0.85
22		Natural crisis	$\eta 2$	0.21
23	Dependent variable	Water crisis	Z	N/A

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Table 6 | Fitness of the structural equation model

CFI	NFI	TLI	PNFI	RMSEA	χ^2	df	χ^2/df
0.969	0.958	0.941	0.338	0.033	481.941	175	2.75

Relative importance index (RII)

The SE model justifies the hypothesis based on the relations of variables and their influence on each other. However, RII provides an individual perception of respondents on specific variables. The RII value ranges from 0 to 1. An RII value as high as 1 denotes the higher significant variables (Hoque *et al.* 2021):

$$\mathrm{RII} = \frac{\sum W}{AXN} \tag{4}$$

Here,

W = weighting of each factor given by respondents
A = maximum weight
N = total number of respondents.

An RII value $1 \geq \mathrm{RI} \geq 0.8$ is considered as high, $0.8 \geq \mathrm{RI} \geq 0.6$ as high–medium, $0.6 \geq \mathrm{RI} \geq 0.4$ as medium, $0.4 \geq \mathrm{RI} \geq 0.2$ as medium–low and $0.2 \geq \mathrm{RI} \geq 0$ as low (Rooshdi *et al.* 2018).

Table 7 shows that according to individual perception, misuse of water during a shower (y1), misuse of water during a laundry (y2), misuse of water during washing dishes (y4), and misuse of water during washing cars (y6) are the significant variables that cause the water crisis in Dhaka city under 'personal misuse' latent variable. Under the natural crisis latent variable, 'groundwater decreasing (y12)' contributes significantly.

Table 7 | Summary of mean, standard deviation, RII, and rank of observed variables according to overall

Latent variables	Description	Mean	Standard deviation	RII	Rank
Personal misuse (η1)	Misuse of water during shower (y1)	2.86	0.78	0.95	1
	Misuse of water during laundry (y2)	2.56	0.79	0.92	2
	Misuse of water during cooking (y3)	2.61	0.82	0.69	7
	Misuse of water during washing dishes (y4)	2.75	0.93	0.88	3
	Misuse of water during toilet flushing (y5)	2.60	0.82	0.77	6
	Misuse of water during washing car (y6)	1.98	0.73	0.85	4
	Misuse of water during watering in the garden (y7)	2.70	0.64	0.32	10
	Misuse of water during cleaning food (y8)	2.50	0.75	0.79	5
	Misuse of water during pool refilling (y9)	2.64	0.80	0.67	8
	Misuse of water during tank refilling (y10)	3.20	1.08	0.33	9
Natural crisis (η2)	Leakage of water tap (y11)	3.68	0.98	0.78	2
	Ground water layer depletion (y12)	2.76	0.55	0.98	3
	Pump capacity (y13)	1.65	0.42	0.74	1
	Increase of salinity (y14)	1.83	0.65	0.72	4
	Drying of river bed (y15)	1.56	0.79	0.43	6
	Climate changing (y16)	2.37	1.24	0.66	5

Figure 6 shows that, according to SEM analysis, water misuse during showers (y1), washing dishes (y4), toilet flushing (y5), cleaning food (y8), and water misuse during pool refilling (y9) variables are the most significant variables that cause the water crisis problem in Dhaka city, but RII analysis shows that misuse of water during shower (y1), misuse of water during laundry (y2), misuse of water during washing dishes (y4) and misuse of water during washing cars (y6) are the significant variables. Figure 7 shows that pump capacity (y13) is the most significant variable according to SEM analysis and RII analysis shows that groundwater layer depletion (y12) is the most significant variable that causes the water crisis in Dhaka city.

The research aim was to identify the prime variables that cause the water crisis in Dhaka city. This study shows that water in Dhaka city is generally wasted due to both personal misuse of water (η1) and natural crisis (η2). Data

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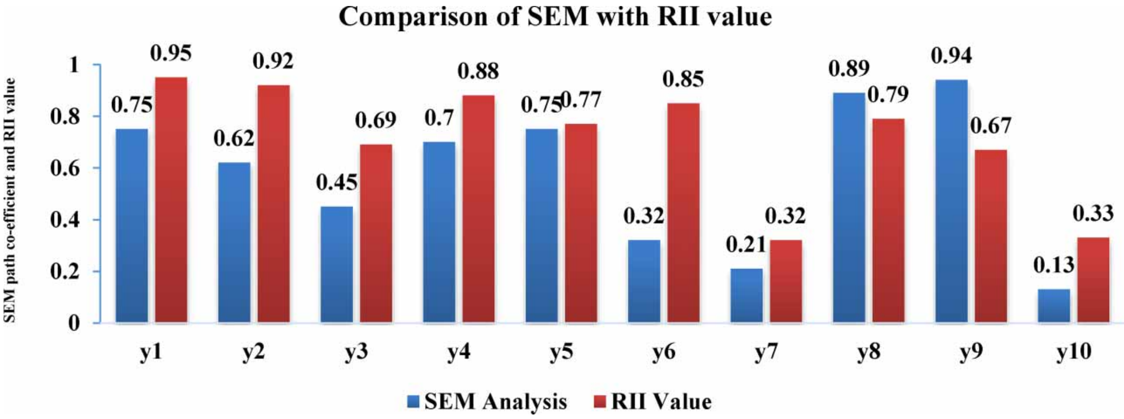

Figure 6 | Comparison of significant variables for SEM analysis and RII under the personal misuse latent variable.

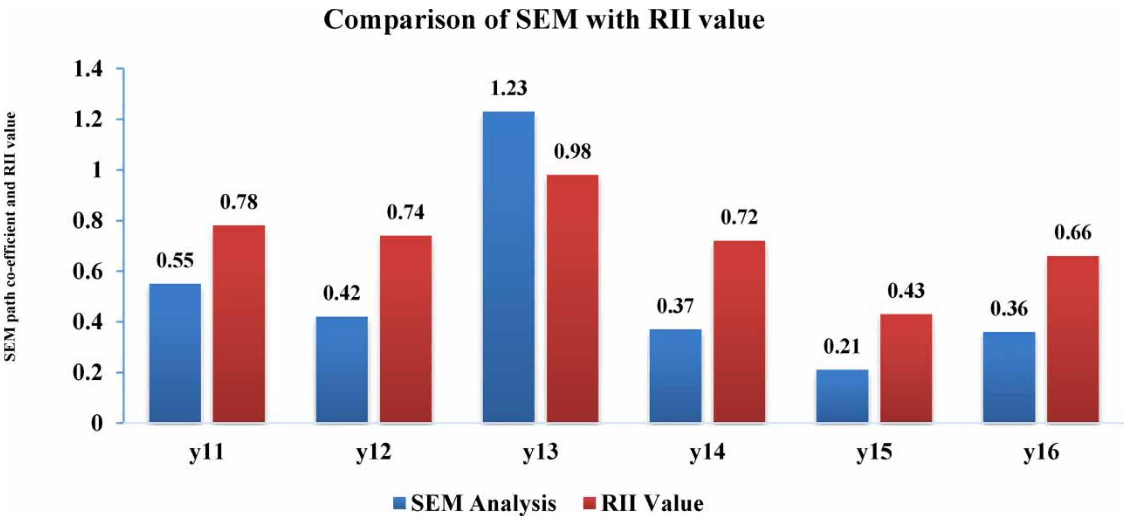

Figure 7 | Comparison of significant variables for SEM analysis and RII under the natural crisis latent variable.

collected for this research are suitable and consistent for factor analysis. Bartlett's test, KMO, and Cronbach's alpha test satisfy the criteria for factor analysis. In Dhaka, city water is wasted due to people's lack of awareness. The main causes of the water crisis are cleaning food (y8) and pool refilling (y9).

Moreover, water is also wasted while taking a shower (y1), washing dishes (y4), and toilet flushing (y5). In Dhaka, WASA-supplied groundwater is the primary water source to fulfil the water demand. This study also found that the groundwater layer is decreasing gradually (y12) and the pump capacity (y13) of WASA is not strong enough to pump water to fulfil the requirement of urban people. The fitness indices of the model are found to be good (CFI = 0.969, NFI = 0.958, RMSEA = 0.033) in this study. Heterogeneity among the respondents may affect the water crisis variables differently. The SE models in this paper are developed considering all types of water users. The effect of water crisis variables is different based on age, gender, occupation and a particular city. The young generation required much water for showers, especially women. Housemaids use more water than the general population for cooking, cleaning food, and washing clothes. Reusing the greywater from the kitchen for toilet flushing will improve resilience against water shortage. Sustainable water management, pollution control, better sewage treatment and, most importantly, water awareness campaigns are the ways for Dhaka city to tackle the water crisis.

CONCLUSIONS

Long-term population pressures in Dhaka, as well as a reliance on groundwater, have contributed to the water crisis. This water issue is mainly caused by the widespread usage of groundwater and the obstruction of natural

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sources. Surface water does not percolate into the groundwater table due to landfilling. However, with all these factors, user behavior and climate change influence water demand in metropolitan areas. Water in Dhaka city is generally wasted due to the personal misuse of water and natural crisis. According to SEM analysis, water misuse during a shower, washing dishes, toilet flushing, cleaning food, and water misuse during pool refilling are the most significant causes of the water crisis problem in Dhaka city. Again, RII analysis results indicate that misuse of water during a shower, misuse of water during laundry, washing dishes and washing the car are the significant causes. Pumping capacity is the most significant variable according to SEM analysis and RII analysis shows that groundwater layer depletion is the most significant variable that causes the water crisis in Dhaka city. This research helps policymakers identify the significant parameters strongly related to water misuse. Eliminating and properly managing these variables will undoubtedly contribute to the solution and ensure water security. Maximum utilization of surface water must be ensured, and no development plan should be pursued that will jeopardize water sources. When combined with integrated water resources management, this research will undoubtedly offer governments a wide framework for aligning water use patterns with the needs and desires of many users, including the environment.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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