Official Journal of the World Water Council
Water Policy





Water Policy Vol 24 No 10, 1676 doi: 10.2166/wp.2022.113

# Identifying determinants of sustainable water management at the household level through rainwater harvesting systems in Nepal

Anusha Thapa[a], Ghanashyam Khanal [b], Sushanta Kumar Mahapatra [c,*], Niranjan Devkota [d], Surendra Mahato [e] and Udaya Raj Paudel [a]

[a] Quest International College, Pokhara University, Lalitpur, Nepal
[b] Presidential Graduate Research Fellow for PhD in Applied Economics (Forestry), Auburn University, Alabama, USA
[c] Department of Economics, IBS Hyderabad, The ICFAI Foundation for Higher Education (IFHE) Deemed University, Dontanapally Campus, Shankerpally Road, Hyderabad, Telangana 501203, India
[d] Quest Research Management Cell, Quest International College, Pokhara University, Lalitpur, Nepal
[e] Nepal Commerce Campus, Tribhuvan University, Minbhawan, Kathmandu, Nepal
*Corresponding author. E-mail: sushanta.mahapatra@ibsindia.org

GK, 0000-0001-6640-6124; SKM, 0000-0002-0831-3621; ND, 0000-0001-9989-0397; SM, 0000-0002-1065-0010; URP, 0000-0002-5234-5081

## ABSTRACT

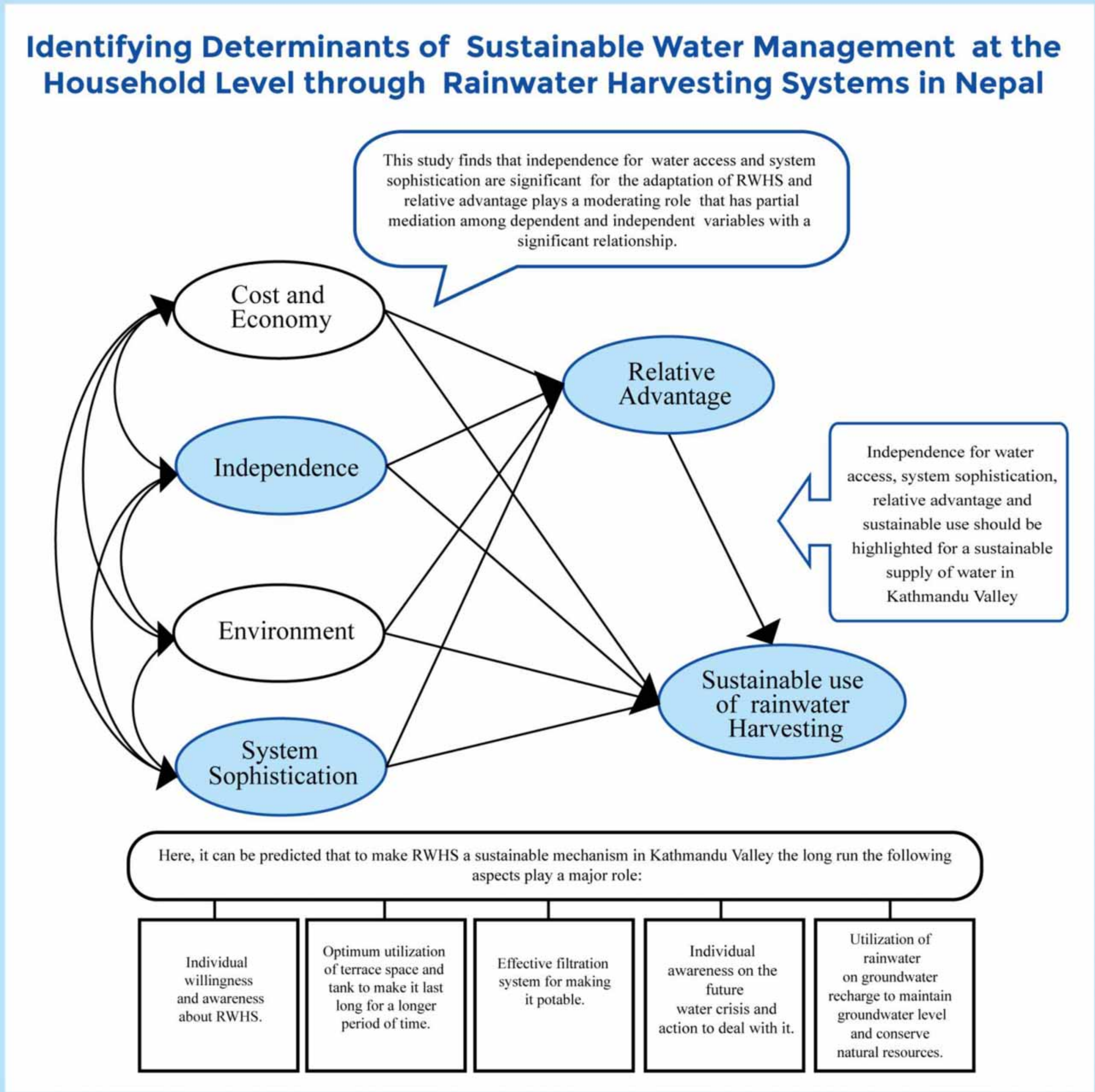
The urban water supply systems around the world are highly stressed at present due to growing water demand caused by rapid population growth and unplanned urbanization. The growing environmental awareness and water supply restrictions have made rainwater harvesting systems (RWHS) a priority as well as a necessity in many countries. To improve urban water security, the practice of an RWHS is increasingly being adopted in the cities and towns of developing countries. This study aims at identifying the factors affecting the adoption of rainwater harvesting for household uses in the Kathmandu valley (KV) of Nepal. The results were drawn from a survey of 405 respondents who reside in the KV. To explain the determinants of adaptation, structural equation modeling (SEM) was used. Results show that independence for water access and system sophistication are significant for the adaptation of RWHS and relative advantage plays a moderating role that has partial mediation among dependent and independent variables with a significant relationship. Thus, variables like independence for water access, system sophistication, relative advantage and sustainable use should be highlighted for a sustainable supply of water. For this, we recommend effective policy interventions at the local and national level for the adoption of RWHS and its advantages in terms of safeguarding water in the long run at the present changing climate scenario.

**Key words:** Kathmandu valley, rainwater harvesting system, structural equation modeling, sustainability, urban water management

## HIGHLIGHT

- Because of environmental awareness and water restrictions, a rainwater harvesting system (RWHS) has become a necessity and a priority in many countries. This study aims to identify factors affecting the adoption of rainwater harvesting for household uses in the Kathmandu valley of Nepal. The results were drawn by surveying 405 respondents who reside in the Kathmandu Valley: Kathmandu, Lalitpur and Bhaktapur districts.

## GRAPHICAL ABSTRACT




## 1. INTRODUCTION

The world today is dealing with the issue of growing pressure on water resources due to increasing population and industrial development (Raut *et al.*, 2021). Proper access to water and sanitation, which is inextricably linked with the availability of water, has become one of the crucial challenges of the 21st century in almost all developing countries. It was reported that more than 750 million people do not have access to better water and over 2.6 billion people feel the absence of basic sanitation in developing countries. For governments throughout the world, it has been a challenging issue to maintain proper access to water supply and sanitation (Krueger *et al.*, 2019; Foster *et al.*, 2020; Kaini *et al.*, 2021; Gleick 1998).

Globally, water demand has tripled since the 1950s, whereas there is a declining rate of fresh water supply (Gurung *et al.*, 2019). Around half a billion people live in countries that are water-scarce and it is predicted that by 2025, the number will grow to three billion because of an increasing population (Hanjra & Qureshi, 2010). In a study, it is reported that per person, 50 L per day of clean water needs to be considered as a fundamental human right (Yang *et al.*, 2021). In developing countries, hundreds of millions of people do not have access to Boiling Water Resistant (BWR) resulting in enormous human suffering (Gleick, 1996). To deal with the water scarcity and work on filling the unmet water demand, many international organizations such as the Water Supply and Sanitation Collaborative Council, the United Nations, the World Bank and international aid organizations have been actively involved (UN Report, 2022).

Rapid urbanization growth in developing nations is habitually accompanied by irresistible demands on current water systems and illegal connections to supply systems in poor neighborhoods (Moe & Rheingans, 2006). Nepal has ~85% coverage in the water supply, with the remaining communities and households that need to be served being remote and in places where groundwater or surface water is not easily accessible (Lanka Rain Water Harvesting Forum, 2014). Kathmandu is the capital of Nepal with a higher population due to urbanization. The water situation in the Kathmandu valley (KV) is dire in terms of availability and quality. Bureaucratic negligence in addressing the situation of water supply and unmanaged urban planning for years has clearly driven the people of Kathmandu towards insufficient and intermittent water supply (Raina, 2017). Despite the potential of rain water harvesting (RWH), its promotion is constrained, probably because of misconceptions regarding rainwater quality and unreliable water supply due to seasonal variation (Hardy *et al.*, 2015).

Several studies have been conducted in the recent past that examined the hydrological feasibility and economic viability of RWHS from South Asia and around the world, and they have analyzed the determinants of adoption and the factors that influence the viability of these systems (Kumar, 2004, 2018; Kumar *et al.*, 2006, 2008; Pacheco & Campos, 2017; Ranaee *et al.*, 2021). Here, we mean RWHS in general, like the construction of RWHS in the natural catchments, rooftop catchments, etc., for irrigation and other purposes. The per capita roof area (Traboulsi & Traboulsi, 2017; Villar-Navascués *et al.*, 2020), the space available for creating storage, rainfall quantum and the pattern of occurrence of rainfall in relation to the water demand pattern and the price/cost of water supplied by the utilities are the key factors that influence the feasibility and viability of these systems in the urban context (Kanno *et al.*, 2021; Snir & Friedler, 2021).

The RWHS has a myriad of benefits. Reddy *et al.* (2020) have shown how supplemental irrigation and water harvesting are the most important and proven technologies for improving crop productivity and the efficient use of water in dryland areas of the semi-arid tropics. A recent study by Nel *et al.* (2017) reported a 55 to 69% reduction of municipal water demand if supplementary water, including rainwater, groundwater and greywater, is employed for nonpotable uses on large properties of more than 1,000 $m^2$. With droughts becoming more pronounced and water resources diminishing, there is a need to move away from reactive management to proactive strategies such as alternative water use, and in this case, RWH can be the best opportunity for supplementing the water supply in urban areas. However, there are plenty of studies which show that RWH systems do not work in semi-arid and arid areas due to low dependability and high cost per $m^3$ of water harvested (Wang *et al.*, 2015; Ammar *et al.*, 2016).

The RWHS was made known to Nepal in 1988 as a pilot project in the middle school of Daungha VDC of Gulmi District, the western part of Nepal, by the initiation of the Rainwater Harvesting Capacity Centre (RHCC), which was established in 2006 with the sole purpose of promoting the technology of rainwater harvesting in Nepal. It provides long-term access to safe water for vulnerable communities, primarily in 'Type 3 areas', where people have no access to the surface water, have no alternative sources such as borehole or spring potential, and/or suffer from restrictions due to poor water quality (Parajuli, 2018).

The RWH system is still new for Nepal as very few people adopt this alternative and those who applied rainwater harvesting mostly adopt the traditional method which is not suitable for drinking because of its low quality. Hence, regular monitoring and awareness programs are necessary for the systematic installation of the RWH system (Khanal *et al.*, 2020). In the case of KV, as most people rely on groundwater, it can be a good mechanism for groundwater recharge.

During a short monsoon period from June to September, around 80% of rainfall occurs, causing flooding in Terai regions, landslides in hilly regions and loss of topsoil (Malla, 2008). At the same time, it also leads to crop failure and heightens food and livelihood insecurity (Gurung & Bhandari, 2009). Because of the lack of irrigation facilities and drying up of water sources, the mountain-dwelling people in Nepal are more vulnerable. In this regard, the need for adoption of the RWH system is increasing as an alternative adaptation strategy (Vidanage *et al.*, 2021).

In the context of the recent growing popularity and reliability of rainwater harvesting systems (RWHS), this study aims to assess the potential of RWHS and identify factors affecting its adoption for household uses in the KV of Nepal. We try to measure the awareness of people regarding the use of RWHS and analyze the determinants affecting the sustainable use of RWHS.

## 2. STUDY AREA

The study area for this research is KV, the capital city of Nepal, including three districts; Kathmandu, Bhaktapur and Lalitpur. KV lies between the latitudes 27°25′30″N to 27°49′30″N north and longitudes 85°10′0″E to 85° 34′0″E east, with the mean elevation of 1,300 m (4,265 feet) above sea level (Rajbhandari *et al.*, 2022). Kathmandu is known as the most crowded city in Nepal. It has a population of 1,52,100 which comprises 24.4% of the total urban population (World Bank, 2022). The findings of the government show that about one-third of the country's economic activities are concentrated in KV (Central Bureau of Statistics, 2012). Having a crowded population, water demand is high in KV; in fact, Kathmandu city has faced an acute water shortage for the last three and half decades (Phuyal *et al.*, 2019). Apart from the modern households, the valley comprises 40 squatters, 5 indigenous settlements and 137 slums in the KV. These groups are facing acute problems with water in terms of quality and quantity (Acharya, 2010; Phuyal *et al.*, 2019). As per Phuyal *et al.* (2020), KV is one of the main cities with the worst water supply systems in Nepal. Seventy per cent of households are connected to *the Kathmandu Upatyaka Khanepani Limited* (KUKL) system (Raina, 2017). The Melamchi Water Transfer Project, which was supposed to supply about 170 million liters of water per day (MLD) in the urban areas of Kathmandu to provide relief from drinking water scarcity to residents of the capital city, is not yet completed and has not started distribution of water (Phuyal *et al.*, 2020). Thus, the scarcity and irregularities in water supply urge alternative sources in the valley (Shrestha, 2017), which led private sectors to promote infrastructure including rooftop tanks, drinking water containers and dispensaries (Rest, 2018). Unfortunately, even today, the water demand and supply are not adequate in KV. Hence, it is necessary to know the factors that are responsible to ensure sustainable and easy use of water via rainwater harvesting in KV (Phuyal *et al.*, 2020). Rainwater harvesting is one of the alternatives. As Khanal *et al.* (2020) noted, if a water supply system is built via RHWS, drinking water sufficiency is possible. Figure 1 shows the study area.

## 3. METHODOLOGY

An exploratory research design was used in the study. The survey questionnaire was used to take interviews with the residents of KV. The survey was conducted through personal interactions and telephone conversations that lasted about 30 min on average per respondent. Following Paudel *et al.* (2020), the sample size formula undertaken for this study is $n = z^2pq/l^2$, where $n$ is the sample size required for the study, a confidence level of 5%,

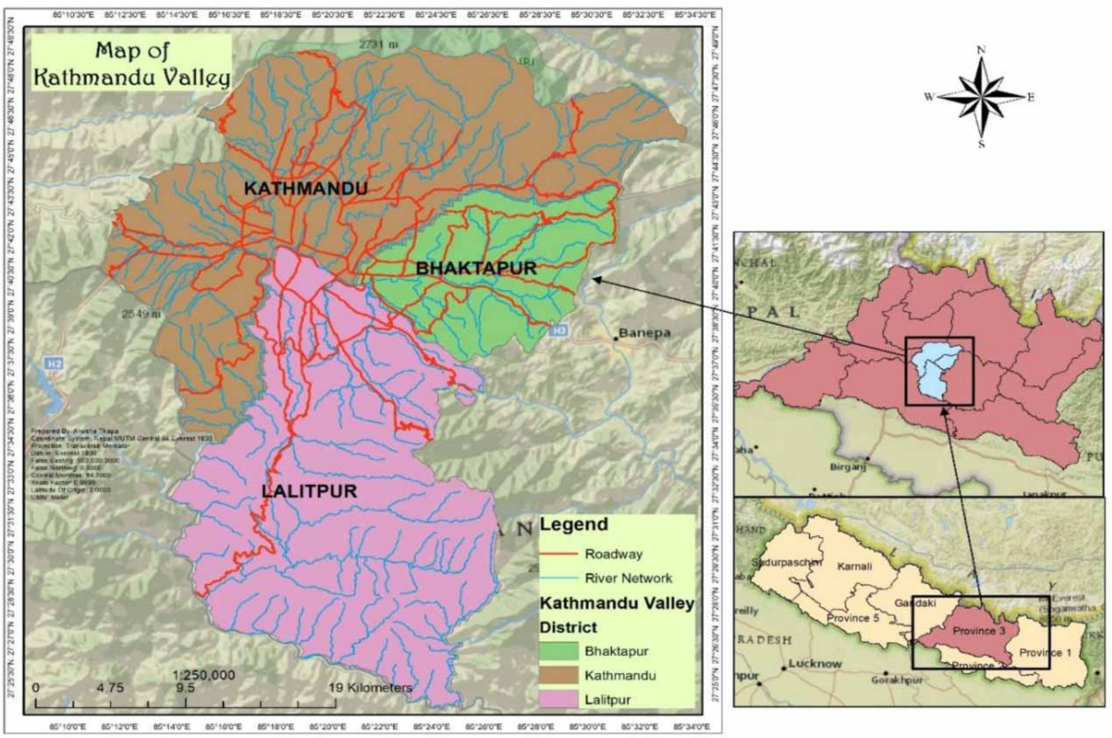



**Fig. 1** | Study area

$p$ is the prevalence or proportion of an event and allowable error that can be tolerated is 5%. With the given value the total population for the study is 284. We add 5% nonresponse error, which gives the total sample population of 403. Thus, following the sample instruction, a total of 405 respondents were purposively selected from three districts. The survey period ranges from December 2020 to January 2021.

Structural Equation Modeling (SEM) is used to test the theoretical model of sustainable water management through a rainwater harvesting system. SPSS and AMOS are used to test the validity and reliability of the composite variables to their indicators. Using SEM, the latent variable and its observed variables are measured and a deliberation of interaction between constructs is made.

Result presentation of SEM may vary from one researcher to another and from one publication to another. While reporting the results of this study, various researchers' viewpoints were taken into consideration (Schumacker & Lomax, 2004; Hadi *et al*., 2016). Anderson & Gerbing (1988) support this method as it delivers a basis to make significant inferences on theoretical constructs and their interrelations as well as avoiding false inferences.

To test the hypothesis under SEM, the following two models are required;

a. Theoretical model
b. Measurement model

Here, *the theoretical model* indicates relations of dependency which are usually accepted to be to some degree causal between the latent variables that are grounded in theory, whereas *the measurement model* represents a group of observable variables as multiple indicators of a smaller set of latent variables. The rationale behind using SEM in the study is that it shows the combined measurement and path models (McDonald & Ho, 2002). Such a type of SEM is frequently used in attitudinal research (Bagozzi & Heatherton, 1994; Frewer *et al*., 2003; Po *et al*., 2005).

## 4. DEVELOPMENT OF THE THEORETICAL MODEL

Research related to rainwater harvesting management for urban supply systems is limited; however, its importance is immense due to the rising water scarcity problem. This research was conducted to know the factors that play a vital role in the sustainable water management system inside KV. Not much research on rainwater has been conducted in Nepal, especially from a management perspective. Previous studies conducted in KV focused on urban water management and groundwater. To mitigate water scarcity, rainwater harvesting could be one alternative among many (Saraswat *et al*., 2017; Shrestha *et al*., 2020).

Most of the studies conducted on rainwater harvesting aim to see its importance from various aspects. In the cases of West Africa and Ghana, where rainwater harvesting has been conducted for household use, the fact that the use of the RWH system helps eliminate the need for extensive and expensive household connections to main distribution lines (Opare, 2012). Similarly, Song *et al*. (2009) mentioned that in Banda Aceh, Indonesia, most households have to face high water costs and are searching for an alternative solution. It was analyzed that the rainwater harvesting system was viable in the case of the social aspect and technical aspect as well as being cost-effective. Rainwater usage can promote substantial potable water savings in many parts of the world if it is well harnessed (Aladenola & Adeboye, 2010; Rahman *et al*., 2012).

Most of the research relating to urban life focuses on social transformation. Through literature review, various theories were identified that could be linked with RWH adoption. Among them, the two most important theories that fit best with this research were Ecological Modernization (EM) and the Diffusion of Innovation (DI). The EM perspective locates households as consumers in a market accepting an attempt towards the utilization of sustainable technologies. DI suggests a multi-stage process model that explains how new and innovative technologies become mainstream. These two theories explore decentralized environmental technology adoption (Ward *et al*., 2012).

Based on the literature review, the factors contributing to the sustainable use of rainwater were pulled down to three major factors, namely independence, system sophistication and relative advantage. A hypothesis based on these factors is discussed below. SEM methods will be used for examining the null hypothesis that there is no relationship between the constructs for reasons of testability.

### 4.1. Independent access to water leads to the relative advantage

The relationship between the independence factor and relative advantage has not been tested previously, so in this study we have tried to address this issue. Relative advantage acts as a mediating factor among independence and sustainable use. It is important to know whether ease of operation and more control over water means there is a relative advantage of rainwater in comparison to other available alternatives.

**Hypothesis 1**: There is a positive relationship between independent access to water and the relative advantage of rainwater.

### 4.2. System sophistication leads to the relative advantage

The test of the relationship between system sophistication and its role in providing the relative advantage over other alternatives is a new one which previous research has ignored. For sustainability, it is important to determine whether technology advancement and standardization could provide a change in the choice of alternative sources or not.

**Hypothesis 2**: There is a positive relationship between the sophistication of the RWH system and the relative advantage of rainwater harvesting.

### 4.3. Independence leads to sustainable use

We try to observe the relationship between independent factors and the sustainable use of rainwater. Benefits could be achieved through freedom from restriction, not having to rely on others, and to have control over our needs. To make sustainable use, it is important to know how much easy access a person can get (Ward *et al.*, 2012).

**Hypothesis 3**: There is a positive relationship between independent factors and the sustainable use of rainwater harvesting.

### 4.4. System sophistication leads to sustainable use

The relationship between system sophistication and sustainable use has not been tested before in the context of rainwater harvesting. Any approach or idea could last a long time if it could provide comfort and quality service to its users (Setiawati *et al.*, 2013).

**Hypothesis 4**: There is a positive relationship between system sophistication and the sustainable use of rainwater.

### 4.5. Relative advantage leads to sustainable use

Relative advantage concerns the convenience perceived by the people through RWHS adoption. This construct was modified as it acts as a mediating factor while addressing the advantages of RWHS technologies, which are relatively superior in comparison to other alternative water supply technologies (White, 2010).

**Hypothesis 5**: There is a positive relationship between the relative advantages of rain and the sustainable use of rain.

### 4.6. Cost and economy lead to relative advantage

The relationship between cost and economy, and relative advantage, is one of the major constraints limiting RWHS adoption and integration, particularly in emerging economies with low incomes. It is important to know whether the minimum cost associated with RWH installation provides a relative advantage in purchasing and using RWH by households.

**Hypothesis 6:** There is a positive relationship between cost and economy and the relative advantages of rainwater harvesting.

### 4.7. Cost and economy lead to sustainable use

We are attempting to observe the relationship between cost and economy and the sustainable use of rainwater. The installation, operation and maintenance costs are associated with the rainwater harvesting system. It is critical to understand the cost-effectiveness of RHWS for local residents in order to make sustainable use of it.

**Hypothesis 7**: There is a positive relationship between cost and economy and the sustainable use of rainwater.

### 4.8. Environment leads to relative advantage

The relationship between the environment and relative advantage has never been investigated before, thus we attempted to do so in this study. Increased environmental awareness encourages the adoption of pro-environmental technology and behaviors, which gives relative advantages for RWH adoption.

**Hypothesis 8**: There is a positive relationship between the environmental awareness of pro-environmental techniques and the relative advantages of rainwater.

### 4.9. Environment leads to sustainable use

This study looked at the link between environmental awareness and the sustainable use of rainwater since it could lower the pressure of processed supply water and enhance green living.

**Hypothesis 9**: There is a positive relationship between environmental awareness and the sustainable use of rainwater.

Figure 2 shows hypotheses regarding the sustainable use of rainwater, which is used in the form of latent constructs. The path described in the hypotheses is indicated by the arrow. All the indicated arrows show the positive relationship among the latent constructs. This model is modified from White (2010), which is based on diffusion theory and EM theory, and shows factors affecting household adoption of RWHS, whereas this study focuses on the sustainable use of rainwater to mitigate future water scarcity problems.

## 5. MEASUREMENT MODEL

For the process of SEM, the next step is to explain the measurement model. The main purpose of this model is to define how well-observed variables act as measurement instruments for latent variables. Each latent variable includes observed variables that describe the data well. The latent variables included in this study are shown in Table 1.

All the observed variables are measured on a five point Likert scale where 1 = strongly disagree to 5 = strongly agree. This scale was selected to make the respondents provide answers in an easy way over the phone and through face-to-face interaction. While analyzing through the Likert scale, the scores of all questionnaire items are added at the end to create a combined score which logically measures a unidimensional trait in totality (Joshi *et al*., 2015).

For SEM models, the optimum number of observed variables (indicators) to be used is widely debated among researchers. Historically, researchers suggested applying four indicators per latent variable. Nonetheless, the minimum number of indicators required for identification is usually two, and numerous cases of models with this characteristic can be found (Williams & Holahan, 1994). On the other side, many researchers also argue that a minimum number of indicators can only be one. Using a single indicator for analysis is supposed to increase the probability of getting a solution that is not feasible (Hurlimann *et al*., 2008). Both single and multiple indicators are used in research by Hurlimann *et al*. In the case of this study, multiple indicators are used, i.e., a minimum of two and a maximum of three, to define constructs.

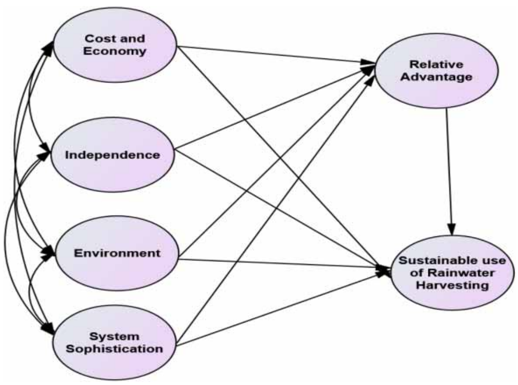



**Fig. 2** | Theoretical model of sustainable water management with RWH.

**Table 1** | Latent variables and their definitions for SEM of sustainable water management with a RWHS.

| Latent variables | Definition of variables |
|---|---|
| Independence | For households, RWH system installation's principle benefits could be freedom of action from the main water supply system, comprising confinements on volumetric and temporal uses (White, 2010). |
| System sophistication | Rainwater harvesting systems differ in their competences, such as treatment commands, which permit a more extensive extent of end uses, the choice of appropriate technology for limited space and the obligation for investment and social involvement (Setiawati *et al*., 2013). |
| Relative advantage | The advantages of convenience are perceived by the users through the adoption of RWH facilities. This construct was modified to act as a mediating factor for factors affecting RWH adoption (White, 2010). |
| Sustainable use | Sustainability focuses on long-term applicability that is directly influenced by consistency in water supply systems, technical ease and community involvement (Masduqi *et al*., 2010). |
| Cost and economy | The cost–benefit is an influential part in an innovation adoption decision having a lower initial outlay as a barrier to entry and likely to adoption and continuous monetary benefit as conducive to continuity. Not only it is costly but the government also plays a vital role in the economy (Setiawati *et al*., 2013). |
| Environment | With the growing environmental awareness regarding the future consequences and supporting actions to mitigate them, individual and households work to diminish their environmental footprints, by encouraging the adoption of pro-environmental technologies (Hurlimann *et al*., 2008). |

Construct reliability was applied to analyze scale reliability for each latent variable. The estimation of true reliability generated by construct reliability was, on average, larger than that produced by Cronbach's alpha. Cronbach's alpha is traditional, while construct reliability is more applicable. There are certain methodological differences between calculating the two coefficients (coefficient alpha is a constrained version of construct reliability). To identify conditions leading to values of coefficient alpha being larger than values of construct reliability, more research is needed (Peterson & Kim, 2013). The CR value needs to be more than or equal to 0.7 to be reliable. Here, the value of the three constructs is perfectly reliable while one construct value, i.e., sustainability, is close to 0.7, which is considerable. A generally accepted rule is that the CR value between 0.6 and 0.7 signifies an acceptable level of reliability and 0.8 or greater signifies a very good level (Ursachi *et al*., 2015).

The most faced problem in SEM is the missing data. In the study, fortunately, there is no missing data. The AMOS program accepts all the processes without any errors. A confirmatory factor analysis (CFA) approach was used to measure the validity and reliability of Likert questionnaires. The Likert questionnaire shown in Table 2 involves all the observed variables of the endogenous, exogenous and mediating variables. The measurement model is fundamentally tested using a CFA, which is grounded in knowledge of theory and empirical research. Previously assumed hypotheses between the observed measures and the underlying factors are statistically tested (Schreiber *et al*., 2006). To evaluate model fit, CFA was attempted using AMOS as the measurement model. The fit statistics for the measurement model presented in Table 3 signify that the data fit well in the measurement model. Likewise, the measures of errors were uncorrelated, which allows headway towards the next step of the SEM process.

## 6. THE STRUCTURAL MODEL

The structural model is a blend of the theoretical model and the measurement model, associating the hypothesized relationships between the latent variables, their observed variables and their associated errors. Hypothesis testing is done through structural model analysis. The AMOS 24 program is used to test the model fit method to estimate parameters. While applying SEM, the major step is to assess the goodness of fit of the

**Table 2** | Latent variables and their reliability as used in the SEM of sustainable water management with RWH.

| Latent variables | Q. No. | Measuring indicators | Mean (standard deviation) | CR |
|---|---|---|---|---|
| Independence | 1 | Additional water supplied by the tank through rainwater will allow us to ease access to household water consumption. | 3.64 (0.69) | 0.76 |
| | 2 | We don't need to rely solely on the main water supply connecting, and when and where to access it. | 3.59 (0.77) | |
| | 3 | We want to install a rainwater harvesting tank to have more control over the water use. | 3.84 (0.59) | |
| System sophistication | 4 | We can use rainwater for nonpotable purposes without any advanced treatment. | 3.42 (0.74) | 0.73 |
| | 5 | Incorporating RWH for potable use using standard technology. | 3.75 (0.61) | |
| | 6 | Technological innovation impact on the decisions regarding household adoption. | 3.85 (0.55) | |
| Relative advantage | 7 | RWH can be as competitive as other alternative water supply technologies in terms of cost. | 3.93 (0.58) | 0.78 |
| | 8 | Globalized advanced technologies lead to the rise in demand for RWH systems. | 4.03 (0.60) | |
| | 9 | RWH is better than any other alternative for household water supply, like a bore. | 3.88 (0.67) | |
| Sustainable use | 10 | Individual households should be responsible for the decision for installing rainwater tank, not the government. | 3.92 (0.60) | 0.69 |
| | 11 | RWH is a perfect medium for conservation and sustainable use of water. | 4.01 (0.46) | |
| Cost and economy | 12 | Installing a RWH system is a one-time investment. | 3.37 (0.81) | 0.929 |
| | 13 | The cost of a rainwater tank is worth the investment. | 3.47 (0.80) | |
| | 14 | The prospect of a rise in demand for mains water rates makes the use of rainwater a necessity. | 3.52 (0.83) | |
| Environment | 15 | It is the household's role for conserving water to minimize water scarcity. | 3.36 (0.72) | 0.852 |
| | 16 | RWH adoption for urban flood control. | 3.20 (0.70) | |
| | 17 | Reducing and conserving high-quality tap water for nondrinking purposes. | 3.31 (0.67) | |

**Table 3** | Fit statistics for the SEM of sustainable water management with RWH.

| Fit statistics | Value |
|---|---|
| CMIN/DF | 2.015 |
| RMR | 0.020 |
| GFI | 0.936 |
| RMSEA | 0.050 |
| CFI | 0.973 |
| IFI | 0.973 |
| TLI | 0.965 |

proposed model with the data. When maximum likelihood is applied for model estimation, the likelihood ratio (LR) test statistic is considered as the most commonly used tool for evaluating the overall goodness of fit (Shi *et al.*, 2019). Results for the multiple fit statistics used for the analysis of the SEM are provided in Table 3.

The given absolute fit statistics of the overall model illustrated a good fit with acceptable fit indices. The model predicts observed covariance well.

Comparing our result with the previous one by Masduqi *et al.* (2010) on the sustainability of rural water supply systems, the values of RMR, RMSEA, GFI, TLI, IFI, CFI and CMIN/DF are perfectly fit.

Furthermore, for the model's overall fit statistics, AMOS generates estimates of regression weights between parameters in the SEM, which include dependent, independent and mediating variables, their associated standard errors, critical ratios and *P* value. These statistics are used to test the hypotheses that were assumed. Table 4 depicts these results (see Figure 3).

**Table 4** | Regression weight between parameters of the SEM sustainable water management with RWHS.

| Parameters | Estimate | Standard error | Critical ratio | *P* |
|---|---|---|---|---|
| Relative advantage ← independence | .207 | .043 | 4.854 | 0.00 |
| Relative advantage ← system sophistication | .367 | .045 | 8.149 | 0.00 |
| Sustainable use ← independence | .198 | .042 | 4.736 | 0.00 |
| Sustainable use ← system sophistication | .070 | .022 | 3.182 | 0.02 |
| Sustainable use ← relative advantage | .204 | .047 | 4.306 | 0.00 |
| Relative advantage ← cost and economy | 0.161 | 0.035 | 4.601 | 0.00 |
| Sustainable use ← cost and economy | 0.044 | 0.044 | 0.992 | 0.321 |
| Relative advantage ← environment | 0.100 | 0.045 | 2.226 | 0.026 |
| Sustainable use ← environment | 0.152 | 0.056 | 2.710 | 0.007 |

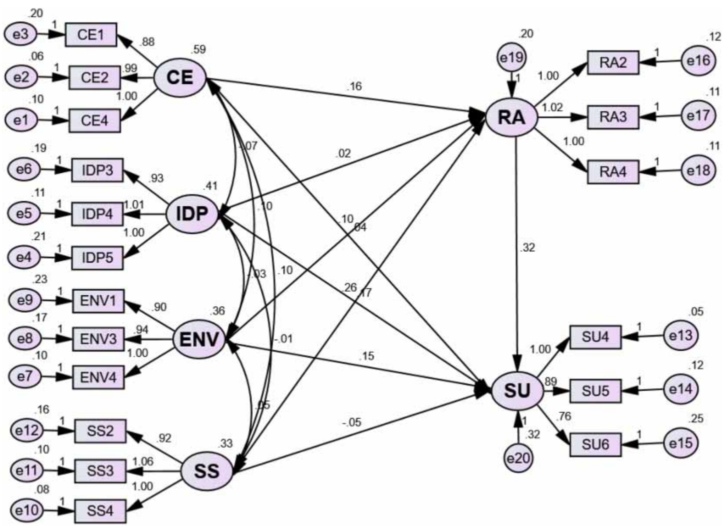



**Fig. 3** | Estimates for the variables in the SEM of sustainable water management with RWH. ***indicates significance at the $P < 0.01$. **indicates significance at the $P < 0.05$.

The null hypothesis of no relationship among variables were rejected as suggested in Table 5, the result shows the role of the independence factor, system sophistication, cost and economy, environment and relative advantage towards the sustainable use of rainwater. It indicates that relative advantages being a mediating factor is important to keep in consideration while measuring the impact of one factor on another. The result shows whenever there is an increase in the independence factor of rainwater harvesting, it will raise sustainability by 0.207. A similar interpretation goes with the regression weight of other variables.

According to Setiawati *et al.* (2013)'s study on sustainable wastewater, all exogenous latent variables seem to influence sustainability directly (with the value at 0.156 on the selection of technology), which explains that whenever there is an increase in Technology Selection (TS), it will raise the Sustainability (S) of 0.156. For other latent variables, a similar analysis was made.

The limitation of this study is that the majority of respondents are nonusers of the RWH system, which indicates a smaller number of respondents are well aware of its technicality based on their own experiences. At the same time, this limitation could also play a vital role as it can provide opportunities for the community to explore the factors of rainwater such as socio-environmental, financial, and technical. This will help to raise people's concern about the water supply management, pressurizing government to acquire new policies for the betterment of the water supply system in KV.

## 7. IMPLICATIONS

Results generated from this study give some insights into what factors lead to the sustainability of use of RWHS. Thus, these factors can also be essential to maintain the urban water supply system in KV.

The result obtained from SEM suggests that those who want freedom of action and control over their water resources are likely to adopt the rainwater harvesting system and perceive rainwater to be a better alternative

**Table 5** | Summary of hypotheses accepted and rejected.

| Hypothesis number | Hypothesis | Accept or reject hypothesis? |
|---|---|---|
| 1 | There is a positive relationship between independent access to water and the relative advantage of rainwater. | Accept |
| 2 | There is a positive relationship between 'system sophistication' and the relative advantage of rainwater. | Accept |
| 3 | There is a positive relationship between the independence factor and the sustainable use of rainwater | Accept |
| 4 | There is a positive relationship between system sophistication and the sustainable use of rainwater. | Accept |
| 5 | There is a positive relationship between the relative advantages of rainwater and sustainable use of rainwater | Accept |
| 6 | There is a positive relationship between cost and economy and the relative advantages of rainwater harvesting. | Accept |
| 7 | There is a positive relationship between cost and economy and sustainable use of rainwater. | Reject |
| 8 | There is a positive relationship between environmental awareness of pro-environmental techniques and the relative advantages of rainwater. | Accept |
| 9 | There is a positive relationship between environmental awareness and the sustainable use of rainwater. | Accept |

when access to other sources of water supply is restricted. This also indicates that it has more advantages over other alternatives.

Likewise, the result indicates that those who are more concerned with the quality aspects could adopt the system if potable water standards are maintained in the system. System sophistication not only focuses on health aspects but also focuses on reliability in operation. The rainwater harvesting option can be superior to other alternatives provided there is sufficient rain and there is a large catchment area. When the conditions with respect to these issues are not favorable, the system may not be viable. Therefore, families who have a large catchment area (rooftop) can benefit most from an RWHS.

Moreover, the SEM result shows that as long as people find other alternatives easy to access and cost-friendly, it is difficult to maintain the use of rainwater harvesting in the long term. Individuals are the end-user, so people themselves need to realize its importance/usefulness. Global acceptance of rainwater harvesting systems helps to change people's perceptions in a positive direction, which also leads to an increased number of users in the time to come.

Here, it can be predicted that to make RWHS a sustainable mechanism in the long run, the following aspects play a major role:

- Individual willingness and awareness about RWHS.
- Optimum utilization of terrace space and tank to make it last for a longer period of time.
- Effective filtration system for making it potable.
- Individual awareness of the future water crisis and action to deal with it.
- Utilization of rainwater on groundwater recharge to maintain groundwater level and conserve natural resources.

## 8. CONCLUSION

This paper presents the factors influencing the sustainable use of rainwater harvesting using SEM. Rainwater harvesting is not a new concept; however, the method of collection and utilization of rainwater has changed over time, making it more systematic. The water situation in KV is dreadful in terms of the availability and quality of the water supplied. Unscientific urban planning has resulted in inadequate and intermittent water supply to the residents of Kathmandu and the policymakers have not been seriously involved in the formation of effective policies and their proper implementation for mitigating these problems. Despite the potential of rainwater harvesting, sufficient promotion and policies seem to be lacking from the government side.

The study's focus was to analyze the key factors influencing the sustainable use of rainwater harvesting systems. The result of this study reveals the relevance of the given factors. Independence factor shows that for sustainable use of rainwater ease of obtaining water, multiple choice options and control over water sources plays an influential role. In the case of system sophistication, knowledge of water treatment for different purposes, use of standard tools and technical innovation all play a major role in social transformation, hence leading to the sustainable use of rainwater. Relative advantage plays a mediator role in which competitive features, global acceptance, and better alternative features lead to making the source superior. Through sustainable use, individual roles for willingness and conservation purposes are the selected manifest variables. By conducting statistical testing, it was found that independence has a significant influence on relative advantage and sustainable use. System sophistication has a significant influence on relative advantage and sustainable use. Similarly, relative advantage has a significant influence on the sustainable use of rainwater.

The model informs us about maintaining each natural resource and utilizing it for better purposes rather than moving it to drainage. Government authorities, concerned institutions and individuals should be aware of and responsible for proper urban water supply, maintaining water quality and groundwater level. The Nepalese government should promote RWH through posters by making it mandatory for new buildings like Chennai city in the Tamil Nadu state of India. To stop groundwater depletion, Tamil Nadu was the first state since 2001 to make rainwater harvesting mandatory for all buildings in its rural areas. The concern of every stakeholder will provide better outcomes, i.e., dealing with water scarcity and managing RWHS at its optimum level by decreasing the risk of perception and realizing its importance for sustainable urban water supply.

## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

## CONFLICT OF INTEREST

The authors declare there is no conflict.

## REFERENCES


Acharya, B. R. (2010). Urban poverty: a sociological study of Shankhamul squatter. *Dhaulagiri Journal of Sociology and Anthropology 4*, 179–192.

Aladenola, O. O. & Adeboye, O. B. (2010). Assessing the potential for rainwater harvesting. *Water Resources Management 24*(10), 2129–2137. https://doi.org/10.1007/s11269-009-9542-y.

Ammar, A., Riksen, M., Ouessar, M. & Ritsema, C. (2016). Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: a review. *International Soil and Water Conservation Research 4*(2), 108–120.

Anderson, J. C. & Gerbing, D. W. (1988). Structural equation modeling in practice: a review and recommended two-step approach. *Psychological Bulletin 103*(3), 411–423. https://doi.org/10.1037/0033-2909.103.3.411.

Bagozzi, R. P. & Heatherton, T. F. (1994). A general approach to representing multifacted personality constructs: application to state self-esteem. *Structural Equation Modelling 1*(1), 35–67.

Central Bureau of Statistics (2012). *National Population and Housing Census*. Central Bureau of Statistics, Kathmandu.

Foster, S., Eichholz, M., Nlend, B. & Gathu, J. (2020). Securing the critical role of groundwater for the resilient water-supply of urban Africa. *Water Policy 22*(1), 121–132.

Frewer, L. J., Scholderer, J. & Bredahl, L. (2003). Communication about the risks and benefits of genetically modified foods: the mediating role of trust. *Risk Analysis 23*(6), 1117–1134.

Gleick, P. H. (1996). Basic water requirements for human activities: meeting basic needs. *Water International 21*(2), 83–92. https://doi.org/10.1080/02508069608686494.

Gleick, P. H. (1998). The human right to water. *Water Policy 1*(5), 487–503. https://doi.org/10.4324/9781315651132.

Gurung, G. B. & Bhandari, D. (2009). Integrated approach to climate change adoption. *Journal of Forest and Livelihood 8*(1), 91–99.

Gurung, A., Adhikari, S., Chauhan, R., Thakuri, S., Nakarmi, S., Ghale, S., Dongol, B. S. & Rijal, D. (2019). Water crises in a water-rich country: case studies from rural watersheds of Nepal's mid-hills. *Water Policy 21*(4), 826–847.

Hadi, N. U., Abdullah, N. & Sentosa, I. (2016). An easy approach to exploratory factor analysis: marketing perspective. *Journal of Educational and Social Research*. (February). https://doi.org/10.5901/jesr.2016.v6n1p215.

Hanjra, M. A. & Qureshi, M. E. (2010). Global water crisis and future food security in an era of climate change. *Food Policy 35*(5), 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006.

Hardy, D., Cubilo, F., Han, M. & Li, H. (2015). *Alternative Water Resources: A Review of Concepts, Solutions and Experiences*. International Water Association, London.

Hurlimann, A., Hemphill, E., McKay, J. & Geursen, G. (2008). Establishing components of community satisfaction with recycled water use through a structural equation model. *Journal of Environmental Management 88*(4), 1221–1232.

Joshi, A., Kale, S., Chandel, S. & Pal, D. K. (2015). Likert scale: explored and explained. *British Journal of Applied Science & Technology 7*(4), 396–403. https://doi.org/10.9734/bjast/2015/14975.

Kaini, S., Nepal, S., Pradhananga, S., Gardner, T. & Sharma, A. K. (2021). Impacts of climate change on the flow of the transboundary Koshi River, with implications for local irrigation. *International Journal of Water Resources Development 37*(6), 929–954.

Kanno, G. G., Lagiso, Z. A., Abate, Z. G., Areba, A. S., Gondol, B. N., Temesgen, H., Wyk, R. V. & Aregu, M. B. (2021). Estimation of rainwater harvesting potential for emergency water demand in the era of COVID-19. The case of Dilla town, Southern, Ethiopia. *Environmental Challenges 3*, 100077.

Khanal, G., Thapa, A., Devkota, N. & Paudel, U. R. (2020). A review on harvesting and harnessing rainwater: an alternative strategy to cope with drinking water scarcity. *Water Supply 20*(8), 2951–2963. https://doi.org/10.2166/ws.2020.264.

Krueger, E., Rao, P. S. C. & Borchardt, D. (2019). Quantifying urban water supply security under global change. *Global Environmental Change 56*, 66–74.

Kumar, M. D. (2004). Roof water harvesting for domestic water security: who gains and who loses? *Water International 29*(1), 43–53.

Kumar, M. D., (2018). Thanking 'rainwater harvesting' and blaming the Rain God. In *Water Policy Science and Politics*. Kumar, M. D. (ed.), pp. 141–153. https://doi.org/10.1016/B978-0-12-814903-4.00009-9.

Kumar, M. D., Ghosh, S., Patel, A., Singh, O. P. & Ravindranath, R. (2006). Rainwater harvesting in India: some critical issues for basin planning and research. *Land Use and Water Resources Research 6*, 1–17(1732-2016-140267).

Kumar, M. D., Patel, A. & Singh, O. P. (2008). Rainwater harvesting in the water-scarce regions of India: potential and pitfalls. *Strategic Analyses of the National River Linking Project (NRLP) of India Series 2*, 289.

Lanka Rain Water Harvesting Forum (2014). Symposium on mainstreaming rainwater harvesting as a water supply option. Mainstreaming Rainwater Harvesting as a Water Supply Option, 92. Available at: http://www.lankarainwater.org/pubs/brochures/Final_CD_Book.pdf#page=88

Malla, G. (2008). Climate change and its impact on Nepalese agriculture. *The Journal of Agriculture and Environment 9*(7), 62–71.

Masduqi, A., Endah, N., Soedjono, E. S. & Hadi, W. (2010). Structural equation modeling for assessing of the sustainability of rural water supply systems. *Water Science and Technology: Water Supply 10*(5), 815–823. https://doi.org/10.2166/ws.2010.339.

McDonald, R. P. & Ho, M.-H. R. (2002). Principles and practice in reporting structural equation analysis. *Psychological Methods 7*(1), 64–82.

Moe, C. L. & Rheingans, R. D. (2006). Global challenges in water, sanitation and health. *Journal of Water and Health 4* (SUPPL. 1), 41–58. https://doi.org/10.2166/wh.2005.039.

Nel, N., Jacobs, H. E., Loubser, C. & Du Plessis, K. J. (2017). Supplementary household water sources to augment potable municipal supply in South Africa. *Water SA 43*, 553. doi:10.4314/wsa.v43i4.03.

Opare, S. (2012). Rainwater harvesting: an option for sustainable rural water supply in Ghana. *GeoJournal 77*(5), 695–705. https://doi.org/10.1007/s10708-011-9418-6.

Pacheco, G. C. R. & Campos, M. A. S. (2017). Economic feasibility of rainwater harvesting systems: a systematic literature review. *Journal of Water Supply: Research and Technology – Aqua 66*(1), 1–14.

Parajuli, I. (2018). Potential and practices of rainwater harvesting system in Nepal. In *Smart Water Grid International Conference. Conference Paper*, 12–13 November 2018, Incheon, Republic of Korea.

Paudel, U. R., Parajuli, S., Devkota, N. & Mahapatra, S. K. (2020). What determines customers' perception of banking communication? An empirical evidence from commercial banks of Nepal. *Global Economy Journal 20*(04), 1–21.

Peterson, R. A. & Kim, Y. (2013). On the relationship between coefficient alpha and composite reliability. *Journal of Applied Psychology 98*(1), 194–198. https://doi.org/10.1037/a0030767.

Phuyal, R. K., Rojita, M., Rajesh, M. & Devkota, N. (2019). Assessments of drinking water supply quality at squatter and indigenous settlements of Bagmati River Corridors in Kathmandu. *Scientific Research and Essays 14*(8), 53-67.

Phuyal, R. K., Bhattarai, M. & Devkota, N. (2020). Dynamics of financing, governance and socioeconomic benefits of Melamchi water supply project in Nepal: lessons learnt. *Modern Economy 11*(7), 1359–1375.

Po, M., Nancarrow, B. E., Leviston, Z., Poter, N. B., Syme, G. J. & Kaechcer, J. D. (2005). *Predicting Community Behaviour in Relation to Wastewater Reuse: What Drives Decisions to Accept or Reject?* CSIRO, Perth.

Rahman, A., Keane, J. & Imteaz, M. A. (2012). Rainwater harvesting in greater Sydney: water savings, reliability and economic benefits. *Resources, Conservation and Recycling 61*, 16–21. https://doi.org/10.1016/j.resconrec.2011.12.002.

Raina, A. (2017). Inequities in household water consumption in Kathmandu, Nepal. *Global Water Forum* 1–10. Available at: http://www.globalwaterforum.org/2017/12/04/inequities-in-household-water-consumption-in-kathmandu-nepal/

Rajbhandari, S., Devkota, N., Khanal, G., Mahato, S. & Paudel, U. R. (2022). Assessing the industrial readiness for adoption of industry 4.0 in Nepal: a structural equation model analysis. *Heliyon 8*(2), e08919.

Ranaee, E., Abbasi, A. A., Tabatabaee Yazdi, J. & Ziyaee, M. (2021). Feasibility of rainwater harvesting and consumption in a middle eastern semiarid urban area. *Water 13*, 2130. https://doi.org/10.3390/w13152130.

Raut, N., Shayka, A., Gurung, S. S. & Dahal, B. M. (2021). Adoption of a multiple use water system (MUWS) to ensure water security for Nepalese hill farmers. *Water Policy 2021*, wp2021066. https://doi.org/10.2166/wp.2021.066.

Reddy, K. S., Ricart, S., Maruthi, V., Pankaj, P. K., Krishna, T. S. & Reddy, A. A. (2020). Economic assessment of water harvesting plus supplemental irrigation for improving water productivity of a pulse-cotton based integrated farming system in Telangana. *India. Irrigation and Drainage 69*(1), 25–37.
Rest, M. (2018). Dreaming of pipes: Kathmandu's long-delayed melamchi water supply project. *Environment and Planning C: Politics and Space 37*(7), 1198–1216.
Saraswat, C., Mishra, B. K. & Kumar, P. (2017). Integrated urban water management scenario modeling for sustainable water governance in Kathmandu Valley, Nepal. *Sustainability Science 12*(6), 1037–1053. https://doi.org/10.1007/s11625-017-0471-z.
Schreiber, J. B., Stage, F. K., King, J., Nora, A. & Barlow, E. A. (2006). Reporting structural equation modeling and confirmatory factor analysis results: a review. *Journal of Educational Research 99*(6), 323–338. https://doi.org/10.3200/JOER.99.6.323-338.
Schumacker, R. E. & Lomax, R. G. (2004). *A Beginner's Guide to Structural Equation Modeling*, 2nd edn. Psychology Press, London.
Setiawati, E., Notodarmojo, S., Soewondo, P., Effendi, A. J. & Otok, B. W. (2013). Infrastructure development strategy for sustainable wastewater system by using SEM method (case study Setiabudi and Tebet Districts, South Jakarta). *Procedia Environmental Sciences 17*, 685–692. https://doi.org/10.1016/j.proenv.2013.02.085.
Shi, D., Lee, T. & Maydeu-Olivares, A. (2019). Understanding the model size effect on SEM fit indices. *Educational and Psychological Measurement 79*(2), 310–334. https://doi.org/10.1177/0013164418783530.
Shrestha, S. (2017). The contested common pool resource: ground water use in urban Kathmandu, Nepal. *Geographical Journal of Nepal 10*, 153–166.
Shrestha, S., Neupane, S., Mohanasundaram, S. & Pandey, V. P. (2020). Mapping groundwater resiliency under climate change scenarios: a case study of Kathmandu Valley, Nepal. *Environmental Research 183*(November 2019), 109149. https://doi.org/10.1016/j.envres.2020.109149.
Snir, O. & Friedler, E. (2021). Dual benefit of rainwater harvesting – high temporal-resolution stochastic modelling. *Water 13*, 2415.
Song, J., Han, M., Kim, T. i. & Song, J. e. (2009). Rainwater harvesting as a sustainable water supply option in Banda Aceh. *Desalination 248*(1–3), 233–240. https://doi.org/10.1016/j.desal.2008.05.060.
Traboulsi, H. & Traboulsi, M. (2017). Rooftop level rainwater harvesting system. *Applied Water Science 7*, 769–775.
United Nations (2022). *The United Nations World Water Development Report: Groundwater: Making the Invisible Visible.* UNESCO, Paris.
Ursachi, G., Horodnic, I. A. & Zait, A. (2015). How reliable are measurement scales? External factors with indirect influence on reliability estimators. *Procedia Economics and Finance 20*(15), 679–686. https://doi.org/10.1016/s2212-5671(15)00123-9.
Vidanage, S. P., Kotagama, H. B., Dunusinghe, P. M., (2021). Sri Lanka's small tank cascade systems: building agricultural resilience in the dry zone. In *Climate Change and Community Resilience: Insights From South Asia*. Haque, A. K. E., Mukhopadhyay, P., Nepal, M. & Shammin, M. R. (eds). Springer, Singapore.
Villar-Navascués, R., Pérez-Morales, A. & Gil-Guirado, S. (2020). Assessment of rainwater harvesting potential from roof catchments through clustering analysis. *Water 12*, 2623.
Wang, Q., Song, X., Li, F., Hu, G., Liu, Q., Zhang, E., Wang, H. & Davies, R. (2015). Optimum ridge–furrow ratio and suitable ridge-mulching material for Alfalfa production in rainwater harvesting in semi-arid regions of China. *Field Crops Research 180*, 186–196.
Ward, S., Barr, S., Butler, D. & Memon, F. A. (2012). Rainwater harvesting in the UK: socio-technical theory and practice. *Technological Forecasting and Social Change 79*(7), 1354–1361. https://doi.org/10.1016/j.techfore.2012.04.001.
White, I. (2010). Rainwater harvesting: theorising and modelling issues that influence household adoption. *Water Science and Technology 62*(2), 370–377. https://doi.org/10.2166/wst.2010.891.
Williams, L. J. & Holahan, P. J. (1994). Parsimony-based fit indices for multiple-indicator models: do they work? *Structural Equation Modeling: A Multidisciplinary Journal 1*(2), 161–189. https://doi.org/10.1080/10705519409539970.
World Bank (2022). *Population Stat, 2017–2022*. World Bank, Washington, DC. https://populationstat.com/nepal/kathmandu.
Yang, Z., Wang, Y. & Peng, T. (2021). Uncertainity propagation and risk analysis oriented stochastic multi-criteria decision making for unconvential water resource management. *Journal of Hydrology 594*. https://doi.org/10.1016/j.jhydrol.2021.126019.

First received 24 May 2022; accepted in revised form 27 August 2022. Available online 6 October 2022