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## RESEARCH ARTICLE

# ASSESSING HOUSEHOLD WATER SECURITY DIMENSIONS FOR SUSTAINABLE WATER MANAGEMENT: A CHOICE EXPERIMENT APPROACH

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## ABSTRACT

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Malaysia has abundant water resources. However, overpopulation, urbanisation, inadequate water management, and climate change contributed to water stress in several states. Water insecurity particularly in household consumption arose from an imbalance between water demand and supply. In this study, household water security was assessed across five key dimensions: pipe bursts, water amount, water pressure, water reliability or resilience, and price. The study aimed to examine the status of these water security dimensions and to estimate households' willingness to pay (WTP) for improvements to strengthen the overall water security framework. A choice experiment approach was employed to estimate WTP for enhancements in each water security parameter. The questionnaire comprised sections on household experiences with water operators, water consumption patterns, choice experiment scenarios with three attribute levels per parameter, and socioeconomic characteristics. The sample consisted of 500 residential consumers. The findings provided valuable insights for developing a comprehensive household water security framework to support the Energy Transition and Water Transformation Ministry's goal of achieving an estimated 180 litres per person per day by 2025, as well as the United Nations Sustainable Development Goal (SDG) 2030 target of ensuring access to clean water and sanitation for all and promoting long-term water security.

## KEYWORDS

household water security, water reliability, affordability, dimensions, water pressure.

## 1. INTRODUCTION

The rapid growth of population and urbanisation across various continents is significantly increasing the demand for water security, which is crucial for human consumption, agricultural practices, and economic activities. Currently, around 25% of the global population lives in 17 countries that face significant water stress, relying on over 80% of their available water resources to support agricultural, industrial, and municipal needs. The challenges related to water availability are not distributed equally. Notably, 12 of these high-stress countries are situated in the Middle East and North Africa. Additionally, urban expansion and industrial operations contribute to greater pollution, health risks, and the degradation of water sources, rendering them unsuitable for various uses. Climate change exacerbates water security issues by intensifying droughts and altering rainfall patterns, frequently resulting in water-related disasters. Over the past 20 years, 90% of natural disasters have been linked to water issues. By 2050, more than half of the global population is expected to face daily challenges related to water availability.

In addition, water security in households is crucial for general public health and well-being, especially in nations where urbanisation and climate change are occurring at a rapid pace. Water security encompasses more than just the availability of water; it also refers to the water's quality,

price, accessibility, and dependability. Concern over water security is growing in Malaysia as a result of issues such as pollution, population expansion, unequal distribution of water resources, and the effects of climate change. Both rural and urban households are impacted by this complex issue, which necessitates rigorous evaluation to guarantee fair and sustainable access to clean water.

Malaysia benefits from an average annual rainfall exceeding 2,500 millimetres, a figure that substantially surpasses the global average of 1,000 millimetres. This significant precipitation endows the nation with a rich abundance of water resources. Compared to the global average of 170 litres per day, Malaysia's average daily water usage is comparatively high at roughly 210 litres per capita. Urbanised cities such as Kuala Lumpur, Penang, Johor Bharu, and Ipoh have seen a steady rise in water demand due to the fast pace of urbanisation. Due to rising demand for both residential and commercial uses, these metropolitan areas use a sizeable amount of the nation's water supply. Water Use in the Home: Drinking, cooking, cleaning, sanitation, and other everyday household tasks are the main uses of water. Due to Malaysia's increasing population, urbanisation, and economic growth, the country's water demand is predicted to keep growing. According to the Malaysia Water Industry Guide, during the coming decades, demand might rise by about 4% to 5% yearly. Water resources will continue to be strained by rising industrial and agricultural

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demand, necessitating more effective water management and conservation measures.

Although Malaysia has comparatively ample water resources, it is getting harder to manage the rising demand for water across several industries. It is anticipated that the country's water supply will continue to be strained by urbanisation, industrialisation, and climate change. Even though the nation has made progress in developing its water infrastructure, long-term water security will depend on tackling issues including water contamination, unequal distribution, seasonal unpredictability, and efficiency.

Furthermore, between 50% and 60% of Malaysia's total water demand is thought to be consumed domestically, making it a major contributor to the country's overall water consumption. This covers both urban and rural households' requirements. A significant amount of water is used by the industrial sector, which includes heavy industries like manufacturing and

electricity generation. Cooling, processing, and cleaning water are frequently employed in industrial operations. Between 30% and 40% of all water use is attributed to the industrial sector. The production of electronics, processing of palm oil, oil and gas industry, and chemical industry are the main sectors that use water.

A large amount of water resources is used in agriculture, especially for irrigation in rice fields and oil palm plantations. Roughly 40% of all water is used for irrigation purposes. Rice, rubber, and oil palm are the three main crops in Malaysia that require a lot of water. Water demand is also influenced by the business sector (hotels, restaurants, retail stores) and public institutions (government buildings, schools, hospitals). Even though the commercial sector's proportion is sometimes lower than that of industrial and agricultural consumption, it is nonetheless substantial, especially in urban areas.

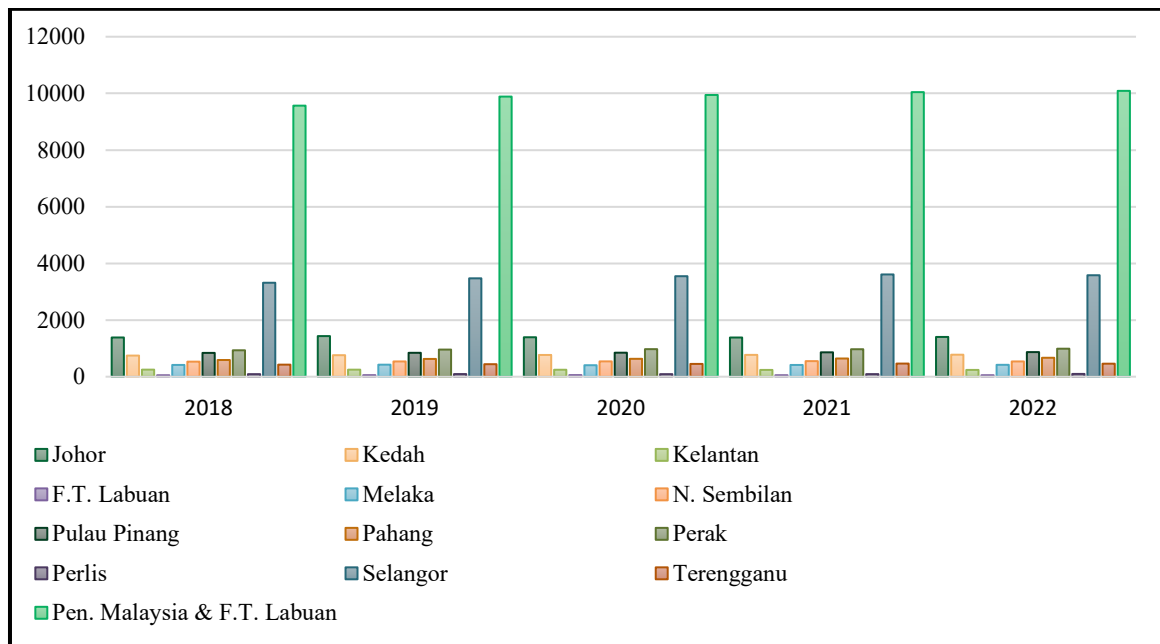


Figure 1: Water Consumption in Malaysia (Source: Water and Sewerage Fact, 2023)

Referring to Figure 1, Malaysians use roughly 210 litres of water per capita per day (L/c/d) on average. Compared to the global average of about 170 litres, this is relatively high. Per capita, water consumption is higher in urban regions, particularly in major cities like Kuala Lumpur, Penang, and Johor Bahru, because of the higher number of economic activities, higher population density, and more developed infrastructure. Rural areas, on the other hand, may have somewhat lower use but more erratic access to water, which increases dependence on non-piped or local water sources. In Malaysia, domestic demand, including drinking and cooking, accounts for the majority of household water usage, as well as sanitation, including showers and toilets, cleaning, and laundry. In suburban and urban regions, water demand is also increased for non-household uses like gardening and car washing.

In conclusion, even though Malaysia has plenty of water overall, household water security is still a complex problem that includes concerns about pricing, sustainability, accessibility, and water quantity. As a result, this paper develops dimensions of household water security and measures the willingness to pay in order to improve the household water security frameworks. This study begins with an introduction, literature review, material and method, and empirical results, and is followed by a conclusion and policy implications. This study investigates household preferences by using a choice experiment approach, which yields important information for enhancing water management plans and guaranteeing that all Malaysians have access to clean, dependable water for household use. Malaysia may improve its water security resilience for future generations by carefully crafting policies that are guided by data from such studies.

## 2. LITERATURE REVIEW

### 2.1 Theoretical Framework and Literature Review

The concept of household water security is multifaceted, including water quantity, pressure, dependability, pipe integrity, and cost. The resilience and sufficiency of the water supply for regular household use are determined by these factors taken together. Improvements in these

characteristics should, in theory, provide households with utility, which can be examined using random utility theory (McFadden, 1974). The choice experiment approach, which allows households to express preferences through trade-offs among attribute levels and estimate willingness to pay (WTP) for improved water services, is based on utility maximisation.

Households prioritise different aspects of water security, according to empirical research. For instance, studies conducted in Pakistan and Europe (Sana Khalil et al., 2023; Latinopoulos, 2019; Willis et al., 2005) show that, while price sensitivity varies by income and education level, water quantity and reliability are consistently valued higher than maintenance-related features such as pipe bursts. Discrete choice models, such as Mixed Logit (MXL) and Multinomial Logit (MNL), are frequently used to capture individual preference heterogeneity and population-level trends. In particular, the MXL model provides more accurate estimates of marginal WTP (MWTP) by accounting for variation in household valuations.

The study develops a conceptual framework that connects household socio demographics, water security aspects, and WTP by integrating theoretical and empirical insights. This framework guides the design of the choice experiment, ensuring that attribute selection considers both consumer valuation and practical policy relevance. In the end, the model makes it easier to comprehend how households value improvements in water services, which informs infrastructure investment, tariff design, and water resource management in Malaysia while supporting SDG 6 (Clean Water and Sanitation).

### 2.2 Household Water Security and Its Dimensions

The ability of a population to ensure sustainable access to enough water of acceptable quality to support human well-being, livelihoods, and socioeconomic development, while protecting ecosystems and reducing water-related risks, is known as water security (UN-Water, 2013). Due to its multifaceted nature, this idea has developed to include not only physical availability but also risk management, governance, and long-term

sustainability (Grey & Sadoff, 2007; Bakker, 2012). In this regard, water security is increasingly recognised as a crucial element of global development, particularly given Sustainable Development Goal 6 (SDG 6), which emphasises universal access to sanitation and clean water.

Despite Malaysia having abundant water resources, global and local drivers such as urbanisation, population growth, economic development, and climate change have exacerbated water supply security issues (Hardy, 2017). These drivers underscore the need for water security concepts to be “operationalised,” as show water security is dynamic and dependent on local governance and environmental conditions (Gerlak et al., 2018).

Within this framework, water security for households emerges as a vital sub-component, focusing on ensuring households’ access to sufficient, safe, reliable, and affordable water for their daily needs (Akinyemi et al., 2022). The literature has also identified several core components of household water security, including quantity, quality, availability, reliability, resilience, and affordability (Global Water Partnership, 2012; Water Aid, 2012). These components are also sensitive to seasonal changes and infrastructural limitations, which can impact water security and health outcomes (Ahmed et al., 2008; Boithias et al., 2016; Tiwari, 2017).

At a broader scale, water security has been conceptualised through various frameworks. For instance, the Asian Development Bank has conceptualised water security as comprising five vital components: water security for households, water security for the economy, water security for cities, water security for the environment, and water security for resilience against water-related disasters (ADB, 2016). Of these, household water security has been recognised as a vital component, as it impacts public health, poverty alleviation, and overall quality of life. Access to reliable piped water, sanitation, and hygiene underpins sustainable development and quality of life (Bizikova et al., 2013).

At a larger scale, the concept of water security has been developed through various frameworks. For example, the Asian Development Bank has developed its own conceptualisation of the concept, identifying five major dimensions of water security: household, economic, urban, environmental, and disaster risk management and resilience. Of these, the concept of household water security is considered the most fundamental, as it is closely related to public health, poverty reduction, and the quality of life (ADB, 2016).

Several indices and frameworks have been proposed for assessing water security at various levels. Global water security indices, such as the Human Water Security Threat Map and the Global Water Security Index, help compare water security levels across countries (Vörösmarty et al., 2010; Gain et al., 2016). Local-level indices such as the Freshwater Health Index and the Urban Water Security Indicators help evaluate water security at specific locations (Vollmer et al., 2016, 2018; Jensen and Wu, 2018). These indices differ in scope but focus on aspects such as water availability, accessibility, quality, and governance, which are taken into account when assessing water security levels.

Following these frameworks, this study adopts a household-centred approach, considering five core dimensions: water quantity, water pressure, water reliability, pipe bursts, and price. These dimensions have been chosen based on service delivery and economic factors, in line with the literature on household preferences for water services. By integrating all dimensions within a single framework, this study aims to offer a more cohesive approach to assessing household water security without repetition or fragmentation.

### 2.3 Choice Modelling and Willingness to Pay for Water Services

Choice modelling, especially discrete choice experiments (DCE), has been widely used to elicit households’ willingness to pay (WTP) for improved water services. Utility theory underlies these approaches, which assume that people derive satisfaction from various attributes of water services, including water quality, reliability, pressure, and accessibility (McFadden, 1974). Empirical results from the literature confirm households’ positive WTP for better water services. To illustrate, reported that urban households in Khulna, Bangladesh, were willing to pay approximately \$2.87 per month for improved water quality, reliability, and filtration services (Ahsan et al., 2021). In another study, reported positive WTP among rural households in South Africa, indicating the applicability of choice modelling in these settings (Kanyoka et al., 2019). In the same vein, other studies from the developed world confirm households’ WTP for better water services, including a study conducted in Melbourne, Australia, which reported households’ WTP for better environmental water allocation services (Cooper et al., 2023).

Apart from households, existing research on agricultural water service users shows that preferences and WTP levels vary with water service

users’ characteristics and policy design. The study observed differences in the level of WTP for the reliability and efficiency of water supply among farmers, as well as some willingness to accept higher tariffs for the implementation of certain technologies, such as water metering and water-saving practices (Guerrero-Baena et al., 2019; Alcon et al., 2019). This implies the potential significance of economic instruments in promoting the efficient use of water resources. Moreover, certain service attributes are identified as significant factors in households’ WTP levels, including reliability, pressure, quality, and ease of access (Adams and Vásquez, 2019; Vásquez, 2012; Chatterjee et al., 2017; Gschwandtner et al., 2020). More recent research findings highlight households’ willingness to contribute to environmental protection, as shown in the study on households’ willingness to pay for improved water service while protecting the environment from certain desalination impacts (Vásquez et al., 2022).

However, there are certain gaps in the literature, given the extensive use of choice experiments, which primarily focus on service improvements rather than other dimensions of integrated water security, including environmental externalities. Additionally, while WTP is often dependent on income, education, and access conditions the current literature has often ignored other factors, including behavioural and psychological effects, that could influence household choice (Islam et al., 2022; Khalil et al., 2023). In addition, the literature, including earlier studies such as indicates the economic value of avoiding restrictions, which further emphasises the need to ensure the reliability of water services (Gordon et al., 2001; Hensher et al., 2005; Willis et al., 2005). However, the applicability of the literature to integrated water security is limited by its lack of contextualisation within the broader policy environment.

### 2.4 Choice Experiment Studies on Water Services in Malaysia

In Malaysia, empirical research on the valuation of water services has primarily relied on stated-preference approaches, including the Contingent Valuation (CV) and Choice Experiment (CE) methods, to elicit households’ willingness to pay (WTP) for improved water services. In the initial study conducted in the state of Selangor, found that households in the region were willing to pay a premium for better water quality, reduced service disruptions, and greater trust in tap water services (Mohd Rusli et al., 2011). In a study conducted in the state of Kelantan, found that households in the region were willing to accept modified water tariffs, provided water services were improved, including reduced water disruptions (Mahirah et al., 2013).

However, more recent research using the choice experiment methodology offers further insights into consumers’ preferences for specific service attributes. The conducted research in Terengganu using the Conditional Logit (CL) and Mixed Logit (ML) models, which confirmed households’ WTP for better water pressure, quality, and service reliability (Nur Syuhada et al., 2019, 2020). Moreover, the study’s results indicated the importance of income, education, and age in people’s preferences. In addition, study in Johor, focusing on water service choice in residential areas, confirmed the importance of WTP, which is influenced by household characteristics such as income, gender, age, and household size (Anang, 2018). This is consistent with the general literature, which has confirmed the importance of people’s economic capacity in their choice of water services.

Despite these findings, some gaps remain, especially in the context of Malaysia. Existing research has been more inclined towards areas with significant water supply issues, potentially overlooking areas with moderate or less prominent water issues. This creates a limitation in understanding consumer preferences across different levels of water security, as discussed in the study. Moreover, there has been limited integration of water service attributes into the context of water security or sustainability. These issues, if addressed through more comprehensive choice experiments and systematic approaches, such as ROSES, would help enhance the relevance of future research and contribute towards more efficient water management strategies in Malaysia (Halim et al., 2024).

### 2.5 Linking Choice Experiment Attributes to Household Water Security Dimensions

Although previous research in Malaysia has successfully implemented the use of choice modelling in assessing the level of preference towards various attributes of water service quality, pressure, and interruption frequency, these attributes are generally examined independently of a more overarching water security service provided to households.

It should be noted that household water security is a multidimensional concept encompassing water availability, accessibility, reliability, quality, and affordability. In this respect, water quality can be seen as an attribute

of water safety and acceptability, implying its suitability for consumption and household purposes. Interruption frequency and pressure stability can be regarded as attributes of water reliability and continuity, implying consistency and reliability for consumption and household purposes. In this respect, water tariffs or payments can be regarded as an attribute of water affordability, indicating their suitability for household consumption and purposes based on household payment capacity. In this respect, diversification of water sources or the availability of alternative water sources can be regarded as attributes of water availability and resilience, implying their suitability for consumption and household use and reflecting the household's capacity to cope with water supply discontinuity.

The Choice Experiment (CE) approach is highly relevant for operationalising these dimensions, as it enables the joint evaluation of trade-offs across multiple attributes. Unlike Contingent Valuation (CV), which estimates a single aggregated measure of WTP, CE disaggregates household preferences into separate measures of marginal utility for each dimension of water security. By operationalising CE attributes for household water security dimensions, this study goes beyond traditional service valuation and offers an integrated behavioural approach to measuring water security preferences in Malaysia.

## 2.6 Research Gap and Contribution

Despite the increased number of valuation studies on water services in Malaysia, three significant gaps have been identified. First, most existing studies have focused on the service's improvement attributes without fully incorporating them into the multidimensional concept of household water security. Second, the application of the Choice Experiment method in Malaysia remains geographically narrow, focusing mainly on service reliability and quality, while the multidimensional concept is not fully considered. Third, the trade-offs among the components of the multidimensional concept of water security for Malaysian households, given their socioeconomic conditions, have not been well explored.

These gaps need to be addressed, especially in the face of increasing climate variability, infrastructure stress, and demand pressures, which is why this study contributes to the literature by incorporating the dimensions of household water security into a Choice Experiment, ensuring a holistic assessment of household preferences.

## 3. MATERIALS AND METHODS

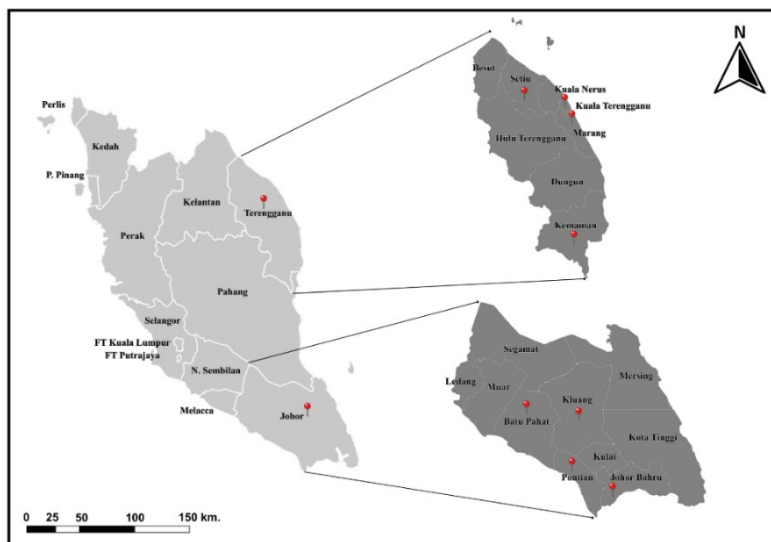


Figure 2: Map of Malaysia

### 3.2 Methodology Framework

Environmental preferences have been assessed through several economic approaches, including cost-based, revealed choice, and stated-preference methods. Among these, stated-preference techniques like contingent valuation (CV) and choice experiments are uniquely suited for valuing non-use aspects (Adamowicz, 1998).

The Choice Experiment (CE) methodology is widely utilised to assess the value associated with alterations in the quality or quantity of various non-market goods and services. This methodology is illustrated through several hypothetical scenarios that may shed light on policy options, including conservation initiatives. In this study, we applied the CE approach to gauge families' preferences regarding water security features. Participants selected their preferred combination of options from

### 3.1 Study Area

Malaysia, a diversified nation with a rich history and a quickly growing economy, is situated in Southeast Asia. Peninsular Malaysia and East Malaysia on the island of Borneo make up its two primary areas and is home to more than 33 million people. The economy is primarily driven by industry, especially electronics; agricultural (palm oil, rubber, and cocoa); services (banking, finance, and tourism); and natural resources (oil and gas). Malaysia's GDP was projected to reach USD 372 billion in 2022, indicating consistent development propelled by these industries. With notable contributions from the Malay, Chinese, Indian, and indigenous communities, the nation is also renowned for its cosmopolitan society.

This study focused on Kuala Terengganu, Terengganu, and Johor Bahru, Johor, as shown in Figure 2. It specifically examined two urban centres: Kuala Terengganu and Johor Bahru. These two cities were selected to reflect the different household water security conditions in Malaysia. Kuala Terengganu was chosen for its medium-sized urban centre with moderate infrastructure-related supply issues, including bursts, unreliable supply, and pressure instability. Johor Bahru, on the other hand, is a rapidly urbanising metropolitan city facing issues of high density, industrialisation, and increased water demands. These cities offer a contrast in terms of urban conditions for assessing household preferences for multidimensional water security attributes.

The choice of only two cities was purposive, informed by methodological, theoretical, and practical considerations. The goal is to achieve analytical generalisation rather than national representativeness. The analysis of two contrasting urban settings provides sufficient variation to estimate trade-offs across the dimensions of water security, while maintaining internal validity in the Choice Experiment (CE) method. Including other cities might introduce complexity and heterogeneity, potentially confounding the estimation of marginal willingness to pay (MWTP) for each dimension of the water security attribute.

Pooled modelling was used to enhance statistical efficiency and elicit overall MWTP values across the two cities, accounting for location-specific heterogeneity by including relevant socioeconomic and contextual factors. The results thus generalise to similar urban settings in Malaysia, offering relevant policy implications without making national statistical claims. In stated-preference research, attribute design depth and internal validity are typically prioritised over geographic scope, especially when aiming to elicit MWTP values for multifaceted service improvements.

different attribute sets, which included the current situation. These alternative configurations incorporated attributes distributed across various hierarchical levels. Consequently, we adhered to the sequential processes established, which entail identifying the qualities and levels related to tiger conservation, designing an experiment, creating a questionnaire, selecting a sample, and analysing the resulting data by (Bateman et al., 2002).

### 3.3 Identifying Water Security Attributes

Building on previous CE studies, this study identified probable variables related to home water security in Malaysia. A series of meetings and group discussions were held with Malaysian homes, Ranhill SAJ Holdings (Johor Water Company), Terengganu Water Company (SATU), and representatives from the National Water Services Commission. The focus

groups sought to identify important features and their levels that most accurately reflect Malaysian family water security concerns. Based on the feedback from these sessions, qualities and levels were collated and validated to form a comprehensive list. There were five variables utilised to identify consumers' WTP for improving water services: pipe-burst, water quantity, reliability, pressure, and price. These traits are classified into levels, with the prerequisites for each level stated in Table 1.

Table 1: Definition of Attributes and their Level	
Attribute	Description
Pipe-Burst	A water supply pipe that breaks due to physical factors or the age of the pipe leads to the uncontrolled release of its contents and results in the water supply being cut off.
Water Quantity	The amount of water available for use in each area or for a specific purpose is an important aspect of water security, as access to an adequate quantity of water is essential for meeting basic human needs.
Water Reliability	The system can supply the necessary demand with sufficient pressure in both standard and abnormal circumstances.
Water Pressure	Water from the household pipe has enough or low pressure for household use.
Water Price	The existing water price is worth the existing water service from the state water company, or the existing price is still low and can be increased for better service.

### 3.4 Experimental Design

After identifying and approving the characteristics and their levels, the statistical software package (SPSS) developed the orthogonal design to assign the attribute level for each choice set properly. An orthogonal experimental design was employed to assign attribute levels to alternatives, ensuring that the traits vary independently from one another and indicating that their impacts on respondents' preferences may be isolated. Orthogonal design is an experimental design that tests the comparative efficiency of numerous intervention components known as interventions, each of which has two or more versions (Zurovac and Brown, 2012).

The next stage was to couple the alternatives, which included the current condition or status quo. The addition of the status quo resulted in a total of three choices for each decision set. This status quo alternative is required to provide a baseline for welfare reform (Basri, 2011). Many investigations of choice experiments have employed the approach of mixing two options and one present condition (Blamey et al., 1999; Boxall and Adamowicz, 2002; Hope, 2006; Bergmann et al., 2008; Kanyoka et al., 2008; Mohd Rusli et al., 2011; Bakti, 2011; Mahirah et al., 2016). Respondents may find it challenging to respond to all 90 choice cards, so the number of choice cards was limited to eight. This was an entirely appropriate and tolerable quantity for respondents.

### 3.5 Questionnaire Design

The questionnaire is organised into six primary sections: the assessment of water service experiences provided by water operators in Johor and Terengganu, patterns of household water use, characteristics related to household water security, factors influencing household water security, the set of choices pertaining to household water security, and the socioeconomic attributes of the households surveyed. The section dedicated to the household water security choice set provides a concise overview of the Choice Experiment (CE) methodology, outlining the attributes of household water security and their associated levels. Subsequently, respondents are guided through the CE protocols, accompanied by an illustrative example of a choice card, as depicted in Figure 3.













	Option A	Option B	Option C
<b>Pipe Burst</b>	 Never <i>Not happen</i>	 Infrequently <i>1 times/month</i>	 Often <i>3 times/month</i>
<b>Water Quantity</b>	 Sufficient <i>100%/day</i>	 Less Sufficient <i>90%/day</i>	 Insufficient <i>80%/day</i>
<b>Water Reliability</b>	 Reliable <i>Not happen</i>	 Less Reliable <i>1 times/month</i>	 Unreliable <i>5 times/month</i>
<b>Water Pressure</b>	 High <i>High water pressure</i>	 Medium <i>Medium water pressure</i>	 Low <i>Low water pressure</i>
<b>Water Price</b>	Increase 20% <i>RM1.26/m<sup>3</sup></i>	Increase 10% <i>RM1.15/m<sup>3</sup></i>	No Change <i>RM1.05/m<sup>3</sup></i>
<b>PREFERENCE CHOICE</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 3: Example of Choice Card Sampling Frame.

### 3.6 Sample design and implementation

#### 3.6.1 Sampling Design

To evaluate households' WTP for improved water services (specifically focusing on five attributes, pipe-burst, water quantity, water reliability, water pressure and water price), the study population was selected through stratified random sampling targeting households in Johor and Terengganu with members aged 18 and above. Individuals in the designated study areas were approached to participate in face-to-face interviews. After completing each interview, the next available passerby was invited to participate. Trained enumerators conducted the interviews, beginning by introducing themselves, seeking permission to proceed, and explaining the purpose of the survey. The enumerators provided a brief overview of the research and the choice experiment method, demonstrating each attribute and level using a colour-coded pictograph. Respondents then reviewed the choice cards and made their selections. Most respondents could answer the questions with ease, and the survey was conducted in May 2024 with around 82% of responses collected over the weekend.

#### 3.6.2 Sample size

To identify an adequate sample size for the Choice Experiment (CE) approach, this study followed principles. It took into account the number of attribute levels, the choice cards issued to each respondent, and the options presented on each card (Kanninen's, 2007).

$$N = 500 \times \frac{L}{A \times C}$$

In this context, N denotes the sample size, L is the maximum number of attribute levels, A the number of possibilities per choice set (excluding the status quo), and C the number of choice questions each respondent answers. Based on these calculations, a sample of 500 respondents was required for this investigation.

#### 3.7 Data analysis

The data were analysed using multinomial logit (MNL) and mixed logit (MXL) models, both of which are grounded in the value theories proposed and the random utility theory (RUT) formulated by (Manski, 1977; McFadden, 1974; Lancaster, 1966). RUT provides a framework for understanding consumer behaviour when choosing from a set of alternatives, each with distinct characteristics. According to this theory, individuals will select the option that maximises their utility. However, because the benefits associated with each alternative cannot be measured with absolute precision, they are treated as random variables. RUT posits that consumer preferences are not directly observable and are instead

composed of both systematic and random components. The systematic component reflects the measurable, predictable factors influencing decisions, while the random component accounts for the unobservable, stochastic elements inherent in individual preferences. The fundamental utility function is presented as follows:

$$U_x = V_x + \varepsilon_x \quad (1)$$

The utility derived from a good or service ( $x$ ), denoted as  $U_x$ , can be expressed as  $V$ . This expression includes not only the systematic, observable portion but also  $\varepsilon_x$ , which represents the random and unobservable aspect that the analyst cannot identify (Hanley et al., 2001). Given that the systematic, observable component of utility  $V_x$  is defined by linear parameters (Train, 2003). The utility function for alternative ( $i$ ) can be expressed as follows:

$$V_{xi} = \beta_1 v_{1xi} + \beta_2 v_{2xi} + \beta_3 v_{3xi} \dots \beta_m v_{mxi} \quad (2)$$

The observable possibility component, represented as  $P$ , is where ( $V_{xi}$ ) comes into play. The symbol ( $\beta$ ) indicates the coefficient of the parameters that require estimation, while ( $v$ ) refers to a vector that details the relevant characteristics. In a straightforward scenario with two binary sets of possibilities ( $i$  and  $j$ ), the probability ( $P_{ni}$ ) of the decision-maker ( $n$ ) selecting alternative ( $i$ ) occurs only if  $U_{ni} > U_{nj}$ , for all  $i \neq j$ , as indicated below:

$$\begin{aligned} P_{ni} &= \text{Prob}(U_{ni} > U_{nj}) && ; j \neq i \\ &= \text{Prob}(V_{ni} + \varepsilon_{ni}) > (V_{nj} + \varepsilon_{nj}) && ; j \neq i \\ &= \text{Prob}(V_{ni} - V_{nj}) > (\varepsilon_{jn} - \varepsilon_{ni}) && ; j \neq i \end{aligned} \quad (3)$$

The MNL model assumes that the error term follows an independent and identically distributed (IID) pattern, with the distribution typically following a Type I extreme value distribution, also known as the Gumbel distribution. This assumption is crucial for the application of MNL models, as it underpins the probabilistic framework that allows for the estimation of consumer choice probabilities (Train, 2003; Hanley et al., 2001). As a result, the probability that a respondent ( $n = 1, \dots, n$ ) chooses alternative ( $i$ ) within the MNL framework is represented as follows:

$$P_{in}(\beta) = \frac{\exp(\beta'V_{ni})}{\sum_j \exp(\beta'V_{nj})} \quad (4)$$

The probability of respondent ( $n$ ) choosing option ( $i$ ) is denoted by  $P_{ni}$ , while  $V_{ni}$  and  $V_{nj}$  refer to the attributes of alternatives ( $i$ ) and ( $j$ ), respectively. The parameter coefficient is represented by  $\beta$ . It's important to note that the total probability of selecting any alternative sums to one (Train, 2003). The MNL model was estimated by employing maximum likelihood methods (ML) estimation via the applicable log-likelihood function (Hanley et al., 2001) as follows:

$$\text{Log}L = \sum_{n=1}^N \sum_j Y_{ni} \log \frac{\exp(\beta V_{ni})}{\sum_j \exp(\beta V_{nj})} \quad (5)$$

where  $\text{Log}L$  is the log-likelihood function,  $Y_{ni}$  is the indicator of respondent's ( $n$ ) choice from the alternatives, which is equal to 1 if the respondent selects alternative ( $i$ ) and 0 otherwise. The MNL model comes with several drawbacks. It presumes that the preferences of respondents are uniform and does not consider variability. This assumption can be addressed by looking into the sociodemographic characteristics of respondents. Such analysis aids in identifying the underlying factors behind changes in visitor preferences. Additionally, the MNL model presumes an IID distribution, leading to the independence of irrelevant alternatives (IIA). This principle indicates that the inclusion or exclusion of any option does not influence the probability of choosing between the remaining options (Train, 2003). To identify any violations of the IIA property, the Hausman-McFadden test was employed (Hausman and McFadden, 1984). Should the IIA assumption not hold, it's recommended to consider alternative models like the MXL and latent class models rather than using the MNL model. The MXL model effectively addresses the shortcomings of the MNL model (Train, 2003). Participants ( $n = 1, \dots, n$ ) will be required to choose between different options ( $i$ ), with each choice representing a unique decision-making scenario ( $t$ ). Therefore, the utility for each alternative ( $i$ ) can be represented as follows:

$$U_{ni} = \beta_n X_{int} + \varepsilon_{int} \quad (6)$$

The variable  $x_{int}$  represents a vector of observed attributes, while  $\beta_n$  denotes the corresponding vector of coefficients associated with the

choices made by respondents. The term  $\varepsilon_{int}$  captures the independently and identically distributed (IID) random error component. The unobserved coefficient vector  $\beta_n$ , which corresponds to each  $x$  and the respondents' choices, varies across individuals in the population according to a distribution defined by the density function  $f(\beta)$ . As described  $f(\beta)$  is a function of the parameter vector  $\theta$ , which encapsulates the population-level means and standard deviations of respondents' preferences and is expressed as  $(\beta_n|\theta)$  by (Bhat, 2003). Based on this, the probability expression for the Mixed Logit (MXL) model is specified as follows: -

$$P_{xi} = \int \left( \frac{e^{\beta x_{ni}}}{\sum_j e^{\beta x_{nj}}} \right) f(\beta) d\beta \quad (7)$$

According to the Mixed Logit (MXL) model is capable of accommodating a variety of distributional assumptions, including normal, lognormal, uniform, and triangular distributions (Train, 2003). The evaluation of the model's integral is carried out using simulation techniques aimed at maximising the log-likelihood function. In practice, researchers often employ 100 Halton draws to approximate the distribution of parameters. Comprehensive explanations of the simulation procedures can be found in (Train, 2003; Hensher et al., 2005). To estimate visitors' willingness to pay (WTP), trade-offs between attribute levels and their associated monetary values are examined through the marginal rate of substitution commonly referred to as the implicit price which reflects the rate at which one attribute can be exchanged for another while maintaining constant utility. The implicit price for each attribute is calculated by dividing the monetary cost coefficient by the corresponding attribute coefficient, as illustrated below;

$$\text{WTP} = \frac{\beta_i}{\beta_{\text{price}}} \quad (8)$$

where,  $\beta_i$  represents the coefficient of a given attribute in the model, while  $\beta_{\text{price}}$  denotes the coefficient associated with the price attribute. Accordingly, all estimations in this study were conducted using NLOGIT version 4.0.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Demographic Features of the Respondents

#### 4.1.1 Descriptive Analysis

The descriptive analysis systematically organises the sample characteristics, enabling researchers to detect trends and patterns in household water security preferences. It surveyed 500 households (aged 20-70 years) and covered a wide range of demographic and socioeconomic factors that affect water consumption behaviour and willingness to pay for investments in improving water security.

Table 2 describes respondents' sociodemographic characteristics. 6.2% of the sample were female and 38.8% male. The respondents were predominantly Malay (64.4%), followed by Chinese (18.2%) and Indian (17.4%), reflecting Malaysia's multi-ethnic population. Most respondents had achieved a high level of education, where 25.8% had undergraduate or postgraduate degrees, and 30.6% possessed a diploma or pre-university qualification, while others completed SPM/A Level/MCE (37.6%). This level of education implies an audience capable of understanding complex information on water supply reliability, resilience, and conservation practices.

The household income level ranged widely from MYR1000 and below to above MYR7000 per month. The most common income group (45.4%) earned between MYR3001 and MYR5000, which suggests that the sample was primarily composed of middle-income individuals. Fifty percent of their employment was in the government sector, leaving a minor share for private employment, self-employment, retirement, and household work.

Household characteristics, including size and type of residence, also affect water use and perceived security. The majority of households consisted of 3-5 members (39.8%) or 6-8 members (51.2%), and lived mainly in terrace houses (35.2%), village houses (24.6%) and bungalows (22%). High water demand is commonly associated with larger household sizes and residence types (e.g., higher-density areas were associated with preferences for quality or pressure and reliability attributes in choice experiments).

**Table 2: Sociodemographic characteristics of the respondents.**

Characteristics	Frequency	Percent (%)	Mean	Std. Deviation	
Gender					
Male	194	38.82	1.61	0.49	
Female	306	61.18			
Races					
Malay	322	64.4	1.61	0.82	
Chinese	91	18.2			
Indian	87	17.4			
Age (Years)					
20 – 30	60	12	41.41	11.7	
31 – 40	239	47.8			
41 – 50	110	22			
51 – 60	53	10.6			
61 – 70	28	5.6			
> 70	10	2			
Household Size (People)					
2	28	5.6	5.23	1.54	
3 – 5	199	39.8			
6 – 8	256	51.2			
> 9	17	3.4			
Type of Residence					
Bungalow	110	22	3.09	1.43	
Twin house	14	2.8			
Terrace house	176	35.2			
Town House	77	15.4			
Village house	123	24.6			
Education Level					
Primary school	PT3/PMR/SRP/L CE SPM/A Level/MCE STPM/Diploma/ Matriculation Degree Master's/PHD	3	0.6	3.88	1.08
		27	5.4		
		188	37.6		
		153	30.6		
		101	20.2		
		28	5.6		
Employment Sector					
Government	251	50.2	2.59	1.65	
Private	66	13.2			
Self-employed	44	8.8			
Retired	35	7			
Student	74	14.8			
Housewife	30	6			
Household Income (RM/Month)					
RM 1000 – RM 3000	172	34.4	RM 3898.	RM 1362.45	
RM 3001 – RM 5000	227	45.4			
RM 5001 – RM 7000	52	10.4			
	49	9.8			
>RM 7000					

**4.2 Empirical Analysis**

**4.2.1 Multinomial (MNL) and Mixed Logit (MXL) Basic Model**

Table 3 presents the estimation results from both the basic Multinomial Logit (MNL) and Mixed Logit (MXL) models. The analysis indicates that all attribute coefficients were statistically significant at the 1% level across both models, except for WP2, which attained significance at the 5% level in the MXL model. The signs for all attributes align with expectations; we anticipate that all attributes, except for the monetary one, would exhibit a positive sign, as shown in Table 1. Additionally, the coefficient values at lower levels are less than those at higher levels, suggesting that high levels generate greater marginal utility compared to low levels. The respondents' top selection was WQ3, which strives to raise water quantity from insufficient to the highest level sufficient. WP2 was the least popular feature, with the lowest coefficient in both models.

**Table 3: Multinomial Logit (MNL) and mixed logit (MXL) basic model results.**

Variable	MNL		MXL	
	Coefficient	Standard Error	Coefficient	Standard Error
PB2	.1329***	.0544***	.1799***	.0744***
PB3	.2049***	.1047***	.2588***	.1348***
WQ2	.2770***	.1435***	.2887***	.1499***
WQ3	.8861***	.4483***	.9186***	.4672***
WR2	.4358***	.2375***	.4557***	.2480***
WR3	.7772***	.3180***	.7968***	.3271***
WP2	.0987***	.0343***	.5289***	.1095***
WP3	.7664***	.3995***	.8068***	.4248***
PRICE	-.2231***	.1141***	-.4060***	.2110***
<i>Standard Deviation</i>	-	-	-	-
PB2	-	-	.1563***	.0632***
PB3	-	-	.2751***	.1263***
WQ2	-	-	.2823***	.1321***
WQ3	-	-	.8630***	.3976***
WR2	-	-	.3015***	.1021***
WR3	-	-	.6308***	.3632***
WP2	-	-	.2143***	.1211***
WP3	-	-	.7812***	.4215***
<i>Summary Statistics</i>				
Number of observations				
Log-likelihood	3974		3974	
Log-likelihood No coefficient	-4262.67		-2631.812	
Pseudo R	-4413.59		-2813.5985	
Adjusted R	0.0353		0.06558445	
Chi-square	0.0333		0.06252275	
Degree of freedom	302.34		367.0685	
	9		9	

Additionally, the MXL model treated all households' water security variables as randomly distributed, except for the monetary attribute. The standard deviations indicate that respondents' preferences are not identical. The MXL model performs better at capturing this than the MNL model. The base MNL model's pseudo-R<sup>2</sup> values are low (0.0353), which is normal for discrete choice models. In these models, pseudo-R<sup>2</sup> doesn't measure absolute goodness-of-fit like R<sup>2</sup> does in linear regression. Instead, it gives a relative measure of fit compared to a null model with no predictors. Low pseudo-R<sup>2</sup> values do not mean the model is not working well; instead, they indicate that choice behaviour is naturally complex and variable, with many factors that are not apparent in decisions. The MXL model makes a big difference in fitness in this study. The pseudo-R<sup>2</sup> goes up to 0.0655, and the log-likelihood goes up from -4262.67 (MNL) to -2631.81 (MXL). This shows that the MXL model better captures differences in household choices by accounting for preference heterogeneity. This makes it a more accurate specification than the MNL model.

4.2.2 Multinomial and Mixed Logit Interaction Models

The MNL and MXL interaction models were examined, and all interaction variables were included. To identify the best interaction model, we systematically eliminated insignificant variables until only significant ones remained. In line with the basic MNL models, all attribute coefficients were statistically significant at the 1% level, except for WQ3, which was significant at the 10% level in the CLM interaction model but became statistically insignificant in the MXL interaction model. Similar to the base models, all variables displayed positive coefficients, except for the conservation fee, which showed a negative sign as theoretically expected. Furthermore, as seen in Table 4, the coefficients' values differed significantly from those of the basic model. In both interaction models, all interaction variable coefficients were statistically significant at the 5% level or higher. Moreover, both interaction models indicated a negative relationship between respondents' genders and their preference for raising the water quantity to the maximum level (WQ3-Gen), as well as between respondents' education level and their preference for elevating the pipe-burst to the highest level (PB3-Edu).

As a result, females prefer larger amounts of water than males. Additionally, respondents with higher education levels showed a greater preference for setting the pipe-burst threshold to the maximum level compared to those with lower education levels. The interaction between respondents' income level and their preference for the highest water reliability (WR3-Inc), as well as the interaction between respondents' total household size and their preference for increasing water pressure to the highest level (PB3-Thh), both exhibited a negative sign. This suggests that respondents from larger households are less inclined to prioritise increasing water pressure to the maximum level.

The MXL interaction model revealed that significant covariates were the cause of the variation in the standard deviation. Therefore, incorporating visitors' sociodemographic characteristics helps clarify the differences observed between the basic and interaction models. Moreover, the enhancements observed in the interaction models are substantiated by higher log-likelihood values and increased pseudo-R<sup>2</sup> statistics, as shown in Table 4.

**Table 4: Results of interaction for MNL and MXL**

Variable	CLM interaction		MXL interaction	
	Coefficient	Standard Error	Coefficient	Standard Error
WQ3_Gen	-.2712***	.1512***	-.4423***	.2599***
PB2_Edu	.2024***	.1183***	-.2855***	.1152***
PB3_Edu	.1577***	.0929***	-.1205***	.1042***
WQ2_Age	-.2883***	.1082***	.3796***	.1398***
WQ3_Age	-.2626***	.0803***	.3589***	.1100***
WR3_Race	-.1506***	.0906***	-.2528***	.1165***
PB3_Race	.1127***	.0700***	-.1564***	.0848***
PB3_Thh	.3049***	.1418***	.6188***	.2658***
WP2_Thh	-.2290***	.0949***	.5941***	.2102***
PB2_Inc	.4069***	.1060***	-.2855***	.1754***
PB3_Inc	.2623***	.0834***	.5961***	.1692***
WQ2_Inc	-.1794***	.0966***	.4058***	.1334***
WQ3_Inc	-.1546***	.0718***	-.2972***	.1503***
WR3_Inc	-.1698***	.0793***	-.2391***	.1190***
Standard Deviation	-	-	-	-
WQ3_Gen	-	-	-.3005***	.1097***
PB2_Edu	-	-	-.2049***	.0857***
PB3_Edu	-	-	-.2190***	.1116***
WQ2_Age	-	-	-.3123***	.1759***
WQ3_Age	-	-	-.3493***	.1934***
WR3_Race	-	-	-.3431***	.1032***
PB3_Race	-	-	.3342**	.1031***
PB3_Thh	-	-	.6857***	.1346***
WP2_Thh	-	-	-.7352***	.1342***
PB2_Inc	-	-	-.2848***	.0874***
PB3_Inc	-	-	.0683***	.0341***
WQ2_Inc	-	-	.5824***	.2301***
WQ3_Inc	-	-	-.2454***	.1235***
WR3_Inc	-	-	.9472***	.1980***
<b>Summary Statistics</b>				
Number of observations		3721		3721
Log-likelihood		-4092.54		-1924.65
Log-likelihood No coefficient		-4343.32		-2467.02
Pseudo R		0.2312		0.5323
Adjusted R		0.3410		0.4325
Chi-square		110.02		302.34
Degree of freedom		11		11

4.2.3 Estimation of Marginal Willingness to Pay

The marginal willingness to pay (MWTP) for each attribute of water security for the households was estimated using the Wald procedure (Delta method) in LIMDEP NLOGIT version 4.0, and the results are presented in Table 5. For all attributes, the MXL model yielded slightly lower estimates than those from the MNL model, although all were positive and substantial, indicating a willingness to pay for improved water security. The highest attribute levels were associated with a much higher willingness to pay, suggesting a preference for premium service levels.

Of all the attributes, water quantity level 3 (WQ3) received the highest MWTP, amounting to RM3.97 in MNL and RM2.26 in MXL, while water pressure level 3 (WP3) received the second highest, amounting to RM3.43 in MNL and RM1.98 in MXL. On the other hand, water pressure level 2 (WP2) in MNL and pipe-burst level 2 (PB2) in MXL received the lowest MWTP, amounting to RM0.44 and RM0.04, respectively. Respondents were willing to pay a premium of MYR 1.05 to 1.26 per 20 m<sup>2</sup> to achieve the maximum water quantity.

The findings show that households value improvements in water quantity and pressure more than other dimensions, followed by improvements in pipe-burst mitigation, implying a relatively low value for this attribute. These findings align with previous literature. For example, Alcon et al. (2019) found that households place relatively low value on pipe-burst mitigation compared with other water-conservation measures. The study indicated that households in Pakistan highly value water infrastructure for water quantity and pressure, similar to WQ3 and WP3 in this study. In other countries, estimated a WTP of USD 2.87 for water infrastructure improvements, while reported a higher WTP of USD 12.3 to increase water quantity (Ahsan et al., 2021; Sana Khalil et al., 2023; Latinopoulos, 2019). This reported households' WTP to avoid restrictions on water consumption, suggesting that households always assign some value to water supply (Willis et al., 2005; Hensher et al., 2005).

Most critically, although absolute WTP values vary, there is a clear trend: households are generally willing to pay more for attributes that improve quantity, reliability, and pressure, while those for maintenance, such as pipe bursts, are generally lower. This implies that any policy intervention aimed at improving water security would need to focus on improving quantity and reliability, as these are the areas that households place the greatest value on. The results also emphasise the need to consider household preferences in the planning and management of water resources, and they can be used for comparative analysis in future studies on the valuation of water security.

**Table 5: Estimation of marginal willingness to pay (MWTP)**

Variable	MNL basic	MXL basic	MNL interaction	MXL interaction
	Coefficient (St. Er.)	Coefficient (St. Er.)	Coefficient (St. Er.)	Coefficient (St. Er.)
PB2	0.596*** (0.273)	0.443*** (0.225)	0.532*** (0.194)	0.421*** (0.201)
PB3	0.918*** (0.282)	0.637*** (0.329)	0.842*** (0.300)	0.830*** (0.298)
WQ2	1.241*** (0.393)	0.711*** (0.243)	0.213*** (0.092)	0.931*** (0.312)
WQ3	3.971*** (0.512)	2.262*** (1.151)	0.753*** (0.391)	2.125*** (1.028)
WR2	1.953*** (0.338)	1.122*** (0.572)	0.421*** (0.163)	1.042*** (0.478)
WR3	3.483*** (0.609)	1.962*** (0.881)	0.102*** (0.043)	1.401*** (0.547)
WP2	0.442*** (0.193)	1.302*** (0.621)	0.415*** (0.129)	0.420*** (0.180)
WP3	3.435*** (0.401)	1.987*** (0.702)	0.301*** (0.183)	2.162*** (0.705)

5. CONCLUSIONS AND POLICY IMPLICATION

This study investigated household water security in Malaysia, using a choice modelling approach to assess willingness to pay (WTP) for water security improvements and identify influencing factors. Key findings include households' WTP for enhanced water quantity, water pressure, and reduced pipe bursts, with a preference for a stable and sufficient supply. The Multinomial Logit Model (MNL) and Mixed Logit Model (MXL) highlighted that water quantity and water pressure are top priorities. Demographic factors, such as household size, income, and education, significantly impact preferences, with larger, higher-income households more willing to pay for improvements. Environmental challenges, including climate change, further affect water availability. Current issues

such as frequent pipe bursts, low pressure, and inconsistent supply are intensified by ageing infrastructure, climate impacts, and growing demand, emphasising the need for targeted investments in water management. This study contributes valuable insights into water policy and highlights directions for future research in water security.

To improve water security, resource management, and equitable access in Malaysia, consumers, water service providers, and policymakers can benefit greatly from the study's findings. Consumers play a key role by adopting water-saving habits, investing in efficient appliances, and promptly fixing leaks. Participation in educational campaigns fosters conservation awareness, and consumers can advocate for sustainable policies by engaging with service providers and policymakers to support water management initiatives.

Additionally, service providers should reduce Non-Revenue Water (NRW) by addressing leaks and unauthorised use through advanced leak detection and smart metres. Upgrading ageing infrastructure, beginning with vulnerable areas, can improve service reliability. Engaging consumers through digital platforms, transparent communication, and customer feedback channels can build trust. Providers should also encourage conservation by offering rebates for water-efficient devices and conducting awareness campaigns on efficient water use.

To encourage conservation while maintaining affordability, policymakers are urged to implement a tiered water-pricing structure that accounts for household usage and income. In such a system, lower rates or subsidies would support low-income households' basic water needs, while higher tariffs would apply to consumption above essential levels. Water operators can also be encouraged to prioritise improvements in high-value attributes, such as water pressure and supply reliability, by implementing performance-based incentives. Tariffs aligned with household values promote infrastructure investment, effective resource allocation, and improvements in service quality. In general, incorporating customer preferences into water-pricing promotes long-term water security, equitable access, and economic sustainability, supporting both SDG 6 (Clean Water and Sanitation) and Malaysia's national targets. Furthermore, strategic infrastructure investments, particularly in high-risk areas, are vital for addressing pipe bursts and reliability issues. Incorporating climate resilience into policies, such as adaptive strategies for water storage and watershed management, is essential to handle climate impacts. Strengthening regulatory frameworks to prevent pollution, enforce standards, and enhance water quality can boost sustainable use and interagency collaboration.

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