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RESEARCH ARTICLE

URBAN WATER SECURITY INDEX ASSESSMENT FOR IBB CITY, YEMEN: COMPREHENSIVE VISION

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ABSTRACT

Water security is a global concern due to climate change and the increasing impact of human activities on water resources. Several issues regarding water scarcity, safety, and administration have been raised in previous studies, which indicated several deficiencies in the sewage systems and water supply of Ibb city, Yemen. However, a comprehensive assessment of water security has not been carried out. Hence, this study aims to develop a framework for assessing the urban water of Ibb city. The study applies the new assessment framework and measures the urban water security index (UWSI) as a decision management tool by using the four dimensions of urban water security: drinking water, ecosystems, climate change and water-related hazards, and socio-economic aspects (DECS). The urban water security index (UWSI) assesses Ibb water security and intervention strategies. According to the study findings, urban water security in Ibb is insufficient to meet basic needs, with flaws in some aspects of the water security dimensions. The UWSI framework promotes rational and evidence-based decision-making, which is essential for improving water resource management in water-insecurity cities.

KEYWORDS

Water Security, Ibb City, DECS Aspects, UWSI Framework.

1. INTRODUCTION

Water security is "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies" (Crey et al., 2012). It poses numerous challenges to water management in the twenty-first century and is critical to achieving sustainable development, specifically the United Nations Sustainable Development Goal (SDG) (Cook et al., 2012; United Nations, 2015). Climate change affects water scarcity and droughts, especially in semi-arid and arid regions creating additional barriers to political stability, economic development, and social cohesion and ultimately threatening ecosystem sustainability (UN-WATER, 2006; UN-WATER, 2007; Moore, 2011). Therefore, water security and sustainable management of water resources are critical policy areas that protect a region's ecological and economic health (Mishra et al., 2010). Urbanization and water security present many issues, ranging from water shortages and a high population density to natural disasters and climatic hazards (Srinivasan et al., 2017; Hoekstra et al., 2018; Roth et al., 2019; Hassan Rashid et al., 2018; Sado et al., 2015). Rapid urbanization without proper planning prevents the government's ability to address a wide range of water issues, including a lack of access to safely managed water supplies and sanitation and a deteriorating environment (Chang et al., 2015; Clifford Holmes et al., 2014; Chen et al., 2015; Da Costa Silva, 2014; Vairavamoorthy et al., 2007).

Yemen suffers from being water-scarce because there are no lakes or rivers (Yogita Mumssen *et al.*, 2018). In addition, climate change has affected rainfall totals and rainy seasons (Yogita Mumssen et al., 2018). Furthermore, access to safe and sustainable drinking water is becoming increasingly difficult in various regions of Yemen due to limited water reserves, groundwater depletion, or impractical use of rainfall during rainy seasons, whether for groundwater recharging or irrigation. Conflicts and wars have also significantly impacted the availability of enough water for drinking and agriculture, as well as the inefficient recycling of wastewater and its treatment difficulties (Yogita Mumssen et al., 2018). Due to Yemen's ineffective central government, there are no significant improvements to urban water management and unsustainable water infrastructure (Whitehead, 2015). As a result, the country's water supply system now serves fewer than 30% of Yemenis, and 17.8 million Yemenis are thought to live without access to clean water to drink and proper sanitary facilities. Millions of Yemenis, especially children and women, are forced to travel far distances to obtain water. Additionally, the country saw the greatest cholera outbreak in modern history in October 2016 as a result of significant health outbreaks, including acute watery diarrhea and cholera that started in response to a lack of clean water (more than 4,000 people have died and 2.5 million cases reported during the cholera outbreak) (ICRC, 2022).

Ibb city is the capital of Ibb Governate, and it's one of the urban areas facing serious shortages in water supply due to its rapid urban expansion and a high number of Internally Displaced Persons (IDPs) over the last eight years from 2015 to 2022 (OCHA, 2021). The current urban water

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security figures in Ibb city help explain several issues. Only 56% of Ibb households have access to the piped water supply system, but the produced water only meets 21% of the population's water needs (IWSLC, 2019), and 23% of produced water is lost due to leaks (GIZ- DAS, 2018). As a result, the population relies on unsafe water supplies to meet 79% of their water needs. On the other hand, only 43% of the households are connected to the city's municipal sewage system, with 60% capacity. However, the wastewater treatment efficiency in the treatment plant is about 70%, indicating that the pollution level caused by outgoing sewage is still high. Energy scarcity and a lack of alternative and low-cost energy sources raise the cost of water production and wastewater treatment. The government's lack of funding to support and develop the water and sanitation sector is a major impediment to improving the water and sanitation services provided to the population.

Several conceptual assessment frameworks for measuring urban water security have been proposed in recent decades. The Asian Development Bank (ADB) established the national water security index utilizing five major dimensions to measure water security performance. These dimensions cover water security's household, economic, urban, environmental, and disaster-resilience aspects (ADBO, 2016). However, most of these frameworks are less suitable locally because it was developed on national and regional scales (Aboelnga et al., 2019). Furthermore, a relatively complex concept can be more understood and implemented if water security is assessed at the municipal scale (Cook et al., 2012). Thus, researchers suggested several measures and indices for worldwide cities' water security assessments.

Ray and Shaw developed a water security index to evaluate the viability of an urban water system that considers the institutional, economic, and physical aspects of municipal water systems (Ray and Shaw, 2019). According to the domestic water supply-to-demand ratio is the household water security index (Thapa et al., 2018). The index was successfully used in Kathmandu, Nepal, to account for urban water security's temporal and spatial variability. In Hong Kong and Singapore, Jensen and Wu use the process analysis method to construct a number of indicators with an emphasis on water supply, hazards, and governance (Jensen and Wu, 2018). UN-Water examined four dimensions of water security (DECS framework): drinking water and human well-being, ecology, climate change, socio-economic issues, and water-related hazards (UNESCO i-WSSM, 2019). A group researchers suggest a comprehensive framework for urban water security that takes into account social, environmental, economic, and organizational aspects (Babel et al., 2017; Aboelnga et al., 2019). A group researchers developed a new urban water security assessment framework, which they then utilized to evaluate the integrated water security index in Madaba, Jordan (Aboelnga et al., 2020).

Based on the exhibited literature review, it is essential to conduct a comprehensive assessment of water security for developing countries such as Yemen. An optimal water security analysis in Urban cities in Yemen, such as Ibb city, is critical because of the issues surrounding its water security. Therefore the assessment framework and working definition in the Yemeni city of Ibb to assess the current condition of urban water security and direct decision-makers in the manner of effective intervention options need to be deployed. Thus the present research was inspired by the mentioned fact to represent severe water shortage issues regardless of complex challenges.

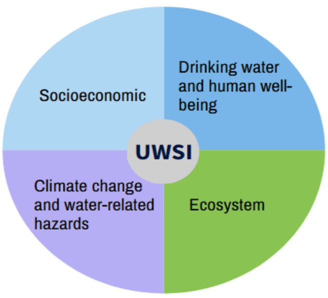

Figure 1: DECS framework to assess the urban water security index (UWSI).

The main objective of this study is to establish a new assessment framework based on the urban water security index (UWSI) as a decision management tool using four dimensions of urban water security, including drinking water, ecosystems, climate change and water-related hazards, and socio-economic aspects (DECS) (Figure 1). Then, a determination for the prioritization of urban water security was investigated. Finally, the measure UWSI was adopted to identify gaps and threats that are currently in place.

2. Methodology

2.1 Study Area

The DECS framework was applied in Ibb city, Yemen, to evaluate the status of the existing water security, which will help the decision-makers to propose appropriate intervention strategies. Ibb city is located in the middle of Yemen at an altitude of 2050 m above sea level and coordinate (13°58'0.01" N, 44°10'59.99" E) with the urban area is about 27 km^2 and is situated 194 km south of Sana'a city (The Capital city) (Figure 2). It is located on a high range and encircled by productive terrain and is considered one of the most important cities in Yemen. The OCHA database (United Nations Office for the Coordination of Humanitarian Affairs OCHA 2021) provides estimates of the population in Ibb city of 1,069,783 inhabits with a growth rate of 7.6% to 11% (OCHA, 2021). These estimates are based on the last official population census in 2004 (CSO 2005), which showed 307,955 inhabits (CSO, 2005). In addition, the number of national refugees or Internal Displacement Persons (IDPs) as a result of war and civil instability in recent years in some Yemeni governorates (Taiz, Aldhalea, Lahj, Abyan, Hodeidah, and others) was estimated to range between 185,500 to 250,000 persons (OCHA, 2021).

The drinking water supply in Ibb city depends on groundwater as the only source through one system that includes two pathways for water supply. The first one is a closed and safe pathway that involves the systems through which water is conveyed directly to the consumer, namely the public network water supply system. The second one is an open and unsafe pathway, in which water is transported directly from private wells to consumers by water tanker or via temporary stops (Sabeel's tanks) before reaching the consumers (NWRA, 2019). The Ibb Water and Sanitation Local Corporation (IWSLC) operates the public water supply network system. The current distribution network is 336 km long, connecting 35,798 homes via storage tanks and wells to customers' meters (IWSLC, 2021). Water is distributed from the wells (29 producing wells and 14 non-producing wells) and one storage reservoir (with a capacity is 4000 m^3) to thirty-four main areas on a daily schedule, with supply hours being uneven due to a lack of water supply. 56% of Ibb households have access to the piped water supply system, but the produced water only meets 21% of the population's water needs.

However, 79% of the population meets their water needs by employing various coping strategies, including using water from unsafe alternate sources such as purchasing private wells (92 wells) provided by tanker drivers and storing it in large tanks (NWRA, 2019). Only 43% of the households are connected to the sewage system of the city municipal. Moreover, there is almost no efficient national policy on wastewater sustainability. In contrast, the city only has one sewage treatment plant designed to treat 3200 m^3/day. Currently, the treatment efficiency of the station, which receives 11,322 m^3/d of wastewater, is less than 70% (IWSLC, 2021). As a result, the quality outflow of water is poor, and this is one of the treatment plant's issues.

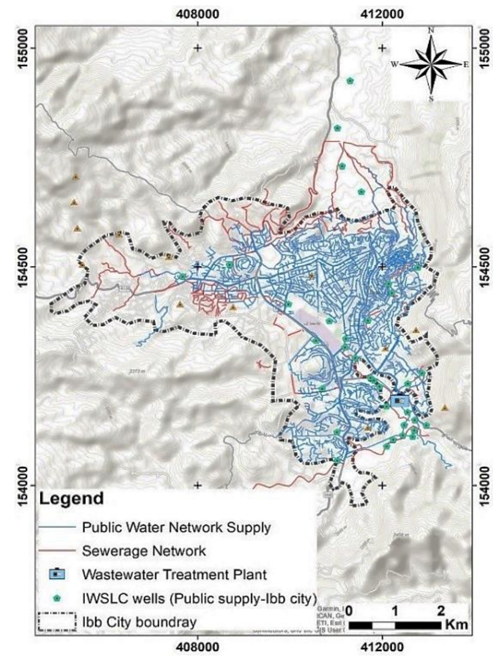

Figure 2: Location and water supply and sanitation systems of Ibb city, Yemen

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2.2 Urban Water Security Index (UWSI)

The study's approach is based on the DECS framework developed by Aboelnga for assessing urban water security, which consists of four dimensions: drinking water, water-related hazards and climate change, ecosystem, and socio-economic elements (Aboelnga et al., 2020).

The methodology is summarized as follows:

1. Measure the DECS framework indicators in Ibb, Yemen.
2. Variables Standardization
3. Measuring the UWSI by assigning weights and results aggregation.

The thresholds are valid in every city and are based on thorough literature reviews on water security. The indicators are measured on a common scale (because they have a variety of units), with 1 being poor and 5 being suitable (Aboelnga et al., 2019). They were selected based on the indicators' relativeness, transparency, data accessibility, and measurability. The Ministry of Health, the National Water Resources Authority (NWRA), the Ibb Water and Sanitation Local Corporation (IWSLC), and other national reports provided all of the information needed to assess urban water security in Ibb (NWRA, 2019; IWSLC, 2021; MoPIC, 2021).

2.2.1 Drinking Water and Human Well-Being Dimension

Water consumption and human well-being are represented by the availability, diversity of water and energy sources, consumption, accessibility, serviceability, quality, adequacy, and equality indicators (Table 1). Per capita, water resource availability is used as a variable in the availability indicator's calculation. The World Bank's estimate of Yemen's per capita water availability serves as the freshwater resource variable for Ibb City (MoPIC, 2021; World Bank, 2017). The population utilizes various unsafe water supply systems to meet their needs, and the contribution of alternative energy sources is considered when calculating the indicators for the energy sources and diversity of water supply. Likewise, the accessibility indicator is measured using water supply coverage (the percentage of the population with access to piped water supply) and sewerage coverage (the proportion of households connected to the city's sewerage system). The Serviceability indicator is calculated using water network capacity (describe the status of water networks), sewerage network capacity (describe the status of sewer networks), and treatment plant efficiency. The percentage of groundwater samples that meet drinking water quality requirements while staying under the allowable limit and the amount of residual chlorine in the water samples that were gathered and tested are also used to determine the water quality indicator. The water supply's length (measured in hours per day) is used to determine the indicator's sufficiency and equity.

Table 1: Benchmarking Drinking Water and Human Well-Being Indicators and Variables (Aboelnga Et Al., 2019).

Indicator, Ij	Variable, Vi	Unit	Standardization				
			1/V_{min}	2	3	4	5/V_{max}
Availability	Freshwater resources per capita	m^3/capita/year	<200	200-300	300-400	400-500	>500
Diversity of water supply and energy sources	Use of unsafe water supply systems	%	>50	50-30	30-20	20-10	<10
	Alternative energy sources' contribution	%	<5	5-15	15-30	30-60	>60
Consumption	Per Capita Water Consumption	L/cap/day	≤20	21-50	51-90	91-100	>100
Accessibility	Public water networks coverage	%	<60	61-70	71-80	81-90	>90
	Sewerage system coverage	%	≤60	61-70	71-80	81-90	90-100
Serviceability	Water networks capacity	%	<60	61-70	71-80	81-90	>90
	Sewerage networks capacity	%	<60	61-70	71-80	81-90	>90
	The efficiency of treatment planet	%	0-60	61-70	71-80	81-90	91-100
Quality	Samples of groundwater or surface water that meet the relevant quality standards (WHO and locally)	%	≤60	61-70	71-80	81-90	91-100
	Chlorination dosage	%	≤60	61-70	71-80	81-90	91-100
Adequacy and Equity	Supply duration	Hr/day	<8	8-16	17-20	21-23	24

2.2.2 Ecosystem Dimension

Three indicators cover the ecosystem dimension (Table 2), i.e., the state of pollution, green surfaces, and effectiveness of stormwater and wastewater network. The state of pollution is used to calculate the percentage of wastewater discharged from the treatment plant with unacceptable levels of pollutants, DO, and BOD. Green surfaces contribute to the overall ecosystem by intercepting runoff and promoting infiltration into groundwater. Therefore, in order to assess groundwater recharge, Ibb's per capita green space was used as a proxy variable. Sewer system blockages, on the other hand, are an indication of the inefficiency of the storm drainage networks and wastewater infrastructure.

Table 2: Benchmarking Indicators and Variables for The Ecosystem Dimensions (Aboelnga et al., 2019).

Indicator (Ij)	Variable (Vi)	Unit	Standardization				
			1/V_{min}	2	3	4	5/V_{max}
State of pollution	Percentage of safely treated wastewater flows (SDG6.3.1b)	%	0-60	61-70	71-80	81-90	91-100
Green surfaces	Green surface area as a percentage of total surface area	%	<5	5-15	15-30	30-60	>60
Effectiveness of stormwater and wastewater networks	Sewer system blockages	No. blockages/km/year	>300	200-300	100-200	50-100	<50

2.2.3 Climate Change and Water-Related Hazards Dimension

Four indicators are used to cover the climate change and water-related hazard components (Table 2), i.e., precipitation, temperature, flood-prone areas, and waterborne diseases. The change in rainfall rates and temperature indicates the climate change impact on the water supply in Ibb City, as well as the increase in water demand rates. Similarly, increasing the flood-prone areas exposes water supply facilities to damage and blockages sewer systems. Additionally, waterborne infections are employed as proxy variables to evaluate the hygiene indicator of Ibb urban water security. To describe waterborne infections in Ibb city, the WHO's record of diarrhea cases per 100,000 persons from October 2016 to March 2021 was used as a proxy

Table 3: Benchmarking Indicators, Variables for Climate Change, and Water-Related Hazards Dimensions (Aboelnga et al., 2019).

Indicator (Ij)	Variable (Vi)	Unit	Standardization				
			$1/V_{min}$	2	3	4	$5/V_{max}$
Rainfall	Annual average rainfall	mm/year	< 100	100 – 300	300 – 500	500–700	> 700
Temperature	Annual average temperature	C°	> 40	35 – 40	30 – 35	25 – 30	< 25
Flood-prone areas	Flood-prone area as a portion of the total surface area	%	> 20	20 - 15	15 - 10	10-5	<5
Waterborne diseases	Incidences of contaminated drinking water (diarrhea)	No./100,000 people	≥ 1000	800 - 500	500 - 100	100- 30	< 30

2.2.4 Socio-Economic Dimension

The productivity component of Ibb urban water security, as well as spending related to the budget allocation for urban water supply and sanitation, are included by applying the socio-economic dimension, which is represented by eight indicators (Table 4). NRW (percentage of water lost due to leakage, theft, etc.), Water energy consumption (average energy consumption to produce 1 m³ of urban water supply), and Wastewater energy consumption (average energy consumption to treat 1 m³ of wastewater in the wastewater treatment plant). Water tariff affordability is used to determine how much people can afford to pay for their water bills. To represent the WASH sector's spending indication, the country's budget allocation for water and sanitation is employed as a variable. The recovery of operating and maintenance costs provides an impression of the organization's ability to adapt and improve performance to provide better service. The number of workers employed by the Water and Sanitation Local Corporation (IWSLC) per 1,000 water connections is used to measure employee productivity. The total number of complaints (leakage, no water, blockage) submitted by users reflects the institution's service quality.

Table 4: Benchmarking indicators and variables for Socio-economic dimensions (Aboelnga et al., 2019).

Indicator, Ij	Variable, Vi	Unit	Standardization				
			$1/V_{min}$	2	3	4	$5/V_{max}$
Water energy consumption	Energy consumption to produce 1 m³ of water	kW h/m³	>1	1–0.75	0.75–0.5	0.5–25	<0.25
Wastewater energy consumption	Energy consumption to treat 1 m³ of wastewater	kW h/m³	>1	1-0.75	0.75-0.5	0.5-0.25	<0.25
Water tariff affordability	Water tariff	US $/m³	> 1	1	0.75	0.5	<0.4
Non-revenue water (NRW)	Lost water/produced water	%	≥25	25-20	20-15	15-10	≤10
WASH budget	Percentage of water and sanitation services budget	%	< 1	1 - 5	5 - 10	10 - 20	20
Cost recovery	Operating expenditure / operating revenue	%	0-60	60-70	70-80	80-90	90-100
Staff Productivity	No. of staff/1000 houses connection	Staff/1000 connections	>10	10-8	8-6	6-5	<5
Complaints	Total number of complaints (blockage, leakage, no water)	number/year/10,000 subscribers	>300	200–300	100–200	50–100	<50

2.3 Standardization

Dimensions, indicators, and variables must be aggregated and measured on different scales with different units to calculate the overall water security index (Onsomkrit, 2015). Consequently, we assign a score of 1 to 5 to each variable, with 5 being the highest level of water security and 1 being the lowest. Benchmarking is carried out using previous studies (Tables 1–4). The following equation is used to standardize the variables suggested in this study:

$$Si = \left(\frac{Vi - Vmin}{Vmax - Vmin}\right)(Smax - Smin) + Smin \quad (1)$$

Where *Vi* is the variable's observed value, the potential maximum and minimum values are *Vmax* and *Vmin*. The scale's minimum and maximum values are S_{min} and S_{max} (1 and 5).

Due to the complexity and potential for misinterpretation involved in addressing or weighing aspects with unrelated difficulties in various units, all variables, indicators, and dimensions in this study have been given equal weights (Manandhar et al., 2012). The aggregation equations of Onsomkrit, which assessed city-scale water security, were adopted (Manandhar et al., 2012). Assigning a score to each of the variables (si) based on their values, as displayed in Tables 1–4, is the first step in computing the urban water security index. Following the assignment of scores to all variables (*Si*), the indicators (*j*), dimensions *I*, and overall UWSI are calculated. The scores given to the variables are used to compute the value of an indicator (*Ij*):

$$Ij = \frac{\sum_{i=1}^{n} Si * wi}{\sum_{i=1}^{n} wi} \quad (2)$$

Where *n* is the number of indicators; *wi* is the weight assigned to variables. The value of a dimension (*Di*) is calculated using the following equation:

$$Di = \frac{\sum_{j=1}^{m} Ij * wj}{\sum_{j=1}^{m} wj} \quad (3)$$

Where w_j is a weight assigned to the indicator, *m* is the number of variables. The total of weights given to indicators equals 1. The UWSI is calculated concerning values of dimensions:

$$UWSI = \frac{1}{4}\sum_{I=1}^{4} Di \quad (4)$$

The Ibb city UWSI scores are interpreted using the grading scale shown in Table 5 (Assefa et al., 2018). The outcome can be interpreted in terms of water security level, which ranges from 1.5 to >4.5; 1.5 is poor, and >4.5 indicates that the urban water security situation is better.

Table 5: Urban Water Security Index (UWSI) scores

Score of UWSI	Water Security Level	Description
< 1.5	Poor	The city is unable to meet its residents' basic water needs.
1.5 - 2.5	Fair	The methods and actions taken by the authorities, which have wide gaps in practically all dimensions, are insufficient to achieve water security.
2.5 - 3.5	Satisfactory	Urban water security is sufficient to meet basic needs, with some aspects that could be improved.
3.5 - 4.5	Good	The water and sanitation sector performs well on most sides of water security.
> 4.5	Excellent	a perfect example of a city with ideal water security.

3. Results and Discussion

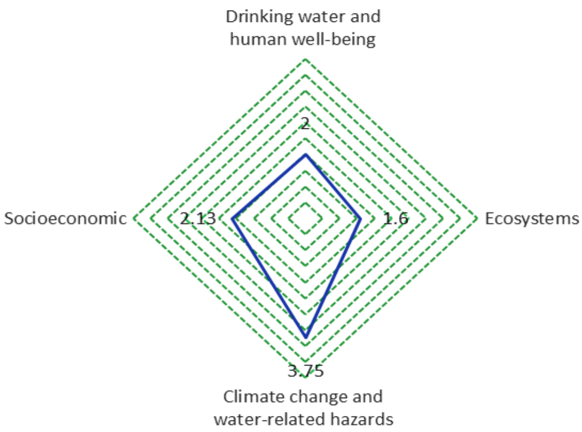

Figure 3: Urban Water Security Index score in Ibb city

UWSI provides insight into the urban water security pattern of a region. In order to secure a complete picture of the current situation of domestic water in Ibb City, the DECS framework technique was used. A total of two or more indicators were selected to reflect each of the four water security dimensions. Several standardized variables on a 1–5 scale were used to estimate the values of each indicator. Our results reveal (Figure 3) a UWSI of 2.37 (Fairly Urban Water Security), indicating that the methods and actions taken by the authorities are insufficient to achieve water security. The total water security is reflected by the score value and the proportional importance of Ibb city.

3.1 Drinking Water and Human Well-Being

The availability, accessibility, and quality of water that is physically, legally, and constantly obtainable to fulfill water demand were considered while evaluating this dimension (Table 6). The overall UWSI for the dimension of water supply is 2 (a fair level) based on the indicator score results. Regarding the accessibility and availability of water resources, the quality of the water, and the dependability of the infrastructure, Ibb has significant gaps and serious concerns. The amount of freshwater consumed per capita, the amount of water consumed per capita, the usage of unsafe water supply systems, and the contribution of alternative energy sources were all taken into account when calculating water availability. According to the water-stress index, the availability indicator performs as poorly as the per capita share of available freshwater per capita is estimated at 85 m^3/year, which puts Ibb below the level of the absolute water poverty line (less than 200 m^3/capita/day) (MoPIC, 2021; World Bank, 2017). We observe a lack of coverage and poor performance of the public water network and not reaching all areas of the city, 79% of the population's forced to rely on unsafe water supply systems to meet their daily water needs, including water tankers from private wells and sabil water tanks (NWRA, 2019). Alternative energy sources make up the entire (100%) contribution to providing water to the people of Ibb (World Bank, 2017). Water consumption per person per day does not exceed 37 L/cap/day, which is a low rate compared to the rate approved by the local corporation of 60 L/cap/day or to daily water consumption rates in the region countries (NWRA, 2019; IWSLC, 2021).

Table 6: Values and Scores of The Human Well-Being and Drinking Water Dimensions.

Indicator (Ij)	Variable (Vi)	Unit	Value (Vi)	Score (Si)
Availability	Freshwater resources per capita	m^3/capita/year	85	1
Diversity of water supply and energy sources	Use of unsafe water supply systems	%	79	1
	Alternative energy sources' contribution	%	100	5
Consumption	Per Capita Water Consumption	L/cap/day	37	2
Accessibility	public water networks coverage	%	56	1
	Sewerage coverage	%	48	1
Serviceability	Water networks capacity	%	77	3
	Sewerage networks capacity	%	60	1
	The efficiency of treatment planet	%	70	2
Quality	samples of surface water or groundwater meeting applicable quality standards (WHO and locally)	%	90	4
	Chlorination dosage	%	55	1
Adequacy and Equity	Supply duration	Hr/day	18	2

According to SDG goals, physical access to water and sanitation facilities is fundamental to realizing the basic human right to water. However, only 56% of households have piped water supply, but it covers only 21% of the population's water needs (IWSLC, 2021). Furthermore, although water network serviceability is fairly performed, the capacity of the water network is about 77% (IWSLC, 2021). Therefore the water network requires some developments to perform better. On the other hand, only 35% of the households are connected to the city's municipal sewage system, while sinkholes are used by 65% of the population to drain wastewater, which considers a source of groundwater pollution (World Bank, 2017). Moreover, the performance of the sewerage network capacity is poor (about 59%) due to old and worn-out sewerage networks due to the lack of financial capabilities of the local corporation (IWSLC, 2021).

The sewage treatment plant's efficiency rating of 70% shows that there is still a significant gap in the sanitation infrastructure and that the pollution level produced by outgoing sewage is still considerable. As a result, Authorities are required to improve the efficiency of the wastewater treatment plant to ensure that all sewage is properly treated before entering the waterways for use in irrigating agricultural lands, parks, and greenbelts, reducing agricultural land reliance on the freshwater outside of Ibb city and resulting in less groundwater withdrawal. Nonetheless, Ibb has a high degree of water security in terms of the quality of the raw groundwater; the majority of the groundwater samples that were taken from different well locations across the city were analyzed and confirmed to be within the allowable limits of WHO drinking water quality criteria (NWRA, 2019; IWSLC, 2021). Concerning water quality, it was discovered that the water chlorination dosage percentage in the public water network supply is 55% (IWSLC, 2021). In contrast, there is no chlorination dosage in water tankers from private wells and Sabil tanks due to limited financial capabilities in government institutions and the financial aid interruption provided by international organizations (UNICEF, WHO, etc.) (NWRA, 2019).

3.2 Ecosystems

According to the related indicators (Table 7), the ecosystem has a fair level of water security (1.6). However, two indicators, the state of pollution and the network efficiency of the storm and wastewater, have significant gaps. The Ibb wastewater treatment plant only treats about 69% of the wastewater, indicating a significant gap in sanitation infrastructure. Blockage complaints (1300 in 2021) in Ibb show wastewater and storm infrastructure inefficiency. It is critical to strengthen infrastructure in order to ensure ecosystem and water security. However, there are many opportunities to use appropriately treated wastewater for urban agriculture and groundwater recharge. Ibb's green surfaces are well estimated at 27%; it can be described as a green city in Yemen, with permeable surfaces that can help with groundwater recharge. Because of the ecosystem aspect, Ibb is vulnerable to urban water insecurity.

Table 7: Values and Scores of The Ecosystems Dimensions.

Indicator (Ij)	Variable (Vi)	Unit	Value (Vi)	Score (Si)
the level of pollution	Percentage of safely treated wastewater flows (SDG6.3.1b)	%	30	1
Green surfaces	Green surface area as a percentage of all surface area	%	27	3
Effectiveness of stormwater and wastewater networks	blocked sewer systems	No. blockages/km/year	1300	1

3.3 Water-Related Hazards and Climate Change

As shown in Table 8, the water-related hazards and climate change findings indicate adequate water security (3.75) in most related indicators. We noted that rainfall is at very good rates and is the highest in Yemen (800 mm/year) (NWRA, 2021). Climate change scenarios suggest that rainfall rates could increase by 13 to 25%, which constitutes a renewable water resource if it is harvested well and exploited to cover the domestic and agricultural needs in Ibb city (World Bank, 2010). This help relieves pressure on groundwater consumed in large quantities for domestic purposes and irrigation in agricultural lands around the city, reducing the rapid groundwater depletion, estimated to be 3 meters per year as a drop in the groundwater levels (NWRA, 2019; IWSLC, 2019). However, urban flooding occurs when heavy rainfall exceeds the drainage system capacity. Flooding causes serious economic and social consequences for cities. Ibb city's flood-prone area is estimated to be 10% of the city's total area. These floods continue to cause severe damage to the infrastructure of the water and sewage networks, with approximately 1300 sewer system blockages recorded in 2021 (IWSLC, 2021). On the other hand, the number of diarrhea cases was recorded at 132/100,000 people based on statistics provided by the World Health Organization (WHO) from 2017 to 2021(WHO, 2021). The results demonstrate that the number of diarrhea cases in Ibb is low compared to the low water consumption rates. It could be attributed to public disinfection awareness as well as Ibb residents' overall hygiene practices.

Table 8: Values and Scores of The Water-Related Hazards and Climate Change Dimensions.

Indicator (Ij)	Variable (Vi)	Unit	Value (Vi)	Score (Si)
Precipitation	Average annual precipitation	mm/year	800	5
Temperature	Annual average temperature	C°	27	4
Flood-prone areas	Flood-prone area as a portion of the total surface area	%	10	3
Waterborne diseases	Incidences of contaminated drinking water (diarrhea)	No./100,000 people	132	**3**

3.4 Socioeconomic

Customer satisfaction is important in achieving urban water security, defined as the utility's ability to operate and manage the water system to meet water demand. Table 9 shows that water security in terms of socio-economic is fair (2.37), with significant gaps in the following critical indicators: water and sanitation budget, affordability of water tariffs, and customer complaints. Yemen's total government budget for the water sector has been cut recently (2015-2022) due to the war. Therefore, the water sector's budget must be returned and maximized for water security in urban areas. In Ibb, the water tariff is high, estimated at 1.5 to 3 US $/m³, which is considered very expensive for a significant portion of the population in Ibb city (World Bank, 2017). Another main issue is complaints about leaks and a lack of water in the Ibb intermittent water supply system, which puts a strain on the performance of the water utilities. Non-revenue water (NRW) is 23% of total freshwater produced due to piping system leakage and theft, with no revenue generated for the water institution (IWSLC, 2021). The performance of the Operating expenditure / operating revenue variable is moderate, with an Operation and maintenance cost recovery rate of 79% of the total financial product of the IWSLC (IWSLC, 2021).

Similarly, the energy consumption variables for water production perform satisfactorily, with average energy consumption of more than 0.68 kW h/m³ for producing water. Also, he energy consumption variables for wastewater treatment perform well, with average energy consumption of more than 0.28 kW h/m³ for treating wastewater (IWSLC, 2021). The number of IWSLC employees working in the water supply and sanitation division was used to evaluate staff productivity. IWSLC performs poorly regarding staff productivity; the number of staff is about 9 per thousand connections (MWE, 2019). In developing countries, less than 5 staff members per 1000 connections reflect higher productivity in the water supply system (Berg et al., 2011; ESAWAS, 2019).

Table 9: Values and Scores of The Socio-Economic Dimensions.

Indicator (Ij)	Variable (Vi)	Unit	Value (Vi)	Score (Si)
Water energy consumption	Energy consumption to produce 1 m³ of water	kW h/m³	0.68	3
Wastewater energy consumption	Energy consumption to treat 1 m³ of wastewater	kW h/m³	0.28	4
Water tariff affordability	Water tariff per each m³	US $/m³	>1$	1
NRW (Non-revenue water)	Water lost/water produced	%	23	2
WASH budget	Percentage of national budget directed to water and sanitation services	%	0	1
Cost recovery	Operating expenditure / operating revenue	%	78	3
Staff Productivity	No. of staff/1000 houses connection	Staff/1000 connections	9	2
Complaints	No. of total complaints (leakage, no water, blockage)	number/year/10,000 subscribers	4736	1

4. Conclusions

In this study, the UWSI was used to develop a methodical way to investigate the mechanics of urban water security in Ibb, Yemen, using various perspectives, including water access, availability, affordability, quality, and management. The water security indexes were estimated by following the framework of city-scale water security. Our findings show that Ibb has a 2.37 cumulative UWSI indicating that the city lacks the necessary environment and system to achieve water security. Thus, authorities must take vigorous and prompt intervention in water security's drinking water, ecosystem, and socio-economic dimensions. Although Ibb has weak major indicators, such as the efficiency of stormwater networks, water availability, reliability, accessibility, and pollution, the findings of this study show it has a fair degree of water security in terms of the ecosystem and drinking water.

Even though the water network supply covers approximately 56% of the city, the produced water only serves 21% of the population. Hence the results showed that the water supply dimension is poorly performed, indicating that the population relies on unsafe water supplies to meet 79% of their water needs. Furthermore, the sanitation dimension shows poor results since there are significant gaps and serious concerns in sanitation and hygiene due to limited access capacity and infrastructure reliability. It was found that the ecosystem aspect of Ibb city water was ominously unsatisfactory and created a problematic challenge to maintaining the ecosystem. This is due to the poor urban expansion planning resulting in insufficient green spaces within the city, which could provide permeable surfaces to aid groundwater recharge. Most indicators related to water-related hazards and climate change show good water security; rainfall is at very good rates, constituting a renewable water resource and relieving pressure on groundwater.

However, approximately 10% of Ibb City is comprised of flood-prone zones, and there is no adequate infrastructure to drain the floods, which causes blockage and destroys the dilapidated water and sanitation infrastructure. As a result, these floods continue to cause severe damage to the infrastructure of the water and sewage networks. The socio-economic dimension is performed fairly with many gaps. For example, the Non-revenue water (NRW) is higher than the global standard. Also, the government's lack of funding to support and develop the water and sanitation sector is a major impediment to improving the water and sanitation services provided to the population. In addition, the water tariff is high, estimated at 1.5 to 3 US $/m^{3,} which is considered very expensive for a significant portion of the people in Ibb city.

To address Ibb's water security situation, it is necessary to focus on finding appropriate solutions to the two main challenges that Ibb faces: (1) insufficient institutional resources (financial, technological, and human) to solve the problems; and (2) the consequences of existing infrastructure, which results in increased cost, time, and effort for upgrades and maintenance.

The research presents the following important policy suggestions for urban water security in Ibb based on the indicators' results, which show large relative weights with low scores:

i. A key component of establishing water security is increasing the water provided by wells by rehabilitating and running out-of-service wells to meet the population's water needs.

ii. To reduce water loss (leakage and theft etc.) in the public water network supply system, it is necessary to rehabilitee and expand the public network water to cover all city neighborhoods.

iii. Supply, installation, and operation of disinfection units in public water network supply systems.

iv. Rehabilitation and expansion of the sewage network to cover all areas and to increase the sewage treatment plant's operational capacity are critical to reducing pollution and improving water security in Ibb.

v. To mitigate future climate extremes, climate resilience measures are required. As a result, establishing flood drainage networks throughout Ibb is critical to reducing flood risk on water and sewage networks (crashes and blockages).

vi. To achieve water security, the budget and government support for water and sanitation services must be increased.

vii. Strengthening the institution's financial, technical, and staff capacity building allows the institution to provide better services and increase the institution's ability to adapt to meet any challenges.

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