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Abstract

Intermittent water distribution poses a prominent challenge for water authorities in developing regions, including Kabul. Escalating water demand in Kabul, driven by population growth and various factors, strains municipal water utilities. This study comprehensively appraises Kabul's water supply system performance, scrutinizing critical performance metrics encompassing demand-supply dynamics, low hydraulic head, water quality, and client satisfaction. These metrics are pivotal in assessing urban water supply system efficacy. Suboptimal water conveyance, client grievances, and water quality anomalies signify service inadequacies. Data collection involving questionnaires and departmental records underscores a 50% demand-supply dissonance. Water quality assessments reveal taste, odour, turbidity, and impurity concerns. Customer discontent associated with inconsistent water access is palpable. This research, which examines critical metrics such as demand-supply dynamics, hydraulic head, water quality, and client satisfaction, is a valuable diagnostic tool for addressing the strain on municipal water utilities. It contributes significantly to society by shedding light on the pressing challenges water authorities face in Kabul, particularly in intermittent water distribution. Kabul's water supply systems grapple with water loss, water quality disparities, hydraulic fluctuations, and uninterrupted water resource provisioning. It is recommended that the water utility develop a strategy and work hard on the indicated system deficiencies, especially on water supply, water quality and pressure variation, to improve the water supply system performance and provide customers with good quality service.

Keywords: *Water Supply and Demand, Water Quality, Pressure Variation, Hydraulic Head*

1. Introduction

The principal objective of any water supply system is to consistently provide safe, potable water catering to domestic, industrial, and fire protection needs [1]. Beyond its immediate applications, water is pivotal in underpinning economic and social development, safeguarding environmental sustainability, and promoting public health. The intricate interplay between water resources and economic activities, job creation, and environmental preservation underscores its indispensable nature in sustaining livelihoods and maintaining hygiene standards within communities and individuals [2].

A comprehensive water supply system comprises a complex interplay of interconnected components, encompassing water procurement, treatment, conveyance, storage, and water distribution [3]. Water sources stem from surface and groundwater reservoirs, with urban centres like Kabul relying heavily on major rivers or lakes (surface water) to cater to their increasing demands [4]. In contrast, smaller settlements often tap into groundwater sources of adequate quality, necessitating minimal treatment, primarily through chlorination for disinfection. Strategically positioned wells within municipalities serve as conduits, channeling raw water to treatment facilities where it undergoes rigorous purification processes to adhere to stringent standards for public consumption [5]. The treated water is subsequently stored in expansive reservoirs, serving as a vital reserve during periods of peak demand and enabling the regulation of pumping rates. High-lift pumps pressurize treated water through rising mains, ultimately distributing it through an extensive network of interconnected pipes [6].

The water distribution network's significance is unmistakable, as it ensures water delivery to consumers at adequate pressure. This network encompasses an array of components, such as pipes, pumps, junctions, valves, fittings, and storage tanks. The water distribution network is critical in delivering water to consumers and holds paramount importance in sustaining public health and promoting economic development [3]. Efficient water distribution systems contribute to the overall well-being of communities by providing a reliable supply of clean water for domestic, industrial, and agricultural purposes. Moreover, these systems are essential for ensuring the resilience of urban and rural areas in the face of population growth, climate change, and other environmental challenge [7].

In Kabul, the exponential and uncontrolled surge in population, a consequence of broader Afghan population growth trends [8], has exerted tremendous pressure on the existing water supply infrastructure. A feasibility study conducted in 2004 projected a population of 4,089,000 for 2015, with an associated water demand of approximately 123.4 million m^3/year. This, however, overshadows the estimated groundwater availability within Kabul city, which stands at approximately 44 million m^3/year. This finite resource is only sufficient to meet the needs of approximately 2 million inhabitants, even at a modest per capita consumption rate of 50 litres/day [9] [10]. Compounded by challenges related to access to clean water supplies and effective sanitation, Kabul faces issues typical of underdeveloped cities. Consequently, this analysis seeks to meticulously evaluate the performance of the water supply system, acknowledging the substantial repercussions of inefficient day-to-day operations that bear economic, social, and environmental consequences. Simultaneously, the study aims to mitigate the risk of major operational failures that could exacerbate the existing challenges [11].

1.1 Problem Statement

Water utility systems face many critical challenges threatening the availability, quality, and reliability of water delivery to consumers. These issues include water quality degradation, low-pressure incidents, capacity limitations, infrastructure ageing and deterioration, and escalating demand. These multi-faceted challenges pressure the water supply system as it ages and grapples with increasing populations. Due to these formidable challenges, the cumulative water demand in numerous developing countries surpasses the available population capacity, engendering a precarious misbalance in the water supply system's equilibrium. This multi-faceted issue necessitates comprehensive examination and targeted interventions to ensure the sustainable provision of potable

water for increasing populations in the face of ageing infrastructure and increasing demand.

1.2 Significance of the Study

This study aims to assess and identify deficiencies within the water supply system, providing insights into water supply coverage, low water pressure issues, and water quality standards. Furthermore, it will analyze customer satisfaction levels regarding service quality and operational maintenance conditions. The outcomes of this assessment and analysis will offer a comprehensive understanding of the overall system performance.

These findings will serve as valuable resources for decision-makers, particularly the city water utility (water supply service office), aiding in planning future expansions and addressing areas characterized by suboptimal water delivery. Additionally, the results will inform the development of remedial measures to rectify system deficiencies, enhancing coverage, service reliability, and water quality. This, in turn, will contribute to the increased efficiency and overall improvement of water supply services. Furthermore, the study's findings may offer important insights for future research endeavours in the field.

1.3 Study Purpose

The primary goal of this research is to evaluate the performance of water supply systems in Kabul. The study is conducted with descriptive and analytical approaches, focusing on key aspects of water supply systems, including water supply and demand dynamics, water quality, and the adequacy of water pressure at consumers' taps.
The specific objectives of this study are as follows:

1. To ascertain whether the existing water supply system effectively meets the water demands of consumers.
2. To assess the quality of water provided by the current water supply system.
3. To determine whether the current water pressure is sufficient for water delivery to consumers' residences.

2. Review of Literature

This section's extensive literature review focuses on assessing water supply system performance, particularly emphasizing key facets of water utility operation. The primary aim of this study is to consolidate the existing body of knowledge related to several pivotal dimensions: the availability of water, residential water demand, water quality, water supply pressure, and levels of user satisfaction. The current piped-water system, managed by the Afghanistan Urban Water Supply and Sewerage Company, provides water to less than 20 per cent of Kabul's population [12]. This system draws water from three distinct sources: the Logar River aquifer located to the south-east of the city, the Afshar well field sourcing water from the Paghman River aquifer to the west, and the Alaudin well field, which extracts water from the Upper Kabul Aquifer situated to the south [13].

2.1 Performance Indicators

Performance indicators are pivotal in assessing water utility efficiency and effectiveness across various operations. These indicators offer quantifiable metrics for evaluating actual performance against predefined objectives, facilitating a clear comparison and aiding in proactive management strategies. The assessment of water system performance necessitates a systematic framework founded on standardized performance measures derived from comprehensive network analyses [14].

Due to a growing awareness of the quality of services offered by the water industry today and the natural evolution of modelling and design methods, performance assessment is becoming a critical component of the engineering approach to control the water supply and distribution system. However, assessing a water system's performance is complex because it is subject to various interpretations and depends on a range of network characteristics and factors, some of which are impermissible. The performance is evaluated using a methodical process involving building a framework with various concepts and criteria. The strategy is predicated on the creation of uniform performance metrics. The results of an expanded network analysis are used to construct the measures [15].

Many stakeholders, such as water utility managers who are interested in streamlining their systems' operations, local authorities who are typically in charge of the water supply and may also own water utility assets, regulatory offices that keep an eye on service quality, pricing, and levels of service, environmental protection agencies that are in charge of safeguarding natural resources for future generations, customers who want low costs and high-quality service, development banks that lend money to utilities, non-governmental organizations, etc., can evaluate a water utility's performance. The goal and extent of the evaluation determine the guiding concepts and techniques for evaluating businesses. An essential component of any such evaluation should always be the energy assessment [16].

To increase the efficiency of a pressurized water system, a pilot example is provided to managers and operators of water networks. The goal is to modify the hydraulic state of the system to operating conditions. To achieve this goal, a hydraulic modelling methodology has been used with field data and site inspection. The chosen water system has significant issues that prevent it from delivering water to the regional reservoir in the intended volume under specific topographic and operational conditions [17].

Systems for supplying and distributing water are essential for several reasons, including maintaining economic and social well-being. Despite this, until there is a significant interruption or operational breakdown, the performance of these systems is frequently overlooked. Even though failure occurrences are probably unavoidable, they are frequently dramatic and expensive, and daily inefficient WDS performance has significant negative effects on the environment, society, and economy. Water distribution networks face deteriorating water quality, limited capacity, aged and crumbling infrastructure, and rising demand [18]. Water distribution network performance is typically assessed following industry standards [19].

2.1.1 Pressure Assessment

Water demand management solutions include pressure management and leak control as essential elements. A study in Mutare looked into the possibility of using pressure

management to prevent leaks in response to high water losses caused by malfunctioning metering, an old distribution system, and excessive system pressures. In the city, the percentage of unaccounted water was 57%; in particular research areas, the average was 47% and 32%. The study area also investigated pressure management to reduce leakage, highlighting the importance of pressure in the functioning of water systems [20].

The building of extra service reservoirs within the service area of the Kwara State Government is indicative of efforts to enhance the quality of water delivery services. The hydraulic analysis considered multiple possibilities related to the placement of reservoirs, real production, and distribution to different zones. The significance of pressure in guaranteeing effective water distribution was emphasized by assessing nodal pressures and examining their compliance with suggested values for acceptable network performance [21].

A different strategy is to replicate the behaviour of the water distribution system under different conditions using hydraulic modelling software [22]. This program can predict pressure levels at any point in the system while accounting for variables like pump performance, pipe features, and demand patterns. A useful technique for spotting possible pressure issues and assessing the success of mitigating actions is hydraulic modelling.

The evaluation of the pressure of water supply systems in Kabul has been the subject of numerous research studies. According to one study, the water distribution network in Kabul frequently has pressure levels lower than the advised minimum of 20 meters of water column (mWC) [23]. Leaks, increased demand, and old infrastructure are some of the reasons for this. According to a different study, the water distribution network in Kabul has frequent pressure variations, with pressure levels drastically falling during times of high demand [24].

2.1.2 Water Quality Assessment

Groundwater, which includes wells, streams, and springs, is the main source of drinking water in many developing country suburbs. Due to inadequate sanitation and hygiene, these sources are susceptible to contamination, which can result in waterborne illnesses. Water resource use and the frequency of waterborne infections were evaluated in survey research conducted in the suburban communes of Selembao and Kimbanseke. Seasonal fluctuations in water quality were found using physicochemical and bacteriological tests, demonstrating the connection between public health and water quality. Waterborne infections accounted for over 75% of patients admitted to nearby medical facilities between 2016 and 2019, highlighting the importance of water quality testing [25].

The phrase "water quality," which is relative, describes the characteristics of water and how it interacts with both natural and man-made processes. Due to leaks and cross-connections, water-related health problems can arise from introducing chemical substances into the water. Since microbiological contamination is the primary cause of most known water-related health issues, expanding access to clean drinking water is crucial. One of the main objectives is to obtain safe drinking water quality, and one of the main concerns is microbiological contamination [26].

A vital framework for guaranteeing the security and adherence of water supply systems to statutory mandates and health-based criteria is the Water Safety Plan (WSP). Water Supply Plans (WSPs), which encompass all stages of the water supply chain from the

source to the customer, are based on thorough risk assessments and management techniques. The main goals are preventing contamination in domestic and distribution networks, avoiding source water pollution, and lowering or removing it through suitable treatment procedures. These guidelines, which aim to protect public health and advance appropriate water delivery methods, apply to all water supply chains, regardless of size or complexity [27].

This paper's literature analysis delves deeply into the performance metrics of water supply systems, emphasizing several crucial aspects such as water supply pressure, water quality, household water demand, availability of water, and user happiness. Although the review offers insightful information on these factors, this paper can fill some specific gaps. One significant gap is the requirement for a more thorough and integrated examination of various performance indicators, combining dispersed knowledge into a coherent assessment of the water supply system's performance. Moreover, the literature study lacks a regional viewpoint but provides insights from stakeholders in other areas. This research aims to contribute by examining the water supply system in Kabul and considering its distinct obstacles and conditions. Additionally, it can delve further into the viewpoints of different stakeholders engaged in assessing water utilities, providing insights into how these viewpoints affect performance evaluation.

3. Research Methodology

An analytical and descriptive methodology is employed to assess the water supply systems in Kabul. Situated at a high altitude of approximately 1800 meters (6000 feet) above sea level, Kabul stands as one of the world's highest capital cities, between Latitude 34-31' North and Longitude 69-12' East. The geographical context of the study area is illustrated in Figure 1.

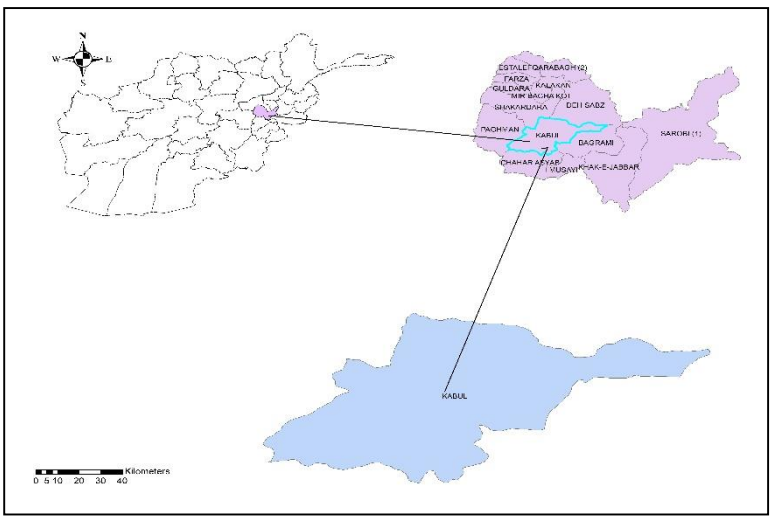

Fig. 1. Study area map

This study's analytical framework is constructed on data collected by the research team, primarily via structured questionnaire-based interviews with consumers across various regions of Kabul. A comprehensive review of published reports, journal articles, and departmental reports was conducted to gather relevant information. The study

interviewed 384 households, and the sample size was determined using Chochron's equation [28].

$$\text{Sample Size} = \frac{Z^2 x\ px(1-p)}{d^2}$$ **Eq. 1:** Sample size determination

Where:
Z is the Z-Score taken as 1.96 for the confidence interval of 95%
P is the standard deviation assumed as 0.5(50%)
d is the margin of error (confidence interval) considered 5%.

3.1 Research Modal

The research model aims to evaluate the effectiveness of Kabul City's water supply system by employing a range of variables and performance indicators. The model encompasses four primary areas: Demand-Supply Dynamics, Hydraulic Head, Water Quality, and Client Satisfaction. Furthermore, it describes data collection methods, analysis techniques, and expected outcomes. The research model provides a comprehensive assessment of Kabul's water supply system, identifying areas for improvement and formulating effective strategies to enhance the system's performance and ensure the delivery of safe, reliable, and accessible water to all Kabul residents.

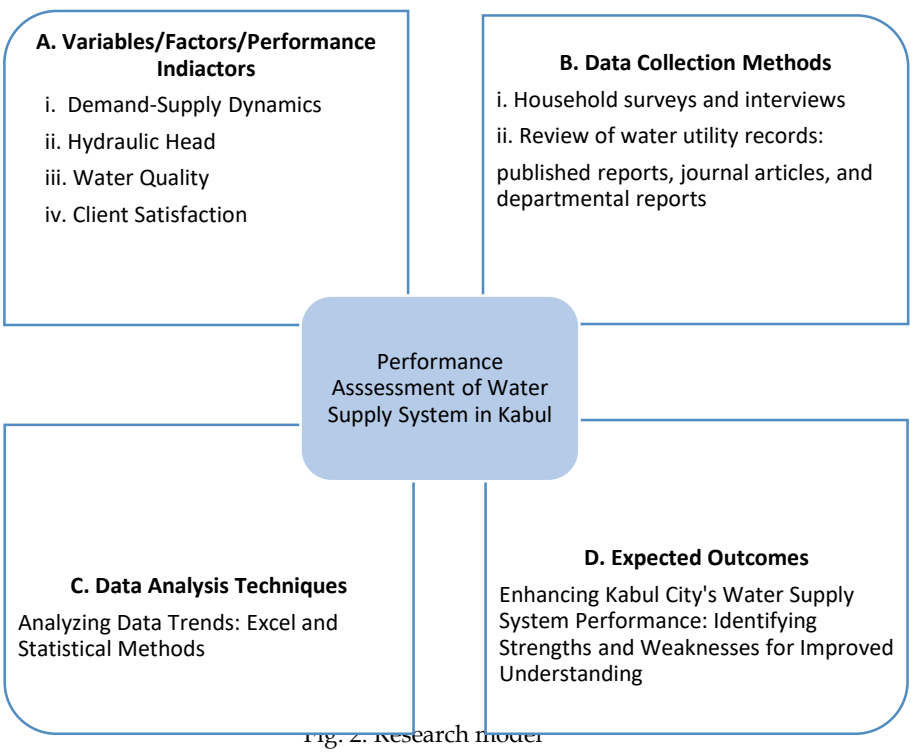

Fig. 2. Research model

4. Results and Discussions

A comprehensive assessment of Kabul's water supply system is conducted to evaluate the water supply and demand, water quality, pressure variations, consumer satisfaction and dissatisfaction with the piped water supply system. The findings, presented in the

subsequent sections, illuminate the intricate dynamics of water supply and demand, water quality, pressure variations, and consumer satisfaction levels, providing valuable insights into the current state of Kabul's water supply system.

4.1 Supply and Demand Analysis

A detailed analysis unveiled a noteworthy inconsistency between the supply and consumer demand in the piped water supply system. The data analysis highlighted a substantial shortage in the volume of supplied water compared to consumer preferences. Specifically, our findings indicated a notable shortfall of approximately 50% in the supplied water volume relative to concurrent demand, as depicted in Figure 3. This finding aligns with previous studies conducted in Kabul, including Amin et al. (2017), Ahmed et al. (2018) and a USAID Report (2013), which similarly reported substantial shortfalls in water supply compared to demand [29] [30] [31].

This observation emphasizes the need for further exploration and improvement in optimizing the efficiency and adequacy of the current water supply infrastructure.

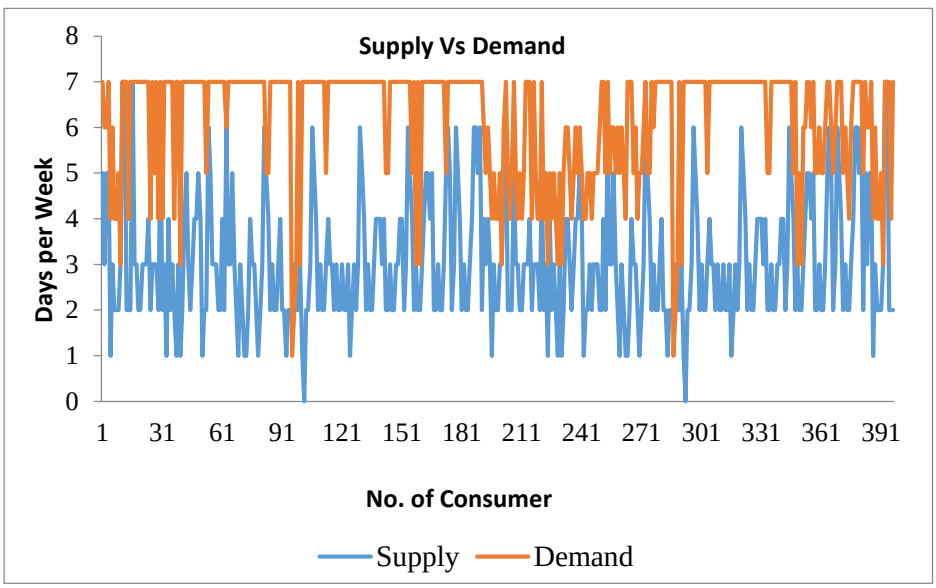

Fig. 3. Water supply vs. water demand

4.2 Water Quality

In this section, we assessed water quality in the water supply systems by considering various physical parameters. These parameters were categorized into three primary dimensions: smell, colour, and taste; each was further subdivided into two distinct sub-categories, as depicted in Figure 4.

Among the 398 respondents who participated in the study, 76% expressed satisfaction with the smell of the water, affirming that it had no noticeable odour. However, the remaining 24% of respondents reported concerns about occasional foul odours emanating from the water, rendering it unsuitable. Similarly, 63% of the respondents indicated that the water's taste was agreeable, while 37% found it unpalatable and unsuitable for consumption.

Furthermore, the majority of participants (67%) voiced dissatisfaction with the water's clarity, asserting that it was not visually clear. In contrast, the remaining 33% expressed contentment with the water's colour, stating that it appeared clear.

These findings align with previous studies, such as Ahmed et al. (2018), Zaryab et al. (2017) and Uhl, J. F. (2006), which also reported concerns about water quality in Kabul's water supply system [30] [32] [33].

These findings underscore the multi-faceted nature of water quality perceptions among consumers in the study area. A significant portion of the population remains concerned about the smell, taste, and clarity of the water supplied, which warrants attention and potential interventions to enhance the overall quality of the water supply.

4.3 Pressure in the Water Supply System

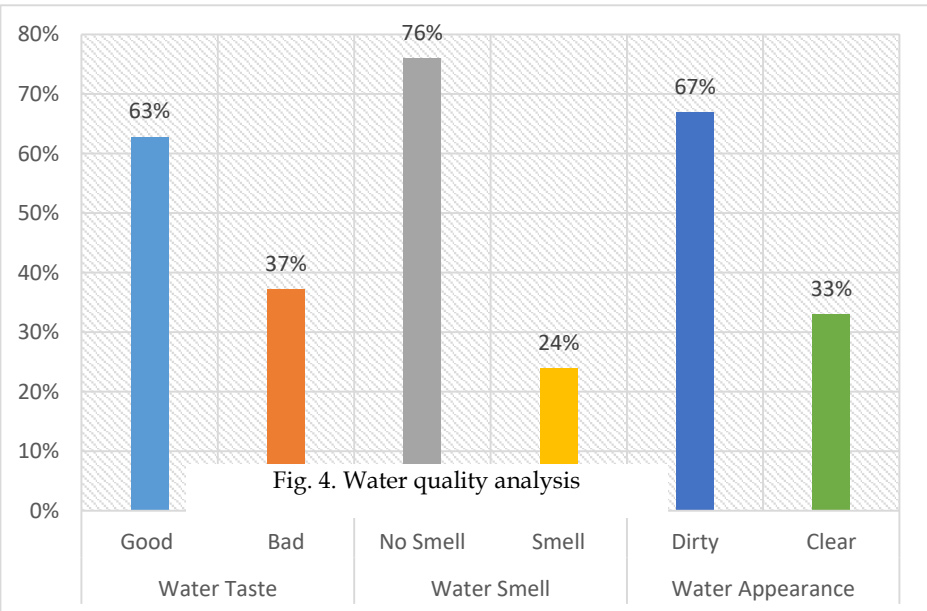

Fig. 4. Water quality analysis

One of the fundamental components within water distribution systems is the pump stations, serving as vital elements in imparting energy to the hydraulic system. Their primary role is to counteract elevation disparities and mitigate head losses from pipe friction and fittings. This process is essential for consistently delivering the designed discharge to the beneficiaries' taps. However, within the current utility system, beneficiaries' experience of receiving water at their taps falls significantly short of these design intentions.

Among the 398 valid responses obtained from the survey regarding the water pressure of the piped water supply, an overwhelming majority of 371 respondents (representing approximately 93%) reported inadequate water pressure at their taps. In response to this deficiency, they have resorted to using supplementary pumps to extract water from the system, underlining the pressing issue of suboptimal water pressure within the distribution network. In contrast, a smaller fraction of 27 respondents (approximately 7%) expressed contentment with the pressure of the piped water supply.

The observed insufficiency in water pressure during peak demand hours can be attributed to the interplay of imbalanced water availability and the local topography of the town. Additionally, respondents residing in higher elevations of the city noted a distinct lack of water pressure reaching their taps, which can be attributed to system leakages or the network's strain caused by excessive connections that surpass the system's capacity.

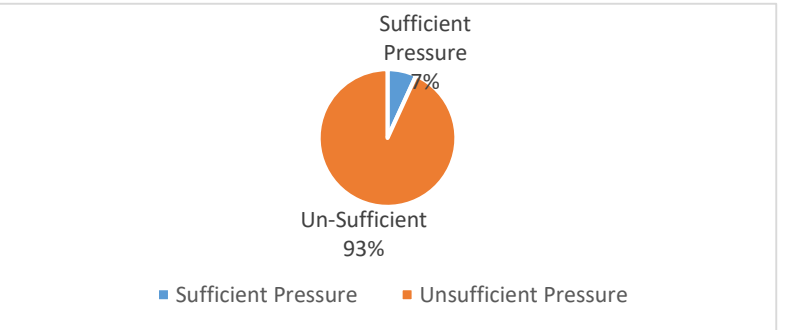

Fig. 5. Water pressure

4.4 Consumers' Satisfaction

Consumer satisfaction plays a pivotal role in understanding the acceptance and preferences of customers within a service context. It fundamentally fulfils a customer's desire for a specified good or service. The degree of consumer satisfaction hinges on the perceived performance of the utility or the evaluation of that good or service concerning the consumer's needs.

Drawing from the study's findings, a majority of the surveyed customers, comprising 247 respondents (62%), expressed contentment with the existing water supply systems. Nevertheless, a notable subset of 151 (38%) out of the total 398 respondents conveyed dissatisfaction with the performance of the current piped water supply system, as visually depicted in Figure 6, which aligns with the findings of Amin et al. (2017) [29].

The primary factors contributing to their dissatisfaction encompassed concerns about deteriorated water quality, low water pressure, inadequate water delivery, and insufficient system coverage. These issues collectively contribute to understanding the multi-faceted dynamics that influence consumer satisfaction and underscore the critical need for addressing these specific areas to enhance the piped water supply system's overall performance and consumer experience.

The study revealed a significant disparity between the available water supply and consumer demand in Kabul city. The supply is approximately 50% less than the demand, and this is due to factors such as population growth, ageing infrastructure, and limited water resources. Additionally, a significant portion of the population remains concerned about the smell, taste, and clarity of the water supplied. Furthermore, the study found that most respondents expressed dissatisfaction with the water pressure of the piped water supply. This is due to factors such as imbalanced water availability, the local topography of the town, and system leakages. These findings underscore the need to

upgrade the existing infrastructure and expand the water distribution network to ensure adequate water pressure for all residents.

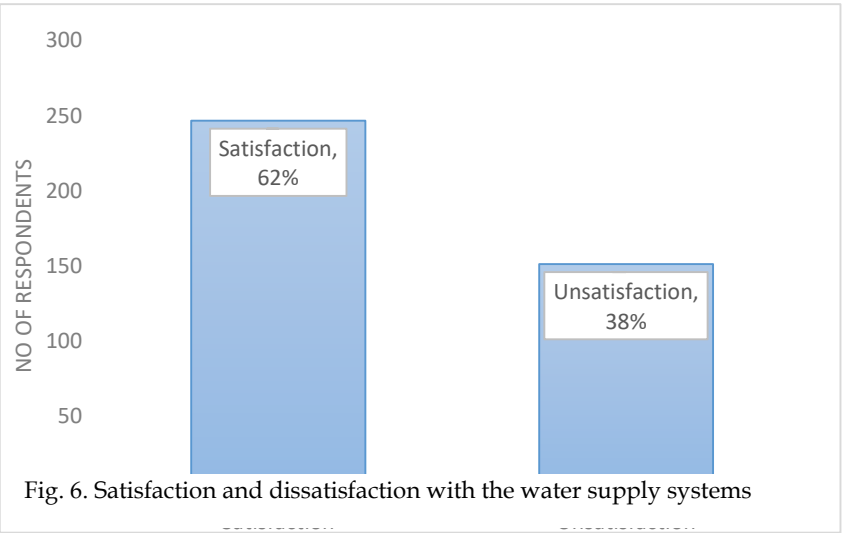

Fig. 6. Satisfaction and dissatisfaction with the water supply systems

5. Conclusions

This research concluded that Kabul's water supply systems have serious problems providing satisfactory service to the community. Based on the findings, the following conclusions can be drawn:

- The water demands of Kabul city exceed supply by about 50%, and its water supply distribution network reaches only about 20% of the capital.
- Currently, 97% of the respondents complain about the low pressure in the system, which is why they use extra pumps to withdraw water from the systems.
- The system also has serious water quality issues, which impact the water's taste, smell, and appearance. Out of the total respondents interviewed, 37% complained about the bad taste of the water, whereas 24% added that the water has a bad smell too. Furthermore, 67% of the respondents added that the water has impurities in it, and the colour of the water is not clear. Out of the 398 respondents interviewed, 151 respondents are not satisfied with the performance of the water supply system.

6. Recommendations

According to the study's findings, the current situation necessitates improvements in the water agency's operations and the deployment of suitable measures to prevent system failures. The following recommendations are provided for the improvement of the water supply systems:

- Use suitable partnership models with well-defined plans and monitoring procedures to improve finance in the urban water sector to guarantee that everyone has access to a minimum level of safe water services.
- In order to ensure that there is a continuous supply of water for longer periods during the day and to work toward a 24-hour supply, the municipal agency should use appropriate technology to monitor water pressure in pipelines, leaks in the

network, and water quality in storage tanks and pipelines. In order to do this, the agency should establish rainwater harvesting systems at potential public places and assist interested consumers in installing these systems. All waste/drain water should be treated and recycled to meet non-portable consumer needs.

- The municipal agency should release water into the network following the finalized schedule, and water supply timings should be set. It is important to notify the customers about the timings.
- Companies should form partnerships to treat and reuse urban wastewater to minimize the amount of freshwater businesses use.
- In conclusion, one of the challenges in comprehending urban water concerns in Afghanistan is the scarcity of data inside the urban setting. In urban planning and decision-making processes, addressing the lack of data collaboratively by the government and other stakeholders would be crucial.

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