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RESEARCH ARTICLE

The Analysis of Water Losses and Leakages in Drinking Water Networks Using Scada System: A Case Study from Yozgat

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HIGHLIGHTS

- *This study contributes significantly to the existing literature on remote water quality monitoring using SCADA systems.*
- *The implementation of SCADA-based management strategies to reduce water losses offers an effective solution for the management and optimization of resources in related domains.*
- *The study presents a compelling case for the significant impact of SCADA systems in water distribution, demonstrating their potential to reduce physical water losses markedly.*
- *The findings are crucial for ensuring clean water through real-time monitoring of sediment formation, aiding in the prevention of infectious diseases.*

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ABSTRACT

For water to be delivered to people cleanly and healthily, the tanks in which it is stored before being made available must also be reliable and clean. Preventing the transmission of infectious diseases through water necessitates rigorous purification and disinfection of water stored in tanks. For this reason, monitoring the sediments in the storage tank and their properties, such as pH, pressure, and temperature, are necessary in real-time. With SCADA systems, water flow is monitored remotely by providing central control and monitoring in drinking water distribution. The data collected allows for the automatic detection of tank issues, intervention in the system, and effective leak management, thereby ensuring the effective delivery of water to users. In this study, data from four pumping stations and 13 reservoirs in Yozgat were subjected to analysis, and all processes from the water source to public use were remotely controlled via the SCADA system. Prior to the implementation of SCADA, the total water losses in Yozgat Province were recorded at 64.35%, with physical losses accounting for 27.59%. From 2019 to 2023, the implementation of SCADA resulted in a 51% reduction in physical losses, thereby demonstrating the effectiveness of the system in water management and its scalability for addressing global water scarcity. Furthermore, the system guarantees the prompt prevention of sediment formation, thereby ensuring the delivery of clean and safe water to users.

Keywords: *Water Tank, pH, Pressure, Sediment*

I. INTRODUCTION

Türkiye is not considered a water-rich country, and it is anticipated that with the growing population, the country may face a significant water crisis in the coming years (Aslan, 2016). For this reason, institutions responsible for water management in the country must establish complete control over all processes leading to water delivery to the end user. However, managing water distribution systems is challenging because they consist of complex networks of interconnected pipes, pumps, valves, and controls. Many of these components are buried, making maintenance and repair operations particularly difficult. Despite these challenges and complexities, distribution systems are expected to supply households and other areas with safe drinking water under pressure (Grigg, 2024). Water management oversees groundwater, drinking water, and wastewater systems. The rapid depletion of water resources, particularly in cities with increasing population density, has shortly heightened the risk of water scarcity. Due to the rising urbanization rate, smart systems must manage water consumption (Uçar, 2022). To address this issue, institutions responsible for water management are undertaking intensive efforts.

In contemporary times, supervisory control and data acquisition (SCADA) systems are employed across various fields, particularly in communication, transportation, and imaging technologies. SCADA is a data-based control and monitoring system. Widely used across various fields, SCADA has played a direct role in developing new methods and engineering products. Predictive solutions to future water scarcity depend on establishing an effective control mechanism in water management systems (WMS). In this regard, it is evident that the SCADA system will provide significant advantages. By enabling centralized monitoring of the entire system, SCADA will expedite the resolution process of disruptions. In addition to tracking illegal water usage and water losses due to malfunctions, SCADA will also facilitate comprehensive water management by detecting potential malfunctions in water storage tanks above and below ground. SCADA systems collect information from sensors installed on network lines, valves, reservoirs, and pumping stations used in distribution, execute control operations requested by operators through remote terminals, and generate statistical data from measurements taken at stations (SUEN, 2017). Implementing integrated systems like SCADA can potentially reduce recorded water losses (Klosok-Bazan et al., 2021).

A. Regional Studies in Turkey

This section will present regional studies related to WMS, leak detection methods, and the use of smart systems in water management in Turkey. An investigation of the amounts of water produced and consumed in Konya province revealed the water loss caused by unknown leaks and illegal connections in the network (Demir, 2001). Although the balance between the flow from wells and the flow at the pump output was maintained using electronic flow meters, the volume of water loss could not be determined due to erroneous readings from old meters. To overcome this issue and identify losses and leaks, meters were installed at meterless usage sites at regular intervals to conduct readings. The data was converted into annual consumption to calculate the unknown water quantity at usage sites. By subtracting the billed water amount from the produced water quantity and the amount used at other locations, the water loss from unknown leaks and illegal connections in the network was determined to be 22.78% of the total water produced. Another study conducted in Konya examined the water loss in the drinking water network of Konya Province by analyzing data obtained from the Konya Water and Sewerage Administration (KOSKİ) for the years 2015-2017 (Körpe, 2018). Water losses from malfunctions in the drinking water network were identified, and the financial cost of these losses to KOSKİ was calculated (Görgülü, 2022). In Kayseri province, the causes and degrees of water loss in three drinking water network pilot areas were investigated using statistical methods. Variables that could directly or indirectly affect the formation of water losses were determined for each pilot area from statistical records, urban planning documents, and network measurements (Pala, 2002). Between 2006 and 2022, data from 8,224 residential water meters, subscribers, and consumption in Kayseri province were analyzed using machine learning methods to identify abnormal drinking water consumption (Güney and Selvi, 2023). In Istanbul, a GIS-based decision support system was applied for water management in drinking water distribution systems (Aydın, 2007). In another study in Istanbul, a case study was conducted in the Sultanahmet and Fatih pilot areas to identify water loss components and determine necessary actions (Karaca, 2009). In Sakarya province, applications were made to reduce water losses through pressure management in the city center of Adapazarı (Cinal, 2009). The software was developed to integrate the database of the SCADA system established for remote monitoring and control of drinking water and sewage systems in Sakarya Water and Sewerage Administration (SASKİ) with the GIS database (Çelik et al., 2016). An assessment of existing water resources in Sivas province was carried out considering future population changes and water needs (Yıldız and Değirmenci, 2010). The levels of water loss and leakage in the drinking water network in the Esentepe and Yunus Emre neighborhoods of Sivas city center were identified (Karakuş et al., 2013). In a study conducted in Diyarbakır city center, information technologies were utilized to detect losses and leaks in an isolated urban water distribution network, and it was reported that physical losses were minimized using these methods (Songur, 2016). In Diyarbakır's central districts (Sur, Bağlar, Yenişehir, and Kayapınar), studies were conducted on water losses in the distribution network using SCADA systems (Yüksel et al., 2018). In the Gölbaşı district of Ankara, improvements to prevent physical water losses in the customer area managed by the Ankara Water and Sewerage Administration (ASKİ) were reported to have repeated failures without a SCADA system, emphasizing the importance of continuous monitoring with a SCADA-like system (Songur et al., 2021). In Kilis, studies were conducted to determine residential water consumption through measurements from the network (Öztürk and Abama, 2023). Antalya determined the water loss ratio by examining the Kaleiçi drinking water distribution network data for 2015 and 2016, using subscriber consumption values, SCADA data, and a water balance table (Gülaydın, 2017). In Tekirdağ, SCADA applications implemented by Tekirdağ Water and Sewerage Administration (TESKİ) within the framework of smart water management were examined (Başa and Kurt, 2017). Results of water balance studies conducted by the Şanlıurfa Water and Sewerage Administration (ŞUSKİ) between 2015 and 2016 to detect drinking water losses and leaks were shared (Gerger and Aslan, 2019). The study reported that the volume of water loss was significantly above desired levels and identified that the high-water loss was due to operating the network at pressures far exceeding regulatory values. Research on urban water management in the Merzifon district of Amasya province addressed groundwater, drinking water, and wastewater management from a holistic perspective (Tuna and Armut, 2021). A water balance was established to determine the level of water loss and leakage in the drinking water network in Merzifon, and the importance of protecting water resources from physical losses in the water network was emphasized (Tuna et al., 2023). In a study for Erzincan province, drinking water network data from 2014-2020 were examined, and comparisons were made between data recorded before and after the installation of the SCADA system in 2018 (Bulut and Ertugay, 2022). The study found that the total physical and administrative water loss rate was 64.46% before SCADA implementation and decreased to 36.53% with SCADA use; physical water loss decreased from 27.89% to 13.64% with SCADA use. In a study conducted for Muş province, water network and drinking water data from 2017-2023 were analyzed, and comparisons were made between data before and after the integration of the SCADA system with the new drinking water network line completed in 2022 (Güçlü, 2024).

B. Studies Across Turkey

This section presents broader and more generalizable studies on WMS, leak detection methods, and the use of smart systems in water management in Turkey. An assessment of water losses in distribution systems was conducted by examining the water resource potential in Turkey (Toprak et al., 2007a). Information on the PROWAT project, in which Turkey is a partner, was provided regarding water losses and potential solutions (Toprak et al., 2007b). Another study emphasized the importance of digitization activities in preventing water losses. It provided insights into the measures taken by municipalities due to recent actions by the Ministry of Forestry and Water Affairs (Alıcı and Özaslan, 2016). It was reported that SCADA systems could not be effectively utilized due to the lack of digitization of all infrastructure facilities. Thus, the lost water could not be reduced to the desired level. By examining the water loss rates in metropolitan municipalities, the benefits and issues arising from using SCADA systems, one of the smart water technologies preferred by municipalities in combating water losses, were identified (Akıllı and Özaslan, 2017). The documents of the water and sewerage administrations (SUKİ) of 30 metropolitan municipalities in Turkey were reviewed to analyze differences in performance indicators and their causes despite the SUKİs being subject to the same regulations (Özaslan and Alıcı, 2018). To examine the sustainable management of water resources in the context of the European Union (EU) Water Framework Directive (WFD), a general framework was provided on the fundamental principles and institutional requirements introduced by the WFD for water management and leakage data from some cities in Turkey and other countries were analyzed (Dilcan et al., 2018). Water losses in drinking water networks in Turkey were classified (Karakaya and Toprak, 2018). Efforts to minimize leakage in water distribution systems through pressure optimization were studied (Köker Gökgöl, 2018). The contributions of software developed for efficiently managing isolated sub-regions by determining the physical leakage amounts in the network to operational efficiency and water management were demonstrated (Kılıç, 2021). To enable systematic, planned, and sustainable water management, calculation tools for water loss analyses were developed and tested on five different pilot datasets (Fırat et al., 2021). The impact of real-time control of pressure-reducing valves on water losses in drinking water networks was studied through model analysis (Olmuştur, 2021). Information on the components of water supply and distribution systems, problems encountered in their construction, solutions, and the current and potential uses of Industry 4.0, Internet of Things, cloud computing, machine learning, and optimization techniques in improving system efficiency was provided. The characteristics introduced to WMS by SCADA systems were also discussed (Kurban, 2022). Leaks were calculated using the Fixed and Variable Area Discharges (FAVAD) equation, which establishes a relationship between leakage and pressure in isolated measurement areas where pressure regulation was applied and compared with field data (Akdemir and Yılmaz, 2023). The study found that the FAVAD equation, which theoretically relates pressure and leakage, provided accurate results only for constant discharge pressure control and was insufficient for other methods. Thus, a new method was developed for calculating the benefits derived from leaks for all pressure regulation methods. Based on the analysis results of the standard water balance (SWB) tables of some metropolitan municipalities in Turkey, it was revealed that errors in detecting administrative water losses led to mistakes in calculating physical water losses and suggestions for solving this problem were provided (Akdeniz and Muhammetoğlu, 2023). To identify the causes of pipe failures, which are a significant factor in physical water losses, factors such as pipe material, age, diameter, burst pressure, and average water pressure were examined using a logistic regression model, and a success rate of 70.1% was reported (Karadirek et al., 2024).

C. Global Studies

This section presents some studies conducted worldwide on WMS, leak detection methods, and the use of smart systems in water management. In a pressure test applied to detect water leaks in the water network of Mecca, it was found that the water loss due to leaks was relatively high, and recommendations were provided on the measures to be taken to reduce the leaks to acceptable levels (Al-Ghamdi and Gutub, 2002). In 2022, Ma et al. employed SCADA systems to identify leakage in urban water distribution networks in real time. An algorithm applicable to SCADA systems in water distribution networks (SDNs) was developed, proposing a new model for leak detection (Radaković and Šenk, 2020). Decision support systems were used to detect and control leaks in water distribution systems (Shabangu et al., 2020). Considering that monitoring and remote-control devices could increase the likelihood of system failures and cyber-attacks, an automatic early warning system for detecting cyber-attacks in water distribution systems was proposed (Brentan et al., 2021). Machine learning models were developed to detect leaks in SDNs, and it was reported that leak detection could be achieved quickly and with high accuracy using machine learning methods (Fan et al., 2021). To objectively compare the performance of methods for detecting leaks and leak areas based on SCADA systems, the results of the 2020 "Leak Detection and Isolation Methods Battle" (BattLeDIM) competition and the analysis of methods used to solve problems in the competition were presented (Vrachimis et al., 2022). A PLC-controlled system was developed to automate water distribution, detect theft, prevent waste, and determine water's pH and dissolved solid content (Babu et al., 2023). An advanced metering infrastructure (AMI) system was proposed for leak detection in water distribution networks, and AMI and SCADA systems were compared (Jun and Lansey, 2023). The combined use of SCADA and GIS for delivering produced water to consumers without loss and reducing non-revenue water (NRW) was reported to achieve successful results in controlling and monitoring water management, early problem detection, increased efficiency, and reduced water loss (Ahmed, 2024). SCADA systems were used to improve pressure monitoring and control to reduce water loss in urban water systems (Stătescu et al., 2024). In a water distribution system serving 200,000 people, the risk of water loss from pipes with potential leak sources was analyzed, and information on appropriate pipe selection was provided (Tchórzewska-Cieślak et al., 2024). A systematic method for the optimal placement of pressure sensors for leak detection in SDNs was proposed (Tornyeviadzi et al., 2024).

This study examined the use of SCADA in the WMS of Yozgat Province and reported that using SCADA system data in field teams' work planning significantly reduced the water loss rate. A comprehensive water management mechanism was created by monitoring water levels, turbidity, temperature, pressure, pH, and chlorine values in water storage tanks in real time from a single center using the SCADA system. While the study is specific to Yozgat, the generalizable data presented is considered a valuable contribution to the literature regarding widespread use and is expected to illuminate future research in similar fields.
This research presents a comprehensive review of the technical and economic impact of SCADA applications in reducing citywide water losses, with a particular focus on the case study of Yozgat. In contrast to previous research, this study examines the issue in greater detail and depth.

II. MATERIAL AND METHODS

A. System Equipment

The automation system installation for Yozgat Municipality’s pumping stations, water collection, and distribution reservoirs, as well as the transfer of data to the cloud-based WMS via a wireless communication network, and the subsequent data interpretation processes, are examined under this heading. The study covers the procurement, installation, and commissioning of control panels planned for the water collection reservoirs, pumping stations, and primary distribution reservoirs within Yozgat Municipality's service area. The scope includes supplying and installing 13 reservoir control panels, updating existing panels at four pumping stations, six pumping SCADA panels, three master panels, and 2 data point SCADA panels. All panels and mechanical components were transported to the designated locations by the institution, and the necessary electrical, physical, and mechanical installations were completed. The study also encompasses the planned refurbishment of the Main Branch, 13 water reservoirs, and four pumping stations, including mechanical installations, remote control and monitoring systems, and water production and distribution network integration into the WMS. The technical design of the WMS control panels was completed, and the panels were manufactured accordingly. Connections between WMS panels and field equipment at specified locations were established, and regional communication infrastructure was set up within the panels. At pressure control locations, WMS panels and pressure, residual chlorine, turbidity sensors, and PT100 temperature sensors were installed. Existing equipment (sensors, flow meters, liquid chlorine pumps, electric actuators, etc.) at all installation sites will be integrated into the new system, enabling monitoring and control via the WMS. The PLC and its modules include at least nine digital inputs, six digital outputs, five analog inputs (4-20mA), two analog outputs (4-20mA), and 4 PT100/thermocouple inputs. Additionally, slim-type relays with 24V DC coils were installed to provide isolation for PLC digital outputs. The panel also includes a UPS with a minimum capacity of 600 VA, a 220V AC power supply, a panel socket, an automatic fuse, a Class C automatic switch, and terminal blocks for input and output connections. All signal cables within the panel were labeled at both ends. NYAF cables, suitable for the current of drivers and other devices, were used for connections, and cables were concealed with perforated cable channels to avoid exposure. The installation of control panels and leading panel equipment, sensors used in drinking water and pumping stations, and other system components was completed, finalizing the hardware operations.

The web-based and HTML5-compatible software interface can perform monitoring, management, graphing, and analysis tasks without additional plugins. The interface software does not utilize plugins that require installation, such as Shockwave, Flash, Java Applet, ActiveX, or Silverlight. It is compatible with all modern browsers, including Internet Explorer, Chrome, Firefox, and Safari. Since the interface software is web-based, it is independent of any operating system and works seamlessly on Linux, Windows, and macOS. The interface design is optimized for mobile device sizes and functions effectively on mobile operating systems (Android, iOS) and devices. The monitoring screens feature dynamic interface updates. Data updates are handled through asynchronous JavaScript scripts, with update intervals ranging from 2 to 10 seconds, depending on the internet speed of the PLC, WMS server, and the user. Parameters on the monitoring screens, such as healthy levels, water cones, reservoir levels, and water flow, are displayed with easily distinguishable animations. For parameters with maximum values, such as reservoir levels, the interface will scale them appropriately to ensure clarity and ease of understanding.

SCADA systems provide centralized control and monitoring for drinking water distribution. These systems manage water distribution by monitoring water flow from remote locations, collecting and transmitting this information, controlling storage tanks, and automatically intervening in emergencies. They are generally controlled systems that observe and record processes within the SCADA environment. A series of functions, including data collection, transfer, computer-based storage, automatic notification, and remote activity control, can describe SCADA. The capability of SCADA systems to use various communication methods for information exchange is crucial. This capability allows SCADA systems to receive and send data from and to remote or other digital systems. SCADA systems can communicate through various protocols, including telephone lines, UHF/VHF bands, microwave systems, satellite systems, and fiber optic cables.

Building on this, particularly in drinking water remote monitoring systems, the integration of SCADA-connected measurements has made these systems more accessible and widespread today. As a result, it has become possible to monitor and control water quality remotely.

Figure. 1. Plan of water storage tanks in Yozgat city center.

Figure 1 shows the locations of the water storage tanks in Yozgat city center. Sediment formation in the tanks is monitored using level sensors, the water supplied to the system is measured with flow meters, and losses and leaks are assessed by comparing the volume of water exiting the tank with the metered volume of water. These parameters are controlled remotely through the SCADA system. The equipment used at the specified work points in Figure 1 is detailed in Table I.

B. Data Monitoring from the SCADA Interface

Figure 2 illustrates the real-time data monitoring from tanks located in various regions via the SCADA interface. These screens show the tank's water volume, chlorine level, turbidity, pH value, and outgoing water in m³/h. Additionally, the panel temperature and indoor temperature are displayed in °C. Blue pipes represent inlets, red pipes represent outlets, and green pipes are overflow discharge pipes. Using the white-colored on/off valves shown on the pipes, blue pipes fill the tanks from the top, while red pipes discharge near the zero-level point.

Figure 3 shows the main monitoring screen of the SCADA system. The screen displays data from the pumping stations of various cities. Additionally, the alarm status for units with a lost communication connection is monitored on this screen.

Table I. Equipment at the work points

Equipment	Bahçeşehir water tank 500 m^3	Muslubelen DSİ 4000 m3	Muslubelen DSİ 2000 m3	Muslubelen pumping station	Sanayi water tank 900 m^3	Treatment pumping station	Prison water tank 500 m^3	Nohutlu water tank 500 m^3	Ahmet Efendi water tank 500 m^3	Bağlar İçi pumping station	Main water tank 15.000 m^3	Fatih pumping station	Fatih water tank 1	Fatih water tank 2	Toki water tank 1000 m^3	Toki water tank 500 m^3	Main branch water tank	Total
Level sensor	2	2	2	2	2	4	2	2	2	2	2	2	2	2	2	2	2	36
Pressure sensor				2		6				2		6						16
Differential pressure sensor				2		4				2		4						12
PT 100 temperature sensor	2	2	2	9	2	16	2	2	2	9	2	16	2	2	2	2	2	76
Master SCADA panel						2						1						3
Water tank SCADA panel	1	1	1		1		1	1	1		1		1	1	1	1	1	13
Pumping SCADA panel				1		2				1		2						6
Data point SCADA panel						1						1						2
DN 80 electromagnetic flow meter												1						1
DN 100 electromagnetic flow meter						2												2
DN 150 electromagnetic flow meter					1	1			1				1					4
DN 200 electromagnetic flow meter	2				1				1					1	1			6
DN 250 electromagnetic flow meter									1									1
DN 300 electromagnetic flow meter							1											1
Ultrasonic flow meter											1							1
Solar energy production system	1				1		1						1	1	1	1		7
Residual chlorine and turbidity			1								1							2
Electrical and mechanical renovation	2				2	3			3	2		2	2	2	2			20

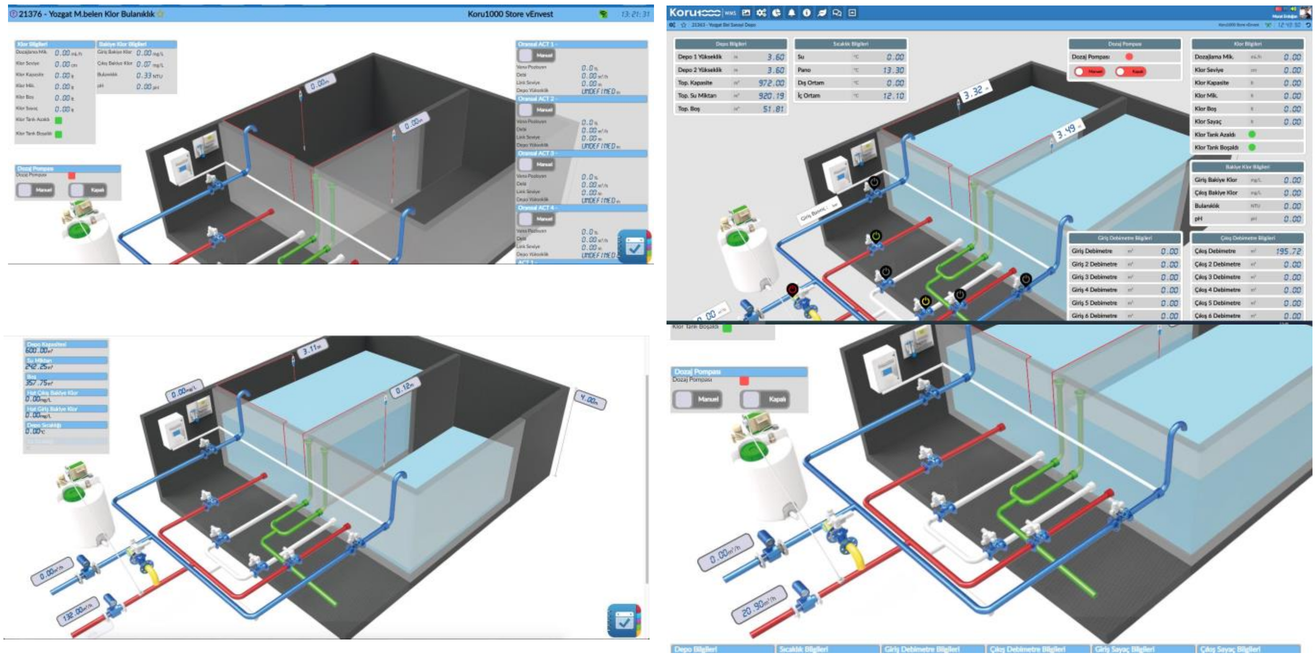


Figure. 2. Data monitoring from the SCADA interface

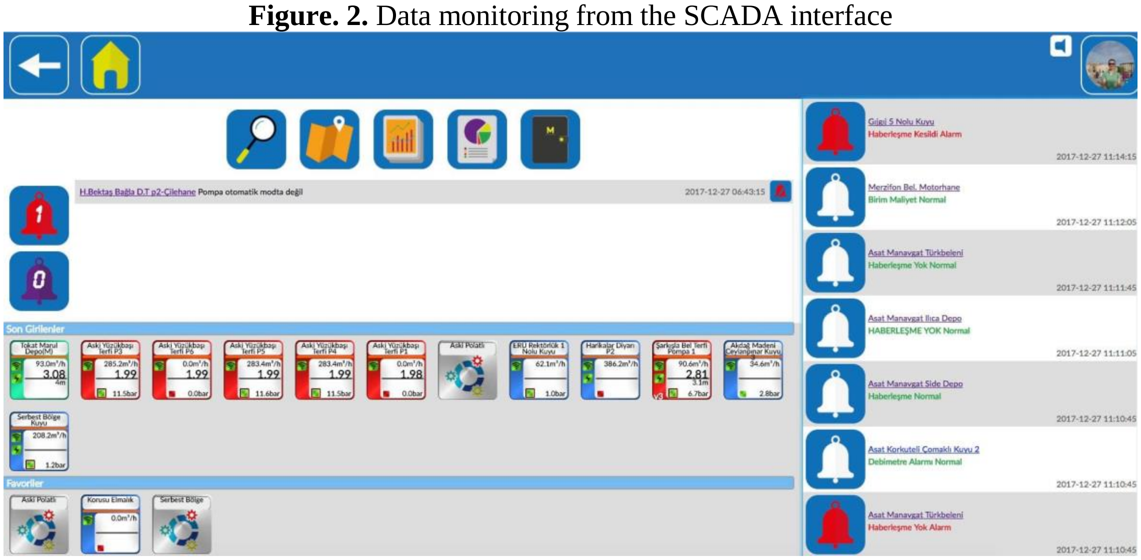
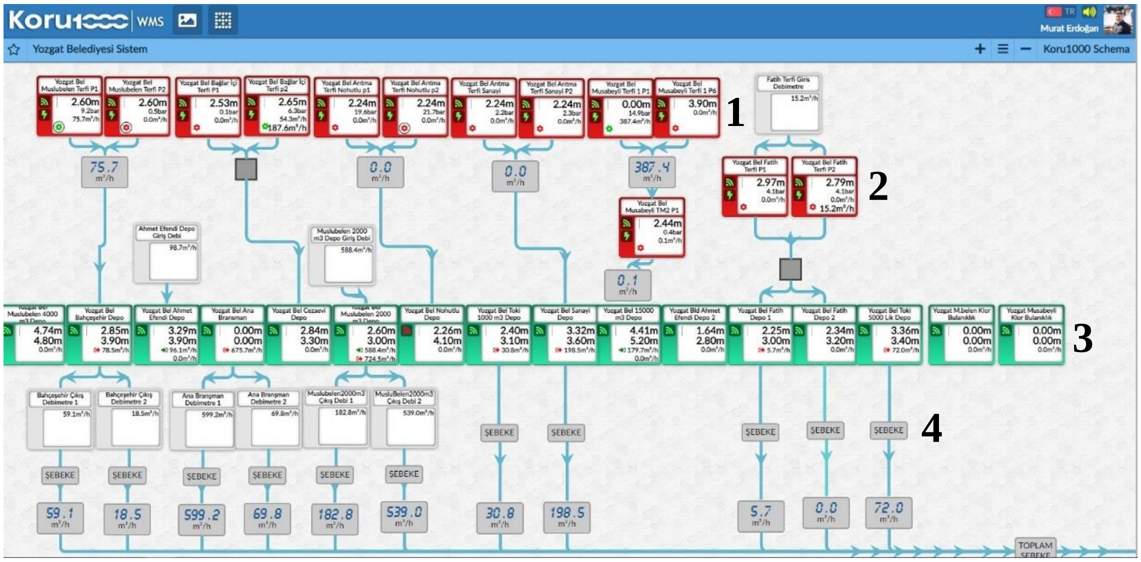


Figure. 3. Central control of the pumping stations

Figure 4 is the screen that displays the Wi-Fi connections, electrical connections, pressure values, and water levels in the pumping stations and storage tanks, as well as the amount of water pumped from the pumping stations to the storage tanks. The red section labeled “1” represents the pumping stations. Section “2” shows how water is transferred from which pump to which storage tank, along with the pressure information of the sent water. The green section labeled “3” represents the water tanks. Finally, section "4" indicates the flow rates of the water sent to the network.



In Figure 5, the left section of the information screen contains data from the recently monitored areas and the favorite storage and pumping stations. The right section of the screen lists the alarm statuses of the storage and pumping stations that have data outside of normal conditions.

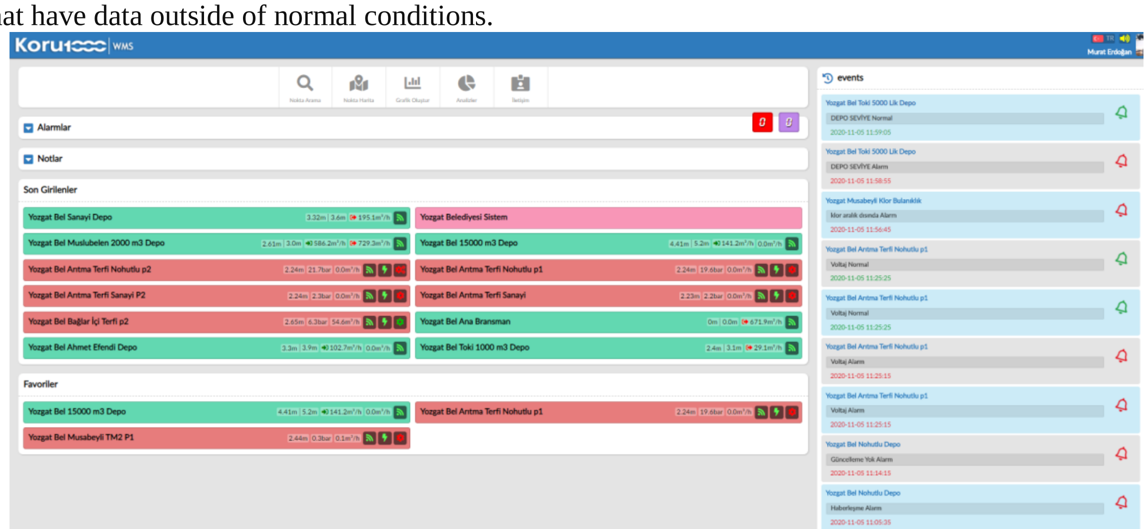


Figure. 5. Real-time notifications from storage tanks at different locations

Figure 6 demonstrates the real-time monitoring of water levels, pressure values, and other critical data from different centers. The platform's capability for simultaneous tracking enables a comprehensive analysis of water levels and pressure values across all centers, facilitating prompt intervention when necessary. Continuous monitoring and real-time data presentation accelerate decision-making processes, aiding in the early detection of potential issues, thus providing a significant advantage in data management and monitoring.

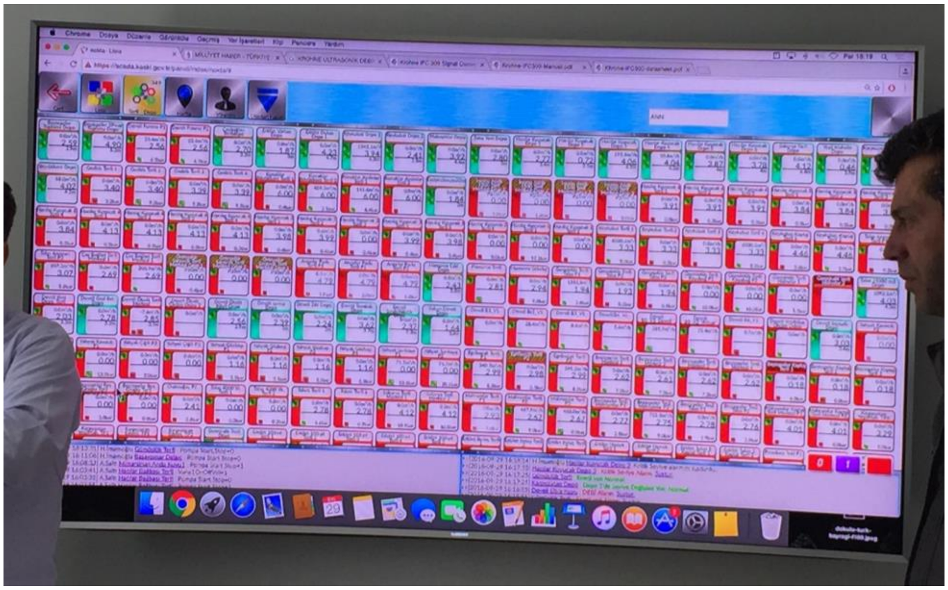


Figure. 6. Monitoring the entire network from the central office

The schematic diagram of the system is presented in Figure 7, with an explanation based on data obtained from the Bağlar İçi pump station. In this figure: Section 1 features a water level sensor placed inside the storage tank, measuring the current water height to detect the amount of sediment accumulated in the tank. Sections 2, 3, and 4 display flow meters that regulate the water pressure increasing it from 0.14 bar to 6 bar, thereby pumping the water to the reservoir that supplies the distribution network. Section 5 represents the valve control buttons for opening and closing. Section 6 contains the SCADA panel.

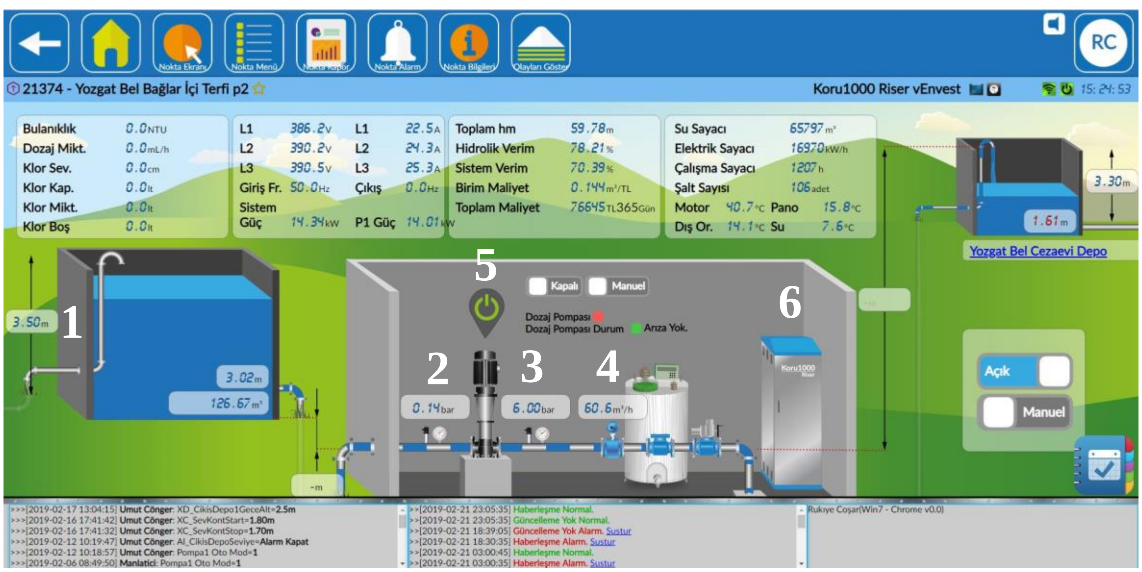


Figure. 7. Data from Bağlar İçi pumping station

Additionally, the screen provides data from voltmeters and ammeters, such as voltage and current readings, maximum water level, hydraulic efficiency, system efficiency, unit cost, total cost, total water supplied since system installation, electricity consumption, the number of opening and closing operations performed, and the temperatures of the motor, control panel, external environment, and water.

In Figure 8, the data from Kayabaşı Pumping Station is presented.

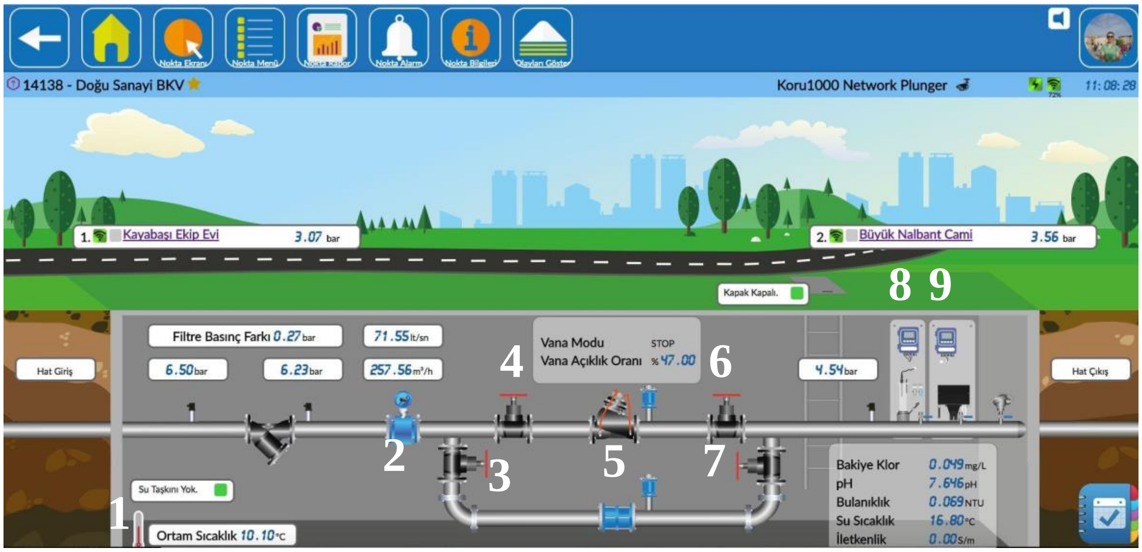


Figure. 8. Data from Kayabaşı pumping station

In this figure: Section 1 represents the thermometer used to measure ambient temperature, providing data on the water temperature. Section 2 corresponds to the flow meter, which measures water pressure. The SCADA system remotely regulates the water pressure to maintain stable flow, preventing pipe damage. Sections 3 to 7 represent the valves controlling the inflow and outflow of water to and from the reservoir. The SCADA system remotely manages the opening and closing of these valves based on reservoir fill levels. Section 8 displays the pH level of the water. Section 9 includes sensors that measure the turbidity level of the water.

Figure 9 presents the graph generated from the Sanayi water tank flow meter data.

Figure. 9. Sanayi water tank flow meter data graph

In this analysis, the hourly monitoring of water levels in the tanks was conducted, and water losses were identified by tracking the hours of least and most intensive water usage. Based on the hourly flow data from Yozgat Municipality’s Sanayi Water Tank between February 19-20, 2019, the average hourly flow was recorded at 200 m³, while between 01:00-06:00 (indicated by the orange zone), an average of 125 m³/h of water was used. Since water consumption is expected to be near zero during these hours, observing such a high usage suggests a potential loss of approximately 125 m³/h, attributed to leakage or unauthorized water use.

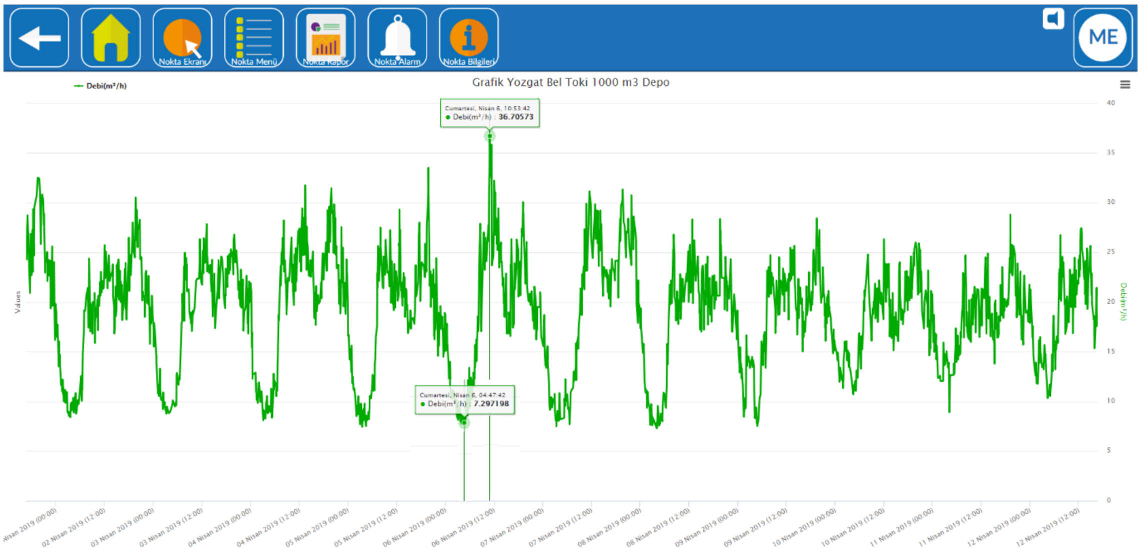


Figure. 10. Flow data for the Toki 1000 m³ water tank over one week

Figure 10 presents the weekly flow data for the Yozgat Municipality Toki 1000 m³ Water Tank. According to the graph, at 04:47 on April 6, 2019, the flow rate was recorded at 7.29 m³/h, with similar low values observed at other low points. The significantly low flow rate can be attributed to the recent completion of infrastructure works and the maintenance of storage tanks and other equipment, contributing to a low water loss rate and unauthorized use.

The graph also indicates that an average of 5 m³/h of water was used between April 1-5, 2019, while the average usage increased to 10 m³/h between April 6-9, 2019. Additionally, it was observed that at 10:53 on April 6, 2019, the flow rate reached 36.70 m³/h. These data suggest that an extra five m³/h of water was supplied to the system during April 6-9, 2019. Upon investigating the cause of this abnormal consumption, it was determined that it resulted from a burst in the drinking water line.

C. Standard Water Balance Table Method

The SWB table recommended by the International Water Association (IWA) is a method used to analyze water losses and usage within water distribution systems. This table helps balance the inputs and outputs of the system and accurately categorize water losses. By identifying inefficiencies in water management, the IWA water balance table enables more efficient use of water resources. The SWB table includes the following parameters (Farley et al., 2008):

Table II. Standard water balance table

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Administrative Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Physical Losses</td><td>Leakage on Transmission and Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to the Point Customer Use</td></tr>
</table>

- System Input Volume: The volume of water entering main reservoirs from pumping stations after disinfection (treatment), measured by inlet and outlet flow meters.

- Billed Metered Consumption: Recorded water bills for consumers registered in the subscriber system of local water and sewerage authorities based on actual consumption.
- Billed Unmetered Consumption: Consumption quantities calculated by local authorities based on standard usage estimates for cases where direct measurement is not conducted.
- Billed Authorized Consumption: Water consumption provided to a specific subscriber or group within a predetermined permit or quota set by local authorities.
- Unbilled Authorized Consumption: Authorized but unbilled water consumption (e.g., for mosques, parks, gardens, government institutions), measured or estimated as permitted by local authorities.
- Unbilled Metered Consumption: Measured water usage for locations with a registered subscriber and meter but unbilled by the authority (e.g., neighborhood fountains).
- Unbilled Unmetered Consumption: Authorized but unmeasured and unbilled consumption by local authorities (e.g., parks and gardens), estimated based on usage patterns.
- Revenue Water: The total of billed metered and unmetered consumption by local authorities.
- Non-Revenue Water (NRW): The volume calculated by subtracting revenue water from the system input volume; this quantity also represents water losses.
- Authorized Consumption: Metered, regularly monitored, and billed water consumption managed by local authorities.
- Water Losses: The amount calculated by subtracting authorized consumption from the system input volume, representing the sum of administrative and physical losses.
- Unauthorized Consumption: Water used through unauthorized connections or faulty meters without local authority knowledge, estimated when detected.
- Customer Meter Inaccuracies and Data Handling Errors: Losses due to human errors or inaccuracies caused by old or malfunctioning meters.
- Administrative Losses: The sum of unauthorized consumption and customer meter inaccuracies.
- Physical Losses: The amount derived by subtracting administrative losses from total water losses in the system.
- Leakage and Overflows at Utility's Storage Tanks: Water is lost due to leaks in utility-owned storage tanks or overflow caused by monitoring system issues.
- Leakage on Transmission and Distribution Mains and Service Connections: Physical losses excluding leaks and overflows from storage tanks, focusing on main transmission, distribution lines, and service connections.

III. RESULTS AND DISCUSSION

This section analyzes the data obtained from the active SCADA system based on the SWB table method. In this context, the data from the last five years were evaluated. Additionally, the data obtained between 2015 and 2019, prior to the installation of the SCADA system, and the comprehensive data obtained between 2019 and 2023, after the SCADA system was installed, were examined. Physical losses significantly affect water losses in the network; however, other factors exist. At this point, losses and leakages can be detected easily in the SWB table. The difference between the amount of water entering the system and the amount of water leaving through flow meters reveals the water loss. While calculating the water loss amounts for the Yozgat province system, the loss-leakage amount was determined by subtracting the accrued water amount from the amount of water entering the system between 2019 and 2023. Table III shows the water produced, billed, and unbilled between 2019 and 2023 and the water loss rates (YOSKİ).

Table III. The quantities of produced and billed water from 2019 to 2023

Years	Number of subscribers	System input volume (m³)	Billed water volume (m³)	Unbilled water volume (m³)	Water loss (%)
2019	34,032	9,980,520	4,616,777	613,089	47.6
2020	34,699	9,395,875	3,715,388	540,000	54.71
2021	35,939	9,592,238	3,085,615	700,000	60.53
2022	36,682	8,873,849	5,113,459	177,481	31.36
2023	37,877	11,603,312	4,841,976	700,000	46.21

Since the data before 2019 belong to the pre-installation period, it is unavailable in the SCADA system. The losses and leakages of the pumping, storage, and drinking water network in Yozgat province between 2019 and 2023 were examined using the SCADA system. Based on the data obtained from SCADA, it was determined that there was a significant amount of loss and leakage in Yozgat province, as well as a lack of maintenance in the storage and pumping centers. These issues resulted in substantial economic losses, corresponding to approximately 60% of the income over the last four years. Consequently, Yozgat Municipality initiated renewal works in all pumping centers, storage facilities, and network systems in 2022, and these efforts are still ongoing. A significant economic gain is targeted as a result of this initiative. Since no SCADA system existed before 2019, the exact amount of economic loss could not be measured. In 2019, the SCADA system recorded all data using flow meters at the inlet and outlet storage facilities. Table IV shows the annual consumption amounts in 2023 according to subscriber types (T.C. Yozgat Municipality, 2023).

Table IV. The 2023 annual consumption volumes by subscriber type

Subscriber information	Number of subscribers	System input volume (m³/yıl)		Billed amount (TL/year)
		Paid	Free	
Official institutions	218	1,196,985		15,368,374.77
Commercial establishments	2,597	306,080		3,717,824.41
Residential areas	34,862	3,271,508		26,953,110.67
Parks, gardens, and wcs			650,000	
Construction sites	176	65,485		1,510,445.84
Dormitories	24	1,918		23,538.81
Total	**37,877**	**4,841,976**	**650,000**	**47,573,294.50**

Table V presents the SWB data for the years 2019 to 2023.

Table V. Data from the Standard Water Balance Table for the years 2019-2023

Year	2019	2020	2021	2022	2023	Unit
Number of subscribers	34,032	34,699	35,939	36,682	37,877	Person
System input volume	9,980,520	9,395,875	9,592,238	8,873,849	11,603,312	m³/yıl
Billed metered consumption	4,569,587	3,715,388	3,085,615	4,189,371	4,841,976	m³/yıl
Percentage	45.79	39.54	32.17	47.21	41.73	%
Billed unmetered consumption	47,190	0	0	924,088	0	m³/yıl

Percentage	0.47	0.00	0.00	10.41	0.00	%
Billed authorized consumption	4,616,777	3,715,388	3,085,615	5,113,459	4,841,976	m³/yıl
Percentage	46.26	39.54	32.17	57.62	41.73	%
Revenue water	4,616,777	3,715,388	3,085,615	5,113,459	4,841,976	m³/yıl
Percentage	46.26	39.54	32.17	57.62	41.73	%
Non-revenue water (NRW)	5,363,743	5,680,487	6,506,623	3,760,606	1,401,100	m³/yıl
Percentage	53.74	60.46	67.83	42.38	12.08	%
Unbilled metered consumption	114,063	0	0	800,000	700,000	m³/yıl
Percentage	1.14	0.00	0.00	9.02	6.03	%
Unbilled unmetered consumption	499,026	540,000	700,000	177,481	700,000	m³/yıl
Percentage	5.00	5.75	7.30	2.00	6.03	%
Unbilled authorized consumption	613,089	540,000	700,000	977,481	1,400,000	m³/yıl
Percentage	6.14	5.75	7.30	11.02	12.07	%
Authorized consumption	5,229,866	4,255,388	3,785,615	6,090,940	6,241,976	m³/yıl
Percentage	52.40	45.29	39.47	68.64	53.79	%
Water losses	4,750,654	5,140,487	5,806,623	2,782,909	5,361,336	m³/yıl
Percentage	47.60	54.71	60.53	31.36	46.21	%
Unauthorized consumption	1,247,565	1,174,484	1,475,650	177,481	0	m³/yıl
Percentage	13	12	15	2	0	%
Customer meter inaccuracies and data handling errors	456,959	432,211	428,645	5000	100	m³/yıl
Percentage	4.58	4.60	4.47	0.06	0.00	%
Administrative losses	1,704,524	1,606,695	1,904,295	182,481	100	m³/yıl
Percentage	17.08	17.10	19.85	2.06	0.00	%
Physical losses	3,046,130	3,533,792	3,902,328	2,600,644	1000	m³/yıl
Percentage	30.52	37.61	40.68	29.31	0.01	%
Leakage and overflows at utility's storage tanks	99,805	93,958	95,527	102,000	500	m³/yıl
Percentage	1.00	1.00	1.00	1.15	0.00	%
Leakage on trans. and dist. mains and service connections	2,946,325	3,439,834	3,806,801	2,498,644	500	m³/yıl
Percentage	29.52	36.61	39.69	28.16	0,00	%

According to the SWB table, the annual billed volume of measured consumption amounts to an average of 41.28% of the total volume of water supplied into the system over the past five years. The unmeasured consumption data for Yozgat, recorded through the SCADA system, only covers 2019 and 2022. As managed by YOSKİ, authorized billed water consumption represents consumption permitted through a subscription and meter registration, which is allowed with or without quotas. The table displays the five-year percentage of billed authorized water consumption relative to the total water input into the system.

Revenue-generating water volume is the most critical component of the SWB table, as it shows the income generated relative to the volume of water supplied. From 2019 to 2023, the average revenue-generating water volume is 4,274,643 m³/year, accounting for 43.46% of the system's total input. The highest revenue (5,113,459 m³/year) was recorded in 2022, prompting Yozgat Municipality to initiate comprehensive infrastructure and renewal efforts to increase this figure further. Non-revenue water (NRW) is another essential parameter, representing the financial impact of lost and unaccounted-for water throughout the entire Yozgat municipal network and reservoirs. However, NRW is not limited to physical losses; unauthorized non-billed water usage also constitutes a large proportion of NRW. Over the last five years, the average NRW rate is calculated to be 47.29%, with a steady decline observed since 2021.

Unbilled metered consumption encompasses usage in public parks, gardens, religious sites, etc., documented by the municipality yet not billed. Nevertheless, the SCADA system records the water volume consumed. Unbilled unmetered consumption, on the other hand, covers water used for public services like maintenance and fire hydrants. According to the SWB table, unbilled authorized consumption has steadily increased since SCADA's installation in 2019, with a five-year average of 846,114 m³/year. The highest authorized consumption was recorded in 2023 at 1,400,000 m³.

The amount of authorized consumption between 2019 and 2023 has not shown consistent trends. An increase in authorized consumption suggests economic efficiency. According to the table, the water loss data for Yozgat from 2019 to 2023 highlights an urgent need for infrastructure and reservoir maintenance and repair. In light of this, Yozgat Municipality intensified its infrastructure renewal efforts in 2022.

The unauthorized water consumption values in the SWB table are approximate due to potential undetected leaks or malfunctioning meters, which prevent precise assessment. Consequently, unauthorized consumption is estimated based on average consumption at suspected locations. Between 2019 and 2023, unauthorized consumption notably decreased, reaching zero in 2023. SCADA system implementation has enabled effective monitoring of unauthorized consumption across regions, contributing to substantial reductions.

Metering errors, expressed as a percentage of the total volume entering the system, can be reviewed via the SWB table. These errors arise from faulty or outdated meters, improper installation, or human error during readings. The SWB table shows a significant decrease in metering errors following the SCADA installation.
The SWB data further indicates a substantial reduction in administrative losses over the past two years, underscoring the savings achieved through SCADA-enabled monitoring of administrative water losses.

Physical losses include leaks and overflows in reservoirs and losses along supply, distribution, and service lines. From 2019 to 2023, physical losses averaged 2,616,778 m³/year, representing 27.62%. A notable decrease in physical water losses, particularly in 2023, was observed compared to previous years.

Inspections of reservoir leaks and overflows reveal recurring losses, largely due to personnel’s inconsistent monitoring of reservoir fill levels. In 2023, significant reductions were achieved through SCADA-controlled sensor monitoring, which mitigates the need for manual oversight. SCADA-based real-time assessments eliminated costs associated with personnel, labor, and transportation previously required for reservoir-level monitoring, providing substantial economic savings.

The SWB data also illustrates that the infrastructure works initiated in 2022 have dramatically reduced the volume of leaks and bursts in supply, distribution, and service connections. Damage from pipe bursts, leaks, and cracks along the network, previously high between 2020 and 2022, has approached zero following extensive renovations since 2022.

All these metrics are measured through the SCADA system. While some parameters are measured precisely, others are estimated. Data collected from SCADA—installed by YOSKİ in 2019 to monitor and control critical parameters such as pH, chlorine, pressure, and especially water losses throughout Yozgat’s pumping stations, reservoirs, and drinking water network—has been compiled into annual SWB data packets from 2019 to 2024, enabling easy access to all WMS data. Consequently, the centralized WMS has facilitated real-time monitoring, rapid intervention, and effective problem resolution. The SWB table was developed to enhance water management effectiveness and align with the national policies on water loss management, promoting water, energy, economic efficiency, and conservation.

Table VI presents the volume, unit price, and total cost of water losses from 2019 to 2023. Over these five years, an average water loss of 4,568,401.8 m³ has resulted in a financial loss of 54,024,662.92 TL due to water loss costs. Minimizing this loss would represent a substantial gain for the municipality.

Table VI. Water loss costs by year for Yozgat province

Year	Water loss amount (m³)	Unit price (TL/ m³)	Total amount (TL)
2019	4,750,654	1.68	7,981,098.72
2020	5,140,487	1.75	8,995,852.25
2021	5,806,623	2.20	12,774,570.6
2022	2,782,909	2.75	7,652,999.75
2023	5,361,336	3.10	16,620,141.6
Average	4,568,401.8	-	10,804,932.584
Total	22,842,009	-	54,024,662.92

Table VII presents the annual billed and system-output water volumes before SCADA implementation, covering 2015–2019.

Table VII. Water billed and water exiting the system by year in cubic meters

Year/Amount	2015	2016	2017	2018	2019
Billed water volume (m³/year)	4815,4	5105,83	4984,72	4322,41	4121,33
System input Volume (m³/year)	12,038.50	11,957.45	11,945.18	11,739.31	10,657.70
Percentage (%)	60.01	57.3	58.27	63.18	61.33

Table VIII provides the monthly billed and system-output water volumes, along with loss-leakage rates, for 2019–2023 following the SCADA installation.

The SWB data for 2019–2023 has been analyzed yearly, comparing the total water supplied to the system with revenue-generating and non-revenue water volumes. The data shows no consistent trends in either revenue-generating or non-revenue water volumes. However, with the SCADA system established in 2019, there have been improvements in unauthorized consumption, metering errors, administrative and physical losses, leaks and overflows in reservoirs, and losses along supply, distribution, and service lines. This outcome has provided economic benefits to Yozgat Municipality. A review of the SWB data reveals a notable decline in water losses and leaks between 2019 and 2023. It is anticipated that the active utilisation of SCADA will result in a further reduction in these losses, with the eventual convergence to zero.

Table VIII. Monthly water loss-leakage table for Yozgat province 2019-2023

Year	Month	Water supplied to the city (m³)	Billed consumption (m³)	Water loss (%)
2019	January	754,467.00	346,895.00	54.02
	February	899,169.00	377,256.00	58.04
	March	847,824.00	369,785.00	56.38
	April	824,725.00	327,898.00	60.24
	May	765,744.64	454,548.00	40.64
	June	888,714.00	356,499.00	59.89
	July	874,603.51	311,258.00	64.41
	August	811,295.00	328,754.00	59.48
	September	733,543.00	343,719.00	53.14
	October	849,148.00	498,751.00	41.2
	November	833,405.91	467,194.00	43.94
	December	897,881.00	434,220.00	51.64
	Total	**9,980,520.06**	**4,616,777.00**	**53.59**
2020	January	782,467.00	310,276.00	60.35
	February	754,879.00	324,531.00	57.01
	March	718,724.00	311,228.00	56.7
	April	845,729.00	314,522.00	62.81
	May	796,133.64	365,348.00	54.11
	June	806,574.00	324,399.00	59.78
	July	765,503.51	389,488.00	49.12
	August	823,659.00	305,560.00	62.9
	September	754,773.00	390,031.00	48.32
	October	759,146.00	381,467.00	49.75
	November	796,305.91	398,462.00	49.96
	December	791,981.00	434,220.00	45.17
	Total	**9,395,875.06**	**4,249,532.00**	**54.67**
2021	January	769,874.40	220,276.00	71.39

	February	699,253.08	254,531.00	63.6
	March	817,273.99	98,228.00	87.98
	April	776,047.49	237,622.00	69.38
	May	796,133.64	265,348.00	66.67
	June	786,889.94	264,399.00	66.4
	July	865,503.51	309,488.00	64.24
	August	865,381.56	305,560.00	64.69
	September	801,321.95	279,831.00	65.08
	October	827,142.13	301,767.00	63.52
	November	796,305.91	298,462.00	62.52
	December	791,111.00	250,103.00	68.39
	Total	**9,592,238.60**	**3,085,615.00**	**67.82**
2022	January	764,985.00	298,855.00	60.93
	February	734,025.00	245,500.00	66.55
	March	727,735.00	485,932.00	33.23
	April	708,082.00	377,223.00	46.73
	May	706,794.00	376,278.00	46.76
	June	758,308.00	435,499.00	42.57
	July	711,880.00	352,955.00	50.42
	August	739,794.00	441,847.00	40.27
	September	767,734.00	591,056.00	23.01
	October	744,518.00	563,273.00	24.34
	November	724,736.00	492,309.00	32.07
	December	785,258.00	452,732.00	42.35
	Total	**8,873,849.00**	**5,113,459.00**	**42.44**
2023	January	930,193.00	347,766.00	62.61
	February	857,695.00	412,586.00	51.9
	March	953,759.00	347,522.00	63.56
	April	921,119.00	380,635.00	58.68
	May	958,175.00	358,174.00	62.62
	June	951,304.00	314,422.00	66.95
	July	1,022,030.00	586,774.00	42.59
	August	1,069,906.00	367,709.00	65.63
	September	1,030,622.00	411,885.00	60.04
	October	1,049,256.00	518,502.00	50.58
	November	847,854.00	379,045.00	55.29
	December	1,011,399.00	416,956.00	58.77
	Total	**11,603,312.00**	**4,841,976.00**	**58.27**

IV. CONCLUSION

The sustainability of water resources, which hold great importance for various aspects of human life, is crucial. Access to safe water depends on the reliability and cleanliness of storage tanks. Therefore, it is essential to measure sediment levels, water levels, pressure, pH, temperature, chlorine, turbidity, and loss-leakage rates in storage tanks, along with disinfection and treatment processes. To prevent the spread of waterborne diseases, continuous monitoring and adequate disinfection and treatment of water are necessary. This study examined data from water reservoirs and pumping stations in Yozgat Province, enabling real-time monitoring of all stages from the water source to storage tanks and distribution networks via the SCADA system. This system immediately detected any abnormal conditions in the reservoirs and pumping stations. Data was remotely monitored from a central point, resulting in efficient water management for the city. Measurements of parameters such as chlorine, pH, turbidity, and pressure through water sensors ensured prompt maintenance and repairs in reservoirs and other essential locations. Centralized monitoring and management have contributed to personnel, fuel, and time savings. With reduced workload for staff and remote access for managers, trust and responsibility in water management have been enhanced, improving functionality across the water management team through systematic control.

Through real-time monitoring, the loss-leakage rate in central Yozgat was precisely determined. Immediate reporting, archiving of past events, and real-time wired and wireless communication between operators and the field enabled quick responses to malfunctions, increasing user satisfaction. The quality of supplied water was maintained, ensuring that safe water reached end users with minimal loss. The SWB table generated with the data collected in this study revealed an average 50–60% water loss rate over the past five years. To address this issue, Yozgat Municipality undertook infrastructure improvements in 2022. The positive impact of these efforts was reflected in the SWB table, with the 2023 data showing minimized water loss.

This study sets an example for institutions across Turkey to reduce water losses and increase efficiency in WMS. Institutions should work meticulously on water management, employing advanced technology to accurately collect data, which expert teams should then evaluate and record in the SWB table to identify profit or loss areas. Timely maintenance, repairs, and renewals should be carried out, considering equipment aging due to its lifespan and environmental conditions. Old and malfunctioning meters should be replaced with digital meters, and pressure values that lead to leaks should be controlled via flow meters. This study recommends SCADA usage as a tool for effective water management. The proposed SCADA-based framework has the potential to serve as a model for other municipalities seeking to implement efficient water management strategies, particularly in regions facing water scarcity.

STATEMENT OF CONTRIBUTION RATE

The authors' contribution rates to the study are equal.

CONFLICTS OF INTEREST

They reported that there was no conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this article, the rules of research and publication ethics were followed.

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REFERENCES

[1] Ahmed, Z. Y. (2024). Reducing Non-Revenue Water. *International Journal of Applied Mathematics, Computational Science and Systems Engineering*, 6, 23-29.
[2] Alıcı, O. V., & Özaslan, K. (2016). *Yerel Yönetimlerde Altyapı Sistemlerinin Sayısallaştırılması ve Su Kayıplarının Önlenmesi. Uluslararası Bilimsel Araştırmalar Dergisi (IBAD)*, 3(1), 204-218.
[3] Akdemir, M., & Yılmaz, S. (2023). *İçme Suyu Sistemlerinde Sızıntıların Uygulamalı ve Teorik Olarak Karşılaştırılması. İleri Teknolojilerde Çalışmalar Dergisi*, 1(2), 55-66.
[4] Akdeniz, T., & Muhammetoglu, H. (2023). Türkiye'de Kentsel Su Dağıtım Şebekelerinde İdari Su Kayıplarının Değerlendirilmesi. *Çevre İklim ve Sürdürülebilirlik*, 24(1), 1-6.
[5] Akıllı, H., & Özaslan, R. (2017). Su Kayıplarının Önlenmesinde Teknoloji Kullanımı: Büyükşehir Belediyelerinde Scada Uygulaması. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 22(Kayfor 15 Özel Sayısı), 1599-1618.
[6] Al-Ghamdi, A. S., & Gutub, S. A. (2002). Estimation of Leakage in The Water Distribution Network of The Holy City of Makkah. *Journal of Water Supply: Research and Technology*—AQUA, 51(6), 343-349.
[7] Aslan, B. (2016). *İçme Suyu Temin ve Dağıtım Sistemlerinde Su Kayıp ve Kaçaklarının Tespiti*. Uzmanlık Tezi, İller Bankası AŞ, Ankara, 88.
[8] Aydın, D. (2007). *İçmesuyu dağıtım sistemlerinde cbs tabanlı su kalitesi yönetimi* (Doktora Tezi, İstanbul Teknik Üniversitesi)
[9] Babu, C. G., Jayakar, S. A., Dhanasekar, R., & Kalaiyarasi, M. (2023, April). Quality drinking water distribution system. *In AIP Conference Proceedings* (Vol. 2725, No. 1). AIP Publishing.
[10] Başa, Ş., & Kurt, S., (2017). Su ve Kanalizasyon İdarelerinde Akıllı Su Yönetimi Uygulamaları: Tekirdağ Örneği. *Süleyman Demirel Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 22(Kayfor 15 Özel Sayısı), 1519-1532.
[11] Bulut, O., & Ertugay, N. (2022). Assessing Water Losses in Drinking Water Distribution Systems Using the SCADA System: The Erzincan Case. *Development*, 2, 2, 141-160.

[12] Brentan, B., Rezende, P., Barros, D., Meirelles, G., Luvizotto Jr, E., & Izquierdo, J. (2021). Cyber-attack detection in water distribution systems based on blind sources separation technique. *Water*, 13(6), 795.
[13] Cinal, H. (2009). *Basınç yönetimi ile içmesuyu şebeke kayıplarının azaltılması: Sakarya örneği* (Master's thesis, Sakarya Üniversitesi).
[14] Çelik, A., Kocaman, H., & İnce, H. C. (2016). Sakarya SASKİ Genel Müdürlüğü SCADA ve CBS Entegrasyonu.
[15] Demir, A. (2001). *Konya içme suyu şebekesinde su kayıplarının belirlenmesi* (Master's thesis, Fen Bilimleri Enstitüsü).
[16] Dilcan, Ç. C., Çapar, G., Korkmaz, A., İritaş, Ö., Karaaslan, Y., Selek, B., (2018). İçme Suyu Şebekelerinde Görülen Su Kayıplarının Dünyada ve Ülkemizdeki Durumu. *Anahtar Dergisi*, S: 354, 10-18.
[17] Fan, X., Zhang, X., & Yu, X. B. (2021). Machine learning model and strategy for fast and accurate detection of leaks in water supply network. *Journal of Infrastructure Preservation and Resilience*, 2, 1-21.
[18] Fırat, M., Yılmaz, S., & Orhan, C. (2021). Su Kayıp Yönetimi İçin Temel Hesaplama Araçlarının Geliştirilmesi ve Temel Su Kayıp Bileşenlerinin Analizi. *Gümüşhane Üniversitesi Fen Bilimleri Dergisi*, 11(2), 405-416.
[19] Gerger, R., & Aslan, A. (2019). Şanlıurfa İli İçin İçme Suyu Kayıp ve Kaçaklarının Tespiti. *Harran Üniversitesi Mühendislik Dergisi*, 4(2), 26-35.
[20] Görgülü, M. E. (2022). *Konya ili içme suyu şebekelerinde işletmeden kaynaklı bakım-onarım işlerinin analizi* (Master's thesis, Necmettin Erbakan Üniversitesi Fen Bilimleri Enstitüsü).
[21] Güçlü, A. (2024). *İçme suyu şebekelerinde oluşan su kayıp ve kaçaklarının SCADA sistemi yardımıyla incelenmesi: Muş ili örneği* (Master's thesis, Lisansüstü Eğitim Enstitüsü).
[22] Gülaydın, O., (2017). *İçme suyu dağıtım şebekelerinde ekonomik su kayıpları seviyesinin belirlenmesi: Antalya Kaleiçi örneği.*
[23] Güney, İ., & Selvi, İ. H. (2023). Makine Öğrenmesi Yöntemleriyle Anormal İçme Suyu Tüketimlerinin Tespit Edilmesi ve Tahmin Modellerinin Geliştirilmesi. *Journal of Intelligent Systems: Theory and Applications*, 6(2), 159-173.
[24] Grigg, N. S. (2024). Water Distribution Systems: Integrated Approaches for Effective Utility Management. *Water*, 16(4), 524.
[25] Jun, S., & Lansey, K. E. (2023). Comparison of AMI and SCADA Systems for Leak Detection and Localization in Water Distribution Networks. *Journal of Water Resources Planning and Management*, 149(11), 04023061.
[26] Karaca, Z. (2009). *İçme Suyu Şebeke Sistemlerinde Su Kayıp ve Kaçaklarının Tespiti. Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü* (Doctoral dissertation, Yüksek Lisans Tezi, İstanbul).
[27] Karadirek, I. E., Kaya-Basar, E., & Akdeniz, T. (2024). A study on pipe failure analysis in water distribution systems using logistic regression. *Water Supply*, 24(1), 176-186.
[28] Karakaya, D., & Toprak, Z. F., (2018). İçme Suyu Şebekelerindeki Su Kayıplarının ZFT Algoritması Kullanılarak Sınıflandırılması. *Su Kaynakları*, 3(2), 22-30.
[29] Karakuş, C. B., Yıldız, S., & Cerit, O. (2013). The Studies of Water Loss and Reducing The Rate of Loss in Sivas City Potable Water Network. *Selcuk University Journal of Engineering, Science and Technology*.
[30] Kılıç, R. (2021). Fiziki Kayıpların Azaltılması İçin İzole Alt Bölgelerin Etkin Yönetimi. *Avrupa Bilim ve Teknoloji Dergisi*, (22), 306-315.
[31] Klosok-Bazan, I., Boguniewicz-Zablocka, J., Suda, A., Łukasiewicz, E., & Anders, D. (2021). Assessment of leakage management in small water supplies using performance indicators. *Environmental Science and Pollution Research*, 28, 41181-41190.
[32] Köker Gökgöl, E. (2018). *Leakage optimization of water distribution networks by pressure control* [Ph.D.-Doctoral Program]. Middle East Technical University.
[33] Körpe, M., (2018). *Konya içme suyu şebekesinde su kayıplarının tespiti ve değerlendirilmesi* (Master's thesis, Necmettin Erbakan Üniversitesi Fen Bilimleri Enstitüsü).
[34] Kurban, R. (2022). Su Temin ve Dağıtım Sistemlerinin Otomasyonunda Endüstri 4.0, Nesnelerin İnterneti, Bulut Bilişim, Makine Öğrenimi ve Optimizasyon Uygulamaları. *Araştırma ve Değerlendirmeler II*, 49-70.
[35] Ma, X., Li, Y., Zhang, W., Li, X., Shi, Z., Yu, J., ... & Liu, J. (2022). A real-time method to detect the leakage location in urban water distribution networks. *Journal of Water Resources Planning and Management*, 148(12), 04022069.
[36] Olmuştur, M. M. (2021). *İçme suyu şebekelerinde basınç kırıcı vananın gerçek zamanlı kontrolünün su kayıpları üzerine etkisinin model analizi ve deneysel incelenmesi* (Master's thesis, Sakarya Uygulamalı Bilimler Üniversitesi).
[37] Özaslan, R. K., & Alıcı, O. V. (2018). Su ve Kanalizasyon İdarelerinin Performans Göstergelerinin Uygulanabilirliğinin Analizi. *Strategic Public Management Journal*, 4(8), 35-51.
[38] Öztürk, Y., & Abama, H. İ. (2023). Kilis' te Evsel Su Tüketiminin Şebekeden Yapılan Ölçümler ile Saptanması. *Euroasia Journal of Mathematics, Engineering, Natural & Medical Sciences*, 10(29), 120-127.

[39] Pala, B. (2002). *İçmesuyu şebekelerinde oluşan su kayıplarının belirlenmesi ve kontrolü: Kayseri İli Örneği* (Master's thesis, Fen Bilimleri Enstitüsü).
[40] Radaković, N., & Šenk, I. (2020). Deep Autoencoder Based Leakage Detection in Water Distribution SCADA Systems. *In Industrial Innovation in Digital Age* (pp. 355-361). Cham: Springer International Publishing.
[41] Shabangu, T. H., Hamam, Y., & Adedeji, K. B. (2020). Decision support systems for leak control in urban water supply systems: A literature synopsis. *Procedia CIRP*, 90, 579-583.
[42] Songur, M. (2016). *İçmesuyu şebekelerindeki fiziksel kayıpları önlemeye yönelik Diyarbakır için örnek bir model geliştirilmesi* (Doctoral dissertation, Sakarya Universitesi (Turkey)).
[43] Songur, M., Dabanlı, A., Yılmazel, B., & Kürkçüoğlu, M. A. Ş., (2021). Su Dağıtım Şebekelerindeki Fiziki Kayıpların Önlenmesinde SCADA'nın Önemi: ASKİ Örneği, *Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi*, 21(6), 1424-1433.
[44] Stătescu, F., Boboc, V., Tatu, G., Sârbu, G. C., Marcoie, N., & Toma, D. (2024, March). Improving pressure monitoring and control in order to reduce water loss in water urban public systems. *In IOP Conference Series: Materials Science and Engineering* (Vol. 1304, No. 1, p. 012031). IOP Publishing.
[45] SUEN- Türkiye Su Enstitüsü (2017). Büyükşehir Su ve Kanalizasyon İdareleri ile Mukayeseli Değerlendirme Çalışması, *SUEN Yayını, İstanbul*. https://www.suen.gov.tr/Suen/catdty.aspx?val=168 (19.05.2024 Ziyaret Tarihi)
[46] Tchórzewska-Cieślak, B., Szpak, D., Żywiec, J., & Rożnowski, M. (2024). The concept of estimating the risk of water losses in the water supply network. *Journal of Environmental Management*, 359, 120965.
[47] Toprak, S., Koç, A. C., Bacanlı, Ü. G., Dikbaş, F., Fırat, M., & Dizdar, A., (2007a). İçme Suyu Dağıtım Sistemlerindeki Kayıplar, *III. Ulusal Su Mühendisliği Sempozyumu*, 601-609
[48] Toprak, S., Dikbaş, F., Fırat, M., Koç, A. C., Bacanlı, Ü. G., & Dizdar, A., (2007b). Su Kayıplarının Azaltılması ve Su Dağıtım Sistemlerinin Performanslarının İyileştirilmesi Üzerine Leonardo Da Vinci Projesi: Prowat, *III. Ulusal Su Mühendisliği Sempozyumu*, 611-618.
[49] Tornyeviadzi, H. M., Owusu-Ansah, E., Mohammed, H., & Seidu, R. (2024). Node search space reduction for optimal placement of pressure sensors in water distribution networks for leakage detection. *Alexandria Engineering Journal*, 94, 325-338.
[50] Tuna. M., Armut, S. (2021). Orta Ölçekli Bir Şehirde Kentsel Su Yönetimi: Amasya İli Merzifon İlçesi Örneği. *Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi*, 8(2), 990-1009.
[51] Tuna, M., Armut, S., & Tombul, M., (2023). İçme Suyu Şebekelerinde Kayıp Kaçak Seviyesinin Belirlenmesi: Merzifon İlçesi Örneği. *Kent Akademisi*, 16(1), 1-17.
[52] Uçar, A. (2022). Akıllı Kentler ve Su Kullanımı. *Medeniyet Araştırmaları Dergisi*, 7(1), 1-14.
[53] Vrachimis, S. G., Eliades, D. G., Taormina, R., Kapelan, Z., Ostfeld, A., Liu, S., ... & Polycarpou, M. M. (2022). Battle of the leakage detection and isolation methods. *Journal of Water Resources Planning and Management*, 148(12), 04022068.
[54] Yıldız, S., & Değirmenci, M. (2010). Sivas Kenti Mevcut İçme Suyu Temini ve Bazı Çözüm Önerileri. *Erciyes Üniversitesi Fen Bilimleri Enstitüsü Fen Bilimleri Dergisi*, 26(2), 125-130.
[55] Yüksel, İ., Songur, M., & Demirel, İ. H., (2018)., Diyarbakır içme suyu şebekesindeki su kayıplarını önlemek için hidrolik yöntem geliştirme. *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 9(1), 535-542.