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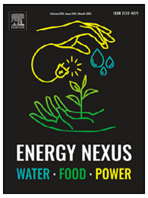

Guidelines for establishing water energy balance database – implementation barriers and recommendations

Ammar Alkhalidi [a,b,*], Mohamad K. Khawaja [b], Mohammad Ali Abdelkareem [a,d,e], A.G. Olabi [a,c]

[a] *Sustainable and Renewable Energy Department, University of Sharjah, Sharjah, United Arab Emirates*
[b] *Energy Engineering Department, German Jordanian University, Amman, Jordan*
[c] *Sustainable Energy & Power Systems Research Centre, RISE, University of Sharjah, Sharjah, United Arab Emirates*
[d] *Center for Advanced Materials Research, University of Sharjah, Sharjah, United Arab Emirates*
[e] *Faculty of Engineering, Minia University, Egypt*

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ABSTRACT

This study presents a set of guidelines for starting a water energy database (WEB). Implementing such a database helps decision-makers select appropriate energy efficiency and renewable energy projects for the water sector. The proposed guidelines encompass various aspects of the database structure including static data, dynamics data, water production, energy consumption, and WEB. Data accuracy is vital for this Database; therefore, a coding system for water utilities is proposed to avoid confusion. Desktop validation and validation through site visits were performed to ensure data accuracy. Recommendations for site visits and data collection procedure were proposed to guarantee the best results. The study proposed techniques that were successfully implemented and tested in the Jordanian water sector.

1. Introduction

Access to water and sanitation are human rights. Clean, safe, and affordable water, sanitation, and hygiene facilities are essential to protect human health and dignity. The treatment and utilization of wastewater have been extensively studied in the literature using various innovative approaches to achieve sustainable development [1]. The United Nations recognizes these as fundamental human rights. The water sector is energy-intensive, and energy consumption varies from one country to another. A country's topology and some water shortage impacts, such as drought, a natural hazard, pose a substantial and imminent challenge for society and agriculture. With the impact of climate change, the frequency, duration, and intensity of drought events are projected to increase [2]. Also the distance between water resources and its inhabitants' cities cause variations in energy consumption among countries [3].

Jordan is considered a Middle Eastern leader in renewable energy (RE), especially solar and wind energy. Several energy storage systems were considered to better utilize the limited energy eventually reducing energy costs and carbon emissions. Several investigations were conducted to select a location and design a sustainable city in Jordan [4]. Moreover, the impact of horizontal wind turbines hanging over a dam's dry side to assess dam space utilization to develop a hybrid photovoltaic-wind system in the Middle East and North Africa (MENA) region was also studied; Wadi Al Mujib Dam in Jordan was selected as the location for this investigation [5]. Energy consumption in the Jordanian water sector (JWS) is very high due to its rough terrain and the fact that the most prominent water aquifer, the Disi water aquifer, is in the southern part of Jordan, where the population density is very low, while the most populated cities are in the north [6].

A plethora of previous studies addressed conceptual water energy balance (WEB) [7–14]. A top-down and a bottom-up approach were presented for carrying out water-energy balances in Portuguese supply systems [8]. In addition to the methodology for evaluating energy efficiency in water distribution systems [11], the water-energy balance (WEB) approach was utilized as well for multi-category drought assessment across globally diverse hydrological basins [12]. Apart from this, the impacts of climate variability and land surface changes on the annual water–energy balance were also analyzed in the Weihe River Basin of China [13]. WEB in the water sector is a performance indicator to assess energy efficiency (EE) and energy consumption in the water supply system [3]. Performance inductors, WEB being one of them, are essential for selecting and prioritizing energy efficiency and/or renewable energy (EE/RE) projects for the water sector. This paper introduces a WEB database framework for the water sector that builds institutional and human capacity for managing energy usage and implementing efficiency measures.

Despite several studies being conducted in Jordan, the Water Authority of Jordan (WAJ) is the largest electricity consumer in Jordan [15]. In 2019, the total electricity cost for water consumption amounted to

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[*] Corresponding author at: Sustainable and Renewable Energy Department, University of Sharjah, Sharjah, United Arab Emirates.
E-mail address: ammar.alkhalidi@sharjah.ac.ae (A. Alkhalidi).

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Nomenclature

AWC	aqaba water company
CD	compact disc
DMA	direct management authorities
DQ	design capacity (m^3/h)
E.E.	energy efficiency
GIS	geographic information system
GPQ	group of utility water production (m^3/year)
IDECO	Irbid district electricity company
JEPCO	Jordan electric power company
JWS	Jordanian water sector
MENA	middle east and North Africa
MWI	ministry of water and irrigation
NEPCO	national electrical power company
Q	capacity
RE	renewable energy
ROU	regional operational unit
SCADA	supervisory control and data acquisition
SPQ	single utility water production (m^3/year)
WAJ	water authority of Jordan
WEB	water energy balance
WTP	water treatment plant
WWTP	wastewater treatment plant
VFD	variable frequency drive
YWC	Yarmouk water company

around 17% of the country's total energy bill, with water sector electricity expenses exceeding 250 million Jordanian Dinars (JOD), which is equivalent to 353 million USD. One contributor to this expense is low pump efficiency, which is caused, at least in part, by a lack of capacity for utilities [16]. Several studies were conducted in Jordan to improve the energy efficiency of the water and wastewater plants [17–22]. However, there are no implementations of the WEB approach in Jordan. It was essential to study the WEB and reduce the energy consumed by this sector via improving the overall operational efficiency. This project aims to achieve comprehensive and systematic energy management in the water sector. Using Jordan's water sector as an example, this project will provide a roadmap for WEB's implementation in the country and a comprehensive database draft.

1.1. Database definition

A database could be defined as useful information intended for a predefined audience, structured and organized, that makes it safely stored, easily updated, and accessible to the intended audience. The water sector could be defined as the industry encompassing drinking water supply, wastewater collection and treatment - including, but not limited to, water and energy resources - treatment plants, water distribution systems, quality control, and water sector management. The WEB approach will be implemented for the first time in Jordan with attention to Jordan's water and energy limitations and eventually to overcome these limitations. A database for the JWS valuable information about the with a guarantee of data accessibility. Accessibility of the database should not compromise the security of this data or the ease of data updates by water sector management employees.

1.2. Characteristics of a good database

It was found that the use of databases of routinely collected healthcare information in pharmacoepidemiology has expanded in the last decade as awareness has increased and more enormous resources have become available. The same approach was used to structure a WEB database due to their efficient and valuable experience in that field and the lack of other competing approaches to create a comprehensive database. The approach to creating a good database should incorporate the following characteristics or answer the following questions in the methodology [23–25]:

Multiple resources: multiple sources of information on water utilities; can data resources be linked (designed data, manual data, and actual readings, for example)?

Linkage: can reliable data sources be linked to an automated feed database that can eventually be integrated into automated system software?

Water utility's data extraction and analysis: specification of extraction, how to extract a water utility's variables, how to merge additional data collected from external sources for water utilities, how to process utility output data and analyze it?

Quality and validation of a water utility's data: must the quality of the database be checked against appropriate overall tests?

Documentation: format, are guidelines for the database include storage methodology and indexing?

1.3. Database applications

Creating a WEB-based database that sheds light on any variation in energy consumption is critical but is absent in the water sector's literature; however, it can be found in other sectors. The energy consumed per unit of water, presented in the proposed database, is essential to assessing the energy efficiency of each utility, which is vital to moving forward with the vision of a more sustainable future. The database stores data for a specific purpose and facilitates searching this dataset for particular data. To achieve this, an index that contains key utility data could be used to find other data that could be utilized to achieve the database's purpose. Different rules can be added to ensure this database is meaningful and logical.

Worldwide energy consumption in the water sector was discussed in the literature; with some studies examining specific areas; reverse osmosis (RO) energy consumption was investigated to reduce water consumption in dairy production [26]. Additionally, energy-efficient water resource recovery in water utility was investigated and mechanisms, factors, practical approaches, and guidelines were discussed using A-stage and high-rate contact stabilization [27]. None of these studies have focused on developing a comprehensive database for tracking energy consumption in the water sector. Furthermore, the WEB balance in the water network was investigated and the energy efficiency of pressurized water distribution systems was assessed; a mathematical model was used to calculate the energy balance [28]. Energy recovery from a water network requires determining the high potential for energy recovery points; the authors devised a methodology to evaluate the network and identify potential high points [29]. However, database creation for the network was not considered.

Furthermore, a study in California used Budget-Based Tiered Rates; investigating a specific site's needs is very important to avoid wasting limited budgets [30]. The economic optimization tool was used to achieve the desired objective [31]. Access to drinking water is challenging in several countries with limited water supply and the need for policies to overcome those problems was highlighted [32]. A water-saving and site selection database would be a great tool to ease those tasks but it was not considered in those publications.

Additionally, energy consumption and energy efficiency in wastewater treatment were investigated in the literature. Energy consumption analysis using Electro-Fenton technology for wastewater treatment was examined via a bibliometric analysis of current and future research trends [33]. Solar energy power management in electrochemical treatments was investigated [34]. Energy generated from sludge in the wastewater treatment plan was reviewed to assess self-sufficiency in wastewater treatment plants [35]. Yet, none of those publications discussed a database on WEB for wastewater treatment. Factors influencing the extent of treatment utilities by surveying residential associations were discussed but the authors did not discuss the possibility of using a database to facilitate this task [32].

Database rules and structure were investigated for different sectors. The healthcare sector relies heavily on the database; many authors have investigated the rules and structures that guarantee comprehensive database genetics. Investigating extensive volume data from biomarkers to design comprehensive analyses to guide patient therapy is another example of utilizing a database in the healthcare sector [36].

In a more commercial sense, an investigation into the usage of the database for customers in the Slovak Republic, where the authors have used small and medium sized enterprises and customer relationship management approaches, provided the basis for further research and support for small and medium sized enterprises [37]. Moreover, airline customer satisfaction using a text mining approach was investigated showing that helping design services that excel in those dimensions will likely improve the company's customer performance [38].

Similarly, a database on energy resources and utilization has been investigated in geothermal energy usage where a database was developed for low-temperature deep geothermal operations in France [39]. Another study exploited a 32-year old database to investigate the effects of wave energy variations on energy conversion, which included consistent data for wave climates assigned to 41 locations in European shelf seas [40].

Apart from this, the water utility policies in some countries were investigated in the literature. In Turkey, a model for predicting non-revenue water was proposed to reduce water loss [41]. Likewise, stakeholders' roles in sustainable water utilities in a socio-economic context were studied in Italy. Here, theoretical and managerial implications were discussed [42]. Similarly, the water rate structure choice by Canadian municipalities was investigated and results showed that local characteristics are assumed to affect costs partially [43]. A structured review of water governance models to meet sustainable development goals was prepared [44] and private investment in the water sector was reviewed globally to show several scenarios of water investment to make the best investment decisions [45].

There is no centralized national water and wastewater utility database in some countries such as Jordan. The difficulty of contacting utilities nationwide to construct a representative national database emphasizes and highlights this significant data gap. The absence of this database creates research challenges and prevents utilities from benchmarking to advance discussions of urban water usage and the energy-water nexus. This paper proposes and implements a database structure for the assessment and development based upon on-field findings for commercial applications in the water and wastewater sector that can be exploited globally. As the world moves towards a more sustainable energy future, a WEB database is crucial for existing and prospective structures and utilities to improve their energy efficiency in the water sector. The study's findings highlighted difficulties with utilities and their equipment naming that were solved using an innovative coding system. Well established WEB database with data frequently updated would reveal any changes in energy consumption. Once collected data shows any sharp changes, an investigation will be conducted to determine the causes of such variations.

2. Methodology

A well-structured WEB database requires an efficient data collection strategy and user-need analysis, essential to building and developing a comprehensive structure for a WEB database. A user-need analysis is beneficial to conduct before designing a product or service to determine what present or future consumers need. This is an excellent opportunity to assess demand before launch to provide the most effective services. Fig. 1 illustrates the methodology to create and implement a well-structured WEB database.

The first step, blue box, shows data prerequisites. The second step, orange box, shows the design procedure. The final step, green box, shows the WEB implementation in Jordan.

A user-need analysis must be paired with limitations and barriers in Third World countries. Among these barriers are poor infrastructure, cultural differences, ethical issues, timely and accurate data collection, and a lack of priority given to research. Therefore, a few things were also considered to structure the WEB database:

i. Include complete documentation of the available water and wastewater utility lists, relevant data for each utility, and missing data for the water sector utilities.
ii. Establish a sorting procedure for water utilities based on capacity, energy consumption, importance to water independence, the number of connected customers, current operational status, etc., must be discussed with stockholders to optimize the selection.
iii. Select the targeted water utilities based on sorted lists and discussions with stakeholders, then combining the technical data for each utility towards WEB, whereas the targeted water utilities are the big utilities with low operational efficiency, leading to higher energy consumption than other utilities.
iv. Define the structure, content, and management of the database, including unified measures and standards and software for database handling that is connected to existing software (supervisory control and data acquisition (SCADA), business intelligence, geographic information system (GIS), etc.).

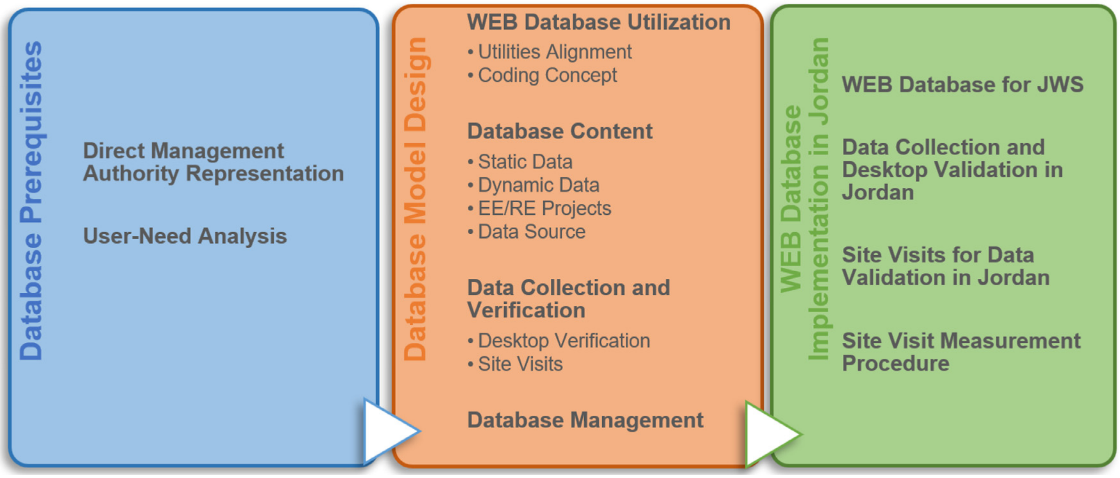

Fig. 1. Water energy balance (WEB) database creation methodology.

In addition to those steps, a set of documents and other sources of information should be utilized to establish a priority list for future EE/RE projects' implementation in the water sector.

2.1. Database prerequisites

A WEB database in the water sector could be defined as a collection of valuable data about the water sector structured to guarantee data accessibility. Accessibility of the database should not compromise the security of this data or the ease of data updates by the water sector management employees.

2.1.1. Direct management authority representation

The first step in the data collection process is to allocate representatives for each direct management authority (DMA) for a water utility. Representatives should be capable of providing documented history and actual data. This data should describe the status of the water distribution network and management. Data were collected in two methods, allocated and compiled in the provided datasheets. The collected data from representatives are expected to be in various formats. PDF® sheets, Microsoft Excel® sheets, and other data management software formats could be as simple as printouts of tables. The suggested data collection methods were emails, phone calls, meetings, workshops, and site visits.

2.1.2. User-need analysis

The WEB database structure for the water sector will be achieved by utilizing user-need analysis. The user-need analysis is part of building the structure for a WEB database and guarantees successfully meeting prospective users' needs such as water amounts, electricity consumption, electrical fees, etc. As a result of user-need analysis, the key performance indicator will be selected based on the end user's needs.

Compiling, reviewing, and cross-referencing data collected by representatives led to the proposed database structure (inputs, outputs, and goals). Additionally, the energy sector's key performance indicators will be proposed. The user-need analysis will be conducted by consulting all stakeholders through one-on-one meetings and workshops. Those meetings are intended to make a trade-off between the options proposed by the consultant. The exchange will be between owners, stakeholders, and target audience groups for the database.

3. Database model design

The database model design proposed by user-need analysis includes compiling the data collected from different sources into a single format sheet using Microsoft Excel®. The proposed structure for a WEB database should meet all the needs and requirements of stakeholders. This structure needs testing with collected data for contradiction, repetition, self-evident incorrectness, handling difficulties, usefulness, and accuracy.

A beneficial database, as found in this work, could have a dual language, English and Arabic for example. The scope of the datasheet should cover water/wastewater utilities in the investigated region and should contain enough data for each typology. The proposed structure should be flexible for expansion, changes, modifications, and easy to update. Each data source for the datasheet must be defined. In other words, it should contain data from designated and accredited sources.

For the database, prepared using Microsoft Excel® should not contain cells with more than one value, no cells could be merged, and the datasheet should not contain vertical and horizontal filling for data.

3.1. WEB database utilization

A WEB database is vital for planning, monitoring, and evaluating energy-related activities in the water sector. The greatest challenge in a WEB database is the utility's alignment in any country, even in small-population countries. Thousands of water utilities need precise alignment toward easy WEB consumption calculation.

Several studies have emphasized the importance of accurate data collection and management for effective energy management in the water sector. For instance, a survey discussed the importance of data-driven decision-making for improving the energy efficiency of water utilities; the authors highlighted the need for accurate and reliable data on energy consumption and performance indicators to support effective decision-making in this area [46].

Similarly, another study explored the development of an intelligent water management system to optimize water and energy use in urban areas; the authors emphasized the importance of accurate data collection and analysis for adequate water and energy management and the need for user-friendly interfaces to support stakeholder engagement and decision-making [47].

Overall, these studies underscore the importance of accurate and comprehensive data management, particularly in the context of energy consumption in the water sector. Developing a web-based database for tracking energy consumption can help address this challenge and support more effective energy management in the water sector.

3.1.1. Group utilities alignment

Utility alignment is the process of sorting utilities into groups. A group of utilities is defined as more than one utility working together to provide a water network with 1 m^3 of water, knowing that the specific energy used for pumping is the energy consumed for pumping a unit of volume in kWh/m^3 [46]. These utilities include a watering point and one or more of the following: water treatment, chlorination unit, pumping system, etc. A utility and group of utilities are visually illustrated in Fig. 2, wherein the upper part of the figure is a group of utilities numbered 1 with all wells and filtration units included as utilities. As the water moves from one utility to another, the following utility is the second, third, fourth, and so on, until it reaches the main stations. All water supply and treatment for the utility are considered utilities for the same utility group. Afterward, the discharge line to the following utility is regarded as the next group of utilities.

For example, a treatment plant has two wells, a microfiltration unit, and pumps. All those are considered utilities. This group of utilities stops at the discharge line to the central reservoir.

3.1.2. Coding concept

A WEB database connects data for water utilities from water and electrical companies in a single formatted file. Water and electrical companies have different coding and referencing system. In general, huge gaps between water and electrical data referencing names and codes could be found as each works separately.

A coding system was proposed to accommodate all water utilities in the water sector. The coding system was devised after collecting, sorting, and processing data. This coding system will solve these issues and ease cross-referencing between water and energy companies.

The coding system is fundamental for the water sector; anyone in the water and electricity companies can obtain the data needed. This code must be used as the base for connecting all utilities in all ministries and related working companies as it will provide seamless integration.

The proposed code*: Governorate – Operator – Utility Group – Utility Group Index. Water Utility Type – Utility Index. Utility Component Type – Utility component index/Well code.*

Table 1 lists the different parameters of the code. In the coding system, like a state or a province elsewhere, the governorate is geographically dependent and is typically given a two-letter abbreviation by its government, A.A.. For instance, the operator is the local DMA XYZ.

Example:

- Governorate: A.A.
- Operator: XYZ
- Utility Group #1: Drinking Water Group #1
- Utility #1: Drinking Water Group #1 Main Station
- Utility #2: Drinking Water Group #1 Well #7

Fig. 2. Utility and group of utilities.

Table 1
Parameters' abbreviation for the proposed coding system.

Utility Group	
Drinking Water Group	DWG
Wastewater Group	WWG
Agriculture Water Group	AWG
Utility Type	
Pump Station	P.S.
Water Treatment Unit	T.U.
Well	W
Water Network	N
Wastewater Network	WWN
Reservoir	R
Water Treatment Plant	TP
Wastewater Lifting Station	L.S.
Wastewater Treatment Plant	WWTP
Utility Component Type	
Pump	P
Air Blower	AB
Chlorination Unit	CU
Reverse Osmosis Unit	RO
Filtration Unit	FU
Chemical Dosing Unit	CDU
Network Fitting (plungers, valve actuators, etc.)	NWF
Pressure Reducing Valve	PRV
Hydro Turbine	HT

- Utility component #1 for Utility # 1: Single Pump
- Utility component #2 for Utility # 1: Reverse Osmosis Unit

Utility Group Code: **AA-XYZ-DWG-1**

Utility # 1 Code: **AA-XYZ-DWG-1.PS-001** (Drinking Water Group #1 Main Pumping Station).

First Utility Component inside Utility #1 Code: **AA-XYZ-DWG-1.PS-001.P-01** (Single pump).

Second Utility Component inside Utility #2 Code: **AA-XYZ-DWG-1.PS-001.RO-01** (Reverse Osmosis Unit).

The proposed coding system will i) allow accurate identification of utilities by all departments; ii) avoid the duplication and multiplication of naming; to better understand and imagine the difficulty of communication when people communicate using different utility names; iii) facilitate electronic data processing by providing a standard code in all IT systems, databases, and software that will ease the interconnection between them; and iv) provide a brief description of the utilities and to which utility and operator they belong.

3.2. *Database content*

The database structure was divided into several categories; color legends were used to distinguish between data types. Static data, colored blue, was defined as data that does not change frequently. Dynamic data, colored orange, was defined as frequently changing data, i.e., monthly or yearly. Priority and long lists, colored gray, and EE/RE projects, clear colored. Data verification are colored green, red, and yellow. The database shows filled-out dates and other data sources and justifications.

3.2.1. *Static data*

Static data consists of the following: indexing, operator, governorate, regional operational unit (ROU) code, group of utility, utility, group of utility's name (Arabic), utility's name (Arabic), type, coordinates, well code (for wells only), utility's status, electricity company, electricity subscription number, electricity meter number, design capacity (DQ) (m^3/h), design head, year or renovation/expansion if after 2014, number of pumping directions, water quantity accuracy, connection to high/medium/low voltage, and previous EE projects.

3.2.2. *Dynamic data*

Dynamic data for water production includes a group of utilities' water production (GPQ) in 2016, 2017, and 2018 (m^3/year), a single utility's water production (SPQ) in 2016, 2017, and 2018 (m^3/year). In certain scenarios, multiple single utilities can operate consecutively to reach a specific area. This could be attributed to the high difference in elevation between the watering point and service area or any other considerations. In this case, each utility will have the same water production as the group utility. Furthermore, a utility group can have multiple watering sources instead of a singular source. In this case, the group utility water production will summate each utility.

Dynamic data includes electrical consumption: a group of utilities' electrical consumption in 2016, 2017, and 2018 (kWh/year), a single utility's electrical consumption in 2016, 2017, and 2018 (kWh/year), WEB (kWh/m^3) 2016, 2017, and 2018.

3.2.3. EE/RE projects

EE/RE projects include ongoing EE projects (year, project's name), planned EE projects (project's name), the capacity of existing RE projects, planned RE projects (project's name), type of RE, available area, to whom the area belongs, and notes.

3.2.4. Data source

The collected data has to come from different sources, like water and electrical companies. It is essential to know what source was used in filling the database for further investigation and verification. The data source section includes data sources (filled data) coded green, data sources (unfilled data) coded red, and data validation coded yellow.

3.3. Data collection and verification

The data collection could be done in two ways. First, allocate representatives for each DMA. The data collection methods were emails, phone calls, meetings, workshops, and site visits. Second, the collection of data through site visits. Site visits help fill in gaps and missing data from the data provided by representatives.

Data accuracy verification should be done by comparing different sources. For example, if two independent sources provide one sample of data, a comparison should be made between the two sources to build enough confidence in either of the samples. Data verification was done in two ways: first, desktop validation, and second, site visits. Whereas desktop validation is a low-cost, easy, and simple data verification method; nevertheless, a site visit is required and mandatory if a data contradiction or mismatch is discovered.

3.3.1. Desktop verification

Desktop verification for data was done by comparing the data sources and how the consultant chose between them. The data received from several sources were compared to one another. A separate report was prepared for each operator in the sector containing the conflicting data. The contradictory data report was discussed with stakeholders, this could be done through a workshop or a site visit. Desktop verification should go through all the data provided by the representatives. This should continue until the investigator makes a valid judgment on the data accuracy's dilemma.

3.3.2. Site visits

Data verification using actual measurements and onsite data collection should be done through site visits. A site visit must be conducted consistently and comprehensively to avoid discrepancies among the visited utilities. Detailed information on the site visit methodology:

1. Define accessible connection points for the power analyzer and the ultrasonic flow meter – 45 minutes.
2. Collect plate information for measurable performance devices on the utility – 30 minutes.
3. Set up the power analyzer for data collection mode – 45 minutes. The most common motors and connections are 3-phase asynchronous motors. Motor measurement connection: 3-wire direct online or 3-wire connected to VSD. Motor winding connection: WYE or Delta.
   (a) Motor setup:
      i. Motor nameplates provide essential information for measurement algorithms. This algorithm selection depends on motor design type, and it follows the National Electrical Manufacturers Association (NEMA) or the International Electrotechnical Commission (IEC). Those are the most common motor types supported by most motor analyzers.
      ii. The nameplate includes default values, settings, and ranges to set up the analyzer limits.
   (b) Set analyzer limits:
      i. The limits are taken directly from the pump's nameplate if the analyzer is connected to one pump feed.
      ii. If the analyzer is connected to multiple pumps, the voltage remains the same but the current must sum up the currents on both pumps.
   (c) Mechanical and electrical parameters are shown relative to industry standards or the NEMA MG 1-2014 standard.
      i. Mechanical parameters: power, torque, speed, and efficiency (ratio between electrical power supplied and mechanical power delivered).
      ii. Electrical parameters: power, power factor, voltage unbalance, and harmonic voltage factor according to NEMA MG1.
4. Set up Ultrasonic Flow Meter – 30 minutes. Pipe thickness measurements, appropriate connections, and more than one set of valid connection points.
5. Collect the information needed for the actual model of utility calculations. (Depending on personnel availability).
6. Verification of measured values against actual model calculations.

3.4. Database management

A database should be sustainable as it should have a method that guarantees continuous feed and update for this sheet. For a WEB database to be sustainable, it should be short, comprehensive, and quickly filled. The Database should contain the most critical data for EE/RE projects, such as the capacity of existing/planned RE or EE audit projects, type of RE, available area, to whom the area belongs, and others mentioned in the supplementary material S1. It should be easy to update, filter, and use the data. A sustainable database must be upgraded to automated software where the sustainable database is an automated feed database that can eventually be integrated into automated system software like Oracle, for example. Autonomous database software will manage autonomous data in the cloud to provide automatic patching, upgrades, and tuning—including performing all routine database maintenance duties while the system operates - without human intervention. This modern self-managing, self-securing, and self-repairing database cloud help to reduce manual database management and human errors.

The authors suggest the following activities manage the datasheet properly. Here is a summary of database management activities:

- Ensure sustainability of data flow by:
   i. Defining the mechanism of data flow and data transfer technology.
   ii. Nominating a responsible person.
   iii. Specifying interval time for data transfer.
- Update the existing data by adding new utilities and newly collected data.
- Define the missing data and add them.
- Define conflicting data and data sources, then verify them.
- Unify methodology of measures and standards.

4. WEB database implementation in Jordan

A database in the Jordanian water sector could be defined as valuable data about the JWS structured in a way that guarantees data accessibility. Accessibility to the database should not compromise the security of this data or the ease of data updates by the water sector management's employees.

4.1. WEB database for JWS

Jordan faces significant challenges related to water scarcity as it is one of the countries with the lowest water resources globally. Jordan depends on significantly deep underground aquifers that require power-consuming pumps to extract water from wells. Moreover, Jordan drags water by conniver pipes more than 300 km from the area near the Jordanian–Saudi borders south of Jordan, where the Disi aquifer is located, up to the city of Irbid north of the country [47]. Water pumping operations in Jordan consume a substantial portion of the country's electricity production; therefore, a WEB database is essential to managing energy consumption in the JWS. However, the authors of this study faced several challenges that caused hardship in managing the JWS. The proposed WEB database was developed to provide solutions *utilities' names.*

The current naming system used for utilities across the JWS is outdated, not systematic, and cannot serve in a database-oriented operation. The current naming system is simple yet serves no general purpose at all. Mostly, utilities are named according to the name of the area in which they are located or after the serviced area.

Renaming the system is of the utmost importance as areas across Jordan are named randomly and according to local standards for each different part of the country, and most names contain characters such as "Um", "Abu" and "Al-" which are commonly used in Arabic and are not at all suitable for database development purposes.

4.1.1. Utilities' locations

A list of utility coordinates was nowhere to be found at any hosting DMAs. Direct contact with operators via phone calls had to be made to obtain road directions every time a site visit was planned. This indicates the impossibility of surprise audits.

Additionally, utilizing smartphone map applications, which help reduce time and effort, is impossible without creating a list of coordinates for utilities across the JWS.

4.1.2. Electrical information

Access to transformers is not guaranteed by DMAs; therefore, verifying the received electricity bills was impossible. Real-time electricity consumption values in all JWS utilities cannot be verified due to having a single source for that information: the responsible electricity distribution company. Access to the transformers and electricity meters was denied to anyone other than the electricity companies' representatives.

4.1.3. Monitoring and Control Systems

Monitoring and controlling systems' status is essential to verifying data previously provided by DMA's representatives. Investigating the status of sensors, wired connections, feed lines, and communication lines between central management and utilities produces a fair judgment on the correctness of the data collected by DMA's staff each year. If the values are not monitored and revised weekly and/or monthly, failures are not detected, and information is not trusted.

The absence of central and local SCADA indicates a high possibility of failure and a long response time from maintenance teams. It also indicates that operations are not continuously supervised. Failure rate, failure time, high demand times, low demand times, maintenance teams' response time, lead time, and many other key performance indicators can only be rendered trustworthy using SCADA systems on both the central and local levels.

Flow is a continuous process, many utilities pump water nonstop 24/7. Manual monitoring or lack of monitoring of any of the values mentioned in the list above indicates that it is impossible to have confidence in the data regarding energy efficiency in the utility. The manual data registry leads to a slower process than the changes that water flow might undergo. Modern type analysis cannot depend on datasets collected manually on paper.

Changes in flow conditions can be detected accurately using flow and pressure sensors using energy formulas. Over time, datasets produced from those readings can be trusted to make a fair judgment on the utility's energy efficiency, which can replace the need to access electricity consumption data.

4.1.4. Documentation and record-keeping

Lack of documentation and record-keeping is a trend across the JWS. The sources of information are strictly staff members who verbally provide information with a deficient sense of confidence. Maintenance reports are not used; flow conditions data are neither saved nor can they be shared. The only way to obtain certain information is by having the staff member responsible for it be available. This resulted in adopting problematic processes instead of simple data and record-keeping and tracking processes.

4.2. Data collection and desktop validation in Jordan

The data collection process was designed first to allocate representatives for each DMA. DMA is defined as an entity that operates under the Jordanian Ministry of Water and Irrigation (MWI). The list of DMAs includes: Miyahuna, Water Authority of Jordan (WAJ), Yarmouk Water Company (YWC), and Aqaba Water Company (AWC).

Representatives provided documented history and actual data that describe the status of the water distribution network and management in the JWS. Data collected was allocated and cooperated in providing datasheets and collecting data from representatives in various formats. PDF® sheets, Microsoft Excel® sheets, other data management software formats, and even simple printouts of tables. The data collection methods were utilized via emails, phone contacts, meetings, workshops, and site visits.

4.2.1. Data sources

The data were categorized into static and dynamic datasets according to their nature. For example, a group of utilities' names, the utility's name, operator, governorate, utility's type, etc., were considered static data as information about a certain utility that is not time-sensitive, i.e., information that does not change over time. Electrical consumption and water flow rate (Q) were considered dynamic data because they are information about a certain utility that changes over time. Data collection came from different sources: Microsoft Excel® sheets provided by either the operators or the focal points appointed by the WAJ, water supply system reports, and Microsoft Excel® sheets provided by the energy team at WAJ for the Jordan Electric Power Company (JEPCO), Irbid District Electricity Company (IDECO), and National Electrical Power Company (NEPCO).

4.2.2. Data verification

Data accuracy was measured by comparison if one sample of data was provided by two different sources with enough confidence in either of the samples. The data verification methods used a desktop verification for data that was done by comparing the data sources and how an expert chose between them, a comparison of data received from several sources to each other, the preparation of a separate report for each operator in the sector containing conflicting data, discussions with stakeholders on conflicting data reports, data verification through a workshop, and data verification through site visits.

4.2.3. Challenges in data acquisition and verification

Table 2 lists the main problems encountered and the corrective measures to combat those challenges.

Table 2
Problems encountered and corrective measures to combat challenges in data verification.

Challenges encountered	Corrective measures
The missing data is needed to complete the datasheet.	Collecting missing data through site visits, phone calls, and emails sent to request the missing data. Collection of missing data through the Energy team at (the Water Authority of Jordan).
Conflicts of data.	Distribution of conflicting data reports to each operator. Separate emails were sent to each operator to solve this problem.
Late or incomplete responses to the requested data of available software in water companies.	Site visits and phone calls.
Some main sub-utilities are based on assumptions because naming creates a conflict between data sources that are unclear on the schematics provided.	More site visits.
There are problems in matching some utilities' electricity and water data.	A desktop verification for data was used by entering data collected from several stakeholders and comparing them. Refer the operator to ask for more clarification via phone calls or emails. Sending two employees, one from (the Water Authority of Jordan) and the other from the electricity company, to each utility to check the water and electricity meters.
The absence of accurate readings in some places poses a major challenge.	Desktop and measurement verifications.
It is hard to validate the non-automated data as a personal effort mainly collects it from a water utility's personnel.	Sort the data into two types estimated data and read data.
Non-automated data could be changed at any moment without knowing.	Continuous follow-up with departments that contain such data.

4.3. Site visits for data validation in Jordan

Site visits were crucial for this study. The selection criteria parameters considered for sites were the production capacity (m^3/year), total electrical consumption (kWh/year), geographical inclusion, management authorities' inclusion, previous EE/RE projects, and DMA of water utility reference. The collected data from site visits were used to verify some static and dynamic data inputs for an energy assessment. As a result, 33 utilities were visited and distributed. 18 utilities were in Miyahuna, 9 in YWC, 5 to WAJ, and 1 to AWC.

Some of the data collected was verified manually on scheduled site visits. Surveying the data source from all specified site locations produced datasets with the highest confidence out of all collected data. Those verified datasets can be used in comparisons and data confidence analyses.

4.3.1. Structure of survey forms

The most inherently correct data collected was electricity consumption figures. The 33 utilities chosen had survey forms printed on A4 paper and filled out by hand on the spot at each visited utility. A three–type category was suggested based on the collected data: static data, dynamic data, and measurements. All data were obtained similarly to the survey handling procedure detailed in the supplementary material S2.

4.3.2. Static data collection

Static data is the set of information about a utility that is not time-sensitive; information that does not change over time such as the location of the utility, the utility's purpose or type, the DMA responsible for the utility, etc. The rest of the information collected in the static dataset are:

i. Utility's name: for each utility DMA, staff often referred to more than one name.
ii. DMA can be one of the four DMAs: Miyahuna, WAJ, YWC, or AWC.
iii. Utility's type: from existing data for utilities, it was concluded that the utility's type could be categorized as follows:
    ○ Well
    ○ Water Treatment Plant (WTP)
    ○ Sewage Lifting Station
    ○ Reservoir
    ○ Office or Building
    ○ Pumping Station
    ○ Booster Station
    ○ Raw Water Intake
    ○ Wastewater Treatment Plant (WWTP)
iv. Coordinates: it is a necessity to have real-time coordinates for each utility.
v. Governorate/City.
vi. Altitude: elevation in comparison with sea level. This information is essential to the basic design of water pumping systems. It can be obtained today using open-source software applications available on most portable, internet-connected devices.
vii. Utility capacity by design: this information helps estimate the ability of a utility to serve its purpose.
viii. Year of construction.
ix. Year of rehabilitation.
x. Utility operator's name.
xi. Utility contact number.

4.3.3. Electricity provider's information

Electricity information is another important factor in studying energy consumption in the JWS. As listed in a utility example in Table 3, those important parameters are electricity provider: which electricity company is responsible for utility connection; subscription number: often not available or known to the DMA's staff; electricity meter number: usually not available or known to the DMA's staff; coordinates of electricity meter: in case of it being outside the utility; and line voltage: utilities can be connected to high, medium, or low voltage lines.

4.3.4. Monitoring and control systems used

The monitoring and control equipment are represented by:

- SCADA system: either operating, needs maintenance, or is not available.
- Pumps control: either manual, local SCADA, or central SCADA.
- Monitoring of inlet flow: either automatic, manual, or non-existent.
- Monitoring of outlet flow: either automatic, manual, or non-existent.
- Monitoring of flow pressure: either automatic, manual, or non-existent.

Table 3
Electricity consumption metering data for a utility.

Electricity provider	JEPCO
Subscription number	XXXXXXX342
Electricity meter number	N.A.
Sub-meter available	N.A.
GPS coordinates of the electrical meter	3X.XXXXXX, 3Y.YYYYYY
Voltage connection	Low
Low (< 400 V)	
Medium (6600 V)	
High (> 11000)	

- Monitoring of flow energy: either automatic, manual, or non-existent.

4.3.5. EE/RE projects' information

The information collection was always negatively affected due to the overestimation of the availability of informative staff at utilities. Planning EE/RE projects are performed in management offices, and information is not made available to the operation staff until the latest execution phases of these projects.

- Planned RE projects: according to the working staff at each utility, information about future RE projects was unavailable.
- Existing RE projects: electricity consumption can be covered by RE plants at each of the utilities. However, RE applications are not yet actively adopted by any DMA.
- Possibility of RE plant at location: this information was to be estimated based on available land for PV plants.
- Year of EE projects after 2014: this information was intended to indicate if the utility was recently subject to EE-aimed projects.
- Funding source.
- Efficiency improvement: this information required having a long-term staff attendant, which was not the usual case.
- Type of previous EE projects: pumps replacement, adding variable frequency drive (VFD) panels, or similar technology applications with considerable electricity consumption reduction potential.
- Planned EE projects: this information was often unavailable because local utility operators were denied access to this information.

4.3.6. Local operators

Local operators play a crucial role in creating a unified database for the JWS as they can provide layout schematics, operation schedules, logbooks, and test/measurement results if available. This information is a measure of the data's availability to staff and knowledgeable/trained teams' availability.

Word-of-mouth is the adopted technique for sharing information between local staff at the utilities. In the form of a simple step-by-step description, experienced team members lead staff to form a better understanding of pumping units' handling.

4.3.7. Dynamic data collection

4.3.7.1. Pumping sets and units. A complete schematic was prepared for each utility, as shown in Fig. 3, a schematic sample of a utility where the pink components are the pump units; each pump motor assembly was numbered. If there was an existing number, it was recorded. In addition, the direction was added to the schematic to eliminate any misunderstandings in pump numbering. Several pumping units and electric motor pump assemblies are used at each utility to create one pumping set. Two or more pumping sets are connected to one header to meet the demand of several service areas.

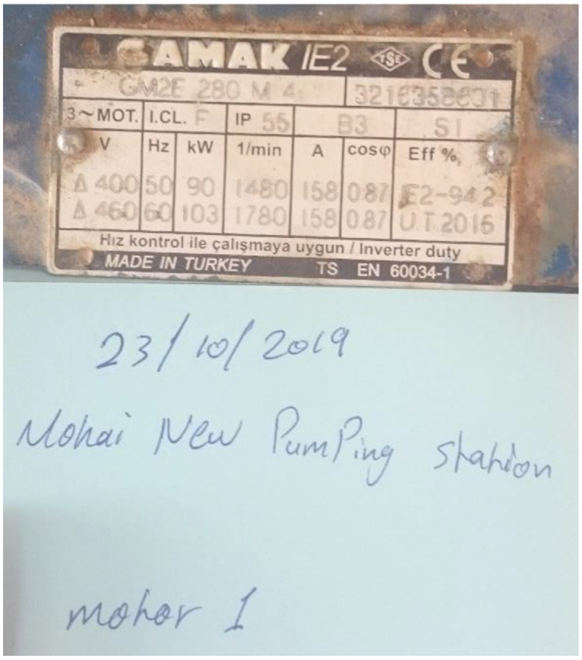

Fig. 4. A motor's nameplate with annotation.

Pumping sets were named in English alphabetic characters. This was done according to each pumping direction. Pumping units were numbered in Arabic numerals to add to the pumping set's character.

4.3.7.2. Nameplate's information. A nameplate's information is essential to any EE/RE project in the future. This information can help generate long-term decision-making factors. A photo was taken for each nameplate with annotations added to the photo to avoid confusion, as shown in Fig. 4.

For the measurement device's needs, the motor analyzer requires entering the nameplate's information of the connected motor to produce mechanical power data. All information logged to the motor power analyzer device was saved and attached to survey-filled forms.

4.4. Site visit measurement procedure

Visual inspection of pumps to check the measuring devices guarantees accessibility, safety checks, connection checks, and where the measurement devices will be installed. Measurements and readings: (i) use thermal imaging sensors to check if there are any losses or problems in the electrical connections, (ii) measure pipe thickness using ultrasonic wall thickness gauge, (iii) operate the pumps, (iv) wait until the pump's motor reaches steady-state operation, this will be reached when

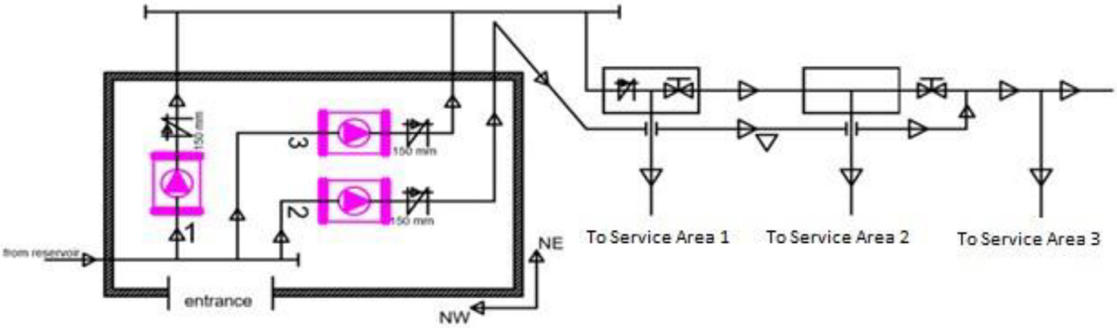

Fig. 3. Schematic for a utility.

the power consumed, measured by a clamp meter, is almost constant, (v) measure the operating head using a pressure gauge, (vi) use an ultrasonic flowmeter to measure the flow rate, (vii) use power quality and motor analyzer to measure the power and viii) ensure all the measurements are carried out and analyze measured data.

4.4.1. Measurements

All measured data is of high confidence, as it is real-time data logged into the data collection device, saved, and recalled upon request. Analysis of these measured datasets can produce a high-confidence judgment on the real-time status of the efficiency of water transport across the JWS.

Steady-state power readings will estimate yearly energy consumption data at visited utilities. This estimation can be produced with complete dependency on the availability of downtime schedules for each pumping unit; however, this information was available only with low confidence. The lack of fully functional SCADA communication on both local and central levels in utilities prevents those schedules from being produced automatically. In addition, the production of such schedules manually will lead to lower confidence and inaccuracies. Adding a manual data entry stage to the process will also increase errors. There is a long-term need for continuous validation and verification.

The only source for downtime schedules is asking local operators how many hours a day this unit stays on? How many days a week is pumping in the direction needed? Is there a time of year when pumping stops? Answers to such questions usually start with words like nearly, about, and almost.

5. Results

5.1. Validation of collected data vs. measured data

The primary goal of the validation procedure of collected data versus measured data is to establish the reliability of data. Desktop validation was conducted using the previously described methodology (Section 4.2). Yearly utility energy consumption data was verified by estimating annual power consumption based upon onsite measurements and operation schemes gathered from the site. It is crucial to authenticate the figures from energy providers since energy consumption significantly exceeded the amount utilized by the utilities in some instances owing to the illegal rerouting of power lines to nearby villages.

The results of the comparison and validation analysis, which assessed the accuracy of the collected data against the measured data, indicated that the total of the 12 utilities demonstrated a reasonable estimation of ±20%, and another 12 utilities had estimates that fell within a range of ±20-60%, whereas six utility estimations were at ±60-80%. It was observed that in four of these utilities, the errors were due to unmeasured elements inside the utilities. Furthermore, two utilities exhibited discrepancies that require further investigations to justify the source of error. These findings were derived from data collected from 30 water pumping stations excluding the three wastewater treatment utilities that were not included in the study. Additionally, specific safety-related issues were identified during site visits and communicated to the DMA to be addressed promptly.

5.2. Efficiency of pumping units

A pumping unit comprised of an electric motor and pump can be evaluated based on pump–motor efficiency. This efficiency is calculated by dividing the useful power transferred to the fluid in the pump by the consumed power of the electric motor. In this study, the efficiency of 95 pumping units was tested, the results are depicted in Fig. 5. Out of these, 17 pumping units exhibited an efficiency greater than 70%, indicating that no direct action is needed for these units. For 33 pumping units, the efficiency was between 55-70%, implying that some action may be required. Among the tested units, 29 pumps exhibited an efficiency of 40-55%, indicating that these pumps will require maintenance shortly. Finally, 16 pumps had an efficiency below 40%, implying that immediate care is necessary for these pumps.

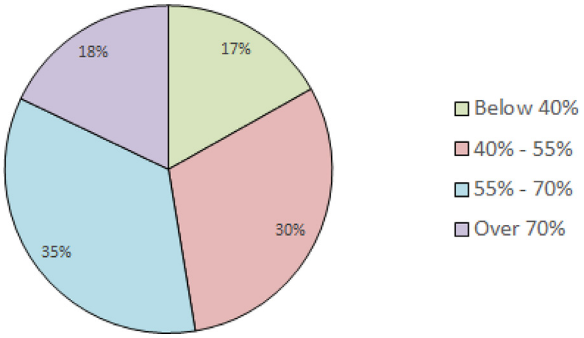

Fig. 5. The efficiency of tested pumping units.

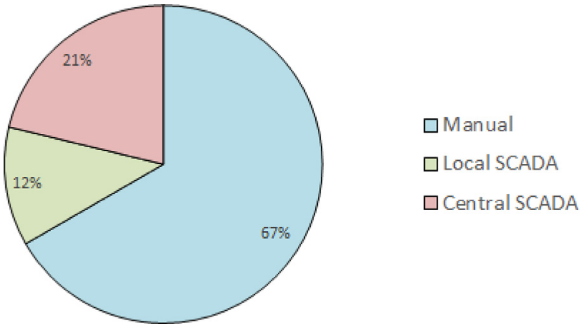

Fig. 6. Pump units' control system.

5.3. Pumping units' control system

The control system employed in utility operation and control were categorized into three types: i) manual, which was the most used type and employed in 22 out of 33 pumps, ii) local SCADA system, which was utilized in 4 out of 33 pumps. And iii) central SCADA system, which was implemented in 7 out of 33 pumps, as depicted in Fig. 6. The status of the SCADA system was also evaluated, which revealed that 16 Utilities out of 33 did not have a SCADA system in place. Of the remaining 17 utilities, 13 had an operating SCADA system, while the other 4 had a SCADA system that required maintenance.

5.4. Energy performance indicators

An energy performance indicator is necessary to facilitate an effective decision-making process. The initial data collected before the site survey only provided yearly electrical consumption data. This information, or lack thereof, led the utilities towards large electrical consumption regardless of pump efficiency and operational status.

The results vary between utilities, depending on each utility operator's selected threshold. As a pumping system efficiency indication, comparisons of, first, the estimated consumption values; second, the annual power consumption for each tested pumping set against power transmission to fluid per 1 m^3 of pumped water values (kWh/m^3); and third of power transmission to fluid per 1 m^3 pumped water per m head values ($kWh/m^3/m$ head).

6. Conclusion

A database is necessary for any water utility's management. A database was proposed and developed in this study. Data updates in this database were based on the frequency of data changes. For example, static data was assumed to be information that does not change as frequently as dynamic data. Energy efficiency and renewable energy information were collected and entered into the datasheet. Data verification and sources were listed by the end of the database for further validation and revision. A sample database is available in the supplementary material S1.

A coding system was proposed to bridge the gap between all stakeholders in the water sector, Direct Management Authorities, Water Authority of Jordan, and electricity companies. This coding system helps eliminate any translation confusion between English and Arabic.

Site visit measurements and verification help validate and clarify several conflicting data. The data collected during those visits helped establish energy performance indicators. Each indicator refers to a particular problem in the water pumping system. Specific problems found during site visits were highlighted to the Direct Management Authorities to be addressed.

7. Recommendations

Circulation of the database to all water sector authorities. Coordination within the water sector is critical in solving difficulties and challenges. Building partnerships between the public and private sectors to improve the sustainability and efficiency of water service delivery Site visits, measurements, and verifications must cover all utilities in Jordan or any country willing to adopt this proposed database structure. Look for solutions to alleviate the challenges faced during site visits. Develop a national policy on water resource management that outlines strategies for promoting water conservation, increasing water use efficiency, and reducing water loss. Low pump efficiency and pump operating on the low head must be addressed. Invest in research to identify new approaches that can help to address the challenges faced in the water sector.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.nexus.2023.100214.

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