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Development of water information system for the Kingdom of Bahrain

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ABSTRACT

The creation of an effective water information system is essential for the formulation of sustainable water resources management, especially in countries where absolute water scarcity exists. This paper reflects on the experience of the Kingdom of Bahrain in developing the first part of its water information and management system – the Bahrain Water Resources Database (BWRDB). The prime objectives of the database are: (i) to provide a reliable, timely, up-to-date, standardized and internationally comparable water data and relevant information for knowledge sharing and dissemination; (ii) to support effective evidence-based decision and policy-making processes in water resources planning and management; and (iii) to provide water data and relevant information for tracking and reporting on progress against the sustainable development goal 6 targets and global indicators. The approach employed for the development of BWRDB is based on the globally accepted experiences in water information storage and management and data quality standards. The developed methodology includes three complementary phases: assessing data and information needs; data collection and quality control; and integration with GIS visualization tools and web-portal facilities. The third phase of the database development is yet to be implemented and will therefore not be covered in this paper. In its current version, the water information system is a simple MS Excel spreadsheet platform comprising 13 components, 31 sub-components and more than 440 statistical topics or variables covering a wide range of data on water resources and uses. It is, however, viewed as a work-in-progress project with ongoing development and improvement in scope and functionality. Being already put in practice, the BWRDB has played a key role and proved to be a valuable tool and a solid information base for serving the previously mentioned objectives. The paper concludes with a series of important next step actions, including strengthening the water data institutional framework by fostering inter-institutional coordination; and constantly upgrading and improving the database as more water data become available and needs for further software applications and evaluation processes arise.

Keywords: Water information system; Sustainable water management; Water data institutions; Water data monitoring system; Kingdom of Bahrain

1. Introduction

In arid regions, freshwater resources may at times be limited to the extent that demand for water can be met only by going beyond sustainable use [1]. Bahrain is not an exception, overexploitation from the available freshwater resources coupled with an inefficient use of water has exerted a major pressure on the water resources, leading to a significant environmental and socio-economic consequences. Over the last four decades, various measures and policy instruments to bring water demand into balance with supply and to ensure effective and sustainable water management have been implemented. These include institutional and legislative reforms and restructuring, supply augmentation through water reuse and desalinated water, and the introduction of numerous policy measures and interventions in the form of demand management instruments. However, the country still faces severe water scarcity. For example, in 2016, the country's level of water stress

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reported at 138%[1] [2]. Furthermore, in spite of the endorsement of the National Water Strategy and its Implementation Plan (NWSIP) in 2018, the country still suffers from major water management and sustainability shortcomings.

Experiences from around the world demonstrate that sustainable water management can only be realised with a rigorous evidence-based decision making that in turn requires a solid and reliable water information base [3]. They also show that efficient water resources management cannot exist without effective access to and management of the necessary data and information [4]. However, when embarking on a task of the creation of an effective water information system, water resources planners and administrators are usually faced with the challenges of (i) how to organise existing water data and water-related information; (ii) how to manage the multiplicity of water data institutions and data delivery formats to ensure flexibility, efficiency, and comparability of datasets; (iii) how to organise the data sharing and information transfers between stakeholders and different data users; and (iv) how to set up and improve data access and processing capacity of the water information system [4].

Countries differ in their capability in developing water information systems depending on their financial ability, institutional arrangement, technical capacity and availability of supporting Information Technology (IT) infrastructure [3]. Obviously, countries with serious water problems such as the case with Bahrain will be the ones in vital need to develop effective water data management systems.

A substantial body of literature has been devoted to developing water information management systems [3,5–18]. In Bahrain, attempts to compile, store and manage water information in a systematic manner dated back to the 1940s of the last century when the Bahrain Petroleum Company (BAPCO) begun to compile large amounts of data and records on water wells and water levels and quality [19]. In 1980, Groundwater Development Consultants (GDC) produced and compiled much water information on these aspects together with additional data on the aquifers and aquitards hydraulic properties, including an extensive hydrogeological and hydrochemical mapping [20]. Prior to that date, in 1979, the Food and Agriculture Organisation of the United Nations (FAO) collected, stored and analysed large amounts of hydrometric, hydrogeological and hydrochemical information on Bahrain as part of an extensive regional study on the shared water resources in the Arabian Peninsula [21].

The country's computer-based efforts towards the development of water information systems commenced in 1985 with collaborative work between the then Water Resources Bureau and the Central Statistical Organisation; the resultant was the creation of a water information system known as Groundwater On-Line System (GWOS). The system comprises on-line computer facilities for nine files: water wells, water license, water meters, water abstraction, water salinity, water analysis, water levels, water codes, and reporting files. Collaborative work with the United Nations Development Programme (UNDP) in 1994 resulted in the establishment of a state-wide groundwater information system termed the Bahrain Groundwater Information System (BGWIS), with the United Nations' Groundwater for Windows (GWW) software being used as an application platform. The system contains one master file and numerous hydrogeological, hydrochemical and geometric main files, including files on thematic maps, graphics, and geological cross-sections [22,23]. In 1998, the Bahrain Centre for Studies and Research (BCSR) forwarded a proposal aimed to link this system to a hydrological geospatial platform – signified as Groundwater Resources Geographical Information System (GWRGIS) [24].

Al-Junaid developed a GIS-based tool for visualizing and handling water data on a sample of boreholes water quality data in the east of Bahrain using ArcView software with a customised graphical user interface [25]. A key conclusion from the thesis is that the developed database is capable of storing data in Excel spreadsheets format and generating visual displays of annual reports on water quality analysis and trends. In 2006, the Water Resources Directorate (WRD) presented a preliminary proposal for the establishment of a GIS-based digital groundwater information system with an end-user interface [26]. This was followed in 2009 by a more detailed project document [27] which integrates two initial proposals; namely, (1) establishment of a water information system; (2) upgrading the groundwater monitoring system; that proposal was also reviewed and evaluated by UNDP for potential technical assistance.

Schlumberger Water Services (SWS) [28] has submitted a document for the implementation of the proposed data management system called the National Integrated Water Resources Information System (NIWRIS). Concurrently, Ribeka presented another customised draft proposal – the Groundwater Information and Monitoring System (GWIM-System) – designed to upgrade the existing groundwater monitoring system and to integrate all the available water data and information into a groundwater information system [29]. Both proposals aimed at, although from slightly different perspectives, improving the existing water datasets by adopting advanced software solutions, including GIS-related software in the form of a groundwater data storage and management system. Unfortunately, none of these proposals has been materialised primarily due to financial constraints. Al-Thawadi [30] developed a relational database for boreholes data using MS Access platform. His database comprises five files, namely; well information, drilling information, full chemical analysis, water meters, and wells photos. The researcher concluded that it would be important to initiate more files such as observation wells network, well abstraction, geophysical logging and pumping tests at later stages to further assess the viability of the database.

This paper provides an overview of the development and organisation of the Bahrain Water Resources Database (BWRDB). The remainder of the paper falls into four sections. Section 2 provides the general background and rationale behind the development of the system. Section 3 describes the employed database development methodology. Section 4 covers the scope and structure of the BWRDB. The final section presents a summary and makes general recommendations as how to enhance and upgrade the BWRDB in terms of scope and functionality.

[1] More than 70% is considered to be very high stress.

2. Background and rationale

Rising demand for freshwater, coupled with increased volatility in global climate patterns means that robust and timely information to support decisions about allocating and managing water resources are more valuable than ever [31]. Integrated water resources management and the assessment and monitoring of water resources and their uses call for improved water statistics that are based on consistent concepts, definitions and terminology and are better integrated with economic, social and environmental statistics [32]. Such water data and related contextual information are also vital for tracking the progress on sustainable development goal 6 (SDG 6) of the Sustainable Development Agenda 2030 (SDGs), the goal that sets to "ensure water availability and sustainable management for all".

As pointed out in Section 1, a large amount of water datasets is available and somewhat easily accessible in Bahrain, but these are generally fragmented, incomplete and heterogenous. This simply calls for an action to organise and maintain these datasets into a consistent, more efficient, harmonised and internationally comparable water information system.

Specifically, the objectives of the BWRDB are:

- to set up a mechanism to organise and tie together water and water-related data and information into a reliable, systematic, consolidated, consistent, timely, and internationally comparable water storage and information system;
- to establish an efficient water data management strategy and analysis tools to support the rigorous evidence-based decision-making process in water resources planning and management;
- to promote good practice in data management and data sharing and information exchange among national institutions and regional and international organisations;
- to foster coordination and collaboration among the water data national institutions and stakeholders and between data producers and users;
- to enable statistical capacity development and to develop human resources capacities to enhance the quality and efficiency of the water data management and administration, and to improve national water data monitoring and reporting capabilities;
- to provide water data and relevant information to support tracking the country progress against SDG 6 targets and global indicators; and
- to meet the specific regional requirements set by the Gulf Cooperation Countries Unified Water Strategy and its Implementation Plan (GCC-UWSIP).

3. Methodology

The BWRDB methodology largely draws on experiences from various international organisations on the development of water data storage and information management systems. In particular, it has been basically built based on the following efforts and contributions: the United Nations Statistics Division (UNSD) and the United Nations Environment Programme (UNEP) Global Unified Water Questionnaire [33], the United Nations International Recommendations for Water Statistics UN/IRWS [32], the multi-purpose conceptual and statistical framework globally known as the Framework for the Development of Environment Statistics (FDES) [34], the FAO's Global Information System on Water and Agriculture – FAO/AQUASTAT [35], OECD/Eurostat Joint Questionnaire on Inland Waters – JQ-IW [36], the reading on International Environmental Statistics developed by the United Nations Economic Commission for Europe (UNECE) [37], the Organisation for Economic Co-operation and Development (OECD) environmental indicators [38], and the UNECE guidelines for the applications of environmental indicators [39].

It has also taken into consideration the International Standard Industrial Classification of all economic activities (ISIC) [40], the principles of the System of Environmental-Economic Accounting of Water (SEEA-Water) [41]. The methodological issues related to the tracking progress towards SDG 6 targets and global indicators are based on the definitions, rationale and methods of computation proposed by the UN agencies on water and sanitation-related indicators [42]. In addition, the country-specific conditions and regional requirements were fundamentally considered during the development of the database.

The developed BWRDB methodology is defined in three complementary phases:

- assessing data and information needs (the initial stage of the database development);
- data collection and quality control (the first implementation stage); and
- integrating and interfacing the generated data and information with a GIS-based platform and web-portal facilities (the second implementation stage).

3.1. Assessing data and information needs

Water data systems need to incorporate not only water data, but also other relevant data to fully serve the purpose of supporting water decisions [43]. Water data and relevant information originate from different sources and produced by diverse institutions and stakeholders at different levels of quality and spatiotemporal coverage using a variety of methods [4]. This phase of the database development includes identifying, prioritizing and assessing water data and information in terms of data sources,[2] data availability and accessibility, data topics, data providers and production procedures. The data and information needs assessment is summarised in Table 1. The assessment process has also touched upon the status of the existing national water data monitoring systems in terms of system design, spatial coverage, operating requirements, reliability of information, instrumentations and data analysis and report generation facilities.

Clearly, the table shows that water data and information required for the development of the water information system are very broad and complex, and dispersed independently over a variety of data producers with

[2] The term "data sources" is used here as defined by reference [32].

Table 1
Summary of the data and information needs assessment

Data sources	Data topics and variables	Data providers
Hydrological monitoring data: These are mainly *in-situ* monitoring data obtained from groundwater monitoring networks.	– *In-situ* observation of historical data on groundwater levels and quality. – Measured historical data on groundwater abstraction and sectoral groundwater use. – Data on the number of water meters installed.	Ministry of Works, Municipalities Affairs and Urban Planning (MoWMAUP) – Agriculture Engineering and Water Resources Directorate (AEWRD)
Administrative data: These types of data are broad in nature and are usually kept by the concerned authorities for administrative, water resources assessment and management purposes, long-term planning and data sharing and dissemination, including geospatial data, and off-line data on rules and regulation enforcement, water license conditions, etc.	– Hydrological data on boreholes logs, aquifer geometry, lithology, hydraulic properties, and geophysical logging. – Data on numbers of boreholes drilled, locations and ownership. – *Ex-situ* data on pumping tests, well yields and aquifer recharge. – Data on springs discharge, number of springs and locations. – Numbers and geospatial data on geographical locations and distribution of hydrological and monitoring data points. – Hydrologic measurements on springs flows and quality. – Topographic and contour maps on groundwater-related datasets. – Measured datasets on volume of wastewater flows and quality of wastewater produced, reused and discharged of to the environment, plants design capacities, sludge production, as well as data related to sanitation services infrastructures. – Measured datasets on quantity and quality of desalinated water produced, desalination plants design capacities and data and information on infrastructures related to drinking water services. – Number of establishments and employment in drinking water and sanitation services. – *Ex-situ* laboratory data on chemical and microbiological quality of drinking water and reused wastewater at end users' outlets. – Off-line data and information on water and sanitation regulations and laws, water use permits, water sales, water tariffs, etc.	– MoWMAUP – AEWRD. – MoWMAUP – Sanitary Engineering Planning and Projects Directorate (SEPPD) – MoWMAUP – Sanitary Engineering Operation & Maintenance Directorate (SEOMD) – Electricity and Water Authority (EWA) – Water Production Directorate (WPD) – EWA – Water Transmission Directorate (WTD) – Ministry of Health (MH) – Public Health Directorate (PHD)
Environmental monitoring data: Includes data collected from *in-situ* measuring points used for monitoring changes on ecosystems health and ambient water quality.	– Data on the state of environment and quality and health of aquatic ecosystems. – Amounts of sediments and nutrients load to receiving water. – Number and locations and distribution of the monitoring points (this may also be regarded as administrative data).	Supreme Council for Environment (SCE) – Environmental Policies and Planning Directorate (EPPD)

(Continued)

Table 1 Continued

Data sources	Data topics and variables	Data providers
Census and other economic and demographic surveys data: Census and surveys of households and establishments etc.	– Population censuses and population projections. – Percentage of the population connected to drinking water services. – Percentage of the population connected to sanitation services. – National accounts and other economic-related data. – Other demographic and socio-economic domains information.	– IGA – MoWMAUP – EWA
Agricultural data and surveys: Statistical and surveys-related data on agriculture variables, including geospatial data.	– Agricultural areas, crop patterns, crop yields and production, evapotranspiration, lands ownership, manpower in agriculture. – Geospatial data on soil patterns and characteristics, agricultural land areas, arable lands and other agriculture statistics. – Surveys on groundwater quality.	– MoWMAUP – AEWRD – MoWMAUP – Agriculture Statistics Department (ASD) – IGA
Meteorological monitoring data: *In-situ* data obtained from meteorological stations.	– *In-situ* observation and/or real-time data on various climatological parameters. – Numbers of meteorological stations and their geographical distribution (this may also be regarded as administrative data).	– Ministry of Transport and Communications (MTC) – Meteorological Directorate (MD) – Other private meteorological stations
Other environmental data: Various types of somewhat administrative and/or geospatial data and water-related information, provided by several institutions, stakeholders and private sectors.	– Land use patterns, land areas, land covers, biodiversity, etc. – Reported data on groundwater abstraction from private wells. – Data on industrial lands, industrial permits, industrial standard classification (ISIC), etc. – Bottled water imports and exports. Data on bottled water use. – Measured data on wastewater flows from private urban and industrial wastewater plants. Data on numbers of plants, establishments and employment characteristics. – Measured data on production from private desalination units. – Data on numbers of plants and employment characteristics.	– IGA – Survey and Land Registration Bureau (SLRB) – Topographic Survey Directorate (TSD) – Ministry of Industry, Commerce, and Tourism (MoICT) – Other stakeholders and private sectors who have their own wastewater treatment and/or desalination facilities
Research data: These are mainly supplementary or gaps fillings primarily of derived nature water data and related information provided by various academic institutions, research centers, consultancy studies, international and regional agencies.	– Supplementary hydrological, hydrometric and meteorological data from various consultancy and academic assessment studies and surveys. – Forecast products, outputs from predictive models, and inference data from remote sensing and other emerging technologies. – Specialised reports and databases of the regional and international organisations.	– Academic institutions – Research centers – Specialised consultant firms – International and regional organisations

numerous sources being used for their production and storage. Moreover, some institutions are having different departments in charge of producing, maintaining and managing water data. Our analysis has also shown that, although all the data producers are operating at the national level, the current institutional and legislative framework lacks the necessary inter-institutional coordination and legislative and institutional tools and procedures that organize and guide the processes of collection, harmonising, storing and dissemination of water data and relevant information. Apparently, the multiplicity of data providers and the absence of proper institutional coordination has led to the existing datasets being usually heterogeneous, incomplete and not comparable.

As a solution to this challenge, the so-called soft approach that focuses on collaboration and coordination arrangements among various water data institutions and other stakeholders were adopted. In this approach, parties formalize their working relationship in a written agreement setting out their respective roles and responsibilities and their commitment to assist one another [3]. Considering that the principal institutional reform for water resources management as a whole had been achieved through the establishment (1982) of the Water Resources Council (WRC)[3] and later by reactivation (2009) of this council with additional mandates and responsibilities, the developed approach appeared to be appropriate for fostering water data inter-institutional coordination.

The Information and eGovernment Authority (IGA) – who is the national statistical office and prime custodian of SDGs monitoring and reporting – took the leading role in coordinating this water data institutional arrangement. During the process, all the water data institutions were approached and several meetings were regularly held to explain the importance of having access to adequate water data and rational data production, and to ensure commitment and involvement of all institutions concerned with water data management. The core of this institutional arrangement is that water data and related information compiled by various data providers are to be coordinated and fed to IGA for data storing, knowledge sharing and dissemination at national, regional and international levels to ensure harmonisation, consistency and international comparability. At a later stage, it is foreseen that the WRC shall closely collaborate and coordinate with the IGA and play an important and supportive role in enhancing this institutional arrangement.

On the other hand, our assessment reveals that the national water data monitoring systems are inadequate and are gradually deteriorating with several shortcomings, including spatial coverage which is sparse and incomplete, common standards and guidelines are absent, groundwater quality monitoring is practically non-existent, in many cases advancement in IT is not incorporated, some water data monitoring points ceased to operate or being diminishing in numbers, and information generation and reporting capabilities are poor. This is another challenge that also needs to be considered and overcome from the institutional reform perspective.

3.2. Data collection and quality control

This phase of the database development involved designing and implementing of comprehensive data collection programme. This includes data and relevant information compilation, highlighting data gaps and limitations, data standardization and data verification and validation for quality assurance. The programme also entails the generation of information and indicators to support SDG 6 monitoring and to cater for the specific requirements of the GCC-UWSIP.

Most of the data topics and variables of interest were made readily available and accessible from various institutions and stakeholders (Table 1) with varying levels of temporal coverage. However, data gaps and limitations were inevitable as some data were not available, while other data were seemingly available but could not be attained due to several constraints. Data standardization was necessary to ensure consistency, comparability with the internationally accepted standards, including the definition of terms, metadata documentation, data formats and units of measurements and calculation rules and procedures. Data verification and validation to ensure quality assurance was achieved based on water data standards and expert checks and opinion substantiated by frequent meetings and consultations with the concerned personnel of the key stakeholders. The process involved checking for accuracy, data balancing, expected order of magnitude and extensive corrections for various datasets, primarily those related to groundwater abstraction and wastewater flows. However, some datasets are still in the process of being validated and updated.

The collected and verified water data and relevant information were then stored and maintained in MS Excel spreadsheet files. Subsequently, a rather straightforward two-digit components/sub-components and variables line coding system was developed for variable identification as will be explained in Section 4.

3.3. Integration database with GIS-based platform and web-portal facilities

This phase is concerned with integrating and interfacing the existing datasets with GIS visualisation tools and web-portal facilities using an advanced user interface such as Oracle, MS SQL Server, MySQL with thematic mapping and graphing facilities, appropriate modelling applications, and data storage in SQL database servers with the ability to perform complex spatial queries as well as a built-in-reporting tool in the form of a relational database. Data and information interoperability and registration of off-line data files that are normally only available in PDF and MS Word formats (i.e., some economic data, water rights and regulations and aquifer hydraulic properties files) would also be considered at this phase of the database development to

[3] A governmental body formed from the concerned ministries and authorities and headed by the Deputy Prime Minister. WRC is responsible for drawing the country's overall water policies and strategies; ensuring effective and efficient cooperation and coordination among the concerned authorities; setting up priorities for work plans and policy programmes; and following up and coordinating policies development and implementation.

enable transformation into a more readily usable format. As previously indicated, this phase represents the second implementation phase of the database methodological development that is currently under initial consideration and will therefore not be further covered in this paper.

4. Scope and structure of the BWRDB

In its current initial version, the BWRDB is a robust, simple and flexible metadata-driven MS Office Excel Spreadsheets data management system. It was originally developed as part of a consultancy agreement between the IGA and the author of this paper, and then incrementally upgraded and slightly aligned to address the specific requirements of the strategic objectives of the NWSIP 2018–2030 and the GCC-UWSIP 2015–2035 [44]. The scope of the BWRDB covers a wide range of water data and their uses as well as relevant information and indicators. The BWRDB organises these datasets in a simple manner into two Master Tables comprising 13 Main Tables[4] (Components), 31 Sub-components, and more than 440 statistical topics or variables. Master Table I: Water Variables (BWRDB_WVAR) contains 10 Components, and Master Table II: Supplementary Variables (BWRDB_SVAR) contains three Components. Fig. 1 shows the BWRDB interface, while the scope and structure of the database is diagrammatically illustrated in Fig. 2.

The first component brings together water data and statistics related to water resources inflows and outflows within the environment. Component 2 groups together statistics relevant to freshwater abstraction and use. Component 3 includes statistical topics on water supplied by the water supply industry and information on population served by drinking water services. Statistics and information relevant to wastewater generation and treatment classified by their type and levels of treatment are included in component 4. Component 5 provides supplementary datasets to those described in the previous component, including population sanitation coverage. Component 6 puts together water data and relevant statistics on water use efficiencies, costs and pricing and other water demand management aspects. This component is currently incomplete; development and categorization are still in progress[5].

The seventh component grouped the water quality data broken down by source, aquifers and levels of treatment. Data on groundwater levels, broken down by aquifers, are assembled in component 8,[6] while component 9 contains a variety of statistics and information on water infrastructure classified by water source and type of monitoring. Component 10 covers water data and statistics related to establishments and employment characteristics in water sectors. The physical and demographic and socio-economic domains related to water use and management are gathered and classified in component 11 (the first component in the Master File II). This component is also still being under continuous development. Component 12 groups together the available climatological parameters. The final component contains a set of economic and social variables and indicators. Efforts are underway to improve this component in terms of structure and inclusion of new variables and indicators.

Table 2 provides descriptions of the database components and sub-components along with their codes and data status and time span coverages. Further details regarding

[4] Each main table or component contains fields (Columns) and records (Rows). The fields describe the values (information) stored and the records are the variables or the categories of interest.

[5] At a later stage, this component shall host and register sub-components of some off-line files such as those related to water regulations and licensing.

[6] At a later stage, this component shall host sub-components related to the aquifer's hydraulic parameters.

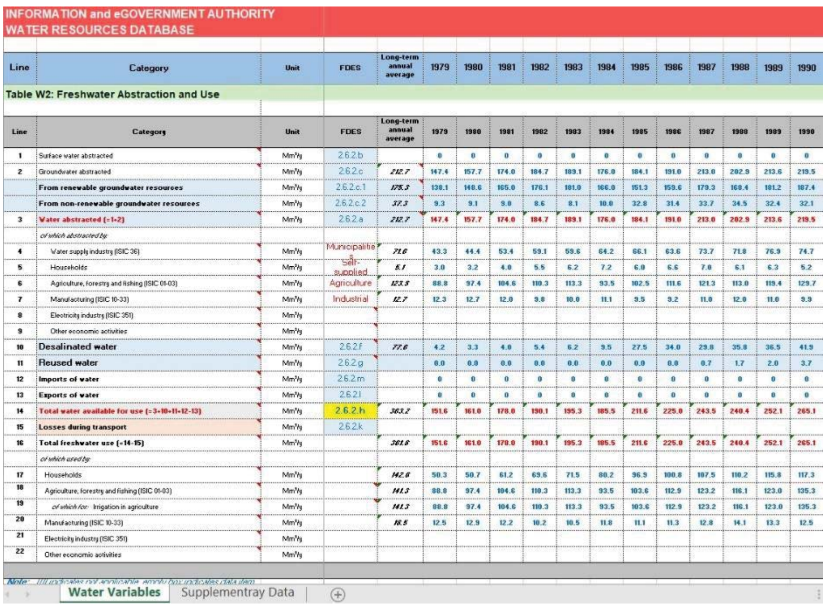

Fig. 1. BWRDB interface.

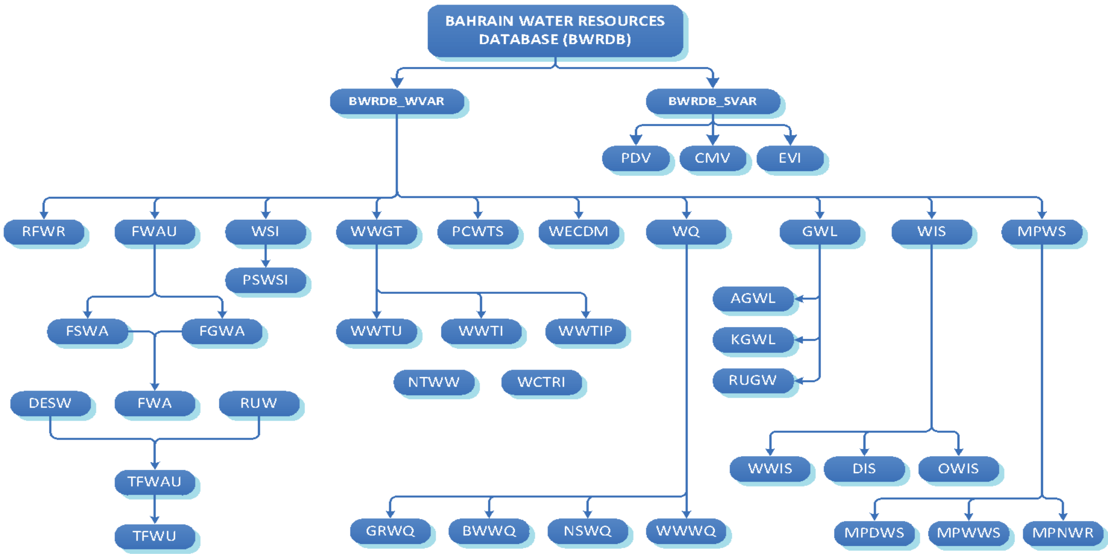

Fig. 2. Scope and structure of the BWRDB.

the structures of the BWRDB components and sub-components can be found in [44].

4.1. Setting variables codes

A rather straightforward two-digit component/sub-component coding system has been developed by assigning a code for each variable. The coding system simply combines the initial of the respective variable with its line and component numbers. A slightly distinctive coding setting was assigned to the variables describing the long-term annual averages, given their positioning in the tables.

To illustrate (Table 3), the variable freshwater abstracted by households (self-supplied) (FWAHH) is located in line (row) 5 of Component 2 "Freshwater Abstraction and Use" and is therefore coded FWAHH_02_05. Likewise, the variable wastewater treated in urban wastewater plants (WWTU) is located in line (row) 7 of Component 4 "Wastewater Generation and Treatment" and is therefore assigned the code WWTU_04_07. The examples given for the variables signifying the rainfall and net water supply by the water supply industry can be correspondingly explained.

The variable total dissolved solids concentration in the Sub-component 7.3 "Blended Water Quality" is coded WQTDS_7.3_04 because it is placed in line (row) 4 of Sub-component 7.3 of Component 7.0 Water Quality (WQ). According to [33], the long-term annual averages (LTAA) are to be computed as arithmetical means for datasets of not less than 30 y. Considering that LTAA is to be computed for most of the variables of interest, we have chosen to assume zero (00) line (row) for this variable, it is therefore coded differently. The coding FGWA_LTAA_00 signifies the variable initial of fresh groundwater abstraction (FGWA), its status as being LTAA and its arbitrary designated (00) line number.

The proposed coding system appears to be sensible and logical at this early stage of the database development, especially that, it clearly differentiates between similar variables such as water use by sectors, wastewater treated at various levels of treatment and most of the water quality parameters. One could argue, however, that this coding system implies some shortcomings; for example removal of an existing variable or creation of a new variable will necessitate recording of several other variables below. Furthermore, placing of the LTAA variables might pose a problem. Yet, it is believed that since the BWRDB is perceived to be as a work-in-progress, such coding problems could be easily overcome and improved in the next stages of the database development.

4.2. Examples for the database component

In Table 4, we present example data for component 2 "Freshwater Abstraction and Use" for the years 2008–2017. Fig. 3 shows the sub-components and statistical topic of this component. It should be noted here that the term freshwater abstraction and use is defined as follows [33]:

> Freshwater can be abstracted from surface waters (rivers, lakes etc.) and from groundwaters (through wells or springs). Water is abstracted by the public or private bodies whose main function is to provide water to the public (the water supply industry). It can also be directly abstracted by industries, farmers, households and others. The component asks for data on abstraction of freshwater, broken down according to the main activity of the water abstractor, as defined by the International Standard Industrial Classification of all economic activities (ISIC Rev. 4). The component covers the amount of water made available for use by abstraction, desalination, reuse and net imports. Total freshwater use equals total water available for use minus losses during transport. The component also covers the overall amount of water used by the main ISIC groupings.

The above definition implies that the terms "Water abstraction" and "Water use" are used here interchangeably,

Table 2
Database components/sub-components along with their codes and data status

Initial code	Component/sub-component/category	Remarks/data status and coverage
BWRDB_ WVAR	Bahrain Water Resources Database – Water Variables	Master Table I
Component 1.0: Renewable Freshwater Resources (RFWR)		
RFWR	Renewable Freshwater Resources	Sub-component 1.1.
Component 2.0: Freshwater Abstraction and Use (FWAU)		
FSWA	Fresh surface water abstracted	Sub-component 2.1. Not applicable to the Bahrain situation
FGWA	Fresh groundwater abstracted	Sub-component 2.2. Time-series records available for years 1979–2017. Data are disaggregated by sector in accordance with ISIC Rev.4
FGWR	Renewable fresh groundwater	Sub-component 2.2.1. Time-series records available for years 1979–2017. Data are disaggregated by sector in accordance with ISIC Rev.4
FGWNR	Non-renewable fresh groundwater	Sub-component 2.2.2. Time-series records available for years 1979–2017. Data are disaggregated by sector in accordance with ISIC Rev.4
FWA	Freshwater abstracted = FSWA + FGWA	Availability for years 1979–2017. Computed and disaggregated by abstraction by the water supply industry, and by sector in accordance with ISIC Rev.4
DESW	Desalinated water	Sub-component 2.3. Aggregated data, available for years 1979–2017
RUW	Reused water	Sub-component 2.4. Summed up data on treated sewage effluent. Availability for years 1982–2017
IOW	Imports of water	Excludes bottled water. Not applicable to the Bahrain situation
EOW	Exports of water	Not applicable to the Bahrain situation
TFWAU	Total freshwater available for use = FWA + DESW + RUW + IOW – EOW	Aggregated time series data available covering the years from 1979–2017
LDT	Losses during transport	Sub-component 2.5. Includes trans. losses only
TFWU	Total freshwater use = TFWAU – LDT	Time-series data available for years 1979–2017. Further computed and disaggregated by sector in accordance with ISIC Rev.4
Component 3.0: Water Supply Industry (WSI)		
WSI	Water supply industry	Sub-component 3.1. Data are available for years 1979–2017. Aggregated data, further disaggregated by sector in accordance with ISIC Rev.4
PSWSI	Population supplied by water supply industry	Sub-component 3.2. Total population served. Classification to urban and rural not applicable
Component 4.0: Wastewater Generation and Treatment (WWGT)		
WWG	Total wastewater generated	Sub-component 4.1. Not measured at present
WWC	Total wastewater collected	Sub-component 4.2. Availability for years 1982–2017
WWT	Total wastewater treated	Sub-component 4.3. Total aggregated data for years 1982–2017. Disaggregated by levels of treatment
WWTU	Wastewater treatment in urban plants	Sub-component 4.3.1. Aggregated total available for years 1982–2017. Data disaggregated by levels of treatment
WWTI	Wastewater treated in other (industrial) plants	Sub-component 4.3.2. Availability for years 1985–2017. Data disaggregated by levels of treatment
WWTIP	Wastewater treated in independent plants	Sub-component 4.3.3. Data available for one plant for years 2006–2016. Due to the small volume, data are included within urban plants
NTWW	Non-treated wastewater	Sub-component 4.4. Available only for some years
WCTRI	Wastewater collection, treatment, and reuse indicators	Sub-component 4.5. Data computed for years 2000–2016. Data for previous years not yet computed
Component 5.0: Population Connected to Wastewater Treatment (PCWCTS)		
PCWCS	Population connected to wastewater collection systems	Sub-component 5.1. Total population served. Classification into urban and rural does not apply to the Bahrain situation
PCWTS	Population connected to wastewater treatment systems	Sub-component 5.2. Total population served. Classification into urban and rural does not apply to the Bahrain situation

(Continued)

Table 2 Continued

Initial code	Component/sub-component/category	Remarks/data status and coverage
PNCWT	Population not connected to wastewater treatment	Sub-component 5.3.
Component 6.0: Water Use Efficiencies, Costs, and Demand Management (WECDM)		
WECDM	Water use efficiencies, costs, and demand management	Only a few data are available. The component is yet to be finalised in terms of data and possible sub-component classifications
Component 7.0: Water Quality (WQ)		
GRWQ	Groundwater water quality	Sub-component 7.1. Data are categorized by aquifers
AAWQ	Alat Limestone aquifer water quality	Sub-component 7.1.1. Time-series data available for years 2005–2017. Also available for specific years
KAWQ	Khobar aquifer water quality	Sub-component 7.1.2. Records are available for years 2005–2017. Also available for specific years
RUWQ	Rus – Umm Er Radhuma aquifer water quality	Sub-component 7.1.3. Time-series data available for years 2005–2017. Available for specific years
RJWQ	Ras Abu Jarjur Wellfield water quality	Sub-component 7.1.4. Time-series records are available for years 1985–2017
BWWQ	Blended water quality	Sub-component 7.3. Data are available for years 2005–2016
NSWQ	Natural spring water quality	Sub-component 7.4. Data are categorized by type of springs. Data are available only for specific years
LSWQ	Land springs water quality	Sub-component 7.4.1. Data are available only for specific years
OSWQ	Offshore springs water quality	Sub-component 7.4.2. Data are available only for specific years
WWWQ	Wastewater water quality	Sub-component 7.5. Data are classified as raw wastewater and levels of treatment. Data available up to the year 2017
RWWQ	Raw wastewater quality	Sub-component 7.5.1. Data are available for years 1996–2017
STWQ	Secondary treated wastewater quality	Sub-component 7.5.2. Data are available for years 1996–2017
TTWQ	Tertiary treated wastewater quality	Sub-component 7.5.3. Data are available for years 1996–2017
Component 8.0: Groundwater Levels (GWL)		
GWL	Groundwater levels	Data categorized by aquifers
AGWL	Alat Limestone groundwater levels	Sub-component 8.1. Time-series data available for years 2005–2017. Also available for some specific years
KGWL	Khobar groundwater levels	Sub-component 8.1. Time-series data are available for years 2005–2017. Also available for some specific years
RUGWL	Rus – Umm Er Radhuma groundwater levels	Sub-component 8.1. Time-series data available for years 2005–2017. Also available for some specific years
Component 9.0: Water Infrastructure (WIS)		
WIS	Water infrastructure	Data classified by type of water infrastructures
WWIS	Wastewater treatment infrastructure	Sub-component 9.1. Data are available up to the year 2016. Data computed and disaggregated by the required parameters. Many data gaps and limitations
DIS	Desalination infrastructure	Sub-component 9.2. Data are available up to the year 2016. Data computed and disaggregated by required parameters. Some data gaps
OWIS	Other water infrastructure	Sub-component 9.3. Data are available up to the year 2016. Data computed and disaggregated by required parameters. Many data gaps and limitations
Component 10.0: Manpower in the Water Sectors (MWS)		
MPWS	Establishments and manpower in the water sectors	Total employment and establishments in the water sector. Data classified by water sector (i.e., natural, desalination, wastewater)
MPDWS	Establishments and manpower in the desalination and water supply sector	Sub-component 10.1. Data available for years 2000, 2005, 2010, and 2015, but with some data gaps

(Continued)

Table 2 Continued

Initial code	Component/sub-component/category	Remarks/data status and coverage
MPWWS	Establishments and manpower in the wastewater and sanitation sector	Sub-component 10.2. Data available for years 2000, 2005, 2010, and 2015, but with some data gaps
MPNWR	Manpower in the natural water resources sector	Sub-component 10.3. Data available for years 2000, 2005, 2010, and 2015, but with some data gaps
BWRDB_SVAR	Bahrain Water Resources Database – Supplementary Variables	Master Table II
Component 11.0: Physical and Demographic Variables (PDV)		
PDV	Physical and demographic variables	Not yet completed. It may be categorised into sub-components. Long time-series records available for most of the variables
Component 12.0: Climatic Variables (CMV)		
CMV	Climatic variables	Data are available for seven climatic variables for time span for years 1979–2017. Evaporation only for years 1983–2017. No time-series data for evapotranspiration
Component 13.0: Economic Variables and Indicators (EVI)		
EVI	Economic variables and indicators	Not yet completed but sufficient time-series records available for most of the variables. Shall host more subcomponents in the third development phase

Table 3
Coding system

Line	Variable	Variable code	Unit	LTAA	2015
5	Freshwater abstracted by households (self-supplied)	FWAHH_02_05	Mm^3/y		2.9
3	Net water supplied by water supply industry	NWSI_03_03	Mm^3/y		260.5
7	Wastewater treated in urban plants	WWTU_04_07	1,000 m^3/d		399.7
4	Total dissolved solids (blended water)	WQTDS_7.3_04	mg/L		246.0
12	Rainfall	CMVRAIN_12_01	mm		65.0
00	Long-term fresh groundwater abstraction	FGWA_LTAA_00	Mm^3/y		

Note: The figures in the last column represent the data values in their respective units of measurement.

meaning that water is abstracted from the environment and used in the economy [32]. It can be seen that the data are coherent, harmonised, standardized, internationally comparable, and are carefully aggregated (total water uses) and disaggregated (sectoral shares), well-checked for data balancing and order of magnitude to provide complete sets of water statistics. In addition, they have been reasonably coded and supported by standardized metadata. All the datasets are given in this component as annual averages expressed in volume per unit of time, million cubic metre per year (Mm^3/y). Apparently, however, data values in other components may be given in various units of measurements (i.e., as average annual values in other appropriate standard units of measurement, absolute annual values, in annual percentage terms, as estimated average values, etc.).

4.3. Putting BWRDB into practice

As mentioned in Section 1, Bahrain has approved its long-term NWS-IP 2018–2030 which is in line with the GCC-UWSIP 2015–2035 [45]. The country has also completed its baseline report for tracking progress towards SDG 6 monitoring [2,46]. These strategic activities relied almost entirely on water resources assessment, formulation of policy objectives and for tracking progress on SDG 6 targets global and regional indicators on the water data and relevant information as well as the derived national and global indicators made available and accessible from the BWRDB platform. In fact, the outcomes from these important projects gave proofs that these water data and relevant contextual information have significant elements and have highly contributed to the success of these projects.

5. Conclusions and recommendations

This paper has shared the experience of the Kingdom of Bahrain in developing and organising Phase 1 of its water information system. It has addressed some water data institutions and national data monitoring challenges facing the development of this system. In its current version,

Table 4
Example for database component: Component 2 "Freshwater Abstraction and Use"

Line	Category/Variable	Variable code	Unit	LTAA	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Fresh surface water abstraction	FSWA_02_01	Mm^3/y		0	0	0	0	0	0	0	0	0	0
2	Fresh groundwater abstraction	FGWA_02_02	Mm^3/y		185.0	169.9	182.6	186.6	180.6	182.1	179.1	159.9	155.9	159.2
	- Renewable fresh groundwater	FGWR_02	Mm^3/y		127.1	112.4	123.2	127.3	132.4	134.2	130.5	112.6	107.3	103.8
	- Non-renewable fresh groundwater	FGWNR_02	Mm^3/y		57.9	57.5	59.4	59.3	48.2	47.9	47.1	47.3	48.6	55.4
3	Freshwater abstracted = FSWA_02_01 + FGWA_02_02	FWA_02_03	Mm^3/y		185.0	169.9	182.6	186.6	180.6	182.1	179.1	159.9	155.9	159.2
Of which abstracted by:														
4	Water supply industry (ISIC 36)	FWAWSI_02_04	Mm^3/y		72.8	59.4	64.6	72.4	63.8	60.9	57.3	35.2	33.3	41.2
5	Households (self-supply)	FWAHH_02_05	Mm^3/y		5.7	4.2	5.0	5.1	6.1	4.7	4.1	2.9	3.7	3.7
6	Agriculture, forestry, and fishing (ISIC 01-03)	FWAAG_02_06	Mm^3/y		90.0	87.7	94.9	91.1	91.3	97.4	98.4	103.9	102.5	97.7
7	Manufacturing (ISIC 10-33)	FWAMG_02_07	Mm^3/y		16.5	18.6	18.1	18.0	19.4	19.1	19.3	17.9	16.0	16.6
8	Electrical industry (ISIC 351)	FWAIN_02_08	Mm^3/y			Included within the manufacturing as available data do not permit further disaggregation by industrial type								
9	Other economic activities	FWAOEA_02_09	Mm^3/y			Included within the manufacturing as available data do not permit further disaggregation by industrial type								
10	Desalinated water	DESW_02_10	Mm^3/y		144.9	176.0	188.3	189.7	196.9	204.8	219.3	241.6	241.9	239.2
11	Reused water	RUW_02_11	Mm^3/y		40.4	38.9	36.2	38.3	37.5	33.1	32.3	30.6	37.4	39.5
12	Imports of water	IOW_02_12	Mm^3/y		0	0	0	0	0	0	0	0	0	0
13	Exports of water	EOF_02_13	Mm^3/y		0	0	0	0	0	0	0	0	0	0
14	Total freshwater available for use = FWA_02_03 + DESW_02_10 + RUW_02_11 + IOW_02_12 – EOF_02_13	TFWAU_02_14	Mm^3/y		370.3	384.8	407.1	414.6	415.0	420.0	430.7	432.1	435.2	437.9
15	Losses during transport	LDT_02_15	Mm^3/y		4.5	3.9	5.2	7.1	6.3	5.6	5.1	7.4	5.1	5.1
16	Brine flow at RAJDP	BFRAJ_02_16	Mm^3/y		12.5	11.6	12.6	12.9	9.1	9.2	10.3	8.9	10.3	9.7
17	Total freshwater use = TFWAU_02_14 – LDT_02_15 – BFRAJ_02_16	TFWU_02_17	Mm^3/y		353.3	369.3	389.3	394.6	399.6	405.2	415.3	415.8	419.8	423.1
Of which used by:														
18	Households	FWUHH_02_18	Mm^3/y		192.2	210.0	226.9	232.0	235.2	241.2	251.3	251.2	252.4	257.1
19	Agriculture, forestry, and fishing (ISIC 01-03)	FWUAG_02_19	Mm^3/y		139.2	135.0	138.0	138.0	138.4	138.2	138.0	140.3	144.5	142.1
	– Irrigated agriculture		Mm^3/y		139.2	135.0	138.0	138.0	138.4	138.2	138.0	140.3	144.5	142.1
20	Manufacturing (ISIC 10-33)	FWUMG_02_20	Mm^3/y		21.9	24.3	24.4	24.6	26.0	25.8	26.0	24.3	22.9	23.9
21	Electricity industry (ISIC 351)	FWUEI_02_21	Mm^3/y			Included within the manufacturing as available data do not permit further disaggregation by industrial type								
22	Other economic activities	FWUOEA_02_22	Mm^3/y			Included within the manufacturing as available data do not permit further disaggregation by industrial type								

Notes:
1. Zero values indicate data items not applicable.
2. Long term average (LTAA) values are not calculated in this table because of the limited data time span.
3. Brine flow at RAJDP is the brine flow rejected to the sea at the Ras Abu Jarjur Desalination Plant which uses non-renewable groundwater as feed water. This amount is to be deducted from the total water available for use because, although it is abstracted, it is not actually used. This variable reflects a country specific case (not shown in Fig. 3).

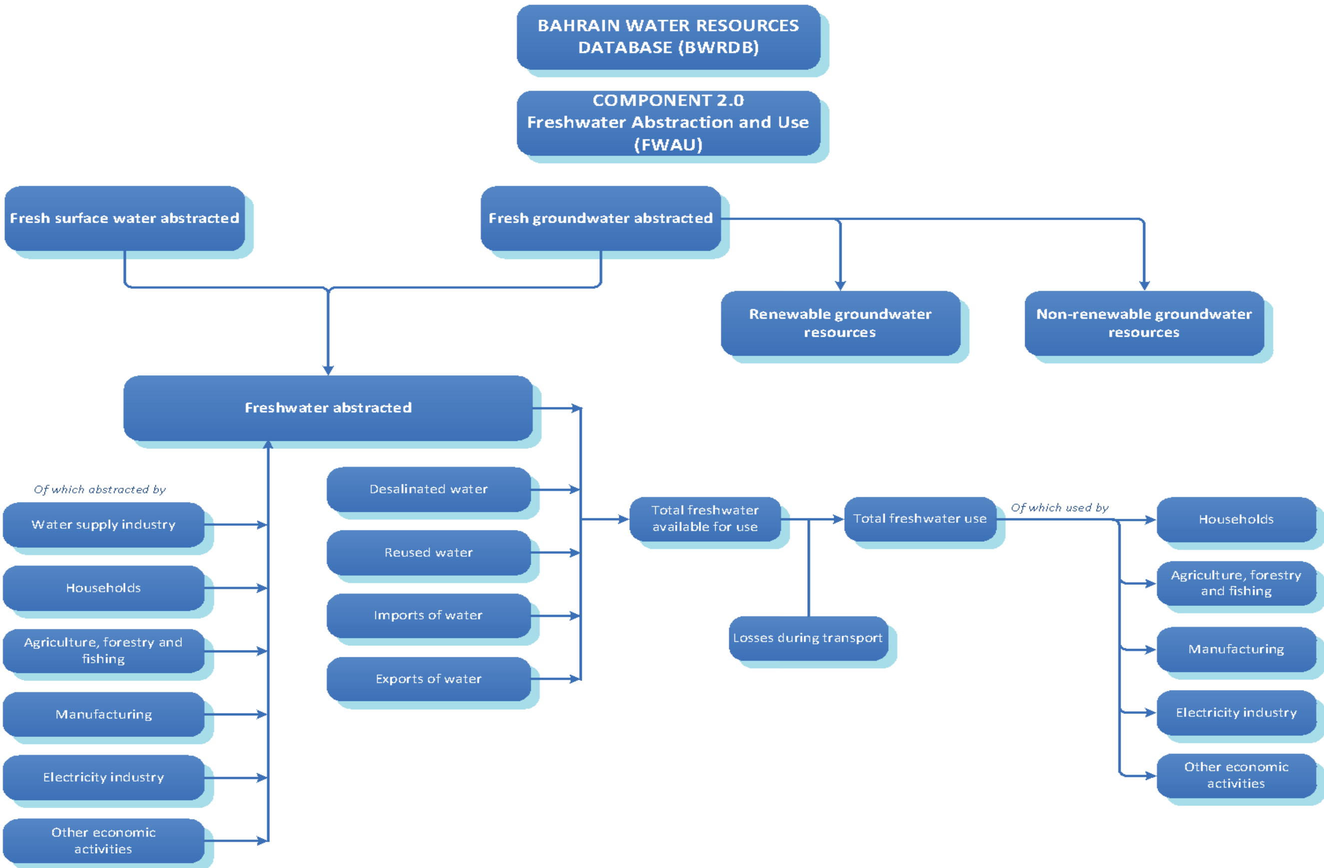

Fig. 3. Component 2 "Freshwater Abstraction and Use".

the BWRDB is a simple and flexible MS Excel platform comprising 13 components, 31 sub-components and more than 440 statistical topics covering a wide range of data and information on water resources and their uses. The BWRDB has basically been designed and structured to be a solid information base to inform sound decision making in water resources planning and management and to support monitoring of progress against SDG 6 global targets and indicators. Being already put in practice, the database gave sufficient proofs for serving and supporting the objectives of these strategic activities.

The paper has offered a number of important next steps actions for further improving the water information and data management system. It is necessary to strengthen the water data institutions by further fostering inter-institutional coordination and collaboration by formulating of a database administrator or inter-sectoral management team (technical steering committee) to be tasked with: (i) organising collaboration and coordination between institutions for more effective data sharing; (ii) specifying the different roles of the main actors and partners; (iii) defining the priorities and developing appropriate water data and information system procedures; (iv) setting up a protocol on the release of data and necessary security measures; (v) managing and controlling activities associated with the information system operation, performance, development, maintenance, data quality assurance and security enforcement; and (vi) improving human resources statistical capacities and implementing training in various database operations.

This committee may preferably be managed by the WRC to ensure better enforcement with close cooperation with the IGA. It is also crucial to improve the existing water data national monitoring systems in terms of data collection and quality control, and processing and reporting capabilities. Finally, great efforts are needed to constantly updating the database and integrating it with GIS-based visualization tools and geospatial data facilities, including mapping features, information-generation applications (modelling), statistical tools and web-portal services.

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