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Development of current condition assessment and target definition model for water balance practices in sustainable water loss management

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ABSTRACT

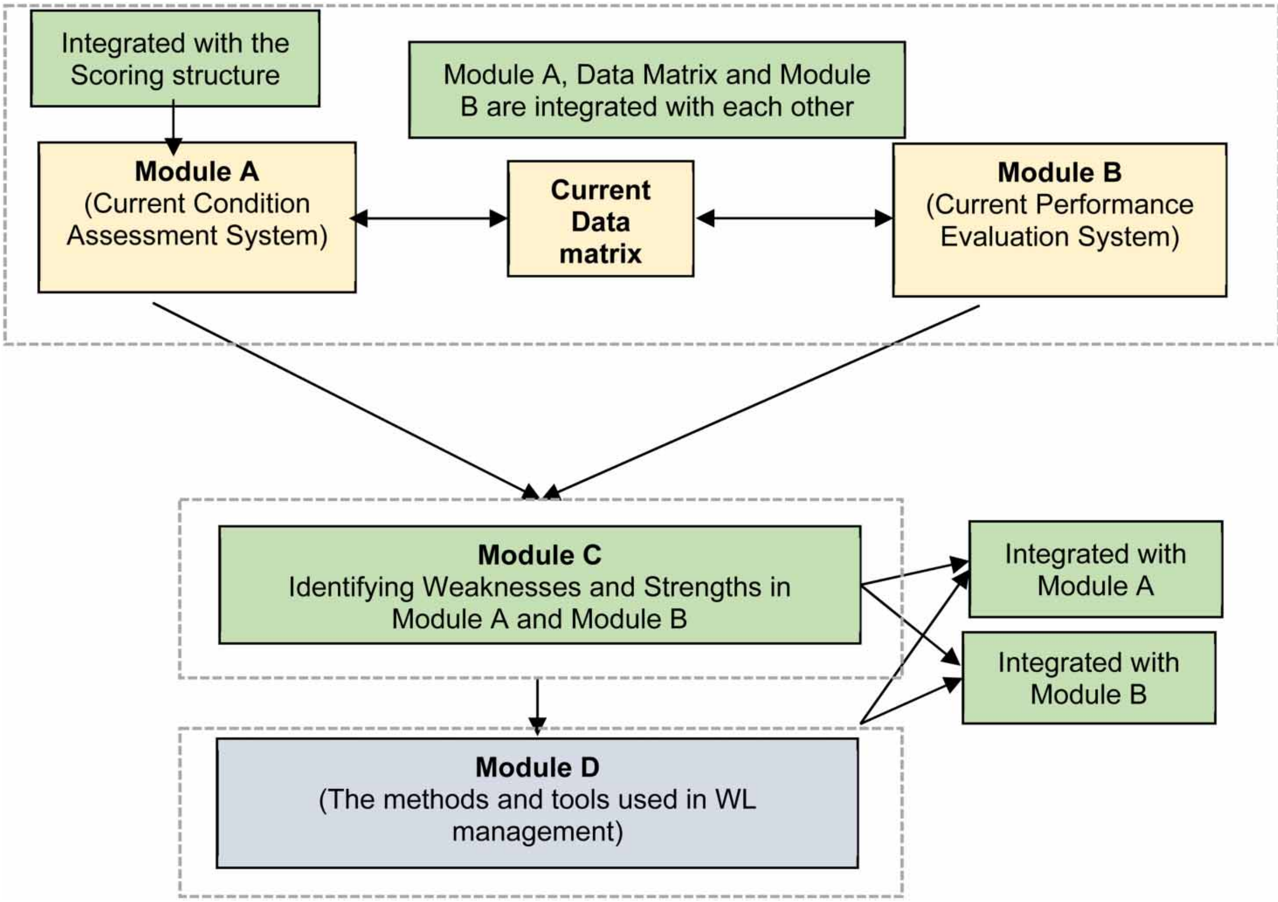
In water distribution systems, water losses should be defined accurately and systematically. The water balance method is one of the most basic analyzes applied in water loss management. In this study, a new method was proposed to evaluate the data quality of water balance components and application levels of water balance practices by considering a total of 27 components. The developed model was applied in 4 pilot water administrations in Turkey. The weaknesses and strengths in water balance practices were determined by considering scoring in accordance with the dynamic structure of each administration. The quality of basic data measurement components and application levels of water balance practices were found to be at a good level in Administrations II and IV, at a poor level in Administration I, and at an average level in Administration III. Moreover, quality of water balance analysis and performance monitoring practices are at a good level in Administrations II and IV, and at a poor level in Administrations I and II. Thus the components that need improvement in each administration were identified and an improvement process was suggested. It is thought that this model will make a significant contribution to the testing of current application levels of water loss management components for practitioners and decision makers.

Key words: assessment system, water administration, water balance, water loss management

HIGHLIGHTS

- A new method is proposed for evaluation of water balance practices.
- The water balance components are scored gradually.
- The weaknesses and strengths of 4 administrations were determined by the scoring.
- The components that need improvement in each administration are identified.
- A gradual improvement process is suggested based on the scoring.

GRAPHICAL ABSTRACT



INTRODUCTION

Non-revenue water (NRW) includes components of apparent losses, real losses and authorized unbilled consumption. Apparent losses consist of losses due to water meter inaccuracies and illegal consumption. Real losses cover the leaks in transmission lines, mains and service connections. Various methods have been used to analyze and monitor these losses in water distribution systems (WDSs). A *standard water balance* was proposed by the International Water Association (IWA) in order to establish the water budget in a standardized structure (Lambert *et al.* 1999; Pearson 2019). The water balance method is the most basic approach applied to determine the main water loss (WL) components in WDSs. However, it is not always possible to obtain field measurements of the input and output components in the water balance and the data are estimated. As a result, an evaluation that does not represent the actual conditions is made (Silva *et al.* 2018). The water balance table proposed by the IWA allows the summarizing of the components and monitoring of the input/output components. However, the reliability of the water balance is directly dependent on the data quality of the components in the table. For this reason, Aboelnga *et al.* (2018) carried out component analysis by considering fault records for the most appropriate leakage management in a WDS. Water balance table, minimum night flow and component analysis (with failure records) methods have been applied for leak estimation in WDSs. The failure rates, network conditions and field data used in these methods are highly effective in estimating leaks (Amoatey *et al.* 2018).

Unreported leaks, which constitute a significant part of the leaks in WDSs, occur mostly at service connections. The active leakage control in district metered areas (DMAs) should be applied in order to improve these leaks in the water balance table and system performance should be monitored regularly (Boztaş *et al.* 2019). Calculating water losses and leaks in WDSs is essential for monitoring performance, active control, estimating its economic impacts, and establishing network management plans. In one study, minimum night flow rate and fault records were considered to estimate leaks (Negharchi & Shafaghat

2020). Apparent losses are another important component in water balance analysis. Meter tests and monitoring of customer consumption profiles are required to accurately determine these losses. Generally, however, apparent loss components are estimated without fieldwork as a percentage of input volume or NRW volume. Therefore, for sustainable water balance analysis, administrative loss components (illegal use, meter errors) should be determined according to field data and the data quality of their components should be questioned (Farley & Liemberger, 2005; Mousavi *et al.* 2017; Ncube & Taigbenu 2019).

Percentage of input volume and process indicators (losses per main length or losses per unit service connection) have also been used to monitor the performance of NRW components in water balance analysis (Al-Washali *et al.* 2019). Similarly, unavoidable real loss (UARL) volume, infrastructure leak index (ILI) and real loss process indicators have been calculated to analyze the performance of leaks (Lambert *et al.* 1999; Lenzi *et al.* 2014; Klosok-Bazan *et al.* 2021). The ILI indicator is calculated as the ratio of the annual volume of physical loss in the system to the UARL. This indicator considers the physical characteristics of a network (network length, number and length of service connections) and system pressure (Lambert *et al.* 1999; Cavazzini *et al.* 2020). The methods applied to reduce the real loss components in the water balance table are generally time consuming and costly. For this reason, economically recoverable leakage rates should be determined by considering the current rate of the components and the benefits and costs of the methods, and the most appropriate leakage rate target should be defined accordingly (Yilmaz *et al.* 2021a, 2021b). In this context, the economic leakage level model was proposed using optimization algorithm in WDSs. The basic data in the system should be obtained correctly in order to perform an accurate analysis with this model (Firat *et al.* 2021). Water utilities work hard to reduce water losses, resulting in high costs. To control water loss, first identify the relative contribution to loss of the various components. Next consider how much would have to be spent for loss reduction in that component. Based on this, determine which investment has the greatest impact for the least cost (Moslehi *et al.* 2021; Serafeim *et al.* 2022).

The water loss rate consisting of apparent and real losses is considered for the performance analysis of administrations in Turkey. The major disadvantage in considering the water loss rate is that, when entering data, authorized unbilled consumptions are often overestimated. Authorized unbilled uses are estimated at higher rates to calculate lower rates of apparent and real losses. This may be due to factors such as political and administrative pressures, lack of awareness and attention, failure to audit the accuracy of the data entered into the table, or the lack of a supervisory mechanism in order to show the institution's water loss rate performance well. To ensure that an administration appears to be doing a good job in reducing water losses, systems in place are needed to ensure that the system is not 'played'.

Therefore, in this study, a new method is proposed to evaluate and highlight the reliability of data of water balance practices and hence the results obtained using the original scoring structure. The purpose of this study is not to propose a new water balance table. Rather, the quality of the data used for standard water balance analysis and the application levels of the applied methods are questioned. Thus, the data quality (quite good, good, doubtful, poor and quite poor) is classified according to the application level of the water balance practices. The class of the component is determined according to the examination and evaluation made in the administration being examined. This classification is not made by the personnel in the administration. For instance, it is not possible to talk about an accurate water balance analysis in systems where the system input volume and authorized billed consumptions, which are the most basic data in water balance analysis, are not measured regularly. These components that do not have a regular on-site measurement (only estimation) are not suitable for use in water balance analysis. Therefore, those components identified as poor data quality (with 0 or 1 points) based on scoring should be improved for an accurate water balance analysis. Similarly, the application quality of the methods applied to determine real and apparent losses in the field is also questioned. Thus, components with poor data quality and application level are identified within the scope of water loss management. Accordingly, it will be possible to provide more accurate data for sustainable water balance analysis in an administration and to make field applications more systematically.

STANDARD WATER BALANCE FOR WATER LOSS MANAGEMENT

In WDSs, the water supplied to the system consists of two basic components, authorized billed consumption (revenue water) and non-revenue water (Lambert *et al.* 1999). Non-revenue water consists of water losses (apparent and real losses) and authorized unbilled uses (Lambert *et al.* 1999; Pearson 2019). A standard water balance table was proposed by IWA to analyze and monitor losses in WDSs to a specific standard (Lambert *et al.* 1999) (Table 1). This table defines standard terminologies to express water balance. In this study, the standard water balance table recommended by IWA and widely used in many administrations is taken as reference. In addition, indicators or components used in establishing the water balance and

Table 1 | Standard water balance (Lambert *et al.* 1999)

(1) System Input Volume	(10) Authorized consumption	(4) Billed authorized consumption	(2) Billed metered consumption (3) Billed unmetered consumption	(5) Non-revenue water (6) Revenue water
		(9) Unbilled authorized consumption	(7) Unbilled metered consumption (8) Unbilled unmetered consumption	
	(11) Water losses	(15) Apparent losses	(12)Illegal consumption (13) Losses due to meter inaccuracies (14) Losses due to reading errors	
		(16) Real losses	(17) Leakages in transmission and distribution systems (18) Leakages in reservoirs (19) Leakages in service connections	

monitoring the process/performance in an administration, which are not included in this table, have also been defined. Components that need to be determined directly in the field in this table are: system input volume, billed metered consumption, billed unmetered consumption, unbilled metered consumption, unbilled unmetered consumption, apparent loss components (illegal consumption, losses due to meter inaccuracies), and real loss components (leakages in mains, services connections and reservoirs). Other components in this table are calculated using these data.

In the literature, *top-down* and *bottom-up* methodologies have been used to analyze a water balance and define WL rates (Lambert *et al.* 1999; Mastaller & Klingel 2017a, 2017b; Mamade *et al.* 2018; Pearson 2019; Chawira *et al.* 2022). Moreover, component analysis based on failure records is also used to estimate the leaks in WDSs (Aboelnga *et al.* 2018; Amoatey *et al.* 2018; Negharchi & Shafaghat 2020). The *bottom-up methodology* includes detailed process steps such as planning and on-site implementation of district metered areas (DMAs) in a WDS, regular monitoring of input flows, minimum night flow analysis, and leak detection (Al-Washali *et al.* 2016; Amoatey *et al.* 2018; Mamade *et al.* 2018). The DMA could be expressed as a zone that is isolated from other networks with isolation valves and generally has 1 or 2 inputs. In a DMA, the input volume, customer consumption and network components are completely separated from other regions. Thus, leaks, customers and other components are managed more effectively (Pearson 2019). Therefore, the bottom-up methodology includes detailed field work and is generally more costly than the top-down method (Pearson 2019; Serafeim *et al.* 2022).

The '*top-down approach*' is suggested as the simplest way to enter data into a water balance table (Liemberger & Farley 2004). This method involves less detailed work and is easier to implement. In this approach, the NRW volume is calculated by subtracting the authorized billed consumption volume from the system input volume measured by a flow meter. Then, water losses are calculated using the authorized billed consumptions and system input volumes. In order to analyze the strengths and weaknesses in the scope of WLM and to make a more accurate assessment of the water loss components, the apparent and real losses should be determined based on field data. However, data for some variables are estimated depending on factors such as lack of data, equipment and personnel in the administration, or technical and financial status. In this case, the sub-components of apparent and real losses are estimated and analysis is not made according to field data. Thus, an accurate assessment is not made about the components that need improvement in the administration. The current application levels of sub-components in the field should be analyzed first to define a more realistic and applicable roadmap for each component.

In Turkey, the 'Regulation for Control of Water Losses in Water Supply and Distribution Systems' published on 8 May, 2014, defined WL targets for administrations. Later, on 31 August 2019, the relevant regulation was updated and the targets were postponed for 5 years. In Turkey, generally the top-down method is used to analysis a water balance. Moreover, a regulation was published on 4 October 2021 in Turkey, which includes methods that water administrations should implement in order to reduce water losses in the next 5 years. These methods are basically the establishment of database systems (GIS, SCADA, and failure management systems), active leak control, DMA planning, night flow analysis and leak detection, meter management and fault management. The DMA method is applied in many administrations in Turkey in order to achieve the water loss rate targets specified in the regulation and to improve system efficiency. Minimum night flow analysis is performed in DMAs to accurately determine leaks (Özdemir 2018). In addition, a SCADA system is used to improve system performance and monitor DMA flow and pressure data (Güngör *et al.* 2019). Pressure control systems are applied in DMAs in order to reduce leaks in distribution systems (Özdemir *et al.* 2021).

EVALUATION MODEL FOR WATER BALANCE COMPONENTS

The main problems experienced in water loss management and water balance analysis in distribution systems can be given as follows: (i) lack of roadmap for data collection, monitoring and analysis, (ii) lack of a methodology to assess the data quality of water balance components and to describe the current state, (iii) lack of a method to identify weaknesses/strengths of water balance components based on current status analysis, and (iv) lack of methods and tools to define targets and components that should be focused on according to the current situation analysis. A model that suggests the current conditions of an administration and queries the effectiveness of the methods applied for the components should be used for effective and sustainable water loss management and water balance analysis in water administrations. In this context, a sustainable strategic WL management model was proposed and outlined by Bozkurt *et al.* (2022), which contains matrices such as Module (Current Condition Matrix), Data Matrix, Module B (Current Performance Evaluation System), Module C (identifying weak and strong components within the scope of water loss management) and Module D (Methods and Tools Matrix) (Figure 1).

In the strategic WL management model, Module A aims to evaluate the data quality of components and current application level of methods in WLM. The data matrix contains the data required for analyzing the performance indicators within the scope of WL management. This matrix is associated with the components in Module A. According to the scoring of the components in Module A, the data quality of the components in the data matrix is defined. Module B includes key performance indicators used in WL management. Indicators are calculated based on data quality. In case of data defined as of poor data quality, a recommendation is offered as 'data quality should be improved so that the indicator can be calculated'. Module C determines the strengths and weaknesses in WL management practices based on Modules A and B, and examines the risks and difficulties for WLM. Module D includes the methods and tools used to improve components in water loss management.

In this study, the current situation assessment structure for water balance components was developed and a scoring structure was determined for the components based on the strategic WL management model proposed by Bozkurt *et al.* (2022). This model aims to evaluate and highlight the reliability of data in a water balance analysis and hence the results obtained. Thus, it aims to identify the components with missing data, to perform gap analysis, to define the components that need improvement, and to identify the weaknesses and strengths of water balance components.

In this study, the standard water balance table given in Table 1 and recommended by IWA was considered in determining the model components. This table defines standard terminologies to express water balance. In addition, the indicators used in

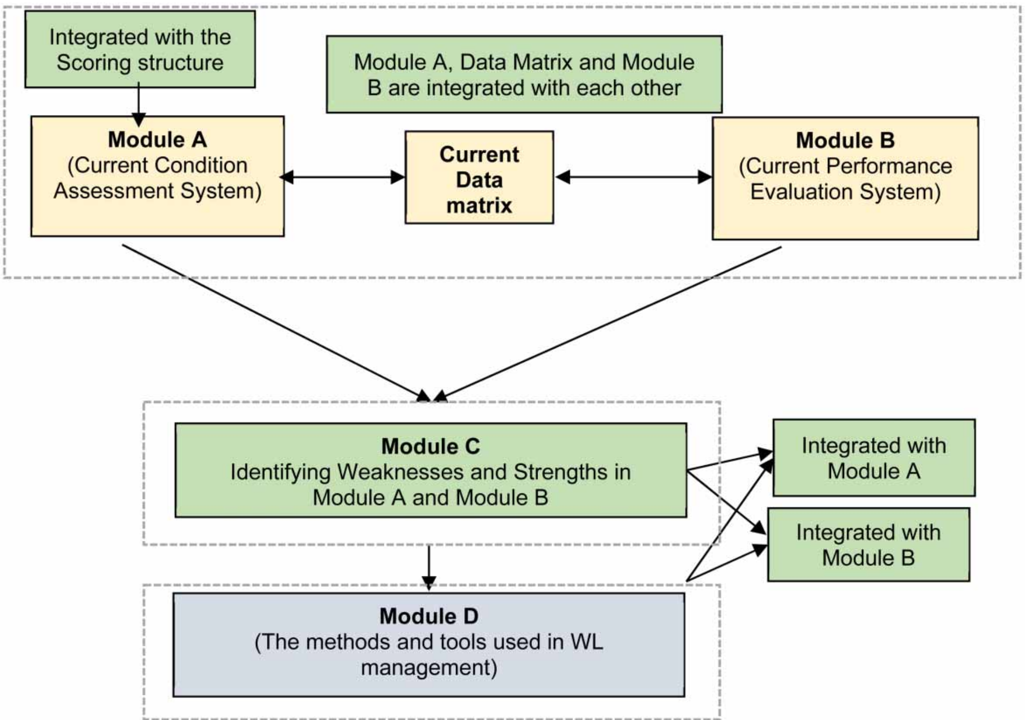


Figure 1 | Main matrices of the strategy model developed for WLM (Bozkurt *et al.* 2022).

monitoring system performance according to the water balance in an administration are also defined as components in the model. Accordingly, a total of 27 components were defined. The components considered in this study are thought to cover all practices in water balance management. However, this number of components can be reduced or increased according to the requirements in future studies. These components can be given as:

(i) Basic data measurement and monitoring: applicability and roadmap of water balance, system input volume, authorized billed metered and unmetered consumptions, authorized unbilled metered and unmetered consumptions)
(ii) Practices for the determination of water balance components: systematic measurement and monitoring of real loss components for water balance calculations, systematic measurement and monitoring of apparent loss components for water balance calculations, losses due to customer water meter inaccuracies, leaks in the distribution system (mains and service connections), leaks in reservoirs, losses due to illegal use.
(iii) Water balance analysis: estimation of leakage components with explosive and background estimates (component analysis), estimation of leakage and establishment of water balance based on minimum night flow, GIS-based water balance analysis, water balance calculation – comparison with different calculation methods, analysis of components that need to be reduced priority according to the water balance table, monitoring water consumption and resource efficiency, GIS-based Integrated Water Loss Management Model.
(iv) Performance monitoring for water balance components: performance monitoring and integration of information systems, analysis and monitoring of NRW and components with different indicators, water balance monitoring, update system and analysis, monitoring of real loss performance indicators, monitoring of apparent loss performance indicators, monitoring authorized unbilled usage changes, target definition for NRW and basic components, definition of economic leakage level (ELL).

In this system, sub-components are classified as 'Basic Level Applications', 'Intermediate Level Applications' and 'Advanced Applications' (Tables 2–4). While grouping the sub-components, their applicability in the field, requirements (data, technological infrastructure, methods or processes to be applied beforehand), difficulty levels in implementation and economic requirements were considered. Thus, information that will form a reference in determining the priority sub-components for improvement will be produced.

The components considered in this study, the most basic components (data, method/field application, and indicator) for which data should be measured in water balance analysis were included in the 'basic level applications' group. Then, the components that need to be determined or calculated according to the experience, data and application results in basic level applications are listed in the 'intermediate level applications' group. Finally, advanced level practices were defined in an administration, considering their feasibility in the field, analysis difficulty and data requirements. For these advanced applications, it is important that the basic and moderate level components have a certain level of application and quality.

In the developed system, a scoring structure between 0 and 100 was defined for the water balance components. The scoring structure created is 'quite poor: 0 points', 'poor: 20 points', 'insufficient: 40 points', 'moderate: 60 points', 'good: 80 points' and 'quite good: 100 points'. The application levels of the water balance components of an administration are determined in the field by considering these scores. Accordingly, the improvement targets of each component and the methods and processes to be applied are suggested considering the nature of the problem and its applicability in the field.

If a water balance component has a score of 0 or 20, that component is defined as a weakness in water balance practices. It is expressed as 'a component with poor data quality, a component that needs improvement in the first degree' for the data to which that component is linked. Moreover, it is recommended not to be used in any analysis. If a water balance component has a score of 40 or 60, that component is defined as a weakness in water balance practices. The data to which that component is linked is expressed as 'data of dubious data quality, data that needs improvement', but is used in analysis. If a water balance component scored 80, that component constitutes a strength in water balance practices. It is expressed as 'data quality is good, economic and technical criteria should be considered for improvement' for the variables in the data matrix to which that component is associated. Finally, if a water balance component scored 100, that component constitutes a strength in water balance practices. It is expressed as 'data quality is very good, the current situation should be preserved' for the variables in the data matrix to which that component is linked. Thus, 'only good quality or regularly measured data' is used in water balance analysis and management. According to these ratings, processes or components that need to be improved primarily in the administration are defined.

Table 2 | The scoring structure for basic level components of water balance in the developed model

Basic Level Components and Description		Quite Poor 0	Poor 1	Insufficient 2	Moderate 3	Good 4	Quite Good 5
Applicability and Roadmap of Water Balance	The existence of a roadmap for the feasibility and analysis of water balance is queried.	No effort for water balance analysis	There is awareness of water balance but no roadmap, sub-components are estimated	IWA water balance is used in Excel, there is a roadmap for the main components, but the sub-components are estimated.	IWA water balance is analyzed and monitored, there is infrastructure and roadmap for some of the subcomponents, and for others work is being done.	There is a road map for determining the main and sub-components, the table is analyzed and monitored systematically.	There is a road map to determine the main and sub-components, the table is analyzed and monitored systematically, GIS-based software is used.
Authorized Billed Unmetered Consumptions	The rate of authorized unmetered billed consumptions is queried.	There is no reliable CIS, no accurate data for customer consumption.	There is CIS and an invoicing system, but it is not up-to-date, the metering efficiency is less than 50%.	Metering efficiency between 50 and 75%, planning is being made for improvement to team size and metering program	Metering efficiency between 75 and 90%, planning is being made for improvement to team size and metering program	A regular metering is done, the metering efficiency is more than 90%.	There is a DMA-based metering plan, the metering efficiency is more than 90%, and GIS integration is available.
Authorized Billed Metered Consumptions	The measurement and monitoring rate of authorized customer consumption is queried.	There is no reliable CIS, no accurate data for current customer consumption.	There is CIS and an invoicing system, but it is not up-to-date, the metering efficiency is less than 50%.	Metering efficiency between 50 and 75%, planning is being made for improvement to team size and metering program	Metering efficiency between 75 and 90%, planning is being made for improvement to team size and metering program	A regular metering is done, the metering efficiency is more than 90%.	There is a DMA-based metering plan, the metering efficiency is more than 90%, and GIS integration is available.
Systematic Measurement and Monitoring of Real Loss Components for Water Balance Calculations	The situation of measuring and monitoring the real loss components in the field is queried.	There are no work to measure the real loss components in the field.	The technical background is not sufficient to monitor the reservoirs and distribution system. Planning is being made for improvement	Controls are made randomly in reservoirs, MNF analysis is planned in the DMA, and technical background is improved.	A certain part of the reservoirs are inspected, leaks are determined on site with MNF analysis in a limited number of pilot DMAs	Reservoirs and DMAs are monitored regularly, leaks are determined and monitored on site with MNF in DMAs.	Reservoirs and DMAs are monitored regularly, leaks are determined on site by MNF analysis in DMAs, GIS integration is available.
Systematic Measurement and Monitoring of Apparent Loss Components for Water Balance Calculations	This component queries whether the sub-components of apparent losses are measured and monitored in the field.	There are no works to measure the apparent loss components in the field.	Technical infrastructure is not sufficient for monitoring and detecting meter inaccuracies and illegal uses, planning is being made for improvement	The meter inaccuracies are determined in pilot DMA (average 2 years), there is no planned inspection policy for detection of illegal uses, and the inspection policy is applied only in the regions with complaints.	The meter inaccuracies are determined every 1–2 years with the samples, there is a team to detect illegal uses, but an audit policy is applied in areas where complaints are received or randomly selected,	In the system, meter inaccuracies are determined annually, a planned audit policy is implemented to detect illegal uses, and data is kept regularly.	In the system, meter inaccuracies are determined annually, a planned audit policy is implemented to detect illegal uses, and data is kept regularly, GIS integration is available.

(*Continued*)

Table 2 | Continued

Basic Level Components and Description		Quite Poor 0	Poor 1	Insufficient 2	Moderate 3	Good 4	Quite Good 5
Performance Monitoring and Integration of Information Systems	The existence of performance analysis/ monitoring and information systems is queried.	No work for performance monitoring system and integration	There is no performance monitoring and management system, the data is provided and calculated in Excel, the background is insufficient for detailed analysis	Performance analysis is carried out in Excel with the data received by the user from various individual information systems, data entry-integration and monitoring mechanism is insufficient.	Performance analysis is carried out in Excel, monthly and annual changes are analyzed, information systems that work correctly, planning for integration with each other	There is a performance monitoring system, but the data is entered by the user, some systems have integration with the performance system, planning is made for the integration of all systems.	Performance analysis for water loss components in distribution system or in DMAs is done through the system, GIS integration is available.
Analysis and Monitoring of NRW and Components with Different Indicators	This component queries whether NRW and its components are monitored according to different indicators.	No awareness and no study for NRW and analysis by basic components	No reliable and regular data for the analysis of NRW and main components with different indicators, planning for improvement	For NRW and main components, the indicators are calculated annually according to the percentage of the system input volume, no detailed analysis	The process indicators for the main components of NRW, real and apparent losses are calculated and monitored on the system in distribution system and DMA	The process indicators for the main components of NRW, real and apparent losses are monitored on the system, ILI is calculated.	The ILI, ELL and process indicators for the main components of NRW, real and apparent losses are monitored on the system, GIS integration is available.
Water Balance Monitoring, Update System and Analysis	This component queries the way of monitoring and updating the water balance.	No work for water balance monitoring and updating system	Water balance analysis is done and monitored in Excel, many components are estimated, annual changes are reported.	Water balance analysis is performed and monitored in Excel with the data received by the user from various individual systems, annual changes are reported.	There are information systems that work correctly, planning is made for their integration with each other, water balance analysis is done and monitored in Excel, monthly and annual changes are reported.	There are information systems that work correctly, some systems are integrated with each other, planning is made for the integration of all, water balance is monitored in Excel	There are integrated information systems that work correctly, all systems are integrated with each other, GIS integration is available
System Input Volume	This component queries whether the water supplied to the distribution system is measured regularly.	The inlet flow is not measured, only estimated.	Only less than 50% of the inlet flow is metered, the devices are not calibrated	More than 50% of the inlet flow is measured by ultrasonic/ electromagnetic flow meter, measurement accuracy is doubtful, device calibration is done in case of doubt	The inlet flow is measured with an ultrasonic/ electromagnetic flow meter, calibration is done very rarely (average 2–5 years)	The volume of inlet flow is measured with an ultrasonic/ electromagnetic flow meter sensitively and with a certain accuracy, the calibration period of the devices is 1–2 years.	The volume of inlet flow is measured with an ultrasonic/ electromagnetic flow meter sensitively and with a certain accuracy, the calibration period of the devices is 1 year.

Table 3 | The scoring structure for moderate level components of water balance in the developed model

Moderate Level Components and Description		Quite Poor 0	Poor 1	Insufficient 2	Moderate 3	Good 4	Quite Good 5
Authorized Unbilled Unmetered Consumptions (hydrant, fire)	This component queries the monitoring and analysis of statutory unbilled unmetered consumptions.	There are no studies for this component	There is awareness to determine the frequency of use of these components, value of this component is estimated for water balance	There is limited data and information about the types of users and the frequency of use, value of this component is estimated for water balance	The users and frequency of use in DMAs are known for the sub-components and value of this component is estimated for water balance based on the user type.	Field work is done for these consumptions, the users and frequency of use are monitored, and value of this component is estimated based on the user type.	Field works are made for the sub-components, the users and frequency of use are monitored, a systematic analysis is made based on the frequency of use, GIS integration is available
Losses Due to Customer Water Meter Inaccuracies	The method followed in calculating the losses caused by customer water meter inaccuracies is queried.	There are no studies for this component	There is not enough data and information to detect these losses, value of this component is estimated for water balance	The water meter inaccuracies are determined with samples in the pilot region (average 2 years), and the volume of losses is calculated for the entire system.	The water meter inaccuracies are determined with samples taken from different regions (every 1–2 years), and the loss volume is calculated accordingly.	The water meter inaccuracies are determined with samples (annually), and the loss volume is calculated. GIS integration is being planned	The water meter inaccuracies are determined with samples (annually), and the loss volume is calculated, GIS integration is available
Leaks in the Distribution System (Mains and Service Connections)	This component queries the practices of on-site detection and monitoring of leaks at network and service connections.	There are no studies for this component	There is no ALC and DMA plan-strategy, site inspection is carried out only where there are complaints, loss volume is estimated	Unplanned inspection is carried out in the regions with complaints or randomly determined, MNF analysis are performed in pilot DMA, and loss volume is estimated.	Leakages are determined on site according to MNF analysis in a certain part of DMAs (50–75%), and loss volume is calculated in other regions.	Leakages are determined on site according to MNF analysis in 75–90% of DMAs, improvement is planned for other regions	Leaks are determined in the field by MNF analysis in more than 90% of DMAs
Leaks in Reservoirs	This component queries the on-site identification and monitoring of leaks in reservoirs.	There are no studies for this component	The technical background is not sufficient for monitoring the reservoirs, there is no reservoir inspection in the field, leakage analysis cannot be done	The water level and flows in main reservoirs are monitored, there is no systematic inspection, and randomly selected reservoirs are controlled.	A certain part (more than 50%) of the reservoirs is randomly selected and inspected, the leakage volume is estimated for all reservoirs.	Reservoirs (between 75 and 90%) are inspected and controlled annually and the leakage volume is calculated.	Reservoirs (more than 90%) are inspected and controlled annually and the leakage volume is calculated.
Authorized Unbilled Consumptions	This component queries the monitoring and measurement activities of legal unbilled consumptions.	There are no studies for this component	There is not enough data and information about the user types and frequency of use, loss volume is estimated for the water balance	The measurement is made by installing a meter in a certain part of the known users (25–50%), the data is saved in Excel, and loss volume is estimated for the water balance	The measurement is made by installing a meter in a certain part of the known users (50–75%), the data is saved in Excel, and loss volume is estimated for the water balance	The measurement is made by installing a meter in a certain part of the known users (75–90%), the data is saved in Excel, and loss volume is estimated for the water balance	The measurement is made by installing a meter (more than 90%), measurement data is used in water balance calculation, and GIS integration is available.
Monitoring of Real Loss Performance Indicators	This component queries the performance indicators calculated for the analysis of the effects of the practices implemented to reduce leaks.	There are no studies for this component	There is not enough knowledge-experience to monitor the performance, percentage of system input volume is calculated, and planning is being done to calculate some basic indicators.	There is a calculation template in Excel for the calculation of basic indicators for real losses in the system and DMAs, analysis of advanced indicators is not done	There is a calculation template in Excel for process indicators in the system and DMAs, the analysis of advanced indicators is being planned, an annual report is prepared	The ILI, ELL and process indicators for real losses in the system and DMAs are systematically calculated, changes are monitored and reported.	The ILI, ELL and process indicators for real losses in the system and DMAs are systematically calculated, changes are monitored and reported, and GIS integration is available.
Monitoring of Apparent Loss Performance Indicators	The performance indicators calculated for the analysis of the effects of the practices implemented to reduce apparent losses is queried.	There are no studies for this component	There is not enough knowledge-experience to monitor the performance, percentage of system input volume is calculated, and planning is being done to calculate some basic indicators.	There is a calculation template in Excel for the calculation of basic indicators for apparent losses in the system and DMAs, analysis of advanced indicators is not done	There is a calculation template in Excel for process indicators in the system and DMAs, the analysis of advanced indicators is being planned, an annual report is prepared	The process and advanced indicators are analyzed and monitored in the system, and changes are monitored and reported regularly.	The process and advanced indicators are analyzed and monitored in the system, and changes are monitored and reported regularly, and GIS integration is available.
Monitoring Authorized Unbilled Usage Changes	This component queries the performance indicators calculated for the analysis of the effects of the practices implemented to authorized unbilled consumptions.	There are no studies for this component	There is not enough knowledge-experience to monitor these consumptions, planning is being done to calculate some basic indicators.	There is a calculation template in Excel for the calculation of basic indicators for apparent losses in the system and DMAs, analysis of advanced indicators is not done	There is a calculation template in Excel for process indicators in the system and DMAs, the analysis of advanced indicators is being planned, an annual report is prepared	A system was developed to monitor these consumptions, the number of users and consumption changes are analyzed and monitored, planning is made for GIS integration.	A system was developed to monitor these consumptions, the number of users and consumption changes are analyzed and monitored, and GIS integration is available.
Target Definition for NRW and Basic Components	This component queries whether there are defined targets for the reduction of NRW and components.	There are no studies for this component	There is no reliable and regular data in target definition for GGS and key components, planning for improvement is made	The indicators are calculated annually for the NRW and main components based on the percentage of the system input volume, the target is defined and monitored.	The indicators are calculated in the distribution system or DMAs based on the water balance for the NRW and main components, the target is defined and monitored.	The ILI and process indicators are calculated in the distribution system or DMAs, the target is defined and monitored.	The ILI, ELL and process indicators are calculated in the distribution system or DMAs by using performance system, the target is defined and monitored.

Table 4 | The scoring structure for advanced level components of water balance in the developed model

Advanced Level Components and Description		**Quite Poor 0**	**Poor 1**	**Insufficient 2**	**Moderate 3**	**Good 4**	**Quite Good 5**
Losses Due to Illegal Use	This component queries how unauthorized usage volumes are determined and monitored.	There are no studies for this component	Technical background is not sufficient for monitoring and detecting illegal uses, there is no control policy, this component is taken as zero for water balance.	There is no planned inspection policy, only in areas where complaints/suspects are received, the data is not regular, and loss volume is estimated for the water balance.	The inspection policy is implemented in the regions determined annually and/or randomly selected, the data is saved, and the rates determined are used in the water balance.	A planned inspection policy is implemented to detect illegal uses, data is saved regularly and used in water balance.	A planned inspection policy is implemented to detect illegal uses, data is saved regularly, and GIS integration is available.
Estimation of Leakage Components with Explosive and Background Estimates (Component Analysis)	This component queries whether the leakage volume is analyzed according to the failure data.	There are no studies for this component	There is no data or information on the number and details of failures and leaks, the technical background is not sufficient	Numbers of reported failures exist, unreported leaks are missing, data is inconsistent, and leaks are estimated based on number of reported failures only.	Reported failures are available, the number of unreported leaks in pilot DMAs is determined, leakage time and unit leakage rate are estimated according to the fault type, leakage analysis is performed	Reported faults are available, Unreported leaks in DMAs are determined on site, details of fault type, duration, unit leakage flow rate are kept according to field data, leak analysis is performed	Reported faults are available, Unreported leaks in DMAs are determined, details of fault type, duration, and unit leakage flow rate are kept according to field data, leakage analysis is performed, and GIS integration is available.
Estimation of Leakage and Establishment of Water Balance Based on Minimum Night Flow	This component queries whether the leakage volume is based on minimum night flow analysis.	There are no studies for this component	ALC and DMA plan-strategy does not exist, information-technical infrastructure is insufficient, background improvement works are carried out	Leaks are determined by MNF analysis in pilot DMAs, there is network and service connection data separately, leakage volume is calculated	The leaks are determined by MNF analysis in 50–75% of the planned DMAs, there is separate network and service connection separation data, leak analysis is performed.	The leaks are determined by MNF analysis in 75–90% of the planned DMAs, there is network and service connection separation data, leak analysis is performed.	The leaks are determined by MNF analysis in 50–75% of the planned DMAs, there is network and service connection separation data, leak analysis is performed and GIS integration is available.
GIS Based Water Balance Analysis	This component queries whether GIS-based water balance analysis is done with the integration of databases.	There are no studies for this component	There are only some databases, but their up-to-date status is doubtful, the background is not sufficient for the integration of information systems, there is no GIS-based water balance analysis	The basic databases are working correctly and up-to-date, the background is being improved for the integration of information systems, there is no GIS-based water balance analysis.	There are information systems (CIS, GIS, SCADA, and Failure Management System) that work correctly. Planning is made for integration with each other, no GIS-based water balance analysis	There are information systems (CIS, GIS, SCADA, and Failure Management) that work correctly. Some systems have integration with each other, planning is being done for all.	There are information systems (CIS, GIS, SCADA, and Failure Management) that work correctly individually. All systems are integrated with each other (GIS-based water balance is calculated)
Water Balance Calculation-Comparison with Different Calculation Methods	This component queries whether the water balance analysis is carried out according to different methods.	There are no studies for this component	The IWA water balance is filled annually on the basis of estimated data, there is no data-information-technical infrastructure for bottom-up analysis.	The IWA water balance is filled in Excel, the MNF analysis is planned in pilot DMA, the technical infrastructure is improved	The IWA water balance is filled annually, leaks are determined and compared by MNF analysis in pilot DMAs.	The IWA water balance is filled and analyzed systematically, leaks are identified and compared by MNF analysis in DMAs	The IWA water balance is filled and analyzed systematically, leaks are identified and compared by MNF analysis in DMAs and GIS integration is available.
Analysis of Components That Need to be Reduced Priority According to the Water Balance Table	This component queries whether the components that need improvement are analyzed according to the water balance table.	There are no studies for this component	No reliable and regular data for the analysis of NRW and main components with different indicators, planning is made for improvement	The indicators are calculated annually for NRW and main components based on the percentage of the system input volume	The process indicators are calculated annually for NRW and main components by using performance system, and evaluation is made according to these indicators.	The ILI and process indicators are calculated annually for NRW and main components by using performance system	The ILI, ELL and process indicators are calculated annually for NRW and main components by using performance system
Monitoring Water Consumption and Resource Efficiency	This component queries what kind of work has been done on monitoring water consumption and resource efficiency.	There are no studies for this component	Water consumption is monitored and reported only on total data, data and information are not sufficient for the efficiency analysis, work is being done for improvement	Water consumptions are recorded regularly in the system, water consumption based on region is graphically analyzed and evaluated in a certain period (every 1–2 years)	Water consumptions are recorded regularly in the system, water consumption based on region or DMAs is analyzed and evaluated graphically annually	Water consumptions in DMAs are regularly evaluated graphically and based on performance indicators, efficiency is analyzed according to leakage management, planning is made for GIS integration	Water consumptions in DMA are regularly evaluated graphically and based on various performance indicators, resource efficiency is analyzed according to leakage management, and GIS integration is available.
GIS-based Integrated Water Loss Management Model	This component queries whether any work has been done on the GIS-based Integrated Water Loss Management Model.	There are no studies for this component	There are only some databases, but their up-to-date status is doubtful, the infrastructure is not sufficient for the improvement and integration of information management systems.	Individually, only the basic databases are working correctly and up-to-date, the infrastructure is being improved for the improvement and integration of information management systems	There are information systems that work correctly, planning is made for their integration with each other, processes such as flow-pressure, water balance analysis are managed in the GIS-based water loss management model, improvement continues	There are information systems that work correctly, some systems are integrated with each other, planning is made for the integration of all, some analyzes in water loss management are made with a GIS-based model, planning is made for all analyzes	There are integrated information systems that work correctly, all systems are integrated with each other (GIS integration is available.), flow-pressure, MNF, performance indicators are made through this model, changes are monitored instantly.
Definition of Economic Leakage Level (ELL)	This component queries whether it has been done in the administration regarding the ELL Identification.	There are no studies for this component	There is not enough information-data-experience for the ELL in the system, there is awareness, planning is being made for the creation of the ELL account base	The components of cost/benefit analysis in the distribution system is calculated with the template created in Excel, the development of the ELL model structure is planned	The cost/benefit and ELL analysis in the distribution system or isolated region is calculated with the template created in Excel, the ELL analysis system is planned.	The cost/benefit and ELL analysis in the distribution system or isolated region is calculated with the developed model, the target is defined accordingly	The cost/benefit and ELL analysis in the distribution system or isolated region is calculated with the developed model, the target is defined accordingly, and GIS integration is available.

During the development of this model, efforts were made to ensure that the scoring structure was appropriate and applicable to the field conditions. Field experience, approaches suggested in the literature and on-site examination activities of administrations were considered as the basis for creating the scoring tables. Moreover, a lot of effort has been made within the scope of grouping the components as basic, intermediate and advanced level. In particular, the data and technical requirements of the components, application costs and applicability in the field were considered in grouping moderate and advanced practices. Also, during the model implementation phase, it was determined that decision makers and technical personnel have sufficient experience for systematic application and awareness in basic and moderate level practices. There was generally no problem in scoring the components in these two groups. However, in advanced applications, it was determined that there is not enough awareness about some components in certain parts of the administrations. The components in this group were scored after detailed explanations were given to the technical personnel in the administrations about the technical details of these components.

ANALYSIS AND DISCUSSION

The current situation assessment matrix given in detail in the previous sections was applied to 4 pilot administrations in Turkey. Scoring was made for each variable in pilot administrations in accordance with the current situation. A unique scoring structure was defined for the components (Tables 2–4). The most important benefit of this model is this scoring structure, which is defined to express the current status of the components. These components are not scored by the administration's technical staff or decision makers. In order to define the current state of the administration, each administration was visited separately by the authors (expert team) of this paper. In this context, all practices in the administration were evaluated in 5 units, namely the Drinking Water Management Unit, the Customer Management Unit, the SCADA Unit, the GIS Unit and the Information Technology Unit.

For basic data measurement and monitoring: in the customer management system, the quality of basic customer data such as the measurement and monitoring quality of authorized billed consumption and monitoring quality of authorized unbilled users and consumption was questioned. In addition, the quality of the system input volume data was evaluated by the queries made in the SCADA unit.

For field practices to determine the water balance components: the activities and reports in the Drinking Water Management Unit were examined to evaluate the quality of the practices for the determination of leakage components in the field. Similarly, the quality of field applications for apparent loss components was evaluated in the examinations made at the Customer Management Unit.

For water balance analysis and performance monitoring: the quality of implementation of different calculation methodologies (component analysis, bottom-up, etc.) for water balance analysis was examined and scored. Similarly, the quality of indicators and processes used to monitor the performance of water balance components was scored.

The score results obtained for each administration are given and discussed in Table 5.

ANALYSIS AND EVALUATION FOR ADMINISTRATION I

In basic level practices, the highest scores were achieved for authorized billed metered and unmetered components. These components constitute the strength of the administration and the data quality is good. However, the components of ID 1, ID 3, ID 4, ID 5, ID 6, ID 7, ID 8 and ID 9 (as indicated in Table 5) are generally of poor condition and constitute weaknesses in water balance practices. Especially since the system input volume has a direct effect on the water budget, all water sources should be measured and device calibrations should be checked regularly. In addition, it is understood that the components (ID 4 and ID 5) which cover the determination of the apparent and real loss components in the field, are of a poor level. Data should be obtained from the field in order to accurately analyze these losses and plan prevention methods. In moderate level practices, it can be said that the components are generally at a quite poor level and constitute weaknesses in water balance practices. These components constitute the sub-components of apparent and real losses, and the activities carried out to determine them in the field should be improved. Similarly, in advanced level practices, it can be said that the components are generally at a quite poor level and constitute weakness in water balance practices. These components constitute the sub-components of apparent and real losses, and the activities carried out to determine them in the field should be improved. Under these conditions, the water balance analysis made by considering these components in the administration is highly unlikely to represent the field. Therefore, these components should be improved as a priority for an accurate water balance analysis. In

Table 5 | The scoring results of water balance components in pilot administrations

ID	Water Balance Components	Administration I	Administration II	Administration III	Administration IV
1	Applicability and Roadmap of Water Balance	40.0	100.0	60.0	80.0
2	Authorized Billed Unmetered Consumptions	80.0	60.0	60.0	100.0
3	Authorized Billed Metered Consumptions	80.0	80.0	60.0	100.0
4	Systematic Measurement and Monitoring of Real Loss Components for Water Balance Calculations	20.0	100.0	60.0	80.0
5	Systematic Measurement and Monitoring of Apparent Loss Components for Water Balance Calculations	20.0	80.0	40.0	60.0
6	Performance Monitoring and Integration of Information Systems	0.00	100.0	60.0	80.0
7	Analysis and Monitoring of NRW and Components with Different Indicators	0.00	60.0	60.0	80.0
8	Water Balance Monitoring, Update System and Analysis	20.0	80.0	40.0	80.0
9	System Input Volume	20.0	60.0	60.0	80.0
10	Authorized Unbilled Unmetered Consumptions (hydrant, fire)	0.00	40.0	40.0	40.0
11	Losses Due to Customer Water Meter Inaccuracies	0.00	40.0	40.0	20.0
12	Leaks in the Distribution System (Mains and Service Connections)	0.00	80.0	40.0	80.0
13	Leaks in Reservoirs	0.00	60.0	80.0	40.0
14	Authorized Unbilled Consumptions	60.0	100.0	80.0	100.0
15	Monitoring of Real Loss Performance Indicators	0.00	80.0	60.0	60.0
16	Monitoring of Apparent Loss Performance Indicators	0.00	80.0	40.0	20.0
17	Monitoring Authorized Unbilled Usage Changes	0.00	80.0	60.0	80.0
18	Target Definition for NRW and Basic Components	0.00	80.0	60.0	80.0
19	Losses Due to Illegal Use	0.00	60.0	40.0	40.0
20	Estimation of Leakage Components with Explosive and Background Estimates (Component Analysis)	0.00	80.0	60.0	80.0
21	Estimation of Leakage and Establishment of Water Balance Based on Minimum Night Flow	0.00	60.0	60.0	80.0
22	GIS Based Water Balance Analysis	0.00	100.0	60.0	60.0
23	Water Balance Calculation-Comparison with Different Calculation Methods	0.00	100.0	60.0	60.0
24	Analysis of Components That Need to be Reduced Priority According to the Water Balance Table	0.00	80.0	60.0	60.0
25	Monitoring Water Consumption and Resource Efficiency	0.00	80.0	80.0	80.0
26	GIS-based Integrated Water Loss Management Model	0.00	80.0	20.0	80.0
27	Definition of Economic Leakage Level (ELL)	0	60.0	20.0	0.00

this developed system, targets are defined according to the dynamic structure and current score of each administration (Figure 2).

The components of the basic level practices (between ID 1- ID 9) are the components that are poor and insufficient level and need improvement (Figure 1, Table 5). The components of ID 4, ID 5, ID 6, ID 7, ID 8 and ID 9 should be brought to the average level first, then to the good level, and to a quite good level based on financial conditions (Figure 1). Hence, since ID 2 and ID 3 components are at a good level in the current situation, this situation should be protected first and then improved to a quite good level according to financial conditions. In moderate and advanced level practices, since all components except ID 14 are quite poor, these components should be improved first to average level (by doing pilot applications), then to good level and to quite good level according to the latest budget conditions.

ANALYSIS AND EVALUATION FOR ADMINISTRATION II

Overall the scores are at good level in Administration II. Especially ID 1, ID 4 and ID 6 components are at a quite good level and constitute the strengths of the administration. Moreover, ID 3, ID 5 and ID 8 components are at a good level, again

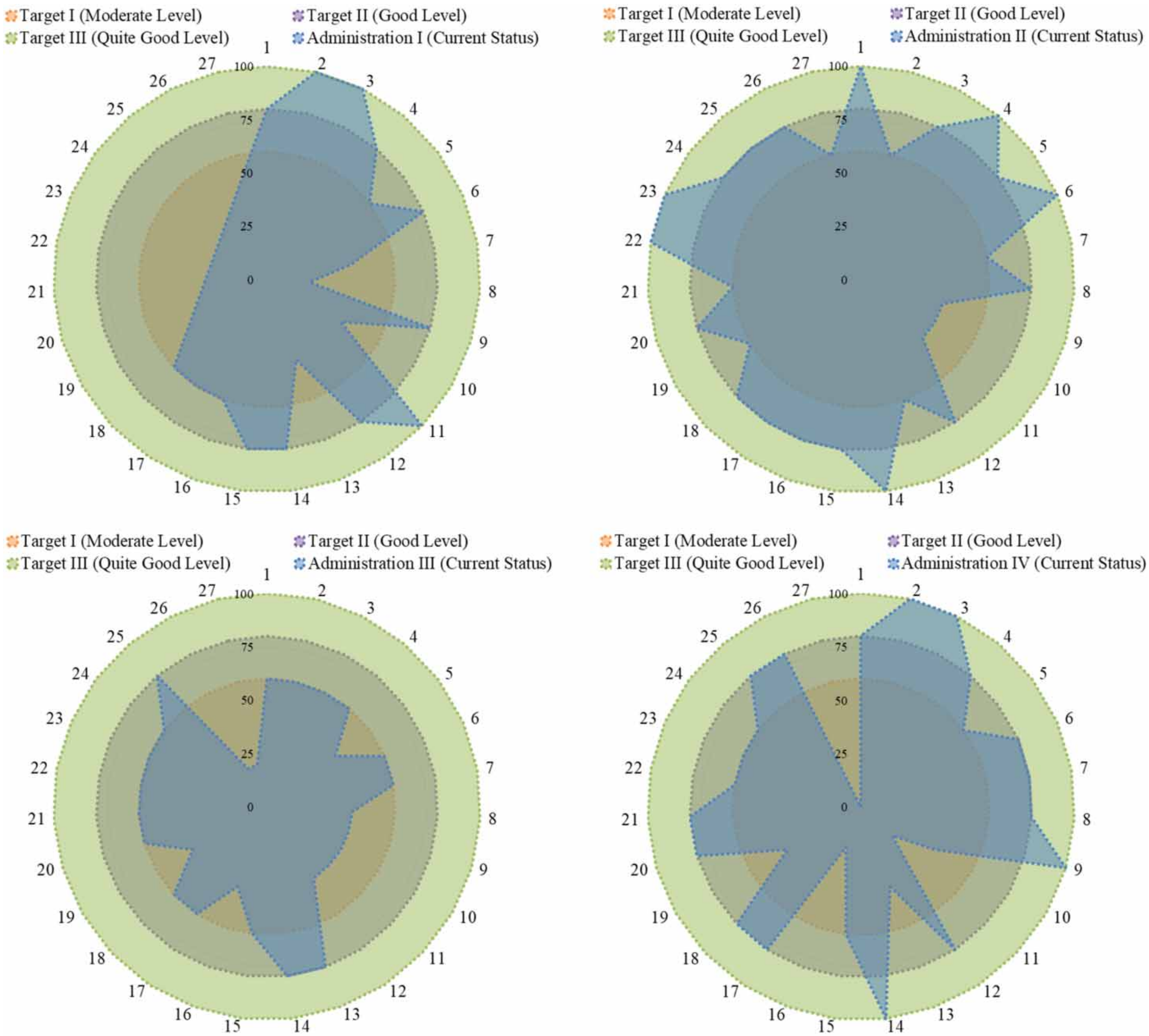


Figure 2 | The current scores and targets in pilot Administrations.

forming the strengths of the administration. These components are important for the systematic implementation of the water balance and for the determination of apparent and real losses according to field data. On the other hand, ID 2, ID 7 and ID 9 components are at an moderate level and need improvement. Especially since the system input volume has a direct effect on the water budget, all water sources should be measured and device calibrations should be checked regularly. In moderate level practices, it was determined that the ID 10 and ID 11 components are insufficient and constitute a weakness in water balance practices. Field activities should be improved as these two components directly cause loss of income. However, the components of ID 12, ID 14, ID 15, ID 16, ID 17 and ID 18 are generally at good level. In advanced level practices, components are generally at good level. The components of ID 19, ID 21 and ID 27 components are average. Practices in this level generally include advanced activities in WL management. Despite this, it is seen that the administration has a good performance. According to these results, it can be said that the data quality for the water balance filled by considering these components in these conditions is at a good level and will represent the field. However, the moderate and insufficient components should be improved to improve the data quality. The targets defined for each component according to the scoring results for Administration II are given in Figure 1. The components of ID 2, ID 7, ID 9, ID 10, ID 11, ID 19, ID 21 and ID 27 which are currently at moderate level should first be improved to good level and then to quite good level. Components with good scores in the administration should be improved by considering economic criteria.

ANALYSIS AND EVALUATION FOR ADMINISTRATION III

In basic level practices, it can be said that the scores are generally at moderate level. It was determined that the ID 5 and ID 8 components are at insufficient level in the administration. The data on these components are generally considered suspicious for the administration and need to be improved. In particular, determining the apparent and real losses in the field, regularly measuring all sources and calibrating the devices is quite important for an accurate water balance analysis. Moreover, it was determined that the ID 10, ID 11, ID 12 and ID 16 components were at insufficient level and needed to be improved. It can be seen that the ID 13 and ID 14 components are at a good level, while the ID 15, ID 17 and ID 18 components are at moderate level. In addition, the components of ID 26 and ID 27 are at poor level and constitute a weakness. The components ID 20–24 were determined as moderate level, while the ID 19 component was determined as insufficient level. According to these results, more field work should be carried out for a correct and representative analysis of the water balance in the administration. The possibility that a water balance created by using data of dubious accuracy to represent the field can also be evaluated as doubtful. In basic level applications, the scores available for the components are generally at moderate level, and all components in this group should be improved to good level first and then to quite good level (Figure 1). Components that are insufficient and poor level in the administration should be improved as a priority. Components with good current scores should be improved by considering economic criteria.

ANALYSIS AND EVALUATION FOR ADMINISTRATION IV

In general, it can be said that the scores are at a good level. The components of ID 2 and ID 3 are at a quite good level and constitute strengths of the administration. Moreover, the components of ID 1, ID 4, ID 6, ID 7, ID 8 and ID 9 are at a good level, again forming strengths of the administration. On the other hand, the ID 10 component is insufficient, the ID 11 and ID 16 components are at a poor level, and the ID 15 component is at moderate level and these components should be improved. The components of ID 12, ID 14, ID 17 and ID 18 are at good level or at quite good level and constitute strengths of the administration. The ID 27 component is at quite poor level, ID 22, ID 23 and ID 24 components are at moderate level. These components should be also improved. According to these results, the activities of systematically applying a water balance, determining the real losses based on field data and monitoring the performance changes are at a quite good level. It can be said that the data quality for a water balance filled by considering these components is at good level and will represent the field. The current scores for the basic level components are at good level, and the ID 5 component should first be improved to good level and then to quite good level. Moreover, the ID 11 and ID 16 components should be improved to moderate level first, then good, and then quite good level. Also, the target defined for components of ID 10, ID 13, ID 15 ID 19, ID 22, ID 23 and ID 24 are at good level then quite good level.

As a result, the developed model considers the dynamic nature of a system in the evaluation of water balance components and defines targets for each component accordingly. Gradual improvement is recommended by considering the current scores and defined targets. Moreover, components with very poor and poor data quality should not be used in analysis and should be improved first. This ensures that only components with good data quality are used. The components that need improvement are defined by considering the current situation of an administration. Thus, an applicable and accessible roadmap can be determined for the improvement of the components.

CONCLUSIONS

In this study, a methodology is proposed to test the current application level of water balance components, which are widely used in WL management. For this purpose, a total of 27 components were defined to cover water balance management practices in administrations. A scoring structure was defined that allows scoring between 0 and 100 for these components. Thus, the application levels of water balance components in administrations were scored gradually and improvement targets were defined accordingly. The developed model was applied to 4 pilot administrations. The improvement targets were defined in accordance with the dynamic structure according to the score obtained by the administrations for each component. In addition, the components that need improvement were determined according to the current scores of the administrations. The water balance analysis made by considering these components in Administration I is highly unlikely to represent the field. Therefore, these components should be improved as a priority for an accurate water balance analysis. Moreover, it can be said that the data quality for the water balance filled by considering these components in these conditions in Administration II is at a good level and will represent the field. However, the moderate and insufficient components should be improved to improve the data quality. On the other hand, more field work should be carried out for the correct and representative analysis of the water balance in Administration III. The possibility that the water balance created by using data of dubious accuracy to represent the field can also be evaluated as doubtful. In Administration IV, the activities of systematically applying the water balance, determining the real losses based on the field data and monitoring the performance changes are at a quite good level. It can be said that the data quality for the water balance filled by considering these components is at good level and will represent the field. The model will especially contribute to the evaluation of the quality of the data of the components used in the water balance analysis. According to this assessment, measurement quality needs to be improved in the field for components with low scores. This will also enable the monitoring of the impact of the actions taken to improve the data quality of the components. Since the performance analysis according to the water balance table is generally performed annually, it is also recommended to evaluate the quality of the data used in this analysis annually, using this model.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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