Environmental Research & Technology

RESEARCH ARTICLE

Application of IWA standard water balance in strategic water loss analysis: Benefits and problems

Salih Yilmaz[1] , Ozgur Ozdemir[1] , Mahmut Firat[1,*]

[1]İnönü University, Department of Civil Engineering, Malatya, TURKEY

ABSTRACT

Water losses occurring in distribution systems have effect on the operating cost, water and energy efficiency, service quality, customer satisfaction, maintenance and new resource demand. The standard water balance recommended by International Water Association (IWA) were used for defining, analyzing, regularly monitoring the water balance and sub-components, and determining the weakness and strengths of system. Water Utilities in Turkey are required to fill the water balance annually in order to analyze and monitor the performance with the regulation published in year 2014. However, in the use of this table, important problems are experienced due to the lack of technical, technological, personnel and economic conditions, data representing the field are not used and in many cases the real performance of the system is not revealed. In this study, the importance of IWA water balance in water loss management and monitoring system performance is emphasized, and the benefits and advantages are detailed by analyzing the pilot regions. In addition, problems encountered during filling the water balance, mistakes made, incomplete or incorrectly filled data and other problems were discussed. It is thought that this study will constitute a reference for the technical personnel in Utilities for measuring the data, analyzing the components and interpreting the results.

Keywords: Water losses, water balance, water loss management, performance monitoring

1. INTRODUCTION

Non-revenue water (NRW) is defined as water that is supplied to the system but cannot generate revenue and consists of three basic components: ApparentLosses and Real Losses and unbilled authorized consumptions [1-2]. The most basic approach for NRW rate is the ratio of NRW volume to system net input volume. In order to put forward a sustainable strategy in water loss management and to reduce this rate, sub-components of NRW should be analyzed and monitored. In the literature, the most common method used to calculate NRW and its sub-components in a certain standard and to reveal the weaknesses of the system according to the sub-components is the "standard water balance" recommended by International Water Association (IWA)[1-2]. In the IWA water balance, it is possible to monitor the real and apparent loss rates and their sub-components, as well as the NRW rate. However, while filling this table, detailed data are needed and in

many cases, data are estimated in developing countries. In Turkey, water loss rates for local administrations were first determined by the "Regulation on Control of Water Losses in Drinking Water Supply and Distribution Systems" (8 May 2014). In this context, Water Administrations have become obliged to reduce their water losses to a maximum of 30% within 5 years and to a maximum of 25% within the following 4 years. Later, due to the fact that the targets were not realistic for the administrations and the difficulties in achieving the determined targets, the values were updated with the regulation on 31 August 2019. In this context, Water Administrations have become obliged to reduce their water losses to 30% at most by 2023 and to 25% by 2028. With this regulation, administrations are required to fill the standard water balance table annually. Thus, it was aimed to regularly monitor the performance of the administrations in water management.

Liemberger et al. [3] emphasized that the amount of leakage in developing countries is approximately 45 million m³ per day. It was revealed that if the average consumption per capita is accepted as 100 liters/day/person, half of the population who cannot reach quality water can be served. Limberger and Farley [4] stated that understanding and realizing water losses and creating a roadmap is the first step in developing a strategy and for this, the standard water balance should be filled. It was emphasized that in the water balance, the components should be filled according to the field data, the calculation of the uncertain leaks in the performance monitoring and the network length and the number of service connections in active leakage control (ALC) should be taken into account. Farah et al. [5] applied the minimum night flow (MNF) method to a large-scale pilot project to predict leaks and monitored the area with a real-time system. It was expressed that with the strategy developed, the rate of water loss has decreased from 43% (2015) to 7% (2016). Mutikanga et al. [6] presented a methodology that determines the administrative loss components for the water distribution system using field audit and operational data. The results showed that measurement errors and illegal use were the most important components of administrative losses. Xin et al. [7] pointed out that most of the apparent losses are present in the distribution system and stated that these losses are often not included in the evaluations due to their complexity and difficulty to control. Lipiwattanakarn et al. [8] reported that after the leakage was repaired in the isolated zone, the isolated zone input flow rate decreased by 9%, and accordingly, the system input energy decreased by 8%, and system efficiency improved with the implementation of active leakage control. Creaco et al. [9] indicated that real-time control and automation systems provide significant benefits in monitoring and controlling water distribution systems and components. Boztaş et al. [10] investigated the effect of breakdowns in service connections in distribution systems on leaks and water losses, and emphasized that according to field data, the quality of workmanship and material can be improved in service connections and the rate of breakdowns and leakage can be reduced. Yazdekhasti et al. [11] stated that in order to ensure water and economic efficiency and to ensure sustainable urban water management, leaks should be detected and the most appropriate detection methods and equipment should be used. Jafari-Asl et al. [12] aimed to reduce and manage pressure with an optimization-based model to reduce the impact of pressure on leakage in distribution systems and showed that leaks can be significantly reduced by monitoring pressure.

The purpose of this study is to analyze the losses and subcomponents in water distribution systems by using the standard water balance, to discuss the problems encountered during filling the IWA water balance table, the advantages and benefits of this method. For this purpose, analysis was carried out for the pilot regions, the water balance was filled, and the evaluation was made on the basis of sub-components.

2. MATERIALS AND METHOD

2.1. Standard water balance

The most basic approach for NRW rate is the ratio of NRW volume to system net input volume. In order to put forward a sustainable strategy in water loss management and to reduce this rate, sub-components of NRW should be analyzed and monitored. In the literature, the most common method used to calculate NRW and its sub-components in a certain standard and to reveal the weaknesses of the system according to the sub-components is the "standard water balance" recommended by IWA(Table 1)[1-2, 13].

The "top-down approach" has been proposed as the simplest way followed in filling the standard water balance table used in establishing the water balance [2,14]. In this approach, the NRW volume is calculated by subtracting the billed authorized consumption volume received from the customer management system from the system input volume measured by the flow meter [1-2,15]. In this method, in the next stage, apparent and real losses and their sub-components are calculated or estimated based on authorized billed consumption and input volumes. The most important disadvantage in this approach is that the physical losses, which constitute the most important part of water losses, are calculated after determining the other components. Therefore, the accuracy of the data of the components (apparent losses, unbilled authorized uses) calculated in the previous stage directly affects the real loss calculation results.

Table 1. IWA Standard water balance [1-2]

(1) System Input Volume	(10) Authorized consumption	(4) Billed authorized consumption	(2) Billed metered consumption	(5) Non-revenue water
			(3) Billed unmetered consumption	
		(9) Unbilled authorized consumption	(7) Unbilled metered consumption	(6) Revenue water
			(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	

On the other hand, during the filling of the standard water balance table with the "top-down approach", the bottom-up approach by using minimum night flow analysis makes significant contributions in the more precise monitoring and determination of the sub-components that have been estimated in many cases, and especially in the detection and calculation of leaks in the WDSs. In the bottom-up method, leaks are determined directly according to field data based on the minimum night flow analysis. To achieve this, it is necessary to create isolated zones in the system, to establish a SCADA monitoring system and to perform minimum night flow analysis. Although the application of this method makes a significant contribution to the correct detection of leaks, field studies and infrastructure requirements create costs for the administration.

Another approach to filling the water balance is the component analysis, which allows to calculate leaks based on field data. In this method, data such as the numbers of the reported and unreported failures recorded in the system, failure intervention time and unit leakage rate in a failure are required. In order to provide these data in an accurate and sustainable manner, a systematic call center should be established. As can be seen, leaks are determined more accurately in bottom-up and component analysis approaches compared to direct field data. However, in the implementation of these approaches, significant investments must be made and the technical and equipment infrastructure must be sufficient.

The standard water balance table, which is filled using real data to represent the system, provides the opportunity to reach information about the sub-components of water losses as well as the NRW ratio. Thus, the loss rates on the basis of subcomponents in the system can be monitored, the component that creates the biggest problem in terms of water and economy for the administration can be determined, and it is possible to have information about the component that needs to be reduced and focused primarily.

2.2. Advantages and problems of the water balance

Measuring or estimating the components in the water balance table directly affects the precision of the water budget. Therefore, in order to fill in the rates of the sub-components in this table correctly, (i) determining and monitoring the meter error rates regularly with the samples to be taken in the field, (ii) making field inspections and inspections similarly for illegal use and illegal consumption rates, (iii) regular monitoring of inflow and outflow rates and level changes in order to detect leaks in the warehouse, (iv) regular inspections to identify and monitor leaks belonging to subcomponents in the distribution system, as well as devices and equipment should be placed and monitored. However, it is very difficult to fill and monitor the sub-components of the water balance in an accurate, continuous and sustainable manner according to the actual field data in the administrations where the existing technical,

technological, economic and personnel background is not sufficient. In cases where the infrastructure of the administration is weak, the ratios of sub-components are entered as estimates in many cases, and this gives results that are far from reflecting the truth in most cases. In such cases, since the standard water balance is not filled according to the actual data, it is not possible to reach the correct conclusion about the components that need to be improved in the system, and to determine the components that should be monitored and focused in inspections.

2.3. Required data and evaluation

The water balance table (Table 1) is filled according to a certain systematic based on the top-down method proposed by IWA. For this, accurate and regular measurement of basic data in the field will provide a more precise assessment of water loss management components. In this section, the data required to fill the water balance according to the top-down approach and their evaluations are presented. The system input volume is obtained by regularly measuring the water from all sources feeding an isolated zone or distribution system. Since this data is the most basic data used in the analysis of water balance and performance indicators, it is very important that the flow meter is calibrated, the data is measured and monitored regularly, and most importantly, and all resources are measured. The main problems encountered in obtaining this data are the lack of calibration of the flow meter, the absence of a Supervisory control and data acquisition (SCADA) system to monitor the data, the lack of measurement in the resources used in the summer when needed and not being included in the water budget. The sum of the billed metered and unmetered usages include consumptions of legal customer registered in the customer management system. Since this component equals the revenue water, it is very important to make regular customer readings, to have high reading efficiency (generally 90-95%), and that customers registered in the system coincide with the field. The unmetered authorized consumption component mainly includes estimated readings or water allocated according to annual agreements with particularly large consumption customers. It is a desired option for the subscriber and the Administration to have the minimum of this component that is to read the consumption regularly as much as possible. The sum of billed metered and unmetered components gives the billed authorized consumption, which is equal to the revenue generating water, the component from which the Administration generates revenue. Therefore, making this component the largest in the water budget should be essential. The NRW volume is obtained by subtracting the revenue water volume from the total inlet volume. The unbilled metered and unmetered authorized uses that are non-revenue water for the administration and include mosque, park-garden irrigation and fire hydrant uses. It is essential to install meters and regularly monitor the water used in mosque and park irrigation in order to evaluate the water budget correctly. Since these two components are non-revenue water, minimizing consumption by raising awareness is very important

in terms of decreasing income loss. The sum of unbilled metered and unmetered components gives the unbilled authorized consumptions. In top-down approach, the total water losses are obtained by subtracting the billed authorized consumptions from the system input volume. Losses due to the inaccuracies in water meters include the losses arising from reasons such as incomplete or no reading in legally registered customer meters. Since this component contains water that is consumed by the subscriber but cannot be charged, it means a direct loss of revenue for the administration. In order for the water budget to be made correctly, it is necessary to determine the weighted error rate by testing the meters purchased in the field annually. Illegal uses include illegal water consumed by unregistered users, resulting in direct loss of revenue for the administration. The sum of the losses due to meter inaccuracies, illegal consumption and losses due to reading errors gives the apparent losses. In order to determine this component, there must be a field-updated subscriber system, audits according to a specific schedule, and legal regulations. In water balance, after the apparent losses are determined, real losses are obtained by deducting the apparent losses from the total water losses. After the total real loss volume has been determined, its sub-components must be defined. For this purpose, leaks in water reservoirs are determined or predicted based on field data. Leaks in distribution systems (main line and service connections) are determined by subtracting this component from the total physical loss volume.

2.4. Establishing water balance and evaluation

Basically, top-down, bottom-up and component analysis approaches are used separately or together in establishing the water balance. However, overall, the top-down approach is preferred because it is easy and less measurement and monitoring activities are needed. In the top-down approach, the system input volume and invoiced legally measured uses are provided from the field and the other components are calculated according to the order given in Table 1. The most important problem in this approach can be shown to determine the physical losses that constitute the highest rate of total losses. In other words, mistakes made in determining the previous components or incorrect or incomplete measurement of data or using estimated data may cause the physical loss volume to be determined incorrectly or incompletely. If the components given in the previous section are determined according to field measurements, a more accurate evaluation can be made about the system and the weaknesses and strengths of the system can be identified. In our country, the water balance table is filled by Water Administrations according to the top-down approach. Considering that the input volume is not measured clearly in some administrations, it is not possible in many cases to fill in such detailed data regularly and

systematically. In order to regularly monitor the data of the components, there must be sufficient equipment, an up-to-date subscriber management system, geographic information systems and SCADA system. As a result, predictions are usually filled with data and unfortunately the system performance is shown well. As a result, it is not possible to regularly measure the event data due to technical, equipment, personnel, knowledge and awareness and economic factors in institutions and the table is filled in a way that does not represent the field. Bottom-up and component analysis approaches, which allow more precise determination of physical losses, are generally applied in isolated areas. Since these methods require detailed data measurement and monitoring, monitoring detailed data at the same time in large systems is costly and time consuming. In these methods, detailed analyzes such as the number of failures (reported and unreported), minimum night flow and pressure changes, determination of the location of leaks by acoustic methods are performed. In this way, the leakage volumes occurring in the system are determined directly according to the field data. It is possible to obtain more precise data without the problems in the top-down method.

3. STUDY AREA AND DATA

In Malatya province, selected as the application area, the water distribution system with the length of approximately 2,000 km network and number of customers 350000 is generally very old and the level of pipe failure is quite high. In order to use the standard water balance, 10 isolated measurement zones (DMA) in the water distribution system (WDS) of Malatya province were determined as pilot areas (Fig 1, Table 1). In the application area, DMA studies were carried out by the Malatya Water and Sewerage Administration (MASKI) between years 2016-2018 to ensure sustainable water loss management. The pipes in the WDS currently serving in the application area were laid at different times and DMA was planned in areas where the failure rate is generally high. Within the scope of this study, leakage rates are at high levels in the selected pilot areas, and mitigation and prevention activities have been carried out by the administration by applying an active leakage control strategy. All of the components of the system are clearly controlled in these areas, which are defined in this way and whose entrance to the system is regularly measured and located within the system. Inlet flow rates are regularly measured and monitored instantly with the SCADA system in DMAs. Network length, number of customers, service connection length and total consumption were determined for each region by using customer management and GIS databases. As a result of these efforts, the rate of non-income water, which was 65-70% in 2015, was reduced to 45-50% in 2018 [16].
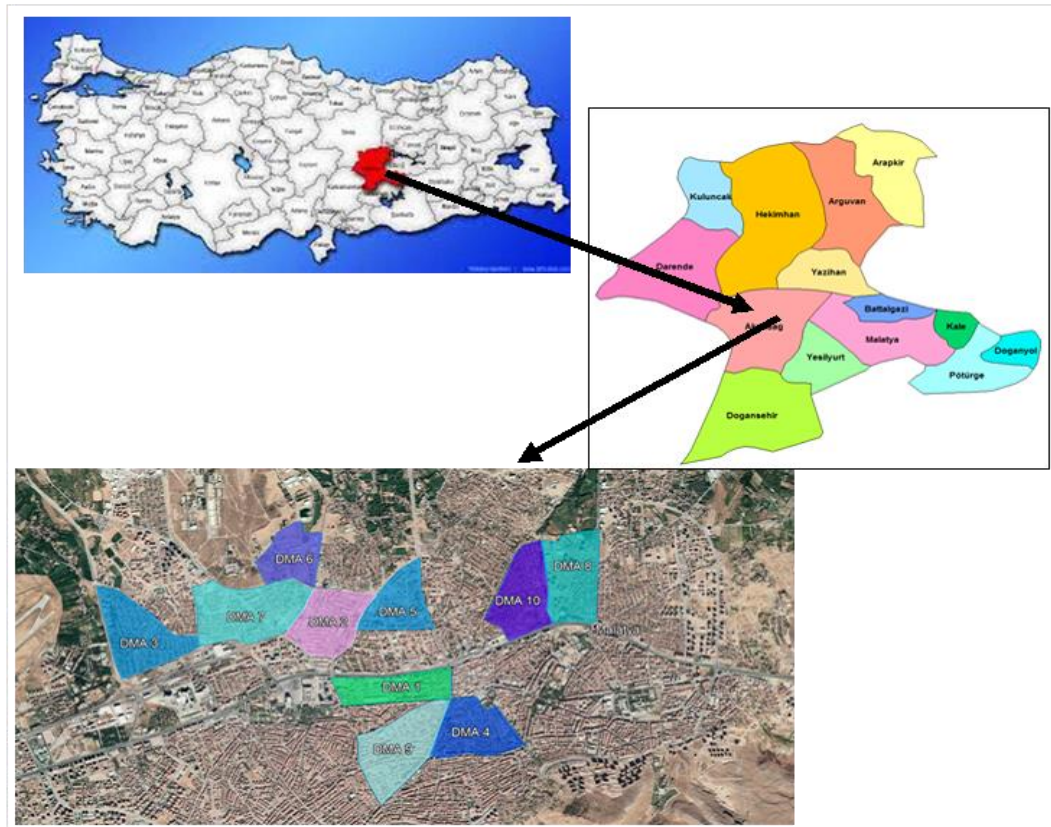
Fig 1. Study area

4. ANALYSIS AND DISCUSSION

In order to use the standard water balance in water loss management, to discuss its advantages and the problems encountered in the calculation of this indicator, an application was carried out for 10 pilot regions in the application area (Table 2). In isolated regions, the water budget was created based on monthly data. While creating the water balance for the pilot regions, the input volumes, billed metered and unbilled metered consumptions were obtained by field measurements. Since there is usually only one entrance in isolated areas, flow meter flows are monitored regularly. As mentioned before, it is very important to calibrate the input flow meters to minimize measurement errors in the flow meter. As a result of the tests performed by the Administration in the application area, weighted error rates were determined as 3.92% meter error rates in the pilot areas. Therefore, this error rate has been taken into account in all pilot regions. This rate is multiplied by the metered usage that are invoiced and not invoiced, to obtain the volumes of lost due to meters. On the other hand, since illegal use rates could not be obtained for the regions, it was taken as zero (0). Using these data, the steps given in the previous section were followed and the water budget was calculated.

When the table is examined, water loss and non-revenue water rates and volumes are given and evaluated separately. The difference between these two components can be expressed as unbilled uses. While the rate and volume of water loss includes real

and apparent losses, NRW volume also includes unbilled uses. When these ratios are considered, it is seen that DMA is at a very high level for 1-2-3 and 7, and it is calculated very close to the 10% limit value recommended in the literature for DMA 6. Considering that the Ministry takes the water loss rates into account in our country and it is considered that the rates are expected to be around 25%, it is seen that some regions are far from this target. In addition, physical and apparent loss rates are given separately in the table and their effects in the total loss are evaluated. Considering that the error rate is taken as the same in the regions, illegal use is not taken into account and the entrance volumes are also close to each other, it is seen that the apparent loss rates are very close to each other in all regions. Calculating these components separately is particularly important in terms of identifying weaknesses, calculating the costs incurred, and monitoring the volumetric and monetary gains achieved through reduction. The table also calculates the unavoidable annual real losses (UARL) parameter, which represents the technically lowest value the leak will get in a network (Equation 1) [1, 14]. UARL is sensitive to system operating pressure and network characteristics and is directly affected by changes in pressure. With this parameter, the physical loss volume is compared and it is analyzed how much the current physical loss volume is technically higher than the lowest value. This UARL value may not always equal the economic leakage level, or it is not always economical to reduce the leak to this level in all systems.

Table 2. IWA water balance for pilot DMAs

Parameters	Unit	DMA1	DMA2	DMA3	DMA4	DMA5	DMA6	DMA7	DMA8	DMA9	DMA10
Number of customers	#	3391	3384	1046	2337	1208	2717	4208	1514	2895	7032
Main length	km	5.8	6.2	4.78	11.01	3.16	3.68	15.62	13.12	6.9	13.48
Number of service connections	#	500	522	315	517	300	384	526	689	427	1386
Pressure	m	38	41	45	55	52	45	51	50	60	55
Inaccuracy rate in water meters	%	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92	3.92
Illegal usage rate	%	0	0	0	0	0	0	0	0	0	0
System input volume	m^3 month^{-1}	79762	128720	33531	39908	26540	32984	35050	25225	46220	109340
Billed metered consumption	m^3 month^{-1}	39439	63890	11446	29123	16700	28911	9900	18022	34080	84144
Unbilled metered consumption	m^3 month^{-1}	1500	1900	500	600	400	500	600	380	690	1650
Losses due to meter inaccuracies	m^3 month^{-1}	4000	5600	1450	1740	1160	1400	1400	1100	2020	4300
Authorized consumption	m^3 month^{-1}	40939	65790	11946	29723	17100	29411	10500	18402	34770	85794
Apparent losses	m^3 month^{-1}	4000	5600	1450	1740	1160	1400	1400	1100	2020	4300
Real losses	m^3 month^{-1}	34823	57330	20135	8445	8280	2173	23150	5723	9430	19246
Water losses	m^3 month^{-1}	38823	62930	21585	10185	9440	3573	24550	6823	11450	23546
Non-revenue water	m^3 month^{-1}	40323	64830	22085	10785	9840	4073	25150	7203	12140	25196
UARL volume	m^3 month^{-1}	686	780	541	1098	557	608	1235	1388	992	2632
Non-revenue water rate	%	51.0	50.0	66.0	27.0	37.0	12.0	72.0	29.0	26.0	23.0
Water loss rate	%	48.7	48.9	64.4	25.5	35.6	10.8	70.0	27.0	24.8	21.5
Real loss rate	%	44.0	45.0	60.0	21.0	31.0	7.0	66.0	23.0	20.0	18.0
Apparent loss rate	%	5.0	4.4	4.3	4.4	4.4	4.2	4.0	4.4	4.4	3.9
Cost of Apparent losses	TL month^{-1}	14000	19600	5075	6090	4060	4900	4900	3850	7070	15050
Cost of Real losses	TL month^{-1}	62681	103194	36243	15201	14904	3911	41670	10301	16974	34643
Cost of Total water losses	TL month^{-1}	76681	122794	41318	21291	18964	8811	46570	14151	24044	49693
Cost of UARL	TL month^{-1}	1235	1404	975	1976	1002	1094	2223	2498	1785	4738

$$UARL = \left(18 * L_m + 0.8 * N_c + 25 * L_p\right) * P \qquad (1)$$

P: the average pressure (m), Lm: the main length (km), Nc: the number of the service connection, Lp: the length of service connection on private property (km). As a result, if the water balance table is filled in according to the actual field data, it is possible to; (i) monitor the performance according to the NRW and its sub-components, determine the strengths and weaknesses on the basis of the component, (ii) monitor the improvements on the basis of the component depending on the implementation of the reduction methods, (iii) demonstrate the economic cost of each component.

5.   CONCLUSIONS

In this study, it was aimed to apply the water balance in order to analyze water losses and sub-components, determine their rates and monitor the performance of the system. For this, the water budget was prepared by collecting data for 10 isolated regions, and component-based evaluations were made. Basically, top-down, bottom-up and component analysis approaches are used separately or together to establish the water balance. However, overall, the top-down approach is preferred because it is easy and less measurement and monitoring activities are needed. For this, accurate and regular measurement of basic data in the field provides a more precise assessment of water loss management components. While creating the water balance for the pilot regions, the input volume, billed metered and unbilled metered consumptions were obtained by field measurements. When the table is examined, water loss and NRW rates and volumes are given and evaluated separately. The difference between these two components can be expressed as unbilled uses. While the rate and volume of water loss includes physical and administrative losses, NRW volume also includes unbilled uses. When these ratios are considered, it is seen that DMA is at a very high level for 1-2-3 and 7, and it is calculated very close to the 10% limit value recommended in the literature for DMA 6. Considering the water loss rate target (25%) defined in the regulation published in 2014 in our country, it is seen that some regions are far from this target.As a result, if the water balance table is filled in according to the actual field data, it is possible to (i) monitor the performance according to the GGS and its sub-components, determine the strengths and weaknesses on the basis of the component, (ii) monitor the improvements on the basis of the component depending on the implementation of the reduction methods, (iii) demonstrate the cost of each component economically. Measuring or estimating the components in the water balance table directly affects the precision of the water budget. Therefore, in order to fill in the ratios of the sub-components in this table correctly, it is very important to determine and monitor the meter error rates regularly with the samples to be taken in the field, and to make field inspections and inspections similarly for illegal use and illegal consumption rates. In addition, it is necessary to regularly monitor the inflow and outflow flows and level changes in order to detect leaks in the warehouse, to identify and monitor the leaks belonging to the sub-components in the distribution system, as well as regular inspections and monitoring by placing devices and equipment.

ACKNOWLEDGMENT

REFERENCES

[1].   A. O. Lambert, T. G. Brown, M. Takizawa and D. Weimer, "A Review of Performance Indicators for Real Losses from Water Supply Systems," *Journal of Water Supply: Research and Technology – AQUA*, Vol. 48 (6), pp. 227-237, 1999.

[2].   M. Farley, G. Wyeth, Z.B.M. Ghazali, A. Istandar and S. Singh, The Manager's Non-Revenue Water Handbook. A Guide to Understanding Water Losses, 2008.

[3].   R. Liemberger, B. Kingdom and P. Marin, "The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries," *The World Bank, Water Supply & Sanitation Sector Board*, PPIAF 8: 1–40, 2006.

[4].   R. Liemberger and M. Farley, "Developing a Non-Revenue Water Reduction Strategy Part 1: Investigating and Assessing Water Losses," Proc IWA 4th World Water Congress and Exhibition, 19-24 September 2004 Marrakech Morocco, pp. 1–10, 2004.

[5].   E. Farah and I. Shahrour, "Leakage Detection Using Smart Water System: Combination of Water Balance and Automated Minimum Night Flow," *Water Resources Management*, Vol. (31), pp. 4821-4833, 2017.

[6].   H.M. Mutikanga, S.K. Sharma and K. Vairavamoorthy, "Assessment of apparent losses in urban water systems," *Water and Environment Journal*, Vol. 25, pp. 327–335, 2011.

[7].   K. Xin, T. Tao, Y. Lu, X. Xiong and F. Li, "Apparent Losses Analysis in District Metered Areas of Water Distribution Systems," *Water Resources Manag*ement, Vol. (28), pp. 683–696, 2014.

[8].   S. Lipiwattanakarn, S. Kaewsang; A. Pornprommin; T. Wongwiset, "Real benefits of leak repair and increasing the number of inlets to energy," Water Science & Technology, Vol. 14 (3), pp. 714–725, 2019.

[9].   E. Creaco, A. Campisano, N. Fontana, G. Marini, P.R. Page, T. Walski, "Real time control of water distribution networks: A state-of-the-art review," *Water Research*, Vol. 161, pp. 517–530, 2019.

[10].   F. Boztaş, Ö. Özdemir, F.M. Durmuşçelebi, M. Firat, "Analyzing the effect of the unreported leakages in service connections of water distribution networks on non-revenue water," *International Journal of Environmental Science and Technology*,Vol. (16), pp. 4393-4406, 2019.

[11].   S. Yazdekhasti, K.R. Piratla, J. Sorber, S. Atamturktur, "Sustainability Analysis of a Leakage-Monitoring Technique for Water

Pipeline Networks," *Journal of Pipeline Systems Engineering and Practice*, Vol. 11(1), 2020.

[12]. J. Jafari-Asl, B.S. Kashkooli, M. Bahrami, "Using Particle Swarm Optimization Algorithm to Optimally Locating and Controlling of Pressure Reducing Valves for Leakage Minimization in Water Distribution Systems," *Sustainable Water Resources Management*, Vol. 6, 64, 2020.

[13]. P. Fallis, K. Hübschen, E. Oertlé, et al, Guidelines for Water Loss Reduction, 236, 2011.

[14]. A. Lambert, B. Charalambous, M. Fantozzi, J. Kovac, A. Rizzo and S. Galea St. John, "14 Years Experience of Using IWA Best Practice Water Balance and Water Loss Performance Indicators in Europe," *Proceedings of the WaterLoss Conference*, 2014.

[15]. M. Farley and R. Liemberger, "Developing a non-revenue water reduction strategy: planning and implementing the strategy," *Water Science and Technology: Water Supply*, Vol. 15, pp. 41–50, 2005.

[16]. MASKİ, Malatya Water and Sewerage Administration, 2018.