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ORIGINAL PAPER

Exceedance probabilities of non-revenue water and performance analysis

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Abstract

Water utilities evaluate the water distribution system performances by taking various performance indicators into consideration. However, it is necessary to digitize the current network characteristics and to provide hydraulic models, district metered area and pressure management system besides monitoring the water distribution systems by SCADA in order to identify an important part of these indicators. On the other hand, these studies are quite costly for underdeveloped countries including Turkey, so they are projected and applied partially in accordance with the budget of water utilities. Nevertheless, the utilities should control the network performance and make investments by taking the income and expenditure accounts into consideration. In this study, the network performances have been evaluated simply on the basis of the probabilities of exceedance determined with the help of innovative models based on risk calculations of non-revenue water volumes determined by using water supply and accrual amounts of the previous year held by water utilities. As a result, it is seen that the non-revenue water reduction performances of İzmit and Kandıra have the highest levels in the evaluation years (2017 and 2018) based on 2010–2016 time period. Körfez has also the highest performance after the above-mentioned districts. On the other hand, the lowest performance occurred in Derince for analysis years. Thanks to the approach suggested in this study, the network performances can be analyzed easily through the data on the previous year water supply and accrual, and thus, future strategies and plans can be identified considering the improvements made.

Keywords Exceedance probability · Non-revenue water · Performance analysis · Risk assessment

Introduction

Increasing migration toward metropolitans of developing countries due to the industrial development, inability of existing water resources to supply the demand, high levels of water loss in water transmission and distribution lines cause crucial problems for water utilities. There are significant studies on decreasing water loss in Turkey, especially the studies carried out by the metropolitan municipalities (Kanakoudis and Muhammetoglu 2014; Boztaş et al. 2018). In order to decrease the physical losses and leakages, water utilities have started certain activities in district metered area (DMA) such as replacement of the outworn water supply networks and active leakage control on the water distribution networks, including pressure management system (PMS). Water utilities replace the water meters that complete their economical life and try to decrease illegal water usages. Despite all these efforts, the water losses do not seem at the expected levels according to the activity reports published by the utilities at the end of the year.

The worldwide non-revenue water (NRW) amount is considered as 346 million m^3 daily, 126 billion m^3 annually, and its economical loss value is approximately 39 billion dollars annually (Liemberger and Wyatt 2019). When the NRW amount has decreased by one-third, water saving can be possible, and hence, the water demand of roughly 800 million people can be supplied (Liemberger and Wyatt,

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2019). Reducing the NRW amount increases both the operation quality of water distribution systems and the quality of supplied water besides reducing in energy consumption (Liemberger and Wyatt 2019). The NRW information of certain settlements is available on the Web site of International Benchmarking Network (IBNET). The developed countries usually have low NRW levels, for instance, Singapore 4%, Denmark 7%, USA 13%, Belgium 21%, Lithuania 21%, New Zealand 24%; on the other hand, the developing and underdeveloped countries have high levels such as Hungary 32%, South Africa 34%, Ukraine 36%, Argentina 42%, Bosnia and Herzegovina 49%, Bulgaria 61% (IBNET 2018). The average NRW rate in Turkey was 43.6% in 2012, according to the data obtained from the Turkish Statistical Institution (Gökdereli 2016). The high levels of NRW result from outdated water meters, illegal water use and physical losses. Within the borders of Kocaeli metropolitan municipality, as it is discussed in this study, the NRW ratio which was 46% in 2011 has decreased down to 32.31% by the end of 2018, through DMA, PMS activities and other investments that aim to decrease the uncertainties.

The water utilities deliver the quality drinking water conforming to the standards and treated in the facilities to the consumers through the water distribution systems (WDS). The outworn water distribution systems, lack of their maintenance and not being operated within a certain plan cause cascading network and service connection failures and serious water losses; these also deteriorate the water quality. In addition, to find a solution to the increasing water demand with additional infrastructure connections in existing water distribution networks brings with it low pressure problems (Saldarriaga et al. 2010). Additional unplanned projects and constant change of water flow and pressure by network connections increase physical water losses. In order to prevent and reduce them, the water utilities should develop effective strategies with a sustainable, economical and correct urban network management under the appropriate PMS in networks (Jang and Choi 2017). For these strategies, the utilities should be careful about the prioritization of the future investments by taking the existing economical resources into account (Halhal et al. 1997; Kanakoudis et al. 2015a, b).

When the water loss is discussed, the physical water loss in water distribution systems is the first thing that comes to one's mind (Toprak et al. 2007). In effect, the total water loss amount is composed of not only physical losses, but also many different uncertain components. In 1990s, there were no international standards to express and evaluate the physical and apparent losses in water distribution systems (Jang and Choi 2017). In order to solve this problem, American Water Works Association (AWWA) and International Water Association (IWA) offered the water budget method in 2003 (AWWA 2003). According to this method, the water budget components are defined, water budget equations are determined and performance indicators are created, all of which are needed to evaluate a water distribution system in terms of water loss. Furthermore, the IWA Task Force offered the international standards for water balance budget table related to the definition, monitoring, management and assessment of the NRW.

The water balance components and performance indicators are important to evaluate the WDS in terms of water loss, and they consist of many variables with various uncertainties. In literature, there are many studies on the subject (Lambert 2003; Kanakoudis and Tsitsifli 2010; Kanakoudis et al. 2013; Kanakoudis et al. 2015a, b; Alegre et al. 2016; Silva et al. 2018). The real losses have an impact on the NRW, and they are usually caused by the leakage activities in the WDS. The leakage activities are decreased by certain applications such as pipeline and assets management, PMS, DMA, active leakage control, repair quality and speed (Kanakoudis et al. 2016; Korkana et al. 2016; Kanakoudis and Gonelas 2016; Chondronasios et al. 2017; Samir et al. 2017; Chatzivasili et al. 2019). The detection and reduction of apparent losses are easier and more economical for water utilities than the real losses. The apparent losses are caused by the water meter errors, water meter reading mistakes and also unauthorized water use. Particularly, the water meter errors have a significant impact on the NRW. It is seen in the literature review that most of the studies on water meters are about the most proper changing time with consideration of water meters age during the service time and the water amount passing through the water meter (Mutikanga et al. 2011; Mbabazi et al. 2015; Arregui et al. 2015, 2018).

The uncertainties with the risk analysis based on expert view have been assessed by using the most proper Probability Distribution Functions (PDFs) for various applications (Şen 2012). While the specific average, standard variation, solutions related to correlation are obtained through the classical analytical and numerical methods, in the probabilistic solutions, more flexible evaluations can be made by taking the different risk levels into account (exceedance probability). The relationship between risk and uncertainty is explained in detail by Şen (1978; 1994) and Şen and Al-Baradi (2018). The NRW and the risk evaluation of its components are also determined by using Bayesian Network and Fuzzy method (Tabesh et al. 2018).

Water utilities usually prefer the performance indicators suggested by Alegre et al. (2016) to evaluate WDS performances. Although WDS performance evaluation with all indicators is quite useful for water utilities in terms of operating services, it does not seem possible for underdeveloped countries including Turkey in practical terms to make performance analysis in a short time by the referred indicators considering some requirements such as technology transfer, cost and qualified personnel. The aim of this study is to calculate the risk values through the probabilistic models obtained by using NRW data for research years and to evaluate simply the network performances, according to these values. The performance comments are determined by accepting the average level of 50% as reference; the level above this rate shows that the performance is getting better, and the level under this rate shows that the performance is getting worse. The referenced level can be determined by experts in a different way considering the current NRW amounts, investment budgets and service qualities of utilities. The monthly historical data between 2010 and 2016 time period of eleven districts in Kocaeli has been used for the model setting. The district risks have been determined in accordance with the established model, and performances of each district have been compared through the determined risk levels. This study guides the future plans targeting low NRW levels in the light of the strategic goals by considering the past performances of the districts in question.

Materials and methods

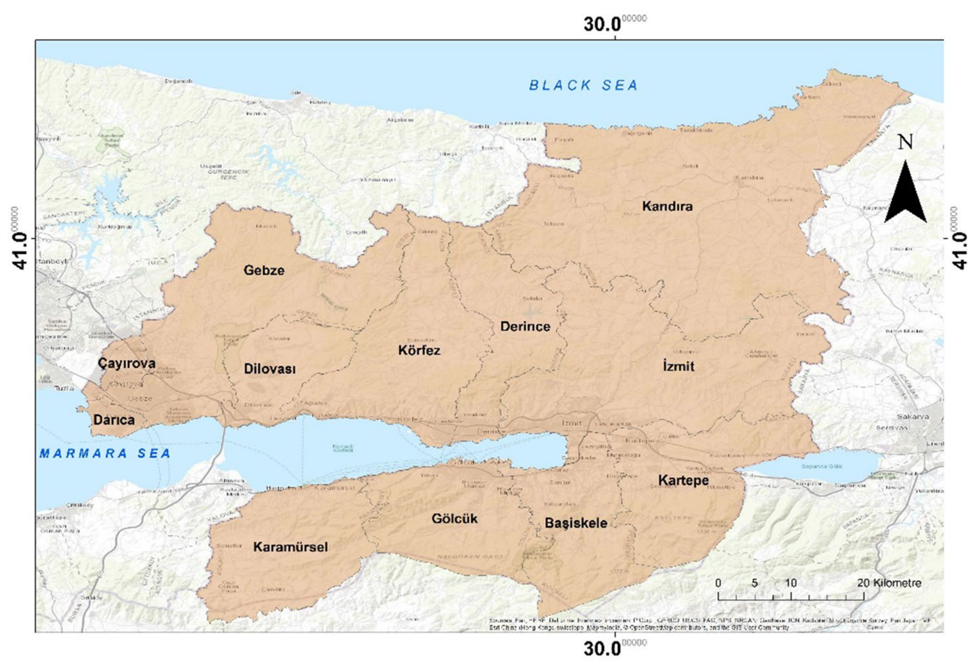
Study area and data

Kocaeli, which has been selected for this study, is a metropolitan city located in the Marmara region of Turkey bordering to Istanbul, Yalova, Bursa and Sakarya cities (Fig. 1). It has coasts to the Black Sea and the Gulf of İzmit, and it gets a significant number of immigrants due to industry. Among the districts of Kocaeli, Gebze and İzmit are the ones with the densest population. On the other hand, the seasonal intensities have occurred in certain districts, such as in Kartepe in the winter season and in Kandıra, Karamürsel, Gölcük and Darıca in the summer season. The total surface area of the city is 3623 km^2, and its population is 1,883,270. In 2018, the amount of used water was 163,627,918 m^3, NRW rate was 32.31% according to measurements, and the total length of the drinking water distribution system was 8,936 km (Şişman and Kizilöz 2020).

The NRW consists of main components such as apparent losses, real losses and unbilled authorized consumption and many different subcomponents as leakage on transmission and/or distribution mains, real losses on raw water mains and at the treatment works, leakage on service connections up to measurement point, leakage and overflows at transmission and/or distribution storage tanks, authorized consumption errors, unauthorized consumption, unbilled metered consumption and also unbilled unmetered consumption (Silva et al. 2018). The uncertainty in each component usually leads to an increase in the NRW amount. Sometimes, the seasonal decrease in these uncertainties could also causes a decrease in the NRW amount. The increases in the NRW amount affect directly and negatively the water utilities budgets.

The annual NRW amounts of districts in Kocaeli are shown in Fig. 2a; these amounts change depending on various factors such as water consumption patterns, consumer numbers, location, population density and climate. The physical water losses in Dilovası have significantly decreased due to the infrastructure replacement. The NRW amount change in this location between 2010 and 2018 time period was more stable by comparison with the other districts. This figure indicates also certain fluctuations, changes and tendencies that are observed in the NRW amount in all districts of Kocaeli, arising out of uncertainties and

Fig. 1 Districts in Kocaeli



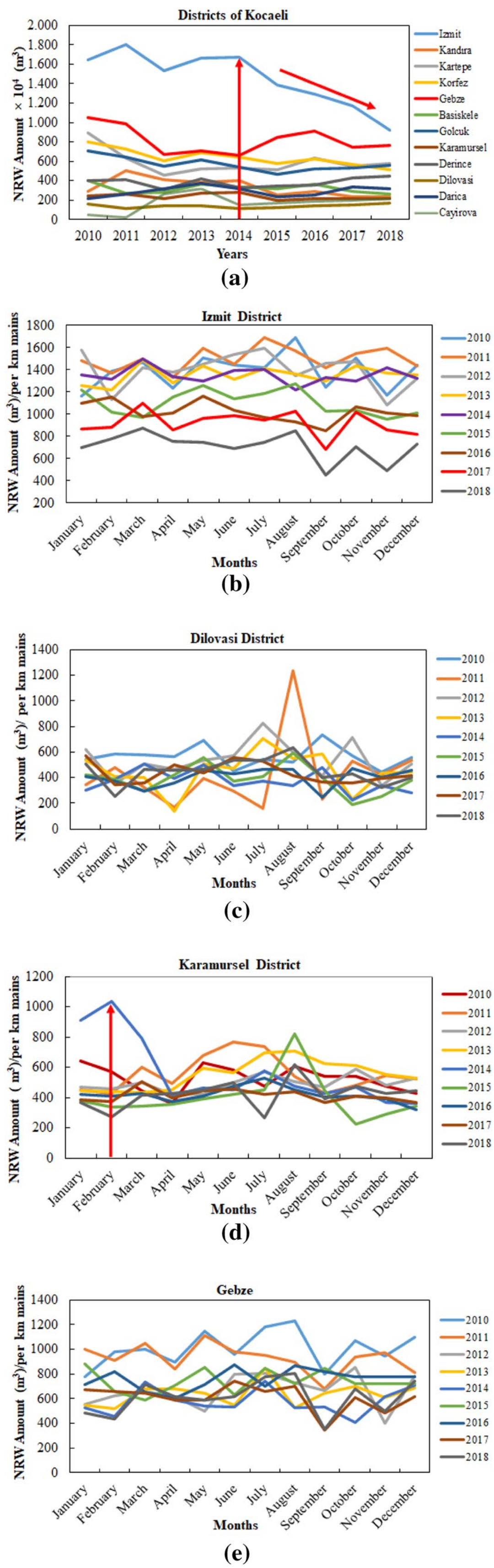


Fig. 2 The NRW change for 2010–2018 time period

amelioration activities. Particularly, a significant decreasing tendency has been observed in İzmit after 2014. This tendency changes from time to time in Gebze, which is one of the most water-consuming districts. The NRW amount was decreased rapidly in 2012 by comparison with 2010 and 2011 time period. However, an increasing tendency took place in 2015 and 2016 following the year of 2014.

When analyzed the monthly time series changes of NRW amount, it is clearly seen in Fig. 2 that the changes are irregular. It is obvious from each graph that there is a random fluctuation, and therefore, a risk analysis is necessary for future estimations. This amount generally decreased in İzmit, while it was increasing in Gebze. The main reason of these changes is the physical water losses. Considering the reasons of physical water losses, it is seen that controlling the NRW amount is quite difficult because of outworn drinking water pipelines. In particular, the number of failures based on network age increases severely, and therefore, significant water losses occur. İzmit is in the first place among the other districts of Kocaeli in terms of total water consumer number, 160,135 as from 2018. The total network length of the district became approximately 1,114 km by the end of the same year. In order to decrease the apparent losses, one of the significant NRW components, in İzmit, most of the water meters in district have been replaced with new ones; on the other hand, the isolated area and pressure management system applications have been performed to decrease physical losses, the other significant component; these studies are extremely difficult and costly activities. With these applications, significant decreases have been observed in the amount of NRW after 2014, as it can be seen in Fig. 2b.

The monthly change of NRW amount per kilometer between 2010 and 2018 time period in Dilovası, the smallest district of Kocaeli, can be seen in Fig. 2c. The infrastructure of this district has been replaced substantially, and thus, the uncertainties arising out of physical losses have decreased to a large extent. The reason of important deviation in NRW amount in the August of 2011 was a malfunctioning problem in the main drinking water network with High Density Poly Ethylene pipes (HDPE). Moreover, the studies on unbilled authorized consumption and apparent losses have been carried out in the district to decrease the NRW and the uncertainties.

The monthly change of NRW amount per kilometer between 2010 and 2018 time period can be seen in Fig. 2d for Karamürsel district. The residential area and population of this district densify toward the beach; the density increases even further especially in the summer months due to those who come to the region for vacation. Most of the water meters in this district have been replaced with the new ones with remote reading system, so that the uncertainties in the apparent losses have decreased. The NRW amounts of the district between 2010 and 2018 time period can be evaluated with the help of the time series graph as in Fig. 2d. The NRW waste in the month of February of 2014 implies a serious amount of unexpected loss. There are no studies made to decrease the uncertainties related to the unbilled authorized consumption and the real losses in the Karamürsel region.

Finally, the NRW data evaluation has been presented for Gebze, a district which has different qualities. In this district, the settlement is dense both in terms of industry and population. In Kocaeli, Gebze is on the first rank with its population, and the second in terms of consumers. The NRW amount reduction can be seen through the change of the NRW amounts between 2010 and 2018 (Fig. 2e). The NRW data fluctuates randomly throughout the year due to the seasonal effects and decreasing tendency, and the variabilities depending on uncertainties have been observed between these years because of the activities in question.

NRW risk definition and reliability

The classical deterministic approaches (newly built and appropriately designed water distribution systems with little uncertainty or not) and the stationary stochastic process analysis (can be well estimated in case of sufficient data—existing slightly worn system) or the non-stationary stochastic process analysis (existing outworn water distribution systems —with large errors in its estimation) can be preferred for NRW parameter calculations and evaluations in accordance with the situation of water distribution system. The NRW amount in water distribution system can change, increase, remain stable or decrease in time depending on the uncertainties. The accurate estimates and evaluations are quite difficult with classical approaches in such problems.

Considering the NRW parameter time series of existing water distribution systems, the fluctuations arising out of the uncertainties of NRW components are clearly seen. Consequently, different analyzes are also necessary for estimation and evaluation of NRW amount in studies on old water distribution systems in addition to the deterministic approaches. Firstly, the term "uncertainty" which causes the change of NRW parameter values and the term "risk" discussed in this study should explain. There is a significant difference between uncertainty and risk terms although they seem to have close meaning (Şen 1978). The risk is defined in relation to the digitized random variables, while the uncertainties are defined as non-digitizable events (Şen 1999). The risk can be obtained from a group of data observed in a laboratory environment or anywhere else (Koch and Link 1971). We can define the risk of an event through PDFs in accordance with the histograms consisting of variable data. The histogram of NRW variable in Körfez and the log-normal PDF function corresponding to this histogram are given as an example in Fig. 3. Supposing that the NRW is targeted to be 550,000 m^3/month maximum, this value divides the PDF curve into two parts, and the area below the right part of this value in the figure is the numerical equivalent of the risk value. Since it is not desirable to exceed 550,000 m^3/month, the total of probability values over this defined value gives the risk value. The determination and evaluation of actual NRW amount risk levels can be considered as performance indicators according to these definitions.

The risk and reliability statements in accordance with the definitions given above are obtained by the help of Eqs. 1 and 2.

$$\text{Risk} = P\left(X \geq X_{\text{c}}\right) = \frac{1}{T_r} \tag{1}$$

In this article, the risk of "X" event is that the NRW value exceeds or equals the determined critical level (X_{c}) in any month. The reliability value of this event is expressed by Eq. 2.

$$\text{Realibility} = 1 - \text{Risk} = P\left(X < X_{\text{c}}\right) = 1 - \frac{1}{T_r} \tag{2}$$

The critical value has been defined as X_{c} for NRW value performance evaluation corresponding to 50% of PDFs that are suitable for these data according to the monthly data of 2010–2016 time period of each district. Then, the monthly data performance of the districts has been investigated and compared in accordance with this critical level.

Methodology

The NRW amounts in WDS change because of network age, network pressure, pipe-type, random pipe burst, errors in meter measurements, water consumption patterns, as well as physical and non-physical effects due to illegal use. The above-mentioned uncertainties cause significant deviances in terms of certain deterministic calculations made by engineers. It is not possible to change totally these uncertainties in distribution systems that need to be removed by the utilities in accordance with the initial design calculations in an economic and exercise sense. Due to the uncertain components in the systems, the regular and controllable management activities cannot be carried out. However, it is possible to make predictions and plans by probability approaches based on historical data. The analyzes in this study are significantly useful for the utilities since it is not possible to renew in a short time the water distribution systems and to reduce the NRW amounts in the countries in which the NRW ratio are high. The NRW variable is one of the most crucial parts of water balance components including various uncertainties in accordance with the available data. The most proper PDF is considered, and the performances of each district are

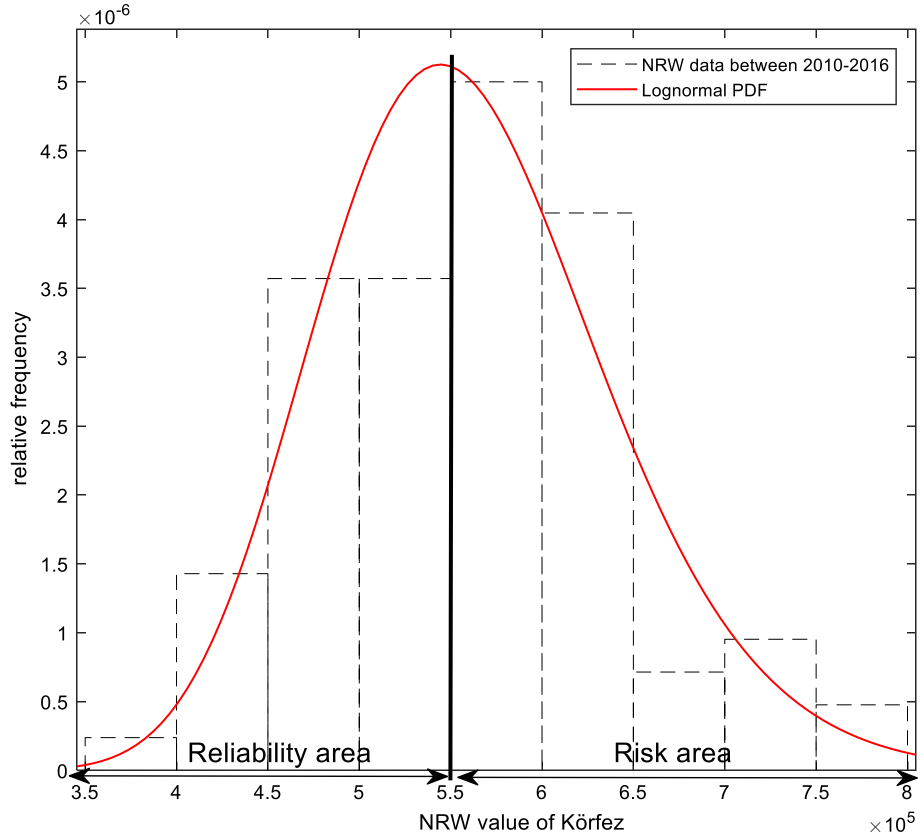


Fig. 3 Graphical representation of risk-reliability relationship

put forth through by this model based on different risk levels. With this innovative and probability-based approach, the theoretical PDFs for the NRW data are determined as an alternative to the classical analytical and numerical methods. The exceedance probabilities (risk levels) for the NRW are evaluated with the experts' view, and the performances of the districts are put forth.

For the model setting in this study, the steps below are followed respectively.

1. First, the number, n, of data is ranked from the smallest to the greatest.
2. The smallness rank, m, is determined for each value starting from the smallest to the greatest, respectively, as $m = 1, 2, \ldots, n$
3. With respect to this order, the exceedance probability for each rank is determined according to $P(X > X_m)$, which shows the exceedance probability of the variable whose sequence rank is m.

$$P\left(X > X_m\right) = (m/n + 1) \quad (3)$$

4. After determining the non-exceedance (reliability) and exceedance (risk) probabilities for each data value, the model scattering graphs are plotted by considering the variable data and exceedance/non-exceedance probabilities.
5. In the scattering graphs, the data values are represented on the horizontal axis, while exceedance (risk) or non-exceedance (reliability) probabilities on the vertical axis.
6. The scatter graphs are prepared at the proper scale with respect to the data interval of the variable and the probability of each data.
7. By using the software instructions of MATLAB, the theoretical curve that is most suitable for the scattering graphs is determined among the PDFs, Gamma, lognormal, extreme value (Gumbel), generalized extreme value (Pearson III) and Weibull by considering the least squares methodology.
8. After the theoretical PDF curves, the performances of each district reflect by the risk levels corresponding to the theoretical PDF of the monthly data. The exceedance probability values above 50% corresponding to the monthly NRWs imply that the performance is better by comparison with the past.

Results and discussion

With the help of the suggested model, under the light of explanations in the previous sections, the necessary applications are performed depending on the infrastructure quality, population density, illegal water use, meter

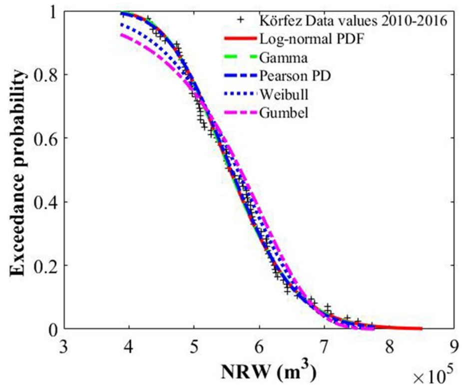


Fig. 4 NRW data exceedance probability (risk) values and theoretical PDF curves

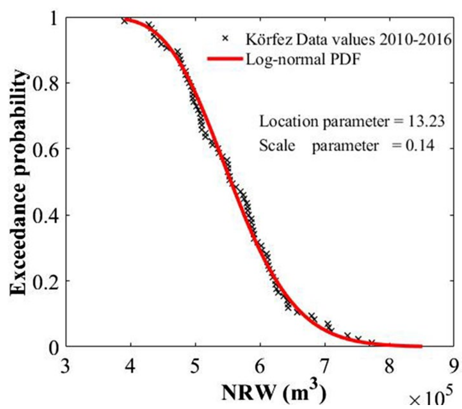


Fig. 5 NRW risk model curve for Körfez

measurement and reading errors, leakages in the transmission/distribution networks and service connections, outflows in storages and uncertainties in the NRW. The NRW amounts are analyzed according to specific exceedance probabilities or risk levels, with the methodology suggested in this study. The theoretical exceedance probabilities (risk levels) corresponding to the monthly NRW for the years 2017 and 2018 have been determined and presented in the following figures.

First of all, the five different PDFs are presented in Fig. 4 for the monthly NRW data of Körfez district in 2010–2016 time period.

Among the theoretical PDF curves, the most proper model is obtained by the log-normal PDF in Fig. 5 via the least square method. By means of this PDF, the exceedance probabilities (risk levels) are determined for the monthly data. The performances of the last two years are evaluated with the help of the model based on the seven years data between 2010 and 2016 time period. To the rightward direction of the model curves, the high levels of NRW are explained with low exceedance probabilities; to the leftward direction, the low levels of NRW are explained with high exceedance probabilities.

The exceedance probabilities corresponding to the monthly NRW amount of Körfez and the other districts are shown in the Table 1. The greatest amount of NRW measured in 2017 is in the month of July, and it corresponds to the 20% exceedance probability. On the other hand, the greatest amount of NRW in 2018 has 64% exceedance probability, in December.

The arithmetical average of the monthly NRW values has been obtained as 79% for 2017 and 91% for 2018, and an improvement (12%) has been observed in 2018 by comparison with 2017. In Table 1, the monthly exceedance probabilities are generally above 50% in 2017 and 2018. This situation demonstrates that the NRWs were improved in 2017 when compared with the years 2010–2016, and especially, in 2018. With the help of the established model, the network pressure arrangements are put into application in Körfez with renewal of the economically outworn meters with new ones, the detection of invisible malfunctions by active leakage control studies, and the positive results of the network renewal activities can be explained through the evaluation of high probability levels corresponding to the monthly NRW in recent years.

When the monthly data for the 2010–2016 time period of Kartepe are considered, it is seen that the most suitable PDF for the model is the generalized extreme value (Pearson PD) (Fig. 6); the corresponding PDF parameters are available in this figure. The exceedance probabilities of NRW in August of 2017 and 2018 are 32% and 8%, respectively, as given in Table 1, and therefore, the August performance of the district is highly weak. In 2018, the NRW consumption corresponding to the exceedance probability of 8% which was hard to achieve carried out. As a result, considering the monthly NRWs in 2017, the arithmetical average of the exceedance probabilities is at 58% level. The average of the year 2018 is almost similar to 2017 with an average of 54%. These levels indicate that the previous performance has been almost maintained. However, these levels are not satisfactory to decrease the losses and leakages, which are at the high levels in Turkey. The experts of water utilities aim to increase the performance values of consecutive years up to 90% in Kartepe in order to achieve a significant performance improvement. Certain activities such as district metered area (DMA) and pressure management system (PMS) applications have been planned in this district to reduce the losses and leakages and to remove the uncertainties.

The most proper PDF for Gebze is the Pearson (Fig. 7). The exceedance probabilities of 2017–2018 data are determined with the help of this curve as given in Table 1. When the NRW amounts are analyzed according to the lowest exceedance probability in Table 1, the greatest NRW

Table 1 Exceedance probability of Kocaeli districts

Year	Month	Exceedance probability % (Performance indicator)										
		Kandıra	Başiskele	Gölcük	Karamürsel	Derince	Dilovası	Darıca	Kartepe	Körfez	Gebze	İzmit
2017	1	91	25	47	77	41	9	70	33	42	54	96
	2	94	27	61	82	36	63	71	55	68	58	95
	3	95	27	32	34	12	58	68	58	69	61	81
	4	93	63	72	72	50	19	51	91	96	75	96
	5	93	59	52	54	11	33	76	90	89	74	91
	6	92	57	60	49	5	10	32	45	95	36	90
	7	93	70	21	63	11	13	5	47	20	56	92
	8	94	65	35	56	1	37	2	32	85	46	87
	9	97	100	100	82	93	53	30	90	100	99	99
	10	96	98	87	67	9	54	6	41	87	68	88
	11	98	90	98	72	30	43	14	74	100	91	96
	12	71	86	86	83	14	34	1	42	92	66	97
	Average	92	64	63	66	26	36	36	58	79	65	92
2018	1	98	97	99	82	55	14	39	76	100	91	99
	2	97	99	94	99	27	85	62	84	100	95	97
	3	96	99	47	65	3	22	42	51	91	40	95
	4	100	67	52	59	18	23	27	83	99	65	98
	5	95	75	56	49	29	21	27	92	99	72	98
	6	93	79	72	32	27	10	41	95	100	64	99
	7	96	82	15	99	2	10	22	35	98	24	98
	8	58	44	8	10	0	3	2	8	69	18	96
	9	63	98	98	71	54	37	94	62	100	99	100
	10	95	55	29	38	1	29	7	15	75	46	98
	11	94	82	81	56	46	64	60	26	94	88	100
	12	91	33	19	48	1	37	21	17	64	30	98
	Average	90	76	56	59	22	30	37	54	91	61	98

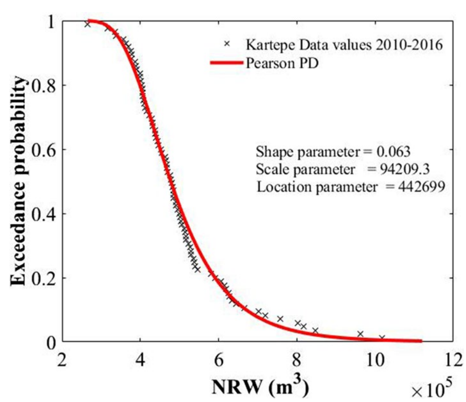


Fig. 6 NRW risk model curve for Kartepe

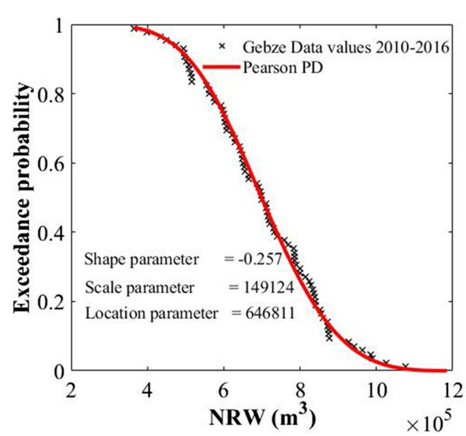


Fig. 7 NRW risk model curve for Gebze

consumption has been occurred in the June of 2017 and August of 2018. Looking at the NRW values, the September months in 2017 and 2018 are very successful in terms of management level corresponding to 99% of exceedance probability. The different probabilities emerged shortly before and after are caused by the authorized and unauthorized consumption uncertainties. The arithmetical average of the monthly data exceedance probabilities for 2017 is 65% and 61% for 2018 (see Table 1). This indicates a decreasing trend in the NRW amount of Gebze, according to the 2010–2016 data and the average of the previous years in 2017. The decrease occurred in 2018 shows a slight deterioration in performance. It is aimed to decrease the losses by taking concrete steps for physical and apparent uncertainties in the region.

The best model for the NRW data in the central district, İzmit, during 2011–2016 time period has been determined as the Gumbel distribution with two parameters as in Fig. 8. During 2017, the exceedance probabilities corresponding to the lowest NRW amount in March, August and September have been determined as 81%, 87% and 88%, respectively. In the last period, the WDS performance has been improved in the district thanks to the pressure adjustment studies in the network to reduce failures and the replacement of outworn drinking water networks and meters that have completed their economic life. When considered the performance analysis suggested in this study, it is seen that the arithmetic average of exceedance probabilities is 92% in the year of 2017 and 98% in the year of 2018. The NRW amount has achieved the best expected performance in the months of August and November of 2018 by comparison with the past performances. If the studies realized in Izmit to reduce the uncertainties are applied to the other districts, it is possible to achieve a NRW decrease under 25% throughout Kocaeli, according to the target value for 2023.

The Gamma and Pearson PDFs are used, respectively, for the districts of Kandıra and Başiskele, (Fig. 9). The means of the exceedance probabilities for Kandıra's NRW data in 2017 and 2018 are 92% and 90%, respectively. When the model graphs analyzed, it is seen that Kandıra is the second one in terms of performance following Izmit. The water demand increased excessively in this district in the months of August and September of 2018 because of the arrival of vacationers to the coastal area and significant performance decreases occurred with accrual loss for billing besides the decreasing exceedance probabilities of NRW amounts (58% and 63%). The situation has been intervened by the management by stabilizing the NRW in a short time. Although the performance of the district in question is high, certain studies should be carried out to prevent such falling effect in 2018.

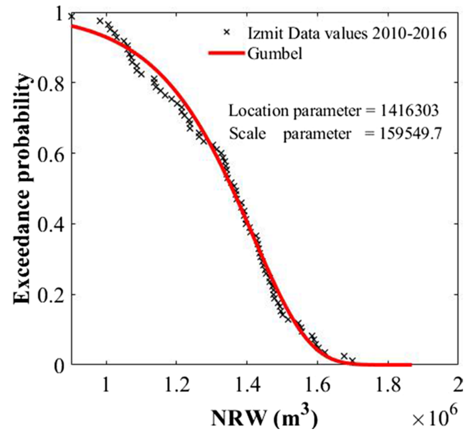


Fig. 8 NRW risk model curve for İzmit

According to the NRW risk model of Başiskele, the first quarter performance in the year of 2017 is far below the average of 50% as can be seen in Table 1; on the other hand, toward the end of the year, this level has increased to over 85% due to the precautions taken. Since, the district is generally located on a rural area and it is rapidly urbanized, the water consumption increases, new infrastructure activities gain speed and thus some fluctuations are observed in the performances as a result of the activities made throughout the year. It is predicted that the performance may increase and become more stable with these ameliorations, after the urbanization process has completed, and the water supply has reached a certain balance.

The PDF reflects the best of the seven years data belonging to the districts of Gölcük and Karamürsel (which have coasts on the Gulf of İzmit) in which Gamma and Pearson PDFs have become valid as in Fig. 10. The arithmetic average of the exceedance probabilities for the NRW amounts of these districts are 63% and 66% for 2017 and 56% and 59% for 2018, according to the model theoretical PDFs (Table 1). These performances are not at the desired level, and only indicate a little improvement when compared to the previous period. The drinking water networks of these

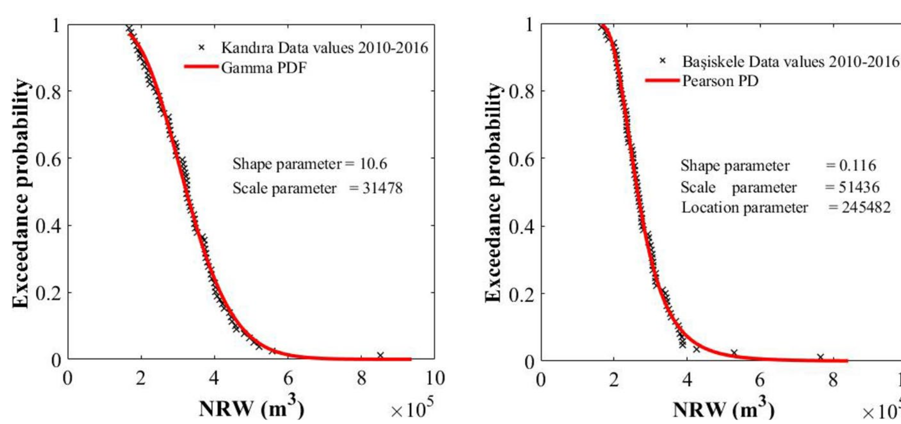


Fig. 9 NRW risk model curves for Kandıra and Başiskele

two districts are old and the physical losses are rather high. The 15% and 8% exceedance probability performances in Gölcük in the months of July and August of 2018 indicate that high NRW with low probability has taken place, and the control of NRW has become difficult. The months of July and August in the year of 2017 are the worst months of the district in comparison to the rest of the year. In order to improve the NRW performances throughout Kocaeli, it is necessary to take managerial decisions to prevent the losses especially in Gölcük and Karamürsel as can be seen in model graphs.

By using the monthly NRW amounts in 2010–2016 time period, the theoretical PDF for Derince has been determined as the Pearson NRW risk graph type with three parameters (see Fig. 11). According to this model, the NRW amount exceedance probabilities of 2017 are below the average of 50% (Table 1) except for September. The NRW amount of August corresponds to 1%. This average indicates that the district has extremely low levels in terms of NRW. When the Table 1 created in accordance with the model and 2017–2018 data is analyzed, it is seen that a similar situation also continues in 2018 time period. Particularly, the performance in the months of August, October and December is very poor. The district general performance in the year of 2018 is worse than 2017 time period as can been seen in Table 1. This indicates the urgent need for amelioration and investment. It is known that the infrastructure of this district is quite old. In order to decrease the losses, the studies on partial network renewal, district metered area and pressure management system applications should be carried out. Another district in Fig. 11, Dilovası, has the Gamma PDF that best represents the NRWs in the Table 1. The arithmetical averages of the exceedance probabilities are 36% for 2017 and 30% for 2018. The average under 50% demonstrates that the performance has deteriorated according to the years based on model installation. Despite the improvement activities, it is seen that the existing situation has not maintained. When the experts are consulted about this issue, it is stated that the district mains break down very often and consequently significant water losses emerge. However, the performance level can be raised through activities decreasing the physical water losses.

The Pearson PDF model developed by using the data of Darıca district in 2010–2016 is given in Fig. 12 and Table 1. The performance in the months of July, August, October and December of 2017 is quite low by comparison with 2010–2016 time period. The NRW amount corresponding to the exceedance probability (risk) average of 1% in December is quite high. The exceedance probabilities in the months of August and October of 2018 demonstrate that any precaution has not been taken. The exceedance probabilities in 2017

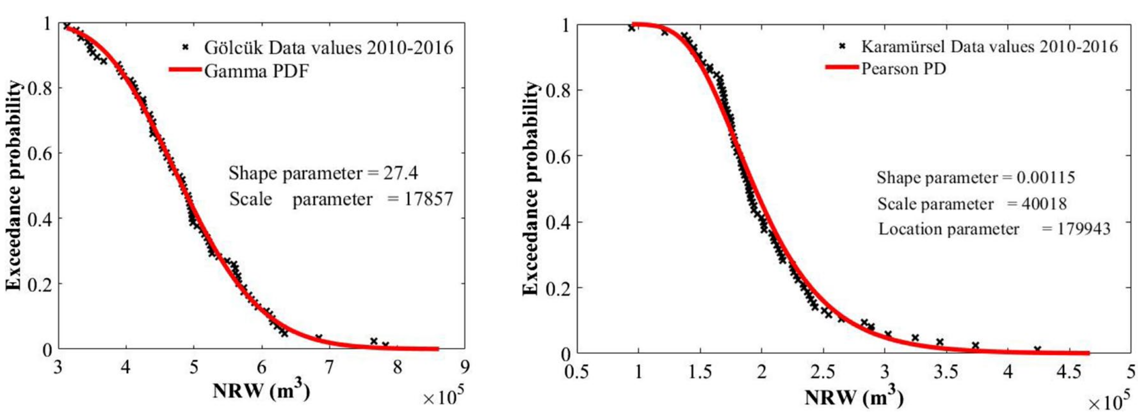
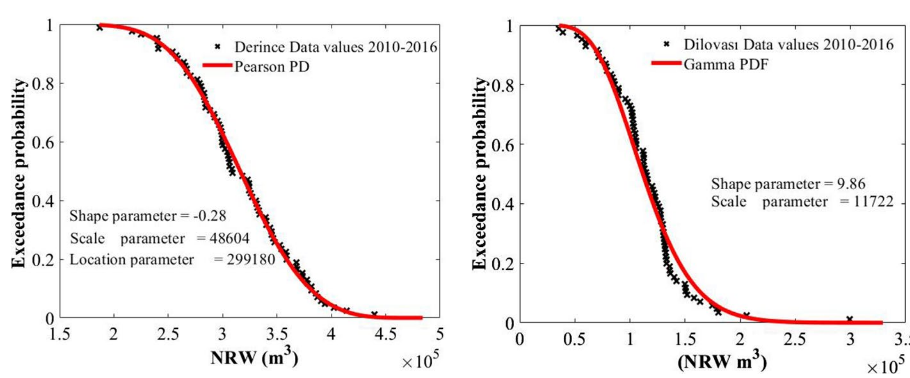


Fig. 10 NRW risk model curves for Gölcük and Karamürsel

Fig. 11 NRW risk model curves for Derince and Dilovası



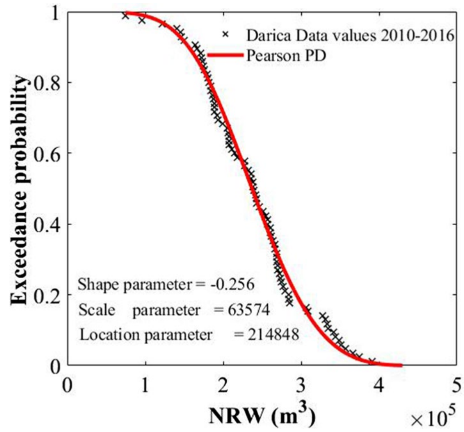


Fig. 12 NRW risk model curve for Darıca

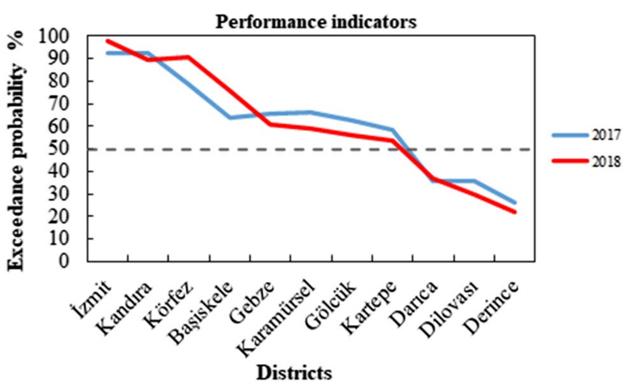


Fig. 13 Performance indicators of districts in Kocaeli

and 2018 are, respectively, 36% and 37%. The levels below the 50% risk average means the situation is getting worse. It is clear according to the model that this district should be monitored closely for reducing NRW amounts.

The 2017–2018 average performances of each district in Kocaeli according to the all model results in Table 1 are presented in Fig. 13. The evaluations are obtained in every district by considering the 50% average risk level. The performances of Derince, Dilovası and Darıca in 2017 and 2018 time period are low according to this average. The performances of Gölcük, Karamürsel, Kartepe and Gebze are not at the expected levels, although they are above the average risk level. In addition, the performance in the year of 2018 is lower than 2017. The performances of Başiskele and Körfez have improved in 2018 by comparison with 2017. Körfez, Kandıra and İzmit can be considered as the best three districts in accordance with the 50% risk level. İzmit has the best performance among the other districts according to the previous years. To control the NRW and to decrease the uncertainties in the variables, the physical and apparent loss activities in İzmit should be taken as an example by the other districts.

Furthermore, when Table 1 is analyzed in detail, the performance of Kartepe that is below 50% average in recent months should be questioned. On the other hand, Gebze shows a decreasing performance with ups and downs. A downward trend has occurred in the improving performance of Körfez in recent months. Although the performance of Kandıra is above the 90% average, the decrease in the months of August and September of 2018 is remarkable. Başiskele has shown a significant progress by carrying its performance to the average about 90%, which was around 20% previously, but its performance is not stable. The NRW reduction should be supported by a high and stable performance. Although the performance of Karamürsel is above the 50% average, it has declined to 59% with a 7 point decrease. As regards to Körfez district, it has achieved to increase its performance by 100% performance level four times. The NRW rates of İzmit are more stable than the other districts.

Conclusion

Reducing high levels of NRW is one of the most important issues waiting for solution especially in water scarce countries. Due to the studies made on reducing high levels of NRW require significant investments, they cause economic difficulties for water utilities. In addition, the failure to take accurate managerial decisions leads to increased operating costs, reduced service quality, a budget deficit and a negative impact on future regional investments. For this reason, it is quite important for underdeveloped countries including Turkey to analyze and interpret accurately the NRW with a variety of uncertainties by water utilities and specially to determine and evaluate the NRW performance.

The NRW performances in districts of Kocaeli have been analyzed through the probabilistic model suggested within the framework of this study with the help of water supply and accrual data. The developed model makes it easy to determine the performance of operated network without the need for detailed network information. In addition, the performances of all water utilities can be compared with each other through the model. Thanks to the existing data on reducing the NRW, the relationship between performance and improvement criteria can be analyzed and interpreted easily, and this may also create the basis of further studies. According to the model results, the required investments should be prioritized to achieve specific strategic goals in the light of accurate managerial decisions for reducing NRW amount. In conclusion, the studies on replacement of old meters, and the district metered area and pressure management system applications performed in Izmit, the district with the best performance according to the model results, should be implemented in other districts in accordance with their performance by taking the budget possibilities into account.

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