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ORIGINAL PAPER

Water Pipe Networks Performance Assessment: Benchmarking Eight Cases Across the EU Mediterranean Basin

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Abstract The high level of the non-revenue water (NRW: water not generating revenues) is a well-acknowledged problem water utilities are straggling with in areas facing water scarcity. High NRW values jeopardize the sustainability of water utilities, especially in cases, where these values exceed 50 % of the System Input Volume. WATERLOSS project developed a Decision Support System to help water utility managers design the most effective/efficient NRW reduction strategy. The project's first step was to evaluate the performance of the water distribution systems selected as case studies. The paper presents the respective results of eight cases from Cyprus, Greece, Italy, France and Spain, based on a modified International Water Association Water Balance adapted to the water pricing practices met across the Mediterranean (high Fixed Charge included in the water tariffs). The results revealed that although almost all cases experience high NRW levels, the high Fixed Charge reduces the actual revenue losses, thus providing a perfect excuse to the managers of the local water utilities do almost nothing to address the actual extent of the NRW problem in their systems.

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Introduction

Non-Revenue Water (NRW: water not generating revenues) consists of the water losses (real and apparent ones) and the unbilled authorized water use. The NRW is one of the primary problems water utilities are facing today. The situation becomes even worse in countries facing water scarcity conditions, such as the Mediterranean basin countries, where NRW levels exceed 50 % of the water entering the water distribution systems (WDSs). NRW results not only to water, but also revenues and energy losses. It is important to realise that every WDS has two kinds of consumers: the people consuming water and the water network itself. The latter actually represents the major water user due to the water losses due to leaks and breaks occurring that may exceed even 50 % of the total water volume entering the system. Most of the water utilities managers have not realized how important the NRW problem is. Globally one third of the total water abstracted from its resources aimed to be used for drinking, is being lost along the "supply chain" due to leaks and breaks (Liemberger et al. 2007). This is actually more than 32 billion m^3 of treated water. At the same time, 16 billion m^3 reach the customers' taps each year but are not being invoiced due to theft, poor metering, or corruption. In some low-income countries the NRW value gets as high as 50–60 % of the system input volume (SIV). A conservative estimate of the NRW-related annual cost to water utilities worldwide exceeds US $14 billion. A water utility manager should realise that before searching for new water resources and designing new water transfer plans, he must minimize water losses occurring in his network, pursuing "water use efficiency and reciprocity". Water use efficiency refers to the minimisation of the water volume being lost and serves as an environmental indicator of system's efficiency. In that case water theft is not considered water loss, as it is finally being used, even not in a conservative manner, as it is free of charge (even though someone may argue that this "water use" may be a conservative one as the water thieve tries to steal only the water volume he needs as fast as possible in order to minimize the possibility to be detected and caught). Water use reciprocity refers to the minimisation of the NRW related revenues losses. In that case water theft is considered water being lost. In the bottom line NRW prevents the water utility manager from implementing a (more) socially fair water tariff as he has to pursuit his utility's sustainability by recovering part of the NRW-related money losses (in terms either of the money spent for the water to enter the network, but finally lost due to leaks/breaks, or of the revenue losses due to water volume failed to be sold/invoiced), through the price of the water finally sold to the customers. The problem will get even worse for the customers, as the EU Water Framework Directive 2000/60/EC "forces" water utilities to implement appropriate pricing policies to recover the full cost of the water services (direct; environmental and natural resource costs). Thus, the NRW becomes even more "expensive" to the water utility and finally to its customers. The need to apply effective and socially fair water prices becomes today one of the water utilities' top priorities, due also to the stressful financial environment.

The first step to confront NRW is to evaluate the performance of the WDS. The present paper presents the respective results from eight WDS in the Mediterranean. The final goal is to identify their common characteristics trying to develop a strategy for NRW reduction, addressing the limitations, acknowledging the challenges, and making gradual improvements to current policies/practices.

Literature Review

As already mentioned, NRW includes the unbilled (metered and unmetered) water use and the water losses distinguished in apparent losses (AL) and real losses (RL). AL main components are the illegal use (water theft); billing/data-handling/and metering errors (Rizzo and Cilia 2005). Field studies proved that AL may range from 1 (Australia) to 9 % (Korea and Malaysia) of the SIV (Lambert 2002). According to Criminisi et al. (2009), although water metering errors are usually considered responsible for the largest amount of AL, they are too difficult to be precisely quantified. Nevertheless there are cases where water theft is the main AL component (e.g. in Africa) (McKenzie et al. 2007). According to Arregui et al. (2006) the key factors affecting water metering errors, include the choice of the meters' appropriate type (volumetric vs. flow meters); their correct sizing; proper installation; and how frequently they are being replaced by the Water Utility. Additionally the key factors for meter under-registration include: water consumption patterns; velocity profile; seasonal water use; water quality; environment conditions; mounting position; and tampering. As water metering errors depend on the flow rate, it is important to know the water use pattern and the specifications of the meter (e.g. metering threshold; sensitivity) at different flow rates (Male et al. 1985; Fereol 2005; Arregui et al. 2006). Different studies revealed that a water meter's economic life lies between five and ten years (Lambert 2002). Criminisi et al. (2009) proved that AL rapidly increases as the meter ages and their value increases by 15–40 % when private water tanks (usually fed by a float valve) exist. Rizzo et al. (2007) suggested that several measures forming an integrated strategy should be applied to tackle AL.

RL consist of water losses due to leaks/breaks/tanks' overflows. According to Lambert (2002), RL include the background leakage (flow rate $< 0.5\text{m}^3$/h) and the reported and unreported leaks and bursts. RL size can be assessed through figuring the system's WB; applying component analysis; and night flow analysis (NFA) (Lambert 2002). Component analysis and water practitioners' experience revealed that in well operated systems RL mainly occur in service connections rather than in water mains (Lambert and Morrison 1996). Thornton (2002) and Farley and Trow (2003) stated that leakage in a WDS can be determined using field studies concepts of yearly WB and Minimum Night Flow assessments, possibly in combination with background and bursts estimates (BABE). Tabesh et al. (2009) claimed that to determine unreported bursts, expensive methodologies based on active leakage control (ALC) techniques are needed. They also determined that all NRW components use real and estimated data and presented a new methodology for leak detection (in pipes/nodes), using a hydraulic simulation model by dividing the total water use in a pressure dependent part and an independent one. Almandoz et al. (2005) developed a methodology for RL evaluation: AL were considered as non-metered use (called "uncontrolled water") depending on the water use patterns, while RL were considered to be pressure dependent (in certain parts of the WDS). Obradovic (2000) strongly stated that the WDS should be well modelled to safely assess its water losses. The main aspect is that although both water demand and water losses depend on the operating pressure, as the relationship between them is not yet determined, this problem needs to be solved first (Kanakoudis and Tsitsifli 2010).

Methodology

To evaluate the performance of a WDS, the water balance (WB) figuring methodology is usually used (Fig. 1). It con-

<table>
<tr><th colspan="5">IWA Standard International WB (Lambert et al. 1999)</th><th>1st modification (McKenzie et al. 2007)</th><th>2nd modification (Kanakoudis & Tsitsifli 2010)</th></tr>
<tr><td rowspan="7">System Input Volume</td><td rowspan="4">Authorized Use</td><td rowspan="2">Billed Authorized Use</td><td>Billed Metered Use</td><td rowspan="2">Revenue Water</td><td>Water billed and paid for (Free Basic)</td><td>Revenue Water</td></tr>
<tr><td>Billed Unmetered Use</td><td>Water billed but NOT PAID for (apparent NRW)</td><td>Water billed but NOT PAID for (apparent NRW)</td></tr>
<tr><td rowspan="2">Unbilled Authorized Use</td><td>Unbilled Metered Use</td><td rowspan="5">Non Revenue Water (NRW)</td><td rowspan="5">Water not being sold (Non-Revenue Water/real NRW)</td><td rowspan="4">Accounted for Non Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Use</td></tr>
<tr><td rowspan="3">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Use</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td colspan="2">Real Losses</td><td>Water generating revenues although not used(Minimum Charge Difference)</td></tr>
</table>

Fig. 1 The IWA standard international water balance and its modifications

sists of the Standard International Water Balance (Lambert et al. 1999) and a set of 170 performance indicators (PIs) (both launched by the International Water Association (IWA) used to monitor the WDS performance level and check the impact of the measures taken (Alegre et al. 2006). The PIs inventory includes six groups: water resources (WR)/4PIs; personnel (Pe)/26PIs; quality of service (QS)/34PIs; operational status (Op)/44PIs; physical status (Ph)/15PIs; and economic/financial status (FI)/47PIs. The PIs aim to assist a water operator monitor the performance of its WDS, benchmark it with other WDSs and check the impact of the measures taken. Water operators should choose the PIs they actually need, following the super-market approach. To calculate the 170 IWA PIs, 232 variables need to be measured in the field.

The WB had to be modified to satisfy local conditions met during the performance evaluation process in different areas of the World. The first modification was proposed by McKenzie et al. (2007), introducing the water volume being charged but not paid for (Non-Recovered) (Fig. 1). This endeavour introduced for the first time the economic dimension of the volumetric IWA WB. In 2010, Kanakoudis and Tsitsifli introduced the 2nd modification (Fig. 1), focusing on a weird water pricing policy adopted by water utilities located across the EU Mediterranean basin. This pricing practice includes a fixed charge, expressed either as a minimum water use (m^3) or as a minimum water charge (€). The former is charged, whenever the customer's actual water use is less than this "minimum use", while the latter is charged regardless of the customer's actual water use (considered thus as an extra charge). To deal with the water volume charged without being actually used, a new element was added in the WB, named "Minimum charge difference (MCD)" or water losses generating revenues (Fig. 1). Such a pricing policy results in underestimating the actual NRW level, since the water utility recovers part of the NRW-related revenues lost (Kanakoudis et al. 2013a). Thus, the water utility does not care enough to reduce its water losses level. If the fixed charge is expressed as a minimum water use, then the MCD equals the difference between the water volume charged and what actually recorded by the water meter. If the fixed charge is expressed as a money charge (in €), then the MCD is the equivalent water volume, that if sold (on net water price, excluding the fixed costs) would have resulted in the same revenues (in €). This (monthly) fixed charge varies from country to country and even within the same country (e.g. 2–5€ in Greece; 4–7€ in France; 5–9€ in Spain; 6–8€ in Italy). In those cases, to transform the MCD from € to water volume (m^3), the mean water unit price is used (water related revenues divided by the water volume sold). Water utilities adopt the minimum charge concept in their effort to balance revenues and costs. However, this process offers them an excuse to avoid investing in NRW reduction measures to reduce water losses levels. The MCD (in m^3) although providing revenues, should be considered water being lost. Whenever a water manager forms the WB of its system to assess its status includes the minimum charge related revenues to those coming from water actually used. This practice, although resulting in reduced NRW-related revenue losses, does not reduce the actual NRW level.

Brief Presentation of the Case Studies from the EU Mediterranean Area Selected

Basic Characteristics

Eight cases from the EU-Mediterranean basin were selected (i.e. four from France; one from Spain; one from Greece; one from Italy; and one from Cyprus) (Kanakoudis et al. 2013b) (Table 1). All of them were identified by the partners of MED project called WATERLOSS (2G-MED09-445) that finally developed a Decision Support System to prioritize NRW reduction measures with special focus on the Mediterranean area. Although some of the WDS selected were more advanced (e.g. Nicosia) regarding the NRW management techniques applied, they all proportionally faced high NRW and water losses values. Their characteristics, operating status and problems were identified (Tables 1, 2)

Table 1 Pilot cases characteristics; operating status and monitoring

Pilot case	Population served	Connections number	Total area (Km^2)	Pipes length (Km)	Mean altitude (m)	Mean pressure (atm)	SCADA system	Pressure zones	DMAs	Simulation software	GIS
Baho (FR)	7,041	1,300	7.9	16.73	50	2.96	Storage tank level	No	No	EPANET	No
Argeles-sur-mer (FR)	10,082/ winter; 100,000/ summer	6,581	58.7	135.77	15	2.96	"WIT" is used. Monitors production, storage, and pumping systems	2	In 90 % of the network	No	Yes
Thuir (FR)	7,519	3,257	19.9	66.70	180	3.00	Monitors 4 meters (production & distribution)	No	No	No	Yes
Castellbisbal (ES)	12,223	3,531	31.0	143.00	132	5.50	2 systems monitoring the water treatment plant and the network	Yes	13	EPANET	No
Kozani (EL)	35,942	9,150	7.99	129.58	750	3–5	Monitors water use, pumping stations. 12 out of 42 stations are functioning	3	No	EPANET	Yes
Melito di Napoli (IT)	34,500	11,700	3.7	95.00	93	1.5–2	No	Yes	7	No	Yes
Nicosia (CY)	223,640	65,094	90.0	1,330.00	120–295	3.5	Monitors flow; pressure; MNF	69	25	No	No
SIEL (FR)	8,003	3,663	5.71	110	11–390	3.5	Monitors night flows daily; leakage detection	No	Yes	No	Yes

Performance Assessment and Missing Data Problem Handling

The second modification of the IWA WB was used to assess the performance level of the eight case water networks. The analysis was performed: a) annually for all cases; and b) per semester for the cases of Argeles and Melito di Napoli. The time period used for the analysis was based on the data availability and the billing periods adopted by the local water utilities. Additionally, Argeles case presents high water demand peaks during summer, since it is a famous summer resort. Kanakoudis and Tsitsifli (2013) proved that in such cases the WB should be assessed in smaller time periods than once a year, to pinpoint the water losses actual peak values and time occurrence, especially when the network is not being regularly monitored. As all eight water utilities include in their water tariffs the fixed charge expressed in Euros (€), the MCD was calculated based on the mean water unit price. The analysis included also the calculation of the infrastructure leakage index (ILI) value for each case network.

During the WB assessment the usual problem of missing data arose. This is a common problem met in the majority of the EU water utilities located across the Mediterranean. It must be pointed out that WATERLOSS project main task was to estimate the NRW overall size for the eight case studies. This was actually the first time a water balance was figured out for each of these networks. The next step was to define, where possible, the NRW components, applying either the top-down or the bottom-up approach, based preferably on field data. In cases where such data was missing, the gap was "filled" by assumptions made based either on the water operators' experience or on values found in the international literature. WATERLOSS defined where specific actions (i.e. field measurements; laboratory tests) should take place to verify/modify the assumptions made. The actual application of these actions was not part of the project that tried to convince water managers about the high NRW values their systems are struggling with, and that they should stop avoiding the problem just because they recover a big part of the NRW related revenue losses through the MCD.

The missing data had to do with the: unbilled unmetered water use; unauthorized water use; water meter/ metering errors; and water billed but not paid for (Table 3). Tips and tricks were used to overcome this problem (Tsitsifli and Kanakoudis 2009), based on the international literature (Kanakoudis 2004; Georgiadis and Kanellopoulou 2008) and the water utilities' personnel experience (Table 3). Using Farley and Trow (2003) field studies' results, the Unbilled unmetered water use level, was assumed to be a small portion of the SIV in all cases except from Kozani where the local water utility estimated this water use to be as much as

Table 2 Problems faced in each case and their causes

Case		Low storage capacity	Pipes (mains) failures	Pressure problems	Water quality problems	High leakage rates	High MNF levels	High NRW levels	Software controlling DMAs operational problem	Meters under-registration
Baho	Problem	√	√							
Argeles-sur-mer	Problem	√		√	√	√				
	Cause	Lack of water resources		Lack of water resources	Water works	dioxide chlorine treatment disinfection; poor installation conditions				
Thuir	Problem		√			√				√
	Cause		Bad network; Premature aging			Bad network; Premature aging				Meters age> 10 years
Nicosia	Problem					√	√	√		
	Cause					Water mains age; soil type	High pressure; intermittent supply; service connections failures			
Castellbisbal	Problem				√				√	
	Cause				Poor pipes drain system				Transmission signal problems	
Kozani	Problem							√		
	Cause							Old & non registered networks; illegal connections; flow meters failures; non existing maintenance policy		
Melito di Napoli	Problem					√		√		
	Cause					Pipes aging; pressure transients effects		Unauthorized consumption		
SIEL	Problem		√					√		
	Cause		Overpressure; pumping station defects					Taxation system; sold water not charged		

Table 3 Data availability and assumptions made

Pilot case	Unbilled unmetered consumption		Unauthorized consumption		Meter/metering errors		Water billed but not paid for	
	Data availability	Assumption	Data availability	Assumption	Data availability	Assumption	Data availability	Assumption
Baho (FR)	Yes	-	No	1 % of SIV	No	5 % of the billed authorized water use	Yes	-
Argeles-sur-mer (FR)	Yes	-	No	10,000 m^3 (per year); 3,000 (winter); 7,000 (summer)	No	5 % of the billed authorized water use	No	Zero
Thuir (FR)	No	2,655 m^3	No	0	No	11,300 m^3	Yes	-
Castellbisbal (ES)	No	0.4 % of SIV	No	0.4 % of SIV	No	1.2 % of SIV	Yes	-
Kozani (EL)	No	2 % of SIV	No	1 % of SIV	No	10 % of billed metered cons.	Yes	-
Melito di Napoli (IT)	No	0.5 % of SIV	No	0.5 % of SIV	No	2 % of SIV	Yes	-
Nicosia (CY)	Yes	-	No	0.5 % of SIV	No	2 % of SIV	Yes	-
SIEL (FR)	No	107,000 m^3	No	3,500 m^3	No	51,747 m^3	No	40,000 m^3

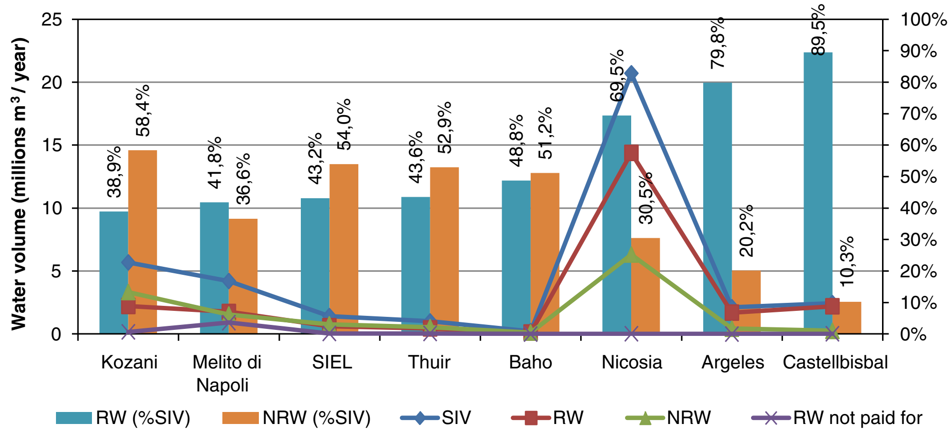
2 % of the SIV. The unauthorized water use level estimations varied amongst cases studied worldwide. Kanakoudis (2004) claimed that based on pilot field studies (surveillance) the water theft level in Athens (Greek capital) network was estimated as 1 % of the SIV, complying with Farley and Trow (2003) who accepted this value as an upper limit. In WATERLOSS project, the water utilities' practitioners were the ones defining the water theft % SIV they have to fight with. They all claimed that this figure was not arbitrarily selected, but was based on network surveillance results. Only in the cases of Argeles and SIEL the water theft was provided as a specific figure in m^3. Regarding the estimation of the water meters' and metering errors level, the local water utilities provided quite different kinds of data. Thuir and Siel defined it as a specific figure in m^3; Castelbisbal, Melito di Napoli and Nicosia claimed that it ranges between 1.2–2 % of the SIV; Baho and Argeles estimated it to be as much as 5 % of the billed authorized consumption; while Kozani stated that it reaches 10 % of the billed metered consumption. They all claimed that the figures provided were based on pilot laboratory tests results (applied regularly like in Nicosia or occasionally like in Kozani) involving at least 1 % of the customers' total water meters installed. As more details were not provided to fully back those statements, the authors believe that the different figures provided were based more on the water meters age and replacement policy, instead of regular testing them (except from Nicosia that provided solid proofs). Finally, regarding the water volume billed but not paid for, all water utilities involved provided solid data, apart from SIEL and Argeles that just estimated it. In any case, the results should be considered as rough ones.

Results and Discussion

The NRW annual level ranges from a too low 10.3 % (Castelbisbal) to an outstanding 58.4 % of the SIV (Kozani) (Fig. 2). Real Losses (RL) are NRW major part, ranging from 73.8 % (Castelbisbal) to a huge 97.3 % (Kozani), while at the same time the AL level ranges from 2.1 % to 22.1 % of the NRW, and the Unbilled Authorised Consumption (UnBAC) level ranges from 0.1 % (Nicosia) to 14.0 % (SIEL) of the NRW (Fig. 3). The ILI values prove the impact of the RL, revealing that in Castellbisbal the Current Annual Real Losses are just almost two times bigger than the Unavoidable Annual Real Losses, while in Kozani are almost 18 times bigger (Fig. 4). Based on the World Bank Physical Loss Assessment Matrix (Liemberger et al. 2007), Kozani, Thuir and Melito di Napoli were classified to group D; Baho to C; Argeles to B; and Castelbisbal to A. Kanakoudis and Tsitsifli (2013) applied a sensitivity analysis revealing that the AL level is strongly being affected by the water meter inaccuracy level. The Unbilled authorized consumption does not seriously affect the results. WATERLOSS project attempted to make water operators realise how big the NRW problem is in their cases and motivate them to take the appropriate actions.

What the specific water operators have chosen to do is to recover part of the NRW-related lost revenues through the fixed charge included in the water tariffs, underestimating the actual problem. Thus, in all eight cases the MCD value ranges from 8.5 % (Thuir) to 40.6 % (Kozani) of the SIV (Fig. 5), being quite a big part of the NRW ranging from 16.0 % (Thuir) to 263.8 % (Castellbisbal) (Fig. 6). Espe-

Fig. 2 SIV, Revenue Water (RW), NRW and RW not paid for



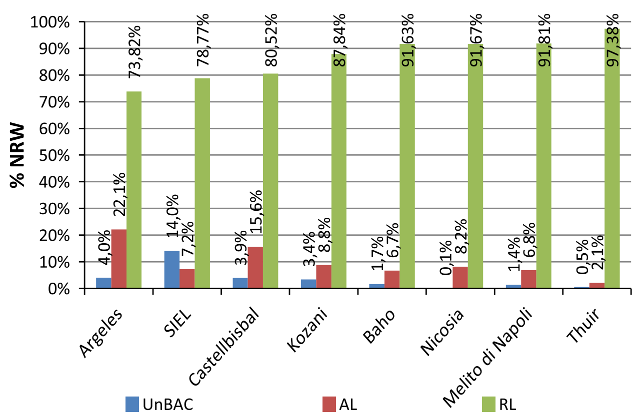


Fig. 3 NRW components

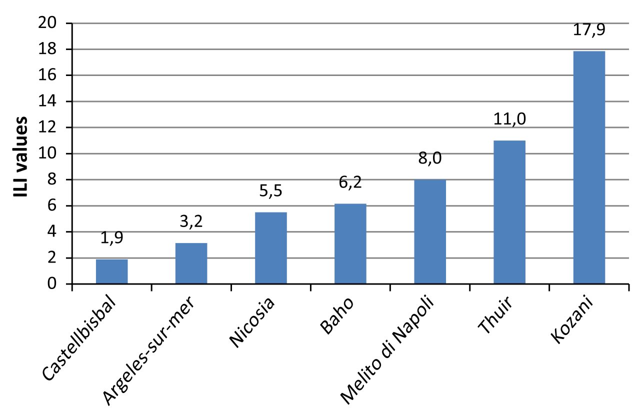


Fig. 4 ILI values for the seven WDS (2010)

cially Castellbisbal water utility recovers more than the actual NRW-related lost revenues through the fixed charge imposed, indicating that the latter is mainly used to balance the utility's expenses. The Accounted for NRW value shows what the water utility perceive as the NRW-related revenue losses not being recovered at the end of the day. In all cases the actual NRW values are higher than the perceived ones by 20–287 %! This is of course one good reason for water utility managers to postpone the adoption of any NRW reduction measures and strategies. The fixed charge included in the water tariffs should be just equal to the water access/opportunity cost, not related to the actual water consumption. Any other additional cost burdening the fixed charge size, that is water-use size dependent should be directly included in the unit water cost (for each scale of consumption). As such data was not available, a more detailed research is needed. Furthermore, it is commonly accepted that new water tariffs have to be designed, to comply with the WFD 2000/60/EC obligation on water services' full cost recovery, remaining at the same time socially fair, respecting the stressful financial conditions the whole world is facing today.

Kanakoudis and Tsitsifli (2013) proved that the WB time period analysis should follow the billing period adopted by the water utility, especially in cases with significant seasonal water demand peaks. Thus, as Argeles-sur-mer is a famous summer resort in France, the analysis was performed twice a year following the local billing practice. RL (and consequently the NRW) values were higher during the first semester (winter) compared to the second one (summer) (Fig. 7). This was expected as RL get higher during winter, when the operating pressure increases due to the reduced water demand. This is common in water utilities experiencing seasonal water demand peaks, and pressure is not being properly adjusted (Kanakoudis and Tsitsifli 2013). To check the results in other non-touristic areas like Kozani and Castellbisbal, the WB analysis was performed per 4 months (Fig. 8a,b). As expected, negligible differences were observed in water supply and demand volumes. Also, the RL values do not significantly vary from one period to the other.

Conclusions

High NRW levels jeopardize the water utilities sustainability since water, revenues and energy are being lost. High leakage levels are often responsible for more than 25 % of the total energy use. Energy use savings might reach up

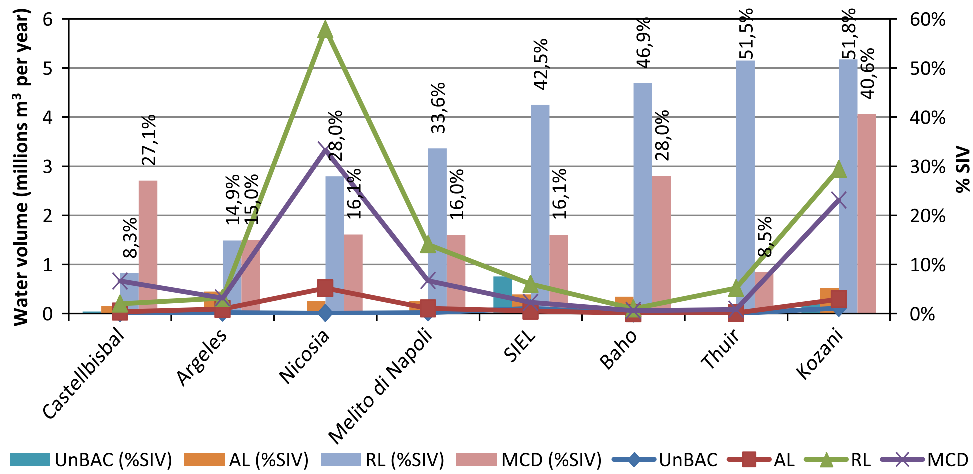


Fig. 5 NRW components and MCD

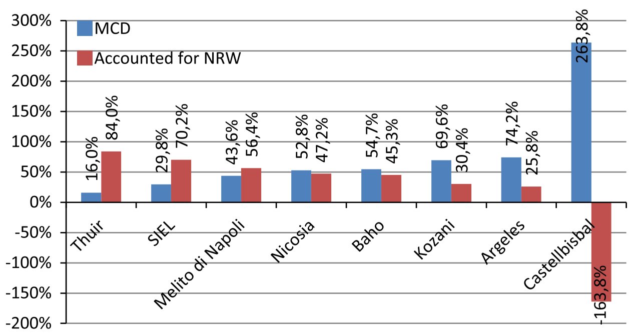


Fig. 6 MCD and accounted for NRW as % of the NRW

to 20–30 % (Feldman 2009). The first step towards NRW reduction is to evaluate the performance level of the water network. This can be done using the IWA Water Balance assessment methodology. The paper compares the respective results from eight water pipe networks (pilot cases of WATERLOSS project) from five Mediterranean countries (i.e. France, Spain, Greece, Cyprus and Italy). The second modification of the IWA WB was applied to consider also the impact of the MCD component, a predominant water pricing practice in the specific area. The WB analysis was annually performed for all eight WDSs, while in some cases (when data was available) it was carried out for periods shorter than 1 year (4 and 6 monthly). The analysis revealed some common aspects. Although NRW is accurately assessed, its components can only be roughly estimated. This is because full data sets necessary to assess specific WB components are not available, something common in several water utilities. Assumptions had to be made to have a rough idea of the impact of RL, AL and Unbilled authorized use to NRW. Unavailable data include unbilled authorized use, unauthorized use, customer meter/metering inaccuracies and water billed but not paid for. These water volumes need to be metered and registered by the water utilities in charge. High NRW values were met in most of the pilot cases ranging from 10.27 to 58.35 % of the SIV. The analysis verified that water utilities implementing measures on network monitoring, sim-

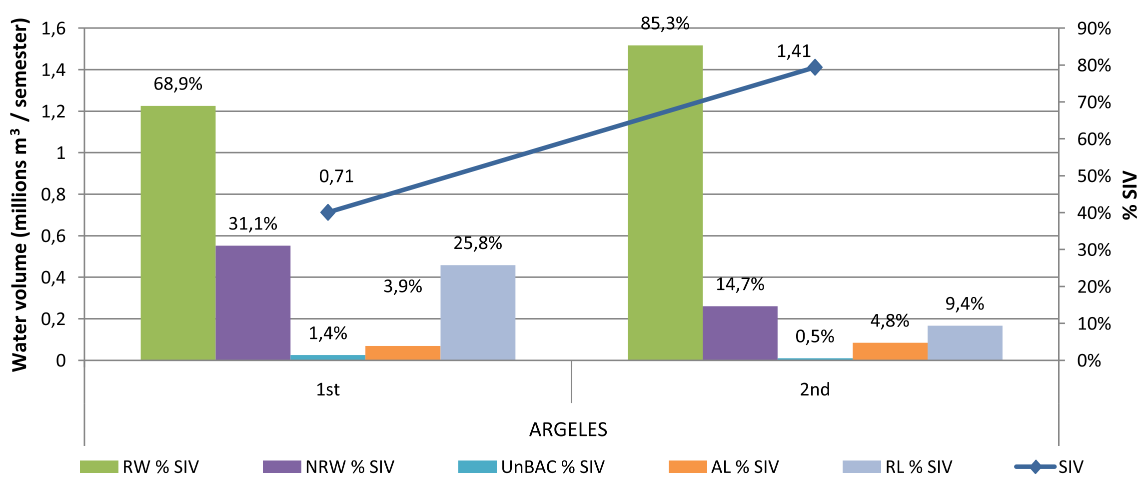


Fig. 7 WB components per semester analysis (revenue water (RW); NRW; unbilled authorized consumption (UnBAC); apparent losses (AL); and real losses (RL)) for Argeles

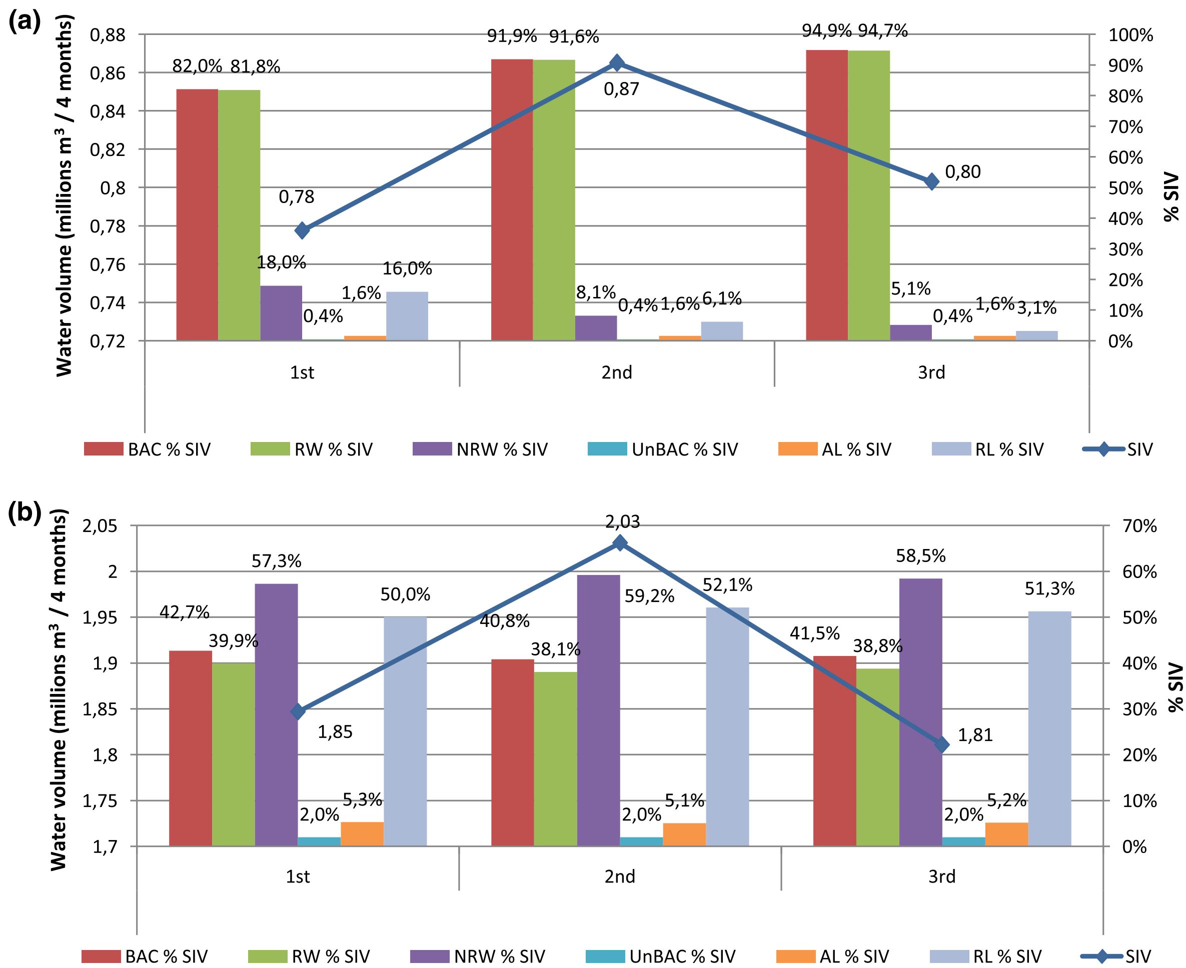


Fig. 8 WB components per 4 months analysis (billed authorized consumption (BAC); revenue water (RW); NRW; unbilled authorized consumption (UnBAC); apparent losses (AL); and real losses (RL)) for: **a** Castellbisbal and **b** Kozani

ulation and leakage reduction have lower NRW values (e.g. Argeles case). In Castellbisbal 70 % of the water used serves the industry. Nicosia is also struggling to reduce its NRW levels, especially after the water intermittent supply period (2007–2008). Back then water was supplied only for 12 h every 2 days due to extremely severe water shortage Cyprus was facing. Real losses were the main NRW component in all eight cases. Therefore the principal NRW reduction strategies should focus on RL reduction. All eight water utilities impose high fixed charge values, to balance their expenses, indicating that the fixed charge billing practice is common in the Mediterranean area. Such pricing policies result in high MCD values, recovering most of the NRW, thus providing a good excuse for water utilities to do nothing to reduce the NRW. It was quite astonishing that in Castellbisbal MCD exceeded NRW, resulting in negative 'accounted for NRW' values. The redesign of the water pricing policies is necessary, to fulfill the WFD obligation towards the recovery of the water services full water cost and to implement socially fair water tariffs. The analysis verified that when significant seasonal peaks occur regarding the water demand, the WB analysis should be performed in smaller time periods than once a year, to study the exact leakage timing occurrence, as Kanakoudis and Tsitsifli (2013) proposed. The performance evaluation of the eight WDSs revealed the magnitude of the NRW problem in water utilities and the reason why water operators do not manage it. This was also one of WATERLOSS project targets: to convince water operators that they should take actions to reduce NRW and stop underestimating it as they recover a big part of it through the MCD.

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References

Alegre H, Baptista J, Cabrera EJr, Cubillo F, Duarte P, Hirner W, Merkel W, Parena R (2006) Performance Indicators for Water Supply Services. 2nd Edition, IWAp., London, UK

Almandoz J, Cabrera E, Arregui F, Cobacho R (2005) Leakage assessment through water distribution network simulation. Water Resour Plan Manage 131:458–66

Arregui F, Cabrera E, Cobacho R, Garcia-Serra J (2006) Reducing apparent losses caused by meters inaccuracies. Water Pract Technol doi:10.2166/wpt.2006.0093

Criminisi A, Fontanazza CM, Freni G, Loggi GL (2009) Evaluation of the apparent losses caused by water meter under-registration in intermittent water supply. Water Sci Technol 60:2373–82

Farley M, Trow S (2003) Losses in water distribution networks: a practitioner's guide to assessment, monitoring and control. IWA, London

Feldman M (2009), Aspects of energy efficiency in water supply systems. In: International conference on the waterloss, IWA, Cape Town, pp 26–30 April 2009

Fereol E (2005) How to measure and reduce water meter park inefficiency? In: International conference on the leakage, IWA, Halifax, September 2005

Georgiadis S, Kanellopoulou S (2008) Pressure management in the water supply network of Athens, Greece. In: International conference on the world water congress, IWA, Vienna

Kanakoudis V (2004) A troubleshooting manual for handling operational problems in water pipe networks. Water Supply Res Technol AQUA 53:109–24

Kanakoudis V, Tsitsifli S (2010) Water volume vs. revenues oriented water balance calculation for urban water networks: the "Minimum Charge Difference" component makes a difference. In: International conference on the waterloss, IWA, Sao Paolo

Kanakoudis V, Tsitsifli S (2013) Using the bimonthly wb of a non-fully monitored water distribution network with seasonal water demand peaks to define its actual nrw level: the case of Kos town Greece. Urban Water. doi:10.1080/1573062X.2013.806563

Kanakoudis V, Tsitsifli S, Samaras P, Zouboulis A (2013a) Assessing the performance of urban water networks performance assessment results across the EU Mediterranean area: the paradox of high NRW levels and absence of NRW reduction measures planning. Water Sci Technol: Water Supply 13(4):939–950

Kanakoudis V, Tsitsifli S, Samaras P, Zouboulis A (2013b) Urban water distribution networks performance assessment: comparing eight cases from Cyprus, Greece, Italy, France and Spain, located within the EU Mediterranean basin. IPWE. In: 6th International perspective on water resources & the environment conference, Izmir, Turkey

Karadirek I, Kara S, Yilmaz G, Muhammetoglu A, Muhammetoglu H (2010) Implementation of hydraulic modelling for water-loss reduction through pressure management. Water Resour Manag 26:2555–2568

Lambert A, Morrison J (1996) Recent developments in application of "bursts and background estimates" concepts for leakage management. Water Environ Manag 10:100–104

Lambert A, Brown T, Takizawa M, Weimer D (1999) Review of performance indicators for real losses from water supply systems. Water Supply Res Technol AQUA 48:227–237

Lambert A (2002) International report: water losses management and techniques. Water Supply, vol 2, pp 21–20

Liemberger R, Brothers K, Lambert A, McKenzie R, Rizzo A, Waldron T (2007) Water loss performance indicators. In: International Conference on the WaterLoss, IWA, Bucharest, vol 1, pp 148–160

Male J, Noss R, Moore I (1985) Identifying and reducing losses in water distribution systems. Noyes Publications, Park Ridge

McKenzie R, Seago C, Liemberger R (2007) Benchmarking of losses from potable water reticulation systems: results from IWA Task Team. In: International conference waterloss, IWA, Bucharest, Romania, vol 1, pp 161–75

Obradovic D (2000) Modeling of demand and losses in real-life water distribution systems. Urban Water 2:131–139

Rizzo A, Cilia J (2005) Quantifying meter under-registration caused by the ball valves of roof tanks (for indirect plumbing systems). In: International conference leakage, IWA, Halifax

Rizzo A, Bonello M, Galea St. John S (2007) Trials to quantify and reduce in-situ meter under-registration. In: International conference on waterloss, IWA, Bucharest, vol 3, pp 696–704

Tabesh M, Asadiyani Yekta AH, Burrows R (2009) An integrated model to evaluate losses in water distribution systems. Water Resour Manag 23:477–492

Thornton J (2002) Water Loss Control Man. McGraw Hill, New York

Tsitsifli S, Kanakoudis V (2009) Evaluating the performance of an urban water distribution network: tips and tricks for troubleshooting. In: 7th international conference EWRA water resources conservation & risk reduction under climatic instability, pp 419–426, Lemessos, Cyprus