Quantifying the global non-revenue water problem

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ABSTRACT

This paper provides a long overdue update on the global non-revenue water (NRW) estimates, initially published in a World Bank publication more than 10 years ago. The authors use a similar approach based on latest data to estimate the volume of water lost by water utilities around the world. The conclusion of this study is that the 2006 estimates were extremely conservative and that realistic NRW estimates are significantly higher. The global volume of NRW has been estimated to be 346 million cubic metres per day or 126 billion cubic metres per year. Conservatively valued at only USD 0.31 per cubic metre, the cost/value of water lost amounts to USD 39 billion per year. Not only is this an enormous financial concern, but elevated NRW also detracts from water utilities, in a time of increasing scarcity and climate change, from reaching their goals of full service coverage, at a reliable level of service at an affordable price.

Key words | non-revenue water, NRW, water losses

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INTRODUCTION

In 2006, Liemberger (together with Kingdom and Marin) calculated the volume of water losses around the word and the approximate cost of these water losses. Since then, the numbers have been quoted in presentations and articles around the world. In 2010, Liemberger (together with Frauendorfer) published updated numbers for Asia, which clearly indicated that the assumptions for the 2006 estimates were far too conservative. The purpose of this paper is to calculate new estimates based on the latest available data and provide a new, reliable source of information.

Wyatt worked extensively on the analysis of the non-revenue water (NRW) situation in Latin America and the Caribbean (LAC), which will be published in a forthcoming Technical Guide on NRW by the Inter-American Development Bank (Wyatt 2017). His extensive data set has been used to check and calibrate the global NRW model.

With this study, the authors would like to highlight the seriousness of the global NRW problem. Chronic water losses have been the hallmark of water utilities in most parts of the world over recent decades. This may not have been a large concern during an era of assumed plenty. But the rapid growth of the world's towns and cities, coupled with the negative impact of climate change, has meant that there is much less water available than in the past. If the world's volume of NRW was reduced by only one-third, the savings would be sufficient to supply 800 million people (assuming a per capita consumption of 150 litres per day). But this is not all; reducing NRW will improve water service reliability, water supply to the urban poor, water quality, decrease energy consumption, and in some cases delay water supply capacity expansions.

The authors are providing all country data and data sources in the Appendix (available with the online version of this paper), so that the assumptions are transparent and might be improved by others who have access to good data for specific countries.

METHODOLOGY

General

WHO/UNICEF JMP (Joint Monitoring Program) is the custodian of global data on drinking water, sanitation and

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hygiene (WASH). Total country population with access to piped water supply has been extracted from WASH data.

Average per capita consumption has been determined on a country-by-country basis and the total volume of domestic water consumption has been calculated. A provisional volume of 30% had been added for non-domestic water use.

In the following calculation, it was necessary to use the assumed percentage of NRW as it was the only widely published data available, but as that performance indicator has well-documented shortcomings, the results will be presented as NRW in litres per capita per day:

P_S	Supplied population	
PCC	Per capita consumption	(l/c/d)
C_D	Domestic consumption	(m^3/d)
C_{ND}	Non-domestic consumption	(m^3/d)
C_T	Total consumption	(m^3/d)
NRW	Non-revenue water	(m^3/d)
SIV	System input volume	(m^3/d)
%NRW	Non-revenue water	(% of SIV)

The different volumes are calculated as follows:

$$C_D = P_S \times \frac{PCC}{1{,}000}$$

$$C_{ND} = C_D \times 0.3$$

$$C_T = C_D + C_{ND}$$

$$SIV = \frac{C_T}{1 - \%NRW}$$

$$NRW = SIV - C_T$$

which can then be brought into one equation:

$$NRW = \frac{P_S \times (PCC/1,000) \times 1.3}{1 - \%NRW} - P_S \times \frac{PCC}{1,000} \times 1.3$$

Per capita consumption

The main data sources are:

- IBNET
- IWA
- AWWA
- EU

Unfortunately for many countries no information, or at least no reliable information, could be found and the authors had to make estimates based on personal experience, other sources of public information, and data from countries with similar conditions. Details can be found in the Appendix (available with the online version of this paper).

Level of NRW

IBNET was the most important source of information for the level of NRW expressed as a percentage of system input volume, but data quality is partly problematic. Some country data are based only on very few, or even only one, water utility and sometimes the latest available data are already more than a few years old, notably in LAC but also in all other regions. But despite all of this, IBNET is the only global source for NRW data. For all the other countries which are not included in the IBNET data set, the authors had to make estimates based on personal experience and data from countries with similar conditions. Details can be found in the Appendix.

Calculating the value/cost of NRW

The cost or value of one cubic metre of NRW for a water utility depends on a number of factors:

- The ratio between commercial (apparent) and physical (real) losses.
- A reduction in commercial losses will lead to increased revenues – consequently commercial losses will be valued using the average tariff. (It has become accepted practice in the USA that sewer service charges, if billed as a function of water volume consumed, are also included in the valuation of apparent losses.)
- If some of the recovered physical losses can be sold to existing or new customers, then that portion of NRW can also be valued using the average tariff.
- In case there is no unsatisfied demand, any reduction of physical losses will only lead to a reduction in variable water abstraction, treatment and distribution cost – and those will of course vary extremely depending on the water source – gravity supply of spring water on the one hand and desalination and/or pumping to high altitudes on the other hand.

- If additional water sources will be needed to meet the increasing demand, then the capital and operating cost of such future water sources will have a significant impact on the value of NRW.

Consequently, it is very complex to calculate the average value of NRW on a country level. Specific studies are required – by location. Therefore, an extreme simplification has been used to provide a country average value of NRW which represents a mix of variable production cost and average tariff.

A simple empirical formula has been developed which is based on the assumption that even in the poorest countries the (realistic) value of a m^3 of NRW will not be less than USD 0.20 and then it will increase in some relation to the country's per capita Gross Domestic Product (GDP):

$$\textit{Value of NRW}\,(\mathrm{USD/m^3}) = \ln(\textit{per capita GDP}) \times 0.035$$

This formula means that NRW in the poorest countries is valued close to USD 0.20 (for example for Burkina Faso (Africa)) while the value would be USD 0.38 for the USA.

More research is needed to improve this method and try to calibrate with good country data.

Methodology used in Wyatt/IDB

Country-level results from Wyatt/IDB were used to cross-check the results of the methodology used in this paper.

The objective of the Wyatt/IDB effort was to assemble a regional database of NRW variables and indicators, with the following considerations:

- Include all countries in the region, to the extent possible
- Focus on urban areas
- Assemble data from a sample of utilities in each country across a range of sizes and climatic conditions
- Utilize primary or secondary data which are internally consistent (cross-check calculated indicators and look at trends for inconsistencies).

Data were collected for 109 water utilities in 28 countries. Many of the smaller countries have a single national water supplier, which facilitated data collection. Sources included water utility websites and annual reports, country studies and sector assessments, regulatory documents, IDB, CAF, CDB or World Bank loan preparation documents, primary data collection from field visits, a large but somewhat out of date website/database developed in 2008 by the World Bank and IDB, and the following documents which contain multi-country data: Andres & Guash (2009), Andres *et al.* (2013), Ducci & Garci (2013), ADERASA (2014), Lentini (2015), Janson (2017).

Data were collected on the following parameters:

- Situational: connections, mains length, median household income, water stress
- Operational: billed volume, continuity, pressure (some estimated), extent of micro-metering, burst rates, staff, complaints
- Financial: revenues, operating costs, tariffs, collection efficiency
- Water balance: approximate split of NRW components (some estimated).

Data were analyzed to determine the following parameters, which correspond well to this broader study:

- Billed Water Use
  - Volume: L/capita/day, L/connection/day, Total in 1,000 m^3/day
- Apparent Loss Indicators
  - Volume: L/conn/day, Total in 1,000 m^3/day
  - Value: USD/conn/day, Total in 1,000 USD/day
- Real Loss Indicators
  - Volume: L/conn/day, Total in 1,000 m^3/day
  - Value: USD/conn/day, Total in 1,000 USD/day
- NRW Indicators
  - Volume: L/conn/day, Total in 1,000 m^3/day
  - Value: USD/conn/month, Total in 1,000 USD/day
- Financial Indicators
  - Unit Water Cost: USD/m^3 produced
  - Estimated Variable Production Cost: USD/m^3 produced
  - Total Water Cost: USD/m^3 sold
  - Effective Average Tariff: USD/m^3 sold.

RESULTS AND DISCUSSION

The global volume of NRW has been calculated to be 346 million cubic metres per day or 126 billion cubic metres per

Table 1 | NRW volume and cost/value per region

	Volume of NRW		Average level of NRW	Cost/value of NRW Billion USD/year
	Million m^3/day	Billion m^3/year	Litres/capita/day	
Sub-Saharan Africa	14.1	5.2	64	1.4
Australia and New Zealand	1.0	0.3	36	0.1
Caucasus and Central Asia	8.0	2.9	152	0.8
East Asia	53.0	19.3	42	6.2
Europe	26.8	9.8	50	3.4
Latin America and Caribbean	69.5	25.4	121	8.0
Middle East and Northern Africa	41.2	15.0	96	4.8
Pacific Islands	0.5	0.2	211	0.1
Russia, Ukraine, Belarus	9.5	3.5	65	1.1
South Asia	63.4	23.2	93	6.0
Southeast Asia	18.4	6.7	81	2.0
USA and Canada	40.7	14.8	119	5.7
Total	**346**	**126**	**77**	**39**

year. To put this in some perspective, this annual volume is about 70% of the average flow of the Niger River – the principal river in West Africa, and nearly 50% of the average flow of the Ganges River in India. But more importantly, the aggregate NRW is 30% of water system input volumes across the world.

The newly introduced NRW indicator – litres/capita/day – was computed by country and by region to understand the level of NRW, independent of country or region size. The introduction of this indicator was necessary because the normal operational water loss performance indicators, like NRW per service connection per day or per kilometre pipeline per day cannot be used because data on network length or number of connections are in most cases not available at country level. The results for the different regions can be seen in Table 1. Details for each region on a country-by-country basis can be found in the Appendix (available with the online version of this paper).

It does not come as a surprise that the regional differences are significant. The lowest NRW levels (36 l/capita/d) can be found in Australia and New Zealand, which is due to the big water loss reduction efforts that have been made during the last 10 to 15 years in the attempt to better cope

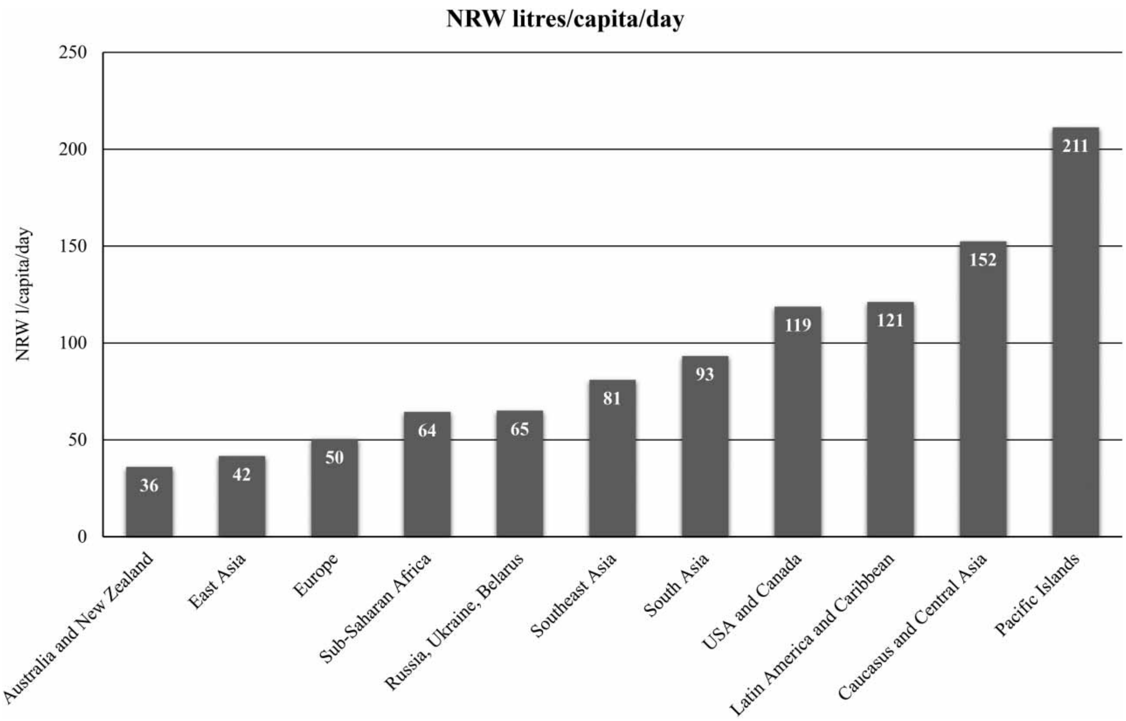

Figure 1 | Regional NRW levels.

Table 2 | Comparison of the NRW model results with data from selected LAC countries

		NRW in l/capita/d			NRW in 1,000 m^3/day			
	Population served	Model	Wyatt/IDB	Difference	Model	Wyatt/IDB	Difference	Percent difference
Argentina	43,019,152	183	189	5	7,894	8,113	−219	3%
Bahamas	369,918	98	98	0	36	36	0	0%
Barbados	278,577	286	300	14	80	84	−4	5%
Belize	297,949	37	37	0	11	11	0	0%
Bolivia	7,915,294	70	63	−7	554	502	52	−9%
Brazil	199,750,809	94	90	−5	18,872	17,879	993	−5%
Cayman Islands	51,572	53	52	0	3	3	0	0%
Chile	17,847,512	91	84	−6	1,620	1,505	115	−7%
Colombia	42,381,111	118	107	−11	4,997	4,547	450	−9%
Costa Rica	4,768,368	206	220	14	982	1,048	−67	7%
Dominica	54,444	69	97	28	3.8	5.3	−1.5	40%
Ecuador	13,833,220	173	174	1	2,388	2,403	−15	1%
El Salvador	5,367,444	106	104	−2	568	556	12	−2%
Grenada	96,055	104	91	−13	10.0	8.7	−1.8	−13%
Guyana	506,840	332	348	17	168	176	−8	5%
Honduras	7,213,368	111	106	−4	798	768	30	−4%
Jamaica	2,259,016	289	261	−28	652	590	62	−10%
Mexico	119,478,951	104	99	−5	12,426	11,817	609	−5%
Nicaragua	4,234,942	206	208	2	874	882	−7	1%
Panama	3,617,503	204	327	123	738	1,183	−445	60%
Paraguay	5,936,257	206	193	−12	1,220	1,147	74	−6%
Peru	26,032,349	94	97	4	2,437	2,528	−92	4%
Puerto Rico	3,465,481	349	357	8	1,209	1,238	−29	2%
St Lucia	176,678	186	205	19	33	36	−3	10%
St Vincent and the Grenadines	101,763	94	104	10	10	11	−1	11%
Suriname	364,343	69	142	73	25	52	−26	105%
Trinidad and Tobago	1,253,202	310	359	49	389	450	−61	16%
Uruguay	3,384,329	152	147	−5	514	496	18	−3%
Total Population	**514,056,446**							
Weighted Average NRW l/capita/day		**116**	**113**	**−3**				
Total NRW Volume 1,000 m^3/day					**59,510**	**58,070**	**1,430**	**−2.4%**

with the long droughts in Australia. The Pacific Islands have the highest NRW level (211 l/capita/d) but data quality is limited and therefore this number is questionable. The average level of NRW in LAC is 121 l/capita/d (Figure 1).

A comparison of the model's results to actual country data from the Wyatt/IDB database shows a very good correlation. The weighted average from the new NRW model is 116 l/capita/day compared with 113 l/capita/day estimated by Wyatt/IDB, which is a difference of only 2% (see Table 2).

However, it has to be noted that there are some countries with significant differences:

Table 3 | Comparison of data of the 10 largest countries in the LAC region

		NRW in l/capita/d			NRW in 1,000 m^3/day			
Ten largest LAC countries	**Population served**	**Model**	**Wyatt/IDB**	**Difference**	**Model**	**Wyatt/IDB**	**Difference**	**Percent difference**
Brazil	199,750,809	94	90	5	18,872	17,879	993	−5.3%
Mexico	119,478,951	104	99	−5	12,426	11,817	609	−4.9%
Argentina	43,019,152	183	189	5	7,894	8,113	−219	2.8%
Colombia	42,381,111	118	107	−11	4,997	4,547	450	−9.0%
Peru	26,032,349	94	97	4	2,437	2,528	−92	3.8%
Chile	17,847,512	91	84	−6	1,620	1,505	115	−7.1%
Ecuador	13,833,220	173	174	1	2,388	2,403	−15	0.6%
Bolivia	7,915,294	70	63	−7	554	502	52	−9.4%
Honduras	7,213,368	111	106	−4	798	768	30	−3.7%
El Salvador	5,367,444	106	104	−2	568	556	12	−2.1%
Total	482,839,210							
% of Region	94%							
Average NRW		**109**	**105**	**– 4**				
Total NRW					**52,550**	**50,620**	**1,930**	**– 3.7%**
% of Region					**88%**	**87%**		

- Dominica – high consumption from cruise ships
- Panama – higher consumption (wastage) due to low level of metering, high illegal consumption
- St Lucia – high consumption from cruise ships
- Suriname – most likely because Wyatt/IDB only had data for one region of the country, a predominately urban region, which is probably not representative of all piped water systems in the country.

Data from the 10 largest countries, each with a population of more than five million, show a similarly good correlation, with a difference of −3.7% in the total volume of NRW. In none of the countries, does the difference exceed ±10% (Table 3).

The new model has now been used to run a simulation with 2005 data to compare the result with the World Bank publication (Kingdom *et al.* 2006) which used 2005 data. The result shows a significant difference which can be explained by the conservative assumptions made in 2006 and the fact that the first model used the supplied urban population only, while this model does not differentiate between urban and rural and includes all piped water supply systems. The difference with the model published by the Asian Development Bank (Liemberger & Frauendorfer 2010) has similar reasons (for all comparisons see Table 4).

Table 1 also provides estimates of the cost/value of the NRW, by region. Estimating the cost/value of global NRW has been as problematic in the previous models as it is in this model. The global cost/value of NRW has been calculated to be USD 39 billion per year but the number can only be understood as a rough estimate. However, it is a clear indication that the high levels of NRW have a massive negative financial impact on the water supply sector.

If global NRW was reduced by one-third (115 million cubic metres per day), the annual financial benefit would be around USD 13 billion. Assuming an average NRW reduction cost of USD 600 per m^3/day NRW reduction,

Table 4 | Annual NRW volume – comparison to previous NRW models

	2005		2009		2016
Billion m^3 per year	**WB publication**	**New model**	**ADB publication**	**New model**	**New model**
World	48.6	97.5			**126**
Asia and Pacific Islands			28.7	47.2	**64**

the investment required to achieve this reduction would be USD 69 billion – a payback time of just over 5 years. This may sound too optimistic, and based on the authors' experience, payback times between 7 and 10 years are in many cases more realistic, but it is still difficult to understand why water utilities and governments are so reluctant to invest in NRW reduction.

It is also important to note that the 115 million m^3/day would serve 800 million people, assuming an average consumption of 150 litres/capita/day. This could address the needs of customers who currently do not have service, expanding current coverage, or could serve the needs of future customers, allowing water source expansions to be postponed or cancelled.

The analysis in Wyatt/IDB indicated that of the 28 countries, 26 could have projects to significantly reduce NRW in the sample utilities, with a payback period of less than 10 years. In 16 of those countries, the payback period would be less than 5 years. The total cost of the projects would be about USD 11 billion. The countries with less favourable payback periods suffer from low tariffs. The resulting water savings could provide water to over 19 million new water connections, which could address current local coverage issues, or cover urban growth for typically 8 to 10 years (assuming a 4% urban growth rate).

CONCLUSIONS

This new analysis of global levels of NRW shows that the current estimated volume is far higher than previously estimated. This is partly due to over-conservative estimates used in previous estimates, as well as growth in population and expansion of water supply systems. The results of this study place the volume of NRW at 126 billion m^3/year, which has a financial cost/value of USD 39 billion/year.

The model has been found to provide very similar results to another study of NRW levels in Latin America – based on a sampling approach. Nonetheless more data and more accurate data would help refine the numbers.

Given climate change, expanding populations' full coverage of improved water service is still a large global challenge. However, NRW can provide many benefits – including reduced operating costs increased revenues, better water resource efficiency and expanded water supply at a cost far lower than new water production facilities.

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