# EVALUATION AND ADJUSTMENT OF INFRASTRUCTURE LEAKAGE INDEX FOR TOWNS IN DEVELOPING COUNTRIES

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## ABSTRACT

*Evaluating water loss and the performance of urban water supply utilities is critical. The objective of this research was to evaluate the applicability of the Infrastructure Leakage Index (ILI) formula for towns of developing countries and suggest adjustment factors. Basic water supply data from nine towns of Ethiopia was used to calculate ILI and develop modification factors. Water supply development level factor was determined based on the actual water production and optimal consumption if there was sufficient supply. Asset management factor was developed considering the categorization of Ethiopian towns which was related to expected water supply level based on development level. The study showed the Unavoidable Annual Real Loss (UARL) formula gave similar values for any type of water supply system whether developed or not. Except for Addis Ababa, the calculated ILIs utilizing the standard formula were less than four indicating unrealistic very good performance. Applying the adjustment factors, realistic ILI values were obtained reflecting the realistic performance of water utilities in developing countries, requiring timely appropriate water loss reduction measures.*

*Keywords: Water loss, ILI, Developing Countries, Adjustment factors, Mode of water supply, Ethiopia*

## 1. INTRODUCTION

One of the major challenges of water supply service provision is the water loss between the production and end use points of a water supply system. A number of efforts were made to quantify the amount of water loss and develop key parameters that can be used to compare the performance of water utilities irrespective of their size with regards to population served and production capacity. The International Water Association (IWA) established a Task Force on Performance Indicators which published the standard international "best practice" water balance [1]. The water balance table which introduced the term Non-Revenue Water (NRW) has been used to assess the overall performance of the system with respect to percentage of water loss from a total production and also components of water loss such as apparent and real losses [2]. However, it was not suitable for assessing the efficiency of the distribution system as it was strongly influenced by consumption and its change and pressure; difficult to interpret for intermittent supply and couldn't distinguish between apparent loss and real loss [3].

The IWA's task force on water loss carried out a review of performance indicators for real losses [4] and developed a method that could represent most of the above factors by introducing the concept of Unavoidable Annual Real Loss (UARL) and Current Annual Real Loss (CARL) to calculate a dimensionless key performance parameter – ILI. ILI was calculated as ratio: CARL/UARL, Restegari [5] stated that the

UARL/ILI approach was better than previous traditional performance indicators for the management of real losses. The basic concept of UARL was that there is no as such zero real loss. Figure 1 shows that if the real loss is to the left of point *'A'*, which is UARL, the cost of active leakage control will not be economically affordable [6]. Thus, the CARL should always be to the right of point *'A' in perfect condition at 'A'* implying ILI greater than or equal to unity implying values closer to one mean good performance.

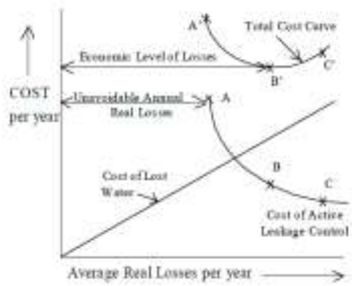


**Figure 1** Unavoidable Annual Real Losses and Economic Level of Real Losses [6]

Equation (1) was developed by the task force to determine UARL (liters/day) taking into account most of the factors that were not addressed in the traditional performance indicators.

$$UARL=(18x\ Lm+ 0.80\ x\ Nc+25xLp)xP \quad (1)$$

Where:

Lm = Mains length in km
Nc = Number of service connections
Lp = Total length in km of underground pipe between the edge of the street and customer meters
P = Average operating pressure in meter

In the development of ILI as a performance indicator to measure the efficiency of water utilities, the basic assumption in determining UARL was utilities will carry out four necessary measures of asset management practice setting standard level of services (LOS) - – pipeline and asset; and pressure management, active leakage control and speed and quality of repairs [7]. As mentioned by Alegre et al [8], the ILI was the result of an empirical expression considering properly constructed and maintained system having the service connection density, average length and the same average operating pressures. It was also mentioned that the indicator doesn't fulfill some of the requirements set for performance indicators. The ILI didn't have a means to consider developmental level of a water supply system. Modifying UARL equation for developing countries to calculate realistic ILI was also discussed by water leakage researchers [9].

Therefore, considering that the ILI was developed based on well-developed water supply systems and utilities the question here was, would such indicator give reasonable values for developing countries? Hence, the first objective of this paper was to check whether the ILI method could give reasonable performance assessment of water utilities in developing countries. The second objective was to recommend adjustment factor to the formula so that the result could reflect the situation of utilities in developing countries.

## 2. METHODS

The study focused on nine towns shown on Fig. 2 including Addis Ababa which is the only metropolitan city with a population of more than a million.


**Figure 2** Location map of study towns in Ethiopia

The key formula and data used to determine the ILI and modification factors to make it applicable to the assessment of the performance of water utilities in developing countries is presented in the following sub-sections. The data were extracted with proper quality checking from project documents and graduate thesis works supervised by the author.

*ILI Calculation*

The towns and key basic data utilized for the calculation of the relevant parameters in the determination of ILI are presented in table 1.

**Table 1** Basic water supply system data of nine towns in Ethiopia

| Town | Year | Population | Production ($m^3$/day) | Billed Consumption ($m^3$/day) | Length of Main (Lm) (km) | System Average Pressure (P) (m) | Number of Connections (Nc) |
|---|---|---|---|---|---|---|---|
| Addis Ababa | 2012 | 3000000 | 307,328.08 | 184,472.88 | 2,840.00 | 25.00 | 298,900.00 |
| Adama | 2014 | 308934 | 18,496.88 | 12,194.47 | 410.00 | 35.00 | 36,226.00 |
| Mettu | 2015 | 46306 | 1,211.67 | 791.98 | 20.92 | 38.43 | 3,109.00 |
| Emdibir | 2017 | 20773 | 512.75 | 404.96 | 21.73 | 32.00 | 1,100.00 |
| Wolkitae | 2016 | 78189 | 2,219.60 | 1,779.15 | 109.00 | 55.80 | 6,909.00 |
| Debre Markos | 2014 | 92470 | 3,809.62 | 2,292.93 | 55.72 | 43.00 | 11,014.00 |
| Robe | 2016 | 80504 | 2,255.07 | 1,686.47 | 60.06 | 52.00 | 8,236.00 |
| Bedeno | 2016 | 13418 | 388.80 | 311.04 | 10.31 | 25.00 | 366.00 |
| Ginchi | 2018 | 53600 | 829.00 | 488.18 | 24.72 | 52.00 | 2,472.00 |

*Sources: [10 -17]*

When utilizing the basic data, some assumptions were made to determine CARL and UARL employing the formulas developed by the IWA taskforce and get the ILI for each town. The various parameters developed in the process of determining ILI with the ones utilized during the development of the ILI formula were compared with coefficient of determination ($R^2$) and a separate data from Addis Ababa Water and Sewerage Authority (AAWSA) branch offices was used to validate some of the relationships developed between UARL's and density of customer connections. The key parameters determined and used to determine the applicability of ILI in the study towns were:

i. UARL=(18 x Lm + 0.80 x Nc + 25 x Lp) x P ; (litre/day) (1)
ii. UARL: litre/connection/day (i/Nc)
iii. UARL: litre/connection/day/meter of pressure (ii/P)
iv. UARL: litre/km of Main/day/meter of pressure (i/Lm/P)
v. CARL : Current Actual Real Loss (75% of NRW) based on estimation of apparent losses and known values of measured and not measured consumptions which ranges from 20% to 30% (average 25%) gives a real loss of 75% of NRW
vi. Density of connection = Nc/Lm
vii. ILI : CARL/UARL

The UARL value of each town was calculated utilizing equation 1 and data in Table 1.

*Technical Performance*

A physical loss assessment matrix, presented in Table 2, that sets technical performance category considering ranges of ILI values based on physical loss in liter/connection/day when a system is pressurized from 10 m to 50 m that was developed by Liemberger et al [18] for developing countries was used to determine performance levels based on calculated ILI values. This was done before and after adjustment of ILI values to check the change in technical performance category.

**Table 2** Physical loss assessment matrix for developing countries [18]

| Technical Performance Category | ILI | Liters/connection/day when the system is pressurized | | | | |
|---|---|---|---|---|---|---|
| | | 10m | 20m | 30m | 40m | 50m |
| A | 1-4 | <50 | <100 | <150 | <200 | <250 |
| B | 4-8 | 50-100 | 100-200 | 150-300 | 200-400 | 250-500 |
| C | 8-16 | 100-200 | 200-400 | 300-600 | 400-800 | 500-1000 |
| D | >16 | >200 | >400 | >600 | >800 | >1000 |

*Water quantity*

Another set of data focusing on water production, billed water consumption and NRW in liter per capita per day (l/c/d) and percentage of mode of water supply connections is presented in Table 3 based on the data on Table 1 and additional regarding connections. This was used to determine modification factor based on water supply development level that depends on the quantity of water used to adjust the ILI in order to make it applicable for developing countries.

**Table 3** Water production, billed consumption and NRW (l//c/d) and percentage of modes of water supply in study towns

| Town | Water production (l/c/d) | Billed water consumption (l/c/d) | NRW (l/c/d) | House Connection (%) | Yard Connection (%) | Public Tap (%) |
|---|---|---|---|---|---|---|
| Addis Ababa | 102.44 | 61.49 | 40.95 | 34.00 | 60.00 | 6.00 |
| Adama | 59.87 | 39.47 | 20.40 | 5.00 | 60.00 | 35.00 |
| Mettu | 26.17 | 17.10 | 9.06 | 2.20 | 43.80 | 25.00 |
| Emdibir | 24.68 | 19.49 | 5.19 | 0.38 | 64.89 | 20.99 |
| Wolkitae | 28.39 | 22.75 | 5.63 | 7.00 | 93.00 | 0.00 |
| Debre Markos | 41.20 | 24.80 | 16.40 | 3.00 | 25.00 | 39.00 |
| Robe | 28.01 | 20.95 | 7.06 | 3.12 | 59.28 | 37.60 |
| Bedeno | 28.98 | 23.18 | 5.80 | 0.00 | 15.00 | 85.00 |
| Ginchi | 15.47 | 9.11 | 6.36 | 2.96 | 51.57 | 34.66 |
| **Average** | **39.47** | **26.48** | **12.98** | **6.41** | **52.50** | **31.47** |

*Asset management*

In Ethiopia, the category of the town in addition to population size reflected the stage of water supply development with respect to service delivery which is highly affected by availability of a systematic asset management. The asset management was reflected by activities which are being carried out by water utilities to provide safe water satisfying standard LOS which includes in general decreasing NRW and particularly water loss. In the Ethiopian context, as per the second growth and transformation plan (GTPII), towns are categorized based on population into the following five categories [19]:

- Category I: > 1,000,000
- Category II: 100,000 to 1,000,000
- Category III: 50,000 to 100,000
- Category IV: 20,000 to 50,000
- Category V: < 20,000

This categorization which indicates the expected l/c/d of water supply of each category as 100, 80, 60, 40, 20 for categories I, II, III, IV and V, respectively was used to estimate asset management factor.

The water quantity and asset management factors were multiplied to determine modified ILI value which better reflects the performance level of the utilities in the study towns.

## 3. RESULTS AND DISCUSSION

### 3.1 Results

#### 3.1.1 Pressure and Density of Connection

The first comparison was made between the UARL estimated (litre/connection/day) utilizing the field data and the table produced by the developers of the formula based on data from 27 countries [6], as shown in Table 4. The field values of average pressure and density of connection per km of main were taken and the UARL was interpolated from the table. For density values greater than 100 Nc/km, UARL values corresponding to 100 Nc/km were taken as values become almost constant as observed from the table developed to estimate UARL during the ILI formula development [4].

**Table 4** UARL values calculated based on field data and interpolated initial ILI document (liter/connection/day))

| Town | Addis Ababa | Adama | Mettu | Emdibir | Wolkitae | Debre Markos | Robe | Bedeno | Ginchi |
|---|---|---|---|---|---|---|---|---|---|
| UARL Field | 33.65 | 48.26 | 49.81 | 48.98 | 81.41 | 54.44 | 67.93 | 42.05 | 70.46 |
| UARL Interpolated | 31.00 | 44.05 | 47.11 | 45.45 | 84.71 | 45.15 | 66.30 | 40.04 | 66.30 |

The coefficient of determination ($R^2$) value of 0.968 for estimated values of UARL based on field data and interpolated based on initial ILI document presented in Fig. 3 shows that the table can directly be used to calculate UARL as long as the basic data in ILI equations are available. The estimation has reasonable accuracy and this indicates that the developed table can be used irrespective of the level of the water supply system of the data source.

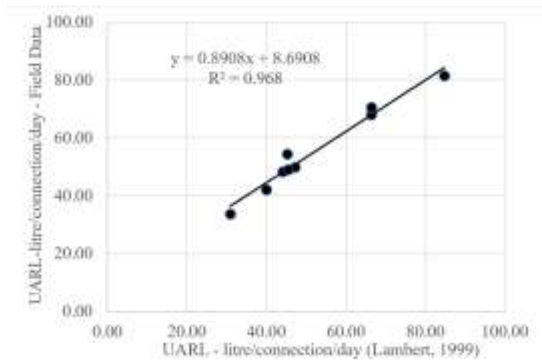


**Figure 3** UARL - Field value as a function of tabular values (Lambert et al, 1999)

### 3.1.2. UARL per Unit Pressure

During the development of the ILI method, graphs were developed which showed the relationship between density of service connections per km and UARL: in litre/km-main/day/meter of pressure and litre/connection/day/ meter pressure when fully pressurized [6]. The developed graphs show as density increases UARL (litre/connection/day/meter pressure) decreases and becomes almost constant if the density of connection exceeds 100 Nc/km. Moreover, the UARL (litre/km of main/day/meter pressure) increases linearly with density of connection except when considering only the main which is constant. Figure 4 and 5 were developed for the nine towns based on field data.

Comparison of the graphical representation of the source document for ILI method and the one plotted for the nine showed that the trends were similar in that UARL – litre/connection/day decreased with increase in density of service connection and vice versa in the case of UARL-litre/km/day/meter pressure.

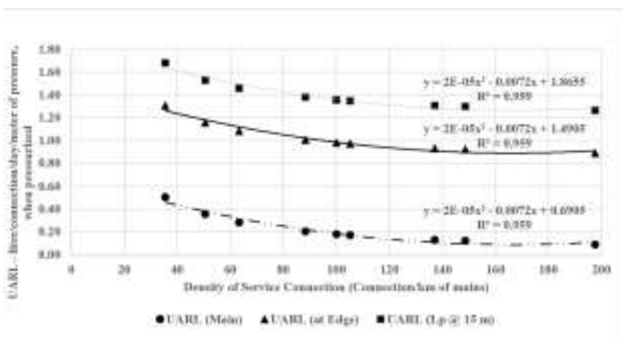


**Figure 4** UARL in litre per Service Connection per Day per Meter pressure, vs Density of Service Connection

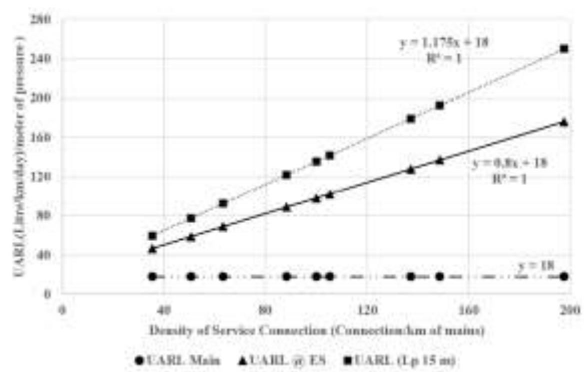


**Figure 5** UARL - litre per Km of Mains per day per meter of Pressure vs Density of Service Connections per km of Main

The equations developed to calculate UARLs per unit pressure based on the density of service connection in Fig. 4 and Fig. 5 needed to be validated. The data for seven branch offices of AAWSA and calculated density and UARLs based on the data and developed equations as shown in Fig 4 and Fig. 5 are presented in Table 5. An average pressure of 25 meter is used as suggested in the Water Audit and Bench Marking Report [20].

**Table 5** Water distribution system data, calculated density and UARLs of AAWSA Branch offices and estimated values based on developed equations

| AAWSA Branch Office | Nc | Lmain (km) | Lp[1] (km) | Density (Nc/km (main) | UARL Calculated based on data[2] | | UARL Calculated based on equation[3] | |
|---|---|---|---|---|---|---|---|---|
| | | | | | (litre/connection/day/meter pressure) | (litre/km (main)/day/meter pressure) | (litre/connection/day)/meter of pressure) ($y = 2E\text{-}05x^2 - 0.0072x + 1.8655$) | (litre/km (main)/day)/meter of pressure ($y = 1.175x + 18$) |
| Addis Ketema | 40693 | 233.04 | 542 | 174.62 | 1.24 | 215.84 | 1.22 | 223.18 |
| Arada | 22317 | 219.91 | 307 | 101.48 | 1.32 | 134.09 | 1.34 | 137.24 |
| Gulele | 41841 | 274.23 | 665 | 152.58 | 1.32 | 200.69 | 1.23 | 197.28 |
| Gurd Shola | 32955 | 333.41 | 391 | 98.84 | 1.28 | 126.39 | 1.35 | 134.14 |
| Megenagna | 28580 | 235.12 | 337 | 121.55 | 1.24 | 151.08 | 1.29 | 160.83 |
| Mekanisa | 38066 | 270.97 | 534 | 140.48 | 1.28 | 179.65 | 1.25 | 183.06 |
| Nifas Silk | 39864 | 316.72 | 569 | 125.87 | 1.30 | 163.61 | 1.28 | 165.89 |

*Calculated based on*

[1] *Lp ranging from 12 m to 16 m is used source being bench marking report*
[2]*Equation 1*
[3]*Equations of Fig. 4 and 5*

The RMSE of UARL (litre/connection /day)/meter of pressure) determined based on field data and developed equation is 0.0476 which is insignificant. Moreover, the coefficient of determination ($R^2$) between UARL (litre/km(main)/day/meter pressure) determined through field data and developed equation was 0.9834. Both validate the equations developed in Fig. 4 and 5.

### 3.1.3 Infrastructure Leakage Index

The key parameter used to determine ILI was CARL which was calculated considering 75% of the NRW based on the estimation of the apparent losses and unmetered and metered unbilled water consumption to be 25% of NRW. Table 6 shows the ILI calculated according to a formula: ILI = CARL/UARL.

**Table 6** Calculated ILI for Ethiopian towns based on field data indicated in table 1.

| Town | CARL (litres/Connection/day) | UARL (litres/Connection/day) | ILI |
|---|---|---|---|
| Wolkitae | 47.81 | 81.41 | 0.59 |
| Robe | 51.78 | 67.93 | 0.76 |
| Emdibir | 73.49 | 48.98 | 1.50 |
| Mettu | 101.24 | 49.81 | 2.03 |
| Debre Markos | 103.28 | 54.44 | 1.90 |
| Ginchi | 103.40 | 70.46 | 1.47 |
| Adama | 130.48 | 48.26 | 2.70 |
| Bedeno | 159.34 | 42.05 | 3.79 |
| Addis Ababa | 311.06 | 33.65 | 9.24 |
| **Average** | **120.21** | **55.22** | **2.66** |

In general, it is clear that increased CARL coupled with decreased UARL results in increased ILI. Comparing average values of CARL of Ethiopian towns with that reported by Lambert et al. [6], it was less than half – 120 against 270 litre/connection/day and corresponding ILI was 2.66. If Addis Ababa is taken out, the average value of the CARL of eight towns is about 96 litre/connection/day while ILI is 1.84. Except for Addis Ababa, all calculated ILI values were less than 4 including less than one values for Wolkitae and Robe towns. The ILI for the towns of Emdibir, Metu, Ginchi and Bedeno were considered though, Nc, is less than 5,000 as most of the towns in developing countries have such nature and checking the applicability of ILI is necessary.

*Technical performance category*

The technical performance category of a utility was determined assuming pressurized system by considering the ILI range, average pressure in the system and the extent of the current actual real loss [21]. The physical loss matrix developed for developing countries was used to categorize the 9 towns as presented in Table 7. Based on the parameters presented in the table, all but Addis Ababa were in the technical performance category of A. This category represents the ultimate good performance where further loss reduction may be uneconomical unless there was shortage of water, which needs careful analysis to identify cost-effective improvement measures. In the case of Addis Ababa, the technical performance category is C which is poor and requires immediate asset management and leakage control actions.

**Table 7** Technical performance category of water supply utilities in study towns of Ethiopia

| Town | System Average Pressure (P) (m) | Infrastructure Leakage Index (ILI) | CARL (litre/connection/ day) | ILI-Range | CARL-Range | Technical Performance Category |
|---|---|---|---|---|---|---|
| Addis Ababa | 25.00 | 9.24 | 311.06 | 8 - 16 | 200 - 400 | C |
| Adama | 35.00 | 2.70 | 130.48 | 1 - 4 | < 150 | A |
| Mettu | 38.43 | 2.03 | 101.24 | 1 - 4 | < 150 | A |
| Emdibir | 32.00 | 1.50 | 73.49 | 1 - 4 | < 100 | A |
| Wolkitae | 55.80 | 0.59 | 47.81 | <1 | <50 | A |
| Debre Markos | 43.00 | 1.90 | 103.28 | 1 - 4 | <150 | A |
| Robe | 52.00 | 0.76 | 51.78 | <1 | <100 | A |
| Bedeno | 25.00 | 3.79 | 159.34 | 1 - 4 | <200 | A |
| Ginchi | 52.00 | 1.47 | 103.40 | 1 - 4 | < 150 | A |

### 3.1.4 Modification factor

The technical performance category of A in Table 8 except for Addis Ababa required attention. The question here was what was the situation on the ground in the various utilities that have registered performance category of A. Do they deserve such high-level technical performance? Does it mean these utilities do not need further leakage control activities? Though developed for developing countries, can one really utilize this table to categorize technical performance in developing countries like Ethiopia? What modification is required to get realistic technical performance measurement? Considering the situation on the ground, there was a need to develop factors to modify calculated ILI.

*Water quantity perspective*

The per capita water production, billed consumption, NRW and mode of water supply of the various utilities can be referred from Table 3. The average per capita production per day was about 40 litres while the billed consumption was just over 26 litres. If Addis Ababa is treated separately the average per capita production and consumption in litres will be about 32 and 22 litres, respectively which is very minimal.

The minimal consumption of water is reflected in the percentages of mode of water supplies in the towns with very low water consumption levels. A very low percentage of house connection of about 6.5 % indicates that the maximum per capita water consumption is governed mainly by yard connection, 52.5 %, which could not be greater than 50 l/c/day. The fact that on the average about 32 % fetch water from public tap with a maximum possible daily per capita consumption of 20 liter justifies the low daily per capita consumption rates.

If Addis Ababa is not considered, the house connection, yard connection and public tap users will be about 3%, 52% and 35%, respectively. Considering similar average pressure and NRW, if the production amount is increased, CARL will increase. However, UARL will remain the same since it is not a function of water production or consumption as the key parameters in the equation are pipe length, number of connection and pressure. The UARL could not differentiate whether the water supply system is highly developed with most population house connected or yard connected or get water from the public taps.

The key implication of the lesser production and insignificant percentage of house connection and hence less CARL coupled with unchanged UARL is that the ILI will be lower. The issue here is to determine a correction factor which is greater than one for the calculated ILI to cater for the development level of water supply system. Considering the factor to be determined the adjusted ILI can be calculated as follows:

$$ILI_{adj1} = WSDLF*ILI \quad (2)$$

Where,

$ILI_{adj1}$ = Adjusted ILI considering the development level of water supply

ILI = ILI determined with available water assuming system is fully pressurized

WSDLF = Water Supply Development Level factor used to adjust ILI

*Asset Management Perspective*

Initially the ILI was developed considering utilities have proper asset management to achieve a certain level of service (LOS) which includes active leakage management practice. A recent study carried out in 10 small and medium towns of East Shoa Zone of Oromia region of Ethiopia [22] showed the following key technical factors which can be considered common problems in almost all towns of Ethiopia.

- the consumption was low due to underdevelopment of the system coupled with NRW which is a big concern and poor management,
- Infrastructure stability was also one attribute with low achievements of the evaluation in which many of the physical assets were found aged and needs replacement and repair; regular inspection periods were missed
- Product quality was very low expressed as service reliability, continuity, interruptions, working hours, and quality of water

Considering the nine towns with regards to asset management, the situation is not different. For example, in Debre Markos town 11.5 burst/km/year of main per year was encountered which clearly shows very poor asset management of the water supply system. Except Addis Ababa which started limited efforts on NRW management, other towns do not have proper asset management that leads to leakage control.

Thus, an ILI which was determined in the absence of sound asset management which contributes towards attaining recoverable real loss needs adjustment with a factor greater than one. Hence, adjusted ILI considering asset management factor (AMF)

$$ILI_{adj2} = AMF*ILI\ldots. \quad (3)$$

Where,

$ILI_{adj2}$ = Adjusted ILI considering lack of proper asset management

ILI = ILI determined with available water assuming system is fully pressurized

AMF = Asset Management Factor to adjust ILI

Combining the two adjustments, the final adjusted ILI that caters for both factors, which address water supply development level and asset management limitations in developing countries like Ethiopia, would give the following equation.

$$ILI_{adj} = AMF*WSDLF*ILI\ldots. \quad (4)$$

Where,

$ILI_{adj}$ =Adjusted ILI considering lack of proper asset management and low water supply development level

ILI = ILI determined with available water assuming system is fully pressurized and proper asset management practiced

WSDLF = Water Supply Development Level Factor used to adjust ILI

AMF = Asset Management Factor to adjust ILI

***Determining Adjustment Factors***

*Water Supply Development Level Factor (WSDLF)*

Water supply development factor can be determined on assumed per capita daily water demand if a substantial population of the urban population is getting water through house connection. The WSDLF is basically determined considering the per capita production should be between 100 l/c/d to 150 l/c/d where more than 80 % of the population is utilizing water from house connection including NRW was considered as optimal. In this study a per capita production of 125 l/c/d which is an average of the two was considered to calculate WSDLF. The factors developed and the resulting adjusted ILI is presented in Table 8.

*Asset Management Factor (AMF)*

The category of the town in the asset management perspective section in addition to population size reflects the stage of water supply development with respect to service delivery which is highly affected by availability of a systematic asset management. Hence, depending on the status of asset management, correction factors that vary from 1.25 to 2.0 have been assigned. The maximum factor is given this range since the level of development with respect to asset management within Ethiopia or other developing country could not be more than double from the best scenario which is one. Otherwise, it can exaggerate the ILI value unnecessarily downgrading technical performance. The minimum AMF was assigned for Addis Ababa as it has a system in place but not that much effective since significant reduction in leakage is not yet observed. Adama is just beginning the introduction of the system with a service delivery improvement support through NRW reduction project and hence an AMF of 1.75 was assigned. For the other towns which have no system or not started proper asset management except some reactive responses when problems are encountered, AMF value of 2.0 was assigned.

Based on these adjustment values the WSDLF adjusted ILI values are multiplied by AMF to get the final adjusted ILI value that takes into account both water supply development level and conditions of asset management as indicated in Table 8.

### 3.1.5 Change in technical performance category

The adjustment of the ILI through the introduction of WSDLF and AMF increased the value of ILI and hence could initiate utilities to improve their water supply system from both perspectives. The last row of table 8 shows the change in technical performance category.

**Table 8** Determination of ILI adjusted for shortage of water and lack of efficient asset management

| Town | Addis Ababa | Adama | Mettu | Emdibir | Wolkitae | Debre Markos | Robe | Bedeno | Ginchi |
|---|---|---|---|---|---|---|---|---|---|
| Production (l/c/d) | 102.44 | 59.87 | 26.17 | 24.68 | 28.39 | 41.20 | 28.01 | 28.98 | 15.47 |
| WSDLF (125/Production) | 1.22 | 2.09 | 4.78 | 5.06 | 4.40 | 3.03 | 4.46 | 4.31 | 8.08 |
| ILI(before adjustment) | 9.51 | 2.97 | 2.25 | 1.63 | 0.64 | 2.10 | 0.84 | 4.09 | 1.62 |
| $ILI_{adj\ (WSDLF)}$ | *11.60* | *6.21* | *10.75* | *8.27* | *2.83* | *6.39* | *3.76* | *17.66* | *13.07* |
| AMF | 1.25 | 1.75 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| $ILI_{adj(WSDLF\_AMF)}$ (after adjustment) | 14.50 | 10.86 | 21.49 | 16.55 | 5.66 | 12.77 | 7.52 | 35.32 | 26.13 |
| Performance Category (before adjustment) | C | A | A | A | A | A | A | A | A |
| Performance Category (after adjustment) | C | C | D | D | B | C | B | D | D |

All utilities that had performance category of A before adjustment are changed to B, C or D category. Those which moved to category D are the ones with connection of less than 5,000 and where the applicability of the ILI method is in question and are in the urban category IV and V except Ginchi. The two towns - Wolkitae and Robe - that had a performance category of B were the ones that had ILI of less than 1 which is unrealistic. This is due to higher average pressure and length of main and connection pipe which increased the UARL without a change in CARL. If the initial ILI is changed to one which is theoretically the least and best value of ILI, the adjusted ILI will be 8.80 and 8.92 for Wolkitae and Robe, respectively which gives a performance category of C for both. Therefore, all the towns had a performance category of poor or very poor that require urgent action to improve the water supply system with respect to real loss which reflects the situation on the ground.

***Sensitivity Analysis of Adjustment Factors***

The WSDL adjustment factor was varied without changing the AMF to check its sensitivity by decreasing and increasing the per capita water consumption by 25 liters to the minimum and maximum values of 100 and 150 l/c/d. No change in technical performance category was observed in the seven towns. Downgrading to the next technical performance level is observed in Addis Ababa and Robe when the per capita consumption level is above 140 l/c/d. A sensitivity analysis was also carried out by varying the AMF factor from 1.25 to 3.00. No change was observed for Bedeno and Ginchi towns as their initial technical performance was the last one D. With the others change was observed when the AMF is doubled from the minimum to 2.5 and more. In general, the sensitivity analysis showed that both the adjustment factors are robust.

### 3.2 Discussion

Globally the utilization of the ILI as an index showing utilities performance with regards to real loss management in the last 20 years has shown its effectiveness in a number of cases. However, there were also questions about its applicability in various circumstances. Most of the issues raised were with regards to the reliability of UARL estimate under various circumstances. The main concern was overestimation of UARL due to high pressure in a system leading to lower and misleading ILI values.

In his evaluation of the ILI Wnarni [3], attempted to show that there is no relationship between ILI and NRW expressed as percentage of system input and hence less percentage of NRW does not mean lower ILI. However, it didn't not cover the issue of very low water consumption due to different modes of water supply and per capita consumption rates as well as the degree of asset management efforts of utilities. Moreover, the issue of lower ILI values even below 1, UARL being greater than CARL was discussed and attempts were made to develop system correction factor. The expected possible causes that justified the development of correction factors were [23]:

- errors in low CARL volumes derived from Water Balances, or Minimum Night Flows and Night-Day Factors
- errors in infrastructure and/or pressure data inputs to the UARL equation
- lower pressure systems where pressure: leak flow rate relationships are more sensitive than the simplified linear assumption used in the UARL equation
- systems where all bursts surface quickly or are easily and rapidly identified from night flow measurements, including small District Metered Areas.

The adjustments made to address these issues did not consider the effect of the low level of water supply development with respect to prevailing mode of water supply and the lack of proper asset management to decrease leakage in the water utilities of developing countries which are the focus of this paper.

## 4. CONCLUSION

Previous efforts to develop factors could give improved ILIs addressing the issues raised. The author explored other dimensions that contribute for low ILI and recommended adjustment factors to the calculated ILI. This research shows UARL formula is dependent on distribution system parameters and gives similar values whether the system is highly developed with a substantial mode of domestic water supply of house connection or not. The low water consumption levels in developing countries which are mostly based on yard connection implies the quantity of CARL is low. On the other hand, ILI assumes the presence of a systematic asset management with leakage management efforts which is not mostly the case in towns of developing countries. Thus, this paper strongly recommends application of adjustment factors while utilizing the ILI formula in towns of developing countries. The two adjustment factors that consider water supply development level and asset management efforts are developed based on Ethiopian experience and tested. The application of the adjustment factors resulted in higher ILI value that is in line with the extent of the problem. Hence, the author highly recommends the utilization of the formula while investigating urban water supply system of developing countries with similar problems of very low house connections and lack of leakage management system so that the results lead to necessary actions to improve the water supply system and achieve reduction of real water losses.

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**CONFLICT OF INTEREST**

No conflict of interest exists with the author

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