Assessment of Non-Revenue Water Situation in Mandalay City: Response to the Management of Sustainable Water Supply System in Mandalay City

Ser Moe Yi[1,2], Kampanad Bhaktikul[1*], Kobkaew Manomaipiboon[1] and Thongplew Kongjun[3]

[1]Faculty of Environment and Resource Studies, Mahidol University, Nakhonpathom 73170, Thailand
[2]Mai Ja Yang College, Kachin State, Myanmar
[3]Royal Irrigation Department, Ministry of Natural Resources and Environment, Bangkok 10300, Thailand

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*** Corresponding author:**
E-mail:
kampanad.bha@mahidol.ac.th

ABSTRACT

Mandalay city is experiencing inefficient use of groundwater resources and inadequate water supply system to residents. The study focused on the issue of non-revenue water (NRW) and stakeholders' perception on its management in order to design the remediation measures for the water lost controls and the sustainable water supply system. A total of 134 samples of water employees, and 383 households were assessed through structured questionnaires. It has been found that more than 50% of the water employees are not aware of the NRW concept. Furthermore, over 90% of the water users are not willing to participate in water management. The WB-EasyCalc software version 4.09 was used to determine NRW and the result of NRW is 46% of the total system input volume. The main causes of water losses in Mandalay city are: 1) a very low pressure system; 2) poor-quality repairs; 3) lack of regular maintenance; 4) water employees' insufficient knowledge; 5) lack of awareness about the NRW concept; 6) poor customer relationships; and 7) water users' lack of willingness to participate in the water losses management. Therefore, it is recommended that water utility service efficiency be optimized by giving capacity building to the water employees. It is also recommended that district metering areas (DMA) be introduced and good customer relationship be established. This is to improve the water users' willingness to participate in the water losses management for the efficient use under scarcity groundwater resources and for the sustainable water supply system.

1. INTRODUCTION

Water is accepted as a basic ingredient for food production, a moderator of economic development and an essential element of the health functioning of all the world's ecosystems. Indeed, having sufficient, safe and clean water is one of the most essential requirements for human being's healthy life. Totally, about 97% of the earth's water is saline water, stored in the oceans and only less than 3% of the total water resources in the world are freshwater. In addition, approximately 69% of the freshwater is stored in glaciers and ice caps, 30% is stored underground as groundwater and less than 1% is found as surface water in rivers and lakes, which are the easiest access to available freshwater resources in the world (Shiklomanov, 1993; UNICEF and WHO, 2012). Issues related to water sustainability become major interest both locally and globally; however, water losses are unavoidable in every water supply system (GWP, 2009). Locally, governments, water authorities and consumers have become increasingly concerned about the condition of non-revenue water (NRW) levels, together with water losses within the utilities system. NRW seriously affects the financial viability of water utilities and significantly threatens the sustainability of water supply systems (Farley et al., 2008). In many countries, surface water resources are being depleted; more new dams are being constructed, while groundwater in some areas is effectively being extracted to such an extent that problems concerning both water quantity and quality have occurred (Farley, 2003). Therefore, it is very important that new approaches be found to manage the water sustainability in urban water supply systems.

NRW is defined as the difference between a systemic input volume and the billed authorized consumption. The system input volume is the annual water volume intake to the water supply system (Farley et al., 2008). NRW is classified as the summation of unbilled authorized consumption and water losses (USEPA, 2013). Water losses are further divided into apparent losses and real losses. The apparent (commercial) losses are the water lost from the managerial system which are mainly caused by water employees and unauthorized consumptions. Real losses (physical losses) are: 1) leakage from transmission lines and distribution mains; 2) leakage and overflow at the utility storage tanks; and 3) leakage from service connections up to the customers' meters (Lambert, 2002). The apparent losses related to water that customers did not pay for (Table 1). These losses consist of four primary components including customer meter inaccuracy, meter reading error, unauthorized consumption (theft, meter bypass, illegal connections, misuse of fire hydrants, etc.) and data handling and billing errors (Mutikanga et al., 2010).

Table 1. The IWA "best practice" standard water balance (Kingdom et al., 2006; Farley et al., 2008)

System input volume (Corrected known errors)	Authorized consumption	Billed authorized consumption	Billed metered consumption	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-revenue water (NRW)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Customer metering inaccuracies	
		Real losses	Leakage in distribution system	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connection up to point of customer metering	

The apparent losses can cause an appreciable revenue loss for water utilities and distort the integrity of consumption data required for various management decisions and engineering studies. This problem is more prominent in the water utilities of the developing countries (Brian, 2010). Unbilled authorized consumption can be metered or unmetered, while unmetered authorized consumption includes water used for public services such as irrigating public parks, landscaping, street cleaning, frost protection, flushing of water mains and sewers, firefighting, etc. (Farley, 2003). There are many factors that can cause the water losses in a utility's water supply system and the most common causes of water losses are briefly described as follows:

- *Pressure:* The pressure needed to supply the water through the pipe network can itself cause water loss in several ways. For example, part of the supplied water can be lost through increased leakage as a result of increased pressure; increased burst frequency as a consequence of increased pressure or so called pressure surges (water-hammer effect). The pressure cycling from frequent on/off switching by pumps or faulty pressure-reducing valves (PRV) also can cause fatigue in plastic pipes (Farley, 2003).

- *Soil condition and movement*: The soil, in which the pipeline is laid, influences the pipeline itself. Corrosive soil deteriorates metallic pipes. Changes in moisture content and changes in temperature (freeze-thaw cycles) can also lead to soil movement and displacements of pipes. Vibrations through the soil from traffic loading can also lead to pipe failure, if the pipes are laid at shallow depths.

- *Poor quality materials and skills*: Faulty laying of pipes and incorrect backfilling will cause rapid pipe failure. Storage of plastic pipes under daily solar heat can cause damage to the pipes during handling and shorten their durability. On the customer's side, it was found that faulty tap washers, ball valves, poor seals, leaking toilets etc. may also cause the losses (Yeboah, 2008).

- *Pipe materials and age*: There are several types of pipe materials available for water supply systems i.e., lead, cast and galvanized iron, copper (housing), different kinds of plastic, asbestos cement and concrete. These materials may suffer from different kinds of deterioration because they will gradually become vulnerable to more impacts over time (Farley, 2003; Yeboah, 2008).

- *Errors in water flow measurements*: Flow measurement in a supply system can be attributed by environmental factors such as impacts on water quality, heat or cold, and climatic impacts. Many reasons, including poor skill labour, lack of proper repair skills, poor routine work concerning testing, maintenance and metering, will also lead to errors in flow measurement (Farley, 2003).

- *Errors in accounting*: The errors can occur due to intentional corruption. Some water users can be deliberately omitted from monitoring records. Erroneous accounting data transfer and management, namely, unintentional structured billing, and errors concerning the meter reading systems are as well included.

- *Unauthorized consumption*: Illegal water withdrawal from the hydrants, illegal water connections to the unexpected pipe networks (water theft) are the most common cases of unauthorized consumption.

- *Human resources errors concerning management and finances*: Lack of training and poor education can indirectly cause the water losses in a utility supply system. It has been stated that top-down management can also contribute to more frequent and complicated problems (Yeboah, 2008).

The overall objective of this research is to evaluate non-revenue water (NRW) situation in Mandalay city. The specific objectives of this study are to determine water users' perception on the water supply system and their willingness to participate in the improvement of water services in Mandalay city. The policies on NRW for sustainable water supply management system in Mandalay city are recommended.

2. METHODOLOGY

The research was designated as one shot case study design. There were three phases in the research. The first one was the identification of research questions that were later converted into research objectives. The second one was the collection of relevant primary and secondary information from a variety of sources and a number of analytical methods. Finally, the findings from the research were analyzed and translated into recommendations of NRW control policy for water sustainability in Mandalay city.

2.1 The study area

Mandalay city is located in the central area of Myanmar and is comprised of six townships, namely, Aung Mye Thar Zan, Chan Aye Thar Zan, Mahar Aung Mye, Chan Mya Thar Zi, Pyi Gyi Ta Gon and Amarapura townships (MCDC, 2015). Mandalay is the second largest city in Myanmar, area of about 121.5 square miles and with a population of about 1.5 million people and is gradually opening up to a range of industries. The challenge is that the city and its suburban areas have suffered from a lack of investment in their urban infrastructure for over 20 years (Figure 1). Mandalay city water supply is an intermittent system. It consists of 28 tube wells, moats, reservoirs, pumping stations and the associated distribution network. At that time, the water supply system served 0.73 million people out of a total population of 1.5 million. This means that the water coverage in Mandalay city is 49% of total urban population (MCDC, 2015). The groundwater withdrawal rate in Mandalay city was 170,000 cm^3/day against the natural recharge rate of about 100,000 cm^3/day. This shows the overexploitation of groundwater resources exceeding 0.7 times the level of natural water replenishment (ADB, 2006). Therefore, the groundwater situation is already critical. The existing water management network in the city is represented by the pipe system, assessed by water users and water employees. The water management program is likely the same as the daily program in underdeveloped countries. There are peak load hours of water use during a day.

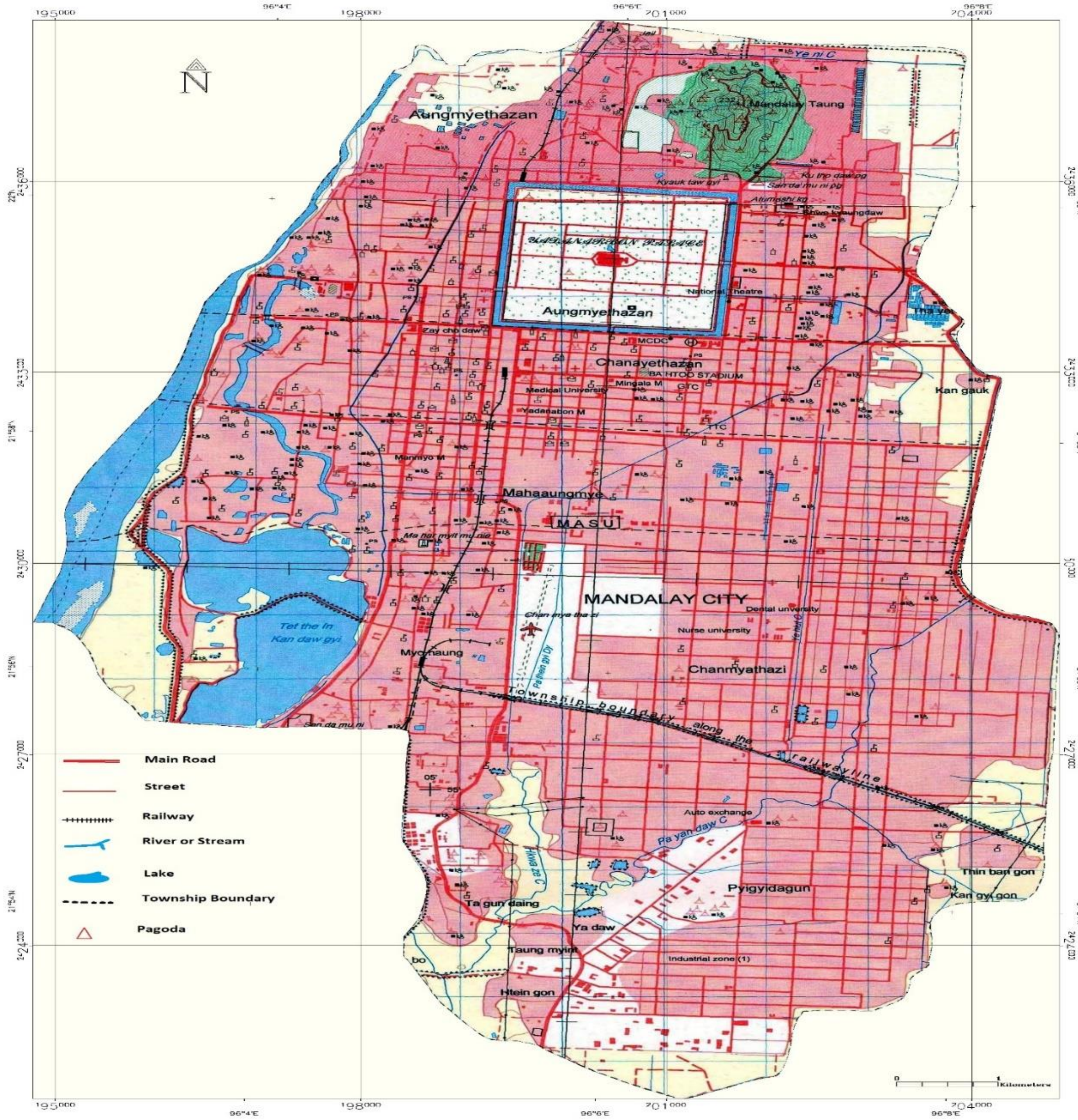

Figure 1. Map of Mandalay city (MONREC, 2002)

2.2 Assessment of non-revenue water

For the assessment of non-revenue water (NRW) situation in Mandalay city, the numerical data (Water distribution data) and the freeware named Water Balance software version-4.09 (WB-EasyCalc V.4.09, May 25, 2015) were used. The software is user friendly and specially designed for intermittent water supply system. The advantage of this software is that it does not only ask for physical data, but also asks information on how accurate this data is. It facilitates the calculation of NRW volume including various components for the accuracy of the volumes (Tsitsiflil et al., 2013). Results were eventually presented in a form of the standard water balance for NRW assessment. Costs of NRW were also computed by this software. The average domestic tariff and water production cost in cubic meter were as well included. The interpretation of parameters was provided for the sensitivity analysis of the results. Hence, the actual quantity of NRW situation in Mandalay city Water Supply System was assessed for one completed fiscal year in 2015.

Infrastructure leakage index (ILI) is defined as a measure of how a distribution network is well managed for the control of real losses at the current operating pressure. Infrastructure leakage index is the ratio of current annual real losses (CARL) to unavoidable annual real losses (UARL) as shown in equation (1). Being a ratio, the ILI has no units and thus facilitates comparisons among countries that use different measurement units (metric, U.S., British) (Farley et al., 2008).

$$ILI = CARL / UARL \qquad (1)$$

The accepted values of water loss indicators are very important for water utilities to manage their water supply system. These values make more efficient in economically, environmentally and sociologically beneficiary. The following equation is used for calculation of ecological leakage index (ELI) in water supply systems (Toprakl et al., 2008).

$$ELI = EI \times LI \qquad (2)$$

Where EI is economical index and LKN = leakage per kilometer per year.

2.3 Assessment of the perception of water authority and water users

Following the research objectives, the structured questionnaires were used for the assessment of: 1) the water authority's perception on the issues concerning NRW of water supply system; 2) water users' perception on water supply system; and 3) their willingness to participate in the improvement of water services. There are two sample groups in the study. Sample A (water users) were investigated in terms of the level of satisfaction with the current water services and their willingness to participate in the sustainable management of water supply system through questionnaire A. Since none of the institutions could manage any system for sustainability without the attention and participation of local people, the awareness of NRW knowledge of Sample B (water employees) was also investigated through questionnaire B. The water utility perception, and understanding on NRW issues were the main factors for sustainable management of water supply system.

The questionnaires for the assessment of water users' perception are comprised of two main parts. The first part is composed of statements highlighting the service of water utilities to reflect the level of satisfaction. The second part mainly concerns the question about the willingness to participate in the water loss management control. These two steps were used to assess the overall water management program of the pipe network system of Mandalay city in 2015.

The required sample size for the social questionnaire assessment is calculated by using the Krajcie and Morgan method (Krajcie and Morgan, 1970) as shown in equation (3).

$$n = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)} \qquad (3)$$

Where,

n = Sample size

X^2= Chi-square for the specified confidence level at the desired degree of freedom

N = Population size

P = Population proportion

d = Degree of accuracy expressed as proportion.

For water balancing, many free water auditing software packages are available. Among them, AWWA-WLCC and WB-EsayCalc water balance software packages are the most commonly used to carry out a water balance audit. The AWWA-WLCC was developed by American Water Work Association and it seems to be designed for the audit of 24-hour water supply system. It doesn't examine the nature of intermittent water supply system while the WB-EasyCalc provides the nature of intermittent water supply system. It provides a simpler and clearer configuration of the results, not only in volumetric units but also in financial values. By using the WB-EasyCalc software, the future projection of water supply can be predicted for effective management of water system. It also formulates good and practicable policies and strategies to control NRW losses. Since Mandalay city water supply system was operating in an intermittent supply system, the WB-EasyCalc water balance version 4.98 was used in this research.

The required sample size of the questionnaire is identified from Krajcie and Morgan Sample Size Calculation Method. The calculated sample size at 0.5 (50%) population proportion, 0.05 (95%) precision, and 95% confidence level were used. The 383 households (Sample A) and 136 water employees (11 officers and 125 normal staffs) of Sample B were used. However, during the study, two officers refused to answer the questionnaire assessment. The primary data obtained from the questionnaire survey and the relevant secondary data were screened for ensuring the data accuracy. Then, all the collected data were analyzed by using the IBM SPSS statistics software (version 21) and then interpreted.

3. RESULTS AND DISCUSSION

3.1 Water balance for Mandalay city water utility

Mandalay city water supply system consists of 28 tube wells, moats, reservoirs, pumping stations and the associated distribution network. There are 91,346 registered water meters. The water service pipes of 36.4 km were set up at the current infrastructures, which serve 0.73 million residents out of a total population of 1.5 million. This means that the water coverage in Mandalay city is 49% of total urban population. The water supply system is operated at a pressure of 4.6 m in average, 7 h/day and 7 days/week. Annually, Mandalay city water utility supplies 30,397,093 m^3 of water volumes through the existing infrastructure to water users. The raw water is collected from two main sources: 1) the groundwater resources in the amount of 27,357,384 m^3; and 2) the surface water resources in the amount of 3,039,709 m^3. Therefore, the ratio of raw water collection is 90% from the groundwater and 10% from the surface water (MCDC, 2015).

The water balance software, WB-EasyCalc V.4.09 was used to evaluate the real amount of NRW in Mandalay city water utility through the water balance standard form recommended by IWA. It was found that, in the year 2015, the water volume of 30,397,093 m^3 was supplied by pipe networks to water users. Only 16,543,104 m^3 was sold as revenue water. This means that the NRW is equal to 46% of total input water volume. The water utility lost 13,853,989 m^3/year, at a cost of 1.2 billion Kyat (Figure 2).

The further analysis was conducted. It was found that physical water losses take 79.7% or 11,039,969 m^3/year of total NRW. The commercial water losses represent 20.1% or 2,796,720 m^3/year of total NRW, and the unbilled authorized consumption is 0.2% or 17,300 m^3/year of total NRW. In terms of the financial values, the physical water losses are worth 939 million Kyat, the commercial losses are 238 million Kyat and the unbilled authorized consumption, which has the lowest financial value, is 1.5 million Kyat. These water losses are shown in Table 2 and Figure 3.

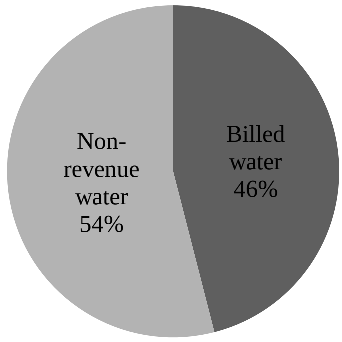

Figure 2. Percentages of billed and non-revenue water in Mandalay city water utility in 2015

It was also found that the value of infrastructure leakage index (ILI) at the current water supply system in Mandalay city is 283. This means that there was a high level of leakage in the water supply pipe networks. There are many reasons that could be addressed here, which are old and outdated infrastructures, a lack of maintenance and awareness, mismanagement, and public participation in water losses management. Theoretically, the minimum achievable volume of physical water losses was 107 m^3/day. So, the water volume of approximately 30,139 m^3 can be recovered from daily physical losses. Thus, if the water utility is operating properly, 11 million m^3 of scarce water resource, which is annually worth 935 million Kyat, can be saved from the water distribution system. For those above mentioned reasons, it could also be indicated that a substantial amount of water was lost during transmission.

3.2 Assessment of the level of water users' satisfaction and participation willingness

The water users, who are the questionaire respondents, actively participated in the assessment. According to the collected data, only 8% of the water users were satisfied with the quantity of water delivered by MCDC in its daily water services. 89% of the respondents were not satisfied with the quality of the water supply system. They answered that committed water supply schedule was not convenient for them. 71% of the water users were not satisfied with the existing water supply schedules. However, 69% of the water users suggested that the whole system network has the common issues regarding the quantity, the quality and the committed water supply schedule.

Table 2. Water balance of Mandalay city water utility (m^3/year) in year 2015

System input volume 30,397,093 m^3/year Error margin [+/-] 0.2%	Authorized consumption 16,560,404 m^3/year Error margin [+/-] 0.0%	Billed authorized consumption 16,543,104 m^3/year	Billed metered consumption 14,888,794 m^3/year	Revenue water 16,543,104 m^3/year
			Billed unmetered consumption 1,654,310 m^3/year	
		Unbilled authorized consumption 17,300 m^3/year Error margin [+/-] 0.9%	Unbilled metered consumption 0 m^3/year	
			Unbilled unmetered consumption 17,300 m^3/year Error margin [+/-] 0.9%	
	Water losses 13,836,689 m^3/year Error margin [+/-] 0.4%	Commercial losses 2,796,720 m^3/year Error margin [+/-] 4.4%	Unauthorized consumption 210,240 m^3/year Error margin [+/-] 5%	Non-revenue water (NRW) 13,853,989 m^3/year Error margin [+/-] 0.4%
			Customer metering inaccuracies and data handling errors 2,586,480 m^3/year Error margin [+/-] 4.8%	
		Physical losses 11,039,969 m^3/year Error margin [+/-] 1.2%		

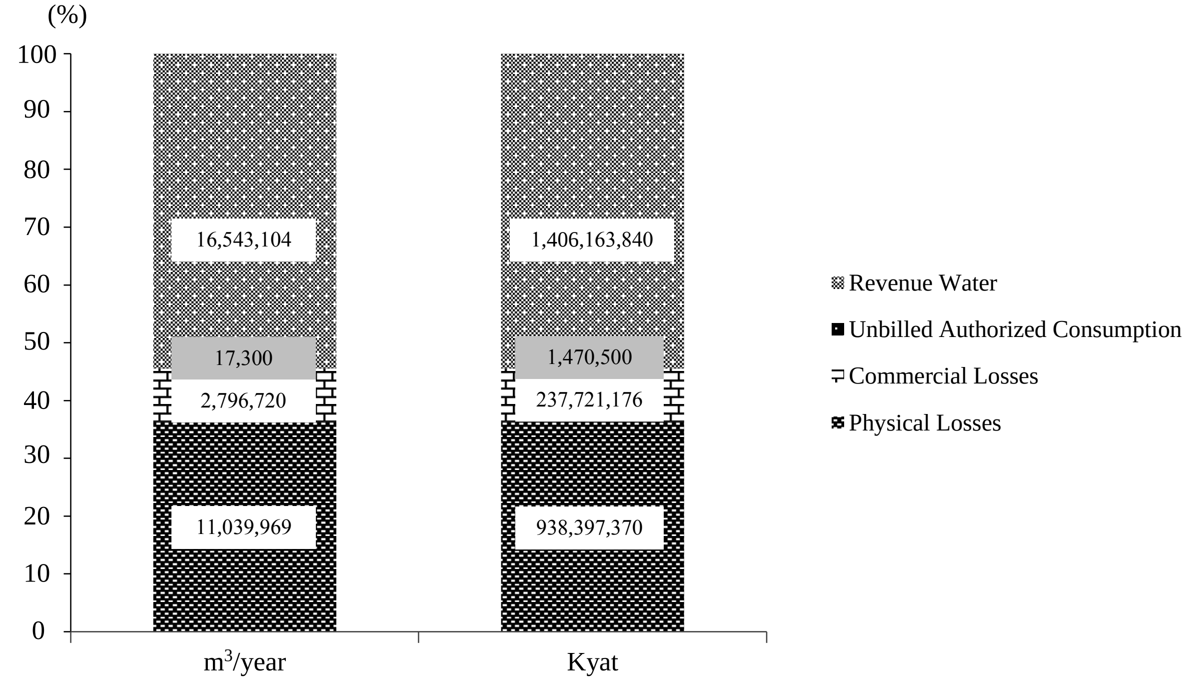

Figure 3. Volumes and values of revenue and non-revenue water in Kyat in 2015

About 58% of the water users responded that they were not satisfied with water employees. 96% of the water users were not satisfied with the water pipes and the meter maintenance services. The compliance services were also not reliable enough, which accounted for 93% of the responses expressing dissatisfaction. Conversely, the water tariff was acceptable and within affordable range. 90% of the respondents were very happy and satisfied with the current water tariff rate. The interpretation of the first part of the questionaire, which assessed the level of satisfaction with the existing water supply services, showed that 67% of total water users were not satisfied and an average of only 33% of the respondents were satified it.

For the assessment of willingness of water users' participation in water losses managements, it was found that 59% of the water users have ever seen and experienced water losses by pipe network failures, illegal water connections, immoral water employees, and faulty and jammed meters around Mandalay city. However, only 6% of the water users reported and complained to the water authority regarding these losses. This means that, only 6% of the water users had willingness to participate in the water losses management and 94% of total water users were not willing to participate.

3.3 Assessment of NRW awareness on water employees

The questionnaires were generally designed to cover the concept of NRW for its methods of measurements, water losses impacts and the water losses control factors. Since these are the main core concepts of NRW management, of which water employees must be aware. Before giving the questionnares to water employees, the designated questionares had been assessed and approved by three water experts. They graduated Master degree and have at least 20 years' working experiences in water related fields. For the structure of the water employees, there are two levels of role in the water utility; the managerial level (officer level), and the operational level (normal staff). Therefore, the questionnares were distributed to the managerial officers and normal staff of Water and Sanitation Department of MCDC. The results show interesting facts and prove the level of awareness of water employees related to NRW concepts.

It was found that the officers do not have a good understanding of the impacts of water losses, e.g., the results show that 56% of the officers are not familiar with the infrastructure leakage index (ILI). Secondly, they do not understand the concept of water losses that influence the tariff price. The 44% of the respondents answered "not aware". Approximately 33% are not aware that water losses are related to many levels of service, incentives of technicians, the functional stability of meter readers, and good customer relationship.

However, the officers have a ful understanding on some part of the NRW concepts. They understand that water losses management requires more budgets for network maintenance, qualified meter readers, and loyalty for the better management of water revenue. The results in this part show the "Aware" responses at 100%. It has been concluded that 76% of officers have a good understanding of the NRW concept, with 24% of the responses stating "Not aware".

The questionnare responses from the normal staff were quite interesting. "Water losses influence the tariff price" is the statement that most of the staff are unaware of; 82% of the answers are "Not aware". 80% of the respondents understand that water losses affect the level of water services while 75% of the respondents do not understand that water loss restricts the water authority from expanding its service coverage. The rest of the stated questions received the "Not aware" answers, ranging from 54-74%. It was found that 64% of the normal staff did not have a clear understanding of the core concepts of NRW management, which means that only 36% of the normal staff were aware of the concepts.

4. CONCLUSIONS

The following conclusions are drawn based on the obvious findings from intensive research of the study. The water balance software WB-EasyCalc version-4.09 is easy to use to evaluate the real amount of NRW in Mandalay city. It was found that, in 2015, 46% of the water volume was lost from the supply pipe networks, at a cost of 1.2 billion Kyat. The water losses are matched by means of NRW system in developing countries, of which the cost of the loss is more than 35%. It could be concluded that the minority (33%) of the water users are satisfied with the current water supply system in Mandalay city.

The majority (94%) of them are not willing to participate in any water losses management activities. The assessment of perception on NRW showed that only 36% of the operational level staff and 76% of the managerial level staff have responsive awareness. Technically, it can be defined that they are not qualified enough to manage the water losses efficiently. There was a high level of commercial water losses, which was mainly caused by the meter reading inaccuracies, data handling errors, meter tempering and bypassing. MCDC water utility is operating with a high level of NRW (46%) and experiencing significant economic operating losses.

It is recommended that MCDC upgrade its existing old aged water supply infrastructure, enhance the capacity building, arrange trainings for water users, and implement district metering areas (DMAs) to streamline the control of NRW losses. The essentials of these improvements include pipe line optimization, assets management, pressure and flow speed improvement, repair system quality enhancement, and leakage leak report activation. High level of NRW have major impacts on the economy in terms of revenues loss, on the environment in terms of water and energy loss, and on the society with regard to the inefficient water pricing policies without the actual water consumption patterns. NRW is a threat to the sustainable management of water supply system in Mandalay city and the water authorities must use the factual findings from this research to develop new strategies and improve the overall system.

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