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Assessment of Non-Revenue Water in Hantana Water Supply Scheme

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ABSTRACT. *Assessment of Non-Revenue Water (NRW) is important for any potable water supply scheme. It is common knowledge that the NRW in any water utility is a percentage of the water that disappears from the system and does not contribute to generate revenues. This simple percentage figure is not sufficient to understand the water utility problems in order to devise appropriate reduction strategies of NRW.*

Assessment of NRW of a scheme is very specific to a given scheme. A NRW assessment conducted for one water supply scheme may not be valid for another. A comprehensive study of individual project or scheme of each water supply is necessary to understand the dynamics of NRW behaviour properly. Further, the management strategies adopted for curtailing the NRW must also be unique although knowledge and experience gathered elsewhere could be definitely useful in identifying general strategies and control mechanisms.

In this regard, a detail NRW reduction programme was carried out during October 2006 and May 2007 to determine and reduce the NRW of Hantana water supply scheme (WSS). The results of the programme were used to check the applicability of latest performance indicators developed by International Water Association (IWA) and modify them to suit local conditions. The average NRW in Hantana WSS is 36.12% where the real and apparent water losses are 9.18% and 26.94% respectively. According to the findings, rectification of water leakages does not significantly reduce the NRW of Hantana WSS. The Unavoidable Annual Real Losses (UARL) for Hantana WSS is 6.4%. The infrastructure leakage index of Hantana WSS is 5.6 which is a very high value in comparison to that of the other water supply systems In conclusion, the experience gained in this exercise would definitely provide a strong support to improve the water supply efficiency of National Water Supply & Drainage Board (NWSDB).

INTRODUCTION

The world has spent billions of dollars to provide safe drinking water for the people during the period of International Water Decade (1980 – 1990) declared by the United Nations. In addition to this, every year a large amount of money is spent for the provision of safe drinking water facilities for the public. All donor agencies allocate higher percentage of their budget to develop potable water facilities. The National Water Supply & Drainage Board (NWSDB) which is the national organization for providing drinking water facilities,

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spent Rs. 16.9 billion and Rs. 17.8 billion in 2004 and 2005, respectively (NWSDB, 2005). In addition to this amount, Provincial Councils, Local Authorities (including Municipal Councils, Urban Councils and Pradeshiya Sabhas), other Government Organizations, Non Government Organizations (NGOs), International Donor Agencies and individuals spent a vast amount of money on drinking water supply during the recent past.

Assessment of Non Revenue Water (NRW) is important for any potable water supply scheme. It is common knowledge that the NRW in any water utility is a percentage of the water that disappears from the system and which does not contribute to generate revenue. NWSDB faces a serious loss from unaccounted water. In distributing water, the NWSDB faces a total loss of about 31 percent while the loss is more acute in the Greater Colombo area (36 percent). This situation impacts adversely on its revenue and investment (Central Bank of Sri Lanka, 2005). The total revenue of NWSDB was Rs. 6,218 million and NRW loss was Rs. 1928 million in 2005 (NWSDB, 2005). Review mission reports issued by the donor agencies very often criticize the high NRW percentage of the water supply systems. This has seriously hampered the decisions for allocation of funds for potable water. At the last water tariff revision meeting held in February 2005, cabinet of ministers also considered this high NRW percentage and instructed to take every possible measure for reducing it.

Even though the assessment of NRW of a scheme is very specific to the particular scheme, significant advances have been made in the understanding and modelling of water loss components and on defining the economic level of leakage for individual systems. Yet, despite some encouraging success stories, most water supply systems worldwide continue to have high levels of water losses, many of which are almost certainly higher than their economic level. Part of the problem was the lack of a meaningful standard approach to bench marking and reporting of leakage management performance. Surprisingly, only a few countries have a national standard terminology and standard water balance calculation.

Being aware of the problem of different water balance formats, methods and leakage performance indicators, the IWA has developed a standard international water balance structure and terminology (IWA, 2000). This standard format has meanwhile been adopted (with or without modifications) by national associations in a number of countries such as Canada, Germany, Australia, New Zealand and South Africa and most recently the American Water Works Association (AWWA). The same formats, methods and indicators were used in the assessment of NRW in Hantana WSS.

The objectives of this research were as follows.

1. To assess NRW of Hantana WSS in detail, according to the methodology developed by IWA.
2. To investigate the effect of reported visible leaks on the performance of Hantana WSS.
3. To modify the Performance Indicators which were newly developed by IWA to suit the local conditions of Hantana WSS.

METHODOLOGY

Study area

Hantana WSS was selected to implement this research. Hantana is located on the southern outskirt of Kandy, about 3 km from Kandy City Centre. The Hantana WSS serves the residents of Hantana Housing Scheme, Hantana Place and other surrounding areas. Two streams flowing across the Hantana Mountain are the water sources for this water supply scheme. Water from these two intakes is gravitated to the treatment plant with a plant capacity of 650 m^3 per day. The water treatment plant consists of an aerator, slow sand filters and a disinfection system (chlorinator). There are three bulk water meters to measure the outlet water from two distribution reservoirs (R_1 & R_2) and pumping water from R_1 service reservoir to R_2 service reservoir.

This water supply system serves a population of about 2500 through 500 water connections. All the connections are metered. Total length of the distribution network is 6 km. The reported NRW for 2005, based on production and metered consumption records, varies from 40 to 45%.

Assessment and reduction of NRW in Hantana WSS

A detailed programme was implemented from October 2006 to May 2007 (eight months) in Hantana WSS to reduce NRW. The programme consisted of

1. repairing appeared and recorded leaks with immediate effects
2. developing a proper database for leakages
3. mapping the leaks and identification of areas prone to leakages
4. investigating high, low, zero and disconnected consumers
5. checking leakages and overflows in tanks
6. replacing bulk meters
7. water quality monitoring
8. training the staff involved

Pipe distribution network was divided into two zones and each pipe line wase numbered for easy reference.

Water pressure distribution along the pipe network was calculated using EPANET computer programme.

Each and every leak was registered. The amount of water leakages were calculated by using pressure values and orifice size. All the leakage data were analyzed at the end of the month. In each month, numeric summary of the leakage amount was noted down in main and service connections of each zone. A pin map was developed to show the situation of the leakages along the distribution network.

Accuracy of the bulk meters was checked comparing the actual quantity that flows to the tank and recorded quantity. Calibration was done accordingly.

Checking was done for low, high and zero consumptive consumers and disconnection premises. The minimum water consumption during the off peak hours (between 00 am and

5.00 am) was monitored regularly to detect major leakages. Tank levels were monitored during the off peak hours to ascertain the possibility of overflowing of storage tanks.

Data analysis

The data were analyzed under three main categories as follows.

(i) Determination of the standard component (developed by IWA) of NRW.
(ii) Analysis of the reduction of NRW by means of statistical t-test and check the effect of visible leaks on performance of Hantana WSS.
(iii) Modification of the performance indicators developed by IWA to suit the local conditions of Hantana WSS.

Determination of NRW

The components of NRW in Hanthana WSS as listed below were determined.

a) Billed Metered Consumption
b) Billed Un-metered Consumption
c) Unbilled Metered Consumption
d) Unbilled Un-metered Consumption
e) Unauthorized Consumption
f) Metering Inaccuracies
g) Leakage on Transmission and Transmission Mains
h) Leakages and Overflows at Utilities Storage Tanks
i) Leakage on Service Connection up to Point of Consumers Service Connection

Analysis of NRW reduction

Total period of research implementation (eight months) was divided into two parts, first half (first four months) and second half (second four months). Student t-test was carried out to determine the level of significance in two sets of data.

Performance indicators

Performance Indicators (PI) are used in many sectors of industries, including the water industry. As long as PIs are only used within a utility, they can be self-defined. However, it is important to have standardized indicators, calculated according to a clearly defined methodology and using standard definitions, particularly with respect to water audits and water loss PIs.

The new and most advanced real loss indicator (recommended by the IWA, 2003) is an Infrastructure Leakage Index (ILI). The ILI is a real loss performance indicator which would allow international comparisons between systems with very different characteristics, e.g. intermittent supply situations, low and high pressure system, differences in consumption levels, etc. The ILI, in the first few years known only to a few insiders, is now widely accepted and used by practitioners around the world, as it best describes the efficiency of the real loss management of water utilities. However, regulators, funding agencies, media and utility managers in most countries continue to use percentage figures and are unaware of how misleading these figures are. The ILI is a measure of how well a distribution network is managed (maintained, repaired and rehabilitated) for the control of real losses, at the current operating pressure. It is the ratio of Current Annual volume of Real Losses (CARL) to Unavoidable Annual Real Losses (UARL) as shown in Equation 01.

ILI = CARL / UARL ……………………………………………………..…..Equation (01)

Being a ratio, the ILI has no units and thus facilitates comparisons between countries that use different measurement units (U.S., metric or imperial). Leakage management practitioners around the world are well aware that Real Losses will always exist, even in new and well managed systems. It is just a question of how high these unavoidable losses exists in a given system. The most "user friendly" versions of the UARL equation require data on four key-system specific parameters:

1. Length of mains
2. Number of service connections
3. Location of the customer meter on service connection (relative to the property boundary)
4. Average operating pressure (when the system is pressurized)

The equation developed for UARL by IWA is shown in equation (2).

UARL (l/d) = $(18 \times L_m + 0.8 \times N_c + 25 \times L_p)P$ ……………..……………….. Equation (02)

Where L_m = Main length (km)
N_c = Number of service connections
L_p = Total length of private pipes (km)
P = Average pressure (m)

The complex initial components of unavoidable annual real losses (UARL) formula were converted to a "user friendly" pressure dependent format for practical use.

RESULTS AND DISCUSSION

Standard water balance for Hantana WSS

The level of water losses can be determined by conducting a Water Audit (North American Term) with the results shown in a Water Balance (International Term). To be consistent with the new international terminology, the term Water Balance has been used in this paper. A Water Balance is based on measurements or estimations of water produced, imported, exported, used and lost. Whilst most water utilities are able to provide estimates of water produced, imported, exported and consumed, they are less able to quantify the different components of water lost.

Table 1 shows the water balance results of Hantana water supply scheme as per the IWA standards.

Table 1. Water balance results of Hantana WSS from October 2006 to May 2007 (average value)

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption 63.88%	Revenue Water 63.88%
			Billed Un-metered Consumption 0%	
		Unbilled Authorized Consumption	Unbilled Metered Consumption 0%	Non-Revenue Water 36.12%
			Unbilled Un-metered Consumption 0%	
	Water Loss	Apparent Loss	Unauthorized Consumption 0%	
			Metering Inaccuracies 26.94%	
		Real Loss	Leakage on Transmission and Transmission Mains 0%	
			Leakages and Overflows at Utilities Storage Tanks 0%	
			Leakage on distribution systems and service connections up to the Point of consumer meter point 9.18%	

Billed authorized consumption

This is the components of Authorized Consumption which are billed and produce revenue (also known as Revenue Water). It is equal to Billed Metered Consumption plus Billed Un-metered Consumption. In Hantana WSS billed authorized consumption is 63.88%.

Unbilled authorized consumption

Those components of unbilled Authorized Consumption which are legitimate but not billed and therefore do not produce revenue. This is equal to Unbilled Metered Consumption plus Unbilled Un-metered Consumption.

Apparent losses

This includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use). Over-registration of customer meters, leads to under-estimation of Real Losses. Under registration of customer meters, lead to over-estimation of Real Losses. In Hantana WSS apparent loss is about 26.94% (average value). This value is comparatively higher due to existence of excessive number of old and defective water meters.

Real losses

This is the physical water losses from the pressurized system up to the point of customer meter point and the utility's storage tanks. The annual volume lost through all types of leaks, bursts and overflows depends on frequencies, flow rates, and average duration of individual leak. Although physical losses, after the point of customer use, are excluded from the assessment of Real Losses, this does not necessarily mean that they are not significant or worthy of giving attention for demand management purposes. The calculated real loss of Hantana water supply scheme is 9.18% (average value).

Billed metered consumption

This refers to all metered consumptions which are billed. This includes all groups of customers such as domestic, commercial, institutional and other non-domestic. In Hantana WSS, billed metered consumption is about 63.88% (average value).

Billed un-metered consumption

In Hantana WSS, all water connections have been metered, so billed un-metered consumption can be considered as zero percent.

Unbilled Metered Consumption

This is the metered Consumption which is unbilled due to any reason. This may, for example, include metered consumption by the utility itself or water provided to other institutions without billing. There is no such institution in Hantana, so unbilled metered consumption is also estimated as zero percent.

Unbilled Un-metered Consumption

This includes any kind of Authorized Consumption which is not billed and un-metered. This component typically includes items such as fire fighting, flushing of mains and sewers, street cleaning, frost protection, etc. As Hantana WSS serves a small community, which is away from the Kandy commercial city, there are no provisions for fire hydrants and street cleaning facilities. Hantana sewer network is also basically a gravity type well operated system with the facility of self flushing. Hantana sewerage plant is facilitated with metered water connection. Unbilled Un-metered Consumption of Hantana WSS is also considered as zero percent.

Unauthorized consumption

This refers to any unauthorized use of water. This may include illegal water withdrawal (*e.g.* for construction purposes), illegal connections, bypasses to consumer meters or meter tampering. Proper investigation was done for individual consumers during the research, but there was no illegal usage detected.

The reason for not having illegal usage of water in Hantana WSS may be the level of income of the consumers. Almost all consumers of Hantana WSS are upper middle class dwellers with averag high income. It is a common experience to the NWSDB that most of the illegal connections are categorized under non-domestic usage. In Hantana WSS non-domestic consumption can be neglected. Unauthorized consumption of Hantana water supply scheme is zero percent.

Customer metering inaccuracies and data handling errors

This includes apparent water losses caused by customer meter inaccuracies and data handling errors in the meter reading and billing system. It was observed in the research that there are number of meters in Hantana WSS which are too old and need to be replaced immediately. Some of the meters are more than 20 years old and still the water consumption is read with them, but the accuracy of these readings are doubtful. Also, there were a number of defective meters recorded regularly during the study period, which were about 15 connections per month (3% of total connections).

There was another set of meters encountered in the research, which were not accessible. Some houses were permanently closed, meter readers cannot enter the premises in some places, some meters were obstructed etc. Two percent of total connections of Hantana WSS can be grouped under this category.

It was realized in the research that there were a number of human errors associated with the processes of meter reading, recording and data entering.

It was estimated that the water losses associated with meters are high as 26.94% in Hantana WSS. This is the most predominant component of the total NRW of the scheme (36.12%) and further studies have to be carried out to understand the situation in detail. Also it is important to consider the accuracy of the available water meters.

Leakage on transmission mains

This covers the water loss from leaks and bursts in a transmission system. Transmission lines of Hantana WSS are well designed. All high pressure transmissions are Ductile Iron Pipes and rest of the lines are heavy duty PVC (Type 1000) pipes. There was not a single breakdown of transmission lines recorded in the research period. It can be concluded that the leakage on transmission mains of Hantana WSS is zero percent.

Leakage and overflows at utility's storage tanks

This is the water lost from leaking storage tank structures or overflows of such tanks caused by operational or technical problems. The storage capacity of Hantana WSS is as high as 1750 m^3, which is sufficient to store 3 days demand of the scheme. High retention capacity of the scheme assures the smooth service to the consumers and also it prevents losses from tank overflow.

According to the readings of level indicators of reservoirs, there were no records detected to reach overflow level during the research period from October 2006 to May 2007. These levels were monitored during non peak hours.

With these results it can be concluded that the leakages from storage tanks can be considered as zero percent in Hantana WSS.

Leakage in distribution and service connections

This is the water loss from leaks in distribution system and service connections from the tapping point to customer meter point. Water lost in Hantana WSS due to these leaks was calculated as 9.18%.

Revenue water

This includes those components of Authorized Consumption which are billed and produce revenue (also known as Billed Authorized Consumption). This is equal to Billed Metered Consumption plus Billed Un-metered Consumption. In Hantana WSS revenue water consumption is about 63.88%.

Non-revenue Water of Hantana WSS

This includes those components of System Input which are not billed and do not produce revenue. This is equal to Unbilled Authorized Consumption plus Real and Apparent Water Losses. In Hantana WSS non revenue water component is about 36.12%.

Reduction of NRW of Hantana WSS

Reduction of NRW during the research period of eight months is shown in Figure 1.

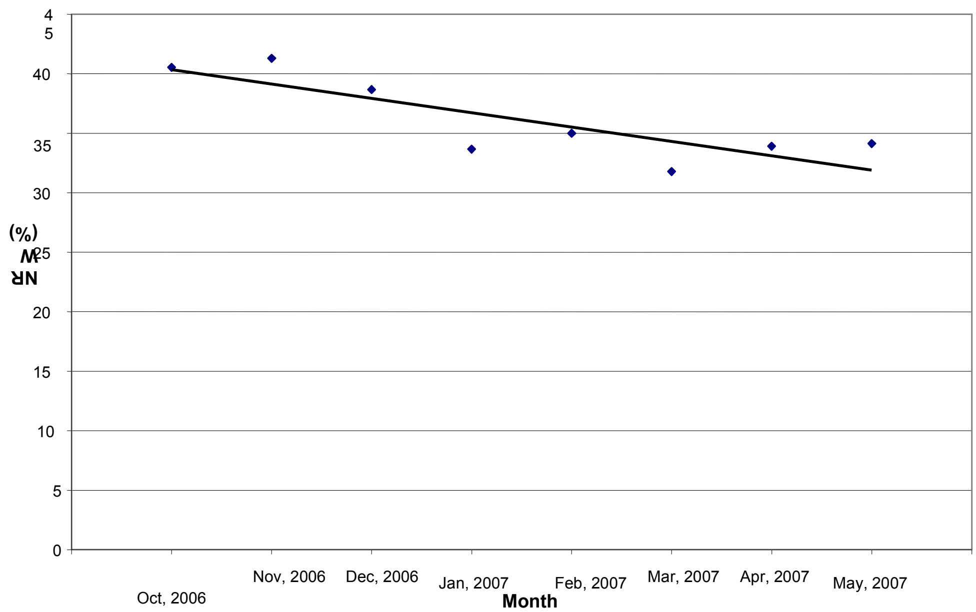

Figure 1. NRW percentage after introducing the reduction strategies

Using the student t-test it can be stated with more than 95% confidence that there is an improvement in the system by implementing the special program in Hantana WSS.

Unavoidable annual real losses (UARL)

The Current Annual Real Losses (CARL) can easily be derived from the Standard Water Balance. The equation developed for UARL by IWA was applied for Hantana WSS and the value of UARL is very low (4.6%) compare to the other water utilities in the world. Therefore the complex initial components of UARL formula were converted to a 'simple' pressure-dependent format for practical use in Hantana WSS as shown in equation (3).

UARL (liters/day) = (18 x Lm + 0.8 x Nc + 25 x Lp + 10 x Y) x P ……….Equation (03)

Where Lm = mains length (km); Nc = number of service connections; Lp = total length of private pipe, curb-stop to customer meter (km); P = average pressure (m), Y= Age of the scheme (yr).

The above equation (Equation 03) has been developed to suit the local conditions of Hantana WSS. It was noticed in the special programme that there are limitations like physical and financial resources to reduce NRW in the scheme.

The infrastructure leakage index (ILI)

The ratio of the CARL to the UARL is a measure of how well the water utility agency operates the system. Although a well managed system can have an ILI of 1.0 (CARL = UARL), this does not necessarily have to be the target as the ILI is a purely technical performance indicator and does not take economic considerations into account.

The Infrastructure Leakage Index (ILI) of Hantana WSS is 5.6 (CARL=36.12% and UARL=6.4%). This value is remarkably high and there is a possibility to reduce this amount by introducing the suitable technical changes and investing required funds.

Leak prone areas of Hantana WSS

The pin map developed to identify the leak prone areas is depicted in Figure 2. There are four major leak prone areas where the water pressure is very high. The propagation of more leaks is concentrated to high pressure areas of distribution system. This map can be used to monitor and rehabilitate the distribution network.

The best way to understand the existing water supply scheme is to develop and update a pin map. A properly updated pin map helps to identify the leak prone areas of the network which helps to develop a leak reduction program to minimize water losses. Four major leak prone areas were identified in the pin map of Hantana WSS.

It was observed in the study that there is a common pattern of pipe bursting in Hantana WSS. Pipes burst at night time (during the off peak hours). They are reported in the morning and repaired afterwards. The best time to detect leaks is at night (off peak hours).

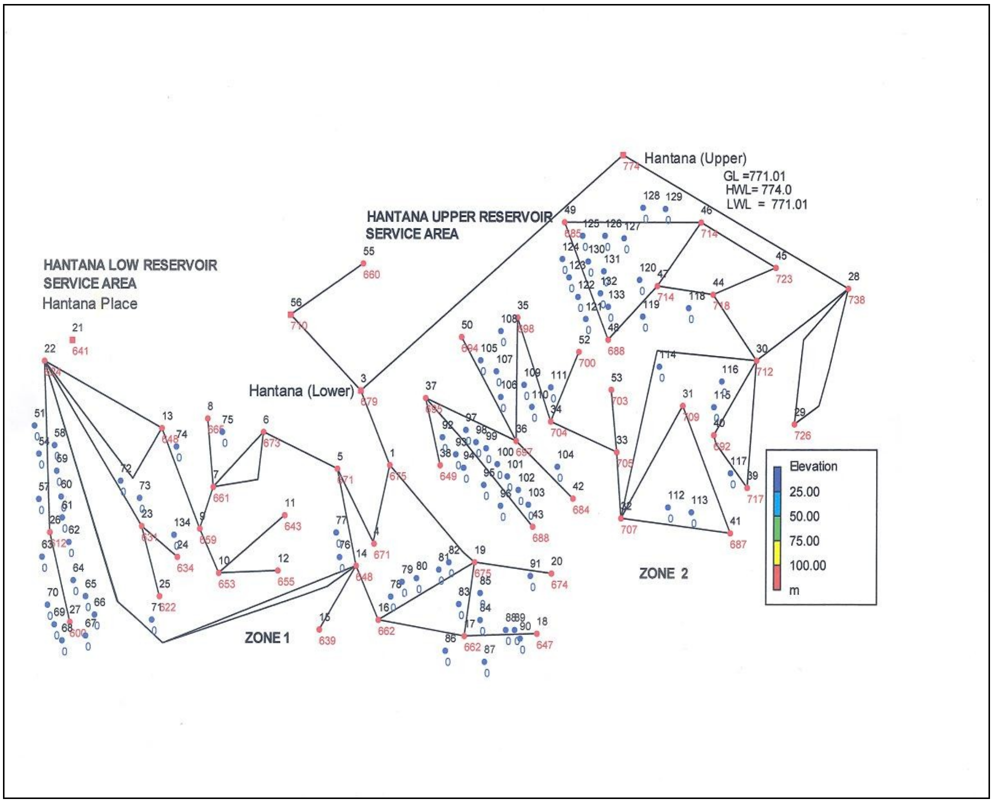

Figure 2. Pin Map of Hantana Water Supply Scheme

Water quality and water meter functioning

According to the test reports, chemical qualities of Hantana water supply system are maintained within the desirable limits. There is no possibility of scaling the impellers of water meters. Therefore, the chemical qualities of Hantana WSS are not affected for the meter functioning.

Table 2 shows the water quality parameters of Hantana WSS during the study period from October 2006 to May 2007.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The real and apparent water losses of Hantana WSS are 9.18% and 26.94% respectively. The apparent loss is remarkably high. Amount of water theft in distribution network of Hantana WSS is zero.
2. Minimizing of water leakages does not significantly reduce the NRW of Hantana WSS. The UARL (as the percentage of production) for Hantana WSS is 6.4%. The Infrastructure Leakage Index of Hantana WSS is 5.6, which is a remarkably higher value than the other water supply systems.

3. At the design phase, no proper attention was given to reduce the excessive water pressure in the distribution network.
4. Continuous night flow measurements are very helpful to identify active and passive leakages. Accordingly, a number of major leaks were identified and rectified immediately during the research period.
5. The number of defective and old water meters in Hantana WSS is very high.
6. The chemical qualities of Hantana WSS does not affect the meter functioning.

Table 2. Water quality parameters of Hantana WSS

Parameters	SLS 614:1983 Part 1 & 2	Maximum		2006 October	2006 December	2007 February	2007 April
		Desirable level	Permissible level				
pH	-	6.5	9.0	7.7	7.37	7.54	6.9
Conductivity at 25^0 C	µs/cm	750	3500	147	95	107	135
Alkalinity total	mg/l $CaCO_3$	200	400	45	32	44	30
Hardness total	mg/l $CaCO_3$	250	600	48	50	50	48
Iron total	mg/l Fe	0.3	1.0	0.04	0.07	0.14	0.02
Residual Chlorine	mg/l Cl_2	0.2	1.0	0.5	1.0	nil	1.0

Recommendations

1. It was found that the water loss due to the Metering Inaccuracies in Hantana WSS is very significant. It is recommended to investigate the effect of meter replacement on the performance of Hantana Water Supply Scheme.
2. It was observed that the average water pressure of distribution system of Hantana WSS is very much higher than the other water supply systems. It is recommended to reduce water pressure of the system which may lead to the reduction in the NRW of the scheme.
3. Four major leak prone areas were identified in the pin map developed in the research. It was observed that the pressures of all identified areas are above average. It is highly recommended to replace the pipes in these areas with high pressure sustain pipes.
4. It is recommended to develop an additional design guideline for designing of water supply networks for hilly areas (small area of coverage, but high elevation difference).

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