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Estimation of NRW using Main Parameters of Water Distribution Systems

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Abstract

The non-revenue water (NRW) is the water losses from unbilled authorized consumption, obvious losses and actual losses among the total amount of water supply (tap water supplied from water purification plants) in the water distribution systems. Various studies analyze data using statistical methods and identify the relationship as a method to estimate the NRW. For estimating the NRW of the water distribution systems, selected main parameters were used to this study. The main parameters were used to ANN model simulation, and compared to observed NRW data to determine the accuracy of NRW estimation. In the results, the method using artificial neural network was found to be more accurate in estimating the NRW than multiple regression analysis. In this study, the effective parameters of the NRW were determined, especially physical and operational parameters have high relationship to the NRW estimation.

1 Introduction

In the early 1990s, no standard term existed to express and assess water losses in the distribution system. The International Water Association (IWA) has acknowledged this problem and established the Water Loss Task Force (WLTF). The WLFT examined international best practices and developed a standardized terminology for non-revenue water (NRW) [1]. NRW includes physical (pipe leaks) and commercial losses (illegal connections, unmetered public use, meter error, unbilled metered water and

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water for which payment is not collected) [2]. IWA has proposed performance indicators for analysis of water distribution systems [3].

Based on an analysis of the effect of pipe damage on the overall pipe network in determining the priorities improving the water pipeline [4], a systematic replacement and remediation plan has been set for the maintenance of the metropolitan waterworks [5]. The index of the NRW of water distribution systems needs to be proven through correlation with the characteristics of the region and quantifying the influence of water supply parameters. Reduction of the NRW is thus essential to maintain sound financial operation of a waterworks business. In operational management, a low NRW signifies proper management from tap water production to bill collection; a high NRW usually means problems in the operation management of the facility (unmeasured quantity by water meter, leaks and illegal use).

In this study, the model of NRW estimation was suggested by using an artificial neural network (ANN) and analysing main parameters of water distribution systems. The statistical method was used to compare the results of ANNs and real measured values of the NRW.

2 Methodology for NRW Estimation

2.1 Calculation of NRW

Non-revenue water (NRW) corresponds to the percentage of water lost due to leaks and commercial problems, such as lack of micrometer precision or mistakes in client databases. In Eq. (1), Ap is the volume of water produced per time unit and Ab is the volume of billed water per time unit [6].

$$NRW = (Ap - Ab) / Ap \tag{1}$$

The definition of NRW could be described as the difference between the volume of water put into a water distribution system and the volume billed to customers. The NRW has three components [6]:

(a) Physical losses comprise leaks from all parts of the distribution system and overflows at the utility's storage tanks. They can be caused by poor operations and maintenance, lack of active leak prevention and poor quality of underground assets.

(b) Commercial losses are caused by the under-registration of customer meters, errors in data handling and the theft of water in various forms.

(c) Unbilled and authorized consumption includes water used for operational purposes or firefighting and that provided for free to select consumer groups.

For NRW estimation, governments around the world are calculating leaks using those occurring in infrastructure and their economies. To calculate NRW, a formalized system is needed that calculates the NRW by introducing physical parameters that reflect regional characteristics.

2.2 Principle of Artificial Neural Network

According to Haykin, a neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use [7]. The neural network resembles the human brain in two respects: knowledge is acquired by the network through a learning process and inter-neuron connection strengths (known as synaptic weights) are used to store the knowledge. The ANN procedure used is a feed-forward network type with input, hidden and output layers. The ANN procedure used is a feed-forward network type with input, hidden and output layers, as shown in Fig. 1.

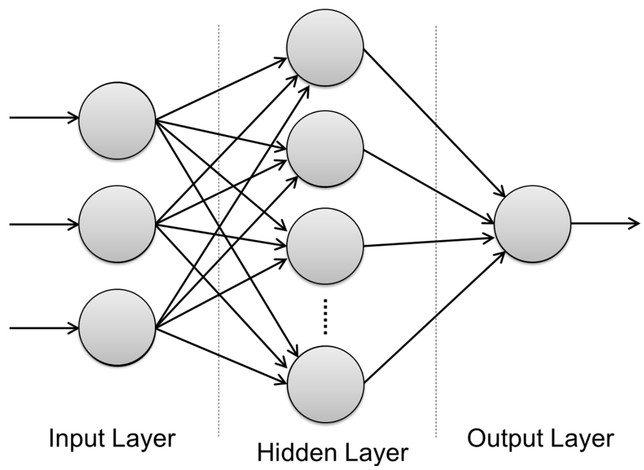


Figure 1. Schematic Diagram of a Multilayer Feed-Forward Neural Network [7]

Learning by the error propagation algorithm compares the calculated value in all directions of the ANN with the target value for learning and adjusts the weighing factor so that the sum of errors is minimized. This is performed until the error meets a certain value, and when the iteration is finished, the final value is calculated as output.

3 Determine of Main Parameters

Prior to estimating the main parameters for NRW estimation, Shinde et al. (2013) selected reliable indicators for water supply and safety in water supply facilities [8]. In Korea, the Ministry of Environment (MOE) set the country's main indicators and classification of water distribution systems. In the evaluation of aging and small DMAs, factors are classified based on the physical parameters of a water distribution system and scoring is done according to the weights.

Direct factors are classified as physical and operational parameters and indirect factors as socioeconomic parameters and others [9]. Classification between quantitative and qualitative parameters is also distributed with a data acquisition condition considering the data characteristics of selected parameters. And quantitative parameters must be converted by using data quantification criteria for each region or country. The selected main parameters showed in Chapter 4 in the ANN simulation cases.

Table 1 Selected main parameters for estimation of NRW [9]

Classification	Parameters
Physical	· Pipe material · Mean pipe diameter · Amount of water supply per No. of demand junction · Pipe length per No. of demand junction · Deteriorated pipe ratio
Operational	· No. of leaks · Demand energy ratio · Leak recovery ratio

Among physical, operational and socioeconomic parameters per the parameter classification system, the selected physical parameters are pipe material, mean pipe diameter, amount of water supply per number of demand junction, pipe length per number of demand junction, and deteriorated pipe ratio. Operational parameters include the number of leaks and ratios of demand energy and leak recovery [9].

4 Estimation of NRW using Main Parameters of Water Distribution Systems

4.1 Simulation Cases and Selection of Test Area

The used data were surveyed on the status of the area, waterworks facilities and their operational status, and the water supply indicators of the basic plans for the Incheon waterworks [10]. In addition, data on water pipe network analysis and simulation were collected [11].

Incheon has a water population of 2,851,491 and a water supply rate of 98.3 percent (Incheon Metropolitan City Waterworks Division, 2015). The daily water supply per person is 343 LPCD (liter per capita per day), and the water supply area has nine districts. Incheon has 24 reservoirs, 68 pumping stations and 3,634 km of water supply pipe from reservoir to water supply tap. Figure 2 shows a map of the city as the test bed of this study [9].

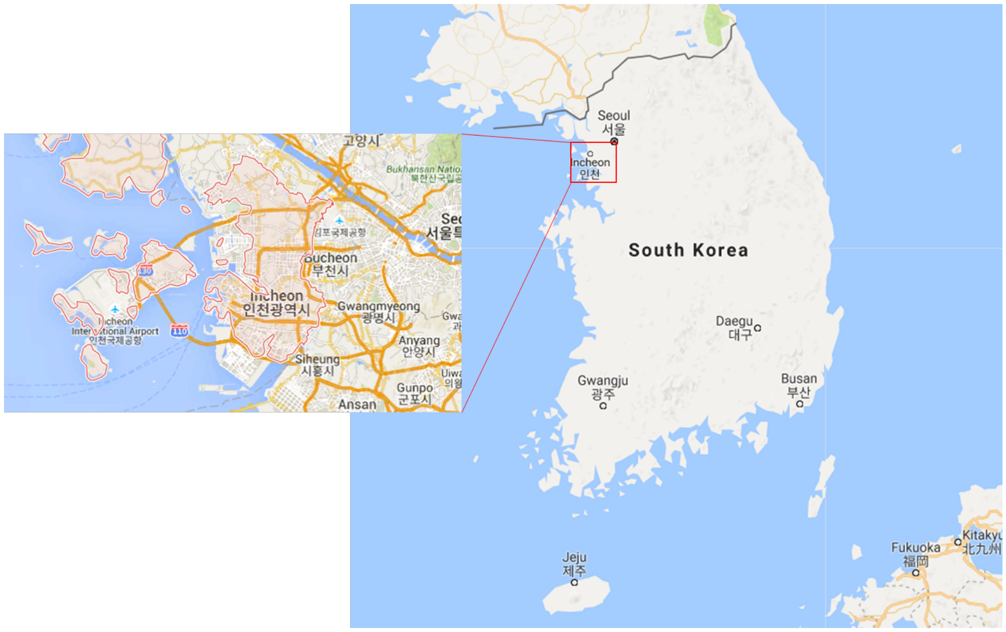


Figure 2. Location of Incheon Metropolitan City [8]

The study area for applying the developed methodology is Incheon, Korea. 173 district metered area were used for model construction and data of main parameters were collected. The entire simulation case is shown in Table 2. Cases were classified into detailed cases and ANNs were applied. The number of hidden layers in the modelling of ANN was divided into number of neurons selected with 12.

Data from the Incheon city for the selected parameters were collected. The data of the NRW ratio, a dependent variable, is based on the measured data of NRW in 2014, as shown in Fig. 3 [9].

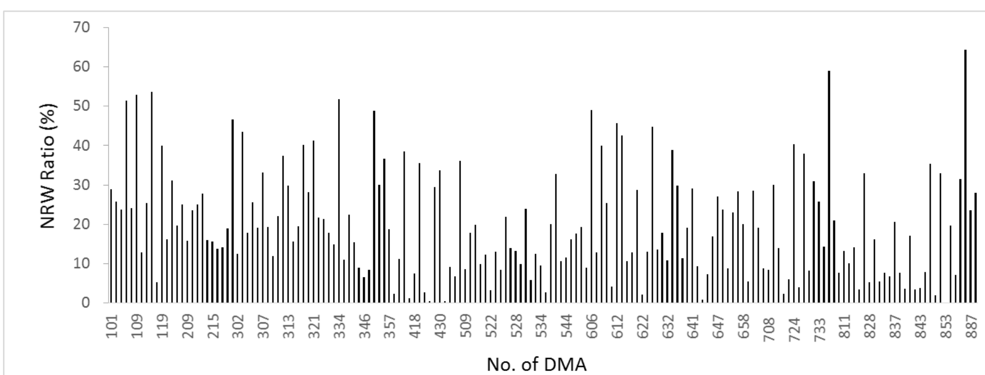


Figure 3. Data status of measured NRW ratio in Incheon city

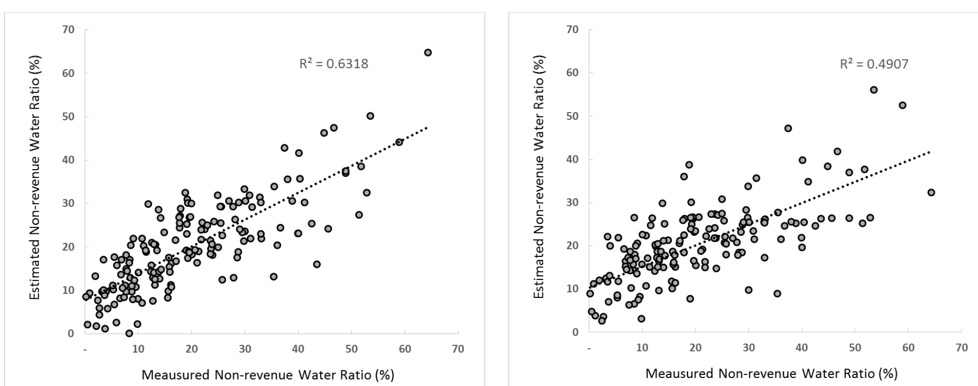
Table 2. Simulation Cases

Classification	Input variables
Case 1	Deteriorated pipe ratio, mean pipe diameter, amount of water supply per demand junction, demand energy ratio, pipe length per demand junction, No. of leaks
Case 2	Deteriorated pipe ratio, mean pipe diameter, amount of water supply per demand junction, pipe length per demand junction, No. of leaks
Case 3	Deteriorated pipe ratio, mean pipe diameter, amount of water supply per demand junction, No. of leaks

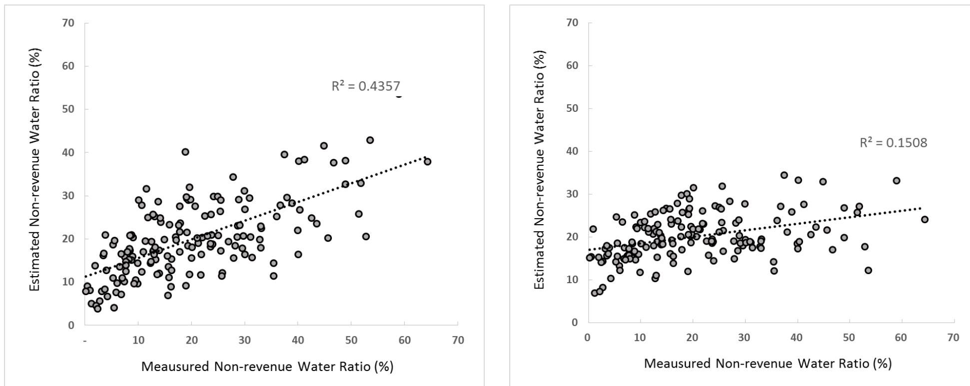
4.2 Estimation of NRW by Using ANN Simulation

The hyperbolic tangent equation is used for the activation function of ANN and the conjugate gradient method is used as the optimization algorithm. The minimum variation of the learning error is 0.0001, and the minimum relative variation of the learning error is 0.001. The results are repeatedly calculated until the error is minimized

The simulation condition of Case 1 is for calculating the NRW through ANN using the deteriorated pipe ratio, mean pipe diameter, amount of water supply per demand junction, demand energy ratio, pipe length per demand junction and the number of leaks including both physical and operational parameters. It is shown that the simulation of NRW using the total of 6 parameters has the highest prediction accuracy as Case 1. In NRW prediction, the R2 value decreased as the main parameter was excluded to ANN simulation. Therefore, it is concluded that 6 major parameters of water distribution systems are important for NRW prediction. In addition, NRW estimation by ANN is more accurate than regression equation by MRA. Simulation results of NRW estimation are shown in Fig. 4.



(a) Case 1 (b) Case 2



(c) Case 3 (d) Regression equation by MRA

Figure 4. Scatter plot between measured and estimated NRW by ANN Simulation [9]

5 Conclusions

Estimation methodology for predicting the NRW using statistical analysis has been proposed. NRW assessment model is developed by ANN which is flexible for defective data, the strength of prediction and classification.

The developed ANN model for estimation of the NRW ratio was applied to the test bed. A comparison was done on the accuracy of multiple regression analysis using the existing probability statistical method and developed ANN model using the main selected parameters in the water distribution systems. As a result, the ANN model was found to better estimate the NRW ratio than multiple regression analysis.

This study applied the main parameters of water distribution systems to ANN. The methodologies and guidelines for estimating the NRW ratio using ANN based on regional data can also be applied to determining on projects to improve the management of water distribution systems. When ANN is used to predict the NRW, finding the significance of parameters is possible because ANN calculates the optimized model considering the interconnection between individual parameters.

In water distribution systems, if the quantified and obtainable data are sufficient for ANN simulation is applicable, ANN's utilization in NRW forecast is suggested over using the equation through multiple regression analysis. This study is also expected to assist the creation of an optimal operating method for water supply facilities vis-a-vis pipe network analysis and DMA construction.

6 Acknowledgement

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