DEVELOPMENT OF FORECAST MODEL FOR DOMESTIC WATER DEMAND IN HUNG NHAN TOWN, HUNG HA DISTRICT, THAI BINH PROVINCE

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SUMMARY

To determine characteristics and construct forecasting models of domestic water demand in Hung Nhan town, Hung Ha, Thai Binh, 110 households were selected randomly for interviewing and measuring from June to August, 2017. Needed information such as: number of people, number of male and female, average income was gathered in each family by interview. Besides, domestic water consumption was recorded by water meter and using water level method. The change in water level in a tank expresses daily use of water in a household. To develop forecast model of domestic water, we used linear and multiple linear regression then its reliable was test by different indices. Main findings of this study are: (1) The domestic water amount varied in different households (0.17 m^3 ~ 1.17 m^3) and daily water consumption of about 0.17 m^3/person; (2) Four forecast models were developed. All models were statistically significant and showed a correlation between variables and domestic water demand but the one constructed based on numbers of male and female (Y_3) was the most reliable with value of NSE, PBIAS, R^2 of: 0.904, 0.07 and 0.73 respectively, while income-based model had lowest confidence (NSE = 0.51, PBIAS = 0.18, R^2 = 63). These finding suggested that all factors: number of people, gender and income had a relationship with domestic water demand and should be included in the forecast model construction in order to minimize the errors.

Keywords: Domestic water demand, forecast model, linear regression, multiple linear regression.

I. INTRODUCTION

Fresh water plays an important role in human daily lives but it tends to be declined because of human overconsumption. In the 20th century, water consumption grew 6 – fold (watercouncil.org, 2015) and predicted to be increased more in the future. A report by the US National Intelligence Directorate (DNI) says that current fresh water supplies would not be able to meet global demand by 2040 (Hoang Tuan, 2016), then water resources will be the oil of the 21st century (Andrew Liveris, 2008). Nowadays, more than 70% of Earth water is used for agricultural activities, 22% for industry, and 8% is used for domestic (Ethnic Minority Information website_2010). It is estimated that one person need 5 liters of water for drinking daily in order to survive with less activity. One American uses 100 to 175 gallons of water in one day and the entire world needs 4 trillion cubic meter a year (thewoldcount.com, 2014). As population grows, pressures on water scarcity intensify due to the higher demand of human.

There are many factors that affect to domestic water consumption such as population, gender and income, etc… The impacts of population on the quantitative need of local people is related to the rate of increase or decrease in population growth. Population is highly correlated with public water supply, about 56 percent of which is allocated for household purposes. According to experts, in the last century, world fresh water use has increased more than 2 times due to population growth and global warming. Otherwise, it is detected that the difference between male and female also affected to water consumption. Normally, female are more intensive water using than male. The last factor mentioned here is income. The higher income, the higher water amount people use. When people get more income, they do not have to pay much attention on how to allocate their finance and obviously, they have ability and are willingness to pay for their demand for higher living standard. Due to the increasing of pressures on domestic water demand, we need to construct proper and reliable forecast model to have a look on water resource and from that, giving more solutions to manage it properly.

Domestic water consumption depends on many factors that were studied from the past. In the world, many researches were conducted for prediction of domestic water demand. Chen and Yang constructed a model based on extended linear expenditure system (ELES) to simulate the relationship between block water price and water demand, which provide theoretical support for the decision-makers. It is used to simulate residential water demand under block rate pricing in Beijing. Schleich and Hillenbrand (2009) analyzed Residential Fresh Water Demand (RFWD) in Germany with aggregated data and proposed that the increasing water prices and lower income levels were causing the recent decrease in water utilization in German new states. Domene and Sauri (2006) investigated additional factors in their household survey and concluded that income, housing type, family size, having a garden, owning a swimming pool and water conservation practices played important roles in water consumption in Barcelona, Spain. Fernando Arbués et al. analyzed several tariff types and their objectives of the literature on residential water demand. In the research water price, income and household composition were crucial determinants of residential consumption. Besides, researchers also took social factors into account. Jorgensen et al. (2009) integrated institutional trust in the household water use model and demonstrated that water conservation was more apparent when individuals were aware of the scarcity of water. However, in Vietnam, water forecast modeling mainly focuses on population changes so the reliability is not high. Therefore, we need to conduct and develop new forecast model combing more factors that is more useful reliable for predicting and sustainable management of water resource.

Hung Nhan town is a small town in Hung Ha district, Thai Binh province. Its population is 15900 (2017) and tends to increase year by year with the annual growth rate is 0.78% (2017). Hung Nhan town has an advantage of geography so that it attracts a lot of investment from both private and common sectors resulted in the lifting up of local people's living standard. Due to the growth of population and development of economic, local water sources tends to decline in both quality and quantity. Local people now use mainly rainwater and clean water provided by the water company. Up to now, there have been no researches studying the water demand as well as the forecast of household use in the locality while the water demand is increasing more and more. To sustainable water use management, a water demand model with high accuracy is useful for the study site and other location in Vietnam. Therefore, the study on "Developing forecast model of domestic water demand in Hung Nhan, Hung Ha, Thai Binh" is necessary.

II. RESEARCH METHODOLOGY

2.1. Study site

This research was conducted in Hung Nhan town, Hung Ha district, Thai Binh province (Figure 2.1). It occupies 8.84 km^2 with the population is 15900 (2017). Hung Nhan town consists of 16 villages, namely Thi An, An Xa, Dang Xa, Van, Buom, An Tao, Dau, Tien Phong, Xuan Chuc, Kieu Thach, Van Dong, Van Nam, Tay Xuyen, Lai and Me. There are two distinct seasons: wet season and dry season. The wet season lasts from May to October and the dry season is from November to April next year. Mean annual precipitation is

1629.6 mm. Mean annual temperature is 25.8°C. According to the statistic of local authority (2017), Hung Nhan town consists of 16 zones with 4695 households, the growth rate is 0.78% and the proportion between male and female is 121:100. Industrial and handicraft production is developing in the direction of concentration and expansion of production scale in the study site. The relatively high growth rate is becoming the spearhead of the town's economic structure. Local authorities maintain 13 developing villages, for industrial cluster planning with an area of 26.5 ha. The number of permanent employees is 3678 employees, accounting for 45.5 % employees in the town.

The research area is geographically convenient for multi-sector economic development, especially services. There are many investors in and out of town who have established companies, private businesses, and manufacturing establishments that promote developed economic and living standard of local people.

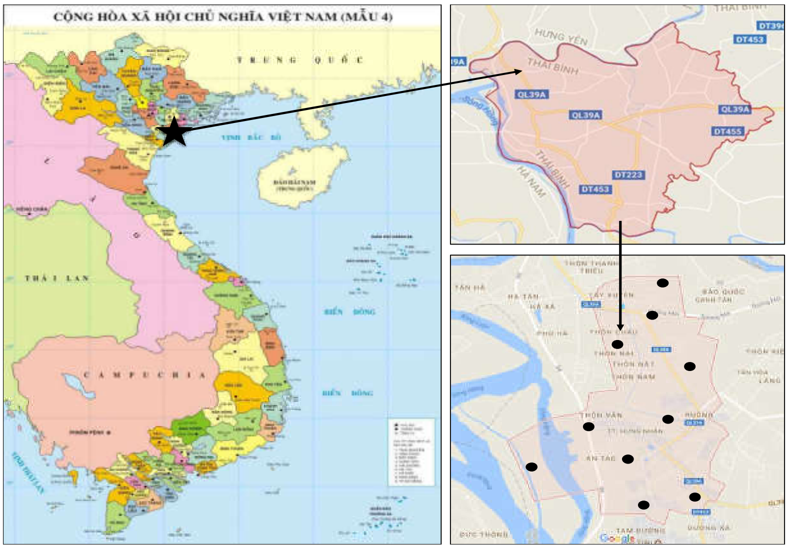

Figure 2.1. Location of study site

2.2. Methods

2.2.1. Evaluating the characteristics of domestic water demand in Hung Nhan town, Hung Ha, Thai Binh

To investigate the characteristic of domestic water demand in the study site, we used interviewing and observation method to get the needed information. 110 households were chosen randomly of which data of 100 households were used for constructing model and 10 households were used for model testing.

a. Interviewing method

A conductor went to each household to collect householder valuable information such as the name of householder, family size, gender components and average income. (From June 15th to 30th).

b. Measuring water demand

- Using water meter device that was installed to measure the volume of water delivered to a property (90_households) (Fig. 2.2a): Every day, researcher went to each household to record a number in the device (June 15th to August 15th).

- Using water level method (20 households) (Fig. 2.2b): Besides using water meters, some households still use well water for daily activities so water level was applied to get the amount of water consumption. We marked the position of water level and came back in the next day to check the change of water level in a specific tank (All the tanks were close to the air to prevent to change of water level due to evaporation and precipitation…) (June 15th to August 15th).

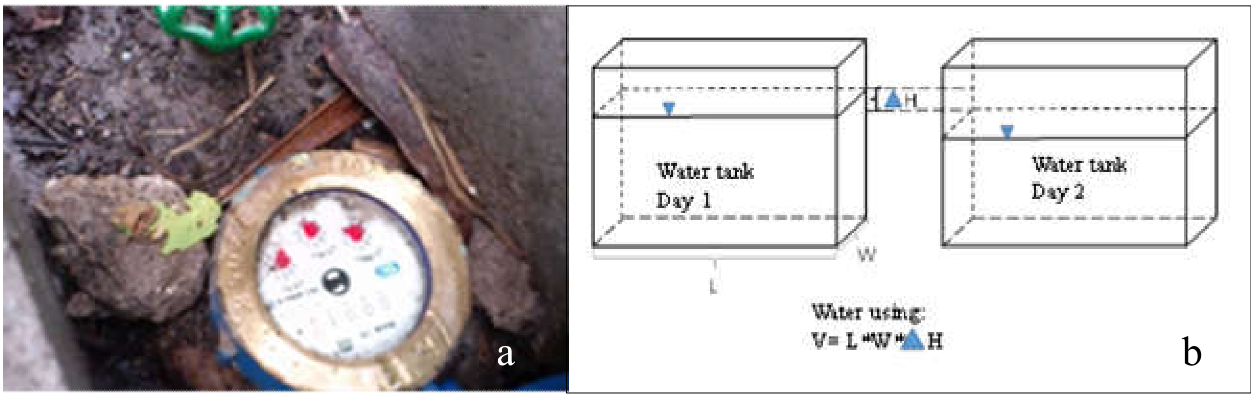

Figure 2.2. Water demand measurement: a. water meter; b. water level method

2.2.2. Developing forecast model of domestic water demand at the study site

After collecting data, R-studio was used to analyze by using data from 100 households.

a. Constructing linear regression

$$y = ax + b$$

In which: y: water demand (m^3); x: factor; a: constant number; b: slope of linear

Linear regression was used to determine the effect of population growth on the need to use domestic water with independent variables being the demographic variable and the effect of income on water demand. To analyze and construct these models, we used a linear model in R to estimate the values of α and β: lm (MW[1]~Variable), and analyzed linear correlation and give equations, models for each variable.

b. Constructing multiple linear regression

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \ldots + \beta_k X_{ki} + U_i$$

In which: Y_i: dependent variable that needs to forecast; X_i: independent variable; U_i: error.

For this types, the subject used predictive models with variables which are the number of people, male, female and income. After using the function "lm" in R, coefficients of β1, β2... βk were calculated and outputs were in the result set. In addition, variance, error, F test were also calculated in a simple way.

[1] MW: Domestic water demand of one household for one day

c. Analyzing variance

The variance analysis method is used to analyze the correlation and assess the reliability of the constructed model. To analyze the variance, the "anova" (analysis of variance) function in the R-studio software was used. This command has the form "**>anova (function_all_query)**". The result of this command gave data such as Sum of squares, Mean sq, F value, or P related to F test (Pr).

d. Model testing method

Data from 10 remain households (as mareked in Fig 2.1.) were used to evaluate the results of the model compared with observed data using the Nash-Sutcliffe efficiency (NSE), Percent Bias (PBIAS) and correlation coefficient (R^2):

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - O_{ave})^2}$$

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i - P_i)}{\sum_{i=1}^{n} O_i} \times 100$$

$$R^2 = \left\{\frac{\sum_{i=1}^{n}(O_i - O_{ave}) \times (P_i - P_{ave})}{\left[\sum_{i=1}^{n}(O_i - O_{ave})^2\right]^{0.5} \times \left[\sum_{i=1}^{n}(P_i - P_{ave})^2\right]^{0.5}}\right\}^2$$

In which: O_i (observed): observed data i; P_i (simulated): value of simulated data i; O_{ave}: mean of observed data i; P_{ave}: mean value of simulated data; n: number of sample.

- The NSE value is in the range from 0 to 1. The higher NSE, the more accurate predicted from the model or the higher the simulation level. The reflecting levels of the NSE coefficient are divided as the table 2.1.

Table 2.1. The simulation level of the model corresponds to the NSE index

NSE	0.9 - 1	0.7 – 0.9	0.5 – 0.7	0 – 0.5
Simulation level	Excellent	Very Good	Good	Bad

- The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate overestimation bias, whereas negative values indicate model underestimation bias. The result is given in percentage (%). Model is considered as reliable when deviation is not over 10%

- Model is acceptable when $R^2 > 0.5$.

III. RESULTS AND DISCUSSION

3.1. The characteristics of domestic water demand in Hung Nhan town, Hung Ha, Thai Binh

Actual water demand in the study area:

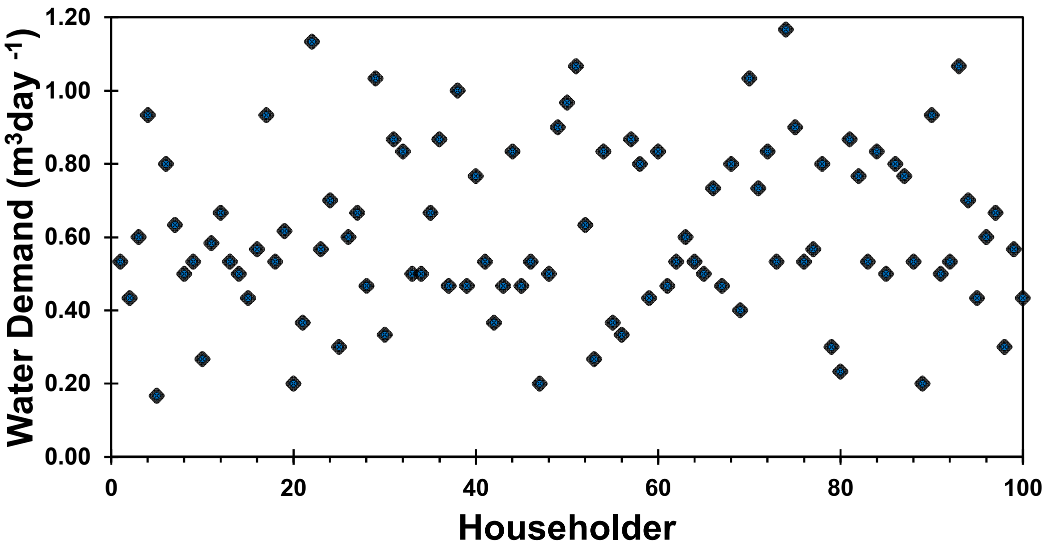

Figure 3.1. Domestic water demand of households in study site

The amount of water used in the daily activities varies among households. The lowest water volume was 0.17 m^3 while the largest was 1.17 m^3 (lower ~ 7 times). Averagely, each household consumed 0.61 m^3 in one day for daily activities. The causes of the difference in demand for water among households are: population, income and sex. The higher the number of family members, the higher the water consumption. Gender difference is also considered to be one of the cause leading to household water disparities as women are more water-intensive than men. In addition, the higher the income, the higher the affordability and willingness to pay. Especially, in the study area local people have to pay for the monthly clean water provided by the company. Therefore, to determine the impact of these factors on the demand for water use, the subject was analyzed in detail based on the models below.

3.2. Forecast model for domestic water demand in the study site

3.2.1. Linear regression model with number of people and income

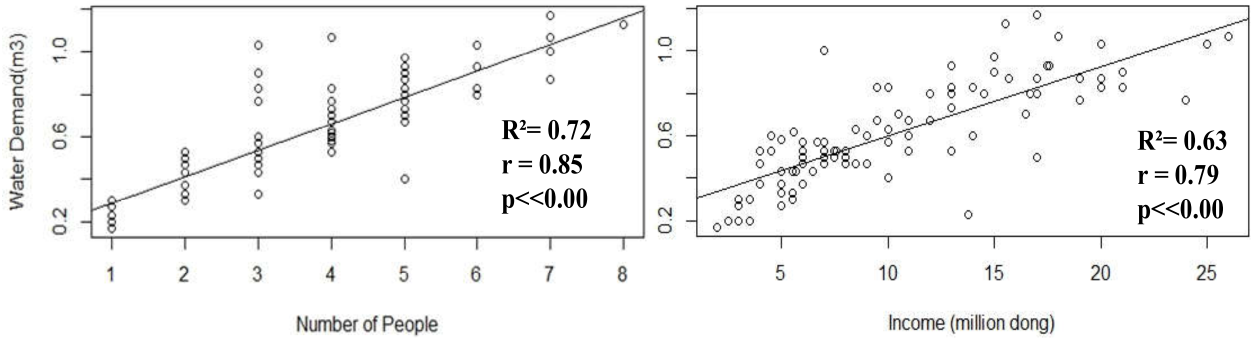

Figure 3.2. Relationship between Water demand and: (a) number of people; (b) Income

The equation expressing the relationship between Water demand and two independent variables: Number of people in one family and Income respectively are:

$Y_1 = 0.162 + 0.1243 * N$ and

$Y_2 = 0.274 + 0.032 * Income$

(N is number of people)

When the number of people increased, the level of water demand also went up. Based on the equation Y_1, *we can predict that when population is added by one person, the water use increases by 0.1243 m^3*. Water demand and Income also has the same trend of relationship. The higher income, the higher demand for water. *If household income rises by 1 million, the demand for water may increase by 0.032 m^3*. However, the degree of confident is not the same because of correlation coefficient value. The first model (Y_1) is more reliable with higher value of R^2.

Table 3.1. Testing value of model Y1 and Y2

	t - value	p - value	F - value	Pr	Signif code	s²	R²
Y_1	16.11	2e - 16	259.7	2.2e - 16	0 '***'	0.1208	0.726
Y_2	13.016	2e - 16	169.43	2.2e - 16	0 '***'	0.1397	0.633

We had the F value and the Pr value in these two models corresponding to the Signif code: 0 '***' meaning that the number of people in one household and income affects to the water demand. However, the first model (Y_1) is more reliable with higher value of R^2 (0.726 > 0.633). It means that 72.6% of the demand for water related to number of people while the figure for income is 63.3%. To sum up, model constructed with number of people is more reliable than the other.

3.2.2. Multiple linear regression with variables: male, female and income

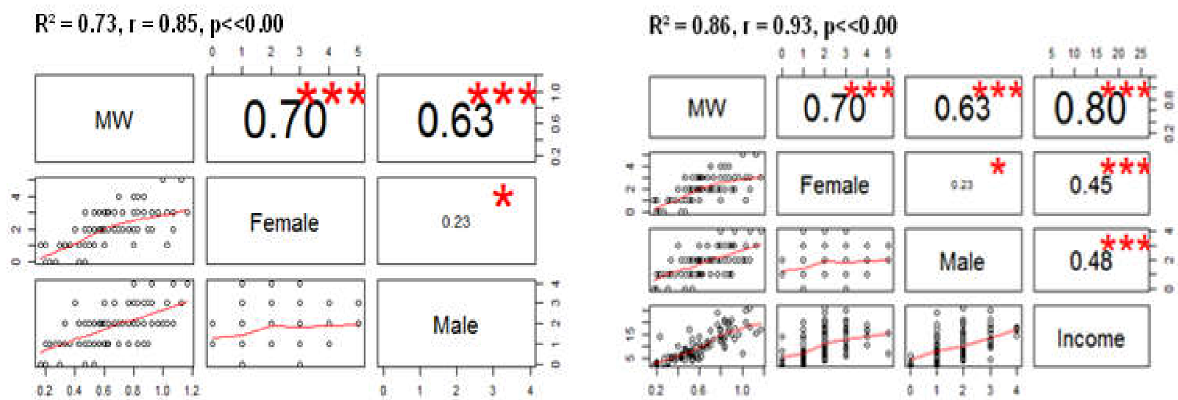

Figure 3.3. Relationship between water demand and female, male, income

The equation shows the relationship between water demand and genders is:

$$Y3 = 0.1622 + 0.12484 * Female + 0.12363 * Male$$

When the population increases by 1 female, the amount of water used will increase by 0.125 m^3*/day* and *each male will increase the water demand by 0.124* m^3*/day*. The demand for water of women is higher than that of men. It is clear that gender affects the demand for water in living.

The equation constructed based on water demand, female, male and income is:

$$Y_4 = 0.112248 + 0.079099 * Male + 0.090104 * Female + 0.018458 * Income$$

This function showed that:

- *If 1 person is added into number of male, water demand will increase by 0.08* m^3 *while this increase will change into 0.09* m^3 *if number of female changes 1 person.*
- *1 million VND increase in Income leads to the change of water demand by 0.02* m^3*.*
- *When combining all three factors: male, female and income to construct model, researchers detected that the correlation coefficient of income has the highest value (0.80) while the lowest belongs to male (0.63).*

Table 3.2. Testing value for Y3 and Y4

	p - value	Pr	Signif code	s^2	R^2
Y_3	2e - 16	2.2e - 16	0 '***'	0.1208	0.726
Y_4	2e - 16	2.2e - 16	0 '***'	0.08764	0.8586

With higher value of R^2 and low value of s^2, multiple linear regression model Y_4 may forecast water demand in the study site more accurately.

All four models Y_1, Y_2, Y_3 and Y_4 had the positive relationship with water demand. Only one of these factors that were used for model construction increases will lead the rise of water consumption.

3.3. Testing forecast model with NSE, PBIAS, R^2

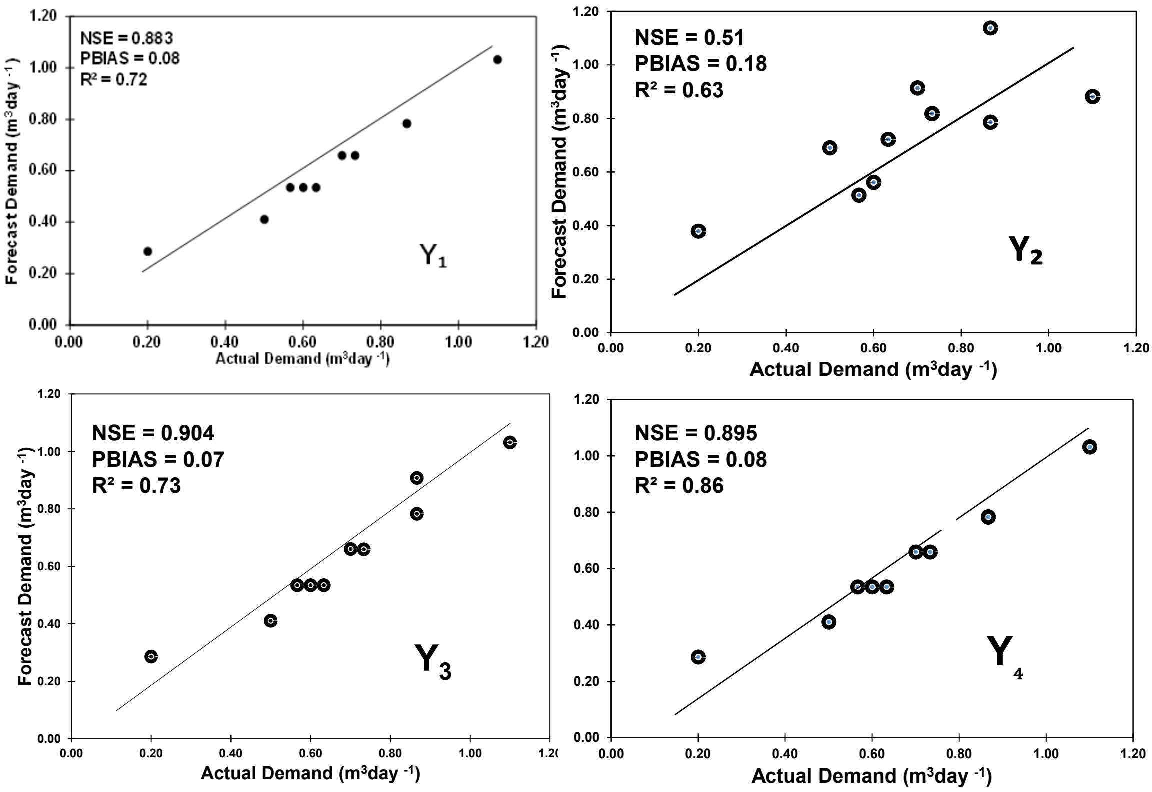

Figure 3.4. Testing model with NSE, PBIAS and R^2

Results of NSE, PBIAS, R^2 showed that all factors: number of people, income, genders had the relationship with domestic water demand in the study site of local people. However, income played less important role in comparison with other factors while gender is the most significant one.

So that, in reality when we want to construct forecast water model, we should separate population into two components: male and female. Model Y_3 is the most reliable one with NSE = 0.904, PBIAS = 0.07 and R^2 = 0.73 while model Y_2 has PBIAS value is overestimated (0.18 > 0.1).

3.4. Proposed solutions for water management in the study site

- Forecast water amount in the following 5, 10 and 15 years of the study site:

Topic used the most reliable model (Y_3) to forecast the amount domestic water demand in the next years [Assumed that in the next years, the growth rate (0.78%) and the ratio between male and female (121 : 100) are not change].

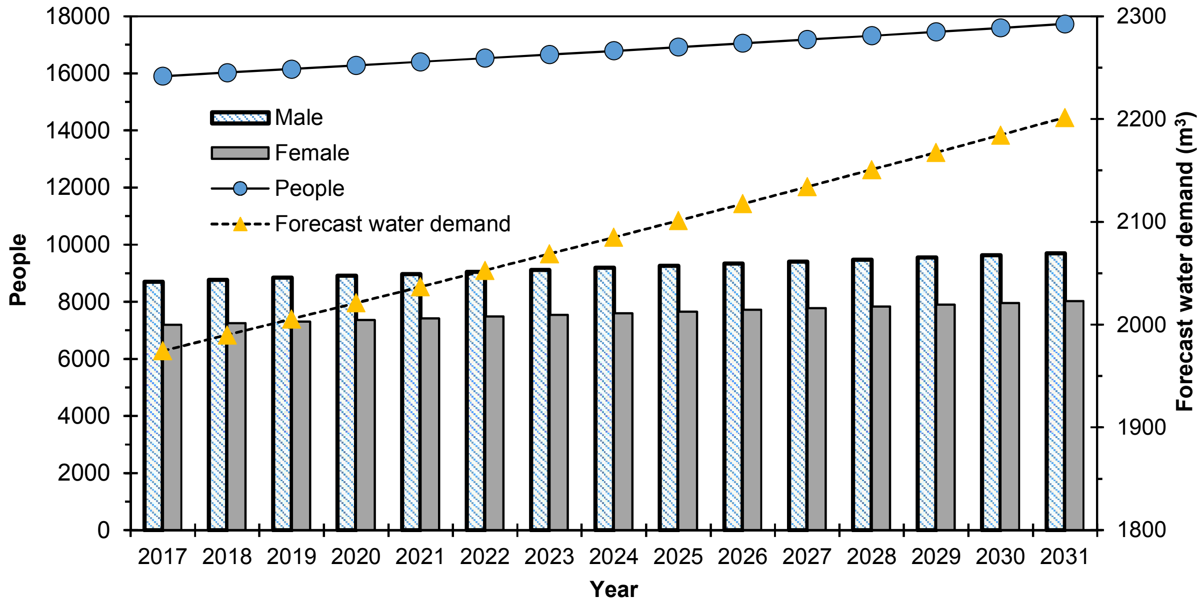

Figure 3.5. Forecast water demand of the study site from 2017 - 2031

Due to the rise of population, the demand for domestic water also goes up. As the results, the domestic water demand reaches 2201.47 m^3 per day in summer time (2031) (increases 11.5%). If there is no proper, economical and effective management, in the future, locale people may face with the lack of clean water. In order to contribute to the sustainable management of this resource for present and future, the topic suggests the following solutions: (1) Boosting family planning and trying to slow down the rate of population growth; (2) Involving social factors: local authorities need to construct more training program about fresh water to raise the awareness of local people, especially for the women – who use more water as the research showed in previous parts; (3) Forming the habit of using water in the family: People only open the faucet when needed and lock the faucet carefully after using to prevent leakage, overflowing wastage. Besides, water pipelines need to be checked regularly to avoid leakage. When taking a bath, using a shower and opening the hose when you need to use it or have it in the pot, to prevent the hose from flowing freely. Moreover, each household should set up water-saving appliances in the home such as shower, toilet with appropriate flush mode. (4) Building waste water treatment to reduce water pollution because sewage water also is one reason leading to the decline of water quality and quantity; especially when industrial activities is expanding in the study site; (5) Educating children from young age about the importance of water resource and guiding them how to use water in save and green way because they are the fortune of our planet and what they are taught today is what they will act in the future; (6) Strengthening staff training, professional fostering, expertise on EM, and protection of water resources; (7) Developing a program for management and protection of water resources with the participation of the community to lift up the awareness of local people in conserving this valuable resource; (8) Completing the policies and laws in water resources management, water exploitation and use.

IV. CONCLUSION

The data from 100 household was used to develop model, while 10 others was served for testing model section. Main finding of this research includes: (1) The using water amount of households in the studysite lies in the range (0.17; 1.17) m^3; one person need 0.17 m^3 per day for daily activities; (2) The research constructed 4 models: 2 based on linear regression and 2 based on multiple ones. In which, 2 models that give more reliable are: models with number of people in one family: $Y_1 = 0.162 + 0.1243 * \mathbf{N}$(NSE = 0.883, PBIAS = 0.08, $R^2 = 0.72$), and the other is constructed with gender & income: $Y_3 = 0.1622 + 0.12484 * \text{Female} + 0.12363 * \text{Male}$ (NSE = 0.895, PBIAS = 0.07, $R^2 = 0.73$); (3) The amount of domestic water demand in summer time (2031) is predicted to go up to 2201.47 m^3 per day (applied model Y_3). In order to manage water resource in the study site, topic proposed some solutions focus on human such as: propaganda family planning widely to cut down growth rate, develop saving water program, educate from young age and intensive involvement of local authorities.

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XÂY DỰNG MÔ HÌNH DỰ BÁO NHU CẦU SỬ DỤNG NƯỚC SINH HOẠT TẠI THỊ TRẤN HƯNG NHÂN, HƯNG HÀ, THÁI BÌNH

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TÓM TẮT

Để xác định đặc điểm sử dụng và xây dựng mô hình dự báo nhu cầu nước sinh hoạt tại thị xã Hưng Nhân, Hưng Hà, Thái Bình, 110 hộ gia đình được chọn ngẫu nhiên để thu thập dữ liệu bằng phương pháp phỏng vấn và đo đạc tại thực địa từ tháng 6 đến tháng 8 năm 2017. Các thông tin cần thiết như: số người trong một gia đình, số nam và nữ, thu nhập bình quân bằng phương pháp phỏng vấn. Bên cạnh đó, lượng nước tiêu thụ được đo bằng phương pháp sử dụng đồng hồ nước và quan sát sự thay đổi mực nước trong bể chứa ngày qua ngày. Để xây dựng mô hình dự báo nước trong nước, đề tài sử dụng hồi quy tuyến tính và đa tuyến tính, sau đó độ tin cậy của mô hình được kiểm tra bằng các chỉ số NSE, PBIAS và R^2. Những phát hiện chính của nghiên cứu này bao gồm: (1) Lượng nước sử dụng của các hộ gia đình dao động trong khoảng 0,17 m^3 ~ 1,17 m^3; (2) Đề tài xây dựng được bốn mô hình dự báo: hai mô hình đơn biến và hai mô hình đa biến. Cả bốn mô hình đều có ý nghĩa thống kê và chỉ ra được mối tương quan giữa các biến với nhu cầu sử dụng nước sinh hoạt của người dân. Tuy nhiên, mô hình Y_3 được xây dựng dựa trên số lượng nam và nữ là đáng tin cậy nhất với giá trị NSE, PBIAS, R^2 lần lượt là: 0,904; 0,07 và 0,73 trong khi đó mô hình với biến độc lập là thu nhập trung bình hàng tháng có độ tin cậy thấp nhất (NSE = 0,51, PBIAS = 0,18, R^2 = 63). Những phát hiện trên cho thấy các biến được xét trong đề tài đều có mối tương quan với lượng nước sinh hoạt tại các hộ gia đình vì vậy các yếu tố trên cần được đưa vào để có thể xây dựng được mô hình dự báo đáng tin cậy.

Từ khóa: Hồi quy đa tuyến tính, hồi quy tuyến tính, mô hình dự báo, nhu cầu sử dụng nước sinh hoạt.

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