การทำนายการใช้ทรัพยากรน้ำของชุมชนบ้านบ่อแก้วโดยแบบจำลองคณิตศาสตร์
Prediction of Water Consumption of Ban Bo Kaeo Community by Mathematical Modeling

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บทคัดย่อ

การวิจัยครั้งนี้มีวัตถุประสงค์เพื่อศึกษาและสร้างแบบจำลองคณิตศาสตร์ในการทำนายการใช้ทรัพยากรน้ำของประชากรชุมชนบ้านบ่อแก้ว ตำบลบ่อแก้ว อำเภอสะเมิง จังหวัดเชียงใหม่ จำนวน 115 ครัวเรือน ในพื้นที่ประมาณ 13 ตารางกิโลเมตร โดยวิเคราะห์ความสัมพันธ์ของข้อมูลเชิงสถิติและคณิตศาสตร์ เพื่อสร้างแบบจำลองการเติบโตของประชากรและพื้นที่การเกษตร โดยสร้างแบบจำลองจากข้อมูลจริงในระยะ 5 ปีที่ผ่านมา เพื่อนำไปเป็นข้อมูลเข้าสำหรับแบบจำลองการใช้น้ำ ผลการทำนายพบว่าในอีก 10 ปีข้างหน้าจะมีการใช้น้ำในบ้านและการเกษตรเพิ่มขึ้นจากปัจจุบันร้อยละ 7.82 และ 63.76 ตามลำดับ

Abstract

This research aims to study and create a mathematical model to predict the water consumption of Ban Bo Kaeo community Samoeng, Chiang Mai. There are 115 households within an area of approximately 13 square kilometers. By analyzing the relationship of data statistically and mathematically, models are created for the population and irrigated cultivated land growth. The models are validated and compared with actual data from five years ago. The prediction of population and irrigated cultivated land are input data for the water demand and consumption model to predict water consumed domestically and used for irrigation over the next 10 years. The models indicate that there will be increases of 7.82 and 63.76 percent for domestic and irrigation water consumption, respectively, from the present figures.

คำสำคัญ: การใช้น้ำ, บ้านบ่อแก้ว, แบบจำลองคณิตศาสตร์

Keywords: Water consumption, Ban Bo Kaeo, Mathematical modeling

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Introduction

In 2009 the estimated annual population growth rate (2009) was 1.10% (Census Bureau, 2009), this number is substantially higher in several other Asian countries that are already overpopulated. In Thailand, the population growth rate is 0.626 % (Indexmundi, 2009). Although, there is quite some uncertainty imbedded in these numbers, it is obvious that the current per capita water availability cannot be maintained, and that more strategic water management plans have to be designed and implemented (Wim et al., 2005).

The effect of climate change on water quantity is becoming a problem, as we know the world is now confronted with climate change which affects all organisms. On a more local level Thailand has a warm, tropical climate affected by an annual monsoon, with a rainy season from June to October and a dry season for the rest of the year. The tropical, rainy southwest monsoon is from mid-May to September. Chiang Mai is in northern Thailand, and it is affected by monsoon from November to mid-March, while the South is always hot and humid (Thailand Meteorological Department, 2010). Temperatures in Thailand average 75 to 92 degrees Fahrenheit, with the highest temperatures from March to May and the lowest in December and January. A change in climate can accelerate the hydrological cycle, which is affected by changes in precipitation, evapotranspiration, run-off and by any changes in the intensity and frequency of floods and droughts. We need to consider the permitted variation of environmental inputs such as the water regime and temperature and to simulate the crop response through several calculated growth parameters such as crop yield. Because of the complexity of the problem, research continues and improvements are constantly being made to models, e.g. for drought impact assessment (J.Eitzinger et al., 2003).

In Ban Bo Kaeo community, farmers take over 50% of water from ponds and lakes and 25% from wells. About 72% of the population use village water management in domestic areas. These water resources depend on the precipitation and the forest. In the future, we should practice water management to prevent drought. Nowadays, about 26% of farmers have problems with a lack of water to irrigate their farms, and thus produce is damaged. This is the main idea in undertaking this research. The aims of this study are to study and create mathematical models to predict water consumption of this community. The water demand and consumption models are the way to help the farmers to plan and use water resources in their community more efficiently and sustainably.

The model will enable us to determine the relationships between sectors and water resources, as well as the corresponding sectoral interrelations. It also allows simulation of the changes that the production structure would undergo if there were variations in water consumption, together with the effects that changes in demand and in sectoral production would have on the water resources of the region (Esther, 2006).

Research Methodology

Ban Bo Kaeo community, in Tambon Bo Kaeo Samoeng Thailand, was selected as the study area and is bounded by 18.85’N latitude and 98.57’E longitude and covers approximately 13 km^2. The study area was surveyed by searching maps, topological data and collecting some direct data using questionnaires and searching for some secondary data and information about the population, water resources and irrigated cultivated land from government offices. Firstly, we analyzed the growth rates of the Ban Bo Kaeo population and irrigated cultivated land by the predicted models.

To get suitable models for forecasting the population growth and irrigated cultivated land growth we compared the models with actual data from the last 5 and 10 years. Secondly, we estimated water consumption for domestic use and irrigation models and demand for domestic use and irrigation models. Then we found the total water consumed. After that the water consumption for domestic use and demand for domestic use for the Ban Bo Kaeo population could be forecasted. Next, we took the actual data from 1993 to 2008 for irrigated cultivated land to find the growth rate. Then we chose the best fit model for predicting the irrigated cultivated land in the next 10 years. The prediction of the Ban Bo Kaeo irrigated cultivated land was used to find the water consumption for irrigation and demand for irrigation models. Finally, we calculated the total water consumption and the total water demand for the next 10 years to help making decisions for planning using water in the community by What-if analysis.

The prediction of population model

Many models, logistic linear exponential and polynomial, have been considered to predict the population growth of Ban Bo Kaeo community. We have chosen exponential population growth to predict the population of Ban Bo Kaeo in 2020, because population growth normally exhibits exponential growth. In particular, when some values in nature grow, they almost always grow at an exponential growth rate (John, 2010). The model has been defined as follow;

$$P(t) = P_0 e^{r_1 t}, \tag{1}$$

where, r_1 is the growth rate of the Ban Bo Kaeo population, which is 0.0074. P_0 is an initial population, at 928 persons in 2005 and P(t) is the current population at year 1st to 15th (from 2006 to 2020). Growth rate is constant at 7 persons per year.

Water demand and consumption for domestic use model

Water demand for domestic use and water consumption for domestic use models (Likasiri, 2004), are calculated as (2) and (3);

$$C_1 = I_1 P \tag{2}$$

and

$$D_1 = \frac{C_1}{E_1}, \tag{3}$$

where C_1 is the water consumption for domestic use as output, I_1 is water consumption for domestic use as input and P is a prediction of Ban Bo Kaeo population which can be calculated from (1). Then D_1 is the proportion between the water consumption for domestic use, C_1, and the domestic water efficiency, E_1. The efficiency is described in percentage form and has taken from FAOSTAT where the domestic water efficiency of China equals 10 % (Likasiri, 2004).

The prediction of irrigated cultivated land model

The model was made from the irrigated cultivated land actual data, collected from 1998 to 2009. This can be predicted by an exponential growth model as shown in the following equation;

$$L(t) = L_0 e^{r_2 t}, \tag{4}$$

where L(t) is the area of irrigated cultivated land in the latest year. L_0 is the initial area at 180 rai, r_2 is the irrigation growth rate at 0.1015 and t means the time in years (t= 0: 19).

Water demand and consumption for irrigation model

Water demand for irrigation and water consumption for irrigation models, as defined in the calculation (Likasiri, 2004), are as follows;

$$C_2 = I_2 L \tag{5}$$

and

$$D_2 = \frac{C_2}{E_2}, \tag{6}$$

where, C_2 is water consumption for irrigation, I_2 is the water consumption for irrigation use and L is the actual irrigated cultivated land which has been substituted in (4). Afterwards, we took C_2 calculated from (5) and substituted it in (6) to calculate the water demand for irrigation, D_2, when E_2 is the water irrigation efficiency. The reference of irrigation efficiency is from FAOSTAT (2000)(specific name is AQUASTAT). The irrigation efficiency of China is 30%, so this number has been used in the equation to calculate water demand.

Total water demand and consumption

The total water consumption and demand models are calculated from the following models.

$$C_T = C_1 + C_2 \tag{7}$$

and

$$D_T = D_1 + D_2, \tag{8}$$

where, C_T is total water consumption of the community and D_T is the total water demand of the community.

Analyses of the models

From the survey, the author collected primary and secondary data to use in the water demand and consumption models. The population of Ban Bo Kaeo from 2005 to 2009 data is compared with the predicted population of Ban Bo Kaeo by the exponential population growth model. This is shown in figure 1.

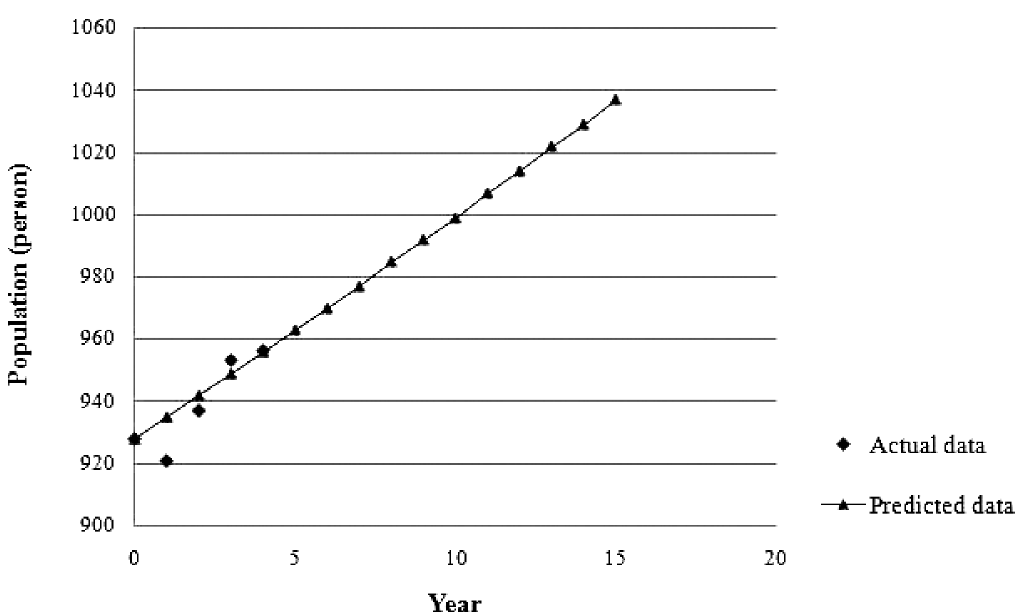

Figure 1. Prediction of Ban Bo Kaeo population by exponential growth model $P(t)=928e^{0.0074t}$.
Source: Samoeng district government office

The model for population growth can probably change, and thus depends on the growth rate over the period of time, but we use this possible model to represent the Ban Bo Kaeo population in 2020. The population would be 1037 in this area.

We then added input, the prediction of Ban Bo Kaeo population from the exponential model, into the water demand and consumption models from (5) and (6). Both equations were calculated and are described in figures 5 and 6, respectively.

To predict the growth of irrigated cultivated land, we must use the area of irrigated cultivated land in the last 10 years from the data in figure 2. In 2019 (20^{th}), the agriculture land will increase to be 2.19 km^2 which means if the farmers still grow a lot of economic crops and expand their irrigated cultivated land then they may end up with water shortage and abandon their crops. The amount of irrigated cultivated land increases when time increases and depends on Thailand's policies, economics, environment, the occupation of the villagers, population of villages, socio-cultural implications of different levels and patterns of cultivation in Ban Bo Kaeo community. For this prediction, we will consider only time change and consider that the pattern of cultivation will continue like this for the next 10 years.

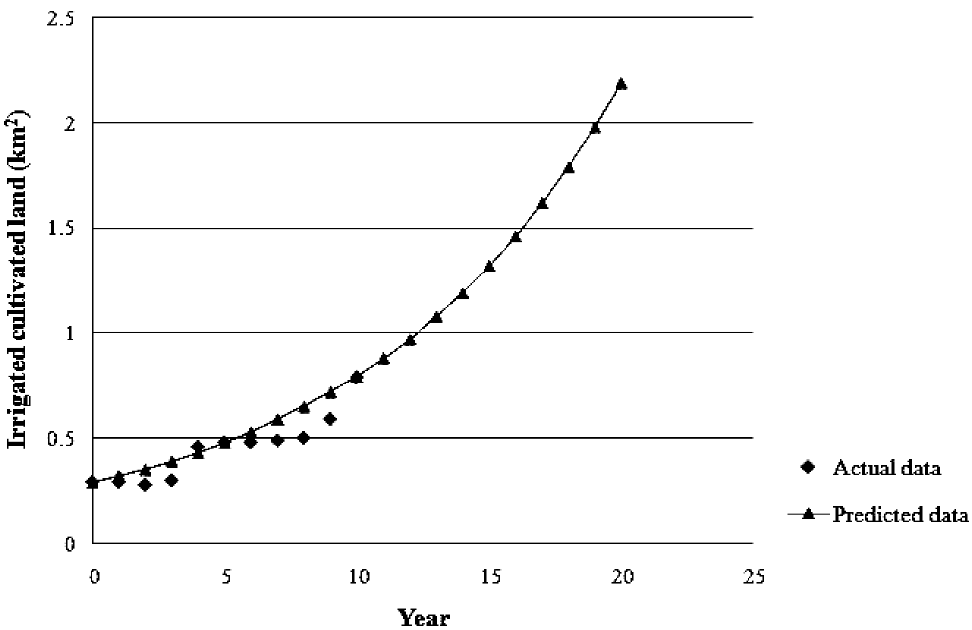

Figure 2. Prediction of Ban Bo Kaeo irrigated cultivated land by exponential growth model compares with actual data from 1999 to 2009.

Source: Suan Doi Kaeo, the agriculture community centre and Tambon Bo Kaeo Administration Organization (2008).

The trend of farm holding in Thailand from 1985 to 1998 has been plotted in figure 3. As you can see, the farm holdings decreased rapidly by about 7.5 % from 1989 to 1990 because between 1989-1995 there was a bubble economy period, so the price of the land was high between 1989 to 1990 at about 44.5% and 54.1% respectively (Kasikornresearch, 2003). This is the reason why the farm land dropped rapidly. It can be clearly seen that the trend of Thai farm land is decreasing. The trend of water consumption and demand for Thailand from 1993 to 2010 increases because of the expanded economy, agriculture, industry, households etc.. Fathis F. Lawgali has said "Water is a natural resource renewable in limited quantities. Demand for water increases with time, population and standard of living increase" (Fathis, 2008).

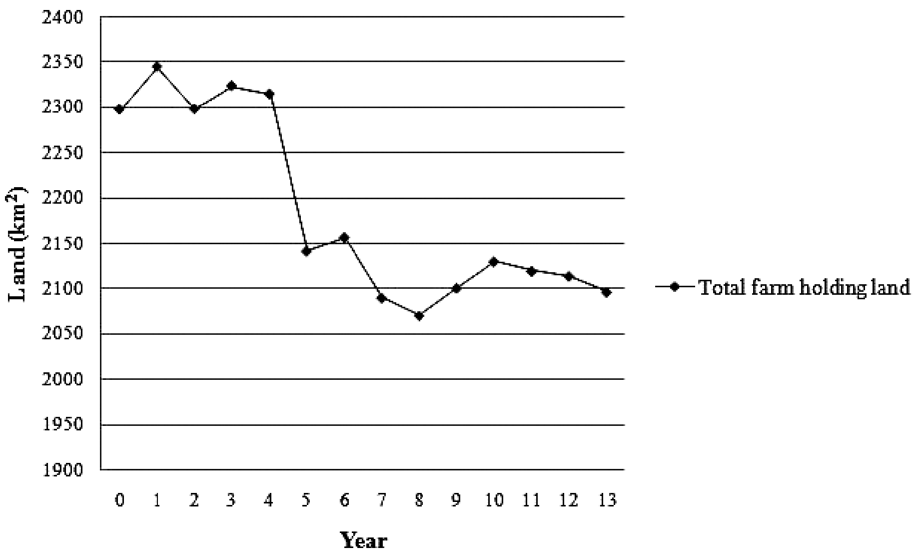

Figure 3. Total farm holding land of Thailand from 1985 to 1998. (Office of Agriculture Economics, 2010)

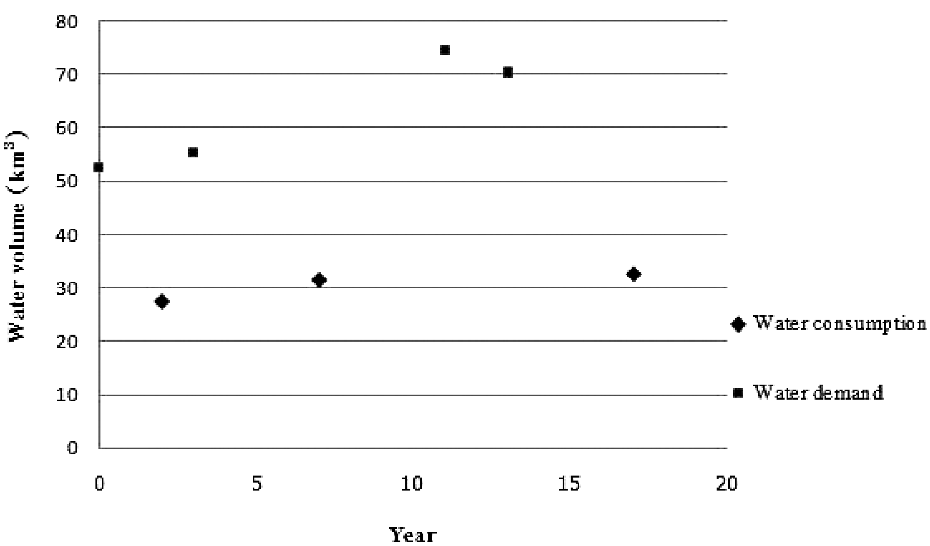

Figure 4. Trend of water consumption and demand for Thailand from 1993 to 2010.

Source: Royal irrigation Department and UNESCO by estimate of SHI (Igor, 1999)

Results

When we have the predicted population of Ban Bo Kaeo, we can predict the water consumption for domestic use and water demand for domestic use by using (2) and (3) models. Also, from the predicted data for the irrigated cultivated land (L), we can predict water consumption for irrigation and water demand for irrigation by input I_2 and L into (5). We then input C2 into (6). Then we analyze the what-if analysis into 3 cases as in the results shown below.

Case 1 Pessimistic Outlook

If the efficiency of using water domestically is 2%, dropped from 5%, the demand would be 1.2443×10^6 m^3/year, see figure 5.

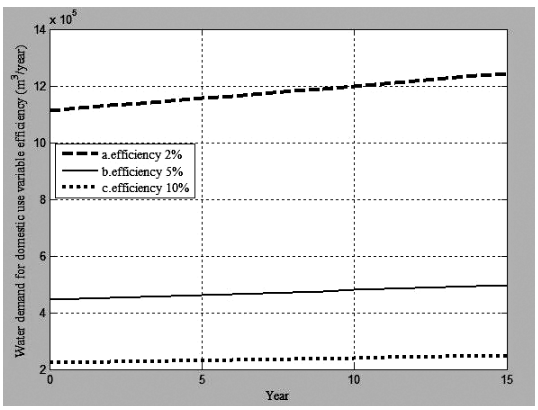

Figure 5. The prediction of water demand for domesticuse (m^3/year) by water demand model when the efficiency varies to a.2%, b.5% and c.10%.

If this community dropped efficiency to use water resources from 30% to be 20% which means it reduces 1% every year until the 10th year, water consumption and demand for irrigation would be 4.9339×10^5 m^3/year and 2.4670×10^6 m^3/year, respectively (see figure 6). The water demand increases but the community has the same amount of water or less which depends on the precipitation for each year.

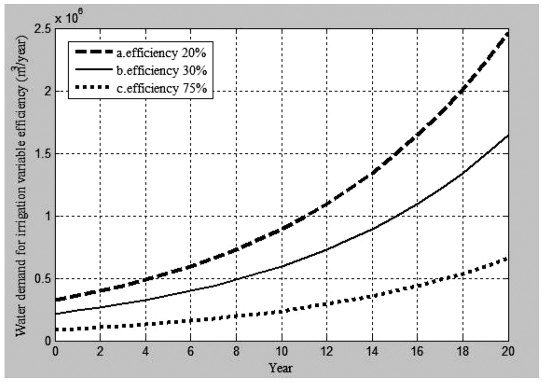

Figure 6. The prediction of water demand for irrigation when the efficiency varies to a.20%, b.30% and c.75%.

Case 2 Business as usual

For the period of time 2005 to 2020, if the efficiency remains at 5%, the demand for domestic use would be 4.9773×10^5 m^3/year, see figure 5.

If water efficiency of this community remains 30% as usual within 10 years while there is population increase, the water consumption and demand for irrigation would be 4.9339×10^5 m^3/year and 1.6446×10^6 m^3/year, respectively, see figure 6. Even though the villagers use the same amount of water and have the same efficiency to manage water, the demand still increases from 0.5385×10^6 m^3/year in 2009 to 1.6446×10^6 m^3/year in 2019.

Case 3 Optimistic Outlook

Water consumption for domestic use would be 2.4887×10^4 m^3/year and when the efficiency is 10%, the demand would be 2.4887×10^5 m^3/year, see figure 5.

If we expect the best outcome at 75% for water efficiency, water consumption for irrigation would be 4.9339×10^5 m^3/year and the demand would be

6.5786×10^5 m^3/year as shown in figure 6. We expect the efficiency will be higher than the usual 50% by increasing 5% in each of the years within 10 years.

From these three cases of what-if analysis we can have an idea about what will happen next. If the efficiency is higher than the current consumption, the demand for water will decrease in the next 10 years. On the other hand, if the efficiency is lower than at present, the water demand will increase.

The total water consumption and demand of this community would be 5.1788×10^5 m^3/year and 2.1423×10^6 m^3/year, respectively.

Conclusion

This study created models for predicting population and irrigated cultivated land growth as shown in (1) and (4), and also created water demand and consumption models for domestic use ((2), (3)) and irrigation ((5), (6)). The total water demand and consumption for domestic use and irrigation models are shown in (7) and (8). We used the models to predict water consumption and water demand for domestic use which would increase to 7.82% in 2020, while water consumption and demand for irrigation would increase to 63.76% and 67.26%, respectively, in 2019. These models will help to forecast the future of water use which is related to the number of households, irrigated cultivated land and water resources. Hopefully, this study will change the attitude of farmers to consume water more efficiently for livelihood sustainability.

Recommendations

- Irrigated cultivated land data is more likely periodic, so the prediction can be a periodic function.
- Precipitation data should be considered and collected for a long term study.
- The Thai government has to be more serious about water shortages because agriculture is one of the main contributors to the GDP of our country and the biggest water consumer.
- The accuracy hasn't been tested yet in this research as it is not the aim of this study.

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