# การวิเคราะห์ความยั่งยืนของแม่น้ำเจ้าพระยาตอนล่างโดยใช้พลวัตระบบ

**รุจิระ ฉายศิริ*** **และจิตรเลขา สุขรวย**

ภาควิชาเทคโนโลยีการจัดการ สถาบันเทคโนโลยีนานาชาติสิรินธร
มหาวิทยาลัยธรรมศาสตร์ คลองหลวง ปทุมธานี 12120
*E-mail: rchaysiri@siit.tu.ac.th

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## บทคัดย่อ

ปัญหาคุณภาพน้ำในแม่น้ำเจ้าพระยาได้รับการบันทึกไว้ในวรรณกรรมจำนวนมาก รวมถึงรัฐบาลได้ออกกฎและมาตรการต่าง ๆ เพื่อลดปัญหาสิ่งแวดล้อมในแม่น้ำ อย่างไรก็ตามปัญหาเหล่านี้ยังคงมีอยู่ ในงานวิจัยนี้คณะผู้วิจัยสร้างแบบจำลองพลวัตระบบที่เรียกว่า เจ้าพีเอสดี (ChaoPSD) ซึ่งเป็นแบบจำลองที่ประกอบไปด้วยสามระบบย่อย ได้แก่ ครัวเรือน อุตสาหกรรม และเกษตรกรรม แบบจำลองติดตามปริมาณไนโตรเจนของแม่น้ำเจ้าพระยาตอนล่างเมื่อเวลาผ่านไป หลังจากทดสอบแบบจำลองแล้ว แบบจำลองพลวัตระบบนำมาใช้เพื่อเป็นเครื่องมือสำหรับการเพิ่มความเข้าใจในความสัมพันธ์ระหว่างพฤติกรรมของผู้ใช้แม่น้ำและสภาพคุณภาพน้ำในแม่น้ำ ผลของการจำลองแสดงให้เห็นว่ามีการเพิ่มขึ้นของปริมาณไนโตรเจนในแม่น้ำเจ้าพระยาตั้งแต่ปี 2561 ถึงปี 2566 คณะผู้วิจัยแนะนำว่าการควบคุมการปล่อยไนโตรเจนลงในน้ำซึ่งสามารถทำได้โดยการเพิ่มประสิทธิภาพของการบำบัดน้ำเสียและการเพิ่มความตระหนักรู้ของผู้ใช้แม่น้ำ มีส่วนสำคัญต่อความยั่งยืนทางสิ่งแวดล้อมของแม่น้ำเจ้าพระยา

**คำสำคัญ:** พลวัตระบบ มลภาวะทางน้ำ แม่น้ำเจ้าพระยา ไนโตรเจน การจัดการน้ำ

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# Sustainability Analysis for the Lower Chao Phraya River Using System Dynamics

**Rujira Chaysiri*** **and Jitlakha Sukruay**

School of Management Technology, Sirindhorn International Institute of Technology,
Thammasat University, Khlong Luang, Pathum Thani, 12120, Thailand
*E-mail: rchaysiri@siit.tu.ac.th

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## Abstract

Water quality issues in the Chao Phraya river have been well–documented in the literature. The government has enforced rules and regulations to mitigate the environmental problems in the river. However, problems still exist. In this research, we constructed a system dynamics (SD) model, called ChaoPSD. The proposed model included three subsystems: (1) household, (2) industry, and (3) agriculture. This model tracked the nitrogen load in the lower Chao Phraya river over time. After the model validation, ChaoPSD was used as a tool for a better comprehension of the interrelationships among the actions of users and the health of the river. The simulation results showed that there will be an increasing amount of nitrogen in the Chao Phraya river from 2018 to 2023. We suggest that controlling the discharged nitrogen by increasing the efficiency of wastewater treatment and increasing people's awareness are essential for environmental sustainability in the Chao Phraya river.

**Keywords:** System dynamics, Water pollution, Chao Phraya river, Nitrogen, Water management

## Introduction

Rapid population growth causes uncontrolled urbanization and industrialization growth and destruction of natural habitats (Cooley *et al*., 2014; Khanh and Thanh, 2010; UN–Water, 2016). The result of population growth is the growing generation of solid wastes, wastewater, and deterioration of the environment, such as air and water quality (Thitanuwat *et al*. 2016; Wang *et al*., 2012) An environmental problem which in the 21st century society has been facing is water pollution. It is a cause of declining global biodiversity due to intensifying water pollution (Convention on Biological Diversity, 2010; Pereira *et al*., 2010; UNESCO, 2018). As a result, the availability of the world's scarce water resources has become even more limited, and water scarcity is projected to worsen in the future.

The Chao Phraya river is a crucial river and plays an important role in the lives of Thai people in central Thailand. It flows southward for 372 kilometers from the central plains through Bangkok's delta, the capital of Thailand's politics, industries, and culture. Then, the Chao Phraya river drains out into the Gulf of Thailand. The drainage area is 160,000 km$^2$, and it covers 30% of the country's total land area. The Chao Phraya river has abundant food and space for utilization. There are approximately 11.5 million people living near the Chao Phraya river (Ministry of Science and Technology, 2012). People gain advantages from rivers that they live close to, such as domestic consumption, trading, agriculture, and transportation (Chen *et al*., 2004).

Factories use water from rivers to power machinery, to cool down machinery, or to wash raw materials. Industrial effluents lead to water degradation. Along the Chao Phraya riverbanks there are approximately 14,000 factories that use a large amount of water and chemicals in production processes. The factories generate a large amount of pollution such as chemical contamination in electroplating, textile, and chemical manufacturing industries (Department of Industrial Works, 2008). These activities have negative effects on water quality. In 2015, approximately 2,942,739 m$^3$ per day of wastewater was released into the Chao Phraya river. Wastewater is released from domestic wastewater, agricultural runoff, and industrial effluents (Carpenter *et al*., 1998; Huber *et al*., 2000; UNESCO, 2018). Only 26.9% of wastewater is collected for treatment (Department of Local Administration [DLA], 2015), whereas some untreated wastewater is directly discharged into the river. Releasing untreated wastewater, which has higher pollution than the river's capacity for self–purification, degrades water quality.

The Pollution Control Department (PCD) reported that the average water quality in the Chao Phraya river is below the surface–water quality standard in Thailand (PCD, 2017). In particular, downstream water quality is currently at a low level. For water quality in the lower Chao Phraya river from 2008 to 2017 as shown in Table 1, the average Dissolved Oxygen (DO) is 2.39 mg/L and the average Biochemical Oxygen demand (BOD) is 3.48 mg/L. DO and BOD for a good water quality should be in the range of 7–11 mg/L and less than 1.5 mg/L, respectively. An acceptable level of the total phosphorus (TP) in the river should be close to 0.1 mg/L. Total Nitrogen (TTN) should be less than 0.3 mg/L to control eutrophication. However, the average total nitrogen in the Chao Phraya river is 3.12 mg/L, which is approximately 10 times over the guidelines. The United States Environmental Protection Agency (US EPA) developed guidelines to classify total nitrogen concentrations in the surface water of China and other countries in order to improve water quality, protect human health and control eutrophication. Nitrogen concentrations in streams and rivers should not exceed 0.3 mg/L or 0.1 mg/L in lakes and reservoirs, respectively (Xu *et al*., 2014). Thus, the TTN in the lower Chao Phraya river needs to be improved.

**Table 1** Water quality in the lower Chao Phraya river from 2008 to 2017

| Year | DO (mg/L) | BOD (mg/L) | TP (mg/L) | TTN (mg/L) |
|---|---|---|---|---|
| 2008 | 2.10 | 3.05 | 0.10 | 1.30 |
| 2009 | 1.35 | 4.05 | 0.21 | 1.74 |
| 2010 | 2.24 | 4.45 | 0.04 | 1.82 |
| 2011 | 2.62 | 2.78 | 0.08 | 2.03 |
| 2012 | 1.98 | 2.40 | 0.13 | 5.18 |
| 2013 | 2.01 | 2.80 | 0.10 | 5.99 |
| 2014 | 3.13 | 3.00 | 0.13 | 6.47 |
| 2015 | 3.27 | 4.18 | 0.19 | 3.76 |
| 2016 | 1.97 | 3.90 | 0.05 | 1.49 |
| 2017 | 3.23 | 4.23 | 0.13 | 1.45 |
| Averages | 2.39 | 3.48 | 0.12 | 3.12 |
| Standard values | 7–11 | < 1.5 | approaching 0.1 | < 0.3 |

TTN is an important water quality parameter. Nitrogen is an essential nutrient for plant growth, but the overloading of nitrogen in rivers can cause excess weed and algae growth, known as eutrophication which leads to low water quality (Smith *et al*., 1999). Furthermore, nitrogen compounds such as nitrate $NO_3^-$ and nitrite $NO_2^-$ are pollutants that have negative effects on the environment and human and animal health (Bruning–Fann and Kaneene, 1993; Morales–Suarez–Varela *et al*., 1995). Human activities can cause nitrogen in the runoff to go into rivers and contaminate a water body. We therefore study the patterns of the water quality to understand people's behaviors that affect water pollution in the rivers. The patterns of water quality are studied by observing the TTN in the river. The amount of nitrogen in a water body mainly comes from municipal, industrial, residential, and agricultural sources that are interrelated. Thus, water quality systems are complex systems which we need to understand to find the root causes of water quality problems in rivers.

Many simulation approaches can explain complex systems, such as Discrete Event Simulation (DES), Agent–based Simulation (ABS), and System Dynamics (SD). Each method is useful for different situations. DES can track individual resources through the system, show the queuing behavior of process performance. It is used in Operations Research (OR) (Borshchev and Filippov, 2004). ABS is used in many levels of abstraction, called bottom–up modeling. ABS is useful for the behavioral aspects of individuals under specific networks while SD looks for principles in system structures (Macal, 2010). SD is suited for a policy–making, such as utility policy, governmental planning for electricity markets, or any other issues that are not related to individual levels (Figueredo and Aickelin, 2011). Although ABS can simulate a system which is constructed from SD by disaggregating into individual levels, the SD approach can help to observe the aggregated individuals (Borshchev and Filippov, 2004; Sumari *et al*., 2013). As a consequence, SD models typically aggregate individuals or agents into a relatively small number of states.

The SD approach has been applied in many fields, including water management, policy analysis, water quality, and waste management, etc. (Kato, 2005; Koch and Vögele, 2009; Pluchinotta *et al*., 2018; Sukholthaman and Sharp, 2016; Venkatesan *et al*., 2011). Developing an SD model for water resources is useful since users can understand the interactions of variables and parameters that can affect a system or its subsystems. There are many studies that provide useful insights into applying SD to water resources modeling. The main categories of previous studies are categorized into three types of modeling approaches for water resources management: 1) predictive simulation models, 2) descriptive integrated models, and 3) participatory and shared vision models (Mirchi *et al*., 2012). Sukruay and Chaysiri (2018) reviewed previous research into the applications of SD in the field of water quality systems and classified them into three subsystems: 1) household subsystem, 2) industrial subsystem, and 2) agricultural subsystem. All these studies are useful in simulating water quality systems by using the SD methodology.

Thus, we create an SD model by using Vensim software, to study the effects of people's behaviors on the water quality system in the Chao Phraya river. The proposed SD model is called the ChaoPSD model, which is an extension of the SD model proposed by Sukruay and Chaysiri (2018). We use this ChaoPSD model to analyze the influence of the variables related to water quality, and identify alternative ways to promote a sustainable solution for improving water quality in the long–term.

## Methodology

### *ChaoPSD model*

The ChaoPSD model is developed from the system dynamics model proposed by Sukruay and Chaysiri (2018). Sukruay and Chaysiri (2018) explained the interactions in a water pollution system which consisted of household, industrial, and agricultural subsystems. The water pollution problem is intensified due to the influence of the amount of nitrogen. In this study, nitrogen was used to represent the water pollution in the Chao Phraya river.

Figure 1 demonstrates the ChaoPSD model. It shows the interrelationships among the amount of nitrogen in rivers and factors affecting nitrogen generation. The amount of nitrogen in untreated wastewater and untreated solid waste that is discharged into a water body influence the water quality. Another factor that affects the amount of nitrogen is the population growth. Population growth leads to urban expansion and increases in food and water demand. As a result, industrial development and agricultural growth increase the nitrogen discharge rate. The amount of nitrogen in rivers is accumulated from the amount of nitrogen in domestic wastewater, nitrogen in wastewater from farms, nitrogen leftover from fertilizer usage, nitrogen in solid waste, nitrogen in wastewater from factories, and the amount of water in the river. Increasing the capacity of wastewater treatment and solid waste treatment plants can reduce the amount of untreated wastewater and solid waste, respectively. Moreover, people's awareness of health factors can indirectly reduce the wastewater discharge and solid waste generation.

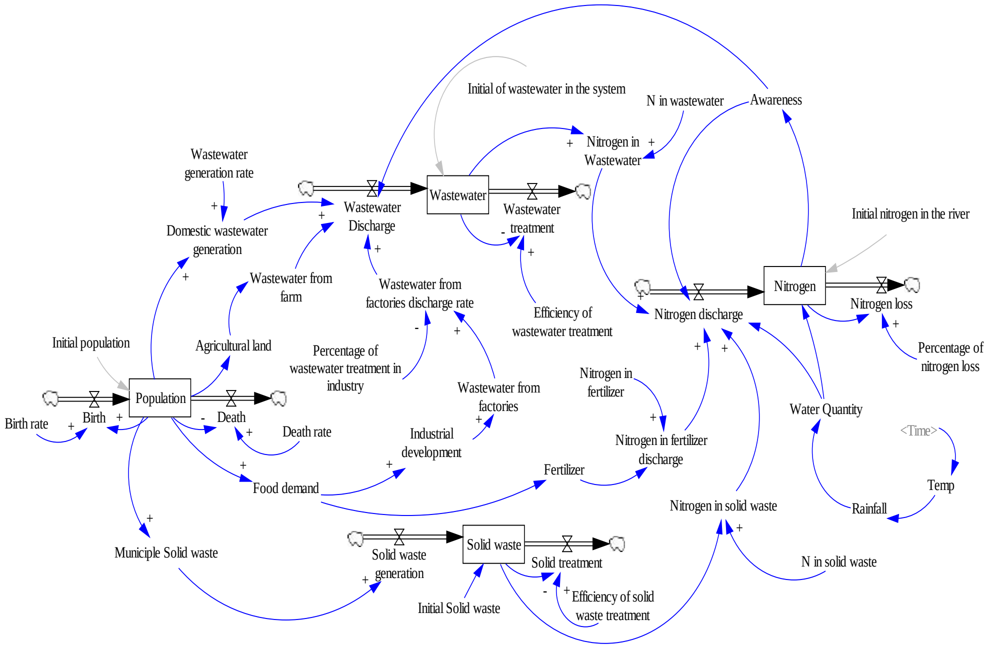


**Figure 1** Stock and flow diagram of water quality, influenced by household sector, industrial sector, and agricultural sector

The ChaoPSD model simulates the amount of nitrogen discharge for the next five years in the lower Chao Phraya river. Table 2 shows all of the functions that are used in this model. First of all, the population depends on the inflow of births and outflow of deaths. The average birth rate (1.209%) in Thailand is higher than the death rate (0.664%) (Official Statistics Registration Systems, 2016). Therefore, an increase in population leads to a higher consumption of water and food. Domestic wastewater generation is calculated from the water consumption rate (108.6 $m^3$/capita/year). Food demand is generated from the food consumption rate (164.25 Kg/capita/year). These consumption rates cause domestic wastewater and solid waste generation to be high. Municipal solid waste, which is approximately 1,520 kg each year, is generated by people (PCD, 2014). Moreover, an increase in food demand results in industrial development and agricultural growth which are sources of wastewater generation. Industrial development is represented by the relationship between the volume of food demand and the percentage of GDP, reported by the World Bank (The World Bank, 2017). The volume of wastewater from factories in the lower Chao Phraya river area is related to the industrial growth (percentage of GDP). Industrial development is generated from the relationship of percentage of GDP and the volume of food demand. For the function of wastewater from factories, we generate the function from the relationship between percentage of GDP and the volume of wastewater from factories in the lower Chao Phraya river area. Wastewater from factories discharge rate is an untreated wastewater from factories. We assume that the percentage of wastewater treatment in factories is 90% of the total wastewater from factories. Some untreated solid waste, which is also a source of nitrogen, is dumped into the river. In addition, wastewater from farming is another source of high nitrogen contamination in rivers. The amount of agricultural wastewater is influenced by the changing of agricultural land each year (PCD, 2017). Some of the wastewater from each source is collected for treatment, but some of the untreated wastewater is released into the river. These untreated wastewater is a source of nitrogen in the river. Furthermore, nitrogen in the river comes from leftover nitrogen in fertilizer which is from increasing food demand. Approximately 50–70% of fertilizer is lost into the environment (Khanh and Thanh, 2010). The range of nitrogen in fertilizer is 1,161–6,320 mg/kg (Kathong and Ruangviriyachai, 2014). We assume that the leftover nitrogen is 40% of the nitrogen in fertilizer, which is approximately 960.80 mg/kg. To conclude, the nitrogen discharge rate is a combination of all nitrogen sources. The last factor affecting the amount of nitrogen in the river is the water quantity in the river. The volume of water in the river depends on the annual rainfall, and rainfall is affected by the changing of temperature of the earth. The function of temperature is created by using the average of the temperature rate for each year. Moreover, the initial values that are used in the model are shown in Table 3.

### *Validation Analysis*

Validation analysis is used to test the accuracy and acceptability of the model. There are three steps, which are conceptual model validation, computerized model verification, and operational validation that are used to test the reliability of the model (Martis, 2006). The Chao PSD model was developed iteratively until the forecasted data from the model was close to the reference data from the Pollution Control Department (PCD), from 2008 to 2014. Nitrogen discharges at both the upstream and downstream Chao Phraya river were simulated. As

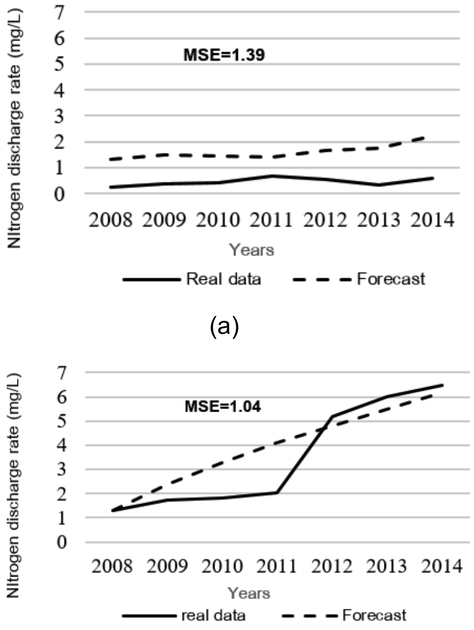
**Table 2** Equations used in the ChaoPSD model for the lower Chao Phraya river

| **Variables** | **Equations** |
|---|---|
| Population | Birth – Death |
| Domestic wastewater generation | Population×Wastewater generation rate |
| Food demand | 164.25×Population |
| Industrial development | 130.21+ [(–7×$10^8$)×Food demand] |
| Municipal solid waste | 1520.5×[(–9×$10^9$)×Population] |
| Wastewater from factories | [(–1×$10^8$)×Industrial development]+2×$10^{10}$ |
| Wastewater from factories discharge rate | Wastewater from factories×Percentage of wastewater treatment in industry |
| Wastewater from farm | (8.04×$10^6$)+[(1.95×$10^6$)×Agricultural land] |
| Agricultural land | –421087+(0.079×Population) |
| Fertilizer | –7.97×$10^8$+(0.349×Food demand) |
| Water quantity | (–3.82×$10^{10}$)+((2.98×$10^7$)×Rainfall) |
| Rainfall | 2531.69 – (1317.64×Temperature) |
| Temperature | (0.02×Time)+0.5486 |

**Table 3** Initial values used for calculation in the ChaoPSD model

| **Variables** | **Initial value** | **Sources** |
|---|---|---|
| Population | 7,910,700 | National Statistic Office [NSO], 2017 |
| Solid waste (kg) | 6.00×$10^6$ | PCD, 2013; Yukalang *et al*., 2017 |
| Wastewater ($m^3$) | 8.59×$10^8$ | Assumed |
| Amount of the total nitrogen in the river (mg) | 1.52×$10^{13}$ | Assumed |
| Food generation rate (kg/capita/year) | 164.5 | Begum and D'Haese, 2010 |
| Domestic water generation rate ($m^3$/capita/year) | 108.6 | Royal Irrigation Department [RID], 2017 |
| Percentage of wastewater treatment in factories (%) | 90 | Assumed |
| Solid waste treatment rate (%) | 35 | Towprayoon, 2007 |
| Wastewater treatment rate (%) | 26.9 | DLA, 2015 |
| Nitrogen loss (%) | 50-70 | Khanh and Thanh, 2010 |
| Nitrogen in wastewater (mg/L) | 63.25 | Water Quality Management Office, 2017 |
| Nitrogen in solid waste (%) | 70.19 | Boonta *et al*., 2010 |
| Nitrogen in fertilizer (mg/kg) | 960.80 | Khanh and Thanh, 2010 |

a result, the forecast data from both points have a similar trend as the reference data, as shown in Figure 2. To see the average errors between the simulation and the observed data, the Mean–square–error (MSE) is used to test the system behavior (Sterman, 1984). The Mean Square Error (MSE) is 1.39 for upstream (Figure 2a), and MSE is 1.04 for downstream (Figure 2b).



(a)

(b)

**Figure 2** Comparison of the total nitrogen discharge from the model with the real data from 2008–2014 at (a) upstream and (b) downstream

## Results and Discussion

The ChaoPSD model was described in the previous section. The model displays the dynamics of the nitrogen discharge in the Chao Phraya river. Figure 3 shows that the nitrogen discharge will increase from 2018 to 2023.

Uncertainties in our model may arise from the aggregated nature of the model because the parameters that are used in the model have been assumed, or selected based on the literature, with limited knowledge. The ChaoPSD model results may vary due to a number of factors, including the limited data on wastewater from farms and wastewater from factories. To assess the impact of each parameter, a sensitivity analysis was conducted. From the ChaoPSD model, the amount of the nitrogen discharge in the river depends on many factors. Some selected scenarios and related parameters are shown in Table 4. The baseline scenario is compared with the scenarios that use the lower and upper bounds of each parameter value. This provides an insight into the uncertain parameters that impact the dynamics of nitrogen in the model.

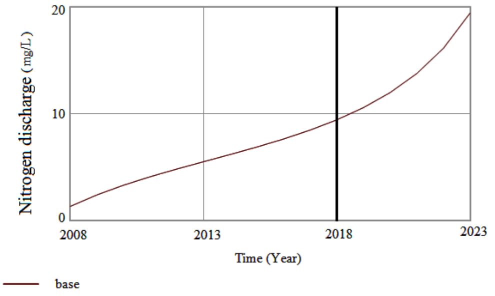
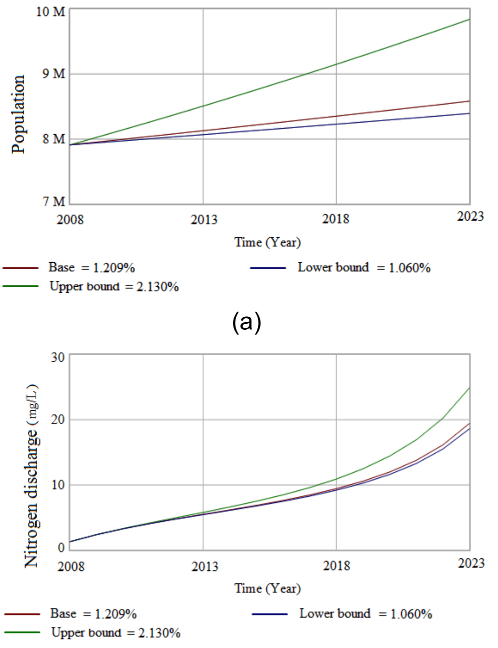


**Figure 3** Forecasted total Nitrogen discharge from 2008 to 2023

Human activity is the main cause of wastewater generation. The population is the primary determinant of higher water consumption. Figure 4a shows the change in population when the birth rate is varied. An increase in birth rate to 21.30% (upper bound) can increase the population. On the other hand, a decrease in birth rate to 10.60% (lower bound) reduces the population. Figure 4b shows that an increase in population causes the nitrogen discharge to increase. Moreover, a decrease in population leads to a slight fall in the total discharged nitrogen when compared with the baseline scenario.

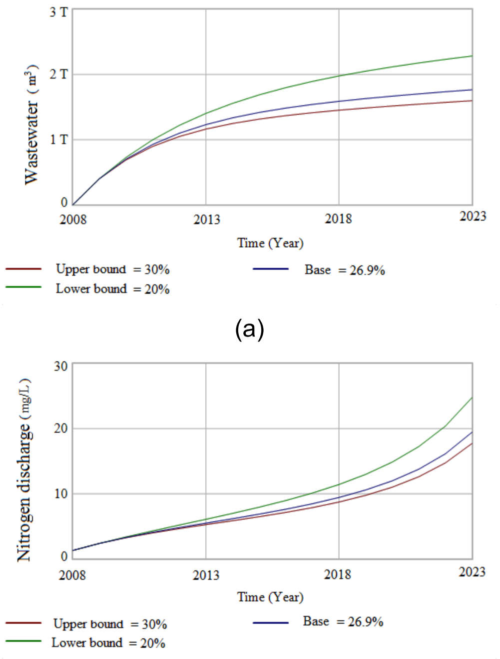


(a)

(b)

**Figure 4** Impact of population on nitrogen discharge (a) population change (b) amount of nitrogen discharge

Increasing the impact of wastewater treatment efficiency (WWTE) can reduce the nitrogen release rate into the river. Scenario 3 shows that an improvement in wastewater treatment efficiency (upper bound) can reduce the amount of wastewater. In contrast, a diminishing wastewater treatment efficiency (lower bound) results in an increase in wastewater as shown, in Figure 5a. An increase in wastewater causes an increase in the total nitrogen discharge into the river, whereas reducing the amount of wastewater causes a decrease in the nitrogen discharge, as shown in Figure 5b.

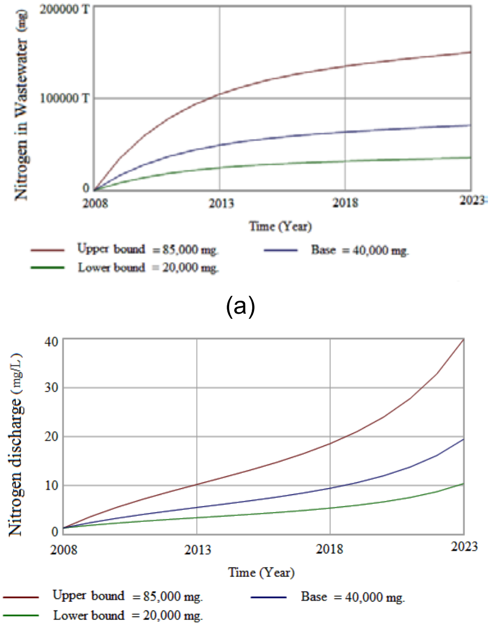


(a)

(b)

**Figure 5** Impact of efficiency of wastewater treatment (WWTE) on nitrogen discharge (a) volume of wastewater, and (b) amount of nitrogen discharge

Nitrogen in untreated wastewater is another source of nitrogen in the river. The nitrogen in untreated wastewater can fluctuate based on many factors such as the WWTE, amount of rainfall, and season. In Scenario 5, the nitrogen in wastewater and the nitrogen discharge rate were measured by changing the nitrogen in untreated wastewater. Figure 6a shows the nitrogen in untreated wastewater, which adds to the nitrogen discharge rate. A high amount of nitrogen in untreated wastewater (upper bound) causes a higher nitrogen discharge. A low amount of nitrogen in untreated wastewater (lower bound) causes a lower nitrogen discharge, which is presented in Figure 6b.

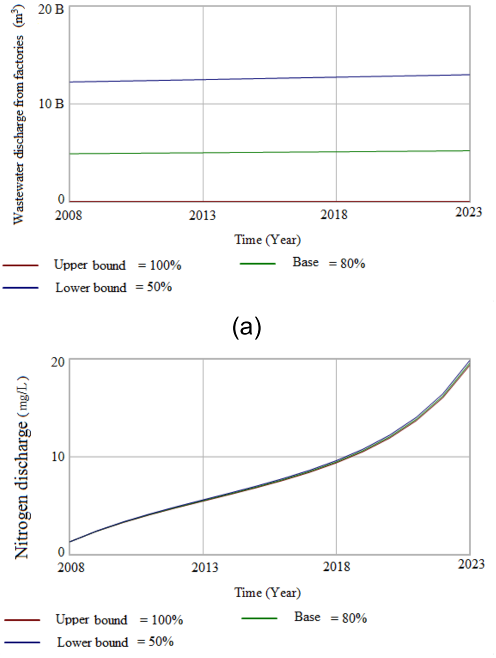


(a)

(b)

**Figure 6** Impact of nitrogen in wastewater on nitrogen discharge (a) amount of nitrogen in wastewater and (b) amount of nitrogen discharge

Lastly, Scenario 8 shows that an improvement in the impact of wastewater treatment efficiency in factories (WWTEF) can reduce the wastewater from factories. If WWTEF is reduced, wastewater from factories would increase, which is shown in Figure 7a. When we improve WWTEF, the nitrogen discharge rate is reduced. In contrast, diminishing the wastewater treatment efficiency results in an increase in the total nitrogen discharge, as shown in Figure 7b.



(a)

(b)

**Figure 7** Impact of wastewater treatment efficiency in factories (WWTEF) (a) amount of wastewater from industries and (b) amount of nitrogen discharge

According to the results of sensitivity analysis, the model shows that increasing the population and nitrogen in wastewater can increase the nitrogen discharge rate. Moreover, increasing the WWTE and WWTEF can reduce the wastewater and nitrogen discharge rates. Therefore, we conclude that human activities are the main cause of nitrogen discharge. We extend the SD model by assuming an awareness function. Thus, we can analyze human behavior in our model. We assume that awareness increases from 0 to 1 when the amount of nitrogen discharge ranges from 0.3 mg/L to 80 mg/L. The awareness function is as follows: Awareness = $(1\times10^{-15})$ × Nitrogen (the total of nitrogen in the river). After awareness increases, people are more aware of their health and they are willing to follow government policies by reducing the discharge of wastewater into rivers. If the awareness is higher than 0.0035, the wastewater discharge is reduced as follows: Wastewater discharge = $(-3\times10^{11})$ × Awareness + $(4\times10^{11})$. If the awareness is higher than 0.0035, the nitrogen discharge rate is reduced. Figure 8 illustrates the impact of awareness on the nitrogen discharge; increasing awareness can control the nitrogen discharge rate, which is below 0.3 mg/L following the US EPA guidelines. Consequently, the government should increase the efficiency of wastewater treatment in communities and factories and present a campaign to raise people's awareness.

## Recommendations

According to the "Statement for the Annual Budget Expenditures for Fiscal Year 2018" of Thailand, the annual budget is set to be 2.9 trillion baht, which is separated into six strategies. Some of the total budget (4.3%) was distributed for environmental management. Pollution control accounts for 0.45% of the total annual budget. The government aims to increase the wastewater treatment efficiency to 47% in 2018 from this budget. This goal was tested by the ChaoPSD model. We found that increasing the wastewater treatment efficiency to 47% can reduce the nitrogen discharge rate by approximately 25%, but the amount of nitrogen is still higher than the US EPA guidelines. Figure 9 shows a comparison of the nitrogen discharge rate between the current nitrogen discharge (base) and the increased wastewater treatment efficiency (goal). From the results of the ChaoPSD model, after adding the awareness function to the model, the nitrogen discharge rate is below the US EPA guidelines. Moreover, if nitrogen is discharged into the river at less than 3%, the amount of nitrogen discharge is less than 0.3 mg/L, which can control eutrophication. Thus, the government should improve the efficiency of wastewater

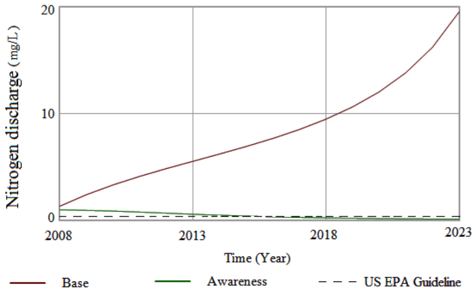


**Figure 8** Impact of awareness on total nitrogen discharge

treatment along with raising people's awareness.

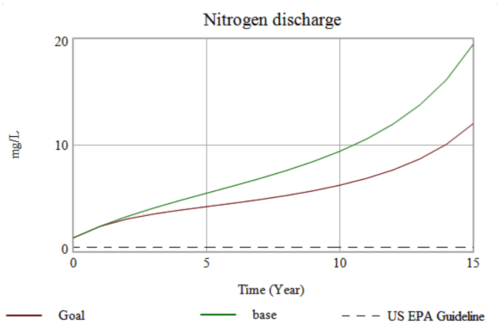


**Figure 9** Nitrogen discharge when increasing wastewater treatment to 47% (Goal)

## Conclusion

The lower Chao Phraya river is an important river for Thai people. In this paper, the lower Chao Phraya river, which has poor water quality, was considered as a case study. We model the water quality system by observing the nitrogen discharge rate in the river. Nitrogen has negative impacts on human and animal health and nitrogen is a cause of eutrophiccation, which degrades water quality. The system dynamics method is used as a tool to understand the behavior of discharged nitrogen in the river. We found that the nitrogen discharge rate will increase in the next five years. According to the scenarios of sensitivity provided in the model, the wastewater that comes from household, industrial, and agricultural sectors affects the amount of nitrogen in the river. Increasing in the efficiency of wastewater treatment in communities and industries can reduce the nitrogen discharge. Moreover, raising people's awareness can reduce the discharged nitrogen in the long term. In 2018, the government wants to increase the efficiency of wastewater treatment from 26.9% to 47%. This goal can reduce the amount of nitrogen in the Chao Phraya river. However, this goal still cannot control the amount of nitrogen to be under the US EPA guidelines. Thus, the government should increase the efficiency of water treatment in treatment plants, improve wastewater collection for treatment, promote wastewater treatment in factories, and raise people's awareness. This combination of actions will lead to environmental sustainability in the Chao Phraya river.

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