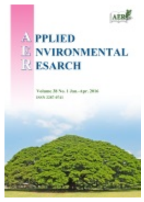
App. Envi. Res. 44(3) (2022): 59-75

Applied Environmental Research

Journal homepage : http://www.tci-thaijo.org/index.php/aer



The Driving Force of Urban Water Body Change in Chonburi Province, Thailand

Nararuk Boonyanam[1,*], Somskaow Bejranonda[2]

[1] Faculty of Economics at Sri-racha, Kasetsart University, Chonburi, Thailand
[2] Faculty of Economics, Kasetsart University, Bangkok, Thailand
[*] Corresponding author: nararuk.b@ku.th

Article History
Submitted: 12 April 2022/ Revision received: 15 July 2022/ Accepted: 22 August 2022/ Published online: 29 September 2022

Abstract

The rapid urbanization from special economic zones (SEZs) in Asia poses a risk on water crisis. This paper identifies water body change trend and its driving force of change in Chonburi province; the most urbanized area in the Eastern Economic Corridor (EEC) of Thailand, in order to analyse the root cause of water shortage in the area. Land use maps from 2006 to 2019 were used to evaluate the changing trend in water bodies using land use transition matrix and land use dynamic degree. Panel data from 364 observations in the Chonburi sub-district was used to assess the driving forces of water body change using panel data analysis. The study reveals that the water bodies are experiencing an increasing trend at the annual rate of 10.72%. The most predominant factor of change is the type of governance, followed by agricultural land use, climate change and population respectively. The results highlight the increasing trend of human-made urban water bodies, the importance of the local authority and the need of international collaboration. Therefore, the government should consider to strengthen measures and policy relative to water body change in the area in order to induce significant impact on future urban water supply.

Keywords: Driving force; Water body change; Urbanization; EEC; Thailand

Introduction

The urban stream syndrome refers to the consistently observed ecological degradation of streams draining urban land [1]. The symptoms include a more impressive hydrograph, raised concentrations of nutrients and contaminants, altered channel morphology, artificial floods, extremely low flows and decreased biodiversity with increased dominance towards tolerant species [2–3]. Many studies reveal that a deterioration in urban water bodies is associated with land use change resulting from increased urbanization [4–10]. Urbanization has profoundly affected landscape characteristics, especially the development of impervious surface areas [11], leading to an increase in surface runoff,

https://doi.org/10.35762/AER.2022.44.3.5

outflow and stream discharge, lower evapotranspiration, infiltration rate and induce water-retention losses [12–15]. Evidence from Srinivasan et al. [16] showed that compact and dense urbanisation increased vulnerability to water stress while Oudin et al. [17] also found that urban area fragmentation can help to mitigate the impacts of urbanisation on water bodies. An increase in urbanization has been found to decrease the average groundwater level [18] while the surface water quality determined by the level of urbanization could be improved by strengthening environmental policies and water management [19].

The water bodies in urban areas are essential for providing ecosystem services to their inhabitants in term of provisioning, regulation and maintenance and cultural services [20]. Huang et al. [21] indicated that different water body types have different effects for urban ecology and environment. There are five classes of water body in urban area (River and canal, lake and lagoon, reservoir, farm pond and irrigation canal). Rivers play an important role in providing domestic water, regulating climate, and transportation; lakes and lagoon are mainly used for conserving water; farm ponds provide places for fishery and planting aquatic products; reservoir and irrigation canal supply water to the agricultural areas and prevent flood risk. Urban growth increases water demand, driven by rises in the population, and therefore, understanding the change in urban water bodies and its driving forces of change could help in making decisions for future urban water body plans.

Many factors cause water body change. Agriculture land use has modified global hydrological cycle in terms of water quality and quantity as it takes 70% of freshwater withdrawals from rivers and groundwater [22]. Climate change induced alterations in temperature and precipitation affect the distribution of water bodies by changing hydrological and biochemical cycles [23]. The development of urban populations, economy, technology and culture either promote or block change in water bodies as economic growth and populations increases per-capital water use which lead to increased water withdrawals and wastewater discharges [24]. The increase in total municipal water demand causes cities to search for new water sources, leading to the construction of urban water infrastructure [25], therefore the capacity of the local authority who is responsible for providing water for the city and the water infrastructure also induced the urban water body change.

Several studies focus on the driving factors of urban water body change. The United Nations Educational, Scientific and Cultural Organization (UNESCO) conducted qualitative research on the driving factors of change in water bodies and concluded that ten drivers induce such change: agriculture, climate change, demography, economics, ethics, governance and institution, infrastructure, politics, technology and water resources [26]. The UN also reported on the driving forces of change in water bodies with a discussion, review and expert consultation, concluding that in 30 years' time, the factors driving water body change are likely to be a rise in population, increasing consumption of food and industrial goods produced using water and trade policy [27]. In China, Jiang et al. [28] found that the driving forces of water body change were identified as annual rainfall, evaporation, quantity of inflow water, volume of groundwater available, urbanization rate and daily average discharge of wastewater. According to Li et al. [29], human activities and terrain conditions had a negative effect on the water body area in the Jing-Jin-Ji region while climate and soil properties had a positive effect. Li et al. [30] also revealed that from 1980–2016, there was a drastic loss of marshland (65.7%) due to rapid paddy field expansion in the Sanjiang Plain, Northeast China, influenced mainly by biophysical, socio-economic and land management factors. Wu et al. [31] reported a decreasing trend in water bodies and an increasing trend in built-up area at Longfeng Wetland Natural Reserve in Daqing city. Exhibiting the greatest effect on water body change were human factors (GDP, population and environmental policy) and natural factors (temperatures, annual precipitation, evaporation and groundwater) respectively. Zhang et al. [32] also found a drastic decrease in the natural water body area and a rapid increase in human-made water bodies in Beijing-Tianjin-Hebei region and its driving factors were gross farm production, total aquatic products and irrigated area. In India, Malik and Rai [33] revealed a reduction in wetland due to the agricultural expansion in Pong Dam wetland in the Western Himalaya, Himachal Pradesh. The main drivers of change were human and livestock activities. These researchers suggested minimizing agricultural activities and instead, encouraging agroforestry activities in the area.

Many Asian countries are creating special economic zones (SEZs) and these are estimated to represent 5% of the total 20,000 economic zones in the world [34]. With massive industrialization, urban land use in Asia has increased rapidly as economies shift from agriculture to manufacturing and services, encouraging large numbers of people to move to cities. Wolfgang et al. [23] indicated that none of the Asian countries have an exclusive national policy on water body protection, including Malaysia, Vietnam, Bangladesh, Cambodia, China, Indonesia, Pakistan, the Philippines and Thailand. At some point, these urban areas will face a water supply shortage resulting in the eventual slow-down of industrial and economic development [35].

Located in Southeast Asia, as of 2010, Thailand had the sixth largest urban land area in the region. Its urban areas have seen an average annual growth rate of 1.4%, with Bangkok, Chonburi and Chiang Mai as its top three most urbanised areas [36]. As Thailand's capital city, Bangkok became urbanised over several decades while for Chiang Mai and Chonburi, urban development has occurred in just over ten years. Among these big urban cities, only Chonburi Province is strategically located in the special economic zone of Thailand, namely the Eastern Economic Corridor (EEC). The project focused on the 3 Eastern provinces, namely Rayong, Chonburi, and Chachoengsao. It commenced in 1981 under the Eastern Seaboard Development Program (ESDP), a special economic zone (SEZ). After the 2014 military coup, the National Council for Peace and Order (NCPO) announced the revitalization of the ESDP with a budget of 15 trillion Baht (US$43 billion) under the scheme Thailand 4.0 with a five-year plan (2017–2022), renaming it the EEC. The Thai government aims to develop the EEC area into a regional gateway for trade, investment and services for the ASEAN. During the establishment of the EEC, the government planned to develop the water bodies in the area due to its geology consisting mainly of granite. However, due to its hardness and lack of water-retention qualities, the use of groundwater was not a good alternative. Desalinated seawater was also discussed but discounted due to the expense involved. Therefore, the plan was to use surface water only as the source. The Strategy and Area Development Planning Department, Office of the National Economic and Social Development Council reported that the water situation in the EEC during 2015–2016 was very well-managed, with plenty of residual water in each reservoir to support the area's activities especially in Chonburi Province [37]. However, when a drought occurred in 2015, caused by the impact of El Nino, all three provinces in the EEC had to divert water from other provinces to support the demand in the area [38].

The root cause of the water shortage in the EEC is due to insufficient knowledge on the actual indicators of the water body change in the area. This research aims to fill in this gap by analyzing water body change trend and its driving force of change in Chonburi Province; the most urbanized area in Thailand's EEC.

Study area and data

1) Study area

Chonburi Province lies in the east of Thailand (Figure 1). It is approximately 80 km from Bangkok, covering an area of 4,507.81 km^2. It is the most urbanized area among the three provinces (Chonburi, Rayong, and Cha-choengsao) designated for development along the EEC [36].

Chonburi Province is home to the country's largest seaport, Laem Chabang; an important hub for Thailand's industry. The registered population as of 31 December 2019 was 1.509 million, excluding 511,356 non-registered persons [39]. The province consists of 11 districts: Mueang Chonburi, Sri Racha, Bang Lamung, Ko Chan, Nong Yai, Ban Bueng, Panusnikom, Phan Thong, Bo Thong, Ko Sichang and Sattahip. Mueang Chonburi is Chonburi's city centre. Industrial estates are located in Sri Racha and Bang Lamung while agricultural areas are situated in Ko Chan, Nong Yai, Ban Bueng, Panusnikom, Phan Thong and Bo Thong Districts. Famous beaches and sea views can be found in Ko Sichang and Sattahip. There are a total of 114 sub-districts in Chonburi.

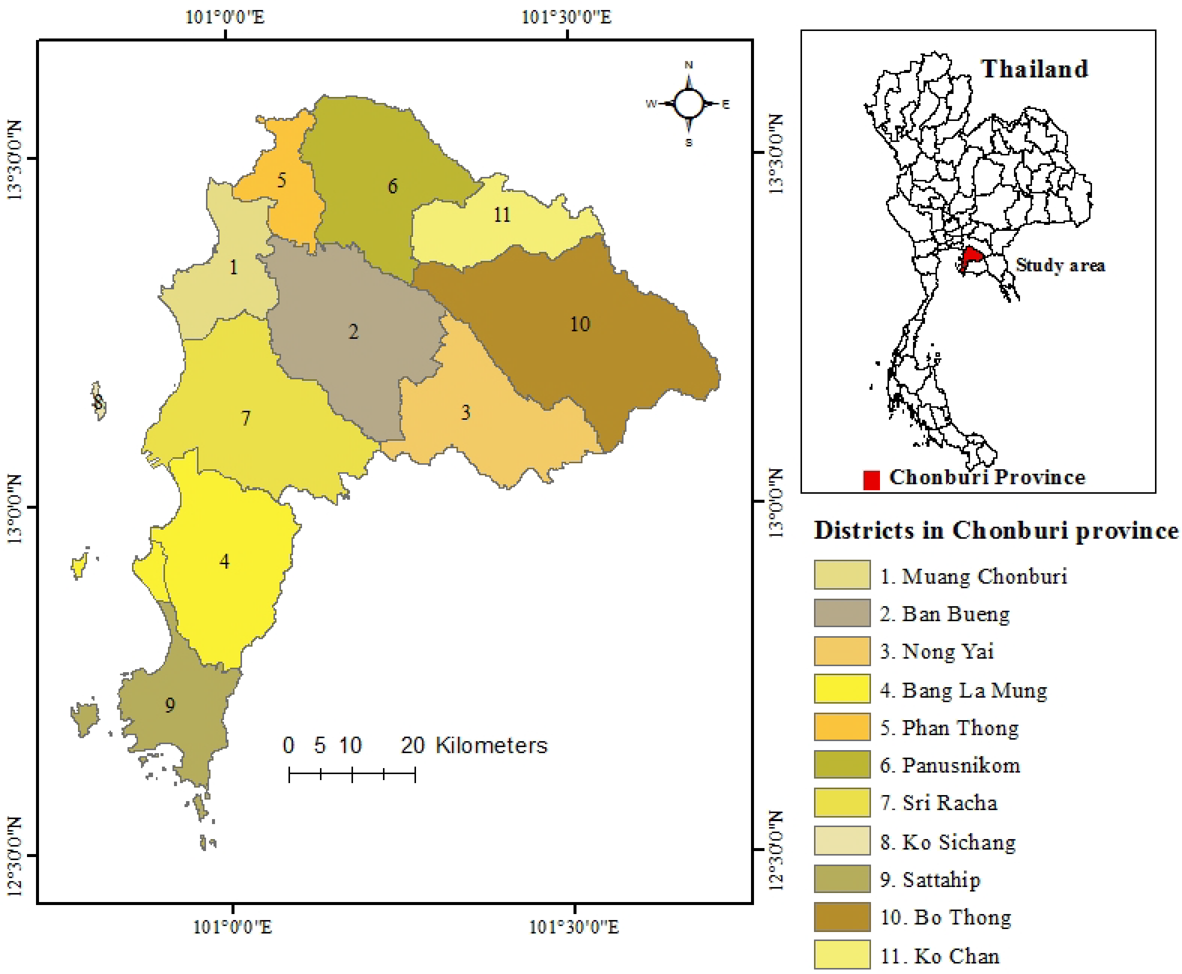


Figure 1 Location of the study area.

2) Data

Land use maps in ArcGIS vector format for the years 2006, 2010, 2013, 2016 and 2019 were obtained from the Land Development Department of Thailand (LDD). These land use maps with a scale of 1: 25,000 were classified from Landsat-5 TM combined with a field survey. Assessment of the land use change trend in water bodies uses data only for 2006 and 2019. There are 108 land use types in the 2006 land use map and 185 for 2019. These have been reclassified into six land use classes based on the theory by Barlowe [40]. These land use classes are agricultural, forest, marsh and swamp, rangeland, urban and built-up area and water bodies, as described in Table 1. The land use data was verified using 600 field data points, with an overall accuracy of 87.33% for year 2006 and 89.33% for year 2019.

Panel data on Chonburi's sub-districts for the years 2006, 2010, 2013, 2016 and 2019 is used to analyze the driving factors of water body change. Chonburi consists of 114 sub-districts, 23 of which are islands with forest cover and no movement in land use during the study period. Therefore, these 23 island sub-districts have been omitted from this study. A total of 91 sub-districts are observed every four years (2006, 2010, 2013, 2016 and 2019). The dependent variable is land use change in water bodies (CWB), so this figure is subtracted from the data available from the previous year. The process resulted in 364 panel data observations. The driving factors for land use change in water bodies are selected based on the UNESCO [26] and UN [27] reports as these factors mostly focus on human activities which caused urban expansion. Some researcher such as Bolca et al. [41] found that these human activities are the most influential factors attributed to water body loss in urban area. The selected factors include agricultural land use area (AG), average annual rainfall (PRECIP), forest land area (FR), sub-district tax revenue (TAX), industrial land use area (IND), number of new businesses established (BUSI), type of local government (MUNI), commercial land use area (COM) and population (POP).

The AG variables represent the agricultural factor while PRECIP and FR variables represent the climate change factor since rainfall and forest have a direct and indirect effect on the temperature in the region. The TAX, IND and BUSI variables represent the economic factor. The TAX variable is a proxy for individual income in the sub-district. Normally, Gross Provincial Product (GPP) best represents individual income but the GPP data is available only at the district level. Numerous studies such as those conducted by King and Rebelo [42] and Jones et al. [43] found that tax revenue is an indicator of economic growth in each area; therefore, the sub-district tax revenue is used as a proxy for GPP. The IND and BUSI variables represent the capital and investment in the area; therefore, these are used as an indicator of its economic level. The MUNI variable represents the type of governance and institutional factors. There are two types of local government in Chonburi Province: municipalities and sub-district administration organizations (SAOs). In the event that the population size is greater than 50,000 with the local revenue exceeding 12 million baht, the area is considered to be a municipality while an area with a population size of 6,000 or lower is categorized as an SAO. Municipalities and SAOs are responsible for urban public services such as land management, infrastructure, public transport, water and sewers, waste management and other related public services in the sub-district. Consequently, they have a direct impact on every type of land use change. The COM variable represents the infrastructure factor.

Table 1 Land Use Classification

Land cover classes	Description
Agricultural (AG)	Paddy field, field crop, perennial, orchard, horticulture, swidden cultivation, farmhouse, aquatic plants, aquacultural land, integrated farms, diversified farms
Forest (FR)	Evergreen, deciduous, mangrove forest, plantation, agroforestry
Marsh and swamp (MS)	Marshes and swamps, pits
Rangeland (RL)	Rangeland, pasture, abandoned fields
Urban and built-up area (UB)	Industrial estates, factories, cities, towns, commercial, villages, institutional land, transportation, communication and utilities, recreational, golf courses, cemeteries, refugee camps
Water bodies (WB)	Natural water bodies, reservoirs

Although the report by UNESCO indicates that infrastructure relates to water such as waterways for transport, irrigation and dams built for hydropower, this research defines infrastructure as a commercial territory with high concentrations of buildings and roads and a water pipe structure. The demography of the area is represented by population (POP). The ethical aspect and the increasing consumption of food and industrial goods produced using water are not included in the model due to the limitations of data collection. Despite the availability of political and trade policy data, this is not suitable for inclusion in the model since it refers to the country level only, rather than differing across sub-districts. Therefore, neither of these variables are included in the model.

Data on the population, tax revenue, and number of new businesses established was obtained from the Chonburi Statistics Office. The Chonburi Meteorological Department supplied the average annual rainfall data while area data on agriculture, forest, commercial and industrial land use area has been taken from the LDD land use map. The type of local government is the dummy variable. In the event that the sub-district is under municipal management, the value will be one and zero otherwise.

Methods

The land use transition matrix and land use dynamic degree model were used to analyse the impact of the changing trend in land use on water bodies while the driving factor of water body change was assessed using panel data analysis.

1) Land use transition matrix model

The changes in land use type between the two study periods were analysed using the land use transition matrix model [44]. The model detects the change information for each land use type. The formula for the land use transition matrix applied in this study is shown in Eq. 1.

2) Land use dynamic degree model

The annual rate of land use change was assessed using the land use dynamic degree model [45] with the value expressed as a percentage of the spatial extent. Values above and below zero indicate gains and losses respectively. The formula is shown in Eq. 2.

$$Lij = \begin{vmatrix} L_{11} & L_{12} & \dots & L_{1n} \\ . & . & & . \\ L_{n1} & L_{n2} & \dots & L_{nn} \end{vmatrix}, i \text{ and } j = 1, 2, 3, \dots, n \quad \text{(Eq. 1)}$$

Where; L is the area, i and j are the land use types before and after transition, respectively.

$$LD = \frac{L_2 - L_1}{L_1} \times \frac{1}{T} \times 100\% \quad \text{(Eq. 2)}$$

Where; LD is the dynamic degree of land use or the annual rate of change in land use type during a certain period, L1 is the number of land use changes at the beginning of the study period, L2 is the number of land use changes at the end of the study period and T is the duration of the study period.

3) Panel data analysis

Panel data provides space as well as time dimensions, meaning individuals are observed at several points in time. It contains a time-invariant variable which differs among subjects but remains constant over time for a given subject. This variable is not directly observable so its contribution to the function cannot be measured. This study includes several time-invariant geophysical factors and climatic variables which are not different across sub-districts, namely slope and average temperature. Therefore, the pooled ordinary least square model is not appropriate for analysis since these unobserved individual-specific effects will cause serial correlation and heteroskedasticity problems. To deal with the time-invariant variable, it is necessary to decide between fixed effect (FE) and random effect (RE) models.

3.1) Fixed effect model (FE)

The extent of the true effect is assumed to be identical in all studies, varying in accordance with the sampling error. Therefore, the summary effect of this common occurrence is estimated in this study. The linear unobserved effects model for N observations and T time periods is considered in Eq. 3.

3.2) Random effect model (RE)

The extent of the true effect can be assumed to vary in each study. Therefore, one true effect is not estimated but the mean of several effects. The RE model includes an additional assumption in that the random effects α_i are uncorrelated with X. Beginning with the same unobserved effects model as before, shown in Eq. 6.

$$y_{it} = \beta_i X_{it} + \alpha_i + \mu_{it}, \quad t = 1, \ldots, T \text{ and } i = 1, \ldots, N \quad \text{(Eq. 3)}$$

Where; y_{it} is the dependent variable observed for individual i at time t, X_{it} is the vector of time-variant independent variables, β_i is the vector of parameters, αi is the unobserved time-invariant variable and μ_{it} is the error term. Since α_i is not observable, it cannot be directly controlled. The FE model removes α_i by demeaning the variables used within the transformation as depicted in Eq. 4.

$$y_{it} - \bar{y}_i = \beta(X_{it} - \bar{X}_i) + (\alpha_i - \bar{\alpha}_i) + (\mu_{it} - \bar{\mu}_i) \quad \text{(Eq. 4)}$$

Where $\bar{X}_i = \frac{1}{T}\sum_{t=1}^{T} X_{it}$ and $\bar{\mu}_i = \frac{1}{T}\sum_{t=1}^{T} \mu_{it}$, Since α_i is constant, $\bar{\alpha}_i = \alpha_i$, the effect is removed. Eq. 2 then becomes Eq. 5.

$$\tilde{Y}_{it} = \beta_i \tilde{X}_{it} + \tilde{\mu}_{it} \quad \text{(Eq. 5)}$$

The FE estimator $\hat{\beta}$ is obtained by the ordinary least squares (OLS) method.

$$y_{it} = \alpha_{1i} + \beta_1 X_{1it} + \ldots + \beta_n X_{nit} + \mu_{it} \quad \text{(Eq. 6)}$$

Instead of treating α_{1i} as fixed, it can be assumed to be a random variable with a mean value of α_1 (without subscript i) and the error term (ε_i) with a mean value of zero and variance of σ_ε^2 expressed as Eq. 7.

$$\alpha_{1i} = \alpha_1 + \varepsilon_i, \text{ i} = 1\ldots\text{i} \quad \text{(Eq. 7)}$$

Substituting (Eq. 5) into (Eq. 4),

$$\begin{aligned} y_{it} &= \alpha_1 + \beta_1 X_{1it} + \ldots + \beta_n X_{nit} + \varepsilon_i + \mu_{it} \quad \text{(Eq. 8)} \\ &= \alpha_1 + \beta_1 X_{1it} + \ldots + \beta_n X_{nit} + \omega_{it} \end{aligned}$$

Where

$$\omega_{it} = \varepsilon_i + \mu_{it} \quad \text{(Eq. 9)}$$

The composite error term ω_{it} consists of two components, ε_i is the cross-section or individual-specific error and μ_{it} is the combined time series and cross-section error. The assumption of the composite error term ω_{it} is expressed as Eq. 10.

$$\varepsilon_i \sim N(0, \sigma_\varepsilon^2) \quad \text{(Eq. 10)}$$

$$\mu_{it} \sim N(0, \sigma_\mu^2)$$

$$E(\varepsilon_i\, \mu_{it}) = 0;\ E(\varepsilon_i\, \varepsilon_j) = 0\ (i \neq j)$$

$$E(\mu_{it}\, \mu_{is}) = E(\mu_{ij}\, \mu_{ij}) = E(\mu_{it}\, \mu_{js}) = 0\ (i \neq j;\ t \neq s)$$

Therefore, if $E(\varepsilon_i) = 0$, then the var(ωit) = $\sigma_\varepsilon^2 + \sigma_\mu^2$. The RE estimator $\hat{\beta}$ is obtained by the generalised least squares (GLS) method.

3.3) Hausman's specification test

Hausman's specification test [46] is used when choosing between FE and RE models by testing for orthogonality in the random effects and regressors. The test is based on the null hypothesis of no correlation, when the OLS in the FE model and GLS is consistent, but the OLS is inefficient when the alternative hypothesis states that the OLS is consistent while GLS is not [47].

Results and discussion

1) Land use transition matrix

The land use transition matrix was used to analyze the changing trend in water bodies from 2006–2019. Table 2 shows that the increase in water bodies was 87.60 km^2 in 2019, of which 58.88 km^2 (67.22%) and 13.22 km^2 (15.09%) were converted from agricultural land and rangeland, respectively. The area of water bodies in 2006 reduced by 13.72 km^2 of which 5.23 km^2 (38.11%) was converted into urban and built-up areas in 2019. Another dominant conversion was the transformation of water bodies into 3.85 km^2 (28.10%) of agricultural land and 2.56 km^2 (18.67%) into rangeland. These findings indicate that water body loss was mainly caused by urban and built-up and agricultural reclamations while water body gain emanated mainly from agricultural land.

The data on new business establishments in each period indicated that around 40% comprised traditional and modern trade such as convenience stores, supermarkets, specialty stores, department stores, hypermarkets and cash and carry. The second highest type of business establishment was accommodation and activities relating to food and beverage services (20%) [39]. Typically, these business types need to be located in prime positions involving a dynamic change in economic activities and land development. It is therefore possible that land reclamations from water bodies existed in these prime zones.

2) Land use dynamic degree

The dynamic degree of land use from 2006–2019 in Chonburi Province was calculated using the results from the land use transition matrix (Table 3). Water bodies were responsible for the highest dynamic degree of land use change (10.72%), followed by urban and built-up area (3.00%), rangeland (2.14%) and agricultural land (-1.29%) respectively. This indicates that water body land use, urban and built-up and rangeland developed rapidly from 2006–2019, while the rate of change for agricultural land experienced a significant decline. The overall variation in the land use dynamic degree in Chonburi Province from 2006–2019 was 14.36%, with water bodies and urban and built-up areas exhibiting the largest increase. As a whole, during this ten-year period, the land use status in Chonburi Province was active due to rapid economic development and urbanization.

Table 2 Transition matrix of land use in Chonburi from 2006 to 2016 (km^2)

Land use type	**2019**						**Total**
2006	**AG**	**FR**	**MS**	**RL**	**UB**	**WB**	**(2006)**
AG	2,252.41	22.79	58.17	149.55	272.18	58.88	2,813.98
FR	17.26	459.09	0.80	3.43	13.86	1.16	495.60
MS	23.05	6.30	47.43	16.62	30.32	7.04	130.77
RL	62.59	15.85	11.71	58.43	59.52	13.22	221.32
UB	91.83	6.46	4.44	38.16	629.03	7.29	777.21
WB	3.85	0.68	1.39	2.56	5.23	55.21	68.93
Total (2019)	2,451.00	511.18	123.95	268.75	1,010.13	142.80	4,507.81

Table 3 Dynamic degree of land use in Chonburi Province from 2006 to 2019

Land use type	**Year 2006–2019**	
	Change area (km^2)	**Dynamic degree**
Agricultural area	-362.99	-1.29
Forest area	15.57	0.31
Marsh and swamp	-6.82	-0.52
Rangeland	47.44	2.14
Urban and built-up areas	232.92	3.00
Water bodies	73.88	10.72
Total		14.36

3) Panel data analysis

The descriptive statistics presented in Table 4 show an average water body change in the 91 sub-districts of Chonburi Province during the study period of 0.520 km^2 with a maximum positive change of 23.643 km^2 and a maximum negative change of -5.699 km^2. On average, around 669 businesses have been established with the maximum number reaching 18,295 in these sub-districts. The average number of population is 11,643. The average tax revenue for the sub-districts in Chonburi Province is 53.576 million baht with the maximum equating to 918 and the minimum 0.102 million baht.

The panel unit root test proposed by Levin et al. [48] shows that all variables are stationary at level except the sub-district tax revenue variable which is stationary at the first difference. Therefore, the tax variable is used at the first difference and the other variables at level for the analysis.

Table 5 presents the results of the Pooled, FE, and RE estimations. In the FE model, local authority has the greatest effect on water body change with a higher R^2 than the Pooled OLS and RE model estimations, indicating an improvement in the goodness of fit model. The Hausman test shows that the null hypothesis cannot be accepted. Therefore, this study focuses on the results obtained from the FE model.

Table 4 Descriptive statistics of the variable fixed effect model

Variables	Mean	S.D.	Maximum	Minimum
Land use change in water bodies: CWB (km^2)	0.520	2.365	23.643	-5.699
Business and industrial establishment number: BUSI (number)	668.743	1,615.420	18,295.000	8.000
Sub-district tax revenue: Tax (Million Baht)	53.576	109.000	918.000	0.102
Population: POP (number)	11,642.970	12,196.800	76,504.000	1,153.000
Type of local government: MUNI (municipality = 1, otherwise = 0)	0.132	0.339	1.000	0.000
Agricultural area: AG (km^2)	41.608	53.884	367.945	0.000
Forest land area: FR (km^2)	19.374	93.967	1,721.699	0.000
Commercial area: COM (km^2)	52.605	24.306	229.162	0.792
Industrial area: IND (km^2)	2.771	4.906	33.610	0.000
Rainfall PRECIP (mm)	91.553	41.865	289.600	3.600

Table 5 Panel data analysis using pooled OLS, fixed effect and random effect methods

Panel data variable	Pooled OLS coefficient	Fixed effect coefficient	Random effect coefficient
Intercept	1.020***	2.089**	1.016***
	(0.394)	(0.893)	(0.393)
POP	-3.350^{-6}	-1.020^{-4}**	-3.66^{-6}
	(1.490^{-5})	(5.240^{-5})	(1.500^{-5})
TAX	-1.340^{-9}	-1.060^{-9}	-1.370^{-9}
	(1.290^{-9})	(2.010^{-9})	(1.280^{-9})
BUSI	5.010^{-5}	3.680^{-5}	5.100^{-5}
	(1.070^{-4})	(3.890^{-4})	(1.070^{-4})
AG	0.012***	-9.474^{-3}*	0.012***
	(0.002)	(0.011)	(0.002)
IND	-0.025	0.077	-0.025
	(0.027)	(0.061)	(0.027)
COM	-0.010*	0.002	-0.010*
	(0.006)	(0.012)	(0.006)
FR	-5.420^{-4}	0.002	-4.900^{-4}
	(0.001)	(0.002)	(0.001)
PRECIP	-0.004	6.217^{-3}*	-0.004
	(0.003)	(0.003)	(0.003)
MUNI	0.997**	1.903***	1.017***
	(0.397)	(0.565)	(0.394)

Table 5 Panel data analysis using pooled OLS, fixed effect and random effect methods (*continued*)

Panel data variable	Pooled OLS coefficient	Fixed effect coefficient	Random effect coefficient
R-squared	0.083	0.341	0.081
Adjusted R-square	0.060	0.293	0.058
S.D. of dependent variable	2.365	2.365	2.347
Durbin-Watson statistic	1.523	2.004	1.541
F-statistic	3.582	1.377	3.481
Prob F-statistic	0.000	0.023	0.000

Note: ***, **, * = statistically significant at the 0.01, 0.05 and 0.10 levels with 364 observations; standard errors are in parentheses

The results from the FE model indicate that the type of local government has the greatest effect on water body change, followed by agricultural land use, climate change and population, respectively. All signs for the significant variables were as expected. When the sub-district is a municipality, it results in an additional 1.903 km^2 change in water bodies. Municipalities and SAOs are responsible for the management of water, land and related resources to balance the economic, social welfare and ecosystem environment. Since municipalities have the ability to generate more local revenue, they are better able to manage the water demand in the area under their responsibility. The finding implies water demand projection in the territory. It is consistent with the works of Srinivasan et al. [16], Zhang et al. [32] and Wu et al. [31] in that the establishment of capable local government authorities and policies have a huge impact on water security and wetland protection.

When looking deeper into the water body type in Chonburi (Table 6), it is obvious that the increased water bodies in the study area are human-made. In 2006, from a total water body area of 68.932 km^2, natural water bodies accounted for 46.504 km^2 (67.463%) and human-made 22.429 km^2 (32.537%). Whereas in 2019, from a total water body area of 142.804 km^2, 35.247 km^2 (24.682%) were natural water bodies and 107.557 km^2 (75.318%) human-made. In terms of net area, natural water bodies in Chonburi Province have slightly decreased but in terms of percentage change, the proportion is quite high. This increasing trend of human-made water bodies is also consistent with the work of Zhang et al. [32] although due to different causes. In the Beijing-Tianjin-Hebei region, the increase was driven by agricultural and grassland expansion while in the case of Chonburi, it was due to industrial and urban development.

Regarding the AG variables, an increase in agricultural land of 1 km^2 will result in a 9.474^{-3} km^2 (or 9,474 m^2) reduction in water bodies. This result is consistent with that of the FAO [49], indicating that grassland and cropland have a negative effect on the availability and quality of water resources. Gordon et al. [50] also pointed out that agriculture drives land use and land cover change and has made substantial modifications to the global hydrological cycle in terms of water quality and quantity. Furthermore, Chaves et al. [51] found that agricultural and pastureland intensity contributed to a significant decrease in the base flow discharge responsible for the maintenance of streamflow. Agricultural water represents 70% of the total water withdrawn for human use while industry and municipal water account for 20% and 10% of water use respectively [22]. Although the AG effect in the study area is quite low compared to MUNI variables, it is likely to have a significant impact on water bodies since it covers a large area of change. Malik and Rai [33] and Zhang et al.

[32] suggested the minimization of agricultural expansion to reduce the negative impact of agriculture on water bodies. The top five crops grown in Chonburi during 2019 were rubber, palm oil, cassava, sugarcane and rice [52]. Rice is the most water-consuming crop and minimization rice growing in the area should help to mitigate the negative impact on water body change. Furthermore, there is no charge for irrigation water in Thailand while the system cannot be accessed equally by all farmers. Tariffs on irrigation water can be part of the solution as it will encourage efficient use of water in this sector. Water rights transfer should also applied for parcels converted from agricultural to municipal use in these area. In addition, the promotion of other water source options such as rainwater harvesting, underground water tank or private wells to meet part of their own demand should also help to reduce the water stress in agricultural use in the area.

The PRECIP variable exhibited a positive impact on water body change, aligning with the findings of the UNESCO [26] and Li et al. [29], indicating that climate change has the positive impact on water body. Our results indicated that an increase in rainfall of 1 mm will result in an additional 6.217^{-3} km^2 (or 6,217 m^2) change in water bodies. The impact from El Nino in 2015 and 2019 in the EEC is the empirical evidence that support the result from our model. When the drought occur, all three provinces in the EEC had to divert water from other provinces to support the demand in the area. The issue is beyond the capability of one nation to deal with, therefore the government need to be coordinated at the international level to develop a plan to solve the global warming problem.

An increase in population will result in a reduction 1.020^{-4} km^2 (or 102 m^2) of water bodies. This result is consistent with the reports by Wu et al. [31], Li et al. [30], UN [27], Li et al. [29] and the WWAP [53]. The WWAP [53] reported that population growth has led to a tripling of water withdrawal over the last 50 years while the UN [27] also indicated that the population influences water resource change due to the wide range of human needs, including food production, industrial development and domestic demand. Population growth puts extra pressure on freshwater resources through the increased need for water. There has been a huge investment in the water supply in the EEC but augmentation of water supply via keep creating new sources cannot be sustainable in the long run. Higher tariffs with spatial price discrimination should be applied in the EEC as the current water price does not include the water delivering costs. A higher tariff based on location would help to reduce water demand and improve efficiency in water use. Currently, Thailand employs the Increasing Block Tariff (IBT); two-part tariff for all user types (residential, government agencies, small businesses, state enterprises and large businesses) while Boland and Whittington [54] argued that the IBT is not widely used in developed countries due to its ineffectiveness. A survey of urban water utilities in Asia found that the majority of utilities in the sample used an IBT pricing scheme [55], therefore water price policy reform needs to be initiated not only in Thailand but throughout Asia.

Table 6 Water body types in 2006 and 2019 (km^2)

Water body type	2006	%	2019	%
Artificial water body	22.429	32.537	107.557	75.318
Natural water body	46.504	67.463	35.247	24.682
Total	68.933	100.000	142.804	100.000

The relatively low adjusted R^2 of the models implying moderate explanatory power. One of the reasons for this shortcoming is likely the lack of variation in selected driving force. The model developed in this study focus on human activities which cause urban expansion. Data on soil properties, which had been found by Baoshan et al. [56] and Meng et al. [57] to be the key predictors in the water body change were not included in the model. More detailed data, especially the topographic might be necessary to improve the model's performance as it has been found that most water body change occurs on flat slope [58]. Finally, the climatic data, such as the annual average temperature and humidity were homogeneous not different across sub-districts, making it unsuitable to include in the model. Therefore, they remain unexplored.

Model validity test: Heteroscedasticity and non-normality are critical in the panel setting. The bias-corrected scaled LM proposed by Baltagi et al. [59] was used to test the hetero-scedasticity and no inefficiency problem was identified in the panel setting. The histogram normality plot and the Jarque-Bera statistic were used to test the non-normality problem. The findings of the test revealed that the residuals were not normally distributed, indicating that the panel setting remains biased. However, Baltagi [60] suggested that the F-test is robust against non-normality. In addition, the result is based on the FE model where the intercept for each observation is different, therefore the mean of the effect does not represent the mean of each observation, making normality less critical in this case.

Conclusion

This study attempts to draw conclusions regarding the impact of urbanisation on the water body change trend and the driving forces of such change in the EEC of Thailand. The findings reveal that water bodies are experienceing an increasing trend. The annual rate of change is the highest (10.72%) among all land use types, followed by urban and built-up area (3.00%), rangeland (2.14%) and agricultural land (-1.29%) respectively. The increase in water bodies during 2019 was mainly due to the transformation of agricultural land (67.22%) and rangeland (15.09%) while water body loss mainly resulted from the conversion of water bodies into urban and built-up areas (38.11%) and agricultural use (28.10%). This implies that the water body gain was mainly from agricultural land while the loss was mainly caused by the reclamation of urban and built-up areas and agriculture. The results also suggest that urban water bodies in the study area are planned and managed by local authorities, under central government delegation because the increased water bodies are mainly human-made. In 2006, human-made water bodies account for 32.537% of the total water bodies in Chonburi while this figure was 75.318% in 2019.

In the final panel model, the selected determinants were generally weak predictors of water body change. However, they are suitable for the analysis in term of water pressure in urban area as they mostly focus on anthropogenic activities which are the most influential factors attributed to the water body loss from urban development. The results revealed striking effects of type of governance, agricultural land use, climate change and population on water body change. The positive effects arise from the type of governance and climate change, while the negative effect is from the agriculture and population factor. Although the negative impact of agricultural land use on water bodies is expected to decrease in the future as it is exhibiting a decreasing trend, diversifying towards crops that use less water than rice could be part of the solution. In addition, irrigation tariffs should induce more efficiency in water use in agriculture sector. The water tariff based on location should also be applied to reduce the negative impact from the population growth. The location based tariff will help to reduce water demand as well as the immigration pressure to the urban area. Among the potential variables, climate change is the factor that needs an international collaboration network while the rest are manageable locally. Therefore, the role of central government in the future management of urban water is particularly crucial.

Funding

This work is supported by the Kasetsart University Research and Development Institute under Grant Number R-M.35.60.

Acknowledgements

The author would like to express deep appreciation and gratitude to Assistant Professor Supachat Sukharom at Kasetsart University for his valuable comments and contribution to the manuscript.

References

[1] Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., Morgan II, R.P. The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society, 2005, 24(3), 706–723.

[2] Paul, M.J., Meyer, J.L. Streams in the urban landscape. Annual Review of Ecology and Systematics, 2001, 32, 333–365.

[3] Meyer, J.L., Paul, M.J., Taulbee, W.K. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society, 2005, 24, 602–612.

[4] Hall, M.J., Ellis, J.B. Water quality problems of urban areas. GeoJournal, 1985, 11, 265–275.

[5] Leopold, L.B. Hydrology for urban land planning-a guide book on the hydrologic effects of urban land use. US Geological Survey Circular 554. United States Department of the Interior, 1968.

[6] Booth, D.B., Jackson, C.R. Urbanization of aquatics systems: Degradation thresholds, stormwater detection, and limits of mitigation. Journal of the American Water Resources Association, 1997, 33(5), 1077–1090.

[7] Nabelkova, J., Kominkova, D., Stastna, G. Assessment of ecological status in small urbans streams of Prague agglomeration. Water Science and Technology, 2004, 50(5), 285–291.

[8] Helms, B.S., Feminella, J.W., Pan, S. Detection of biotic responses to urbanization using fish assemblages from small streams of western Georgia. Urban Ecosystems, 2005, 8, 39–57.

[9] Kominkova, D., Stransky, D., Stastna, G., Caletkova, J., Nabelkova, J., Handova, Z. Identification of ecological status of stream impacted by urban drainage. Water Science and Technology, 2005, 51(2), 249 –256.

[10] Katarzyna, G.L., Golas, I., Koc, J., Plachta, A.G., Harnisz, M., Rochwerger, A. The impact of urban areas on the water quality gradient along a lowland river. Environmental Monitoring and Assessment, 2016, 188(11), 624.

[11] Yang, G., Bowling, L.C., Cherkauer, K.A, Pijanowski, B.C. Niyogi, D. Hydroclimatic response of watersheds to urban intensity-an observational and modelling based analysis for the White River basin, Indiana. Journal of Hydrometerorology, 2010, 11, 122–138.

[12] Lepeska, T., Wojkowski, J., Walega, A., Mlynski, D., Radecki-Pawlik, A., Olah, B. Urbanization-its hidden impact on water losses: Pradnik river basin, lesser Poland. Water, 2020, 12(7), 1958.

[13] Konrad, C.P. US geological survey fact sheet 076-03, effects of urban development on floods. U.S. Geological Survey-Water Resources, 2003.

[14] Rosburg, T.T., Nelson, P.A., Bledsoe, B.P. Effects of urbanisation on flow duration and stream flashiness: A case study of Puget Sound streams, western Washington, USA. Journal of American Water Resource, 2017, 53, 493–507.

[15] Salvadore, E., Ronders, J., Batelaan, O. Hydrological modelling of urbanised catchment: A review and future direction. Journal of Hydrology, 2015, 529, 62–81.

[16] Srinivasan, V., Seto, K.C., Emerson, R., Gorelick, S.M. The impact of urbanisation on water vulnerability: A coupled human-environment system approach for Chennai, India. Global Environmental Change, 2013, 23, 229–239.

[17] Oudin, L., Salavati, B., Furusho-Percot, C., Ribstein, P., Saadi, M. Hydrological impacts of urbanisation at the catchment scale. Journal of Hydrology, 2018, 559, 774–786.

[18] Dams, J., Woldeamlak, T., Batelaan, O. Predicting land use change and its impact on the groundwater system of the Kleine Nete catchment, Belgium. Hydrology and Earth System Sciences, 2008, 12, 1369–1385.

[19] Wang, J., Da, L., Song, K., Li, B.L. Temporal variations of surface water quality in urban, suburban and rural areas during rapid urbanization in Shanghai, China. Environmental Pollution, 2008, 152(2), 387–393.

[20] Jakubiak, M., Chmielowski, K. Identification of urban water bodies ecosystem Services. Acta Scientiarum Polonorum Technologia Alimentaria, 2020, 19(3), 73–82.

[21] Huang, X., Fang, X., Xie, C., Zhang, L. Combining pixel and object based machine learning for identification of water body types from urban high resolution remote sensing imagery. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2015, 1939–1404, 1–14.

[22] Shiklomanov, I. A., Rodda, J.C. World water resources at the beginning of the 21st century. United Kingdom: Cambridge University Press, 2003.

[23] Wolfgang, J.J., An, S., Finlayson, C.M., Gopa, B., Kvet, J., Mitchell, S.A., Mitsch, W.J. Robarts, R.D. Current state of knowledge regarding the world’s wetlands and their future under global climate change: A synthesis. Aquatic Sciences, 2013, 75, 151–167.

[24] McDonald, R.I., Green, P., Balk, D., Fekete, B., Revenga, C., Todd, M., Montgomery, M. Urban growth, climate change and freshwater availability. Proceedings of the National Academy of Sciences of the United States of America, 2011, 108, 6312–6317.

[25] Brown, R.R., Keath, N., Wong, T.H.F. Urban water management in cities: Historical, current and future regimes. Water Science Technology, 2009, 59, 847–855.

[26] UNESCO (United Nations Educational, Scientific and Cultural Organization). The dynamics of global water futures driving forces 2011–2050. UNESCO, 2012.

[27] UN (United Nations). Comprehensive assessment of the freshwater resources of the world. United Nations, 1997.

[28] Jiang, W., Wang, W., Chen, Y., Liu, J., Tang, H., Hou, P., Yang, Y. Quantifying driving forces of urban wetlands change in Beijing City. Journal of Geographic Science, 2012, 22(2), 301–314.

[29] Li, B., Hu, Y., Chang, Y., Liu, M., Wang, W., Bu, R., ..., Qi, L. Analysis of the factors affecting the long-term distribution changes of wetland in the Jing-Jin-Ji region, China. Ecological Indicators, 2021, 124, 107413.

[30] Li, Z., Liu, M., Hu, Y., Xue, Z., Sui, J. The spatiotemporal changes of marshland and the driving forces in the Sanjiang Plain, Northest China from 1980–2016. Ecological Processes, 2020, 9(24).

[31] Wu, X., Gong, W., Xu., Y. Analysis of urban wetland changes and their driving forces based on RS and GIS: A case study in the Longfeng Wetland Natural Reserve, China. Nature Environment and Pollution Technology, 2016, 15(2), 377–384.

[32] Zhang, L., Zhen, Q., Cheng, M., Ouyang, Z. The main drivers of wetland changes in the Beijing-Tianjin-Hebei region. International Journal of Environmental Research and Public Health, 2019, 16, 2619.

[33] Malik, M., Rai, S.C. Drivers of land use/ cover change and its impact on Pong Dam wetland. Environmental Monitoring and Assessment, 2019, 191, 1–14.

[34] UNIDO (United Nations Industrial Development Organization). Economic zones in the ASEAN. UNIDO, 2015.

[35] Bao, C., Fang, C.L. Water resources constraint force on urbanization in water deficient regions: A case study of the Hexi Corridor, arid area of NW China. Ecological Economics, 2007, 62(3–4), 508–517.

[36] WBG (World Bank Group). East Asia's urban changing landscape measuring a decade of spatial growth. WBG, 2015.

[37] NESDC (Office of National Economic and Social Development Council). Progress in the development of the Eastern seaboard area report. The Strategy and Area Development Planning Department, NESDC, 2014.

[38] Green News. Risk of Water fight in EEC from Climate change, 2018. [Online] Available from: https://greennews.agency/?p=16539 [Accessed 20 September 2018] (in Thai).

[39] Chonburi Statistic Office. Census Statistics. 2020. [Online] Available from http://chonburi.nso.go.th/index.php?option=com_content&view=article&id=600:20220520-1&catid=102:2012-01-09-07-05-22&Itemid=507 [Accessed 5 February 2020] (in Thai).

[40] Barlowe, R. Land resource economics: the economics of real estate. New Jersey: Prentice-Hall, 1978, 200–213.

[41] Bolca, M., Turkyilmaz, B., Kurucu, Y., Altinbas, U., Esetlili, M.T., Gulgun, B. Determination of impact of urbanization on agricultural land and wetland use in Balcovas' delta by remote sensing and GIS technique. Environmental Monitoring and Assessment, 2007, 131, 409–419.

[42] King, R.G., Rebelo, S. Public policy and economic growth: Developing neoclassical implications. Journal of Political Economy, 1990, 98(5), 126–150.

[43] Jones, L.E., Manuelli, R.E., Rossi, P.E. Optimal taxation in models of endogenous growth. Journal of Political Economy, 1993, 101(3), 485–517.

[44] Bell, E.J. Markov analysis of land use change: An application of stochastic processes to remotely sensed data. Socio-Economic Planning Sciences, 1974, 8(6), 311–316.

[45] Li, Y., Liu, G., Huang, C. Dynamic changes analysis and hotspots detection of land use in the central core functional area of Jing-Jin-Ji from 2000 to 2015 based on remote sensing data. Mathematical Problems in Engineering, 2017, 2183585, 1–16.

[46] Hausman, J.A. Specification tests in Econometrics. Econometrica, 1978, 46, 1251–1272.

[47] Green, W.H. Econometic analysis. 5th Edition. New Jersey: Prentice Hall, 2003,

[48] Levin, A., Lin, C.F., Chu, C.S.J. Unit root tests in panel data: asymptotic and finite-

sample properties. Journal of Econometrics, 2002, 108(1), 1–24.

[49] FAO (Food and Agriculture Organization). Sustainable land management fact sheet. 2008. [Online] Available from: http://www.fao.org.docrep/010/ai559e/ai559e00.htm [Accessed 18 July 2018].

[50] Gordon, L.J., Finlayson, C.M., Falkenmark, M. Managing water in agriculture for food production and other ecosystem services. Agricultural Water Management, 2010, 97, 512–519.

[51] Chaves, H.M.L., Camelo, A.P.S., Mendes, R.M. Groundwater discharge as affected by land use change in small catchments: a hydrologic and economic case study in Central Brazil. *In:* Treidel, H., Luis, J., Bordes, M., Gurdak, J.J. Climate change effects on groundwater resources: A global synthesis of findings and recommendations. England: Taylor and Francis Group,LLC. 2011, 49–62.

[52] Chonburi Ministry of Industry. Chonburi's Economic Situation Report Year 2019. 2020. [Online] Available from: https://data.go.th/dataset/da1a77e2-fded-4b8d-b554-cbc864731be5/resource/58b13b60-78e2-4ced-b489582aa75dd81c/download/-6-63.pdf [Accessed 31 May 2022].

[53] WWAP (The United Nations World Water Assessment Program). Climate change and water: An overview from the world water development report 3: Water in a changing world. WWAP, 2009.

[54] Boland, J.J., Whittington, D. Water tariff design in developing countries: Disadvantages of Increasing Block Tariffs (IBTS) and advantages of Uniform Price with Rebate (UPR) designs. World Bank Water and Sanitation Program, 2000, 1–37.

[55] McIntosh, A.C. Water utilities data book: Asian and Pacific region. Philippines: Asian Development Bank, 1993.

[56] Baoshan, C.U.I., Qiang, H.E., SinSheng, Z.H.A. Researches on the ecological thresholds of Suaeda salsa to the environmental gradients of water table depth and soil salinity. Acta Ecologica Sinica, 2008, 28, 1408–1418.

[57] Meng, Y., He, Z., Liu, B., Chen, L., Lin, P., Luo, W. Soil salinity and moisture control the processes of soil nitrification and denitrification in a Riparian Wetlands in an extremely arid regions in Northwestern China. Water, 2020, 12.

[58] Creed, I.F., Sanford, S.E., Beall, F.D., Molot, L.A., Dillon, P.J. Cryptic wetlands: Integrating hidden wetlands in regression models of the export of dissolved organic carbon from forested landscapes. Hydrological Processes, 2003, 17, 3629–3648.

[59] Baltagi, B.H., Feng, Q. Kao, C. A Lagrange multiplier test for cross-sectional dependence in a fixed effects panel data model. Journal of Econometrics, 2012, 170(1), 164–177.

[60] Baltagi, B.H. Econometric analysis of panel data. 2nd Edition. England: John Wiley and Sons Ltd, 2001, 72.