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Analysis of water resources and water potentials under conditions of land use-urban-industrial-agricultural change and climate change in the Eastern region of Thailand

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Abstract Analysis of water resources and rainwater-runoff potentials were investigated under climate change conditions and land use development, urban, economic and industrial change in the eastern region, as well as analyzing models and evaluating water costs in the eastern watershed, namely the Eastern Coastal Basin, Bang Pakong River Basin, Prachinburi Basin, Tonle Lake Basin by using the SWAT model (Soil and Water Assessment Tool) and a Cellular Automata (CA)- Markov chain model and predicted land use change related the amount of runoff demand for water in the year 2012-2018 recorded that an averaged water demand of 10,316.44 - 13824.96 million cubic meters (consumption 158.40-212.27 million cubic meters, industry and tourism 369.36-494.98 million cubic meters, agriculture 9,338.18 – 12,514.05 million cubic meters). The economic development of the Eastern Seaboard area has changed to higher temperatures, hot and drought during summer as high as 35 - 45 degrees Celsius, along with changes in land use of the eastern region from the year 2006 to the year 2016. It was increasing urban areas, industries, and buildings mostly infrastructure by 305.29 square kilometers, especially in Rayong, Chonburi, and Chachoengsao provinces. The agricultural area is increased by 446.74 square kilometers, growing by 10 – 15% due to government policies, the development of special economic zones, Coastal Economic Corridor, and water demand is increased by 10 – 20 % per year in each sector. The Water Supply of Eastern Thailand has 56 reservoirs, with 6 large reservoirs with a combined capacity of 1,467.75 million cubic meters and 49 medium-sized reservoirs with a total capacity of 647 million cubic meters which is a storage volume of 2,115 million cubic meters. The Eastern Region has 48 industrial estates and total factories located inside and outside, about 10,853 factories. Water demand of the agriculture sector is used at about 85-90 % or more than 5,600 million cubic meters/Year of the total water supplies. Industrial sectors used about 8-10 % or more than 57.0 million cubic meters/Year. Urban, domestic, and tourism used about 5 - 7 % or more than 370 million cubic meters/Year.

Keywords: SWAT: Soil and Water Assessment Tool, Eastern basin, CA-Markov Chain

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Introduction

The eastern region is located on the east side of Bangkok. Located between latitude 11 ° 39' to 14 ° 30' N and longitude 100 ° 52' to 102 °58' E. It covers 7 provinces, including Chonburi, Rayong, Chachoengsao, Prachin Buri, Chanthaburi, Trat, and Sa Kaeo. The total area is 34,380 square kilometers which accounts for 6.7 percent of the country's area. Physical characterized by a plateau with a corrugated plateau and the mountains in the north, the San Kamphaeng and the Central Chanthaburi Mountains with the top of Soi Dao, the highest peak located in the east and southeast with a mountain range between Thailand and Cambodia. Coastal flatlands interspersed with mountains spread west. The geologic characteristics of granite are inserted into the sandstone and sedimentary rocks. Clay is cand mixed with sand and sediment. The topography of the eastern region consists of 3 parts: the mountainous area, the river basin, and the sloping plains and coastal plain areas. Climate characteristics of the eastern region Consist of the upper part of the region with the weather of Savannakhet (Aw) and the lower part having a tropical climate like the monsoon (Am) with heavy rain and a humid climate. The province with the highest rainfall is Trat and the least rainy province is Chonburi. (Soytong *et al.*, 2018).

The eastern region is covered in 5 watershed areas, including (1) Eastern Seaboard Basin (2), Bang Pakong River Basin (3), Prachin Buri Basin (4), Tonle Lake Basin, and (5) Chao Phraya Basin. The main rivers in are 7 main lines, consisting of (1) Bang Pakong River (2) Rayong River (3) Prasae River (4) Chanthaburi River (5) Phang Rat River (6) Trat River and (7) The Weru River, the location of the river basin and the back river in the eastern region. Land use/Land cover of the eastern region is mostly agricultural areas, followed by forest areas urban community and buildings areas, and water sources, the industrial movement gradually expanded areas and open space. Provinces that have a higher proportion of urban growth and industrial land use tend to increase, most of which are in Chonburi, Rayong, and Chachoengsao (Soytong *et al.,* 2018). The industrial sector has a production ratio of 56.1 percent of the value of the product sector in 2560 (NESDB, 2016). The eastern region has the potential for urban development both physically and economically. The level of urbanization of the region, the level of urbanization of the eastern region, found that the city population accounted for 29 percent of the population, including the region (Department of Public Works and Town Planning, 2007). The prediction of land use change uses the MARKOV Chain model which can be significant land use and land cover potential in Eastern Area.

The Eastern region has 46 reservoirs. The amount of water that flows into the reservoir is about 1,987.4 million cubic meters (MCM) but the reservoir has a storage capacity of 1,569.8 MCM. The 4 large reservoir capacities are a total of storage capacity 948.75 MCM (Department of Water Resources, 2016). Water sources in the eastern region are mainly allocated for household use and agriculture. The construction of the Khao Rakam, Bang Phra, and Dok Krai reservoirs has increased water management stability. The industrial of the eastern region related to the Eastern Economic Corridor (EEC), Chonburi, Rayong, and Chachoengsao, is approximately 325 MCM and has a water source costing 427 MCM (Royal Irrigation Department, 2017). Therefore, the water demand, resources management, and water potentials are necessary for the analysis of the physical characteristics and database of the SWAT Model under the conditions of Land Use/Land Cover (LULC) Change and Climate Change of the Eastern Region of Thailand.

The objectives were to analyze land use changes in Eastern Thailand in 2008, 2014, and 2019 and predict the potential land use in 2024, and 2029 with the CA Markov chain model, to analyze climate change and the factors of physical characteristics and database setup into the SWAT model, and to analyze the water runoff, resources management, and water potentials under conditions of land use lan climate change conditions l in Eastern Thailand.

Materials and methods

Analysis of Water Resources and Water potential under Conditions of Land use and land cover and Agriculture-Industrial - Urban Development Change and Climate Change were analyzed with the Cellular Automata (CA) - MARKOVchain and SWAT model. Methods and steps of Land use and land cover (LULC) classification of satellite imagery in 2008, 2014, and 2019 and The CA Markov model have used simulation changes and prediction of LULC in 2025 in the Eastern Region.

Land use and land cover classification

Remote Sensing (RS) data from Landsat Satellite is classified LULC using Geography Information System: GIS Program. RS data consists of Landsat-5 satellite images and Landsat-8 which were satellites in many waves with 30-meter picture detail years 2008, 2014, and 2019. Land Use Data Implemented (Supervised Classification) and analyzed land use trends in 2024 by using the CA Markov model with the application of GIS ArcGIS.

Markov Chain process is variated in each cell by analyzing together with the Cellular Automata (CA) that was developed by Ulam in 1940 (Mishra and Rai, 2016; Amini Parsa *et al*., 2016). CA consists of a grid or a raster space of adjacent areas (5 x 5) with the overlap of one cell and repeats until the number of rounds. The Markov Chain Model describes the LULC change from 2014 and 2019 to predict the future in 2024 and 2029. In the Eastern of Thailand with the equation: If the land use types (X) transition probability (p_{ij}) will process from state i to state j:

$$P\{X_{n+1} = j \mid X_n = i_n, X_{n-1} = i_{n-1}, \ldots\ldots\ldots X_1 = i_1, X_0 = i_0\} = P_{ij}$$

$$P_{ij} \geq 0, \quad i, j \geq 0, \quad \text{and} \sum_{j=0}^{n} P_{ij} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Multiple transitions (The Chapman-Kolmogorov equation):

- n-step transition matrix = $\underline{P}^n$
- Unconditional probability of a state at $t = n$:

$$P\{X_n = j\} = \sum_{i=0}^{N} P_{ij}^{n}\, \alpha_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where α_i is the initial probability of state i.

$$\underline{P}\{X_n\} = [\alpha_0\ \alpha_1\ \ldots\ \alpha_N]\ .\ \begin{pmatrix} P_{00} & P_{01} \ldots P_{0N} \\ P_{10} & P_{11} \ldots P_{1N} \\ . & . \\ P_{N0} & P_{N1} \ldots P_{NN} \end{pmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Analysis of agriculture, industrial and urban development change

Analysis of water resources potentials affecting climate changes

Analysis of Climate Change:

Weather stations and data:

Temperature calculated Land Surface Temperature (LST) from the equation:

$$T_s = \gamma\left[\frac{1}{\varepsilon}(\varphi_1 L_{sen} + \varphi_2) + \varphi_3\right] + \delta \quad \ldots\ldots\ldots\ldots\ (4)$$

When $\gamma \approx \dfrac{T^2_{sen}}{b_\gamma L_{sen}}$; $\delta \approx T_{sen} - \dfrac{T^2_{sen}}{b_\gamma}$

$\varphi_1 = \dfrac{1}{\tau}$; $\varphi_2 = -L_d - \dfrac{L_u}{\tau}$; $\varphi_3 = L_d$

T_s is Land Surface Temperature; T_{sen} is Brightness Temperature,
L_{sen} is Spectral Radiance; ε is Land Surface Emissivity;
τ is Atmospheric Transmittance; L_d is Downward Atmospheric Radiance*;*
L_u is Upward Atmospheric Radiance.

Rainfall stations and data were got from 30-year rainfall data from the Meteorological Department Data including maximum-lowest temperature, heat, and humidity covering the Eastern of Thailand from 1987-2017.

The soil and water assessment tool (SWAT) model

SWAT requests weather, water, soil, land use, and topography data for the watershed network.

The Global Digital Elevation Model data was posted on a 1-arc-second grid and referenced to WGS84. The ArcSWAT extension is used by Watershed Delineation to run DEM of Eastern Thailand for calculated flow direction, water storage, and building a water route.

Subdivision of sub-river boundaries using DEM data and watershed network data and water routes, the program calculated the main water route and the gastric juice path that corresponds to the real landscape according to the direction of the water flow. The model calibrated the exit point of water in each sub-basin, the reservoir or dam's location, and the water's final point in the basin. DEM created a stream network and determines the outlet point of each river and watershed scope.

Soil data were collected from 62 soil group data from the Land Development Department, Ministry of Agriculture and Cooperatives is a map of soil series.

Land use and land cover data for SWAT land use classification were recorded.

SWAT Definition defines the conditions for creating hydrological response units for each sub-basin by the spread of land use, soil classification, and slope data. Analysis of water resources and runoff for water potential factors were runoff concerning the surface and water runoff, volumes, water demand, and water bodies, watershed networks reservoirs, dams, and irrigation were evaluated.

The basic data table was prepared then, and the SWAT model brought ring all the data that are imported to read and check to create new files for analysis and simulation of watershed areas. The model is used to simulate various situations in the Eastern Basin of Thailand as shown in Figure 1.

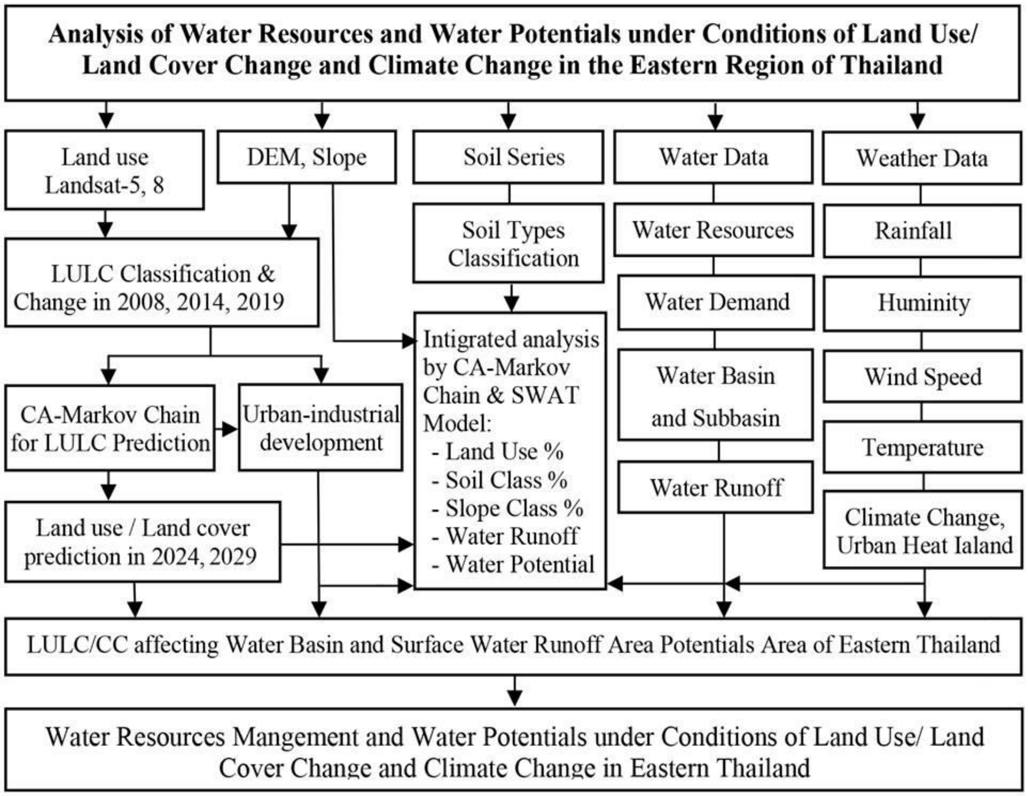
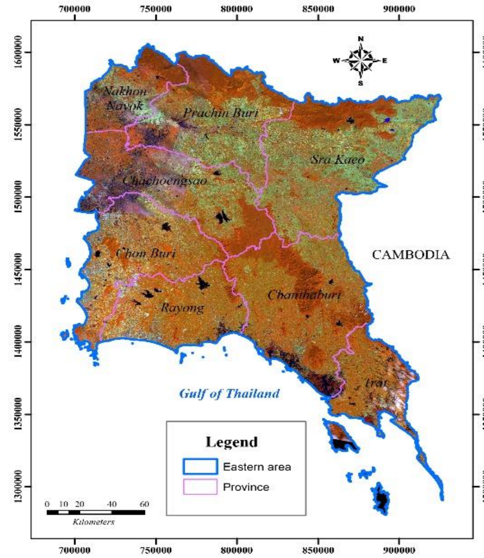


Figure 1. Water Study under Conditions of LULC and Climate Change Methods

Land use and land cover classification and prediction of land use change in the Eastern region of Thailand using the MARKOV chain model

Land use and land cover classification of the Eastern region of Thailand

Land use data were classified using ArcGIS's supervised classification method with Maximum Likelihood Classification (MLC) from satellite imagery Landsat-5 for 2008 and Landsat-8 for 2014 and 2019. Urban-industrial, forest, and water area have increased and agriculture area has decreased area. The expansion and change of urban, industrial agriculture land extracted from the spatial distribution are shown in Figures 2, 3, 4, 5, 6, 7 and Table 1.



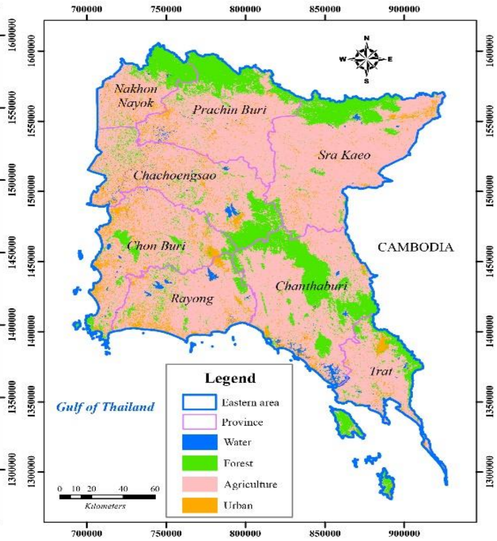
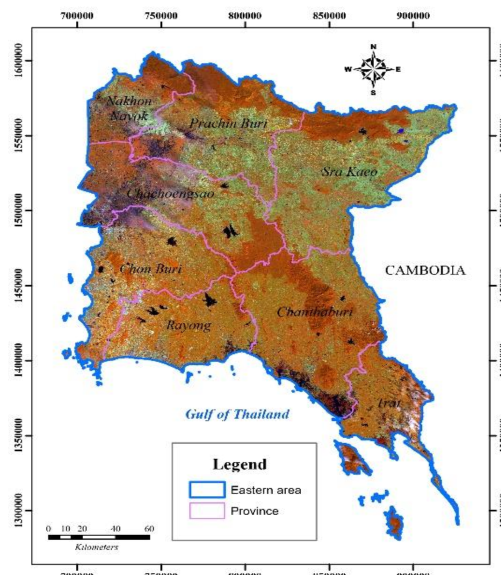


Figure 2. Landsat Image 5 in 2008 **Figure 3.** Land use and Land cover 2008



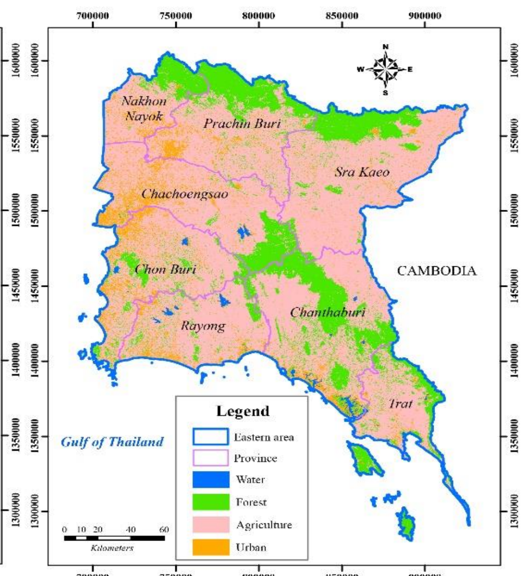
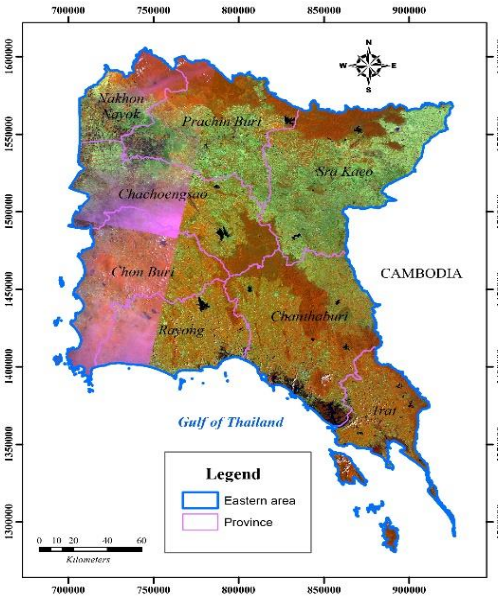


Figure 4. Landsat Image 8 in 2014 **Figure 5**. Land use and Land cover 2014



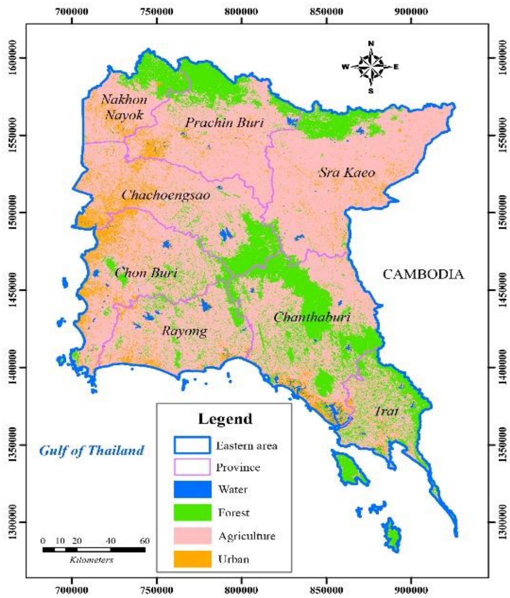


Figure 6. Landsat Image 8 in 2019 **Figure 7.** Land Use and land cover 2019

Table 1. Land use area during the years 2008, 2014, and 2019

LULC type	2008		2014		2019	
	Area (km2)	%	Area (km2)	%	Area (km2)	%
Water	424.11	1.16	423.81	1.16	441.79	1.21
Forest	7229.06	19.75	7777.50	21.24	8064.21	22.02
Agriculture	26078.38	71.21	25289.2	69.05	24964.92	68.17
Urban	2889.89	7.89	3130.93	8.55	3150.52	8.60
Total	36621.45	100	36621.45	100	36621.45	100

Prediction of land use changes using the CA-MARKOV CHAIN model

The results of estimating land use changes from 2014-2019 be calculated using the CA-MARKOVchain model to predict future land use changes as shown in Table 2.

Table 2. Prediction of land use changes from 2014 -2019

Land use type	Water (W)	Forest (F)	Agriculture (A)	Urban (U)
Water (W)	0.816	0.000	0.014	0.170
Forest (F)	0.001	0.647	0.341	0.011
Agriculture (A)	0.003	0.168	0.710	0.119
Urban (U)	0.080	0.010	0.427	0.484

The probability of changes in various land use types from 2014-2019 shows that Wathe ter (W) area had a probability of being changed to Agriculture (A) at 1.4 % and Urban (U) at about 17.0 %. Forest (F) area had a probability of changing to Water (W) at 0.1 %, Agriculture (A) at 34.1 %, and Urban (U) at 1.1 %. Agriculture (A) area was likely to change to Water (W) at 0.3 %, Forest (F) at 16.8 %, and Urban (U) at 11.9 %. Urban (U) area has a probability of changing to Water (W) at 8.0 %, Forest (F) at 1.0 %, and Agriculture (A) at 42.7 %.

Prediction of land use change in the Eastern region of Thailand using the CA-MARKOV chain model

The results of the land use change predictions are recorded in the land use data analysis from 2014 and 2019 using the CA-MARKOV Chain model. The prediction of land use change in the eastern region resulted in to divide into 2024 and 2029 as shown in Table 3 and Figures 8 and 9 land use predictions in the eastern region.

Table 3. Prediction of land use change in the Eastern region of Thailand

Year (km2)	Prediction of land use change in the Eastern region of Thailand in 2008 -2029							
	Water (W)		Forest (F)		Agriculture (A)		Urban (U)	
	Area	(%)	Area	(%)	Area	(%)	Area	(%)
2008	424.12	1.16	7229.06	19.75	26078.38	71.21	2889.89	7.89
2014	423.81	1.16	7777.51	21.24	25289.20	69.05	3130.93	8.55
2019	441.79	1.21	8064.21	22.02	24964.92	68.17	3150.52	8.60
2024	446.78	1.22	7763.75	21.20	25049.07	68.40	3361.85	9.18
2029	461.43	1.26	7580.64	20.70	25016.12	68.31	3566.93	9.74

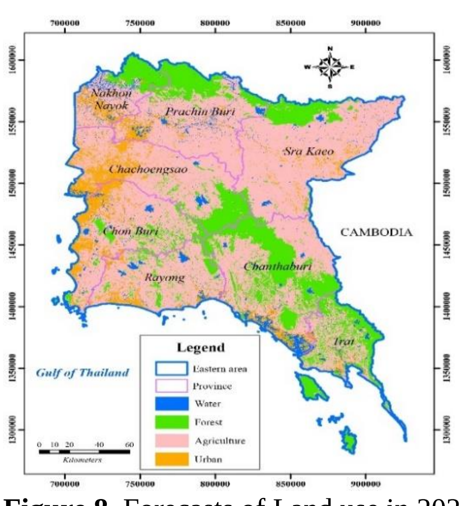


Figure 8. Forecasts of Land use in 2024

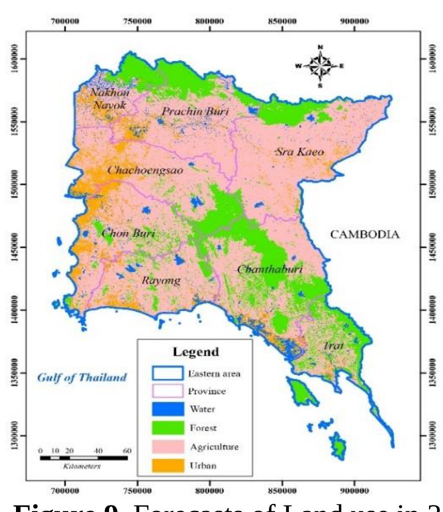


Figure 9. Forecasts of Land use in 2029

Physical characteristics and database of the SWAT model

Digital Elevation Model (DEM), the data are posted on a 1 arc-second (approximately 30 m at the equator) grid and referenced to the 1984 World Geodetic System (WGS84)/1996 Earth Gravitational Model (EGM96) geoids. This DEM had an overall accuracy of around 17 m. at the 95% confidence level, and a horizontal resolution on the order of 75 m., as shown in Figure 10 for the Digital Elevation Model of the Eastern region of Thailand.

Soil series were 62 soil group data from the Land Development Department, Ministry of Agriculture and Cooperatives Is a map of soil series section 1: 25,000 and physical and chemical data of each soil layer because soil data had explored only in areas with a slope below 35% for areas with a slope, exceeding 35% has created a soil unit according to the morphology from the analysis of quantitative data of the topography (DEM), consisting of the curvature of the terrain surface (Plan and Profile Curvature), slope (slope), the level difference (Elevation) and the humidity indicator relative to the condition. Topographic Wetness Index (TWI) and using similar soil series as representatives are shown in Figure 11 for the soil series of Eastern Thailand.

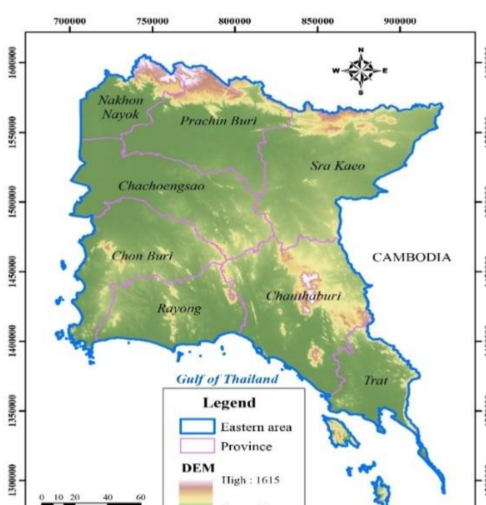


Figure 10. Digital Elevation Model

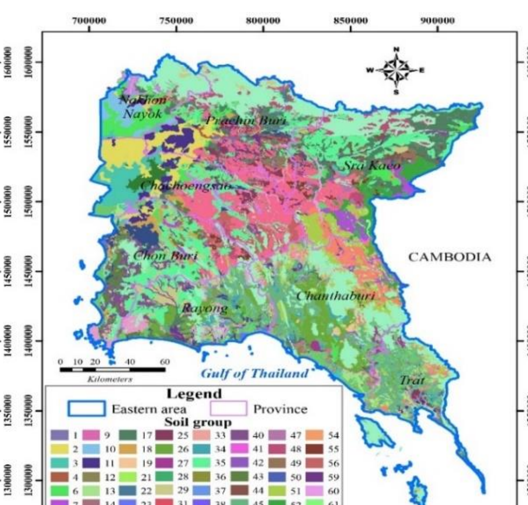


Figure 11. Map of Soil Series

Rainfall data for 30 years from the Meteorological Department Data consisted of 16 daily rainfalls covering the eastern part of Thailand from 1987-2017 run-ins SWAT model. The weather station expressed the amount of rainfall, temperature, and humidity spread cover in the Eastern region of Thailand in 2018. Rainfall, temperature, and humidity are high covers in Trat and Chantaburi provinces and some parts of others provinces of the region. The hot weather is shown high temperatures in summer, covering Chonburi, Sakaew, Rayong, and Prachinburi provinces as shown in Figures 12, 13, 14, and 15.

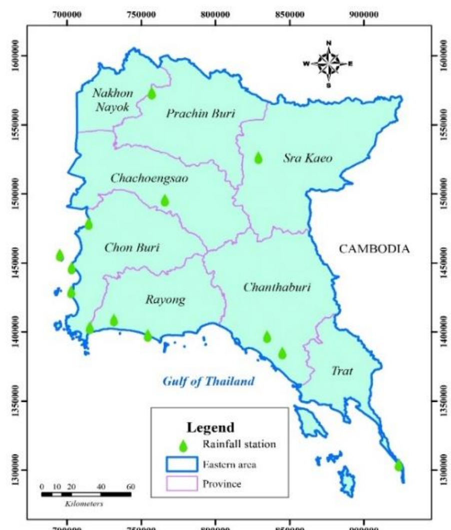


Figure 12. Weather station

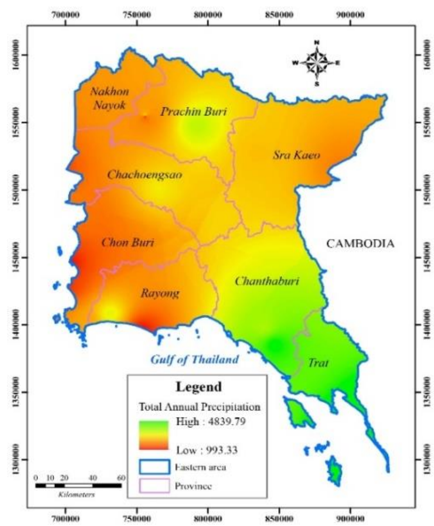


Figure 13. Amount of rainfall in 2018

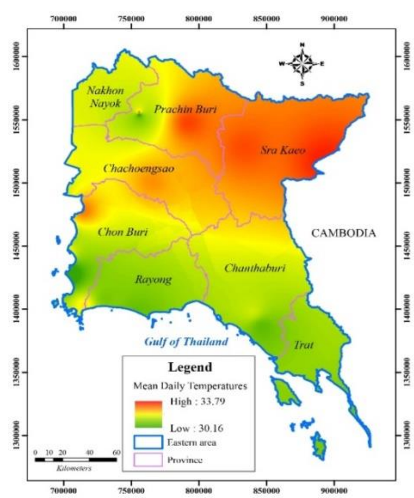


Figure 14. Mean daily temperature in 2018

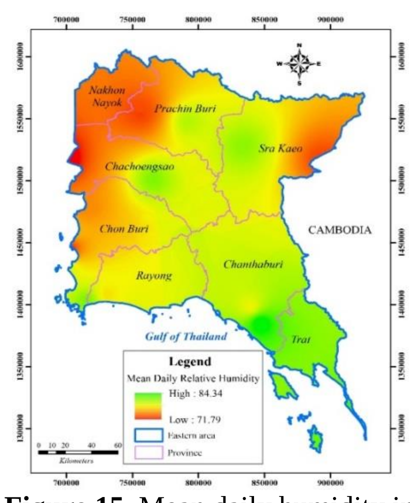


Figure 15. Mean daily humidity in 2018

Analysis of temperature and climate change in the Eastern region of Thailand

The eastern region increased an average temperature that had an average temperature of 28.24 degrees Celsius (℃) in 2006. Chonburi province had the highest average temperature of 29.85 ℃, followed by Rayong, Sa Kaeo, and Prachinburi. Chanthaburi and Trat provinces with the average minimum temperature of 26.14 and 26.59. In 2011, Rayong province had the highest average temperature of 31.36 ℃, followed by Chonburi. Trat and Sa Kaeo with an average temperature of 30.48 28.51 and 28.30 ℃. Prachinburi and Chachoengsao with the lowest average temperature in the area were 27.40 27.56 and 27.81℃. In 2017, Chon Buri province had the highest mean temperature in the eastern region at 33.18 ℃, with the highest average temperature being followed by Sa Kaeo, Prachin Buri, and Rayong with temperatures of 32.82 ℃, 32.14 ℃, and 31.72 ℃. The provinces with the lowest temperature are Trat, Chanthaburi, and Chachoengsao with temperatures at 26.66 ℃, 27.98 ℃, and 31.13 ℃ respectively. Most of the heat is distributed in Chonburi, Rayong, Sa Kaeo, Chachoengsao, and Prachinburi in urban an 'Urban Heat Island'. There is some heat in Chan Buri and there is no heat in Trat province. This heat image is reflected in relation to the heat island phenomenon. The highest urban heat island phenomena have Chon Buri, Prachin Buri, Sa Kaeo, and Chachoengsao provinces but Chanthaburi province has only a slight heat island and Trat province is no heat island as in Figures 16 (a, b, c, d) and Table 4. Land cover is one factor that affects the average temperature of the area if the ground cover is permanent, such as in industrial areas, cities, and buildings the average temperature of the area is quite high. Most areas are covered by forest or green areas. The average temperature of the area would be noticeably lower. Chon Buri, Rayong, and Chachoengsao provinces under the Eastern Seaboard Development toward Eastern Economic Corridor had significantly higher than Chanthaburi and Trat provinces.

Table 4. Surface temperature statistics by provinces, Eastern Thailand

Province	The temperature Year 2006			The temperature year 2011			The temperature year 2017		
	Min	Max	Min	Max	Min	Max	Min	Max	Average
Chon Buri	15.31	44.89	29.85	16.44	48.40	30.48	18.00	45.99	33.18
Rayong	15.22	44.70	29.36	16.43	48.49	31.36	18.00	45.99	31.72
Chanthaburi	15.11	44.49	26.14	16.38	46.74	27.40	18.00	42.75	27.98
Trad	15.12	40.36	26.59	15.50	44.34	28.51	17.33	38.18	26.66
Chachoengsao	15.44	44.66	27.94	16.46	48.95	27.81	18.00	44.70	31.13
Sa Kaeo	18.37	44.68	29.05	16.42	48.59	28.30	20.02	45.50	32.82
Prachin Buri	15.12	44.71	28.78	16.40	48.63	27.56	18.00	46.00	32.14

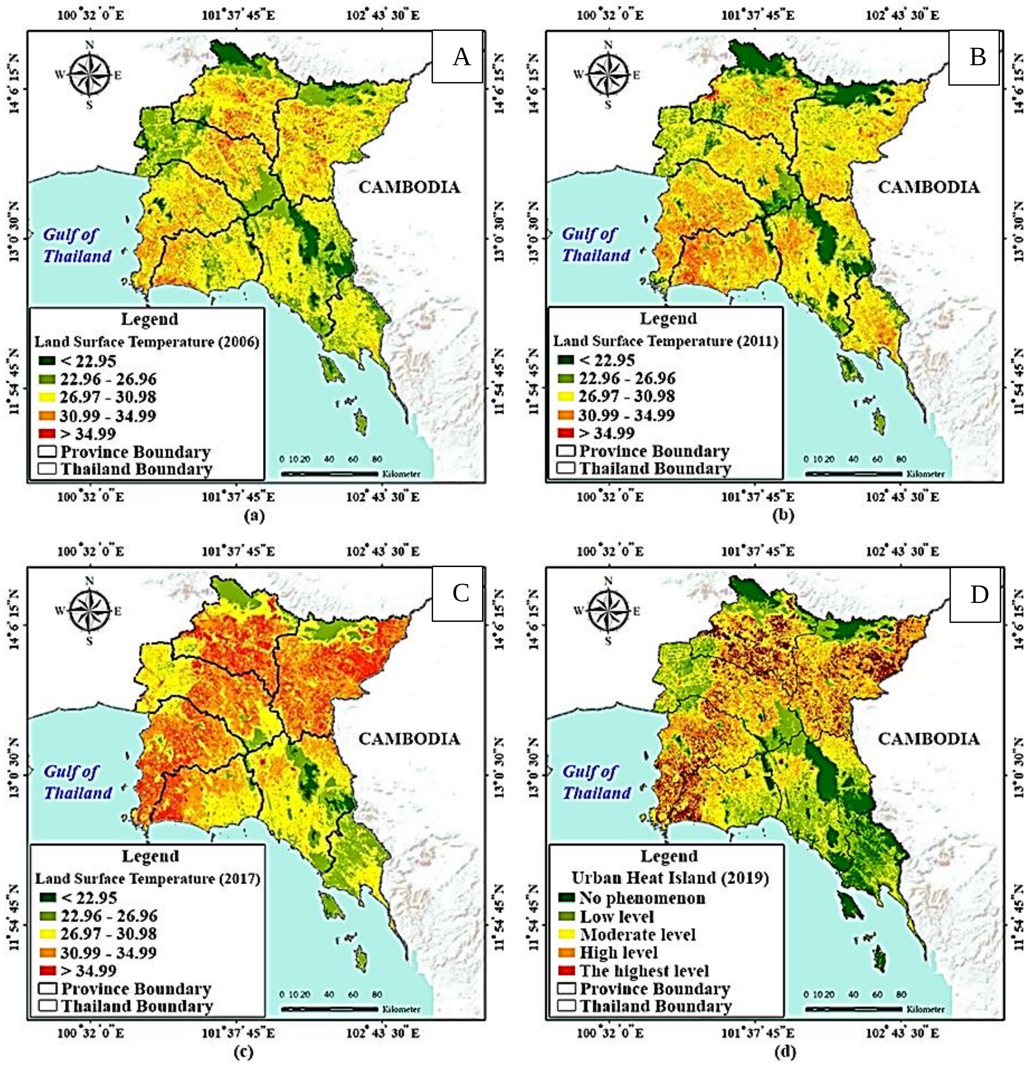


Figure 16. Surface Temperature in 2006, 2011, 2017, and Urban Heat Island in 2017

Industrial number, water resources, and water demand in Eastern Thailand

In August 2019, the Eastern region had 48 industrial estates and 613 factories, and the total factories both located inside and outside industrial estates were about 10853 factories. The factories located outside industrial estates total about 10,240 including EEC (43 estates and 8,339 factories). Water demand of the agriculture sector is supplied by about 85-90 % or more than 5,600 MCM/Year of the total water supplies. Industrial sectors used about 8-10

% or more than 570 MCM/Year. Urban, domestic, and tourism used about 5 - 7 % or more than 370 MCM/Year. The Water Supply of Eastern Thailand has 56 reservoirs with 6 large reservoirs with a combined capacity of 1467.75 MCM and 49 medium-sized reservoirs with a total capacity of 647 MCM that a storage volume of 2,115 MCM. The amount of water flowing into the basin is 2,582.2 MCM in 2018. Water allocation or water demand needs 1,568.3 MCM for water supply, consumption, industry, agriculture, and ecology, the data is shown in Tables 5 and 6.

Table 5. Water sources and water demand in Eastern Thailand

Provinces	**No of reservoirs (places)**	**Total water flow into the basin (MCM)**	**Catchment capacity (MCM)**	**Water allocation or water demand (MCM) in 2010**						
				Water Supply	Consume	Agriculture	Industry	East Water	Ecology	Total
Chon Buri	12	99	197.0	54.1		11.5	3.9	9.5		79
Rayong	5	652.4	542.9	31.2	20.9	204.5	32.4	167	94.4	550.4
Chachoengsao	5	337.8	468.1	0.9	19.0	200.3	7.0		75.00	302.2
Chantaburi	2	286.5	82.1		0.9	80.3			52.7	133.8
Trat	5	355.8	74.9	13.8		86.3			5.1	105.1
Prachinburi	4	307.4	300.5		4.6	0.3				4.6
Sa Kaeo,	14	214.5	199.3	0.1	28.9	126.8			0.2	156.1
Nakhon Nayok	8	328.8	250.2	4.4	13.7	155.2			63.6	236.8
Total	55	2582.2	2115	104.5	87.9	865.1	43.3	176.5	291.0	1568.3

Source: adapted for The Royal Irrigation Department, 2017.

In the past, water sources in the eastern region were mainly used for household and agriculture. Currently, the water demand and potential for consumption and industry are increasing, especially in EEC. EEC area is Chonburi, Rayong, and Chachoengsao provinces. EEC has increasing water demand toward 5 provinces in the other provinces in the eastern region, total 8 provinces of the Eastern Region, Chonburi, Rayong, Chachoengsao, Chanthaburi, Trat, Prachinburi, Nakhon Nayok, Sa Kaeo, as shown in Table 6. All water uses are classified into 3 sectors: domestic and tourism, industry, and agriculture.

Table 6. Water use demand in Eastern Thailand from 1996-2016

Province	Sectoral	1996		2006		2016	
		MCM	%	MCM	%	MCM	%
Chonburi	**Domestic and Tourism**	81.1	15.27	116.2	18.65	161.6	22.66
	Industrial	63.5	11.95	120.4	19.32	165.1	3.15
	Agricultural	386.6	72.78	386.6	62.03	386.6	4.2
	Total	531.2	100	623.2	100	713.3	100
Rayong	**Domestic and Tourism**	26.7	2.75	41	3.88	49.4	4.46
	Industrial	77.7	8	149	14.1	191.1	17.26
	Agricultural	867	89.25	867	82.02	867	78.28
	Total	971.4	100	1,057.00	100	1,107.50	100
Chachengsao	**Domestic and Tourism**	22.3	1.21	30.8	1.64	38.2	2.01
	Industrial	24.7	1.34	50	2.67	70.6	3.71
	Agricultural	1,792.70	97.45	1,792.70	95.69	1,792.70	94.28
	Total	1,839.70	100	1,873.50	100	1,901.50	100
Total 3 Provinces (EEC)	**Domestic and Tourism**	130.10	3.89	188.00	5.29	249.20	6.69
	Industrial	165.90	4.96	319.40	8.99	426.80	11.47
	Agricultural	3,046.30	91.14	3,046.30	85.72	3,046.30	81.84
	Total	3,342.30	100.00	3,553.70	100.00	3,722.30	100.00
Chanthaburi	**Domestic and Tourism**	23.3	4.01	30.4	5.12	38.1	6.28
	Industrial	10.5	1.81	15.8	2.66	21.1	3.48
	Agricultural	547.1	94.18	547.1	92.21	547.1	90.24
	Total	580.9	100	593.3	100	606.3	100
Trat	**Domestic and Tourism**	9.9	3.27	12.8	4.15	16.1	5.1
	Industrial	3.7	1.22	6.6	2.14	10.3	3.26
	Agricultural	289.2	95.51	289.2	93.71	289.2	91.63
	Total	302.8	100	308.6	100	315.6	100
Prachinburi	**Domestic and Tourism**	16.2	3.32	22.6	4.26	27.9	4.98
	Industrial	22.6	4.63	58	10.95	82.6	14.76
	Agricultural	449.3	92.05	449.3	84.79	449.3	80.26
	Total	488.1	100	529	100	559.8	100
Nakhon Nayok	**Domestic and Tourism**	8.1	1.55	10.4	1.97	13	2.44
	Industrial	2	0.38	4	0.76	5.8	1.09
	Agricultural	513.2	98.07	513.2	97.27	513.2	96.47
	Total	523.3	100	527.6	100	532	100
Sa Kaeo	**Domestic and Tourism**	17.5	2.11	23	2.73	28.8	3.36
	Industrial	7.6	0.92	15.5	1.84	24.3	2.83
	Agricultural	804.5	96.97	804.5	95.43	804.5	93.81
	Total	829.6	100	843	100	857.6	100
Total 8 Provinces	**Domestic and Tourism**	205.1	3.38	287.2	4.52	373.1	5.66
	Industrial	212.3	3.5	419.3	6.6	570.9	8.66
	Agricultural	5,649.50	93.12	5,649.50	88.88	5,649.50	85.68
	Total	6,066.90	100	6,356.00	100	6,593.50	100

Source: adapted from Royal Irrigation Department, 2017.

Water use demand in Eastern Thailand is 3 main sections the agricultural sector used 5,649.5 MCM (85.68%). The industrial sector used 570.9 MCM (8.66 %) or an increasing average of 179.3 MCM/Year and the domestic and tourism sector used 373.1 MCM (5.66 %) or an increasing average of 84 MCM/Year during 1996-2016. EEC water resources are 23 reservoirs in with a total capacity of approximately 1,300 MCM. The important reservoirs are Bang Phra, Nong Kho, Nong Pla Lai, Dok Krai, Khlong Yai, Prasae and Khlong Si Yat reseroirs. Currently, the water is allocated to different sectors, a total of 1,188.20 MCM per year, and can be reserves of approximately 100 MCM of water per year, which can support a balanced water use focus on consumption and industry up to 2022. The Royal Irrigation Department (2017) predicted water demand and water resources potential for consumption and industry in EEC as in Figure 17.

The Information of the Eastern Region Special Development Zone Policy Office (2018) has forecasted water demand in the EEC area in every activity in 2017 that demanded 2,404.91 MCM, which increased to 2,777.68 MCM in 2027 and 2,977.55 MCM in 2037. The water demand in all activities increased from the first 10 years (the year 2027) at the base year analysis to 372.77 MCM and in the second 10 years (the year 2037), increased from 2017 in the amount of 572.64 MCM for water resources potential of use in Eastern Economic Corridor Area of Thailand.

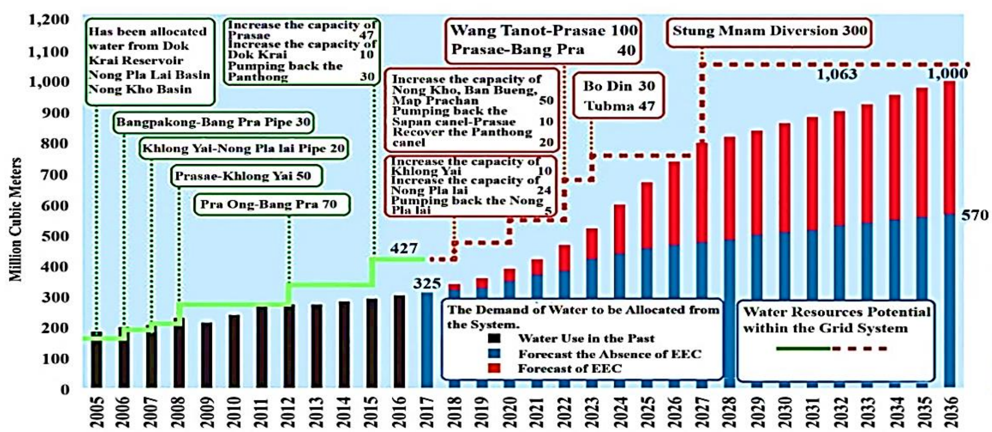


Figure 17. EEC Water Demand and Potential for Consumption and Industry
Source: adapted for the Royal Irrigation Department, 2017

The volume of water demand used within the Eastern Economic Corridor was about 3,342.30 MCM in 1996, 3,553.70 MCM in 2006, and 3,722.30 MCM in 2016 which have increased by 19.00 MCM/Year. All Eastern areas have about 6066.90 MCM in 1996, 6356 MCM in 2006, and 6,593.50 MCM in

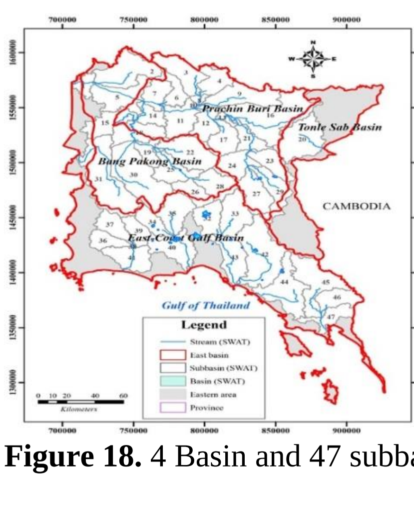
2016 which has increased by 26.33 MCM/Year. The total water flows into the basin in 55 reservoirs is about 2,582.20 MCM and the catchment capacity is about 2,115.00 MCM. Therefore, total volumes of water demand more than water flow and reservoir capacity the water resources potential may come from rainfall, groundwater, ponds, lakes, etc. located in private and public areas. Water resources are located and flowing networks from water bodies that receive water from all subbasins upstream of the Eastern region. Evaporation of intercepted rainfall is especially significant in forests and agricultural areas. Water resource and potential content exceeds the volume of percolation in the soil layer. Climate influences temperature, wind, rainfall, humidity, land use, and land cover to study the effects of predicted climate change on water resources and potential in Eastern Thailand.

Water resources management and water potentials under conditions of land use/land cover change and climate change using the SWAT Model

The results of the SWAT model have simulated 4 basin and 47 subbasin water runoff directions and the amounts of area. The SWAT model simulated water resources, water resources potential, land use, and climate change in Eastern Thailand as shown in Table 8 and Figures 18, 19, 20, 21, and 22.

Table 8. Water Basin and Surface Water Runoff Area of Eastern Thailand

Basin /Total	Subbasin	Mean ElevMin	Mean ElevMax	Area (km2)
Bang Pakong Basin	12	8.166	461	8867.509
East-Coast Gulf Basin	16	5.625	779.06	9582.476
Prachin Buri Basin	18	5.055	607.55	8996.381
Tonle Sab Basin	1	27	286	999.7432
Total 4 Basin	**47**	**11.4615**	**533.4025**	**28446.1092**



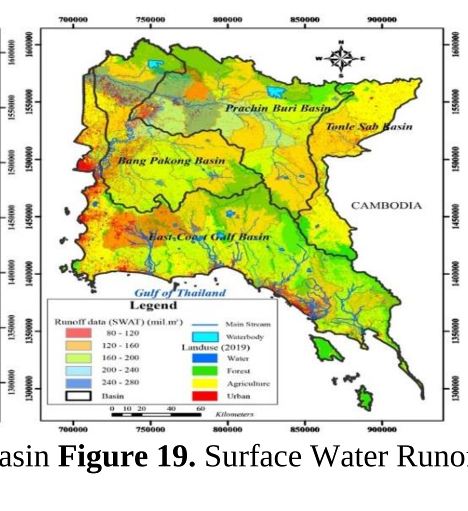


Figure 18. 4 Basin and 47 subbasin **Figure 19.** Surface Water Runoff Direction

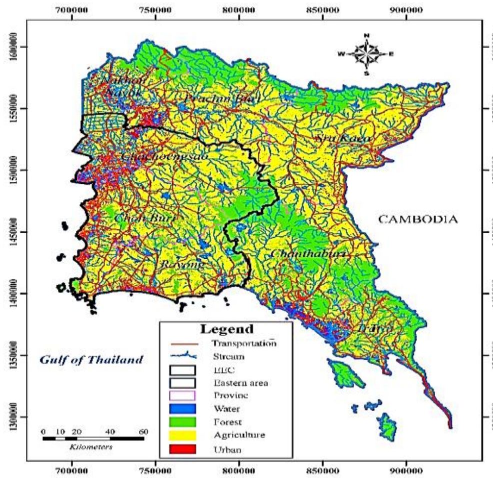


Figure 20. Prediction of Land use in 2024

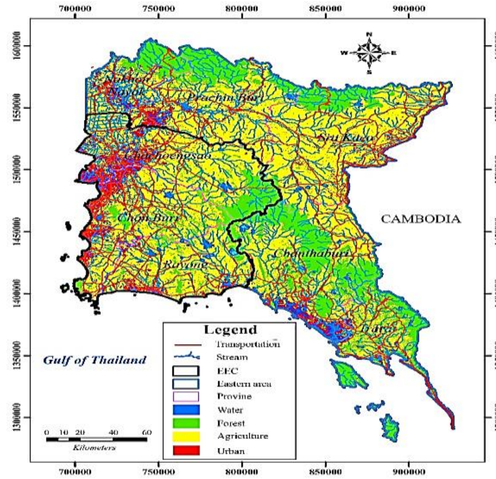


Figure 21. Prediction of Land use in 2029

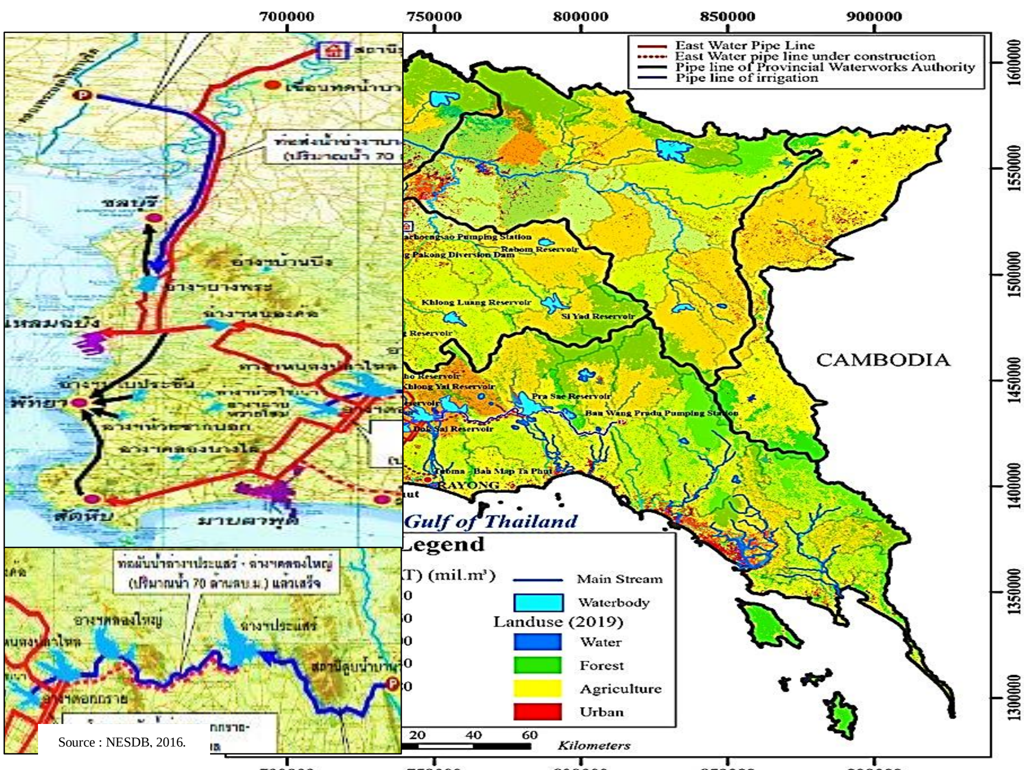


Figure 22. Water Resources Management and Water Potentials under Conditions of Land Use/ Land Cover Change and Climate Change using SWAT Model

Finally, land use and land cover have changed in Eastern, especially EEC development areas from agriculture to urban, industrial, and infostructure areas. In the future, water demand is needed for the raw water diversion systems in the EEC area that are constructing the water supply pipe system including 1) the Khlong Phra Chao Chaiyanuchit-Bang Phra, 2) Bang Pakong River, 3) Bang Phra River, 4) Prasae-Ang Nong Pla Lai, 5) Prasae-Ang Khlong Yai, 6) Dok Krai - Nong Pla Lai Basin, and 7) Khlong Yai - Ang Nong Pla Lai. The total water diversion system is 330 MCM/ year. The government has developed the water source and water supply plan with 7 measures, including 1) Improving the original reservoir capacity, 2) Developing additional reservoirs in the EEC and outside the EEC area, 3) Developing a water diversion system linking the water sources, 4) Developing private water reserves, 5) Develop groundwater for the industrial sector and supplement it in deficient areas, 6) Use new technology such as producing fresh water from seawater and treated wastewater is utilized, and 7) Demand Side Management is to increase water efficiency. The water system needs good management for sustainable water development in Eastern, Thailand.

Discussion

Land use/land cover and climate changes are two main factors directly affecting hydrologic conditions (Ngo *et al.,* 2020). As confirmed by UN-HABITAT's Cities and Climate Change report released at Resilient Cities 2011, urban areas contribute significantly to climate change, and at the same time, climate change could have serious consequences for urban populations (Otto-Zimmermann, 2011), especially in developing countries, as they have fewer resources to adapt both socially and technically. Cities and regions around the world face changes in the seasons, including increasing temperature, fluctuations in precipitation patterns and rainfall (leading to droughts and floods), changes in the severity and frequency of extreme events, and faster sea-level rise.

Moreover “some of the largest cities (with five million or more people) have on average one-fifth of their population and one-sixth of their land area within the coastal zone”, the rise in sea levels and greater storm intensity, coastal settlements will be put under a significant amount of risk. (Yuzva, 2012). This implication confirming with the 2013 annual report on the climate change vulnerability index ranked cities as most vulnerable to climate change by analyzing the trends of various disasters caused by the changing world's climate, it appears that Bangkok ranks third in the world and ranks as very high risk (extreme) behind cities located along the coast. namely Dhaka City

Bangladesh, first ranked, and Manila City Philippines, second-ranked (Department of Disaster Prevention and Mitigation, 2016). Consequently, the Eastern of Thailand which is the coastal region may be affected by the change in the climate.

The results of finding land use and land cover change in Eastern Thailand from 2014-2019 that has found land use change from agriculture to the urban and industrial area at 11.9 %, forest at 16.8 %, and water at 0.3 %. Forest area has a probability of changing to water at 0.1 %, agriculture at 34.1 %, and urban at 1.1 %. The result done by the Department of Public Works and Town and Country Planning in 2019, indicated that the EEC town plan does not affect agriculture much, according to the decrease of the agricultural areas is about 8 %, it will increase urban areas by 3% and industrial areas by 2 %, while the other 3 % are environmental conservation areas.

The impact of climate change on Eastern, Thailand has included higher surface temperatures at 31.72 - 33.18 ℃. Most of the heat is distributed in Chonburi, Rayong, Sa Kaeo, Chachoengsao, and Prachinburi in urban an ‘Urban Heat Island’. In consequences of climate change, Laung-Aram, V. (2008) that simulating future climate scenarios for Thailand and surrounding countries have been the prediction on the increase in mean annual temperature with the longer period of summer and more days of higher temperatures than 33^{o} C as Bangkok is vulnerable to climate change and water resources. Changes in temperature extremes have also been documented in a review by Kiguchi *et al*. (2021) which indicated that the average minimum temperature is approximately 20 ℃ and occurs between November and February, while the maximum temperature of ~35 ℃ occurs between March and June, however, a large increase occurred in southern Thailand, moderate increases in eastern and northeastern regions of the country, and small increases in its northern and central regions.

Kiguchi *et al.* (2021) found that mean annual precipitation in Thailand has been analyzed using meteorological station datasets, with many studies showing decreasing trends, a report of decreasing trend in annual precipitation during the period 1951–2007 for the whole of Thailand, the decrease was largest in the eastern region.

The results of the SWAT model were simulated in 4 Eastern basins and 47 subbasins. The subbasin sources of Eastern Thailand are 56 reservoirs with 6 large reservoirs and 49 medium-sized reservoirs with a total capacity of a storage volume of 2,115 MCM. The amount of water flowing into the flowing is 2,582.2 MCM in 2018. Water allocation or water demand need 1,568.3 MCM needs is focusing on Eastern Economic Corridor focusing the water supply, this is consistent with the study results of Abbas *et al.* (2016) that emphasize that where the water resources are constrained, the water balance is often fragile and the situation can be easily exacerbated by climate change which can be unprecedented because the water system is vulnerable to climate change. This demonstrates that the demand and supply for water balance need to be considered in the future, the total water demand and potential support to all sectors that the government would cooperate with the private sector in the plan for planning reservoir capacity, developing reservoirs, developing a water diversion system, developing ground developing the industrial sector, and supplementing, using new technology and increasing water efficiency.

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