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Analytical Approach to Deforestation Effect on Climate Change Using Metadata in Thailand

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Abstract

One of the major environmental concerns is deforestation which is occurring in many parts of the world, particularly in developing countries. Deforestation is one of the largest sources of anthropogenic greenhouse emissions. Therefore, it is necessary to investigate the cause and effects of deforestation on the environment and on climate change. This study examined the correlations between: 1) human driving forces and deforestation; and 2) deforestation and climatic effects. Metadata of Thailand's forests were collected and analyzed using Pearson's correlation (r) and simple linear regression analyses. The results showed that the cause of deforestation was related to population, gross domestic product, and agricultural land, with correlation coefficients of 0.792, 0.773, and 0.724, respectively, that were statistically significant at the 0.01 level. Forest area had a significant inverse relationship with temperature (r = -0.575). Furthermore, the results indicated that decreasing the forest area by 1 hectare was related to agricultural land expansion of 38.5 hectares or a gross domestic product increase of USD 3.69 million. Deforestation can be increased depending on population growth by 0.000016 hectares per person and its could be a crucial factor in climate change with an increase of 1°C in temperature for every 498,008 hectares of deforestation.

Keywords: Forest loss; Human driving forces; Environmental and information analysis; Statistical process

1. Introduction

Forest plays a key role in the environmental system (Chakravarty *et al.,* 2012), as it impacts on the global biodiversity (Sheram, 1993), the hydrological cycle, carbon stock (Gatti *et al.,* 2021), and the prevention of climate change (Bennett, 2017). In human dimensions, forest is very important for survival (Giliba *et al.,* 2011) as it provides resources for the four basic needs of food, clothing, shelter, and medical materials. Futhermore, over 75% of freshwater around the world comes from forested watersheds, many of which are used to support human livelihoods (FAO and UNEP, 2020). More than 180 million hectares of forest are used for many activities such as agriculture, industry, log production, domestic usage, forest tourism, and recreation (Millennium Ecosystem Assessment Board, 2005; Lee *et al.,* 2010). Chakravarty et al. (2012) reported that forest ecosystems contain 28,000 plant species for medical use and forest resources have been processed for export to 145 countries.

During 2010 – 2020, the world's population increased by 838 million people (National Research Council, 2000; Worldometer, 2021) with flow on effects increasing forest resource usage for human activities and land use. Those activities led to deforestation for 1) agricultural land and industrial land (FAO and UNEP, 2020), where agricultural land conversion was generally the main cause of deforestation, contributing around 60% (De Fries *et al.,* 2010; Keenan *et al.,* 2015), 2) infrastructure and urban expansion for human settlement, roads, mining, and hydrolectric dams (Hosonuma *et al.,* 2012). Overpopulation requires extra infrastructure to support the increased needs and demands that in turn result in clearing more forest area (Chakravarty *et al.,* 2012; Sands, 2013). During 1992 – 2015, urban area expanded from 33.2 to 71.3 million hectares, leading to 3.3 million hectares of deforestation and indirect forest loss of 17.8 – 32.4 million hectares (Van Vliet, 2019). Land degradation can result from "slash and burn" practices whereby landless communities take advantage of a forest area over a long time and then migrate to explore for new forest areas as soil fertility decreases, leading to further deforestation as the cycle repeats (Geist *et al.,* 2002). Deforestation affects the environment and all living things therein.

The loss of forest or its degradation directly affects the environment and humans, resulting in environmental crises such as: 1) reduced access to clean drinking water (Mapulanga and Naito, 2019); 2) flooding in the downstream watershed; and 3) climate change as reflected for example by temperature changes, unstable rainfall or missing seasonal rainfall, soil erosion, and nutrient leaching (Bennett, 2017; Houspanossian *et al.,* 2017).

Thailand's forestry statistics data for 1973 – 2020 indicated that the forest area had decreased by 5,794,142.56 hectares (from 43.21% to 31.64%) (Royal Forest Department, 2021). Therefore, Forest conservation is very important at this time and a necessary component to build sustainable management. According to Sustainable Development Goal 15 by the United Nations in 2015 focused on promoting the sustainability of terrestrial ecosystems including reducing deforestation and improving human resources to achieve sustainable forest management (Sayer *et al.,* 2019) Consequently, this study investigated the causes of deforestation and the effects of deforestation on the environment and climate.

2. Materials and Methods

The study was designed in three parts: 1) examination of human driving forces causing deforestation, where human driving forces refers to human activities or motivations such as agriculture, industry, increasing population, log production, and growing economic wealth (Walker *et al.,* 1996); 2) deforestation refers to the decrease in forest area due to natural conditions or human activities; and 3) climate change and its links to the environmental effects of deforestation. Climate change refers to changes in temperature and weather patterns (Pielke and Roger, 2004). There were three steps in the research method: 1) data collection and pre-processing; 2) analysis of the relationship between the human driving forces and deforestation to examine the causes of deforestation; and 3) analysis of the relationship between deforestation and climatic effects to examine the effect of deforestation on climate change. The system design for the study is shown in Figure 1.

2.1 Study areas

The study was divided into two aspects: 1) analysis of the causes of deforestation, focusing on all of Thailand; and 2) analysis of the climatic effects of deforestation, focusing on Northeastern Thailand as the largest region where most of Thailand's forest loss has occurred.

2.1.1 Study area for causes of deforestation analysis

The analysis commenced with analysis of the relationship between human driving forces and deforestation. The study area was approximately 51,312,000 hectares covering all 76 provinces of Thailand: Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, Phrae, Uttaradit, Ang Thong, Ayutthaya, Chai Nat, Kamphaeng Phet, Lop Buri, Nakhon Sawan, Phetchabun, Phichit, Phitsanulok, Saraburi, Sing Buri, Sukhothai, Tak, Uthai Thani, Amnat Charoen, Bueng Kan, Buriram, Chaiyaphum, Kalasin, Khon Kaen, Loei, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nong Bua Lamphu, Nong Khai, Roi Et, Sakon Nakhon, Si Sa Ket, Surin, Ubon Ratchathani, Udon Thani, Yasothon, Nakhon Nayok, Nonthaburi, Pathum Thani, Samut Prakan, Kanchanaburi, Nakhon Pathom, Ratchaburi, Samut Sakhon, Samut Songkhram, Suphan Buri, Chachoengsao, Chantaburi, Chonburi, Prachinburi, Rayong, Sa Kaeo, Trat, Chumphon, Krabi, Nakhon Si Thammarat, Narathiwat, Pattani, Phang Nga, Phattalung, Phetchaburi, Phuket, Prachuap Khiri Khan, Ranong, Satun, Songkhla, Surat Thani, Trang, Yala, and one special administrative area, Bangkok. The geographical range was from latitude 20.464569 to 5.612674 and from longitude 105.635063 to 97.345810. The study area for causes of deforestation analysis is shown in Figure 2.

2.1.2 Study area for climatic effects of deforestation analysis

The examination of the climatic effects of deforestation commenced with analysis of the relationship between deforestation and meteorological data in Northeastern Thailand covering the 20 provinces of: Amnat Charoen, Bueng Kan, Buriram, Chaiyaphum, Kalasin, Khon Kaen, Loei, Maha Sarakham, Mukdahan, Nakhon Phanom, Nakhon Ratchasima, Nong Bua Lam Phu, Nong Khai, Roi Et, Sakhon Nakhon, Si Sa Ket, Surin, Ubon Ratchathani, Udon Thani, and Yasothon. The geographical range was from latitude 18.44788 to 14.120089 and from longitude 105.635063 to 100.833570. The study area for this part of the research in Northeastern Thailand is shown in Figure 3.

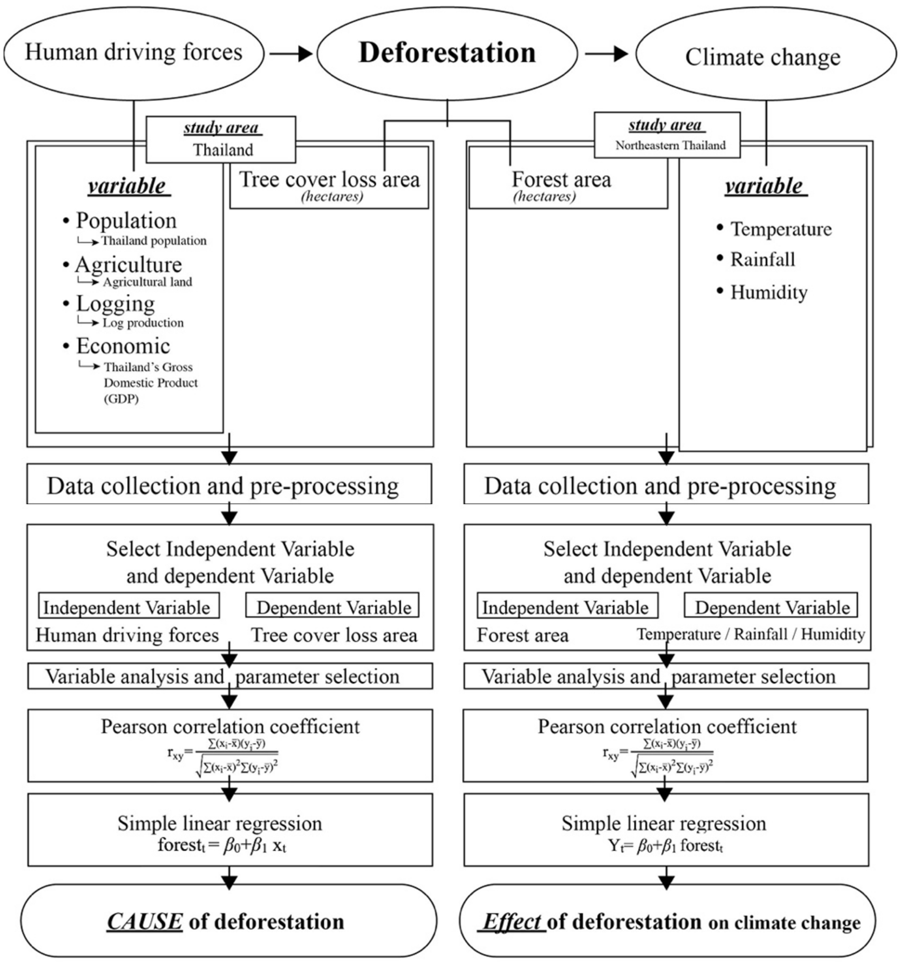

Figure 1. System design in the study

Figure 2. Map of Thailand

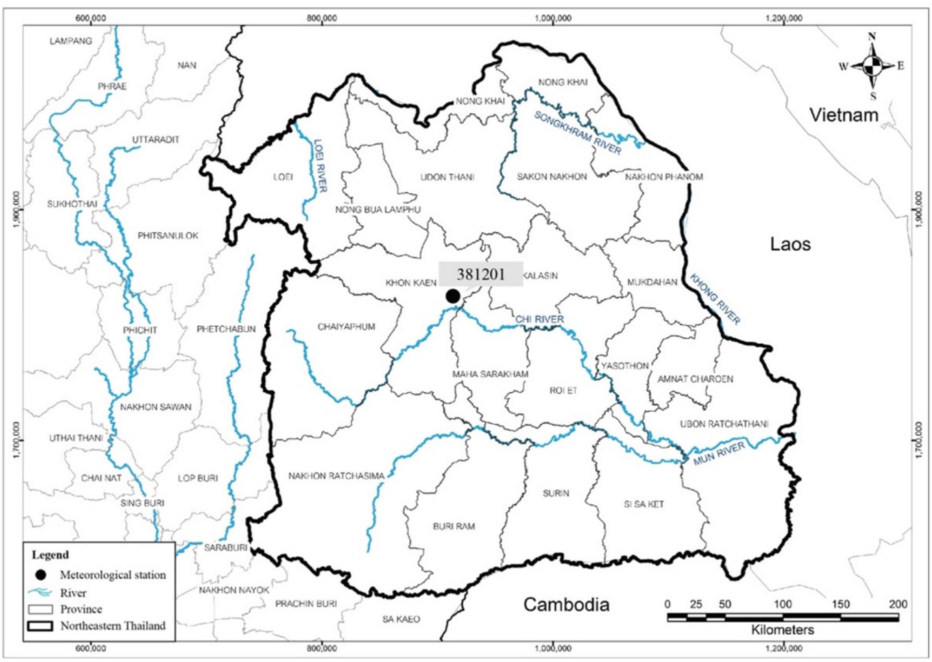

Figure 3. Map of study area in Northeastern Thailand

2.2 Data collection and pre-processing

Data preparation for analysis involved three steps: 1) data collection for analysis of relationship between human driving forces and deforestation; 2) data collection for analysis of relationship between deforestation and climatic effects; and 3) integration of data variables.

2.2.1 Data collection for analysis of relationship between human driving forces and deforestation

2.2.1.1 Thailand tree cover area loss data were obtained from Global Forest watch during 2010 – 2020 (n = 20) in units of hectares (ha).

2.2.1.2 Population data for Thailand were obtained from the United Nations Population Division during 1960–2020 (n = 61) in units of per 1,000 people.

2.2.1.3 Agricultural land data were obtained from The World Bank during 1961 – 2018 (n = 58) in units of ha.

2.2.1.4 Data on Thailand's log production were obtained from UN DATA during 1961 – 2019 (n = 59) in units of cubic meters (m^3).

2.2.1.5 Economic data were represented by Thailand's gross domestic product (GDP) provided by the Office of the National Economic and Social Development Council during 1993 – 2018 (n = 26) in units of THB million.

2.2.2: Data collection for analysis of relationship between deforestation and climatic effects

2.2.2.1 Secondary data on the forest area in Northeastern Thailand were collected from the Royal Forest Department during 1973 – 2019 (n = 46) in units of rai that were converted to hectares using 1 ha = 6.25 rai.

2.2.2.2 Secondary meteorological index data were gathered from the Meteorological Department of Thailand for each sampling point in Khon Kaen (station code: 381201) during 1996 – 2020 (n = 24) for rainfall in units of millimeters (mm), maximum and minimum temperatures in units of degrees Celsius (°C), and relative humidity in units of percentage (Chomtha, 2007).

2.2.3 Data pre-processing

The data were pre-processed with parameter selection relationship between human driving forces and deforestat deforestation and climatic effects based on the research missing values were determined using mean substitution and Kiyoki, 2018; Sillberg *et al.,* 2021).

2.3 Analysis of relationship between human driving forces and deforestation

From Figure 1, this part analyzed the relationship between the human driving forces and deforestation using statistical analysis consisting of 4 steps: 1) selection of independent and dependent variables; 2) variable analysis and parameter selection; 3) correlation analysis of human driving forces and deforestation; and 4) regression analysis of human driving forces and deforestation.

2.3.1 Selection of independent and dependent variables

This step was used to identify the significant causes of deforestation. Various parameters (population, agricultural land, log production, and GDP) were analyzed as independent variables and tree cover loss area was analyzed as the dependent variable.

2.3.2 Variable analysis and parameter selection

Selected data from the previous step were matched based on years and any incomplete datasets were discarded. The remaining data were prepared for statistical analysis (correlation and regression analysis) using the SPSS software version 27.

2.3.3 Correlation analysis of human driving forces and deforestation

Pearson's correlation coefficient was used in the relation analysis between independent variables and the tree cover loss area using Equation 1:

$$r_{xy}=\frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}} \quad (1)$$

where r_{xy} is the correlation coefficient,
x is the independent variable (population per 1,000 people, agricultural land in hectares, log production in cubic meters and GDP in THB millions), and
y is the tree cover loss area (ha).

2.3.4 Regression analysis of human driving forces and deforestation

Simple linear regression analysis was used in the analysis of cause and effect. The mathematical representation used for simple linear regression analysis is shown in Equation 2:

$$forest_t = \beta_0+\beta_1 x_t \quad (2)$$

where $forest_t$ is the tree cover loss area (ha) at time *t*; and *t* is time (years),
β_0 is the regression constant,
β_1 is the regression coefficient describing the relationship between independent variable and the dependent variable, and
x_t is the independent variable (population per 1,000 people, agricultural land in hectares, log production in cubic meters, and GDP in THB millions).

2.4 Analysis of relationship between deforestation and climatic effects

From figure 1, this part analyzed the relationship between deforestation and climatic effects using statistical analysis consisting of 4 steps: 1) selection of independent variable and dependent variable; 2) variable analysis and parameter selection; 3) correlation analysis of deforestation and climatic effects; and 4) regression analysis of deforestation and climatic effects.

2.4.1 Selection of independent variable and dependent variable

From the collected data on the climatic effects of deforestation, the forest area in Northeastern Thailand was selected as the independent variable and the dependent variables were temperature, humidity, and rainfall.

2.4.2 Variable analysis and parameter selection

Selected data from the previous step were matched based on years and any incomplete datasets were discarded. The remaining data were prepared for statistical analysis (correlation and regression analysis) using the SPSS software version 27.

2.4.3 Correlation analysis of deforestation and climatic effects

Pearson's correlation coefficient was used to analyze the correlation between forest area and the dependent variables. Pearson's correlation formulation is shown in Equation 3:

$$r_{xy}=\frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}} \quad (3)$$

where r_{xy} is the correlation coefficient,
x is the forest area (ha), and
y is the dependent variable: temperature in °C, or relative humidity as a percentage, or rainfall in millimeters.

2.4.4 Regression analysis of deforestation and climatic effects

Simple linear regression analysis was used in the analysis of the cause and effect of the relationship between forest area and meteorological data. The mathematical representation used in simple linear regression analysis is shown in Equation 4:

$$Y_t= \beta_0+\beta_1 forest_t \quad (4)$$

where Y_t is the dependent variable (temperature in °C, relative humidity as a percentage, and rainfall in millimeters),
β_0 is the regression constant,
β_1 is the regression coefficient describing the relationship between the independent variable and dependent variable, and
$forest_t$ is the forest area in hectares, and t is the time in years.

3. Results and Discussion

3.1 Data collection and pre-processing

The results from data collection and pre-processing for the analysis of the relationship between human driving forces and deforestation identified 5 related parameters: Thailand tree cover loss area, population, agricultural land, log production, and GDP. The results of data collection and pre-processing for the analysis of the relationship between deforestation and climatic effects identified 4 related parameters: forest area, temperature, humidity, and rainfall. The dataset of related parameters was utilized for the Pearson's correlation and simple linear regression analyses.

3.2 Correlation analysis of human driving forces and deforestation

From the correlation results between human driving forces and deforestation using Pearson's correlation with 4 independent variables, the related variables were: population, agricultural land, log production, and GDP. The dependent variable of deforestation was tree cover loss area and the correlation analysis was based on 20 datasets and tested at the 0.05 level of significance. The highest correlation was the positive relationship between population and tree cover loss area (r = 0.792, *p*-value = 0.000, df = 18). Second was agricultural land and tree cover loss area, with a positive relationship (r = 0.724, *p-value* = 0.001, df = 16) that was statistically significant. Third was log production and tree cover loss area also with a positive coefficient (r = 0.535, *p-value* = 0.018, df = 17) that was statistically significant. Lastly, the relationship between GDP and tree cover loss area (r = 0.773, *p-value* = 0.000, df = 18) was statistically significant as well. The correlation results of human driving forces and deforestation are shown in Table 1.

3.3 Regression analysis of human driving forces and deforestation

The cause and effect relationship between human driving forces and deforestation using simple linear regression used 4 independent variables (population, agricultural land, log production, and GDP), and tree cover loss area as the dependent variable of deforestation. The analysis was based on 20 datasets and tested at the 0.05 level of significance. The unstandardized coefficient (β) from the analysis represents the degree of change in the outcome variable for every 1 unit of change in the dependent variable. For the cause and effect relationship between human driving forces and tree cover loss area, the lower the *p-value*, the greater the statistical significance of the relation analysis.

The results showed that population had an impact on tree cover loss area that was statistically significant (β = 0.016, *p-value* = 0.000). Thus, an increase in population of 1 person would result in a predicted forest area decrease by 0.000016 ha or a population increase of 62,500 peoples would result in a forest area decreased of 1 ha. Furthermore, the regression coefficient for agricultural land on tree cover loss area was statistically significant (β = 0.026, *p-value* = 0.001) with an expansion in agricultural land of 38.5 ha resulting in a forest area decrease of 1 ha. Log production did not have a significant impact on tree cover loss area (β = 0.011, *p-value* = 0.18). Based on significance testing at 0.05, log production was almost unchanged, while tree cover loss area changed in the same period (5 years) of the analysis. In addition, the impact value for GDP and tree cover loss area was statistically significant (β = 0.008, *p-value* = 0.000), with a GDP increase of THB 1 million decreasing the forest area by 0.008 ha which equates to a GDP increase of approximately USD 3.69 million resulting in a forest area decrease of 1 ha (GDP converted from Thai baht to US dollars at the rate THB 1 = USD 0.030 current on 2 December, 2021 at 10:14 UTC) The regression results for human driving forces and deforestation are shown in Table 2.

Table 1. Correlation results of human driving forces and deforestation

Correlations						
		Tree cover loss area (ha)	Population (thousands)	Agricultural land (ha)	Log production (m^3)	GDP (THB million)
Tree cover loss area (ha)	Pearson's correlation	1	0.792**	0.724**	0.535*	0.773**
	Sig. (2-tailed)		0.000	0.001	0.018	0.000
	N	20	20	18	19	20
Population (thousands)	Pearson correlation	0.792**	1	0.925**	0.597**	0.989**
	Sig. (2-tailed)	0.000		0.000	0.007	0.000
	N	20	20	18	19	20
Agricultural land (ha)	Pearson's correlation	0.724**	0.925**	1	0.357	0.934**
	Sig. (2-tailed)	0.001	0.000		0.145	0.000
	N	18	18	18	18	18
Log production (m^3)	Pearson's correlation	0.535*	0.597**	0.357	1	0.516*
	Sig. (2-tailed)	0.018	0.007	0.145		0.024
	N	19	19	18	19	19
GDP (THB million)	Pearson's correlation	0.773**	0.989**	0.934**	0.516*	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.024	
	N	20	20	18	19	20

Remark **. Correlation significant at 0.01 level (2-tailed).
*. Correlation significant at 0.05 level (2-tailed).

Table 2. Regression results of human driving forces and deforestation

Parameter	**Unstandardized coefficients**		**Equation**
	β	**Sig.**	
Population	0.016	0.000	Forest= 0.016 Population-941454.41
Agriculture	0.026	0.001	Forest= 0.026 Agriculture-438142.05
Logging	0.011	0.180	Forest= 0.011 Logging + 45536.185
GDP	0.008	0.000	Forest= 0.008 GDP + 19557.659

Remark β is unstandardized value.
Sig. is statically significant at 0.05 level.

Based on the regression results, population, agricultural land, and GDP had significant positive relationship with tree cover loss area, while log production had no significant impact on tree cover loss, because the log production data for 2013 – 2019 showed a stable trend.

In the next part, the effects of deforestation that impact on climate change were analyzed for the specific study area in Northeastern Thailand.

3.4 Correlation analysis of deforestation and climatic effects

Correlation analysis between deforestation and the climatic effects based on Pearson's correlation considered forest area as the independent variable of deforestation and 3 dependent variables (temperature, humidity, and rainfall), with 16 datasets at the 0.05 level of significance. There was a significant negative relationship between forest area and temperature (r = -0.575, *p-value* = 0.02, df = 14). In contrast, there was a positive relationship between forest area and rainfall (r = 0.198, *p-value* = 0.492, df = 14) as was the relationship between forest area and humidity (r = 0.22, *p-value* = 0.936, df = 14). The correlation results of deforestation and climatic effects are shown in Table 3.

The results indicated that there was a significant inverse relationship between forest area and temperature, with decreasing the forest area leading to a higher temperature due to: 1) forests conserve carbon in the soil and biomass, so that where deforestation occurs, it releases carbon into atmosphere, leading to increased greenhouse gases (GHG) that increase the global temperature (West *et al.,* 2019; Gatti *et al.,* 2021); 2) the decreasing amount of forest produces a lower rates of evaporation and photosynthesis in the forest, resulting in an increased temperature in the atmosphere, similar to the findings of Chakravart *et al.* (2012); 3) deforestation affects cloud-formed condensation, water flows, and wind flow, resulting in deforestation creating hotter weather and drier areas, leading to a higher temperature in the area (Chakravart *et al.,* 2012); and 4) decreasing the amount of forest also impacts the albedo condition, which is the measure of the reflection of solar radiation (Longobardi *et al.,* 2016),

Table 3. Correlation results of deforestation and climatic effects

		Forest area (ha)	Temperature (°C)	Humidity (%)	Rainfall (mm)
Forest area (ha)	Pearson's correlation	1	-0.575*	0.022	0.198
	Sig. (2-tailed)		0.020	0.936	0.462
	N	16	16	16	16
Temperature (°C)	Pearson's correlation	-0.575*	1	-0.575*	-0.395*
	Sig. (2-tailed)	0.020		0.020	0.130
	N	16	16	16	16
Humidity (%)	Pearson's correlation	0.022	-0.575*	1	0.692**
	Sig. (2-tailed)	0.936	0.020		0.003
	N	16	16	16	16
Rainfall (mm)	Pearson's correlation	0.198	-0.395	0.692**	1
	Sig. (2-tailed)	0.462	0.130	0.003	
	N	16	16	16	16

Remark ** Correlation significant at the 0.01 level (2-tailed).
* Correlation significant at the 0.05 level (2-tailed).

where by increasing albedo values lead to higher reflection of solar radiation in deforested areas to the atmosphere, resulting in a slight lowering of the temperature in that area (Popkin, 2019). Forest area had a positive relationship with relative humidity and rainfall because trees are involved in the water cycle and trees use approximately 2% water in photosythesis and approximately 98% in the transpiration process (Schlesinger and Jasechko, 2014). Trees absorb water from the ground and release it to the atmosphere through leaves. The vapor condenses in clouds and then falls as precipitation. Part of the vapor in the atmosphere increases the relative humidity (Houspanossian *et al.,* 2017). Thus, a decrease in forest area results in reduced rainfall and relative humidity (Staal *et al.,* 2020).

3.5 Regression analysis of deforestation and climatic effects

Simple linear regression analysis was used to investigate the cause and effect relationship between deforestation and climatic effects. The analysis utilized 3 dependent variables (temperature, relative humidity, and rainfall) and forest area as the independent variable at the 0.05 level of significance. The results showed that forest area had a significant impact on temperature (β = -2.008 x 10^{-6}, *p-value* = 0.02), with a decrease in forest area of 1 hectare resulting in a predicted temperature increase of 2.008 x10^{-6} °C that equates to a forest area decrease of 498,008 hectares resulting in a predicted temperature increase of 1 °C. There were also impacts of forest on rainfall (β = 2.259 x 10^{-5}, *p-value* = 0.462), on humidity (β = 2.321x10^{-7}, *p-value* = 0.936). The regression results of deforestation and climatic effects are shown in Table 4.

4. Conclusions

Increasing the population, agricultural expansion, and a growing economy are human driving forces that can lead to deforestation. From data collection in Thailand, human driving forces and tree cover loss area were analyzed using Pearson's correlation and simple linear regression analyses. The analysis of correlations between human driving forces and tree cover loss area identified that population, agricultural land, and GDP had significantly positive relationship with tree cover loss area. In summary, there would be a decrease in the forest area by 1 hectare in Thailand for a population increase of 62,500 people, or agricultural land expanding by 38.5 ha, or a GDP increase of approximately USD 3.69 million (converted from Thai baht, using THB 1 = USD 0.030 for the rate on 2 December, 2021 at 10:14 UTC). The second part of the study identified correlations between deforestation and climate change. Temperature was a significant variable to predict the climatic effect of deforestation, with a forest area decrease of approximately 498,008 hectares causing a temperature increase of 1 °C. On the other hand, there was less of a relationship between rainfall and relative humidity.To maintain a balance in the environmental system, it is necessary to manage forest for sustainable life according to Sustainable Development Goal 15 of the United Nations. Sustainability could be improved by raising forest conservation awareness though environmental education and including knowledge of the environmental processes that could lead to conservation and pro-environmental behavior. Such awareness should be included in environmental education programs to prevent deforestation and to maintain the environment to combat climate change.

Table 4. Regression results of deforestation and climatic effects

Parameter	Unstandardized coefficients		Equation
	β	Sig.	
Temperature	-2.008E-6	0.020	Temperature =($2.008x10^{6}$)forest+ 32.363
Rainfall	2.259E-5	0.462	Rainfall =($2.259x10^{-5}$)forest+49.008
Humidity	2.321E-7	0.936	Humidity =($2.321x10^{7}$)forest+70.090

Remark β is unstandardized value.
Sig. is statically significant at 0.05 level.

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