Deforestation alters rainfall: a myth or reality

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Abstract. To cope with the issue of food safety and human shelter, natural landscape has gone through a number of alterations. In the coming future, the expansion of urban land and agricultural farms will likely disrupt the natural environment. Researchers have claimed that land use change may become the most serious issue of the current century. Thus, it is necessary to understand the consequences of land use change on the climatic variables, e.g., rainfall. This study investigated the impact of deforestation on local rainfall. An integrated methodology was adopted to achieve the objectives. Above ground biomass was considered as the indicator of forest areas. Time series data of a Moderate Resolution Imaging Spectroradiometer (MODIS) sensor were obtained for the year of 2000, 2005, and 2010. Rainfall data were collected from the Department of Irrigation and Drainage, Malaysia. The MODIS time series data were classified and four major classes were developed based on the Normalised Difference Vegetation Index (NDVI) ranges. The results of the classification showed that water, and urban and agricultural lands have increased in their area by 2, 3, and 6%, respectively. On the other hand, the area of forest has decreased 10% collectively from 2000 to 2010. The results of NDVI and rainfall data were analysed by using a linear regression analysis. The results showed a significant relationship at a 90% confidence interval between rainfall and deforestation ($t = 1.92$, $p = 0.06$). The results of this study may provide information about the consequences of land use on the climate on the local scale.

1. Introduction

It has been documented that tropical deforestation plays a crucial role in the alteration of regional or global climate [1]. Moreover, the change in agricultural patterns and productions can alter the rainfall by intervening in the process of the heat energy flux and evapotranspiration of the earth surface. The conversion of forests to agricultural and urban lands disrupts the natural cycle of evapotranspiration. This consequently results in reduced rainfall due to the low humidity of the atmosphere [2].

In recent years, there has been an increasing amount of literature on the consequence of deforestation on the regional and global scales [3-6]. A key study examined the effect of deforestation in the Amazonian climate in which the researchers simulated the model for twenty years. The results of this study showed the 60% reduction in the rainfall [7]. To better understand the mechanism of deforestation and its impact on the global scale, a study found that the increase in land cover change, especially deforestation, by 8% leads to an increase in the global temperature by 0.02oC annually [8]. Another study over the Amazonian basin has highlighted the reduction in rainfall up to 1.8% during the deforestation in 2010 [9]. In 2013, a study found that the decrease in evapotranspiration due to the complete deforestation over the African continent can reduce the rainfall by 50 % [10]. Furthermore, a longitudinal study used the general circulation model (GCM) to investigate the impact of deforestation over the Asian region. Their results concluded that large-scale deforestation can lead to reduced precipitation [11].

Recently, investigators have examined the effects of deforestation on Southeast Asia, Africa, and Amazonian regions [12-15]. These studies have demonstrated that partial or complete deforestation of tropical forests can lead towards the increased global mean temperature. However, the variations in regional climate are influenced by many factors, such as vegetation, soil type, and land water relationship. Therefore, it is impossible to anticipate the changes in one region by extrapolating the changes from other regions [6].

The amount of published literature describing the role of describing the role of complete or partial deforestation in the Amazon forests is comparatively high from the African and Southeast Asian forests [1, 3, 9]. Moreover, it has been reported that the effect of land use change is more complex in the Asian tropical forests as compared to African and Amazonian forests [16]. The underlined reasons include the distribution of land and oceans, which is far more different from Amazonian forests. Moreover, the inclusion of monsoon circulations changes the situation in Asian tropical forests to a significant extent. In spite of these, only a few studies have investigated the effect of deforestation on Southeast Asian and African forests. A study has predicted a drier climate over the Southeast Asian deforested areas simulated by the GCMs [17]. Whereas, another study in Congo Basin, Africa has revealed that decreased evapotranspiration due to deforestation can reduce the rainfall up to 50 % over the entire basin [10].

Traditionally, climate change is believed to be a natural phenomenon but recent studies on global warming have heightened the need to consider the other factors as well. Over the past decade, researchers have agreed that the increase in temperature is due to anthropological changes, such as greenhouse gas (GHG) emissions and land use changes [18]. Whereas, in the context of Malaysia, the temperature and wind patterns of the Indian Ocean are amongst the most important factors to determine the rainfall distribution over Peninsular Malaysia. However, in this regard, a recent study by the Department of Irrigation and Drainage (DID) Malaysia, points out the two major factors for the increase in temperature and decline in rainfall in Southeast Asian forests, which are forest fires in Southeast Asian forests and rapid land use change [19].

The information regarding the changes in land use is of critical importance for the assessment of the relationship between natural and human-induced factors. The advancement of satellite remote sensing has made it easy to investigate the changes in land cover over the local or regional level. The use of Normalised Difference Vegetation Index (NDVI) values extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, onboard NASA's Earth Observing System (EOS), Terra and Aqua satellites, for the assessment of forest cover, has been reported in several parts of world [20, 21]. The higher NDVI values indicate the presence of vegetation and vice versa. Therefore, the assessment of NDVI values extracted at different time span can provide the value of change [21].

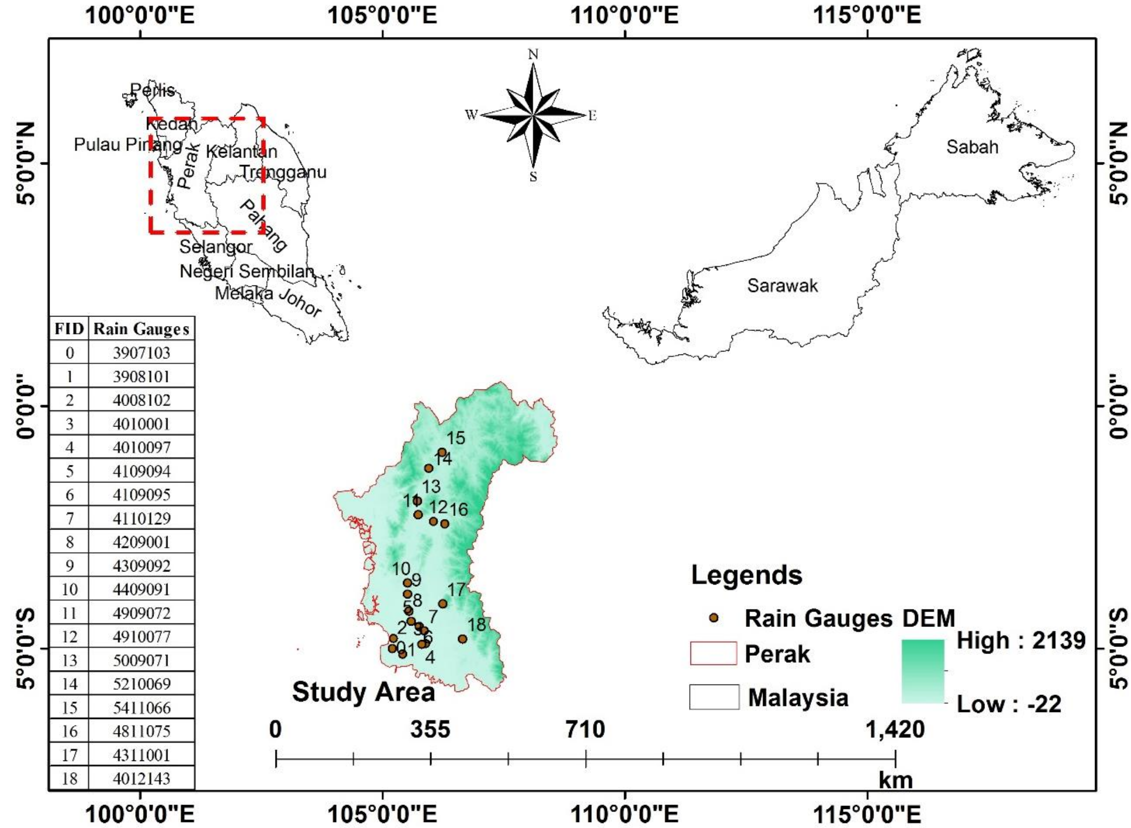
Considering all of these evidences, it seems that much less is known about how deforestation really affects the precipitation at the local scale. Therefore, the objective of this study was to determine the association of precipitation and deforestation on a local scale. The methodological approach taken in this study is an integrated methodology based on the calculation of the rate of deforestation from 2001 to 2010 and quantifies the change with rainfall data using a simple linear regression model.

2. Methodology

2.1. Description of the study area

Perak is located in the western region of Peninsular Malaysia and covers an area of 21,035 km^2. Geographically it lies between 100^{o}0'E to 102^{o}0'E latitude and 3^{o}30'N to 6^{o}0'N longitude (Figure 1). The Perak river basin has a catchment area of about 14,908 km^2, which covers about 70% of the Perak state. The climate of the Perak river basin can be characterised by four seasons as of the whole Malaysia, from which two are monsoon and the other two are inter-monsoon seasons. The first monsoon season also called the southwest monsoon (SWM), comprises four months starting from May to August. Whereas, the northeast monsoon (NEM) occurs from November to February. Eastern parts of the Peninsula receive heavy rainfall during the northeast monsoon [22].

For the investigation of the rate of deforestation, the NDVI time series at 250 m × 250 m resolution at the time interval of 16 days were acquired for 2001, 2005, and 2010 from the MODIS sensor. Whereas, the selection of rain gauges was established based on (i) the land use changes in the study area as indicated in Figure 1 and Figure 3, and (ii) consistency of the data. Thus, daily rainfall data from 19 different rain gauges were acquired from the Department of Irrigation and Drainage for the period of 2000 to 2010.



FID	Rain Gauges
0	3907103
1	3908101
2	4008102
3	4010001
4	4010097
5	4109094
6	4109095
7	4110129
8	4209001
9	4309092
10	4409091
11	4909072
12	4910077
13	5009071
14	5210069
15	5411066
16	4811075
17	4311001
18	4012143

Figure 1: Description of the study area.

2.2. *Data pre-processing*

It was necessary to pre-process the MODIS data before land use classification to acquire better classification accuracy. The pre-processing included the extraction of the Normalised Difference Vegetation Index (NDVI) dataset from the composite datasets of MODIS product (MOD13Q1). After separating the NDVI dataset from the rest of the values, the next step was to re-project the dataset from the MODIS Integerised Sinusoidal Projection (ISN) to the World Geodetic System (WGS) 1984 North Zone 47 and then, sub-set the area of the Perak river basin.

2.3. *Normalized Difference Vegetation Index (NDVI)*

The use of the Normalised Difference Vegetation Index (NDVI) is a well-established approach for the assessment of above ground biomass. NDVI provides the information regarding the energy balance, i.e., energy received from the sun and emitted back by the Earth's objects. Concerning the plantation, it gives the information about the greenness or the health of the plants. Its values range from -1 to +1. In the practical scenario, it is considered that water bodies and barren land give the NDVI value less than 0.1. In contrast to this, the vegetation and forests depict the higher photosynthetic values and their NDVI ranges from 0.4 to 0.8, respectively [23]. NDVI can be explained as in equation (1):

$$NDVI=\frac{NIR\text{-}R}{NIR+R} \qquad (1)$$

where the NIR represents the Near Infrared band of light spectrum and R represents the Red spectrum band.

2.4. Classification of land cover

The rate of deforestation was detected by subtracting the classified NDVI images over the entire Perak state. The time series information concluded the 12 images in each of the three years. All the images for each year were separately pre-processed and layer stacked. The time series analysis helped to analyse the trend of land use change in the study area. Classification of remotely sensed images can be categorised into two broad classes as pixel-based and object-based classification. Object-based image analysis (OBIE) has the ability to classify the images more accurately but it is only effective for high-resolution data as mentioned by [24]. This study used the moderate resolution data with a spatial resolution of 250 m × 250 m for the extraction of Normalized Difference Vegetation Index (NDVI) values. Therefore, the pixel-based hybrid classification method was used due to its appropriateness for coarse and moderate resolution data sets [25-27]. Another study in this context discovered that the accuracy of OBIE is much less as compare to Pixel based classification for MODIS images [28].

Due to above-mentioned limitation, the pixel-based hybrid classification was applied. In hybrid classification, first unsupervised classification was applied. Unsupervised classification works on the basis of spectral information from the different ground objects. It extracts the information of land covers depicting the same spectral signature and then combines them in one class [29]. For classification, a number of trials were performed to find the appropriate number of spectral classes for NDVI classification. It was observed that 20 classes were insufficient, as it was not providing the true classification of the NDVI images (i.e. forest and water zone were merged etc.). On the other hand, when 40 numbers of classes were used, then the overlapping behavior of classes was observed. Only 30 numbers of spectral classes were found optimum as the result showed the appropriate classification. The second step in hybrid classification was to combine the same spectral groups by analysing their spectral signatures. The four major land cover classes were developed based on the standards of Food and Agriculture Organisation (FAO) of United Nations [30]. The detail of combined classes is presented in Table 1. Moreover, the combined classes were then verified by using previously available ground truth information and past GPS surveys. In the end, we obtained the classified land cover maps for the years of 2000, 2005, and 2010.

Table 1: Level I and level II classification system

Level I	Class	Level II	Description
1	Water	11	Streams and Canals
		12	Lakes
		13	Reservoirs
2	Urban or Built-up Land	21	Residential
		22	Commercial and Services
		23	Industrial
		24	Transportation, Communications, and Utilities
		25	Industrial and Commercial Complexes
		26	Mixed Urban or Built-up Land
		27	Other Urban or Built-up Land
3	Agricultural Land	31	Cropland and Pasture
		32	Orchards, Nurseries, and Ornamental Horticultural Areas
		34	Confined Feeding Operations
		35	Other Agricultural Lands
4	Forest	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land

2.5. Hypothesis development
Numerous studies have attempted to explain the effect of deforestation on the amount rainfall on the local scale as mentioned by [31], who stated that land use change plays an important role in altering the global temperature, which consequently alters the other climatic variables. Two hypotheses were drawn to analyse the effect of deforestation on local rainfall patterns.
H_o: Deforestation does not alter the rainfall on the local scale.
H_1: Deforestation does alter the rainfall on the local scale.

3. Results and discussion

3.1. NDVI classification
Figure 2 shows the results obtained from the NDVI classification. We also considered the NDVI value range given by [27] for the different objects in Malaysia. The classified images consisted of four classes, which were water, urban land, agricultural lands, and forests. The classified images were attributed in such a way that the value of the NDVI was more than 0.7 depicting the forest class, 0.4 to 0.69 presenting the agricultural lands and the NDVI values less than 0.4 were considered for the urban lands. Whereas, the negative values of the NDVI were considered as the water class. From the data in Figure 2, it is apparent that the water class shows negative or zero NDVI values for all years. The NDVI values of urban lands show the normal behaviour for the years of 2000 and 2005; but, for the year of 2010, some of the NDVI values reached up to 0.58. It is somewhat surprising, but it was due to the presence of some agricultural lands within the outskirts of the urban areas. Values for the agricultural and forest classes show the downward trend from 2000 to 2010. As with the deforestation, the value of above ground biomass also decreased which was explained by the NDVI values.

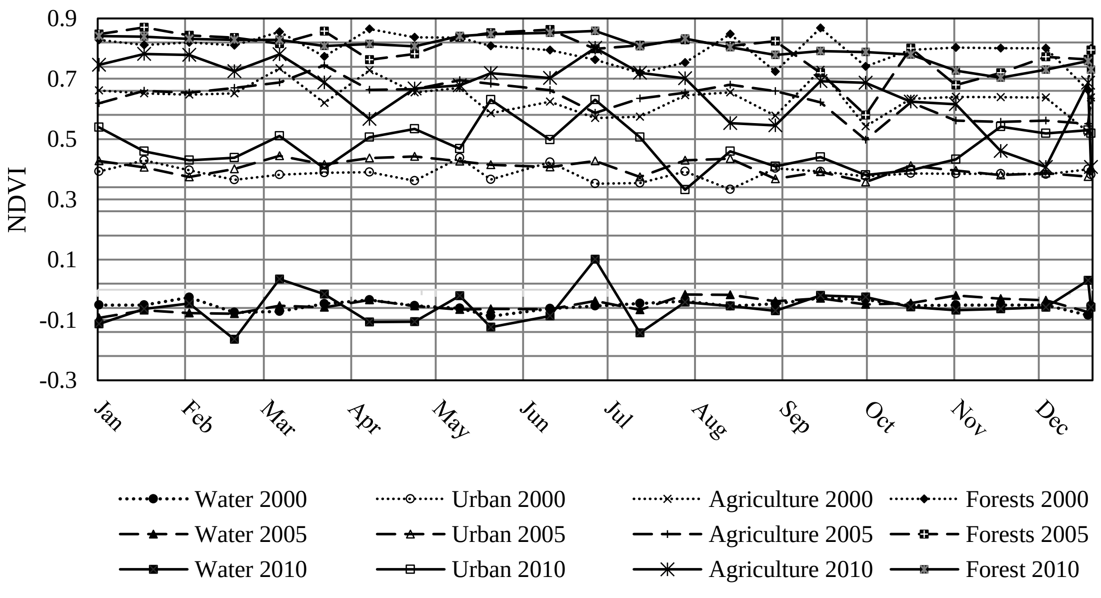


Figure 2: NDVI signature for all land cover classes.

3.2. Change in forest cover
The classified images for the years 2000, 2005, and 2010 are shown in Figure 3. Table 2 presents an overview of land use changes within the Perak river basin. In 2000, the area under the water class was 66,143 ha, which slightly increased in 2005 to 80,018 ha and reached up to 107,368 ha in 2010. These slight positive changes can be argued by the guidelines provided by the Department of Irrigation and Drainage in the manual of Urban Storm Water Management (MSMA) to build up the detention ponds in the urban areas for flood protection. The urban area was 112,110 ha in the year of 2000 and it

slightly increased in 2005 and ended up at 161,152 ha in the year 2010. The behaviour of the agricultural class depicts rather different behaviour than the proceeding classes. It jumps up to 217,341 ha and then to 343,218 ha from 2000 to 2005 when the forests were cleared chiefly for the plantation of palm trees.

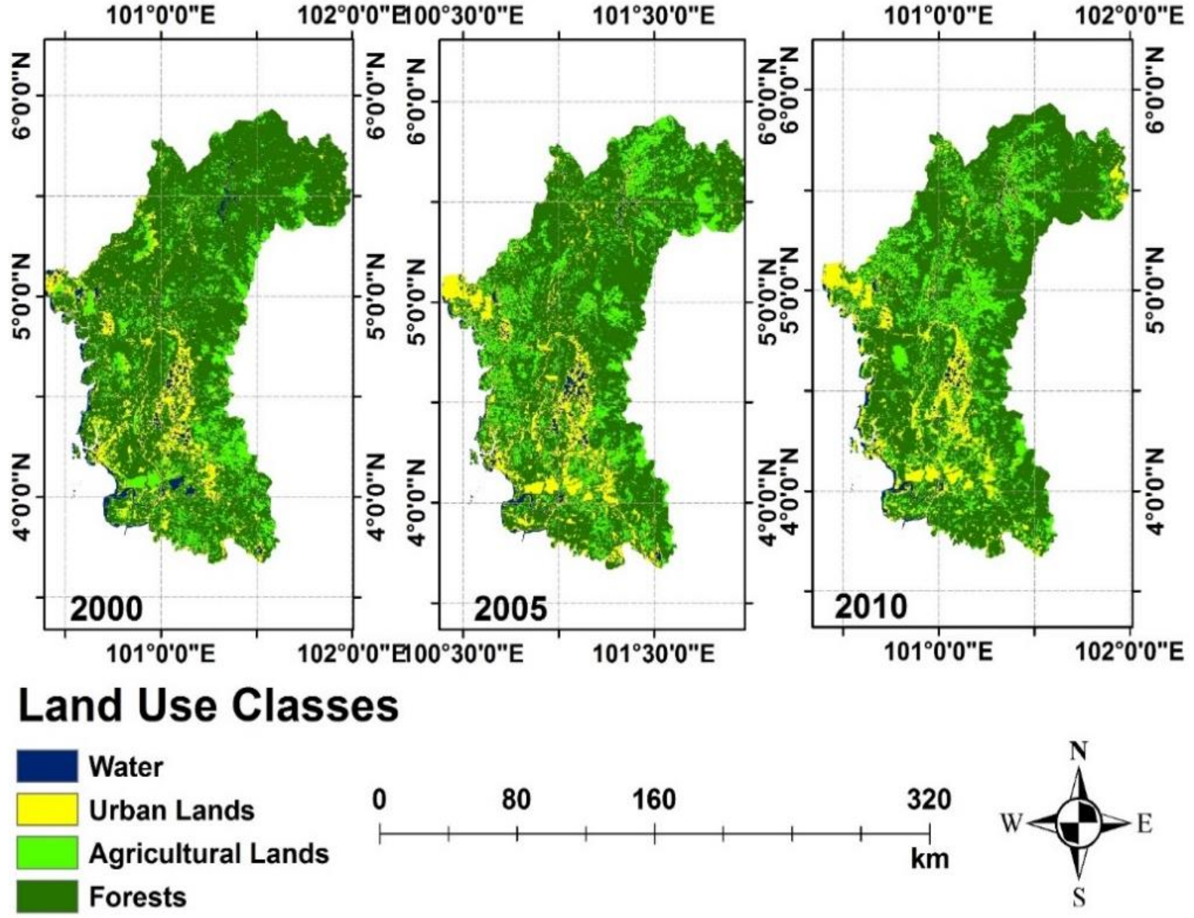


Figure 3: Land use classification for 2000, 2005, and 2010.

After 2005, there was no significant increase and it ended at 351,445 ha in the year of 2010. The forest class showed a significant decreasing trend. It was reduced from 1,663,179 ha to 1,507,383 ha from 2000 to 2010 (Table 1).

Table 2. Land use change (2000 - 2010).

Years	Classes Area (ha)				Percentage Change			
	Water	Urban	Agriculture	Forest	Water	Urban	Agriculture	Forests
2000	66143	112110	217341	1663179	3%	5%	11%	81%
2005	80018	139787	343218	1550850	4%	7%	16%	73%
2010	107368	161152	351445	1507383	5%	8%	17%	71%

3.3. Regression analysis between deforestation and rainfall

The regression analysis was used for the prediction of any significant relationship between the deforestation and rainfall. The details of the descriptive statics are given in Table 3. For the purpose of uniformity of both data sets, rainfall and deforestation information was used on a monthly basis. For three years, the total number of observation was 36. The mean value of the forest biomass was 0.8 and the mean value according to the logarithmic scale for the rainfall was 2.218. The standard deviation value for the forest biomass was 0.04 and for the rainfall, it was 0.18.

Table 3. Description of deforestation and rainfall data.

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Deforestation (Forest Biomass)	36	0.70	0.89	0.79	0.04	0.002
Rainfall	36	1.70	2.48	2.21	0.17	0.029

Table 4 reports the regression results for four different models which were the Southwest Monsoon model, Northeast Monsoon model, Inter-Monsoon model and a combined model. In the case of the Southwest Monsoon and Inter-Monsoonal seasons, the p-values 0.223 and 0.100 were found to be insignificant in the regression model, which implies that there was no relationship between the deforestation and the Southeast Monsoon and Inter-Monsoon rainfall. Opposite to that, the results of the Northeast Monsoon model reported that a unit increase in deforestation would increase the values of rainfall by 2.577 units. Therefore, the alternative hypothesis, in this case, is supported which stated that deforestation does alter the rainfall on the local scale. It is somewhat surprising, but these results are in accord with recent studies indicating that deforestation results in locally increased rainfall [32]. In contrast to the Northeast Monsoon model, the combined model for all seasons shows that a unit increase in deforestation will decrease the value of rainfall by 0.791 units. These results support the results from previous studies in this regard as the deforestation really affects the patterns of rainfall on the local scale [2].

Table 4. Regression analysis.

Season	Independent Variable	Dependent Variable	Linear Regression Model	Significance Value (P)
Southwest Monsoon	Deforestation	Rainfall	$R = 1.102 + 1.274_{F} + 0.46_{\Sigma t}$	0.223
Northeast Monsoon	Deforestation	Rainfall	$R = 4.229 + 2.557_{F} + 0.38_{\Sigma t}$	0.000
Inter-monsoon	Deforestation	Rainfall	$R = 1.196 + 1.358_{F} + 0.40_{\Sigma t}$	0.100
Accumulative	Deforestation	Rainfall	$R = 2.843 - 0.791_{F\,+}\,0.34_{\Sigma t}$	0.000

Overall, these results indicate that deforestation has an impact on rainfall. The present study raises the possibility that a rapid decrease in forest areas may lead towards the drier climatic seasons. Similar results have been obtained from several other parts of the world [1, 33, 34]. Certainly, the study adopted the standard processing methods to quantify the impacts of deforestation on rainfall. However, most of the recent studies only rely on the complex climatic modelling [10, 11, 35], whereas, this study opted an observational approach in this regard as suggested by [1]. This study is a way forward to understand the impact of anthropogenic changes on regional climate. Moreover, this work will also serve as a base for future studies in term of town planning and land management on the regional or local scale. Furthermore, the results of this study are in line with the previous studies on the Southeast Asian forests which explain the significance of the study [17]. Despite these promising results, several questions remain unanswered at present. There is abundant room for further progress in determining the long-term effect of land use change on the climatic issues to understand the underlying phenomenon.

4. Conclusion

In this investigation, the aim was to assess the impact of deforestation on the rainfall distribution. The analysis of MODIS images reveals that the area under urban land is growing bigger and the area under agricultural and forest land is decreasing. The research has shown that the above ground biomass can be utilized for the indicator of deforestation. The lower value of biomass indicates the lower forest reserves and vice versa. This study has also identified the positive relationship of deforestation with the rainfall for the Northeast Monsoon season. This combination of findings provides some support for the conceptual premise that there exists a relation between deforestation and rainfall as has been shown by the regression analysis. This research will serve as a base for future studies and further research in order to understand the underlying phenomenon of complex climatic behaviour with land use change. More information on the relation of deforestation and rainfall would help us to establish a greater degree of accuracy on this matter.

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