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Rainfall model investigation and scenario analyses of the effect of government reforestation policy on seasonal rainfalls: A case study from Northern Thailand

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ABSTRACT

In this work, 4 models for predicting rainfall amounts are investigated and compared using Northern Thailand's seasonal rainfall data for 1973–2008. Two models, global temperature, forest area and seasonal rainfall (TFR) and modified TFR based on a system of differential equations, give the relationships between global temperature, Northern Thailand's forest cover and seasonal rainfalls in the region. The other two models studied are time series and Autoregressive Moving Average (ARMA) models. All models are validated using the k-fold cross validation method with the resulting errors being 0.971233, 0.740891, 2.376415 and 2.430891 for time series, ARMA, TFR and modified TFR models, respectively. Under Business as Usual (BaU) scenario, seasonal rainfalls in Northern Thailand are projected through the year 2020 using all 4 models. TFR and modified TFR models are also used to further analyze how global temperature rise and government reforestation policy affect seasonal rainfalls in the region. Rainfall projections obtained via the two models are also compared with those from the International Panel on Climate Change (IPCC) under IS92a scenario. Results obtained through a mathematical model for global temperature, forest area and seasonal rainfall show that the higher the forest cover, the less fluctuation there is between rainy-season and summer rainfalls. Moreover, growth in forest cover also correlates with an increase in summer rainfalls. An investigation into the relationship between main crop productions and rainfalls in dry and rainy seasons indicates that if the rainy-season rainfall is high, that year's main-crop rice production will decrease but the second-crop rice, maize, sugarcane and soybean productions will increase in the following year.

1. Introduction

More than 75% of Thai agriculture depends on natural rainfalls (Supasod, 2006). Drought and floods are therefore major concerns for crop farming in Thailand (Pavelic et al., 2012). Rice is a major food staple grown in all regions of the country, accounting for more than 55% of total cultivated area (Niroshinie et al., 2011). In 2011, severe flooding significantly damaged agriculture and homes in 65 out of Thailand's 77 provinces. Although drainage control systems including dams, irrigation canals and basins have been implemented throughout the country, they are inadequate to prevent floods (Thanasupsin, 2012). The country's Central Region suffered the most from the 2011 floods because its plain topographic character allowed large amounts of water from the Northern Plateau to flood large swaths of farmland and key industrial areas of national importance (Kritayanavaj, 2011). The following year, however, agriculture in 22 provinces around the country was damaged by drought. Such phenomena as drought and floods are mainly the results of unsuccessful water managements and severe rainfall fluctuations caused by the rise in global temperature (Vellinga and van Verseveld, 2000). There is evidence that climate change partly results from the decline in forest cover (IPCC-Intergovernmental Panel on Climate Change, 1995). According to statistical data from Thailand's Department of National Parks, Wildlife and Plant Conservation, forest cover in 1973 constituted 43.21% of total country area, decreasing over time to 33.44% in 2008 (Sripraram et al., 2012). Furthermore, wildfires, mostly caused by humans, remain a major threat to the country's forests, especially in the North (Chien et al., 2011). The same set of data shows that the area of northern forests damaged by wildfires totaled 13.019 km^2 in 2011, increasing to 34.235 km^2 the following year, when much of the region suffered from drought (DNPWPC-Department of National Parks Wildlife and Plant Conservation, 2013).

The single major cause of climate change is the rise in greenhouse gas emissions from human activities such as transportation and industry, and from wildfires, mostly caused by humans (Qureshi and Evatt, 2011). Greenhouse gases trap thermal radiation within the earth's atmosphere, causing a rise in global temperature (Meinshausen et al., 2009). The amounts of greenhouse gases in the atmosphere depend partly on forest cover, because forests consume carbon dioxide, which is the second largest by volume but the most important of all

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greenhouse gases (Hansen et al., 1981). Moreover, climate change phenomena such as El Niño also have an effect on rainfall fluctuations. Global temperature and rainfalls are therefore directly correlated (Sura, 2011). Furthermore, an increase in forest cover will also lead to more rainfalls, as more water vapor from plant respiration evaporates into the atmosphere and condenses into rain droplets (Street and Cockburn, 1972). All of this shows that global temperature, forest cover and rainfalls are all related.

Forests are important both because they are the origins of rivers and because they help slow down runoffs from heavy rainfalls (Calder et al., 2007). Logging, although illegal in Thailand, still persists and even increases every year. Campaigns to stop deforestation in Thailand date back as far as 1979; and in 1989, forest concessions were cancelled by the government (Rosander, 2008). In spite of these developments and the widespread knowledge about the adverse effects of deforestation, this man-made phenomenon has continued apace. In an effort to counter this, restoration of degraded forests through the planting of community forests has been implemented over the past few decades (TDF-Thai Department of Forestry, 2013). At the national level, the Thai government has included a reforestation policy in the current National Economic and Social Development Plan (2012–2016), which targets forest area expansion to 40% of total country area by 2016.

Several models have been constructed to forecast the variables related to climate change, including differential equation models representing the relationship between global warming and carbon dioxide amount (Caetano et al., 2008); relationship between saturated water vapor, cloud water, rain water and air density (Haile et al., 2011); the influence of evaporation, runoff and rainfall on soil moisture (Verma et al., 2011); the influence of carbon dioxide on global warming (Ghommem et al., 2012); and the relationship between global temperature, forest area and seasonal rainfall (known as TFR model) (Likasiri et al., 2014). Moreover, various models on rainfall, one of the important variables indicating climate change, have been proposed, including statistical model (Flamenco et al., 2006), statistical downscaling model (Yang et al., 2011), artificial neural network (Kuok and Bessaih, 2007; Roman et al., 2012; Nastos et al., 2013), autoregressive moving average (ARMA) model (Nugroho and Simanjuntak, 2014), time series model (Li-li et al., 2010; Olatayo and Taiwo, 2014), distribution functions (Ahammed et al., 2014), linear mixed effects model (Kamruzzaman et al., 2016), nonlinear prediction model (Dhanya and Kumar, 2010) and GMLSS model of rainfall and temperature (Villarini et al., 2010). Studies have been conducted on the accuracy and applications of these models, as well as on the use of scenario analysis to investigate future trends e.g. the effects of global temperature and forest cover changes on seasonal rainfall fluctuations (Duangdai and Likasiri, 2015); effect of climate change on rainfalls and flooding (Niroshinie et al., 2011); rainfalls fluctuations and water resources (Riesgo and Limon, 2006; Ni et al., 2012); water usage and management (Lake and Bond, 2007); influence of carbon dioxide on global warming (Peng et al., 2009); prediction of flood events (Ghizzoni et al., 2010); effect of climate change on water and carbon change (Kumagai et al., 2004); effect of land use change on water resources (Huisman et al., 2009). The literature on models and scenario analyses is summarized in Table 1.

Effective water management relies to a large extent on accurate rainfall predictions. Of all existing models, the time series and ARMA models are widely used to predict time series data while the TFR and modified TFR models can be used to give rainfall predictions related to forest cover and global temperature. In this work, these 4 models are investigated in order to predict rainfall amounts.

According to Thailand's Royal Forestry Department, forest cover in the northern region has been declining since 1973. We are therefore interested in examining the effect of the abovementioned government policy on rainfalls, i.e. how forest-cover changes that occur as a result of the policy affect rainfall amounts. Three projected scenarios are considered: 1) forest cover continues to decrease at the current rate (Business as Usual or BaU scenario); 2) forest cover remains constant (Constant Forest Area or CFA scenario); and 3) forest cover increases at some constant rate to meet the government's goal (Evenly Distributed Forest Area or EDFA scenario). Since time series and ARMA models involve only one variable, predicting the amount of rainfalls using these 2 models can be done only under the BaU scenario. In other scenarios, the prediction of rainfalls is only done via TFR and modified TFR models. All predictions are given through the year 2020. In addition, the IPCC's rainfall projections under IS92a scenario are compared with those from the four models being studied.

In addition, the effects of rainfall on the nation's crop production are studied via an analysis of 4 of Northern Thailand's main crops, rice, maize, sugarcane and soybeans. Rice farming in the region includes the rain-dependent ‘main crop’ whose growing season is May to October; and the ‘second crop’, which relies on irrigation, and whose growing season is November to April. Maize, which depends on natural rainfalls, has no fixed growing season and maize production data are

Table 1
Summary of literature on global warming modeling.

Model/scenario	Variables	Authors/year
System of 3 first order differential equations model	Global warming and carbon dioxide	Caetano et al., 2008
System of 4 first order differential equations model	Saturated water vapor, cloud water, rain water and air density	Haile et al., 2011
First order differential equation model	Evaporation, runoff and rainfall	Verma et al., 2011
First order differential equation model	Carbon dioxide on global warming	Ghommem et al., 2012
System of 4 first order differential equations model	Global temperature, forest area and seasonal rainfall	Likasiri et al., 2014
Statistical model	Rainfall	Flamenco et al., 2006
Statistical downscaling model	Rainfall	Yang et al., 2011
Artificial neural network model	Rainfall	Kuok and Bessaih, 2007; Roman et al., 2012; Nastos et al., 2013
ARMA model	Rainfall	Nugroho and Simanjuntak, 2014
Time series model	Rainfall	Li-li et al., 2010; Olatayo and Taiwo, 2014
Distribution functions	Rainfall	Ahammed et al., 2014
Linear mixed effects model	Rainfall	Kamruzzaman et al., 2016
Nonlinear prediction model	Rainfall	Dhanya and Kumar, 2010
GMLSS model	Rainfall and temperature	Villarini et al., 2010
Scenarios analysis using linear mixed effects model	Climate change on water and carbon change	Kumagai et al., 2004
Scenarios analysis using multi-attribute utility theory method	Rainfalls fluctuations and water resources	Riesgo and Limon, 2006; Ni et al., 2012
Scenarios analysis by Australian academic of technological sciences and engineering (AATSE)	Water usage and management	Lake and Bond, 2007
Scenarios analysis using process-based model	Carbon dioxide on global warming	Peng et al., 2009
Scenarios analysis using hydrological models	Land use change on water resources	Huisman et al., 2009
Scenarios analysis using multivariate skew-t approach	Flood events	Ghizzoni et al., 2010
Scenarios analysis via global circulation model	Rainfall and flooding	Niroshinie et al., 2011
Differential equation models and scenarios analysis	Global temperature and forest cover effects on rainfall	Duangdai and Likasiri, 2015