The Impacts of ENSO Phases on the Variation of Rainfall and Stream Flow in the Upper Ping River Basin, Northern Thailand

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Abstract

The aim of this study is to investigate and identify the impacts of the large scale El Niño-Southern Oscillation (ENSO) on rainfall, generalized monsoon index (GMI) and stream flow in the Mae Rim watershed which is connected to the Upper Ping River Basin (UPRB), a tributary of the Chao Phraya River Basin in Central Thailand, to help water management decisions. The monthly serial data of rainfall, GMI and stream flow of the Mae Rim watershed during 1982 to 2011 were used to study for a correlation with the ENSO index. South oscillation index (SOI) is the selected ENSO index representing the optimized correlation with the serial rainfall and stream flow of the study area. The two methods used to investigate impact on the rainfall are the cross-lag monthly correlation and the ENSO phased classification within three phases of El Niño, La Niña and Normal and sub-phases of strong, medium and weak. The results indicated that the impacts of SOI on rainfall and stream flow are only found to be significant during the strong and medium of El Niño and La Niña phases. Additionally, significant impact mostly occurred in the early months of the southwest monsoon season. Thus, the 3-mrm SOI is the available index used to forecast rainfall, GMI and stream flow up to 8 months in advance, especially for the hydro climates in April to July. The methods employed in our study may be modified to gain a better understanding of the impact of the large scale ENSO on rainfall, GMI and stream flow in other locations in Southeast Asia.

Key words: ENSO/ El Niño and La Niña/ Upper Ping River Basin/ GMI/ Rainfall/ Stream flow

1. Introduction

Rainfall and stream flow are fundamental water resources for human activity. The considerable year-to-year variations in rainfall and stream flow are the cause of drought or flood problems on different scales of severity. The variations in rainfall and stream flow give rise to challenges in managing the associated risks and opportunities of water resource systems in rural and urban environments (Chiew et al.,

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2003); especially, for monsoon rainfall which is a critical factor in water resources and agricultural planning and management. A comprehensive understanding of the variability of monsoon rainfalls over Thailand and their potential severity are needed for planning risk management and for mitigation in extreme rainfall fluctuations (Chitradon, 2009; Singhrattna et al., 2005).

The El Niño-Southern Oscillation (ENSO) phenomenon is a major cause of year-to-year variability of rainfall and stream flow in the world (Nicholls and Wong, 1990; Dettinger and Diaz, 2000). The extreme rainfall anomalies have been associated with both; the El Niño phase when rainfall has been below normal and the La Niña phase when the rainfall has been above normal. The ENSO extreme phases are always linked with the events of floods and droughts taking place in many parts of the world (as in Barlow et al., 2001; Zhang et al., 2007; Yin et al., 2009), which seem to have occurred with enhanced frequency and duration in recent years (Diaz et al., 2001; Anderson et al., 2002). Paeth et al. (2008) studied the future climate change under the increasing GHG concentration linked to the large scale indicators of ENSO phenomenon in the summer monsoon season. The results suggest the decrease of rainfall in the monsoon regions and the impact of ENSO will partly shift towards a higher frequency. Many studies have indicated the tele-connection of ENSO to the rainfall variability (Nicholls and Wong, 1990; Wikarmpapraharn and Kositsakulchai, 2010), and also to the stream flow variability (Kahya and Dracup, 1993; Dettinger and Diaz, 2000; Chiew *et al*., 2003; Shrestha and Kostaschuk, 2005). The connections revealed the difference of the ENSO effects on time and volume of rainfall and stream flow depending on location and season of the regions. The relationship between ENSO phases, El Niño and La Niña events, with the extreme rainfall and stream flow was presented for predicting and forecasting in advance, the amount of stream flow for water use planning and management on a regional scale (Chiew et al., 1998; Chiew et al., 2003; Singhrattna, et al., 2005; Wikarmpapraharn and Kositsakulchai, 2010) and watershed scale (Boonchabun et al., 2004; Shrestha and Kostaschuk, 2005). The ENSO- stream flow tele-connection and the serial correlation in stream flow can be used in system simulations to provide an indication of the available water resources through an irrigation season, to allow irrigators to make more informed risk-based management decisions (Chiew et al., 2003).

Thailand is located within a tropical climate which is susceptible to flooding and drought during monsoon seasons. The impact of ENSO phenomena in Thailand has been found to cause rainfall anomalies, but it was found to be significant in the late 70's (Limsakul et al., 2007) or in the 80's (Singhrattna et al., 2005). The worst impact by ENSO during a strong La Niña phase happened in 2011 (Thailand Integrated Water Resource Management (TIWRM), 2013). The accumulated precipitation from January to October was 35% higher than the average value (TIWRM, 2013). The disaster resulted in severe impairments to the country's economy, industrial sector, and society (HAII, 2012). The flood crisis impacted a total of 4,039,459 households and 13,425,869 people; 2,329 houses were completely destroyed (TIWRM, 2013). As of December 2011, the World Bank estimated damages to have reached THB 1,440 billion. Otherwise, El Niño events revealed as critical drought in Thailand, for example in 1998, in north-east Thailand, the annual rainfall was below normal by 14.5%. Especially in June, the rainfall was revealed below normal levels by 36.6% (Nounmusig et al., 2006). Although recent studies showed that the ENSO phenomenon affected the annual and seasonal rainfall in Thailand (Limsakul, 2007) but rarely affected paddy rice production in Thailand between 1951 and 1999 (Otarig, 2000) and between 1980 and 2002 (Jintrawet and Buddhaboon, 2012). However the decrease in lychee production was found to be significant in the year 1998, with production decreasing by 13% (Sethpakdee, 2000).

Some literature referred by Mavromatis et al. (2002) about the influence of ENSO phase on crop yield: It was found that $165 million of loss in economic activities to agriculture and forestry in Florida was due to the 1997-98 El Niño event, and the ENSO phases have had measurable effects on yields of 7 of the 10 most important crops to the economy of the Southeast USA. The El Niño was also associated with reduction in winter yields of tomato (18% of long-term average), bell pepper (18%), corn (10%), sweet corn (15%) and snap beans (12%). El Niño events were associated with increased sugarcane yields following the La Niña years, and increased yields of grapefruit (5%) and tangerines (13%), but reduction in lime yields in the harvest following El Niño events. Furthermore, ENSO has been significantly associated with corn and tobacco yields, areas of soybean and cotton harvests, and total values of corn, soybean, peanut and tobacco in Alabama, Florida, Georgia and South Carolina. Mavromatis et al. (2002) found that the improving peanut crop performance by adapting the planting dates to ENSO conditions can enhance the peanut yields from 1-8% and reduction yield variability by 2-10% and reducing potential environmental damage from nitrogen leaching by 1-11%. Little is known about how either planting date and irrigation practices based on ENSO may improve crop yields in the regions. The causes of the decreasing crop yields, is related to drought or floods and the change of annual rainfall distribution. Further research and studies are needed to use ENSO indicators for water management decisions, not only for agricultural practices but also for consumption, industrial and environment.

Singhrattna *et al*. (2005) adapted the two approaches for an ensemble forecast of Thailand summer monsoon rainfall (August-October) by using the rainfall data in the central region. The first is a traditional linear regression approach and the second is a nonparametric technique based on local regressions. They found that SOI, the SLP-based ENSO index, and IOD index showed a strong correlation with monsoon rainfall. The indicators show that rainfall is predictable one or two seasons in advance from the previous seasons. The two models exhibit significant skill at 2-5 months' lead time. The nonparametric method seems to show improved skill in the extreme years, especially in wet years. However, further testing and improvements of the models are required.

Wikarmpapraharn and Kositsadulchai (2010) studied the response of monthly rainfall in the central plain of Thailand to the ENSO. The correlation analysis is used to investigate the ENSO relationship with SPI (standardized precipitation index). The ENSO index of MEI was selected to form regression equations with a 1 to 6 month time scale of SPI. The results indicated that the MEI with a statistical approach produced a model that can be used to forecast SPI at least one fortnight ahead at a 10% significant level during the dry period from November to April. However, the equations are necessary to synthesize for a proposed model on a regional scale.

The Upper Ping River Basin (UPRB) is the largest headwater resource in Northern Thailand, where most of the area (about 80%) is covered by mountain ranges. It is also the largest headwater, supplying a total water volume to the Chao Phraya River, which is the main water resource of the central part of Thailand. UPRB is usually damaged by flood and drought disasters (TNA, 2011). In the modern era in Thailand, the problems of water management have been found to be a conflict between the upstream and downstream people (Becu et al., 2003). Therefore, to help water management decisions in the headwater of the Ping River, especially during the extreme ENSO phases, this study aims to investigate and identify the influence and impacts of ENSO phenomenon on the changes of behavior by volume and pattern of rainfall and the connection to changes of stream flow in the UPRB, and to discuss the potential of using the ENSO indicators to predict stream flow in advance months. The study expects that the results will be of benefit to the planning of water use management in local watershed scale in mountainous areas, the important headwater in upper Northern Thailand.

2. Methodology

2.1 Study Site

The headwater of the Upper Ping River Basin originates within the mountainous area of Northern Thailand. The climate of the basin is classified as equatorial monsoonal (Kottek et al., 2006). The rainfall distribution is highly variable because of the influence of the regional climate systems which are under the Indian SW monsoon and the ENSO system (Lim and Boochabun, 2012). The flow from UPRB flows through Chiang Mai city which has been gauged at the P1 station.

In this paper, the Mae Rim watershed is selected as a case study site for the ENSO impacts studies in UPRB. The outlet water from Mae Rim watershed is gauged at P21 station which is approximately 16 kms. from the P1 gauge station as shown in Figure 1.

This is because we found that the stream flow dataset from the P21gauging is available for giving the highest relationship ENSO indices as shown in Table 1 comparison among the other upper Ping's tributary watersheds, and it has a relatively high relationship between the monthly stream flow from P21 and P1 (Pearson's correlation coefficient r = 0.86).

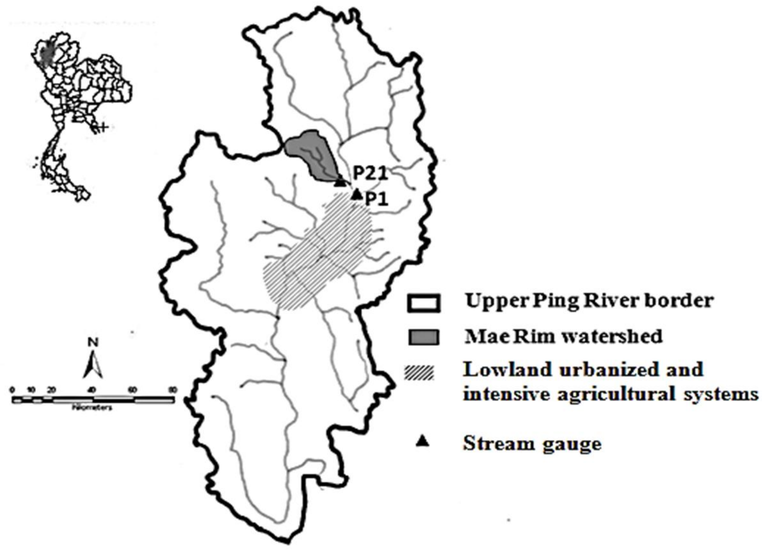

Figure 1: Location of Mae Rim watershed in Upper Ping Basin

2.2 Data and Indices

The 30 years continuous recorded monthly data of rainfall, stream flow and calculated ENSO indices during 1982 to 2011 are used in this study. For rainfall data, the average rainfall data in Mae Rim watershed is averaged from the 4 rainfall gauge stations around the watershed. The rainfall data are obtained from the Royal Irrigation Department (RID), the Royal Project and the Mae Tang Headwater Research Station. The monthly rainfall data in June, July, August and September is characterized to GMI described in the next section. For stream flow data, the data gauged from P21 station are used. The stream flow data are obtained from the RID. To select the appropriate ENSO index with its associated impact in UPRB, the comparison between the standard ENSO indices (NINO3, NINO4, NINO 3.4 and SOI), which were downloaded from the NOAA website (accessed on January 11, 2013), and accumulated rainfall and stream flow in rainy season data was carried out and tested by using the Pearson correlation method. Then, the index giving the highest correlation was selected. The SOI is the highest correlation as shown in Table 1, thus it was a selected for using to study the impact of ENSO on rainfall and stream flow anomaly in UPRB. The SOI is the ENSO index measured based on the difference of the atmospheric pressure above sea surface between Darwin and Tahiti in the Pacific Ocean. It is in agreement with the research's result of Singhrattna et al. (2005) that SOI shows a strong correlation with monsoon rainfall during the concurrent season and also one or two seasons prior. The method to classify ENSO phase (El Niño, La Niña and Normal) used by NOAA and the three monthly running mean (three-mrm) which is calculated by the 3 months moving average of the SOI is used in this study.

Table 1: Correlation coefficient (r) between the three months running mean (three-mrm) of ENSO indices (NINO3, NINO4, NINO3.4 and SOI) and the cumulative rainfall and stream flow in summer monsoon (May to October) during 1982 to 2011 (n=30) in Mae Rim watershed. The values in bold are statistically significant at 95% level.

	Three-mrm ENSO indices											
	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO
Rain												
NINO3	-0.15	-0.16	**-0.44**	**-0.43**	**-0.42**	**-0.38**	**-0.33**	-0.23	-0.16	-0.12	-0.13	-0.14
NINO4	-0.10	-0.11	**-0.33**	**-0.35**	**-0.34**	**-0.33**	-0.30	-0.27	-0.22	-0.16	-0.12	-0.10
NINO3,4	-0.14	-0.15	**-0.39**	**-0.41**	**-0.41**	**-0.40**	**-0.38**	-0.29	-0.20	-0.12	-0.13	-0.14
SOI	**0.31**	**0.34**	**0.48**	**0.45**	**0.47**	**0.47**	**0.43**	**0.31**	0.26	0.22	0.20	0.20
Streamflow												
NINO3	-0.15	-0.14	-0.30	**-0.31**	**-0.36**	**-0.42**	**-0.45**	**-0.36**	-0.27	-0.21	-0.20	-0.18
NINO4	-0.07	-0.08	-0.19	-0.23	-.24	-0.24	-0.22	-0.16	-0.09	-0.04	-0.05	-0.05
NINO3,4	-0.12	-0.11	-0.27	**-0.31**	**-0.35**	**-0.37**	**-0.39**	-0.29	-0.20	-0.10	-0.11	-0.12
SOI	0.27	0.27	**0.45**	**0.40**	**0.43**	**0.45**	**0.44**	**0.36**	0.28	0.24	0.21	0.22

2.3 Generalized Monsoon Index (GMI)

Generally, most of the rainfall in Thailand occurs during the southwest monsoon season, from mid-May to mid-October, and its variability is a crucial factor for socio-economic development, water resources and agricultural management. However, the spatio-temporal variation of inter-annual monsoonal rainfall was found (Limsakul, 2010). To evaluate the extreme high or low rainfall during the monsoon season, the generalized monsoon index was applied to establish the relationship between ENSO phases and rainfall. The GMI is used for agricultural assessment in Thailand by TMD (Thai Meteorological Department) and the Philippines (PAGASA, 2011). The GMI was developed in 1982 as an agro-climatic index. It is a simple tool to monitor rainfall conditions during the monsoon as well as the overall crop conditions (Sukamoto et al., 1984). The GMI is available for continental countries. The value of GMI indicates the strength of drought impact, which be calculated from the monthly rainfall during southwest monsoon season. For Thailand, the southwest monsoon season starts on mid-May to mid-October. Thus, the GMI of Thailand uses the amount of rainfall in June to September that is fully influenced by the southwest monsoon. The weighting factor of rainfall in each month is specified by the crop growth stages as the planting starts in the early part of the rainy season. The highest water requirement of crops is in the flowering/reproductive stage. The GMI is defined as:

$$GMI = w_6P_6 + w_7P_7 + w_8P_8 + w_9P_9 \quad (1)$$

Where w and P is the weighting factor and monthly rainfall, respectively; the number of 6, 7, 8 and 9 are the southwest monsoon month (June, July, August and September, respectively). The weighting factors for the monthly rainfall are 0.125, 0.125, 0.5 and 0.25, respectively. These weights are linked to the crop water requirements in a general way. The GMI is in millimeter (mm) units. Then, the GMI is transformed to a percentile rank (GMI_{pct}) by ascending order, in the value of GMI to get the ranging number then calculate for the GMI_{pct} using the equation as follows:

$$GMI_{pct} = \frac{r*100}{(n+1)} \quad (2)$$

where r is the ranging number and n is total number of years.

The GMI_{pct} is defined as the strength of rainfall impacting on main crop condition (Sukamoto et al., 1984). In Thailand, the Meteorological Department used GMI to assess the impact of rainfall on crops (Meteorological Department, 2011, and 2013), by the categorized GMI_{pct} rank as follows;

GMI_{pct}	Crop condition
0-20	Severe drought impact
21-30	Drought impact
31-40	Moderate drought impact
41-60	Normal crop condition
61-90	Possible above normal crop
91-100	Possible excessive moisture

2.4 Analysis Methods

To identify any useful predictors of the summer rainfall in Thailand, a good correlation between rainfall and ENSO indicators and a reasonable lead time are the two main requirement factors (Singhrattna et al., 2005). The approaches also have been used to identify predictors for stream flow in northern Brazil and in the Truckee-Carson River in USA (cited by Singhrattna et al., 2005). For this study, we focus on the impacts of ENSO on hydro climates (rainfall, GMI index and stream flow) in the change of annual distribution and behaviors, especially for the change during monsoon season (May to October). Thus the monthly correlation coefficients(r), of hydro climates were calculated with the monthly ENSO index. And, to identify the reasonable lead time of the ENSO index impact to the hydro climates, the relationships between the time series for each month of hydro climates and three-mrm ENSO index (SOI) at lag zero (the monthly hydro climate and ENSO index in the same month) for twelve months were calculated. The significant ENSO- hydro climate correlations indicate the potential of using the indicator to predict behaviors of hydro climates.

To identify the impacts of ENSO events changing the quantity and pattern of the hydro climates, the monthly data of hydro climates were classified as the ENSO events, namely; El Nino, La Niña and Normal for our study periods, and then the t-test method was used to test for the statistical significance of difference.

2.4.1 Hydro climate-ENSO index correlation

The relationship between the time series for each month of rainfall and stream flow by simple linear correlation and t-test for significant testing were used in Dettinger et al. (2000), Chiew and McMahon (2002) and Reda et al. (2013). In this study, the hydro climates (Rainfall, GMI and stream flow) and three-mrm of ENSO index (SOI) during 1982 to 2011 was determined by using Pearson's correlation coefficient (r) method which is given in the following equation:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2(y_i-\bar{y})^2}} \quad (3)$$

Where r is Pearson's correlation coefficient; x_i and y_i are the values of ENSO index and hydro climatic respectively at the time i; $\bar{x}$ *and* $\bar{y}$ is the average of the ENSO index and hydro climatic; and n is the total number of year. The t-test is used to test for the statistical significant of the correlation coefficients calculated as the equation:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \quad (4)$$

The $t_{(n-1),0.5}$ is considered for determination significant of r values by comparison with the critical value at $t_{(n-1),0.5}$.

2.4.2 ENSO phase and events classifications

To study the impacts of SW monsoon on seasonal rainfall (May to October) and stream flow, the ENSO phase in each year was classified by using the serial data of three monthly running mean (three-mrm) of SOI during 1982 to 2011 (Singhrattna et al., 2005).The three main ENSO phases are Normal, El Nino and La Niña which defined by the value of three-mrm of the SOI between -0.5 and +0.5, <-0.5 and >0.5, respectively (Kiem and Franks, 2001). This is due to the conflict of several study results about the impacts of ENSO on total rainfall (Wikarmpapraharn and Kositsadulchai, 2010), then, the phase of El Nino and La Niña are identified by separating the strength levels of each phase to strong, medium and weak events. The threshold value of <-0.5 to -1.0(>0.5 to 1.0), <-1.0 to -1.5(>1.0 to 1.5) and <-1.5 (>1.5) are classified to weak, medium and strong events of El Nino (La Niña), respectively. The thresholds are classified by using the approach of Gergis and Fowler (2005) and considering of the past events of floods and droughts in Thailand. Table 2 shows the list of ENSO events of each year during 1982 to 2011, which the three-mrm SOI was categorized by finding out the consecutive five months or more within the annual cycle from ASO to JAS.

2.4.3 Significant difference testing of hydro climates in ENSO phases

The serial of monthly hydro climates data during 1982 to 2011 was identified following the ENSO events in Table 1.Then the significant differences between each level of El Nino (La Niña) phases and normal phase were analyzed by t-test method. The significance (*p-value*) is used to describe the chances of the hydro climates have a difference from normal phases in each level of ENSO phase and also for the change of their behaviors. The equation of t-test as:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad (5)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the means of the two samples of El Nino (La Niña) phase and Normal phase, s_1^2, s_2^2 are the variances of the two samples of El Nino (La Niña) phase and Normal phase, n_1, n_2 are the sample sizes of the two samples. The null hypothesis (H_0: $\bar{x}_1 > \bar{x}_2$ for El Niño and $\bar{x}_1 < \bar{x}_2$ for La Niña) is rejected when the $t < t_{\alpha,n-1}$ and $t > t_{\alpha,n-1}$ respectively.

Table 2: Classification of the three ENSO phases and three sub-phases by the value of three months running mean (three-mrm) of standardized SOI during 1982 to 2011 using to identify the ENSO impact on rainfall, GMI and stream flow of Mae Rim watershed in UPRB.

ENSO Phase	Level	Three-mrm of SOI							
		Year	ASO	SON	OND	NDJ	DJF	JFM	FMA
		1983/84	-1.43	-1.8	-2.10	-2.77	-2.13	-2.70	-2.00
	Strong	1998/99	-2.50	-2.47	-2.37	-2.37	-1.68	-1.97	-1.27
		1987/88	-0.03	0.77	-1.03	-1.5	-1.30	-1.70	-1.73
	Medium	1992/93	-0.5	-1.0	-1.2	-1.8	-1.2	-1.7	-1.37
El Niño		1988/89	-1.10	-0.97	-1.20	-0.93	-0.60	0.03	0.23
		1993/94	-0.03	-0.53	-0.93	-0.90	-0.58	-0.50	-0.83
	Weak	1995/96	-0.53	-0.50	-0.70	-0.67	-0.50	-0.30	-0.20
		2003/04	-0.97	-0.90	-0.87	-0.90	-0.63	-0.77	-0.33
		2010/11	-0.23	-0.37	-0.53	-0.90	-0.90	-1.33	-0.73
		2000/01	0.90	1.23	1.67	1.87	1.75	2.10	1.90
	Strong	2008/09	1.13	1.07	1.53	1.50	1.55	1.77	1.63
		2011/12	1.83	2.00	2.47	2.27	1.68	1.83	1.67
		1989/90	1.00	1.20	1.00	1.13	0.75	1.23	0.83
La Niña	Medium	1999/00	0.40	0.63	0.90	1.53	1.30	1.97	1.77
		1996/97	0.70	0.80	0.97	0.97	0.70	0.90	0.83
	Weak	2001/02	0.57	0.90	1.07	1.37	0.88	1.10	0.60
		2006/07	0.37	0.60	0.97	0.97	0.63	0.67	0.53
		2009/10	0.43	0.73	1.17	1.20	0.85	0.80	0.63
		1982/83	-0.10	0.00	0.07	-0.23	-0.28	-0.20	-0.27
		1984/85	-0.23	-0.23	-0.17	0.10	0.35	0.57	0.47
		1985/86	0.13	0.17	-0.03	0.20	0.45	0.63	0.70
		1986/87	0.07	-0.03	0.10	0.43	0.40	0.47	0.10
		1990/91	0.43	0.07	0.20	-0.27	-0.15	-0.70	-0.37
Normal		1991/92	0.20	-0.07	-0.20	-0.20	-0.18	-0.17	-0.37
		1994/95	-0.60	-0.20	-0.13	0.23	0.18	0.30	0.20
		1997/98	0.53	0.47	0.27	0.47	0.35	0.23	-0.23
		2002/03	0.53	0.63	0.00	-0.10	-0.35	-0.10	-0.10
		2004/05	0.00	-0.07	-0.10	-0.03	0.08	0.03	0.10
		2005/06	-0.30	-0.30	-0.27	-0.10	-0.30	-0.17	-0.47
		2007/08	-0.57	-0.47	-0.20	-0.20	0.03	-0.10	0.40

El Nino :three-month running mean of SOI <-0.5 for five or more consecutive months between April of the year to March of the following year

La Nina: three-month running mean of SOI >0.5 for five or more consecutive months between April of the year to March of the following year

Normal: three-month running mean of SOI <-0.5 to>0.5 for five consecutive months or more between April of the year to March of the following year

3. Results and discussions

3.1. Hydro climates-SOI Correlation and Lag-Forecast Potential

3.1.1 Rainfall

Monthly rainfall-SOI correlations during 1982 to 2011 are shown in Table 3. The results showed that the rainfall in April, May, June and July had significant correlation at 5% level with three-mrm of SOI for zero to nine months in advances. As the results, a study in Northeast of Thailand found that the relationship between monthly rainfall and the large scale ocean and atmospheric circulation variables as SSTs and SLP had been found rather than the relationship with annual or total rainfall (Nounmusig et al., 2006), and some studies did not find the relationship between and annual rainfall in Thailand (Jintrawet and Buddhaboon, 2012; Otarig, 2000). This is due to the uncertainty of the variation of rainfall distribution in annual cycle which depends on the influence of rain generations in Thailand, e.g. monsoon rain, orographic rain, convective rain and cyclonic rain (Jutakorn, 2010a), and may due to the large spatial and temporal variation of monsoon rain (Wikarmpapraharn and Kositsakulchai, 2010), or due to the analysis method. In eastern Australia, Chiew *et al.* (1998) found that the association between rainfall and the indicators of ENSO phenomenon (SOI and SSTs) were very poor in the first half of the year, but they were better in the latter part of the year.

The results in Table 3 provide some indication on the potential for forecasting monthly rainfall. The significant correlations (95% confidence level) of lag-zero to lag-nine months are found mostly in April, May, June and July. In particular, May's-rainfall that indicated the highest significant correlation with the prior SOI from lag-zero (May-MAM) to lag-six (May-SON), but April's rainfall is significantly correlated during lag-zero (April-FMA)to lag-six(April-ASO).June's rainfall shows a significant correlation during lag-zero (June-AMJ) to lag-two (June-FMA), and in July, the rainfall shows a high correlation during lag-nine (July-ASO) to lag-four (July-JFM). The results agree with the typical significant lag correlation of the JJ of SOI with spring rainfall (SON) and the ASO of SOI with summer rainfall (DJF) in eastern Australia (Chiew et al., 1998), and also for the lag correlation and regression between DJF of NINO3.4 index and the following June precipitation (Lin and Lu, 2009). The significant lag correlations indicate that rainfall of the watershed is predictable one to six months in advance.

Like previous research on the Chao Phraya River basin in the central part of Thailand which attempted to develop a statistical forecasting model after they found a significant correlation of the large-scale ocean-atmospheric circulation variables (SST base and SLP base) with summer (August to October) monsoon rainfall at three month lead time (Singhrattna, 2005b).

Table 3: Cross-lag correlation, between monthly rainfall amount and three-mrm SOI. The values in bold, are statistically significant at 95% level.

	Three-mrm SOI											
Rain	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS
OCT	0.08											
NOV	-0.02	-0.04										
DEC	-0.15	-0.25	0.30									
JAN	**0.37**	**0.34**	**0.39**	0.29								
FEB	**0.40**	**0.37**	**0.35**	0.28	0.27							
MAR	0.20	0.30	0.30	**0.32**	0.28	0.28						
APR	**0.31**	**0.32**	**0.38**	**0.36**	**0.37**	**0.35**	**0.32**					
MAY	0.27	**0.40**	**0.48**	**0.50**	**0.49**	**0.51**	**0.59**	**0.63**				
JUN	0.05	0.14	0.17	0.16	0.19	0.23	**0.34**	**0.38**	**0.42**			
JUL	**0.39**	**0.40**	**0.36**	**0.38**	**0.32**	**0.34**	0.21	0.13	-0.03	-0.02		
AUG	0.08	0.06	0.04	-0.01	-0.05	-0.05	-0.09	-0.12	-0.17	-0.19	-0.17	
SEP	**0.40**	**0.34**	0.28	0.22	0.21	0.19	0.19	0.12	0.01	-0.02	-0.05	-0.02

The study had tremendous implication for water resources planning and management, in general, and for early warning and preparedness, in particular. However, further testing and improvement of the model are required. This is indicated by the possibility that the detection of SOI-May rainfall in Mae Rim watershed can be further investigated and developed as a forecasting model for local rainfall patterns and amount of Mae Rim watershed. To evaluate and interpret the impact of the rainfall situation on agriculture practices, the next section of this paper presents the general monsoon index (GMI) as a tool for the rain fed agricultural planning and risk management.

3.1.2 General monsoon index

After the GMI_{pct} in June, July, August and September were computed from the average monthly rainfall in Mae Rim watershed; the cross-lag correlation with three-mrm SOI was calculated. The results are shown in Table 4. The significant correlations at the 95% of confidence level are found only in June and July of GMI. Especially for GMI on July which showed a significant correlation with SOI by ASO to MJJ, but for GMI on June which showed significance with SOI by FMA to AMJ.

However, the highest correlation for GMI in June and July occurred by AMJ and JFM of SOI respectively. This means that the forecast potential for the available water for agriculture and for quantifying dryness and wetness events in June, and July can be forecasted for zero and four months in advance respectively. This agreed with the results of SOI-rainfall correlation that the impacts of SOI occurred only in early monsoon rainfall in the study area. The results may be useful for water manager of Mae Rim watershed and downstream farmers to plan for crop planting. As a previous study showed a strong relationship between the ENSO phase, SSTs, SOI and MEI, between MEI and standardized precipitation index (SPI, an indicators reflecting to the precipitation deficiency) in the Central Plain of Thailand (Wikrampapraharn and Kositsakulchai, 2010), but only in the dry period (November to April). Their study used SPI-MEI multiple regressions equation with 1-6 months scale of SPI, and showed that the model could forecast SPI from the MEI at least a fortnight ahead at a 10% significant level, the model should be adapted and the equation was proposed for application on a regional scale.

Table 4: Cross-lag correlation, between three-mrm SOI and monthly GMI during cultivated season from June to September. The values in bold are statistically significant at 95% level.

	Three-mrm SOI											
GMI_{pct}	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS
JUN	0.16	0.24	0.27	0.26	0.26	0.29	**0.39**	**0.45**	**0.49**			
JUL	**0.41**	**0.48**	**0.44**	**0.46**	**0.43**	**0.49**	**0.47**	**0.47**	**0.38**	**0.39**		
AUG	0.27	0.26	0.22	0.21	0.16	0.19	0.13	0.12	0.04	0.01	0.03	
SEP	0.32	0.30	0.24	0.22	0.18	0.20	0.14	0.11	0.01	-0.03	-0.09	-0.13

3.1.3 Stream flow

The results of the correlation between SOI and stream flow from Mae Rim watershed are shown in Table 5. The results mostly agreed with the results of the rainfall-SOI correlation. But it is surprising that the significant correlations with stream flow are found to be longer and stronger than the correlation with rainfall, which could have occurred as the land-hydrologic process is depending on the characteristics of the watershed (Dettigger et al., 2000). The significant stream flow-SOI correlations occurred in March to July of stream flow and the SOI during ASO to MAM by between one and seven months in advance. The maximum level of SOI-stream flow correlation is mostly found in May, especially for FMA-MAY (r = 0.72) with one month in advance. The SOI giving the maximum correlation with stream flow in March, April, June and July are OND, JFM, MAM and MAM with three, four, one, four and two months in advance respectively. The results indicated that the forecast potential by SOI for stream flow is greater than for rainfall. The longer lead time for stream flow up to nine months than for rainfall (eight months) is indicated by Kiem and Franks (2001), which studied the Williums River catchment, New South Wales, Australia (1,300 km^2). Another study of water management in eastern Australia, using seasonal stream flow as a predictor, showed that using SOI and serial correlation of stream flow are statistically significant and useful for the seasonal forecast of available water resources throughout an irrigation season, to allow irrigation to make more informed risk-based management decisions, although the correlations are not stronger for the management of conservative low-risk water resources systems (Chiew et al., 2003).

Table 5: Cross-lag correlation between three-mrm SOI and monthly stream flow amount. The values in bold, are statistically significant at 95% level.

Stream	Three-mrm SOI											
flow	ASO	SON	OND	NDJ	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS
OCT	0.01											
NOV	0.03	0.06										
DEC	-0.03	-0.02	-0.02									
JAN	-0.03	0.00	0.03	0.02								
FEB	0.22	0.19	0.23	0.17	0.21							
MAR	**0.31**	**0.35**	**0.42**	**0.36**	**0.34**	0.27						
APR	**0.36**	**0.50**	**0.57**	**0.59**	**0.59**	**0.61**	**0.63**					
MAY	**0.44**	**0.55**	**0.63**	**0.64**	**0.65**	**0.65**	**0.72**	**0.71**				
JUN	0.21	**0.34**	**0.39**	**0.43**	**0.45**	**0.52**	**0.59**	**0.62**	**0.59**			
JUL	0.11	0.25	0.27	**0.32**	0.28	**0.36**	**0.36**	**0.44**	**0.39**	**0.36**		
AUG	0.25	**0.33**	**0.33**	**0.31**	0.24	0.27	0.27	0.28	0.23	0.20	0.20	
SEP	0.26	0.28	0.26	0.20	0.14	0.13	0.16	0.12	0.07	0.03	0.03	0.01

3.2 Chance of Extreme Rainfall, drought and Stream flow in ENSO phase

This section illustrates the estimation of hydro climates by classification into ENSO phase method. The significant difference between hydro climates in each level of El Niño (La Niña) phase and in Normal phase was analyzed by t-test. The *p*-value from t-test was shown in Tables 6-8.

Table 6: The significance (p-value) calculated by t-test between rainfall (monthly and accumulated) in each level of El Nino (La Nina) phase and in Normal phase. The values in bold are statistically significance at 95% level.

ENSO Phase	Level	Rainfall APR	MAY	JUN	JUL	AUG	SEP	OCT	Total	Rainy season	Dry season
El Niño	**Strong**	0.313	0.314	0.454	**0.018**	0.279	0.178	0.333	0.297	0.231	0.401
	Medium	0.428	**0.003**	**0.001**	0.191	0.475	0.310	0.488	0.065	**0.003**	0.291
	Weak	0.233	0.393	0.299	0.281	0.323	0.352	0.143	0.162	0.099	0.153
La Niña	**Strong**	**0.046**	0.076	0.121	0.131	0.174	0.119	0.076	0.062	0.060	0.349
	Medium	**0.036**	0.290	0.363	0.253	0.116	0.177	0.376	0.336	0.343	0.340
	Weak	0.182	0.199	0.406	0.202	0.490	0.145	0.273	0.302	0.373	0.318

For rainfall (Table 6), the significance affect at the 95% level is found in July for strong El Nino phase, in May and June for medium El Nino phase, and in only April for strong and medium level of La Niña phase. The significance affect at the 90% level for the accumulated rainfall as annual and rainy season (May to October) is found in the medium events of both El Nino and La Niña. There are indications that the impacts of strong and medium phases have a chance of occurring during extreme (high or low) rainfall only in the initial months of the southwest monsoon periods (during April to July). The results confirm the correlation test in the first section, although, there is no significance between the difference and normal with the reason of the high standard deviation of rainfall in both normal phase and ENSO phases. However, in the quantitative consideration, the monthly rainfall during strong El Niño phase was reduced from normal phases. The high reduction of monthly rainfall amount are found especially in April, May, June, July, September, and October, by -30.8, -14.9, -14.6, -40.5, -38.6 and -33.6% from the normal amount, respectively. The annual and seasonal rainfall in strong and medium events was reduced from the normal phase in similar amount by an average of -13.7% and -16.5% from the normal phase, respectively. The increase of monthly rainfall in La Niña phases are also found especially in strong event between Jan and October by 143.6, 57.4, 35.8, 24.0, 28.9, 43.2 and 90.3% from the normal phase, respectively. This is in response to the increase in annual and seasonal rainfall in the strong La Niña by 44.6 and 41.5% from the normal phase, respectively. Therefore, the effects of strong El Nino on rainfall reduction occurred between April and October, but the highest chance of significant reduction was found to be in May, June and July. It is indicated that the rainy season during the strong El Niño phase occurred later than normal. While in the strong La Niña phase, the increase in monthly rainfall occurred between April and October, but the significance showed only in April. Thus, the rainfall period in the strong La Niña phase start earlier and lasted longer than the normal phase. There are similar results shown in Jutakorn (2010b) which studied the start and end date of rainfall in El Nino and La Niña years in northern Thailand. The study found that in El Nino years the rainy season started one month later than normal years and ended 27 days before normal condition, and in La Niña years, the rainy season started 12 days earlier than normal, but finished at the same time as the normal years.

Table 7: The significance (p-value) calculated by t-test between GMI (of June, July, August and September) in each level of El Niño and La Niña phase and in Normal phase. Values in bold are statistically significant at 95% level.

ENSO Phase	Level	Rainfall			
		JUN	**JUL**	**AUG**	**SEP**
El Niño	**Strong**	0.061	**0.000**	**0.042**	**0.004**
	Medium	**0.008**	**0.049**	0.399	0.411
	Weak	0.210	0.106	0.234	0.183
La Niña	**Strong**	0.093	**0.031**	0.101	0.109
	Medium	0.415	0.422	0.063	0.065
	Weak	0.481	0.214	0.377	0.424

GMI_{pct} : the percentile rank of generalized monsoon index (GMI)

Although, the significance of rainfall among the ENSO phase rarely occurred, but when the rainfall was characterized to GMI, the significance at 90% level can be found in the strong El Nino phase throughout the monsoon season or cultivating season, and in the medium El Nino phase during the first half (June and July) of monsoon season as shown in Table 7. The GMI_{pct} in the significance of the El Nino phase was lower than 25, which meant drought to severe drought condition. The significance of the GMI was also found in June and July on strong La Niña phase with the GMI_{pct} higher than 75 meaning the condition of over wet for normal crops. The results indicate that using the GMI for interpreting wet or drought events in La Niña and El Nino phase is a clearer method than using the significance method on rainfall data. This indicated that the rainfall characterized by GMI may be a good monitor of crop management in the ENSO phase of the study area. These are similar to the results of a study that used the ENSO phase to simulate peanut yield, the study found that the ENSO conditions could enhance and reduce yield by adaptation of planting dates and could reduce environmental damage from nitrogen leaching (Mavromatis et al., 2002). Additionally, the study of Wikarmpapraharn and Kositsakulchai (2010) in the central part of Thailand showed that the ENSO index by MEI could be used to forecast for the SPI (standardized precipitation index) at least one fortnight ahead, and therefore models could be presented which could contribute to irrigation water management and planning during the dry period from November to April.

Table 8: Probability distribution (p-value) calculated by t-test of the difference of mean between the stream flow (monthly and accumulated) in each level of El Niño and La Niña phase and in Normal phase. Values in bold are statistically significant at 95% level.

ENSO Phase	Level	Rainfall								Rainy	Dry
		APR	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**Total**	**season**	**season**
El Niño	**Strong**	**0.002**	**0.008**	**0.038**	**0.000**	0.118	0.247	0.276	0.231	0.152	0.472
	Medium	0.332	**0.050**	0.069	**0.000**	0.468	**0.007**	**0.001**	0.135	**0.029**	0.370
	Weak	0.493	0.290	0.377	0.244	0.328	0.267	0.201	0.431	0.492	0.167
La Niña	**Strong**	**0.002**	**0.046**	0.153	0.267	0.225	0.334	0.274	0.190	0.209	0.314
	Medium	0.364	0.212	0.345	0.306	0.394	**0.003**	0.393	0.098	0.109	0.446
	Weak	0.107	0.144	0.483	0.112	0.225	0.316	0.268	0.267	0.263	0.200

The impacts of ENSO phase classification on stream flow are showed by the *p*-value in Table 8. The significant difference at 95% level of stream flow was found in April to July for strong El Nino event and in May, July, September and October for medium El Nino event, but did not display a weak level event. The significance in La Niña phase was rarely found. The results indicated that the effects of ENSO phase on stream flow are responded in only strong and medium conditions of El Niño phase. Our results agreed with the quantitative decrease of monthly stream flow that were almost always found in strong and medium El Niño phases affecting the accumulated annual and seasonal stream flow decreasing from the normal phase by -36.3% and -44.7% in strong level and -31.5% and -38.6% in medium level respectively. For the La Niña phase, in strong events, most of the monthly stream flow also increased, especially in April and May which were found with very high increasing levels from 103% to 174% above the normal phase, respectively. The increase of stream flow in the strong La Niña phase affected an increase of annual and rainy seasonal stream flow to 36.1% and 41.7% above the normal phase, respectively. But, in medium La Niña phase, the stream flow increase was found insignificant in March to June, and did not display an increase in annual and rainy seasonal stream flow because of the uncertain fluctuations during July to October.

4. Conclusions

The present study indicated that the signal of global scale of ENSO phenomenon effected on the anomaly of rainfall and stream flow in local scale of UPRB. The study for the impacts of the large scale of ENSO by using SOI on hydro climates conditions as rainfall, generalized monsoon index (GMI) and stream flow, on a local scale was conducted in Mae Rim watershed for connecting to the water management decisions in the UPRB. The two methods, the lag-cross correlation and the ENSO phase's classification, were used to investigate. The two methods for analysis are corresponding results, although, the results had been shown for the responding of SOI to stream flow relatively clearer than rainfall. However, the use of GMI, which is characterized by monsoon rainfall, was also found to respond to SOI which was clearer than the use of rainfall directly. The impacts of SOI on rainfall and stream flow were mostly found only between April and July, the initial influence of southwest monsoon. The three-mrm SOI have the potential to be used as a forecasting tool to predict the quantity of rainfall and stream flow and the association of the drought-wetness indicator by GMI with the linear regression for one to seven months in advance. The equation model was not developed in the study. However, the method of ENSO phase classification found that the significant impacts of the large scale ENSO by SOI were mostly found within strong and medium level of El Niño phases and La Niña phases, but there were less found at weaker levels. The results show the possible use of the available existing SOI data for estimating rainfall, stream flow and GMI in advance for the benefit of crop planning in the monsoon season on a small scale within the Mae Rim watershed and therefore, can connect to the larger scale of the Upper Ping River Basin by implication of the strong relationship with both rainfall and stream flow. Our methods may be applied to other small watersheds in Thailand and in mainland Southeast Asia, where production of various cropping systems are under rain fed conditions.

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6. List of Abbreviations

ENSO	El Niño-Southern Oscillation
GHG	Green House Gases
GMI	Generalized Monsoon Index
HAII	Hydro and Agro Informatics Institute
IOD	Indian Ocean Dipole
JJ	June-July
MEI	Multivariate ENSO Index
NOAA	National Oceanic and Atmospheric Administration
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
RID	Royal Irrigation Department
SLP	Sea-Level Pressure
SOI	South Oscillation Index
SST	Sea Surface Temperature
SW	Southwest
THB	Thai Baht
TIWRM	Thailand Integrated Water Resource Management
TMD	Thai Meteorological Department
TNA	Thai National Assembly
UPRB	Upper Ping River Basin

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