Meteorological Drought Classification Using Normalized Difference Vegetation Index

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ABSTRACT

The severity of drought has been impacting on various activities in Thailand such as agriculture, industry, and socioeconomic etc., in term of areal extent and intensifies degree for a long period of time. Nowadays, the solutions of this problem using a quantitative analysis in term of figures or indices of agricultural drought, meteorological drought, hydrological drought, and socioeconomic drought also have been accepted and used in several developed countries around the world.

In this study, therefore, the meteorological drought classification using techniques of normalized difference vegetative index have been applied for the quantitative analyses. This process was mainly consisted of 2 parts like as:

Firstly, using the Palmer meteorological drought index method to identify the drought areas throughout Thailand. To come up with the result of this step, the daily meteorological data from 53 meteorological stations over Thailand during 1982-2002, soil physical and chemical properties data, land-use data and crop phenological data, where all are at the same areas as a data input in the agrometeorological model so-called “SWAP” to calculate the water balance parameters such as Potential Evapotranspiration, Precipitation, Run off, Water Loss, and Water Recharge etc., respectively and then, these parameters output were used as data input in Palmer meteorological drought index equations to calculate the monthly and average monthly values of severity of drought in every meteorological stations throughout Thailand.

Subsequently, all results in term of Palmer meteorological drought index at each meteorological station have been defining on the base map of Thailand in scale 1:250,000 and then, the spatial analysis process for the non-meteorological station region using the grid cell “Kriging” technique have been interpolating and later on generating a digital map, which showing the severity of Palmer meteorological drought indices in any area of Thailand in various levels from –4.00 or less (Extreme drought) to 4.00 or more (Very much wetter than normal) for monthly average in a period of every 4-5 years like as 1982-1985, 1986-1989, 1990-1993, 1994-1997 and 1998-2002 respectively with totally a numbers of 60 map sheets. Nevertheless, these digital maps can be used in operational process as a preliminary guidance for decision-maker to construct a plan for preventing and alleviating the hazardous of drought severity in any area of Thailand.

Secondly, the technique of satellite remote sensing in term of normalized difference vegetation index is necessary to use for integrating with all digital map products as aforementioned to get the better results in trend and foreseen estimation of drought severity as requirement. To come up with the result of this step, the Palmer meteorological drought indices in dry season from November to March during 1992-2000 of 19 agrometeorological stations throughout Thailand have been compared and correlated with Normalized Difference Vegetation Index (NDVI) of NOAA-AVHRR
imageries with a definition of the corresponding area within a radius of 5 km in surrounding to each
agrometeorological station at the same area and time. The result was 92 linear regression equations
for all stations with correlation coefficient, \( r = 0.47-0.99 \), \( df = 3-6 \) respectively. Afterwards, the
verification processes using another imageries data set of NOAA-AVHRR NDVI and SPOT 5
(vegetation) of January and February for 1994, 2001 and 2002 have been manipulated and
compared with a corresponding equations of each station and later on, coming up with the
satisfaction output of Root Mean Square Error (RMSE) for January; 0.01-10.5 and February; 0.33-
12.6 lastly.

Finally, for application of these methodologies on the reality in Thailand. It needs to make a
cross check by using a ground truthing technique at field scale and then, extend to regional or
country level respectively. To be successful at this step, the 19 rain fed rice training sites, where are
at least 2 X 2 km\(^2\) areas within Nakhon Ratchasima, Khon Kaen, Buri Rum and Maha SaraKham
provinces were classified as the drought areas at various severity level according to the climatic
record and a real environmental circumstances, and correlated with a 30 meter spatial resolution of
LANDSAT-NDVI imagery of November 2004, which is the driest month at the same area and time.
At this stage, also the LANDSAT-NDVI imagery have been correlated with the NOAA-AVHRR
NDVI imagery at the same spatial resolution and time with correlation coefficient \( r = 0.68 \), \( df = 8 \).
Subsequently, it has been coming up with the relationship between the drought areas at various
severity levels in real environmental circumstances with the NOAA-AVHRR NDVI imagery, which
these related to the Palmer meteorological drought index as aforementioned in form of
NDVI/Drought areas/Palmer drought index map of Thailand at 1:250,000 scale lastly. These results
could be used in implementing continuously of operational process as a preliminary guidance for
decision-maker to construct a plan for preventing and alleviating the hazardous of drought severity
in any area of Thailand and also, to get the better results in trend and foreseen estimation of drought
severity in related fields for a beneficial of our own requirements finally.

1. INTRODUCTION

Most of upper areal of Thailand have been always facing with problems on implementation of
water resources management for usage and consumption. In this regards, like as more excess water
to flooding in rainy season and followed by water shortage in dry season continuously within a
short period of time. Whenever these events have been occurring, the strategic of old water
resources implementation have to be developed and improved as soon as possible to maintain any
products loss. The dry spell of Thailand will be prolonged at longer time, which starting from the
beginning of winter season to the mid of summer. Some areas are scare of rainfall throughout 5-6
months that is lead to lacking of soil water content and affected on agricultural plantation areas and
so on. Consequently, a degree of dry spell will be depending on theirs own factors in each area such
as land use, a size of residential area, a rate of water uses, and water management lastly.

To over come these problems, the methodology of quantitative drought classification in term of
figures or indices is necessary to be commonly used. Nevertheless, unfortunately, up to this moment
no more those indices have been accepted at national or international level absolutely. However, the
development of drought study has been done in a number of decades ago. The result was depended
on its concept or approaches uses, which some was considering on rainfall and conversely, other
was water cycle and its effect on any activities. Subsequently, the definition of drought still has a
number of questions and diversifies meanings. Thus, in this moment, the drought index can be
classified into four categories as follows; meteorological drought, agricultural drought, hydrological
drought, and socioeconomic drought respectively (Noohi, 1988). In this study, we are just focusing on the Palmer Meteorological Drought Index only because this has been already applied and summarized that it could be used for any related activities in a variety of developed countries. The concept of Palmer in relating to a drought phenomenon as follow; “Drought can be considered as a strictly meteorological phenomenon. It can be evaluated as a meteorological anomaly characterized by a prolonged and abnormal moisture deficiency” (Palmer, 1965).

2. RATIONALE OF PROBLEM

In Thailand, amount of rainfall is the important phenomena, which be used for agricultural planning like as crop cultivation planning, water uses planning, and water storage in reservoir and so on. In practice, if rainfall is less and not appropriate period of time, the occurring of meteorological drought will be eventually prolonged and furthermore if it is also taken in a longer time then, the heavily meteorological drought would has been happened frequently and continuously. Consequently, this is causing of strongly agricultural drought and hydrological drought lastly. As aforementioned, therefore, the study of meteorological drought in term of quantitative analysis using Palmer’s classification in figures or indices as shown on Table 1 is necessary and furthermore, combined with a technique of GIS spatial analysis then the clarified outcome in form of digital maps showing the severity of Palmer meteorological drought indices in any area of Thailand in various levels from –4.00 or less (Extreme drought) to 4.00 or more (Very much wetter than normal) would be come up lastly.

Table 1: Level of the severity of Palmer meteorological drought indices (Alley, 1984 and Maria et al, 1987).

<table>
<thead>
<tr>
<th>Index</th>
<th>Character of recent weather</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00 or more</td>
<td>Very much wetter than normal</td>
</tr>
<tr>
<td>3.00 to 3.99</td>
<td>Much wetter than normal</td>
</tr>
<tr>
<td>2.00 to 2.99</td>
<td>Moderately wetter than normal</td>
</tr>
<tr>
<td>1.00 to 1.99</td>
<td>Slightly wetter than normal</td>
</tr>
<tr>
<td>.50 to .99</td>
<td>Incipient wet spell</td>
</tr>
<tr>
<td>.49 to -.49</td>
<td>Near normal</td>
</tr>
<tr>
<td>-.50 to -.99</td>
<td>Incipient drought</td>
</tr>
<tr>
<td>-1.00 to –1.99</td>
<td>Mild drought</td>
</tr>
<tr>
<td>-2.00 to –2.99</td>
<td>Moderate drought</td>
</tr>
<tr>
<td>-3.00 to –3.99</td>
<td>Severe drought</td>
</tr>
<tr>
<td>-4.00 or less</td>
<td>Extreme drought</td>
</tr>
</tbody>
</table>

3. OBJECTIVE AND SCOPE OF RESEARCH STUDY

The objective and scope of this research study as follows;

1. To define the research study areas, where were the 53 provinces attached with located meteorological stations throughout Thailand and in addition, with the daily meteorological parameters used in this study as solar radiation, maximum-minimum air temperature, relative humidity, rainfall, and wind speed of years 1982-2002. These parameters were the main data input for “SWAP” agrometeorological model.

2. To compute the water balance parameters namely; potential evapotranspiration, precipitation, run off, water loss, and water discharge etc., for each meteorological station
throughout Thailand using “SWAP”.

3. To compute the severity of Palmer meteorological drought indices in each meteorological station throughout Thailand in various levels from −4.00 or less (Extreme drought) to 4.00 or more (Very much wetter than normal) using Palmer’s classification.

4. To interpolate and extend the severity of Palmer meteorological drought indices from 3 to other areas without meteorological station using GIS spatial analysis “Kriging techniques” in form of grid cell digital maps of Thailand in scale 1:250,000 showing the severity of Palmer meteorological drought indices throughout Thailand.

5. To find out a relationship between the Palmer meteorological drought indices from 4 and the Normalized Difference Vegetative Index (NDVI) of NOAA imageries.

4. RESEARCH DESIGN

The conceptual framework of research design has been showing as follow;
Meteorological Drought Classification
Using Normalized Difference Vegetative Index

**STEP 1:**
- Water balance computation
  - Daily met. parameters like as solar radiation, rainfall, air temp., humidity, and wind speed from 53 met. stations during 1983-2002
  - Soil data from LDD

**STEP 2:**
- Palmer met. drought index computation
  - "SWAP"
  - Analytic tools

**STEP 3:**
- Digital Maps of Palmer Meteorological Drought Indices
  - "Computer Program"
  - Monthly Precipitation values
  - Runoff and Potential runoff
  - Loss and Potential loss
  - ET and PET
  - Recharge and Potential recharge

**STEP 4:**
- Analysis of NOAA imageries using Normalized Difference Vegetative Index techniques
  - Surfer, Arcview
  - The average every 4-years monthly values of drought severity during 1983-2002 from 53 Meteorological Stations throughout Thailand

**STEP 5:**
- Comparison between Palmer Meteorological Drought Indices (3) with Normalized Difference Vegetative Index (4)
  - ENVI, IMAGINE
  - "Kriging technique" GIS spatial analysis in form of grid cell digital maps of Thailand in scale 1: 250,000

**Data input**
- Daily NOAA imagery during 1992-2000 from Thai Meteorological Department
- NDVI techniques (NIR-VIS) / (NIR+VIS)

**Technique used**
- PET computation using Penman-Monteith equation
- Soil properties computation using Darcy and Richard equation
- Soil moisture index equation
- Palmer drought index’s classification
- Extreme wet computation
- Extreme drought computation

Remark: LDD is Land Development Department of Thailand
OAE is the office of Agricultural Economics of Thailand
5. MATERIALS AND METHODS

According to the conceptual framework of research design, which can be divided a data processing into 3 steps as follow;

STEP 1: Water balance Computation

1. Data input consisted of 3 data set namely;

   1.1 Daily meteorological data
   These are a daily met. parameters such as solar radiation, rainfall, air temperature, relative humidity, and wind speed, which have been collected from 53 met. stations throughout Thailand during 1982-2002.

   1.2 Soil data
   These are physical, hydraulic, and chemical properties of soil series in Thailand using Darcy and Richard’s computation such as Available Water Capacity (AWC), Field Capacity (FC), Permanent Wilting Point (PWP), and pH etc. (Yingjajaval, 1993).

   1.3 Agricultural data
   These are a group of data from the land use digital map of the Office of Agricultural Economics in 2000, which was showing the crop cultivation areas in districts throughout Thailand.

2. Data processing and Output
   All data input have been converted into an appropriate format and processed using agrometeorological model so-called “SWAP” (Soil-Water-Atmosphere-Plant), which have been developed by Kroes et al., 1999 from Department of Water Resource, Wageningen Agricultural University of the Netherlands.

   The SWAP outputs were daily water balance parameters in along with 53 meteorological stations throughout Thailand, which would be used for the next step such as Potential water runoff, Water runoff, Potential water loss, Water loss, Potential water recharge, Water recharge, Potential evapotranspiration, and Evapotranspiration respectively.

STEP 2: Palmer meteorological drought index Computation

1. Data input consisted of a data set, which has been a resulted from STEP 1.

2. Data processing and Output
   The Palmer meteorological drought index has been computed using a visual basic computer program, which had been developed by a staff of Thai Meteorological Department (TMD) with the approaches following;
   
   2.1 To find out “Z”, which is a negative value continuously with a changing rate of accumulated “Z” in comparing with time as the maximum value in each met. station.

   2.2 To construct a scatter plot graph of those accumulated “Z” in relating to a period of time (t) using the linear regression relationship: ΣZ(t) = mt + n; m, n was constant values as shown on Figure 1. Then, the accumulated “Z” changing rate line would be a defining representative of Palmer meteorological drought index as equal to –4. Therefore, it consequently was able to generate the Palmer meteorological drought index equation in a form of X(t) = ΣZ(t)/(pt + q); p, q was constant values of climatically parameters of Thailand.

   Subsequently, nevertheless, it could rewrite this equation into X(t) = cX(t-1)+Z(t)/(p+q); c was constant value. By using this existing equation, the outputs would have been the average every 4-years monthly values of drought severity in various levels along with all met. station throughout Thailand, which would be used for the further step. In addition, all used parameters in a computation of Palmer meteorological drought index would be shown on Table 2.
Figure 1: The relationship between accumulated Z and period of time t

![Figure 1: The relationship between accumulated Z and period of time t](image)

Table 2: All used parameters in a computation of Palmer meteorological drought index

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Equations</th>
<th>Meanings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Evapotranspiration ($\alpha$)</td>
<td>$\alpha = \frac{ET^<em>}{PE^</em>}$</td>
<td>ET* is average actual Evapotranspiration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PE* is average Potential Evapotranspiration</td>
</tr>
<tr>
<td>Coefficient of Recharge ($\beta$)</td>
<td>$\beta = \frac{R^<em>}{PR^</em>}$</td>
<td>R* is average Recharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PR* is average Potential Recharge</td>
</tr>
<tr>
<td>Coefficient of Runoff ($\gamma$)</td>
<td>$\gamma = \frac{RO^<em>}{PRO^</em>}$</td>
<td>RO* is average runoff</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PRO* is average Potential Runoff</td>
</tr>
<tr>
<td>Coefficient of Loss ($\delta$)</td>
<td>$\delta = L^<em>/PL^</em>$</td>
<td>L* is average Loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PL* is average Potential Loss</td>
</tr>
<tr>
<td>CAFEC Precipitation ($P^*$)</td>
<td>$ET^{**} = \alpha PE^*$</td>
<td>CAFEC is Climatically Appropriate For Existing Conditions in that individual month; ET**, R**, RO**, L**, and</td>
</tr>
<tr>
<td></td>
<td>$R^{**} = \beta PR^*$</td>
<td>P** is precipitation</td>
</tr>
<tr>
<td></td>
<td>$RO^{**} = \gamma PRO^*$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$L^{**} = \delta PL^*$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$P^{<strong>} = ET^{</strong>} + R^{<strong>} + RO^{</strong>} - L^{**}$</td>
<td></td>
</tr>
<tr>
<td>Precipitation Excesses and Deficiencies ($d$)</td>
<td>$d = P - P^{**}$</td>
<td>d is the difference between the actual precipitation and the CAFEC precipitation for each month</td>
</tr>
<tr>
<td>The Climatic characteristic ($k$)</td>
<td>$k = \frac{(PE^* + R^<em>)}{(P^</em> + L^*)}$</td>
<td>k is the first approximation average climatic characteristics</td>
</tr>
<tr>
<td>The Moisture anomaly index ($z$)</td>
<td>$z = dk$</td>
<td>$z$ is the moisture anomaly index</td>
</tr>
</tbody>
</table>
STEP 3: Digital maps of Palmer meteorological drought indices

1. **Data input** consisted of a monthly and average monthly data set, which have been a resulted from STEP 2 and were converted to a new format in along with a Georeferenced values for each met. station (Latitude, Longitude) to new working sheets for further GIS spatial analysis.

2. **Data processing and Output**
The topographic general map of Royal Thai Survey Department of Thailand in scale 1:250,000 have been used as a base map in this study. In addition, all the average every 4-year monthly values of drought severity in various levels would be placed on corresponding to a location of each met. station throughout Thailand and then, a “Grid Cell Kriging interpolation technique” of GIS spatial analysis would have been used to analyze all related data. The outputs were the grid cell digital maps of Palmer meteorological drought indices throughout Thailand in scale 1:250,000, which showing the colorful severity of drought in various levels from –4.00 or less (Extreme drought) to 4.00 or more (Very much wetter than normal) respectively.

STEP 4: Analysis of NOAA imageries using Normalized Difference Vegetative Index techniques

1. **Data input** consisted of a data set of the daily NOAA imagery in total 33 imageries, which has been receiving from the meteorological satellite receiving station of Thai Meteorological Department and Geo-Informatics and Space Technology Development Agency (GISTDA) during 1992-2000.

2. **Data processing and Output**
The techniques of digital image processing like as; Geometric correction, Masking, Band combination and NDVI \( \frac{\text{NIR-VIS}}{\text{NIR+VIS}} \) have been used respectively to manipulate on each of 33-daily NOAA imageries of Thailand. The outputs were the NOAA-imageries data set, which showing the NDVI values on some areas in each province of Thailand on map scale 1:250,000.

STEP 5: Comparison between Palmer Meteorological Drought Indices with Normalized Difference Vegetative Index

1. **Data input** consisted of the outputs from step 3 and step 4, which have been compared and correlated for a relationship.

2. **Data processing and Output**
The techniques of overlaying and cell to cell profile analysis have been used to find out a relationship between Palmer Meteorological Drought Indices and Normalized Difference Vegetative Index, with the specific condition as “they should be the areas within radius of 5 km in each of 19 agrometeorological stations of Thailand, where circumstance are very much suitable for agricultural activities”. The outputs were NDVI-NOAA imageries, which showing the severity of drought in various levels in term of NDVI values according to Palmer index in each province of Thailand on map scale 1:250,000.

Application for Operational Routine Work

For application of this research results for operational routine work in the near future, it needed verification for errors of the output firstly and then, up scaling this output to regional level respectively. Subsequently, the verification at the field scale have been done using the high resolution satellite imagery NDVI-LANDSAT comparing with NDVI-NOAA with the same 30 m spatial resolution and also, with the collected data from the field survey for the frequently prolonged
drought areas in northeast of Thailand. Afterward, the relationship of these 3 parameters would be used for routine application lastly. The linkage of up scaling was shown on Figure 2.

**Figure 2: Linkage the framework of this study**

6. RESULTS

Firstly, the results were the Grid Cell Digital maps, which have been showing the severity of Palmer meteorological drought indices in any area of Thailand in various levels from –4.00 or less (Extreme drought) to 4.00 or more (Very much wetter than normal) in different period respectively as follows; average monthly digital maps for period 1982-1985, 1986-1989, 1990-1993, 1994-1997, and 1998-2002 in which in totally 60 digital maps. Some examples of those Grid Cell Digital maps were shown on Figure 3-5.

**Figures 3-5: The average monthly values of the severity of Palmer meteorological drought indices in various levels throughout Thailand during January-March for period 1982-1985 [brown (wild drought)-green (slight wet rather normal)].**
Secondly, the results of a comparison between Palmer meteorological drought indices and the NDVI values of NOAA imageries at the same period of time have been shown in form of digital map of Thailand on Figures 6-7, which have been showing the severity of drought in any area of Thailand.

![Drought area](image1)

![Drought area](image2)


Thirdly, the NDVI values dataset of NOAA-AVHRR imageries at 19 agrometeorological stations of Thailand have been categorized in corresponding with the severity of Palmer meteorological drought indices dataset at the same duration of time during November – March of 1992-2000 and then, the relationships of both dataset have been correlated in 92 linear regression equations with correlation coefficient, $r = 0.47-0.99$, $df = 3-6$ as shown the some equations following;

<table>
<thead>
<tr>
<th>Region</th>
<th>Station</th>
<th>Month</th>
<th>Equation</th>
<th>$r^2$</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Chiang Rai Agromet.</td>
<td>1</td>
<td>$y = -0.0729x + 0.003$</td>
<td>0.7623</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>$y = -0.013x - 0.134$</td>
<td>0.5433</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>$y = 0.0135x - 0.2177$</td>
<td>0.2492</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doi Muser</td>
<td>Agromet.</td>
<td>1</td>
<td>$y = -0.5307x + 0.1539$</td>
<td>0.8524</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>$y = -0.0165x + 0.1062$</td>
<td>0.3798</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>$y = 0.0162x - 0.0982$</td>
<td>0.4433</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11</td>
<td>$y = 0.1488x - 0.2159$</td>
<td>0.2351</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12</td>
<td>$y = -0.0656x + 0.089$</td>
<td>0.2366</td>
<td>5</td>
</tr>
</tbody>
</table>
7. DISCUSSIONS & RECOMMENDATIONS

For the further research and operational routine works, we sincerely would like to make
suggestion as follow;

1. By comparison between the average monthly values of the severity of Palmer meteorological
drought indices in Thailand during 1982-2002 with a monthly climatic patterns of summer, rainy,
and winter seasons throughout Thailand then, it has been found that both data set have been very
corresponding and compromising in term of areal coverages for each season respectively.

2. The example of up scaling from field to regional or national level in this study has been
just preliminary ideal, therefore, the more revision processes and various circumstances of
areas should have been involved in consideration for clarified conclusions in the future.

3. The integration of Satellite Remote Sensing (SRS) and Numerical Weather Prediction
(NWP) techniques should have been used to increase an accuracy and potential of
meteorological drought estimating and forecasting for a routine work.

4. A very high resolution satellite imageries of both passive and active remote sensing like
as; SPOT 5, THEOS, IKONOS, QUICKBIRD, RADARSAT, ERS-2 etc, should have been
involved in term of increasing accuracy of a field surveying for the appropriate conclusion
and very beneficial implementation for decision maker in policy level.

8. ACKNOWLEDGEMENTS

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