Desertification Risk Assessment in Pa Deng sub-district, adjoining area of Kaeng Krachan Natural Park, Thailand

Saowanee Wijitkosum*, Kanoktat Yolpromote, Luechai Kroutnoi
Environmental Research Institute, Chulalongkorn University, Bangkok, Thailand
*E-mail: i_am_saowanee@hotmail.com

Abstract

A desertification risk assessment for Pa Deng sub-district, adjoining Kaeng Krachan Natural Park, Thailand was performed by spatial analysis using remote sensing and geographical information system techniques. The objectives of the study were to assess the desertification risk and prepare a desertification risk map that could serve as a database for setting area-based mitigation measures. The study examined five risk factors: aridity index, soil texture, soil fertility, land use and soil erosion risk.

The study findings indicate that aridity index has a low or zero correlation with desertification risk in the study area, while soil texture affected on the desertification risk in the study area at low level. In addition, the soil fertility is at low level which influences on the desertification risk in the study area at very low level to high level. Moreover, the land use investigation showed that land use in the study area can be classified as five types e.g. forest area, agricultural area, community area, bare land and water body. Furthermore, the result of soil erosion assessment showed that the very high risk category of soil erosion occupied most of the centre plain area of Pa Deng. The desertification risk assessment revealed that the desertification risk areas of Pa Deng sub-district in low level, moderate level, and high level were 2.00 %, 9.14 % and 0.79 % of the total area, respectively. However, forest area and water body were considered as the area that do not affect on the desertification.

Keywords: desertification, aridity index, soil texture, soil fertility, land use, soil erosion
1. Introduction

Desertification is considered as one of the major causes of land degradation, blamed for the disappearance of agricultural land, reduced land productivity and adverse environmental impacts (Gao & Liu, 2010). The United Nations Convention to Combat Desertification (UNCCD) defines desertification as “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities,” while the arid, semi-arid and dry sub-humid areas have been defined as “areas, other than polar and sub-polar regions, in which the ratio of annual precipitation to potential evapotranspiration (P/PET) falls within the range from 0.05 to 0.65” (Land Development Department, 2004). The P/PET is referred to as the aridity index (AI). Since some parts of Thailand are classified as dry sub-humid areas in which the aridity index falls within the range from 0.51-0.65, Thailand can be considered as an affected country despite its prevailing monsoon climate.

Thailand’s Land Development Department is the main agency for managing land degradation identifies the major causes of desertification in Thailand as: (a) climatic factors i.e. heavy rain during the monsoon period dissolves and translocates soil minerals and seasonal drought; (b) human activities i.e. land use without soil improvement, over-exploitation of land, land use on steep-slope lands causing soil erosion and expansion of saline soils (LDD, 2004).

Many previous studies revealed that climatic factors, soil properties and human activities such as deforestation and over-cultivation, are key factors leading to desertification. For instance, the World Meteorological Organization (WMO) claims that soil properties and key processes such as organic matter decomposition, leaching, and soil water regimes are influenced by temperature increase (WMO, 2007).

Moreover, in the drier areas of Latin America, climate change is expected to lead to salinisation and desertification of agricultural land. Furthermore, Sarah (2006) concluded that soil organic matter (SOM) increased significantly with decreasing aridity. High SOM content can lead to high aggregate stability which results in higher resistance to wind and water erosion (Sivakumar, 2007). In addition, a study of the relationship between changing soil cover and land degradation in Northeast China attributed the worsening trend in land degradation to excessive reclamation of grassland for farming, over cultivation, overgrazing, and deforestation (Gao & Liu, 2010).

Assessment of desertification risk aims to identify the major factors contributing to desertification. Its use in combination with other techniques such as geographic information system (GIS) and remote sensing (RS) can contribute to developing effective spatial management strategies. GIS and RS have an important role in graphical visualization of spatial data, facilitating interpretation. For this reason, these techniques have been applied in many studies of desertification (van Lynden & Mantel, 2001; Santini M. et al.; 2010, Gao & Liu, 2010; Ladisa et al., 2011).

Pa Deng sub-district, Kaeng Krachan, Phetchaburi Province in Thailand was selected for the current study. The area is adjacent to Kaeng Krachan National Park, which contains the country’s largest national reserve forest. Currently, trespassing in the National Park and reserved forest in the study area have become more serious, impacting on land use and introducing landslide and soil erosion problems in the study area (Wijitkosum, 2012). It is possible that desertification in this sensitive area may carry severe consequences, in accelerating loss of forest area.

In the current study, climate, soil properties such as soil texture and soil fertility, land use and soil erosion were identified as the dominant factors influencing desertification in the study area. The objective of this paper is therefore to identify the influence of these factors. The data and findings of the study will also serve as an important foundation for spatial development planning for the study area.
2. Study area

The study was performed in Pa Deng sub-district, Kaeng Krachan district, Phetchaburi Province in Western Thailand. Its location lies between 99°20’E to 99°37’E latitude and 12°33’N to 12°45’N at an altitude of 140 m above mean sea level. The study area, Pa Deng, covered approximately 41,780 hectares. Geologically, Pa Deng is a piedmont plateau, sloping gradually from west to east. The majority of the land is slope complex land with slopes greater than 35%. Due to their slope, soils in these areas have not yet been surveyed or classified. Overall, the terrain at Pa Deng has been classified as undulating and rolling terrain. The topsoil texture is sandy loam or loam with medium to high soil permeability. The main occupation of the majority of the population is agriculture, dominated by monocracy and livestock farming. Some regions of Pa Deng lie within the perimeter of the national forest reserve forest and Kaeng Krachan National Park, comprising tropical rain forest. Pa Deng is surrounded by mountains with a plain at the centre. The Tanowsri Mountain Range, which runs from north to south, forms the western boundary of the site. The mean annual temperature and rainfall are 27°C and 1,070 mm, respectively. The rainy season extends from May to November. The area faces increasing population pressure due to limited utilizable land: the central plain of Pa Deng which can be utilized for agriculture or housing represents only 12% of the total area, whilst population growth is 2.80% p.a.

3. Materials and Methods

3.1 Climatic data collection and preparation

Climate data was collected from the nearest agro-meteorological station at Nong Phlup. Data on mean temperature, maximum and minimum temperatures, relative humidity, sunshine, wind speed, rainfall and evaporation data were collected for the 30-year period from 1981 to 2010. Using these data, the Penman-Monteith equation (1) was used to calculate the reference evapotranspiration (ET0) (FAO, 2009). The potential evapotranspiration (PET) was calculated by multiplying the crop coefficient (Kc) by ET0. Then the aridity index (AI) was calculated by dividing annual rainfall by PET (2). The results were prepared as spatial data in shapefile format using ArcGIS software.

\[
ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma (T + 0.34 u_2)}
\]  (1)

where

- \(ET_0\) = reference evapotranspiration (mm/day)
- \(R_n\) = net radiation at the crop surface (MJ/m²/day)
- \(G\) = soil heat flux density (MJ/m²/day)
- \(T\) = mean daily temperature at 2 m height (°C)
- \(u_2\) = wind speed at 2 m height (m/s)
- \(e_s\) = saturation vapour pressure (kPa)
- \(e_a\) = actual vapour pressure (kPa)
- \(e_s - e_a\) = saturation vapour pressure deficit (kPa)
- \(\Delta\) = slope vapour pressure curve (kPa/°C)
- \(\gamma\) = psychrometric constant (kPa/°C)

\[
Aridity\ Index = \frac{P}{PET}
\]  (2)

where

- \(P\) = annual precipitation (mm)
- \(PET\) = potential evapotranspiration (mm)

3.2 Soil properties investigation

Using a 1 x 1 km grid size plotted on the plain area of Pa Deng, 59 soil samples were collected from the area in order to investigate soil texture and soil fertility. Soil texture and soil fertility data were individually prepared in shapefile format using ArcGIS software.

3.3 Land use types investigation

Landsat-5 TM satellite data from 2010 were used to classify the various land use types in ENVI by applying supervised and unsupervised classification techniques. The image was classified into four land use categories, namely forest area, agricultural area, community area, and water bodies.
3.4 Soil erosion assessment

Soil erosion risk was determined based on factors defined by the Universal Soil Loss Equation (USLE) (Wischmeier & Smith 1978). The USLE evaluates the long-term average annual soil loss (A) from sheet and rill erosion. The USLE is defined as

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \] (3)

where A is the average annual soil loss (mass/area/year), R is the rainfall and runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness index, C is the land cover/management factor, and P is the soil conservation factor. Thailand’s Land Development Department (LDD) has adjusted and validated this model for local conditions. According to the LDD study, each factor can be determined as described below (Wijitkosum, 2012).

The rainfall and runoff erosivity (R) is determined as a function of total storm kinetics energy (E) and its maximum 30-min intensity (\(I_{\text{max}30}\)). The appropriate equation for determination of rainfall and runoff erosivity factor in Thailand is:

\[ R = 0.4669X - 12.1415 \] (4)

where R is the rainfall and runoff erosivity (Mg/ha/yr) and X is the average annual rainfall (mm/yr). The average annual rainfall of the study area was calculated based on rainfall data from the 30-year period from 1981 to 2011, collected from the adjacent weather station.

The soil erodibility factor (K) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The national database of the K factor indicates that the K factor of soils in Thailand ranges from 0.04 – 0.56.

The slope length factor (L) is expressed as the ratio of expected soil loss to that observed for a field of 22 m in length. The slope steepness index (S) is the ratio of expected soil loss to that observed for a field of specified slope of 9%. In addition, the national database of both L and S factors for all slope gradients corresponding to soil series found in Thailand record that the LS factor of land in Thailand ranges from 0.226 – 4.571.

The land cover/management factor (C) is an index of protective coverage of canopy and organic material in direct contact with the ground. Therefore, the C factor also depends on land use types. The national database for the C factor showed that the C factor ranges from 0.001 for tropical rain forest to 1.000 for bare ground. Since most regions in Thailand have no conservative practice management, the P factor has been defined as 1.0.

All factors required for the USLE were prepared as data layers for Arc GIS. These data layers were then overlaid and annual soil loss calculated according to the USLE equation.

3.5 Desertification risk assessment

The spatial data and attribute data of concerned factors e.g. aridity index, soil texture, soil fertility and land use were prepared in shapefile format for input into ArcGIS software. The desertification risk level was identified for each factor. Then a desertification risk map of the study area was created by overlaying the prepared shapefiles using ArcGIS. Since the majority of Pa Deng sub-district lies within the national forest reserve and Kaeng Krachan National Park area, assessment of desertification risk of Pa Deng was conducted only for the plain area of Pa Deng which can be utilized for cropping.

4. Results

4.1 Aridity Index

The aridity index calculation revealed that the aridity index for the study area ranged from 0.58 to 1.73 (Figure 1). The results indicate that aridity index has a low or zero impact on desertification risk in the study area.
4.2 Soil texture
Analysis of soil texture and field observation indicated that approximately 85% of the total area of Pa Deng comprises slope complex land with slopes exceeding 35%. The dominant soil texture within the plain area is sandy loam, followed by silt loam and loamy sand, respectively (Figure 2). Due to the prevalence of fine-textured soils, the water-holding capacity and soil moisture within the study area were high (Buchanan et al., 2010). These factors contribute to high aggregate stability and resistance to wind and water erosion (Sivakumar, 2007). For this reason, soil texture carries only a low level impact on the desertification risk in the study area.

4.3 Soil fertility
Laboratory analysis of soil samples collected from the plain area of Pa Deng revealed soil pH ranging from 3.8 to 7.4, organic matter ranging from 0.52% to 4.57%, available phosphorus ranging from 1.0 to 1,204.0 mg/kg, exchangeable potassium from 20.0 to 740.0 mg/kg, calcium from 40.0 to 4,400.0 mg/kg and magnesium from 7.0 to 400.0 mg/kg. Soil fertility in the study area was investigated by applying the GIS technique. The findings revealed high levels of soil fertility (Figure 3). For this reason, soil fertility impacts on desertification risk in the study area at a low level.

4.4 Land use types
Figure 4 shows land use in Pa Deng sub-district, classified into five types: forest, agriculture, community area, bare land and water bodies. The largest area was covered by forest (84.65% of total area), followed by agriculture (14.91%), community areas (0.23%), bare land (0.11%) and water bodies (0.11%), respectively (Wijitkosum, 2012). The agricultural and community areas were located within the central plain area, covering approximately 12% of the total area. The eastern zone lies within Kaeng Krachan National Park, whilst the western zone is part of the national forest area.
4.5 Soil erosion

Soil erosion risk in the study area was assessed using the USLE. The findings indicated that for 2010 the majority of the study area (approximately 85% of the total area) was characterized by low soil erosion risk (0 – 12.5 Mg/ha/year). However, virtually the entire central plain area was found to be at very high risk of soil erosion, as shown in Table 1 and Figure 5 (Wijitkosum, 2012).

Table 1 Soil erosion risk. Pa Deng Sub-District (2010)

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (0-12.5 Mg/ha/year)</td>
<td>35,669.79</td>
<td>85.4</td>
</tr>
<tr>
<td>Slight (12.5-31.25</td>
<td>1,626.49</td>
<td>3.9</td>
</tr>
<tr>
<td>Mg/ha/year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate (31.25-93.75</td>
<td>1,639.00</td>
<td>3.9</td>
</tr>
<tr>
<td>Mg/ha/year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High (93.75-125 Mg/ha/year)</td>
<td>565.80</td>
<td>1.4</td>
</tr>
<tr>
<td>Very high (&lt;125 Mg/ha/year)</td>
<td>2,280.90</td>
<td>5.5</td>
</tr>
<tr>
<td>Total</td>
<td>41,781.98</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: modified from Wijitkosum, 2012

4.6 Desertification risk

Each factor considered: aridity index, soil texture, soil fertility, land use and soil erosion were assumed to equally influence desertification. The study results show that Pa Deng sub-district comprises 2.00% with low desertification risk; 9.14% with moderate risk; and 0.79 % of the total area with high risk (Table 2 and Figure 6). Forest areas (36,705.94 ha) and water bodies (89.14 ha) were considered as unaffected by desertification risk.

Table 2 Desertification risk, Pa Deng central plain (2010)

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
<th>(% of total area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Low</td>
<td>837.30</td>
<td>2.00</td>
</tr>
<tr>
<td>Moderate</td>
<td>3,821.00</td>
<td>9.14</td>
</tr>
<tr>
<td>High</td>
<td>328.60</td>
<td>0.78</td>
</tr>
<tr>
<td>Extremely high</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Total area, central plain</td>
<td>4,986.9</td>
<td>11.9</td>
</tr>
<tr>
<td>Total area, Pa Deng</td>
<td>41,781.98</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Study results
5. Discussion

The result of aridity index calculation showed that the majority of Pa Deng is categorized as a humid area with AI over 0.65 (Land Development Department, 2004). It is therefore concluded that AI is not an impact factor for desertification in Pa Deng. Secondly, the soil properties investigation revealed that in the plain area of Pa Deng, the predominant soil texture was sandy loam containing 57-75% sand, 8-28% silt, and 8-19% clay. Likewise, soil organic matter in the study area was high. Since high SOM is associated with high plant diversity and cover, with resulting low runoff potential (Xu et al., 2008), neither soil texture nor soil fertility in Pa Deng are significant risk factors for desertification.

The land use investigation revealed that most of the plain area of Pa Deng area was occupied by agriculture, with monoculture and livestock farms predominating. According to the previous study of Wijitkosum (2012), the cultivated area of Pa Deng had increased by 4.03% in 2010, as compared with 1990. Moreover, approximately 2.80% of the 1990 forest area had been transformed to agricultural use by 2010, with population growth as the main driver.

Increase in cultivated area can lead to elevated desertification risk due to use of inappropriate agricultural practices (Danfeng et al., 2006). Although the desertification risk map categorization indicates that most of the plain area of Pa Deng is at moderate risk of desertification, virtually the entire area is nevertheless at severe risk of soil erosion, corroborating the author’s earlier field observations, revealing that Pa Deng’s cultivated area is at high risk of soil erosion due to its slopes and the absence of soil conservation measures (Wijitkosum, 2012).

The high risk of soil erosion can result in land degradation, in turn triggering desertification processes (López-Bermúdez, 1990; Ravi et al., 2010). This is because soil erosion removes the top soil, which contains a high proportion of organic matter and finer mineral fractions that provide nutrients essential to plant growth (Bell, 1999).

6. Conclusions

The majority of the plain area of Pa Deng area (9.14% of the total area) is at moderate risk of desertification. However, due to the high risk of soil erosion resulting from inappropriate agricultural practices and lack of implementation of soil conservation measures, desertification in Pa Deng can potentially become more severe. For this reason, land cover management and soil conservation measures are recommended for implementation in all cultivated areas in Pa Deng.

7. Acknowledgments

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8. References