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Critical Factors Affecting the Desertification in Pa Deng, Adjoining Area of Kaeng Krachan National Park, Thailand

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Abstract

The aim of this study is to bring forward and analyze key factors that have an effect on the desertification in Pa Deng Sub-district in order to assess the desertification risk of the sites. The MEDALUS Model was used to conduct the desertification risk assessment. The spatial analysis study was done with Geographic Information System (GIS) and Remote Sensing (RS) programs. The key factors that had an impact on the desertification in Pa Deng area are climatic factor (aridity index: AI), soil factors (soil texture, soil fertility and soil erosion) and human activity factor (land use). The results revealed that the majority of the plain area in Pa Deng was at a moderate desertification risk. The critical factor that increased the risk of desertification was soil erosion.

Keywords: critical factor; desertification; soil erosion; land use; climate change

1. Introduction

Desertification predicates current features of a global problem despite different characteristics in distinct geographical locations, economy, social and environmental conditions. The United Nations Convention to Combat Desertification (UNCCD) defined the desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (FAO, 1993). Desertification has become more severe. Hai *et al.* (2013) examined human activities that affected the desertification including high population and poverty, inappropriate cultivating techniques, deforestation, ill-adopted legal frameworks, weak management capacity, lack of adequate knowledge, and lack of awareness in local population. The unsustainable land use may lead to soil degradation which is known as desertification (Núñez *et al.,* 2012; Cebecauer *et al.,* 2008; García-Ruiz, 2010).

Desertification is nothing new in Asia. Many studies have been undertaken for assessing and mapping desertification risk in particular areas but the identification of critical factors that affect desertification risks have not been thoroughly studied. Thailand is a tropical country that has savanna climate (*Aw*), the climate change that affects evapotranspiration is expected to cause an increase of drought and an expansion in dry areas. Some parts of the country are classified as dry sub-humid areas, aridity index (AI), between 0.51 and 0.65, which showed that Thailand can be considered as an affected country although it is located in monsoon climate. Similar to other countries, many studies conducted in Thailand focus on the overall desertification risks of the country, but not specific on spatial study. Moreover, no further study has been conducted in the areas identified as high desertification risks, thus the critical factors and how they affect the risks have not been identified.

This study was conducted in the Pa Deng Sub-district, the adjoining area of Kaeng Krachan National Park, Thailand, where the desertification can potentially become more severe. Pa Deng has a plain area of approximately 49.87 km^2 located on the central part (11.94% of the whole area). The major part of the plain area (76.62%) is at a moderate risk of desertification (Wijitkosum, 2012).

The population of Pa Deng has expanded their settlements and cropping in the plain area that lies between the National Park and the reserved forest of Kaeng Krachan National Park. Currently, the trespassing in the study area has become more serious which triggers land use, land use change, landslide and soil erosion problems. It is possible that the desertification in this sensitive area may carry severe consequences due to an accelerating loss of forest area (Wijitkosum, 2012). Therefore, the study of factors affecting the desertification in Pa Deng, which can be applied for desertification risk assessment, aims to provide a significant database for developing plans and measures against the desertification based on the sustainable development concept. In addition, the study results are applicable for spatial development plan setting.

The objective of this study was to indicate and analyze the key factors that impact on the desertification in the Pa Deng area in order to assess the desertification risks of the site.

2. Materials and Methods

2.1. Study area

The Pa Deng Sub-district is located in Kaeng Krachan District, Phetchaburi Province, in the watersheds of the Pranburi River. The study area, Pa Deng, covers an area of approximately 417.80 km^2. Geographically, it lies between the latitudes 99˚20'E to 99˚37'E and 12˚33'N to 12˚45'N at an altitude of 140 m above mean sea level.

Pa Deng is piedmont plateau, sloping gradually from west to east. The majority of the land is slope complex with slopes greater that 35%. Overall, the terrain at Pa Deng has been classified as undulating and rolling terrain. Due to the slopes, soils in these areas have not yet been surveyed or classified.

Some parts of the area lie within the perimeter of the reserved forest and the Kaeng Krachan National Park, which is a tropical rain forest. Pa Deng is surrounded by mountains with a plain area at the center. Agriculture is the main occupation of the majority of the population; dominated by monoculture. The agricultural practices were implemented without soil improvement and there was no livestock farming.

The mean annual temperature and annual rainfall are 27˚C and 1,070 mm respectively. The area was facing an increasing population pressure due to limited utilizable land. The central plain (9.14% of the total area), which can be utilized for agriculture or housing, represents only 12% of the total area while the population growth is 2.80% (Wijitkosum *et al.,* 2013)

2.2. Data analysis

The critical factors that affect the desertification were identified by the results of the analysis of factors that affected the risks. The characteristics of each factor were compared with specifications defined by both national and international organizations that attempted to monitor and assess desertification. In Thailand, the Land Development Department of Thailand (LDD) took part in assessing and monitoring desertification as well as conducted several geographic studies using the Remote Sensing (RS) and Geographic Information System (GIS) (van Lynden *et al.,* 2001; Santini *et al.,* 2010; Rangzan *et al.,* 2008); the responsibility included soil survey and classification, soil analysis, land use planning, conducting experiments and carrying various aspects of land development. The data collected was used for spatial analysis and mapping.

Spatial data and attribute data for the five factors; AI, soil texture, soil fertility, soil erosion and land use were prepared in shapefile format for ArcGIS software. Following the analysis of the desertification risk level for each factor, a desertification risk map of the study area was created by overlaying the prepared shapefile data using ArcGIS.

2.2.1. Assessment of desertification risk factors for desertification risk mapping

Desertification occurs when the land became arid and barren because topsoil was completely eroded. In Thailand, the two major causes of desertification are (a) climatic e.g. leaching and translocation of soil minerals and seasonal drought and (b) anthropogenic e.g. land use without soil improvement, over-exploitation of land, inappropriate use of steep-slope lands causing soil erosion and salinization. The investigation of the desertification risk indicators was taking into account the parameters suggested by previous research in the regional scale (LDD, 2004) as well as the actual possibility of having specific databases at national scale. The desertification risk assessment required an input of data of the three major factors and their indicators; climatic factor (AI), soil factors (soil composition, soil fertility and soil erosion) and human activity factor (land use), in order to be analyzed in 5 map units.

The desertification risk assessment was calculated by using the MEDALUS approach (Kosmas *et al.,* 1999). The MEDALUS model, "Mediterranean Desertification and Land Use", aims to assess the sensitivity of the desertification area (Honardoust *et al.,* 2011; Abdalla, 2008; Giordano *et al.,* 2002). This approach is suitable for Asian regions and can be applied to reliably evaluate desertification conditions in many countries in Asia (Sepehr *et al.,* 2007; Gholam *et al.,* 2006; Rangzan *et al.,* 2008; Farajzadeh *et al.,* 2007). In the study, the MEDALUS model was modified by integrating five factors as information layers providing an overall picture of the environmental conditions without taking into account the land management factor in the area.

The model takes in broad systems of five indicators at the minimum set of selected data that had to be assessed (Sepehr *et al.,* 2007; LDD, 2003; Bayramin, 2003). Each system has a "quality index" which incorporates several parameters. According to the developed algorithm, the geometric mean was used to compile maps of ESAs to assess the desertification (Sepehr *et al.,* 2007; EEA, 2004).

Throughout the model, each individual index was applied a quantitative classification scheme with values of 1 and 2. The value 1 was assigned to areas

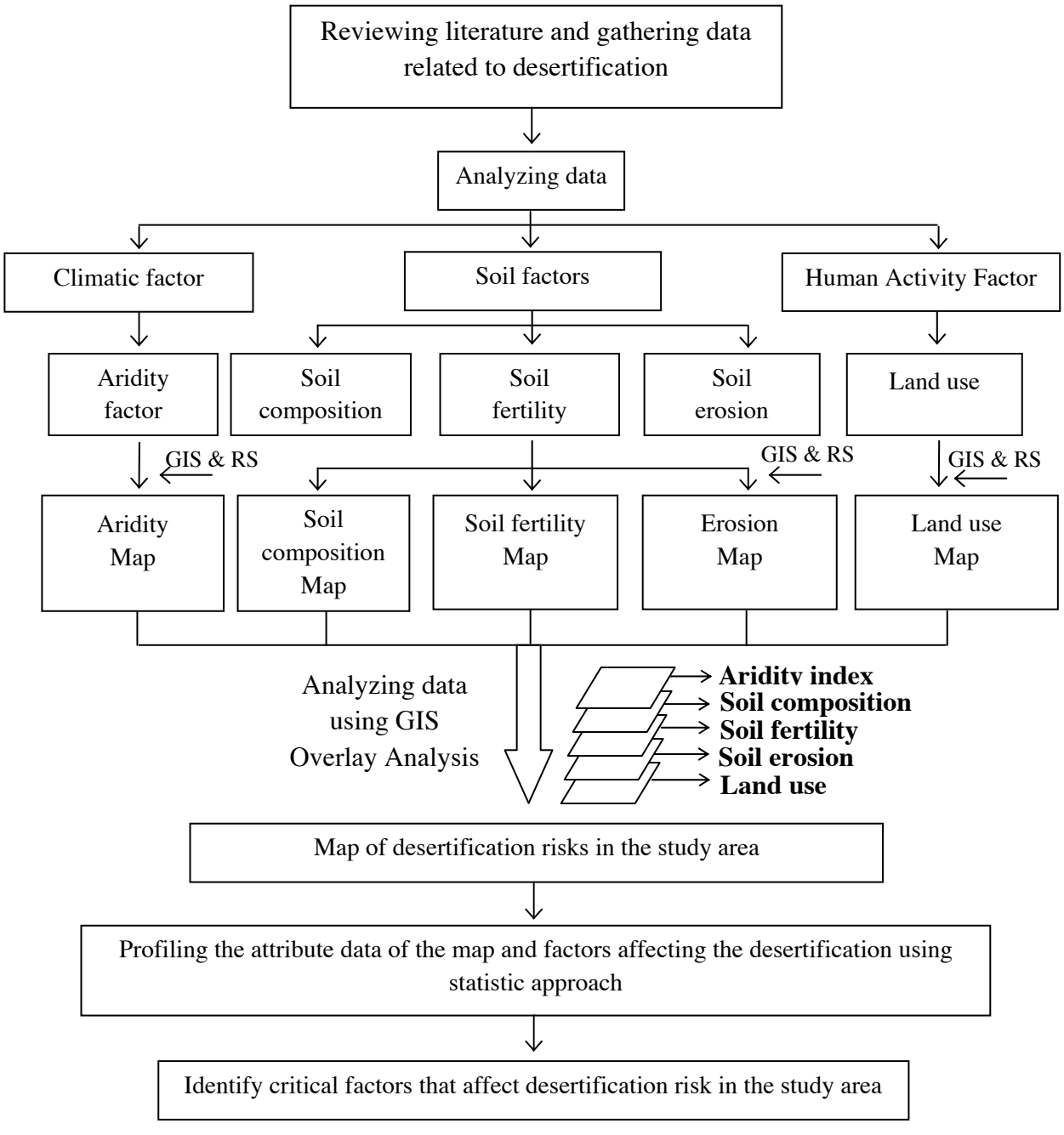

Figure 1. Framework and study method

with the least sensitivity and the value 2 was assigned to areas with the most sensitivity. The quality indices were computed and employed in the GIS technique for computing the Desertification Sensitivity Index and mapping the desertification sensitivity areas.

The first factor concerned one indicator; the AI in which the climate data had been collected over a 30-year period at Nong Phlab Agrometeorogical Station, the representative station in the area. The reliability and stability was analyzed using the Double Mass Curve method (Wilson, 1983; HPTA, 1999; Sharad *et al.,* 2007). Since Pa Deng is partially located in the national reserved forest and close to the Thai-Myanmar border, the Nong Phlab Agrometeorogical Station was the only representative station of Pa Deng area due to its strategic location and an available of complete climate data. Moreover, other candidate meteorogical stations were located in hill shade areas which might have affected the data. Therefore, since the station is the only station available in the area (Wongpimool, 2009), the Nong Phlab Agrometeorogical Station could be used as a representative meteorogical station. The Penman-Monteith Equation was used to calculate the reference evapotranspiration (ET0) (FAO, 2009). The aridity index was calculated by, firstly, multiplying the crop coefficient (Kc) by ET0 to find the potential evapotranspiration (PET) and then dividing the annual rainfall by the PET for the aridity index result.

The second factor consisted of three indicators; soil composition, soil fertility and soil erosion. The soil composition and the soil fertility were investigated by collecting 59 soil samples from a 1x1 km grid size plot in the study area. However, the soil erosion indicator was investigated based on six factors defined by the Universal Soil Loss Equation (USLE) which evaluated the long-term average annual soil loss from sheet and rill erosion. This is considered a suitable empirical model for estimating soil erosion by water (Wijitkosum, 2012).

The last indicator was associated with land use. The classification of the use of land is much more difficult to quantify (Verburg *et al.,* 2009). However, RS and GIS technology can be integrated to classify and map both land use and land cover data to identify patterns and understand the processes that underlie the observed patterns (Lillesand *et al.,* 2008).

In this study, Landsat-5 TM satellite imagery was imported into the ENVI image processing software and the image geo-referencing accuracy was initially checked with a reference map for the area. Both the RS technique and the field survey were applied to interpret the satellite images taken by the Landsat-5 TM satellite in order to investigate the land use of the study area. The identified land use categories were classified into five types according to the national common system of land use classification: forest area, degraded forest, community and agricultural area, bare land and water bodies.

2.2.2. Analysis of the characteristic of factor identifying the critical factors that affect the desertification

Data gathered from the map of areas at risk of desertification in Pa Deng has been used to analyze the characteristics of desertification factors. The attribute data was used to asses and construct the frequency distribution of different levels of desertification caused by various factors. The results presented different percentages in the form of bar charts. These characteristics were used to analyze critical factors that affect desertification. Then, the attribute data gathered from the map was analyzed in order to profile the factors affecting the desertification using descriptive statistics methods (Ferrara, 2005).

3. Results and Discussion

3.1. Factors affecting the desertification of the Pa Deng Area

The AI ranged from 0.58 to 1.73 which indicated that it had a low or zero impact on the desertification risk in the study area. The result backed up the study conducted by the Land Development Department that an AI higher than 0.65 typically identifies a country located in the tropical zone but are not under the risk of desertification (LDD, 2002) or drought (Chomtha, 2007). Moreover, the study of Wang *et al.,* (2003) also indicated that it is difficult to conclude that the rainfall and the aridity index are keys factors for desertification. Even though the potential evaporation was increased, it could not be implied as a primary cause of desertification.

Most of the study area (85% of the total area) was slope complex with slopes exceeding 35%. The dominant soil textures in the plain area were loamy sand. Soil samplings were collected from the study area and examined in a laboratory. The results indicated that the soil had a moderate level of fertility and a low level of available phosphorus (1.0 to 1,240.0 mg/kg), but had a high level of exchangeable potassium (20.0 to 740.0 mg/kg), magnesium (7.0 to 400.0 mg/kg) and calcium (40.0 to 4,400.0 mg/kg) and a moderate level of organic matters (0.52 to 4.57 mg/kg). The results were compared with a soil laboratory analysis standard set by the Land Development Department and Department of Environmental Quality Promotion. The soil organic matter and the soil texture influence the water holding capacity of the soil. The effect pronounced itself when the fine texture was coupled with an appreciable amount of organic soil matter (Adamu *et al.,* 2012). Therefore, the soil texture and soil fertility carried a low level impact on the desertification risk.

The land was classified into five categories: forest (84.65% of total area), agriculture (14.91%), community area (0.23%), bare land (0.11%) and water bodies (0.11%) accordingly (Wijitkosum, 2012). The agricultural and community areas were located on the central plain which was found to be at a very high risk of soil erosion (>12,500,000 kg/km^2/yr) (Wijitkosum, 2012). The factors that affected the desertification in the area are shown in Fig. 2.

Taking all factors in consideration, the assessment showed that majority of the plain area of Pa Deng was at a moderate risk of desertification. However, due to the high risk of soil erosion from inappropriate agricultural practices and the lack of implementation of soil conservation measures in the area, the desertification in Pa Deng has a potential to be more severe (Wijitkosum *et al.,* 2013). The desertification of an area begins when certain land components have been brought beyond their specific thresholds and these changes may be irreversible (Tucker *et al.,* 1991; Nicholson *et al.,* 1995). Many methodologies developed for combating desertification were designed at regional and global scales. Methods such as mathematical models, parametric equations, remote sensing, direct observation and measurements were invented to combat desertification. Recently, models for assessing

Table 1. Risk level of factors affecting desertification

Risk level	Description
Aridity Index: AI	
None	> 1
Very low	0.65 - 1.00
Low	0.50 - 0.65
Moderate	0.20 - 0.50
High	0.05 - 0.20
Very high	< 0.05
Soil texture	
None	Watershed
Very low	Buildings and community area
Low	Clay and loam
Moderate	Shallow soils and organic soils
High	Sandy loam
Very high	Sand or soil on slope complex
Soil fertility	
None	Low fertility at 5-6 points
Very low	Low fertility at 8-7 points
Low	Moderate fertility at 9-10 points
Moderate	Moderate fertility at 11-12 points
High	High fertility at 13-14 points
Very high	High fertility at 15 points
Land use	
None	Watershed
Very low	Evergreen forest > 70% Rice field > 70%
Low	Mixed rice paddy 50% Fruit trees and perennial plants 50%
Moderate	Natural grasslands
High	Field crops and other areas 50%
Very high	Field crops > 70% Deciduous forest > 70%
Soil erosion	
None	Watershed
Very low	Very low (0-1,250,000 kg/km2/yr.)
Low	Low (1,250,000 - 3,150,000 kg/ km2/yr)
Moderate	Moderate (3,150,000 - 9,400,000 kg/ km2/yr)
High	High (9,400,000 -12,500,000 kg/ km2/yr)
Very high	Very high (>> 12,500,000 kg/ km2/yr)

Source: Adapted from LDD, 2004 and Sepehr et al., 2007

desertification and land degradation have been presented (Sepehr *et al.,* 2007). Among these models, the MEADALUS model was the most suitable for assessing desertification risk in Asian regions. It provided clear results able to effectively analyze areas at risk of desertification (Gholam *et al.,* 2006; Rangzan *et al.,* 2008; Farajzadeh *et al.,* 2007). In Thailand, most desertification studies focus on the overall areas and takes in specific data such as drought index, soil erosion and the loss of forest (LDD, 2003), but spatial analysis was not widely conducted. Since each part of the country has its own spatial characteristics, Thailand

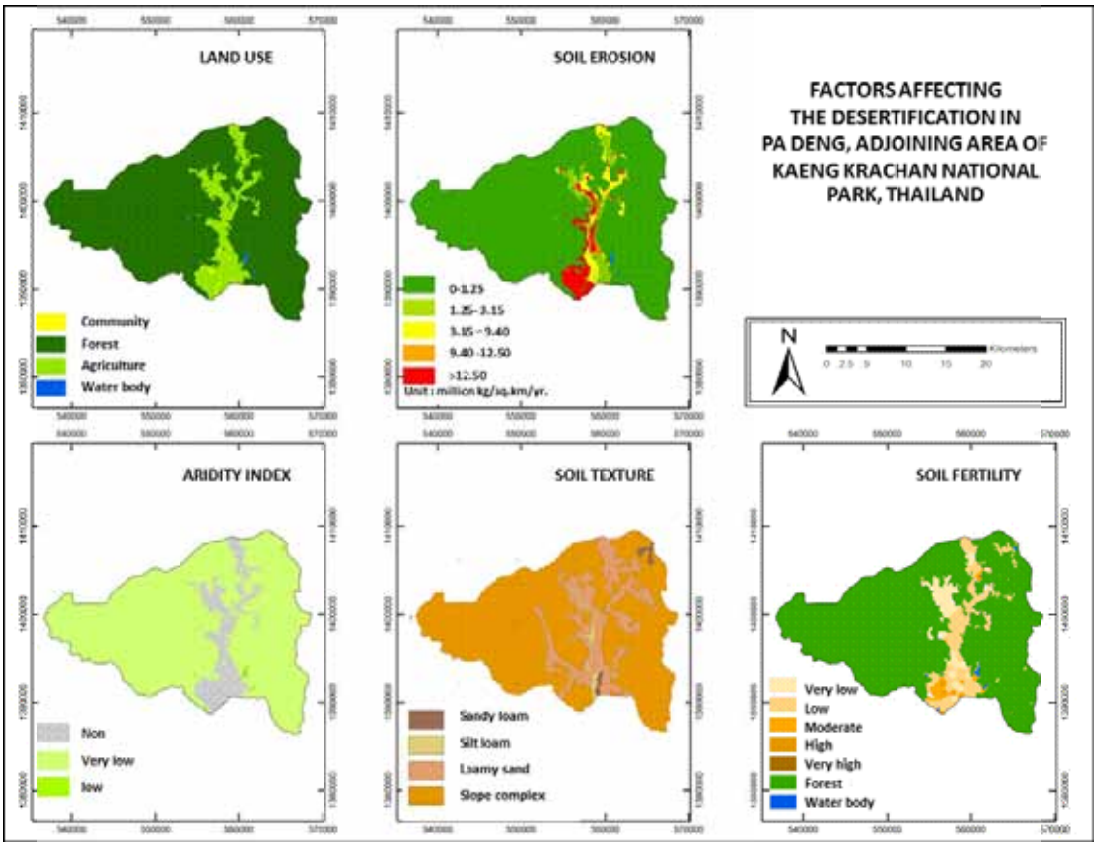

Figure 2. Factors that affect the desertification in the Pa Deng area

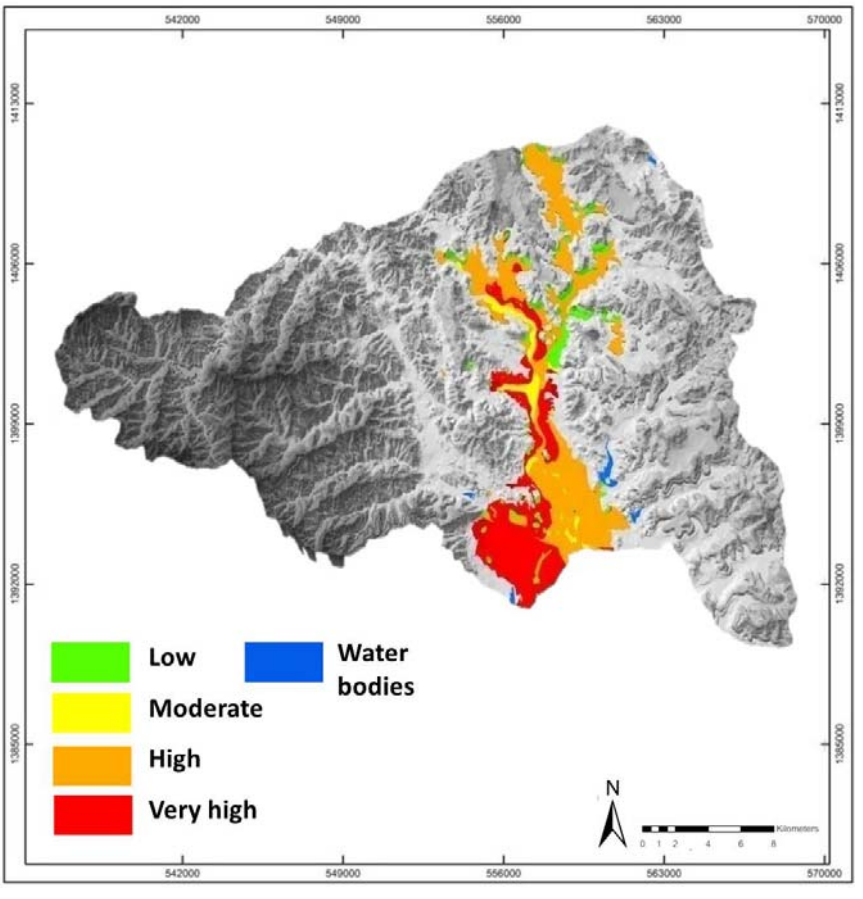

Figure 3. Desertification risk area in the Pa Deng central plain

should focus more on the development of research on spatial analysis. The spatial characteristics in Thailand ranges from environmental factors, soil quality to land use activities. These factors greatly affect the characteristics of the problems caused by desertification and should be thoroughly studied.

3.2. Critical factors that influence desertification

The characteristics showed that each factor influenced the desertification causes differently (Fig. 4). The soil erosion factor had different levels of effect from a very low level (Level 1; 1.00) to a serious level (Level 5; 5.00), but most areas in the Pa Deng area were at moderate (Level 3; 3.00) and serious level (Level 5). Moreover, the land use factor only had a moderate effect (Level 3; 3.00) on the desertification, while the climatic factor had no effect (0.00). Both the soil texture factor and the soil fertility factor had low level effects (1.00) on the desertification in the Pa Deng area.

From the characteristics, the data showed that soil erosion from the changes in land use in the area was the main factor that affected the desertification. A previous study showed that changes in size and pattern of the land use influenced the soil erosion risk in the area during the 1990-2010 periods. From the study, the area with a smaller land cover clearly showed a higher risk of soil erosion than the area with larger land cover (Wijitkosum, 2012). From the desertification risk assessment in the Pa Deng area, the results showed that the study area can be divided into three desertification zones according to the desertification risk levels; low risk zones, moderate risk zones and high risk zones as shown in the following bar charts. The data gathered

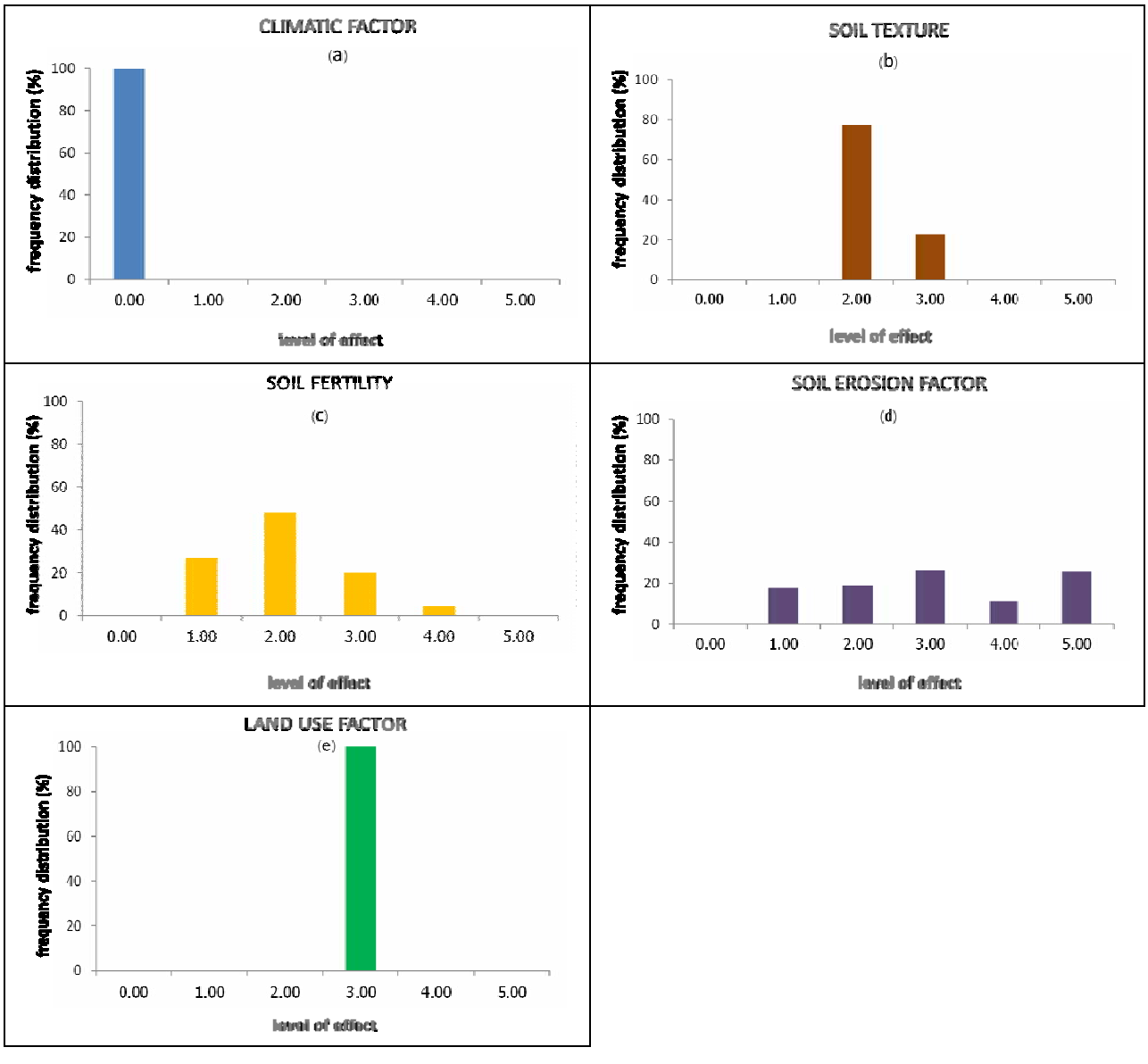

Figure 4. Characteristics of factors that affect the desertification in the Pa Deng area

from these three zones were collected and analyzed to find the characteristics of the critical factors which set them apart (Fig. 5 to 7)

From Fig. 5, the characteristics of factors that affected the low risk zone was the land use factor (Fig. 5(e); 3.00) which had a moderate risk effect on the area. Thus, the graph showed that the climatic factor had no effect on the desertification risk while the soil texture, soil fertility and soil erosion had a low effect on the risk.

Fig. 6 showed that characteristics of critical factors that affected the desertification in the moderate risk zone. Fig. 6(e) showed that the land use factor was the critical factor that affected the desertification (Level 3; 3.00). Thus, the climatic factor had no effect on the desertification, while the soil texture and soil fertility had a low effect and soil erosion had moderate effect.

The characteristics of critical factors that affected the desertification in the high risk zone were shown in Fig. 7. The soil erosion (Fig. 7(d)) had a very high effect (Level 5; 5.00) on the desertification. However, while the climatic factor had no effect on the desertification, the soil texture, soil fertility and land use had a moderate effect.

The cause of desertification was a combination of factors that changed over time and vary by location (MEA, 2005; Wang *et al.,* 2006; Xue, 2009). The soil erosion was a critical factor that had an effect on the desertification risk of the Pa Deng area. The high risk of soil erosion is a possible cause for land degradation and desertification (Dregne, 1986; Abahussain *et al.,* 2002; Wang *et al.,* 2006; Cantón *et al.,* 2009; Ravi *et al.,* 2010; Kairis *et al.,* 2013) because soil erosion is removing topsoil (Abahussain *et al.,* 2002; Yan *et al.,* 2008) and decreasing nutrient and soil fertility (Bauer *et al.,* 1994) as well as porosity (Ebeid *et al.,* 1995). Moreover, the changing of land use affects the intensity of runoff soil erosion (Wang *et al.,* 2005; Cebecauer *et al.,* 2008; Garcia-Ruiz, 2010). This is a result of the forest areas being converted into monocropping plots which have reduced and have destroyed both the land cover and the vegetation cover. Moreover, the agriculturists in the areas did not follow the soil conservation

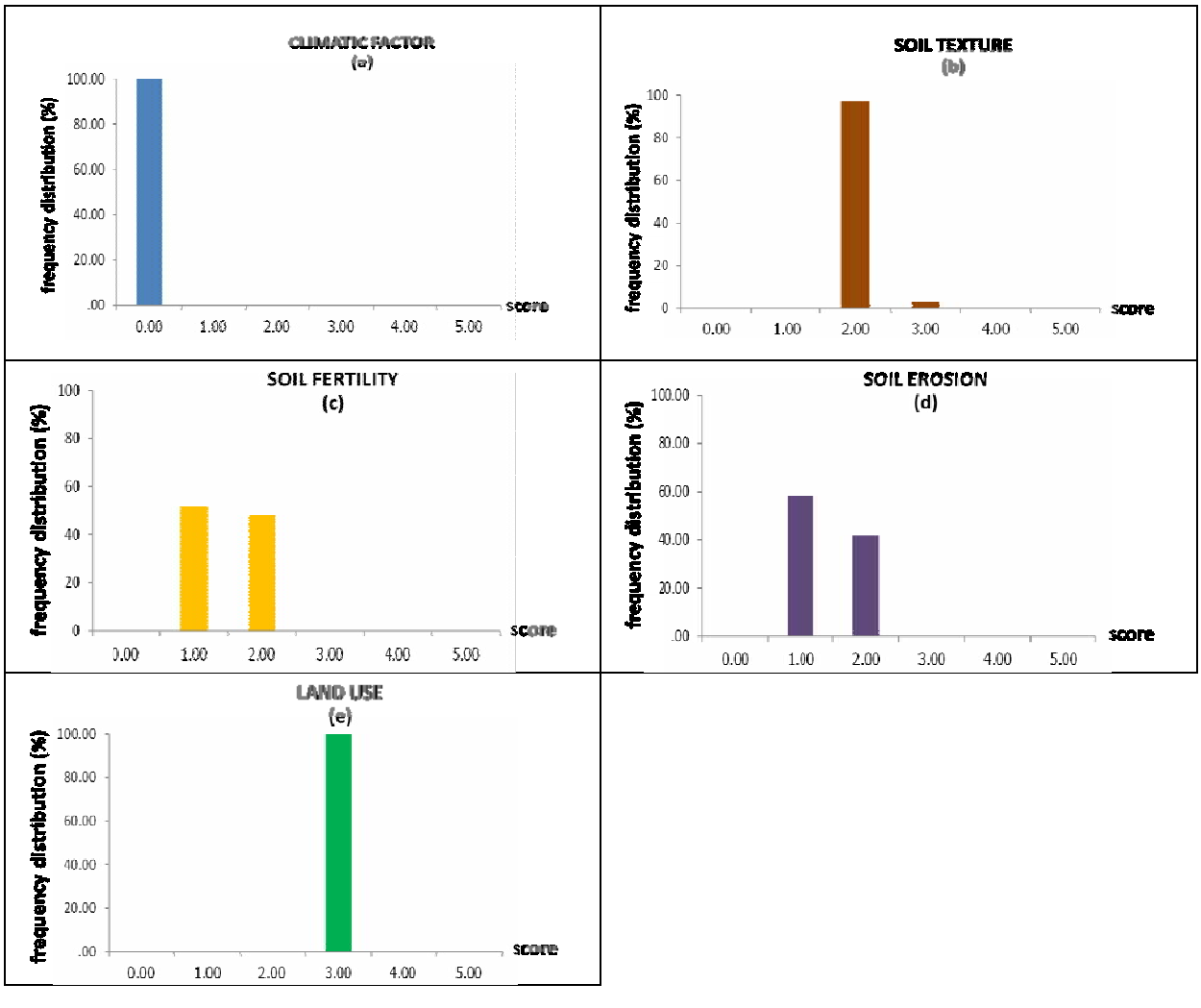

Figure 5. Characteristics of factors affecting the low desertification risk zone

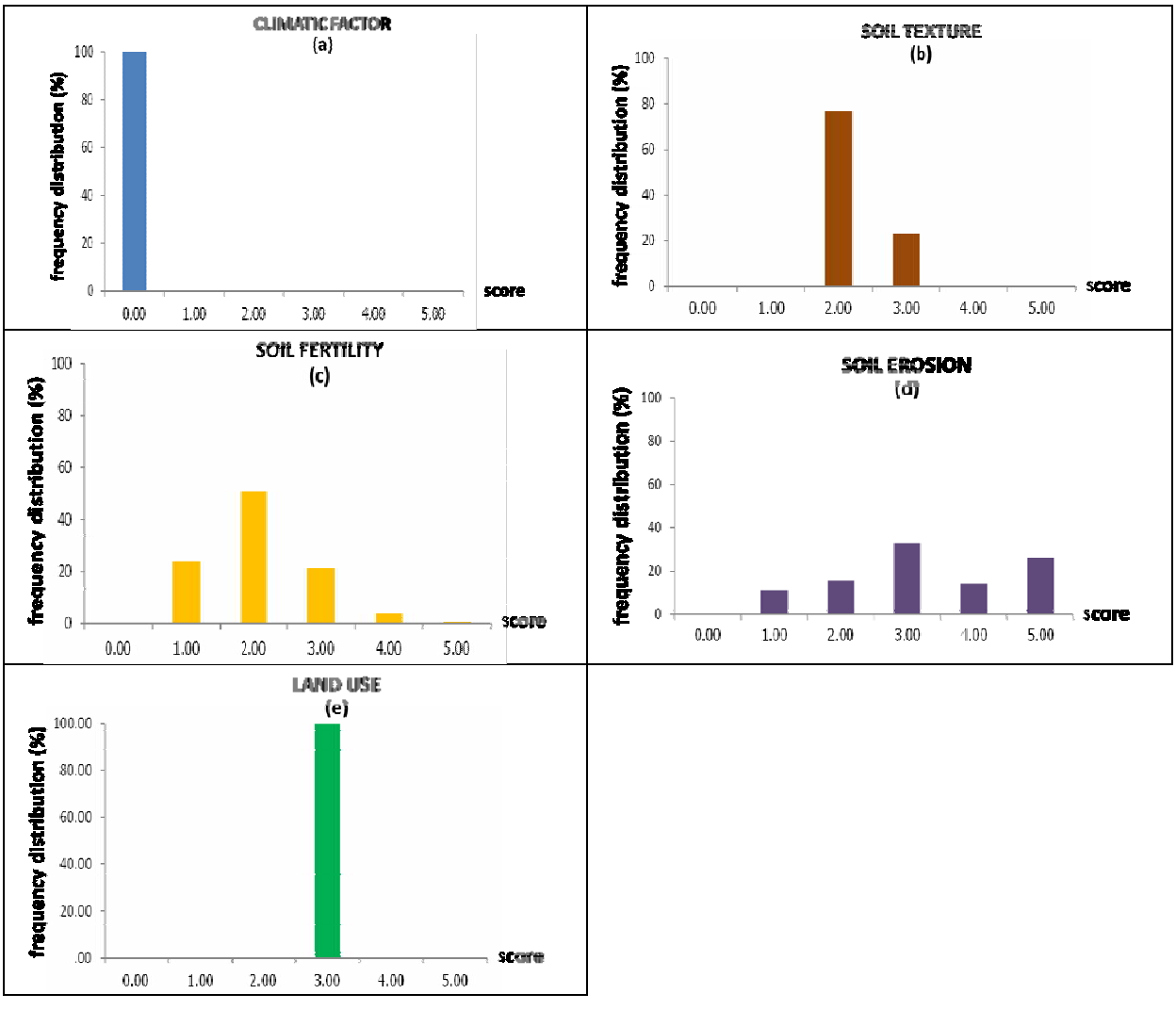

Figure 6. Characteristics of factors affecting the moderate desertification risk zone

measures closely which resulted in a high rate of soil erosion (Wijitkosum, 2012) that might have further affected the causes of desertification.

4. Conclusions

Desertification is a multifaceted issue caused by a variety of climatic factors and human activities which needs to be examined from various aspects (UNEP, 1992; FAO, 1993; Wallace, 1994; Gray, 1999; Warren, 2002; Chen and Tang, 2005). Many studies have identified human as a key factor of causing desertification in many parts of Asia (Zhu *et al.,* 1981; Sun, 2000; Chen and Tang, 2005; Wang *et al.,* 2006) despite the fact that it may be triggered by both human activities and natural causes. In Pa Deng, the majority of the plain area (9.14% of the total area) was at a moderate risk of desertification due to the soil erosion problems. Using US and GIS techniques along with a mathematical model may provide variations on the location and the severity of the degradation within a region, but it does not reveal what caused the desertification (Ellis *et al.,* 2002). Based on each individual situation and its severity, different methods should be employed to prevent and solve the problems. This proves the significance of spatial research on desertification. Analyzing critical factors that affect the risk of desertification, the results showed that soil erosion was the critical factor that affects the desertification in Pa Deng area. In Thailand, soil erosion by water has been considered as one of the primary causes of land degradation due to loss of surface soil and plant nutrients (LDD, 2000). However, this study revealed that the land use factor is another key factor that contributed to the soil erosion problem in the area (Wijitkosum, 2012). The land use factor refers to changes in the ways men utilize the natural resources including overgrazing, land clearing, overcropping, cultivating marginal lands and using a land in an inappropriate way for its local conditions (Abahussain *et al.,* 2002; Zhou *et al.,* 2008;

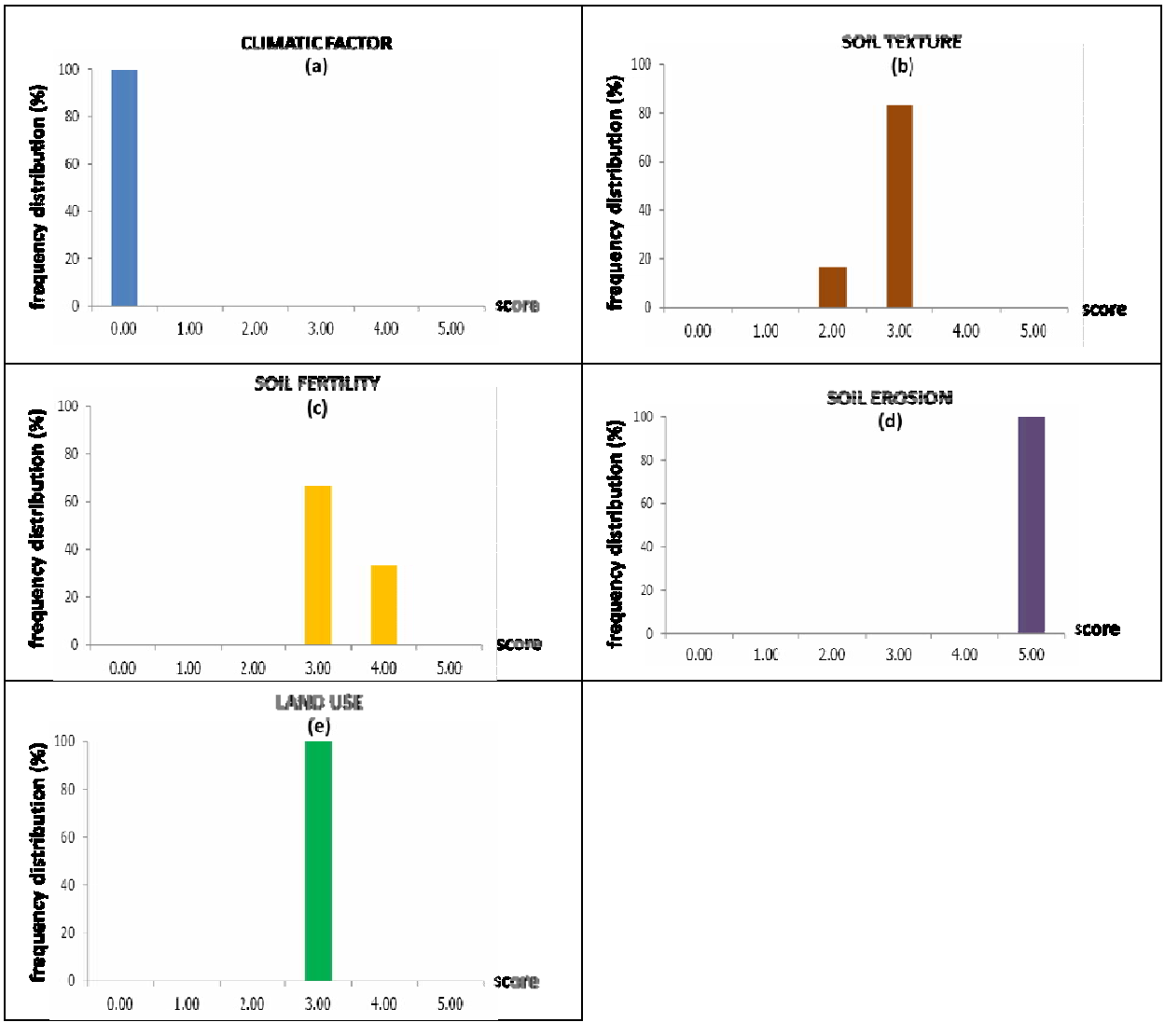

Figure 7. Characteristics of factors affecting the high desertification risk zone

Mohammad and Adam, 2010). The results obtained will be used for planning mitigation measure to cope with the soil erosion problems in the study area. Moreover, the mitigation measures for the desertification in the Pa Deng area should also include the monitoring of land use. In order to prevent the soil erosion both mechanical measures and agronomic measures should be taken into account including contour cultivation, tied riding, bedding and terracing, cover cropping, mulching, intercropping and vetiver grass growing. These mitigations are highly recommended for the agricultural area (Wijitkosum, 2012).

The implementation of soil conservation measures has not been widely applied in Thailand due to the shortage of well-trained man power and financial support. However, since the spatial study of the Pa Deng area was conducted under the project of Huay Sai Royal Development Study Centre, the results of this study will be forwarded to the Huay Sai Royal Development Study Centre and relevant agencies as resources for the establishment and the implementation of soil conservation measures and management of land use.

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