DESERTIFICATION ASSESSMENT USING MEDALUS MODEL
IN UPPER LAMCHIENGKRAI WATERSHED, THAILAND

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ABSTRACT:

Desertification is a global environmental problem. It affects harmful on economic, social and environmental that ultimately effects on quality of human life. Thailand is the 174th member of the UNCCD, according to the Thailand report of desertification by LDD (2004). It was found that the area of degraded land or desertification land in Thailand was 33.57 million hectares which were agricultural soil problem. Soil erosion and soil salinity are major problems for agricultural soil in Thailand. Thus, to prevent and fix such problems, assessment and evaluation of soil properties are essential. Lamchiengkrai watershed in Nakhon Ratchasima province presents soil salinity exposure area which is a major problem in the Northeast region of Thailand. This study aims to access a new approach for assessing the extent and the risk of desertification land by MEDALUS model based on geoinformatics technology in upper Lamchiengkrai watershed, Nakhon Ratchasima province. MEDALUS model is the factors of desertification assessment. Four groups of factors were examined, including vegetation (fire risk, erosion protection, and drought resistance), climatic (rainfall and rainfall erosivity), soil (soil texture, electrical conductivity, organic matter, soil depth, drainage, and slope), and human activity factor (land use and soil erosion). The results of the study indicated that 67.25% of the area was classified as high risk, 30.54% was classified as moderate risk and 2.22% was classified as low risk to desertification land. In addition, the factors affected on the high-risk area were climate and vegetation factors. Moderate risk area was influenced by the human activity factor and soil factors.

1. INTRODUTION

Desertification is a global environmental problem (Anuluxtipun, 2017). It has harmful impacts on economic, social and environmental that ultimately affect human sustenance and quality of life. 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; Wijitkosum, 2016). According to the definition of the United Nations Convention to Combat Desertification, Thailand is classified as an affected country although it is located in a monsoon climate (LDD, 2004). Thailand is the 174th member of the United Nations Convention to Combat Desertification (UNCCD). According to the Thailand report of desertification by LDD (2004), it was found that the area of degraded land or desertification land in Thailand was 33.57 million hectares of problem soils for agriculture. Anuluxtipun (2017) stated that 6.93 Million rai of the area in Thailand (2.17%) severely impact of desertification in Thailand. The causes of desertification are 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 the local population (Hai et al., 2013). The unsustainable land use may lead to soil degradation which is known as desertification (Núñez et al., 2012; Cebecauer et al.,2008). LDD (2004) stated that the major causes of desertification found in Thailand are: (a) climatic

factors (heavy rain during the monsoon period dissolves and translocate soil minerals and seasonal drought); (b) human activities (land use without soil improvement, over-exploitation of land, land use on steep slope lands causing soil erosion and expansion of saline soils). Soil erosion and soil salinity are major problems for soils for agriculture in Thailand (Katawatin and Sukchan, 2012). There is numerous techniques has been used for the desertification assessment such as observation and measurement, mathematical models and parametric equations, estimates, remote sensing (RS) and other indicators (Rubio and Bochet, 1998; Ladisa, Todorovic, Liuzzi, 2012). Anuluxtipun (2017) indicated that the desertification in Thailand has been studied to allocate the potential drought hazard areas and early warning for arable land. Consequently, to prevent and fix such problems, Thailand needs implementation. This study aims to study a new approach for assessing the extent and the risk of desertification land by Mediterranean Desertification and Land Use (MEDALUS) based on geoinformatics technology in upper Lamchiengkrai watershed of Nakhon Ratchasima province in Thailand. This area represents the soil salinity exposure area which is major problems in the Northeast region of Thailand. MEDALUS model is the factors of desertification assessment must take in considerations of AGENDA 21 and UNCCD. The Study examined four groups of factors: vegetation (fire risk, erosion protection, and drought resistance), climatic (rainfall and rainfall erosivity), soil (soil texture, electrical conductivity, organic matter, soil depth, drainage, and slope), and human activity factor (land use and soil erosion) for evaluation.

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2. MATERIALS AND METHODS

2.1 Study Area

The study area was a part of Upper Lamchiengkrai watershed which originated from the mountainous area in Bamnet Narong district, Chaiyaphum province. It locates in Nakhon Ratchasima province. The study area covered the area of 464.96 sq. km. (Figure 1).
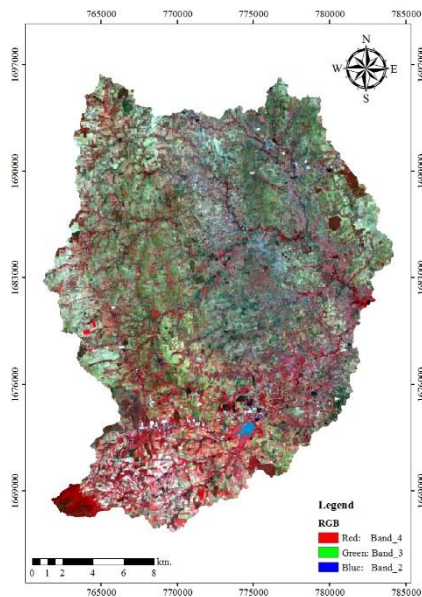

Figure 1. Landsat 8 data of the study area

2.2 Scope of the study

1. Land use and land cover data in 2015 are extracted from Landsat data, spectral indices, and bio-physical factors based on an optimum decision tree with CRT algorithm and based on the study of Plaiklang (2017).

2. Soil erosion, soil salinity and organic matter content in this study are based on the study of Plaiklang (2017).

2.3 Limitations of this study

This study utilizes available spatial and non-spatial data for desertification assessment. Thus, the accuracy of desertification assessment depends on the accuracies of the available data.

2.4 Research methodology

We use the methodbased on the original model of MEDALUS, developed in a large project established by the European Commission (Faraizadeh and Eqbal, 2007). The MEDALUS is one of the most widely used models in monitoring desertification sensitivity. Several studies were based on it, especially in Euro-Mediterranean countries. In Thailand, which was less numerous, were conducted to assess desertification, namely these of Wijitkosum on the premises of the Huay Sai Royal Development Study Centre, in Petchaburi (Wijitkosum, 2016), and Anuluxtipun used the similar model for Thailand (Anuluxtipun, 2017).

The MEDALUS identifies the environmentally sensitive areas and involves soil, vegetation, climate, and human activity indicators. Each indicator is represented by an index which is calculated by the combination of sub-indexes. The output map corresponds to desertification sensitivity areas (Benabderrahmane and Chenchouni, 2010).

Research methodology was designed to serve the main objectives of the research included (1) data collection and preparation, (2) to assess soil quality index (SQI), (3) to assess vegetation quality index (VQI), (4) to assess climate quality index (VQI), (5) to assess human activity quality index (HQI), and (6) to assess desertification risk.
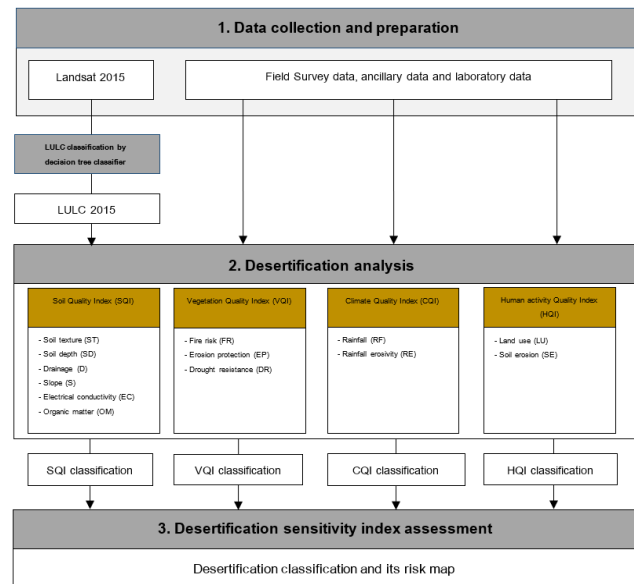

Figure 2. Workflow diagram of the research methodology.

Component 1: Data Collection and Preparation
In this study, we used data set included remotely sensed data, GIS data and field survey data. We used equipment for soil survey included soil core, GPS and digital camera.

Component 2: Desertification analysis
1. Soil Quality Index Assessment
Soil quality index (SQI) contained six correlated parameters: soil texture (ST), soil depth (SD), drainage (DR), slope (S), electrical conductivity (EC), and organic matter content (OM), was processed by using ESRI ArcGIS environment (Figure 13). The parameters are linked with drought and desertification. The soil is the important factor which can be related to water availability, erosion resistance and capacity to sustain the growth and maintenance of vegetation. Also, the slope is a crucial factor in the processes of soil erosion (Kosmas, Ferrara, Briasouli, and Imeson, 1999).
The algebraic expression reflecting the effect of soil factor is given by Equation (1):

$$SQI = (ST * SD * DR * S * EC * OM)^{1/5} \qquad (1)$$

Where SQI is the soil quality index; ST is the soil texture, SD is the soil depth (SD), D is the drainage (DR), S is the slope, EC is the electrical conductivity, and OM is the organic matter content.

The sub-indexes ST, SD, and D were created from soil series map of LDD in 1999. Slope parameter was derived from a digital elevation model of USGS in 2014. EC and OM data were created from previous studies of Plaiklang (2017). All the variables correspond to weights (Table1) and are dimensionless.

(2) Vegetation Quality Index Assessment

The VQI was assessed in three aspects: Fire risk, Erosion protection, Drought resistance. The algebraic expression reflecting the effect of vegetation indicators is given by Equation (2):

$$VQI = (FR * EP * DR)\ 1/3 \qquad (2)$$

Where VQI is the vegetation quality index; FR is the fire risk, EP is the erosion protection, and DR is the drought resistance.

The sub-indexes all parameters were created by land use 2015 and correspond to weights (Table 1).

(3) Climate Quality Index Assessment

The CQI in the MEDALUS model was aimed to assess water availability at the plantation. Two parameters were used to access CQI: rainfall and rainfall erosivity. The algebraic expression reflecting the effect of climate indicators is given by Equation (2):

$$CQI = (RF * RE)\ 1/2 \qquad (3)$$

Where CQI is the climate-quality index; RF is the rainfall and RE is the rainfall erosivity.

The sub-indexes the rainfall was created by surface interpolation from mean rainfall data of TMD in 2015. The rainfall erosivity was derived from rainfall erosivity equation. All the parameters correspond to weights (Table 1).

(4) Human Activity Quality Index Assessment

The HQI was assessed in two aspects: land use and soil erosion. Soil erosion in the study areas was caused by human activities which affected land use and management.

$$HQI = (LU * SE)\ 1/2 \qquad (4)$$

Where HQI is the human activities quality index; LU is the land use and SE are the soil erosion.

The sub-indexes all parameters were generated from ancillary data of previous studies of Plaiklang (2017) and all parameters correspond to weights (Table 1).

Component 3: Desertification Sensitivity Index Assessment

In this section, multiple indicators (SQI, COI, VQI, and HQI) were combined using the multiplicative method for soil degradation evaluation. In this section, the quality indices were computed and employed in the GIS model for computing the DSI and for mapping the desertification sensitivity map. The Desertification Sensitivity Index (DSI) assessment was computed as a function of the SQI, CQI, VQI, and HQI as shown in Eq. (5):

$$DSI = (SQI * COI * VQI * HQI)\ 1/4 \qquad (5)$$

The mapping of the desertification sensitivity map was analyzed by integrating the analyses of both spatial and attribute data. Integration, management, and processing of data were performed using processing under ESRI ArcGIS environment. The scoring and classification categories of the indices for mapping are shown in Table 2. The severity of desertification was classified as high severe, severe, moderate or low severe (Wijitkosum, 2016; Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007). Based on the estimated DSI values, the classes of desertification sensitivity in the area can be shown in Table 3.

Indictors	parameters	Description	Classes	Weight	Reference
Soil	Texture	Good	L, SCL, SL, LS, CL	1	Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim, 2017
		Moderate	SC, SIL, SICL	1.2	
		Poor	Si, C, SiC	1.6	
		Very poor	S	2	
	Slope (%)	Very gentle to flat	<6	1	Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim, 2017
		Gentle	6–18	1.2	
		Steep	18–35	1.5	
		Very steep	>35	2	
	Soil depth (cm)		>75	1	Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim, 2017
			30-75	1.2	
			15-30	1.6	
			<15	2	
	Drainage	Well-drained		1	Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim, 2017
		Imperfectly drained		1.2	
		Poorly drained		2	
	Electrical conductivity (EC)	Very low	<4	1	Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007
		Low	4–8	1.2	
		Moderate	8–16	1.4	
		Almost high	16-32	1.6	
		High	32-64	1.8	
		Very high	>64	2	
	Organic matter (OM)	Very good	>3	1	Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim, 2017
		Good	2-3	1.2	
		Moderate	1-2	1.5	
		Poor	0.5-1	1.7	
		Very poor	<1	2	
Climate	Rainfall		<280	2	Tavares et al, 2015
			280-650	1.8	
			650-1000	1.5	
			>1000	1	
	Rainfall erosovity		>160	2	Tavares et al, 2015
			121-160	1.8	
			91-120	1.7	
			60-90	1.5	
			<60	1	
Vegetation	Fire risk	Low	Bare land	1	Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007
		Moderate	Annual agricultural crops, cereals and annual grasslands	1.5	
		High	Gardens and orchards, evergreen rangelands	2	
	Erosion protection	Very low	Bare land	2	Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007
		Low	Annual agricultural crops, cereals, and annual grasslands	1.6	
		Moderate	Permanent grasslands and rangelands	1.3	
		High	Gardens and orchards, evergreen rangelands	1	
	Drought resistance	Very low	Bare land	2	Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007
		Low	Annual agricultural crops, cereals, and annual grasslands	1.6	
		Moderate	Permanent grasslands and rangelands	1.3	
		High	Gardens and orchards, evergreen rangelands	1	
Human activity	Water erosion	Very low	1	1	Sepehr, Hassanli, Ekhtesasi, and Jamali, 2007
		Low	2	1.2	
		Moderate	3	1.5	
		High	4	1.7	
		Very high	5	2	
	Land use		Water Bodies, Built-up land, Evergreen / Semi-evergreen forest, Littoral/Swamp/Mangrove	1	Salunkhe, Bera, Rao, Venkataraman, Raj and Murthy, 2018
			Deciduous forest	1.3	
			Degraded forest	1.4	
			Grassland & grazing land, Plantation / Orchard	1.5	
			Double/Triple crop land	1.6	
			Scrub land	1.7	
			Kharif only, Rabi only, Zaid only (crop lands)	1.8	
			Current fallow land, Shifting cultivation	1.9	
			Rann, Other waste lands, Gullies/Ravines	2	

Table 1. Classes and assigned weighting index for parameters

Indicators	Sub indicators (layers)	Quantitative	Qualitative	Class
Soil quality	Texture Slope (%) Soil depth (cm) Drainage Electrical conductivity (EC) Organic matter (OM)	< 1.13 1.13–1.45 > 1.46	Low Medium High	S1 S2 S3
Climate quality	Rainfall Rainfall erosivity	1 1.1–1.5 1.6–2	Low Medium High	C1 (Humid) C2 (Semi-arid) C3 (Arid)
Vegetation quality	Fire Risk Erosion protection Drought resistance	< 1.13 1.13–1.38 > 1.38	Low Medium High	V1 V2 V3
Human activity quality	Water erosion Land use	1 1-1.4 1.4-2	Low Medium High	H1 H2 H3

Table 2. Quantitative scores and qualitative classes of considered indicators (indices)

Class	DSI	Sensitivity area to desertification	Risk
1	1.00-1.22	Low	Low
2	1.23-1.37	Moderate	Moderate
3	1.38-1.53	High	High
4	1.54-2.00	Very high	Severe

Table 3. Ranges and classes of desertification sensitivity index (DSI) (Wijitkosum, 2016).

3. RESULTS AND DISCUSSION

3.1 Data Collection and Preparation

Remotely sensed data and bio-physical data were collected and prepared for analysis and modelling and are shown in Table 4. In this study, Landsat 8 data, Path 129 and Row 49, acquired date 9 March 2015 was downloaded from the USGS website (www.earthexplorer.usgs.gov).

Data collection	Data Preparation	Source	Year
Landsat data: Path 129 Row 49	Completeness checking	USGS	9 March 2015
Administrative boundary	Completeness checking	DEQP	2011
DEM	Completeness checking	USGS	2014
Slope	Extract from DEM	USGS	2014
Soil series	Completeness checking	LDD	1999
Soil texture	Completeness checking	LDD	1999
Soil depth	Completeness checking	LDD	1999
Soil drainage	Completeness checking	LDD	1999
Rainfall	Surface interpolation	TMD	2015
Rainfall erosivity	Derive from rainfall erosivity equation		2015
Fire risk	Create from Land use		2015
Erosion protection	Create from Land use		2015
Drought resistance	Create from Land use		2015
Land use and land cover	Previous studies of Plaiklang (2017)		2017
Electrical conductivity (EC)	Previous studies of Plaiklang (2017)		2017
Organic matter (OM)	Previous studies of Plaiklang (2017)		2017

Table 4. List of data collection and preparation

3.2 Soil Quality Index Assessment and its severity

The result of the soil quality index and its severity in 2015 with the MEDALUS model is further reclassified its severity as suggestion by Wijitkosum (2016); Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim (2017); Sepehr, Hassanli, Ekhtesasi, and Jamali, (2007) as shown in Figure 4 while area and percentage of soil quality index classification is summarized in Table 5. As a result, the dominant soil quality index classes in the study area are low and it covers an area of 332.02 sq. km or about 71.41% of the total study area. Besides, the soil quality assessment in this study is similar to the previous work of Wijitkosum (2016), who applied the soil texture and the soil fertility factors for soil quality index assessment and both the soil texture factor and the soil fertility factor had low-level effects on the desertification risk in the Pa Deng area.
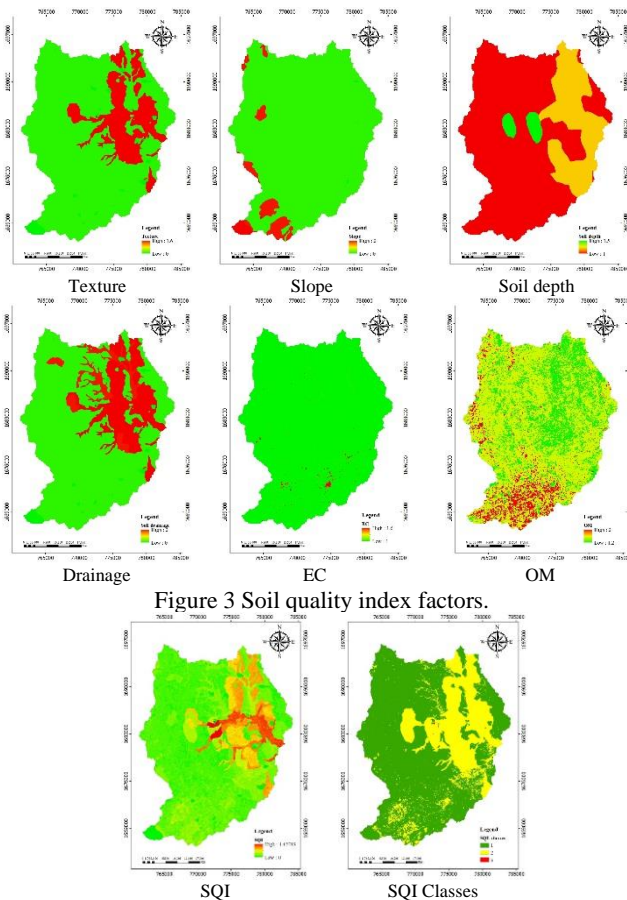

Figure 3 Soil quality index factors.

Figure 4 The distribution of soil quality index classification.

Indicators	Sub-indicators (layers)	Range	Class	SQI classes	Sq.km.	%
Soil quality	Texture	< 1.13	S1	Low	332.02	71.41
	Slope (%)					
	Soil depth (cm)	1.13–1.45	S2	Moderate	132.86	28.57
	Drainage					
	Electrical conductivity (EC)	> 1.46	S3	High	0.08	0.02
	Organic matter (OM)					

Table 5. Quantitative scores and qualitative classes

of soil indicators.

3.3 Vegetation Quality Index Assessment and its severity

As a result, it was found that vegetation quality index and its severity in 2015 with MEDALUS model is further reclassified its severity as a suggestion by Sepehr, Hassanli, Ekhtesasi, and Jamali (2007) as shown in Figure 6 while area and percentage of vegetation quality index classification are summarized in Table 6. The dominant vegetation quality index classes are high risk and it covers an area of 419.38 sq. km or about 90.20% of the total study area. In addition, the vegetation quality assessment in this study is similar with the previous work of Boudjemline and Semar (2018) who applied the erosion protection, fire risk, drought resistance, and plant cover factors for vegetation quality index assessment and all factors had high-level effects on the desertification risk the mostly area of the basin of Hodna in Algeria (35.26%).

Indicators	Sub-indicators (layers)	Range	Class	VQI classes	Sq.km.	%
Vegetation quality	Fire Risk	< 1.13	V1	Low	0.00	0.00
	Erosion protection	1.13–1.38	V2	Moderate	45.58	9.80
	Drought resistance	> 1.38	V3	High	419.38	90.20

Table 6. Quantitative scores and qualitative classes of vegetation indicators

Fire risk   Erosion protection   Drought resistance
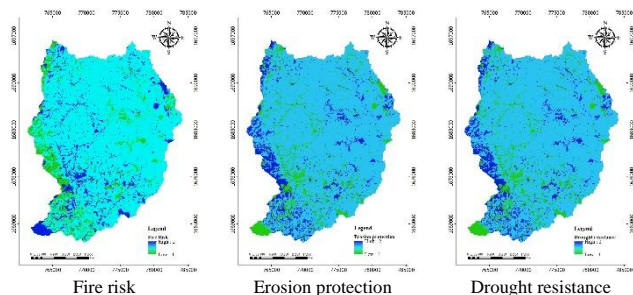Figure 5. Vegetation quality index factors
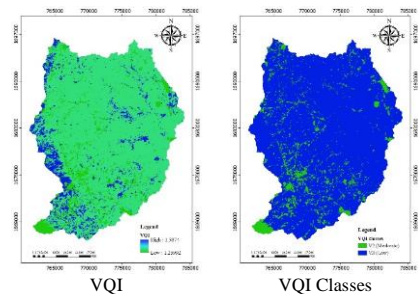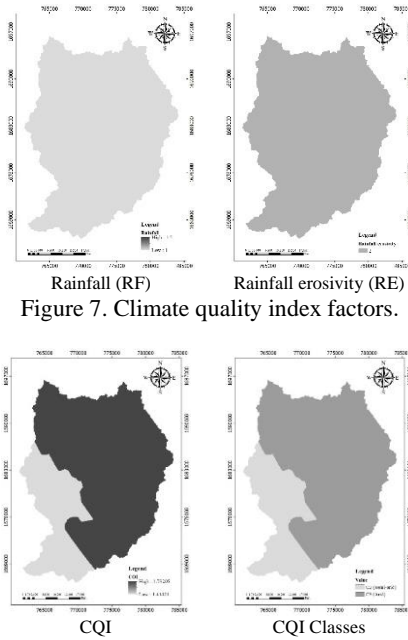

VQI   VQI Classes
Figure 6. The distribution of vegetation quality index classification.

3.4 Climate Quality Index Assessment and its severity

As a result, it appeared that climate quality index and its severity in 2015 with MEDALUS model is further reclassified its severity as a suggestion by Tavares et al (2015) as shown in Figure 8 while area and percentage of climate quality index classification are summarized in Table 7. The dominant climate quality index classes are high risk and it covers an area of 351.16 sq. km or about 75.53% of the total study area. In addition, the climate-quality assessment is similar to the past work of Boudjemline and Semar (2018) who applied the annual precipitation, aridity, field orientation factors for climate-quality index assessment and all factors had high-level effects on the desertification risk the mostly area of the basin of Hodna in Algeria (61.87%).

Indicators	Sub-indicators (layers)	Range	Class	CQI classes	Sq.km.	%
Climate quality	Rainfall	1	C1 (Humid)	Low	0.00	0.00
	Rainfall erosivity	1.1–1.5	C2 (Semi-arid)	Moderate	113.80	24.47
		1.6–2	C3 (Arid)	High	351.16	75.53

Table 7. Quantitative scores and qualitative classes
of climate indicators.

Rainfall (RF) Rainfall erosivity (RE)

Figure 7. Climate quality index factors.

CQI CQI Classes

Figure 8. The distribution of climate quality index classification.

3.5 Human Activity Quality Index Assessment and its severity

As a result, it was noted that human activity quality index and its severity in 2015 with the MEDALUS model is further reclassified its severity as suggestion by Sepehr, Hassanli, Ekhtesasi, and Jamali (2007); Wijitkosum (2016); Salunkhe, Bera, Rao, Venkataraman, Raj and Murthy (2018) as shown in Figure 10 while area and percentage of human activity quality index classification is summarized in Table 8. The dominant human activity quality index classes are high risk and it covers an area of 438.49 sq. km or about 94.31% of the total study area. In addition, the human activity quality assessment is similar to the previous work of Lahlaoi, Rhinane, Hilali, Lahssini, and Moukrim (2017) who applied the grazing, the population density, and the conservation practices for human activity quality index assessment and all factors had moderately level effects on the desertification risk of the mostly area of Oued El Maleh watershed in Morocco (71.22%).

Indicators	Sub indicators(layers)	Range	Class	HQI classes	Sq.km.	%
Human activity quality	Water erosion	1	H1	Low	23.49	5.05
	Land use	1- 1.4	H2	Moderate	438.49	94.31
		1.4-2	H3	High	2.98	0.64

Table 8. Quantitative scores and qualitative classes
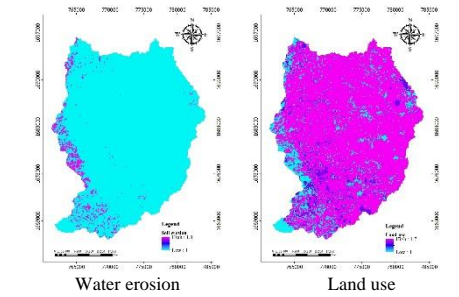of Human activity quality indicators.

Water erosion Land use

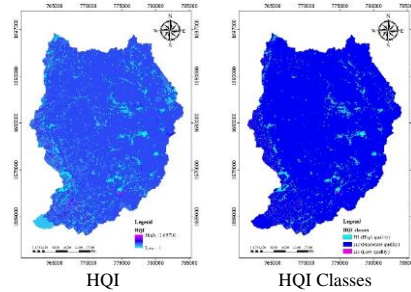Figure 9. Human activity quality index factors

HQI HQI Classes

Figure 10. The distribution of human activity index classification

3.5 Desertification Sensitivity Index Assessment

The study of the desertification risk in the study area, classified the severity of the desertification risk into three levels: low; moderate; high risk. The derived desertification risk is further classified its severity according to Wijitkosum (2016) as shown in Figure 11. The area and percentage of desertification sensitivity index classification are presented in Table 9.
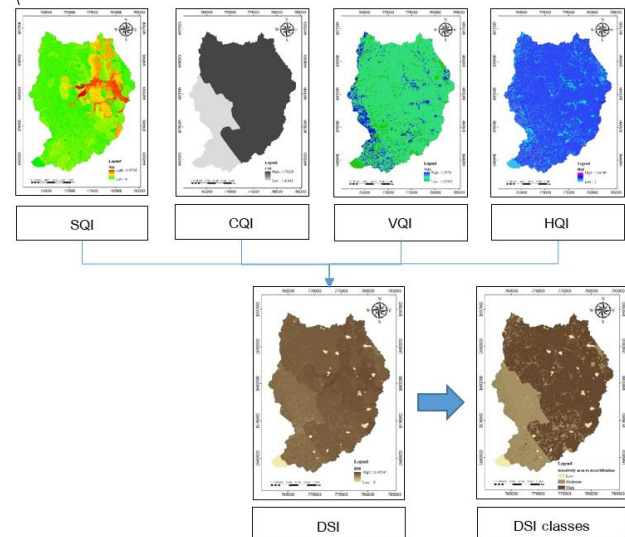

SQI CQI VQI HQI

DSI DSI classes

Figure 11. the distribution of desertification sensitivity index classification.

Class	DSI	Sensitivity area to desertification (Risk)	Sq.km.	%
1	1.00-1.22	Low	10.24	2.20
2	1.23-1.37	Moderate	143.85	30.94
3	1.38-1.53	High	310.86	66.86
		Total	464.96	100.00

Table 9. Severity classes of desertification sensitivity index (DSI)

4. CONCLUSIONS

Desertification is an irreversible process of soil degradation. It impacts on economic, social and environmental that ultimately affects human sustenance and quality of life.
The methodology is based on the use of the MEDALUS model. The model includes four factors; soil, vegetation, climate, and human activity. Each factor is assessed by the combination of sub-factors first and then combined to assess desertification classes and its risk.

The study findings indicate that 67.25% of the area is classified as high-risk, 30.54% as moderate risk and 2.22% as lowly affected by desertification land. In addition, the high risk area is affected by the climate factors (75.53%) and vegetation factors (71.41%) and 94.31% of the human activity factor is classified as moderately affected and 71.41% of the soil factors are classified as moderately affected by desertification area in this study.

In conclusion, it appears that application of geoinformatics technology can be used as an efficient tool to assess soil quality index and its severity, to assess vegetation quality index and its severity, to assess climate quality index and its severity, to assess human activity quality index and its severity, for desertification risk area assessment. It can save cost, time, and quickly assess data. It is expected that the approach will greatly benefit to another area which faces similar desertification risk area problems.

5. RECOMMENDATION

Many objectives were here investigated and implemented, the possibly expected recommendations could be made for further studies as following.
(1) For the MEDALUS model, some input factors of the MEDALUS model were acquired from the literature review. Therefore, more field measurement is recommended for the input factors in order to achieve the realistic model results and it should validate the model from data collection of the field.
(2) Desertification risk assessment should be tested in another area that faces similar desertification risk problems for verification and validation of the method.

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