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Desertification Assessment Using MEDALUS Method and GIS Techniques in North America Arid Environments

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THE UNIVERSITY OF NEW HAVEN

DESERTIFICATION ASSESSMENT USING MEDALUS METHOD AND GIS TECHNIQUES IN NORTH AMERICA ARID ENVIRONMENTS

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Desertification Assessment Using MEDALUS Method and GIS Techniques in North America Arid Environments

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ABSTRACT

Desertification is a massive issue that affects many countries that have dry climates. The impacts of this phenomenon threaten the sustainability of natural resources, as well as agricultural, water, and food resources. Several factors that affect directly or indirectly desertification and making it worse are population growth, climate change, deforestation, overgrazing, natural disaster, and urbanization and other types of land development. This thesis research evaluated the desertification index in three counties in California State and three counties in New Mexico State by using the MEDALUS model (Mediterranean Desertification and Land Use) within a geographic information system (GIS). The model includes four indices that can affect desertification: soil quality, climate quality, vegetation quality, and management quality. For each quality index, several parameters were identified. For instance, soil quality index has five parameters that are slope, depth, organic matter, texture, and drainage. Each of these parameters is quantified according to MEDALUS method by giving them a sensitivity coefficient. Then the quality index obtained by combination of parameters.

The final results, assessed with the proposed Land Desertification Sensitivity Index by using the MEDALUS method (based on 14 sub-indicators), showed that approximately 82% of the total study areas are critically sensitive to desertification, mainly due to aridity index, precipitation, fire risk, and land use in California counties, while in New Mexico the critical factors were organic matters, aridity index, precipitation, and land use. From the results it is clear that the MEDALUS method was appropriate to apply to study areas. In addition, this study suggests that the maps of ESAs can represent a valuable tool to promote and orientate effective policies of desertification mitigation and prevention.

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CHAPTER I

INTRODUCTION

Desertification is the process of land degradation in arid, semi-arid, and sub humid areas. Desertification occurs when the land that was originally one type of biome changes into a desert biome due to overgrazing, deforestation, farming practices, urbanization and land development, climate change, and natural disasters. Desertification has become a significant issue throughout the world occurring in almost in every country that has dry environments (Adeel et al., 2005).

Deserts are formed naturally through climactic processes, and can also become non-desert areas due to climate changes as well ("Desert," 2012). Due to climate change, low or no rainfall land loses its moisture and become dry or barren example of arid plains in north of Cape Town (Momirovic et al., 2018). Due desertification is not caused due to nature; it is caused by human alteration of environments and landscapes often due to unplanned consequences of human activity, negligence, and ignorance of nature's law. Desertification is the process in which land quality deteriorates; fertile land becomes arid desert, not suitable for vegetation (Bouhata & Kalla, 2014).

Desertification occurs due to many reasons including, drought, deforestation, wildfires, soil erosion, over usage of natural resources like land, surface water and groundwater, and over grazing of vegetation by livestock (Pravalie et al., 2017). In addition, deterioration of the land increased due to the increase of population, places to live, and food demands. All these factors can promote desertification. Another factor affecting desertification are inappropriate methods of agriculture and irrigation leading to loss of natural vegetation and thereby diminishing quality of soil (Capozzi et al., 2018).

Desertification is a warning signal of global change, and is an environmental concern for the whole world. It has affected over 168 countries of the world (UNCCD). Desertification impact is mainly on Tropical Islands and humid areas of Deliblato Sands, Serbia (Kadovic et al., 2016). The most affected are African and Asian countries, and specifically in North Africa, Egypt, Morocco, Algeria and Libya (Sepher et al., 2007). Among Asian countries the include China, Mongolia, Pakistan, Kazakhstan and India. 70% of Africa is barren land and 30% of North America is arid land, with about 40% of the whole continental United States at desertification risk (Lamqadem et al., 2018). One of the main impacts of desertification if active measures are not taken to improve the situation is by 2050 parts of many countries will not be suitable for the habitats as it is drastically affecting the flora and fauna across the globe. Furthermore, approximately, 12 hectare of land becomes deserted globally every year (Pravalie et al., 2017). Many economic, social and political initiatives a taken by nations to improve the conditions leading to and the impacts of desertification. For example, in 1994 the United Nations Convention to Combat Desertification (UNCCD) was established. Parties to the Convention work together to maintain and restore land and soil productivity, and to mitigate the impacts of drought in drylands — the arid, semi-arid and dry sub-humid areas (Martin F, 2015). 192 countries discussed desertification which was declared by UNCCD as a critical global challenge in Rio, in the 12th session of conference of parties held in Turkey (Kadovic et al., 2016).

Aubréville (1949) first used the word desertification. The United Nations Convention to Combat Desertification (UNCCD) defined desertification as ‘land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities’ (Sepher et al., 2007). Also, land degradation can be defined as ‘the reduction or loss of biological or economic productivity (Capozzi et al., 2018).

The Sahel region in eastern Africa is probably the area on earth that is most affected by global warming. The temperature there is very high, with low or no rainfall and an overall dry climate. The average high temperatures are generally between 36 and 42 °C and the average annual precipitation between 100- and 200-mm. Desertification has affected Africa to a great extent leaving lot of land not suitable for agriculture (Kadovic et al., 2016).

The Great Plains of the United States experienced desertification in the 1930's. Known as the Dust Bowl, it was the result of drought and poor farming practices. After the damage of the Dust Bowl, the U.S recognized desertification as a national issue and the government began supporting and educating farmers to reduce the amount of soil loss and to improve irrigation ("Desertification," 1997). Catastrophic dust storms eroded soil leading to poor visibility and causing medical conditions affecting people with lungs diseases most of the people left their farms on the Great Plains and moved towards west (Pravalie et al., 2017). Initiative taken by USA includes establishing soil conservation service (SCS), providing funds and allocating resources to improve agricultural practices and thereby reducing soil erosion and reeling upon renewable energy sources (Momirovic et al., 2018). To achieve this mission, they got support from federal agencies and non-governmental organizations.

Measures taken by developing countries includes a low-cost land restoration technique known as Farmer-managed natural regeneration (FMNR). Regeneration and management of trees is done to reduce the impact of extreme climate conditions. Farmers are encouraged to increase food and timber production to meet the increasing demand (Bouhata & Kalla, 2014). Positive results have been seen in efforts in Niger and Ethiopia that financed by World Bank Bio Carbon Fund. Managing gazing can also reduce desertification by allowing new grass to grow from any remaining roots (Lamqadem et al., 2018).

Today, the southwest United States is affected by desertification. Based on soil type and climate data, seventeen states are categorized as arid, dry sub humid, and semi-arid region, at potential risk of desertification without proper management. The most affected areas within the US are located in New Mexico, Texas, Nevada, California, and Arizona. Several studies have noted the recent increases in temperatures, drought, and disappearance of green areas in the southwest part of the U.S and these drought effects are expected to increase in the near future (Dregne, 1986). Furthermore, According to NCEI's report in 2018, large parts of Colorado, New Mexico, Arizona, Utah and Oregon experienced drought throughout the vast majority of the year. Smaller parts of northern North Dakota, West Texas and Southern California did as well (Lindsey R, 2019).

California is one of the main agricultural states in the US. With the increasing population and requirements of food, place excessive farming i.e. over cropping and deforestation is happening in California (Pravalie et al., 2017). California has opted for water rationing in order to meet the growing demand for water and the related issue of which share of the water belongs to farmers and industrialists (Frattaruolo et al., 2008). The drought in California is having an impact on people and wildlife (Beaudry F, 2018).

More generally, people migrate in search of livelihood. Due to industrialization and economic reform people are moving toward urban area from dry rural areas due to poverty thereby affecting the economy and the nation that has huge area of desertification (Sobhani et al., 2017).

Limited resources and more food demand had affected the land of California. Cutting woods is affecting the climatic conditions by less rain, not enough water, drought, and reduced level of oxygen all leading towards making California an inhabitable land (Pravalie et al., 2017). If no changes are made in the level of usage of water and protection of environment soon California will become a deserted state with a harsh climate (Momirovic et al., 2018). In the arid climate places due to dryness there are more chances of wildfires causing soot in the air thereby increasing levels of carbon dioxide in the atmosphere and making it more difficult to live for the people suffering with asthma and other respiratory diseases (Sobhani et al., 2017).

Areas near the seven main deserts of the world are most likely to get affected namely the Sonoran Desert in northwest Mexico and southwest USA; the Atacama Desert of South America; the Kalahari Desert, Sahara Desert, Gobi, Taklimakan (Pravalie et al., 2017). The most affected states in the US are New Mexico, Texas, and Arizona along with 17 other states of western United States (Dutta & Chaudhuri, 2015). Based on the studies conducted to understand the soil texture and climate of the US, they found that the arid, semi-arid, and dry regions are more affected by desertification (Lamqadem et al., 2018).

Desertification in the US, has likely been due to improper irrigation methods and agriculture techniques, and overgrazing, which in turn can increase erosion by wind and water (Bouhata & Kalla, 2014). US government has taken corrective measure to this national problem of desertification after the 1930 dust bowl, but increasing temperature are making it hotter in southwest US leading to the drought (Capozzi et al., 2018).

The land loses its water as a result of desertification and the dryness make the land barren and not suitable for agriculture and wildlife. Dry soil blows away with the wind or is washed off by floods, making the soil infertile (Pravalie et al., 2017). The other reasons associated with desertification is change in climatic conditions. Increasing carbon -dioxide concentrations in the atmosphere due to human activities adds to increases in greenhouse gases which cause global warming by trapping heat and other harmful gases in the atmosphere (Frattaruolo, et al., 2008).

A CLUVA (Climate Change and Urban Vulnerability in Africa) project was carried out to study climate change and vulnerability in sub-Saharan African peri-urban areas of Ouagadougou (Burkina Faso) and Saint Louis (Senegal). The purpose of the project was to manage the climatic changes taking place and improving the ways to cope up with the risks within these environmental conditions (Capozzi et al., 2018).

In Senegal, the National Environmental Action Plan (NEAP) highlights the environmental and social crisis, due to accelerated degradation of natural resources under the combined effects of a worsening climate and human pressures (Lahlaoi et al., 2017). The NEAP concluded that desertification on the African continent is due to human activities, overgrazing and over exploitation of resources because of heavy demographic pressure, and lower Aridity index and mean annual rainfall (Frattaruolo et al., 2008).

The factor having direct or indirect impact in making the situation worse such as over exploitation of resources like land and water due to increasing demand of food and shelter (Lahlaoi et al., 2017). People are cutting more and more trees to make homes, and over cropping the land for meeting the food demand, leading to negative impacts on soil quality and reductions in groundwater levels (Capozzi et al., 2018).

Increased air pollution caused by the industries releasing poisonous gases in the atmosphere and because of deforestation not having much trees to absorb the carbon dioxide existing in the environment and for releasing oxygen (Bouhata, Kalla, 2014). More plants need to be planted an initiative has been taken by China as “great green wall” by planting trees. The climatic changes can be slowed down resulting in moderate temperature and increase in rainfall level to solve the underground water problem. All these small changes may have a large impact on tackling global desertification (Momirovic et al., 2018).

The sensitivity of desertification index (SDI) of the study area in southern Italy show that approximately 50% of the study area was moderate sensitivity to desertification where around 4 % of the study area was non-sensitive to desertification (Canora et al., 2014). The Mediterranean Desertification and Land Use (MEDALUS) model along with GIS and remote sensing identifies and maps areas that are at risk for desertification. It provides information to the land managers, government and other stakeholders to make decisions regarding protecting land from further deterioration because of desertification (Sobhani et al., 2017).

The only drawback, which came to highlight of MEDALUS model, is that it requires large geographical databases of different environmental factors, which might not be temporally synchronized to give accurate answers for the calculation of indices and overall sensitivity of the area (Frattaruolo et al., 2008).

In 2005, Dipace and Baldassarre used the MEDALUS method in Tavoliere, Southern Italy which is one of the most sensitive areas to desertification and they obtained good result in that area (Frattaruolo et al., 2009).

The SDI corresponds to weights rather than the physical size. The area with high quality soil, climate, vegetation and well managed quality of land have low sensitivity index compared to the area with poor quality of soil, dry arid climate, less vegetation and over exploited by human activities have high sensitivity index of desertification (Momirovic et al., 2018). With the help of available information and from various tools and models it becomes easier for the authorities to monitor desertification sensitivity and make appropriate decisions (Capozzi et al., 2018).

The EU MEDALUS (Mediterranean Desertification and Land Use) key indicators were used in the sub-Saharan environment, to locate Environmental Sensitive Areas (ESAs) and environmental sensitive areas index were calculated. The ESAI Index is the index in which environmental quality and anthropogenic factors (land management), are included and mapped (Momirovic et al., 2018).

One of the main benefits of the MEDALUS model is that allows for a change in the number of variables to be used for assessing the sensitivity to desertification. For example, in a study conducted in Serbia, they used three parameters for soil quality index, three for climate quality index, tow for management quality index, and three for vegetation quality index (Kadovic et al., 2016). While in another study in Italy, they used six parameters for soil quality index, fore for vegetation quality index, tow for management quality index, and three for climate quality index (Paola F et al., 2013).

Objective of the study:

Research on desertification has been conducted a long time (Kosmas et al. 1999), and many models for desertification assessment have been developed (e.g., Kosmas et al. 1999; Joshiand Solanki 2009; Ajai and Dhinwa 2018). The objective of this work was to adapt the MEDALUS method that considers factors such as soil, climate, vegetation and management indices to identify the sensitivity and vulnerability to desertification within areas of the southwest United States. Although some researchers claim that the MEDALUS method does not include socio-economic variables, such as population density and population growth rate, the MEDALUS method is widely used directly or indirectly in different parts of the world including India, Iran, Egypt, and Morocco to define environmental sensitive areas (ESAs) (e.g., Sepehr et al. 2007; Afifi et al. 2010; Dutta and Chaudhuri 2015). The overall goal of this work will be to study and develop maps of vulnerability to desertification due to using a number of factors as noted Above. The goal of this work was to help decision makers utilize quantitative date to make more informed decisions about environmental policy choices, especially when it comes to reducing the causes and identifying the critical source areas that could increase the risk of the desertification on humans. The MEDALUS method and the GIS techniques used for this research can be effective and replicable because of the reduction in cost and better compared to the continuous field monitoring, particularly in large areas. The research is also novel as the MEDALUS method has not been used before in North America for desertification assessment.

CHAPTER II

MATERIALS AND METHODS

Study Areas

For this research I selected three counties located in the states of California and New Mexico, where there are significant threats in terms of land degradation. The study areas are located in south western California (Ventura county, Los Angeles county, and Kern county) (Fig.1) and north western New Mexico (Bernalillo County, San Juan County, and Sandoval County) (Fig.2). These counties have varying characteristics in land use, soil type, and elevation. According to the 2011 census, The New Mexico State's counties (Bernalillo, San Juan, and Sandoval) had the population of 670968, 128200, and 134259 respective. While the California State's counties (Ventura, Los Angeles, and Kern) had population of 854223, 10163507, and 893119 respectively.

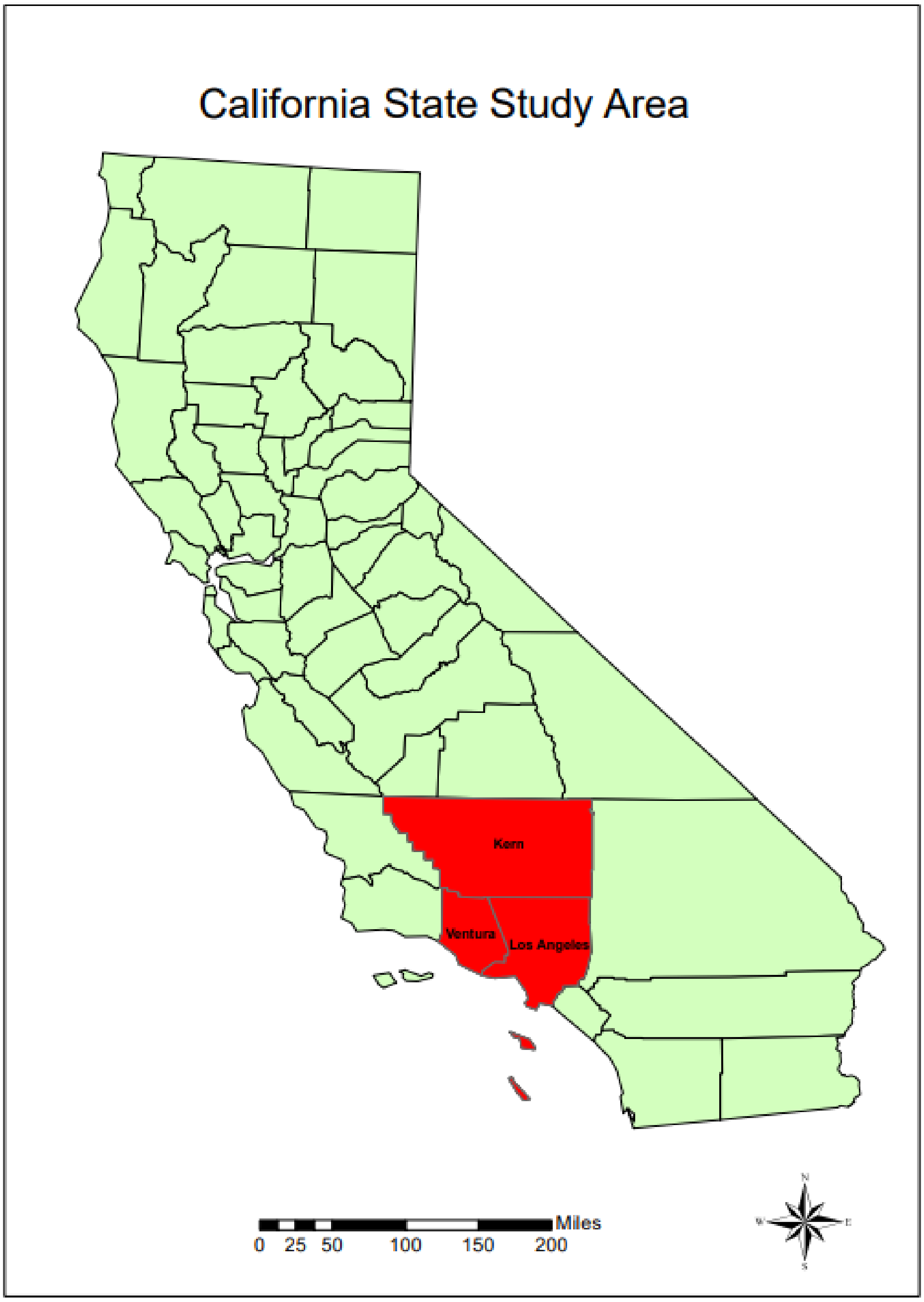

Fig 1. California State study area

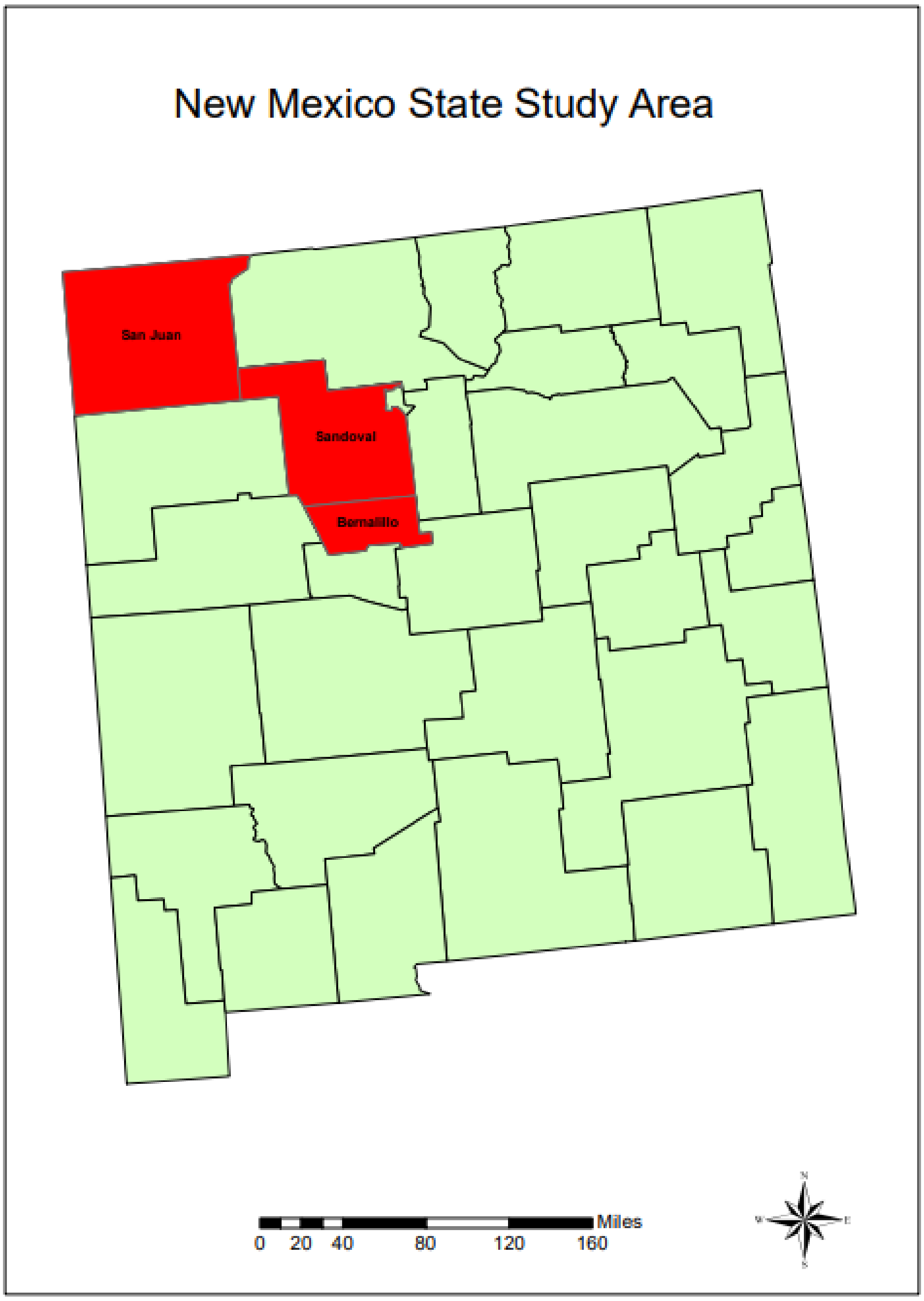

Fig 2. New Mexico State study area.

MEDALUS Method:

The methodology used for this study is based on the original model of MEDALUS that was developed by the European Commission (Dutta and Chaudhuri 2015). MEDALUS is one of the most widely used models in monitoring the sensitivity of land areas for desertification (Afifi et al. 2010). MEDALUS identifies environmentally sensitive areas by assessing factors such as, soil, vegetation, climate, and population size. Each factor is represented by an index that is calculated by the combination of sub-indexes (Afifi et al. 2010). For example, areas with high soil, climate, vegetation quality and effective management have a low sensitivity desertification index. In contrast, areas with low soil, climate, vegetation quality and poor to no land management have a high risk of desertification sensitivity.

After analyzing what desertification means and how it is caused it is very important to understand are there ways to control and analyses the level of desertification. Human beings are responsible for exploiting natural resources more than the rational level. There is continuous degradation of land taking place (Capozzi et al., 2018).

As per the conference of UN held in RIO in the year 1992 due to desertification there is total or partial loss of agricultural land shortage of grazing land because of arid soil and thereby leading to climatic imbalance high temperature less moisture in air and water level going down and hence more deforestation to meet the growing need of land to live due to population explosion, wood for cooking and other purposes which cause disturbance to wildlife and nature (Frattaruolo et al., 2008). Farmers are forced to leave their agricultural land and migrate to urban region in search of living. The chemicals products and sediments coming out of industries are polluting the surface water in the rivers causing water erosion and less production of electricity and energy.

There is a continuous attempt by the scientists to study the reasons and impact of desertification (Sobhani et al., 2017). Many models have been developed and tested. The mostly used model is MEDALUS, which stands for Mediterranean Desertification and land use, recognized by European commission. This modal takes into consideration all the variables such as soil texture, vegetation, climatic conditions, human activities and land management (Momirovic et al., 2018). This modal calculates the environmentally sensitivity of area/ land to desertification. To calculate level of sensitivity they depend upon the GIS means geographical information system techniques. Each variable/ factor is signified by an index, which is calculated with the help off further sub- indexes (Frattaruolo et al., 2008).

Data for the model come from several different sources. Information relating to rainfall, climate (temperature), land use, soil analysis and soil types were collected from the Geospatial Data Gateway and Global Aridity and PET data. The elevation data used in the model was from a digital elevation model (DEM) obtained from the United States Geological Survey agency. Also, I Used GAP/LANDFIRE National Terrestrial Ecosystems data set that provides information on the distribution of native vegetation types, modified and introduced vegetation, developed areas, and agricultural areas of the United States for further analysis regarding the land exposed to desertification based on various indexes. Other types of data which are important for assessing the sensitivity to desertification are population density and human practices such as agriculture and livestock production (Sobhani et al., 2017).

The methodological approach for analyzing and mapping the sensitivity to desertification that was used in this thesis is based on general methodology described by Kosmas et al. (1999), focusing on the identification of Environmentally Sensitive Areas (ESAs) to desertification through the evaluation of an Index of Environmental Sensitivity (ESAs) (Figure 3). The ESAs is determined by the following equation (Kosmas et al. 1999):

$$(ESAs) = (SQI * CQI * VQI * MSQI)^{1/4} \quad (1)$$

Where CQI is climate quality index, SQI is soil quality index, VQI is vegetation cover quality index, and MSQI is the management system quality and human influence index. The data for these four main factors were collected for each study area and inputted into a geographic information system (GIS). Hence, the GIS and model were used as a decision-making tool.

As outlined in Figure .3, each indicator is constructed from several parameters, which are combined to obtain a quality indicator using the general formula:

$$\text{Quality indicator} = (\text{parameter}_1 * \text{parameter}_2 * \text{parameter}_3 \ldots\ldots\ldots * \text{parameter}_n)^{1/n} \quad (2)$$

In this equation each quality indicator is based on parameters that are scored as very high, high, moderate, low or very low, where n is the number of parameters.

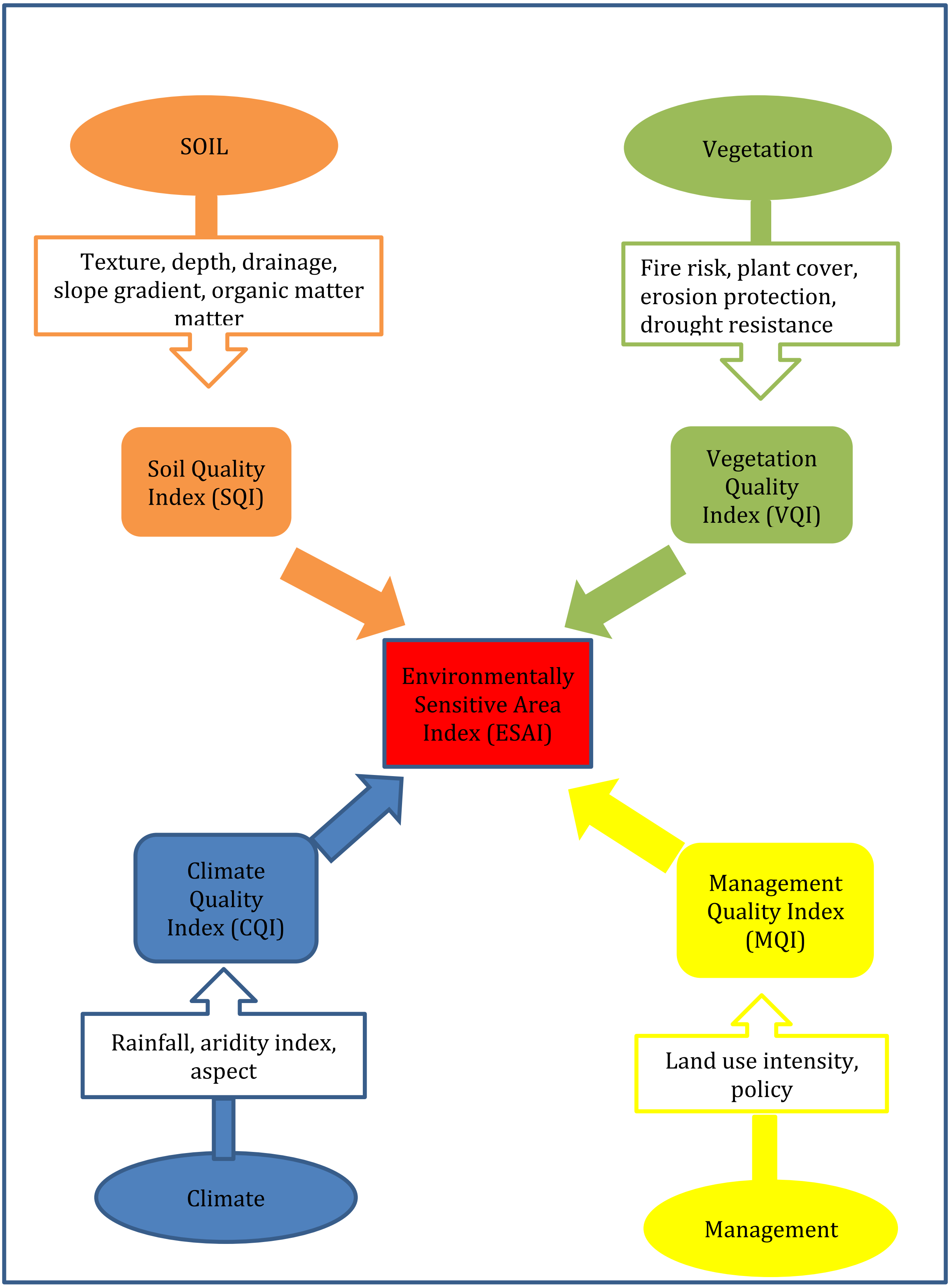

Fig. 3. Flowchart showing the process of developed model.

MEDALUS model indices:

Soil Quality Index (SQI)

Soil is a significant factor in evaluating desertification sensitivity of an ecosystem, especially in areas that are arid or semi-arid. Soil properties related to desertification phenomena affect retention capacity, water storage and erosion resistance (Afifi et al. 2010). The SQI is calculated using an algebraic equation that considers soil texture (sandy, clay), its water retention ability and drainage, slope, organic matter, and depth of the surface horizon. This index is important for knowing the fertility of land and ways of protecting it from climatic changes and harmful agricultural practices (Frattaruolo et al., 2008). The soil index expresses the susceptibility to the fine soil particles to removal via rain, runoff, and the mechanical effect of wind, considering the importance of consistency and relative distribution of soil (Bouhata & Kalla, 2014).

Organic matter is the plant and animal residue in soil at various stages of decomposition. Organic matter affects water-holding capacity, cation-exchange capacity, and is a source of plant nutrients. The content of organic matter typically decreases with soil depth. The estimated content of organic matter is expressed as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The content of organic matter in a soil can be maintained by returning crop residue to the soil. Organic matter has a positive effect on available water capacity, water infiltration, soil organism activity, and source of plant nutrients. It is a source of nitrogen and other nutrients for crops and soil organisms. An irregular distribution of organic carbon with depth may indicate different episodes of soil deposition or soil formation. Soils that are very high in organic matter have poor engineering properties and subside upon drying (Bot & Benites, 2005).

Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. Slope gradient is the difference in elevation between two points, expressed as a percentage of the distance between those points.

"Drainage class (natural)" refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. The drainage may determine which type of plant that grow best in the area. (Soil Drainage, 2005).

I used soil data viewer tool to obtain soil properties such as organic matter, texture, drainage, slope, and depth. This tool provides users access to soil interpretations and soil properties from soil database.

The SQI layer was created according to ESAs model, and it considers a collection of parameters including soil texture, rock fragments, soil depth, parent material, drainage and slope. The soil quality index is given by the following equation:

$$SQI = (T * D * OM * Dr * S)^{(1/5)} \quad (3)$$

Where SQI is the soil quality index; T is the texture (silt, sand, clay); D is the depth of the surface horizon; S: the slope; Dr is the drainage; OM is the organic matter.

Each of these variables is weighted based on its effect quality relative to potential for desertification (Table 1). The soil quality index classification shows on the table (2) that it has three classes (high quality, Moderate quality, and low quality).

Table 1: Classes and corresponding weights of Soil quality. L = loam, SCL = sandy clay loam, SL = sandy loam, LS = loamy sand, CL = clay loam, SC = sandy clay, SiL = silty loam, SiCL = silty clay loam, Si = silt, C = clay, SiC = silty clay, S = sand

Texture	class	Description	Texture	Weight
	1	Good	L, SCL, SL, LS, CL	1
	2	Moderate	SC, SiL, SiCL	1.2
	3	Poor	Si, C, SiC	1.6
	4	Very poor	S	2
Slope	class	Description	Slope (%)	Weight
	1	Very gentle to flat	< 6	1
	2	Gentle	6-18	1.2
	3	Steep	18-35	1.5
	4	Very Steep	≥ 35	2
Drainage	class	Description		Weight
	1	Well drained		1
	2	Imperfectly drained		1.2
	3	Poorly drained		1.6
Soil Depth	class	Description	Soil Depth (cm)	Weight
	1	Deep	≥75	1
	2	Moderate	30-75	2
	3	Shallow	15-30	3
	4	Very Shallow	<15	4
Organic Matter	class	Description	OM (%)	Weight
	1	Good	≥3	1
	2	Moderate	2-3	1.2
	3	Poor	1-2	1.5
	4	Very poor	<1	2

Table 2: Classes of the soil quality with respect to desertification

Soil quality index	Class	Description	Range of SQI
	1	High quality	<1.13
	2	Moderate quality	1.13 – 1.45
	3	Low quality	>1.46

Vegetation Quality Index (VQI):

The vegetation quality index measures the extent and quality of plant cover in an area, which is a key factor in terms of reducing the kinetic energy of rain with respect to erosion and other properties that can affect desertification. Other variables that are considered include fire risk (FR), protection against erosion (PR), drought resistance (DR), and coverage (C) (Capozz et al., 2018). The vegetation quality index (VQI) was calculated using the formula:

$$VQI = (FR * EP * DR * DL)^{(1/4)} \quad (4).$$

Where: VQI is the vegetation quality index; FR is the fire risk; EP is the erosion protection; DR is the drought resistance; C is the coverage. All the variables correspond to weights table (3) and are dimensionless.

Table 3: Classes and weighing indices of parameters used for vegetation quality.

Erosion Protection	class	Description	Type of vegetation	Weight
	1	Very high	Mixed evergreen forests	1
	2	High	Pine forest, Permanent grasslands, evergreen perennial crops	1.3
	3	Moderate,	Deciduous forest	1.6
	4	low	Deciduous perennial agriculture crops	1.8
	5	Very low	Annual agriculture crops	2
Fire Risk	class	Description	Type of vegetation	Weight
	1	low	Bare land, perennial agriculture crops, Annual agriculture crops (maize, tobacco, sunflower).	1
	2	Moderate	Annual agriculture crops (Cereals, grasslands), Deciduous oak, (mixed), Mixed ever green forest., Permanent grasslands, evergreen perennial crops	1.3
	3	High	Mediterranean macchia	
	4	Very high	Pine forests	2
Drought Resistance	class	Description	Type of vegetation	Weight
	1	Very high	Mixed evergreen forests, Mediterranean macchia.	1
	2	High	Deciduous, olives, conifers	1.2
	3	Moderate	Perennial agriculture trees (Vines, almond)	1.4
	4	low	Perennial grasslands	1.7
	5	Very low	Annual agriculture crops, Annual agriculture crops	2
Plant cover	class	Description	Plant cover (%)	Weight
	1	High	>40	1
	2	low	10 – 40	1.2
	3	Very low	<10	1.4

Then the vegetation quality index is classified into three classes as shown in the table (4).

Table 4: Classes of the quality of vegetation with respect to desertification.

Vegetation Quality	class	Description	Range of VQI
	1	High quality	1 - 1.6
	2	High quality	1.7 – 3.7
	3	Low quality	3.8 – 16

Climate Quality Index (CQI):

The climate quality index (CQI) is calculated using information on annual Rainfall (R), evapotranspiration, (AI) for Aridity index (Momirovic et al., 2018). The formula is:

CQI = (RF * AI * A)1/3 (7)

Where CQI is the climate quality index, RF is the rainfall (mm), and A is the aspect.

The climate index significant indicator for the analyzed desertification obtained by using three variables that belong to the MEDALUS framework which they are rainfall, aridity and aspect (Pravalie et al., 2017). The aridity index is calculated by following formula:

AI = P/PET (5)

Where AI is aridity index, P is precipitation (mm), and PET is potential evapotranspiration (mm). The aridity index data is calculated by using ArcMap tools.

Table 5: Classes and weighing indices for climate quality

Rainfall	Class	Description	Rainfall (mm)	Weight
	1	High	>650	1
	2	Moderate	280 - 650	1.5
	3	Low	<280	2
Aridity	Class	Description	Aridity Index	Weight
	1	High	AI ≥ 1	1
	2	Moderate	0.1 < AI < 1	1.5
	3	Low	AI ≤ 0.1	2
Aspect	Class	Description	Aspect	Weight
	1	Low	N, NW, NE, W, flat	1
	2	High	S, SE, SW, E	2

Then the climate quality is classified to three classes (Table 6).

Table 6: Classes of the quality of climate with respect to desertification.

Climate quality index	Class	Description	Range of CQI
	1	High quality	< 1.15
	2	Moderate quality	1.15 – 1.81
	3	Low quality	>1.81

Management Quality Index (MQI):

Human activities have great impact on desertification. The Management Quality index (MQI) considers several types of human activities that impact desertification including grazing by cattle's (G), population density (PD), and conservation practices (CP) (Sobhani et al., 2017).

According to Kosmas et al. (1999), land classifications that can be used to evaluate the management quality index (MQI) are as follows: Land use intensity:

This classified to 5 categories based on the major land:

1- Agriculture land including:
   a- Cropland: It is classified to three classes based on several factors such as types of plant varieties used, application of fertilizers and agrochemicals, frequency of irrigation, etc.
   b- Pastureland: It is classified to three classes based on the ratio of ASR/ SSR. Where the (SSR) is the sustainable stocking rate and the (ASR) is the actual stocking rate.
2- Natural areas including: It is classified to three classes based on the ratio of A/S. Where the A is the actual and the S is sustainable yield.
   a- Forest b- Shrub land c- Bare land
3- Recreation areas such as parks, compact tourism, tourist areas, etc. It is classified to three classes based on the ratio between actual and the permitted number of visitors per year that is A/P.
4- Recreation areas such as parks, compact tourism, tourist areas, etc. It is classified to three classes based on the ratio between actual and the permitted number of visitors per year that is A/P.
5- Infrastructure facilities such as roads, dams, etc.

Policy: the policies that linked to environmental protection are classified based on their degree in which they are enforced for each type of land use.

In terms of land use, the policy on environmental protection and the intensity of land use is assessed. Each type of land use classified to three classes with different ranges (Table 7). The management Quality index (MQI) is computed by using the following formula and then the (MQI) is classified to three classes (Table 8):

$$MQI = (\text{Land use intensity} * \text{Policy enforcement})^{(1/2)} \quad (8)$$

Table 7: Classes and weighing indices of parameters used for land management quality index.

Land use intensity of cropland and recreation areas:

Cropland	Class	Description	Index
	1	Low land use intensity (LLUI)	1
	2	Medium land use intensity (MLUI)	1.5
	3	High land use intensity (HLUI)	2

Recreation Areas	Class	Description	A/P visitor's ratio	Index
	1	Low	>1	1
	2	Moderate	1 – 2.5	1.5
	3	High	>2.5	2

Table 7 (continued): Land use intensity of mining, pasture and natural areas

Mining Areas	Class	Description	Erosion control measurements	Index
	1	Low	Adequate	1
	2	Moderate	Moderate	1.5
	3	High	Low	2
Pasture	Class	Description	Stocking rate	Index
	1	Low	ASR < SSR	1
	2	Moderate	ASR = SSR to 1.5*SSR	1.5
	3	High	ASR > 1.5*SSR	2
Natural Areas	Class	Description	Management characteristics	Index
	1	Low	A/S = 0	1
	2	Moderate	A/S <1	1.2
	3	High	A/S ≥ 1	2

Policy	Class	Description	Degree of enforcement	index
	1	High	Complete: >75% of the area under protection	1
	2	moderate	Partial: 25 - 75% of the area under protection	1.5
	3	low	Incomplete: <25% of the area under protection	2

Table 8: Classes of the quality of management with respect to desertification

Management Quality Index	Class	Description	Range of MQI
	1	High	1 – 1.25
	2	Moderate	1.26 – 1.50
	3	Low	>1.51

Index of Environmentally Sensitive Areas (ESAI):

The index of environmentally sensitive area (ESAI) is calculated by combining SQI, VQI, CQI, and MQI. The value of ESAI lies between 1 and 2 (Capozzi et al., 2018). The final step of the MEDALUS method is that comprises the management quality and the physical environment qualities include soil quality, climate quality, and vegetation quality for various types of ESAS to desertification. The final environmental sensitive area index (ESAI) is calculated by multiplied the four derived indices as the following:

$$ESAI = (SQI * VQI * CQI * MQI)^{(1/4)} \quad (9).$$

The ranges of environmental sensitivity area index for each type of the ESAs (SQI, VQI, CQI, and MQI), including three subclasses in each type that are ranging from 3 which is high sensitivity to 1 which is low sensitivity.

According to Kosmas et al. (1999), the ESAI classified to four main classes which are critical, fragile, Potential affected, and non-affected and are further classification (critical and fragile) into three subtypes in term of sensitivity from high sensitivity to lower sensitivity that are C3, C2, C1 for critical and F3, F2, F1 for fragile as given in table (9).

Table 9: Classification carried out over the range of values of the ESA index (ESAI) used for the maps of environmental sensitivity.

Type	Subtype	Range of ESAI
Critical	C3	>1.53
Critical	C2	1.42 – 1.53
Critical	C1	1.38 – 1.41
Fragile	F3	1.33 – 1.37
Fragile	F2	1.27 – 1.32
Fragile	F1	1.23 – 1.26
Potential	P	1.17 – 1.22
Non-affected	N	<1.17

CHAPTER III

RESULTS AND DISCUSSION

The MEDALUS model was used in the selected counties in New Mexico State and California State for calculating the ESAI to assess current conditions and characteristics of variables that are associated with desertification and the likelihood of this occurring in these counties a Generally, the ESAI is a composite index based on four sub- indices including soil quality index, climate quality index, management quality index, and vegetation quality index. Each index has several parameters that are weighted waited in relation to their effects and contribution to desertification. Each of these indices is classified to three classes of high, moderate, and low. Subsequently they are combined to assess and visualize / map spatially the sensitivity to desertification in a specified area. This chapter I present the results of my analyses for each of the indices individually and then the composite analysis to assess the certification potential within the selected counties in New Mexico and California.

Soil Quality Index (SQI)

For the soil quality index, it was obtained by the overlaying of five soil characteristics that are slope, depth, organic matter, texture, and drainage. Most of them inferred by the GIS from available soils data and using soil data viewer tool.

With reference to the soil depth factor, deeper soils assure a greater water reserve and a sufficient depth to the root system of the plant, providing a widespread vegetation cover especially for plants that has extensive root system. When soil depth is less than 30 cm, generally this may cause an area to be sensitive to erosion. Soil depth in California's counties and New Mexico's counties vary from 4 cm to 200 cm (Tables 10 and 11). In addition, the soil depth California's counties were broken down into 4 classes (deep, moderate, shallow, and very shallow) while the New Mexico's counties had just 3 classes which are deep, moderate, and very shallow. Based on the result, I found that the soil depth of New Mexico's counties does not have shallow class which it ranges between 15 and 30 cm.

One of the main factors that cab influence desertification is soil structure in terms of soil absorbency and the risk of erosion. According to this methodology, Soil in both study areas were assigned a value between 1 which is good and 2 which is very poor. Around 90% of the study are in California in the good quality and more than 95% of the New Mexico' counties in the good quality degree class of soil texture.

Drainage is significant factor to determine the rate at which water infiltrates into the deep soil layers and the distribution of the soil salts. Soils with good drainage are more subject to desertification. This is due to water is removed from soil rapidly while soils with poor drainage are less subject to desertification (Kosmas et al., 1999). Based on the results of drainage, more than 99.5 % of study areas are characterized with good or moderate drainage quality.

The digital elevation models for the study areas yielded 4 classes of slope gradient: Very gentle to flat, Gentle, Steep, and Very Steep as shown in table (10). Erosion increases with increases in slope. In the California counties, 40 % of the area is very gentle to flat, 22.2 % is gentle, 6.2 % is steep, and 40.8 % is very steep. In the New Mexico counties, 36.1 % of the area is very gentle to flat, 22 % is gentle, 10.5 % is steep, and 31.2 is very steep.

Loss of soil by rainfall and surface runoff is one of the significant causes of desertification due to a reduction in organic matter and nutrients in the top soil necessary for plant growth l. Also, this amount of organic matters decreases with increase the soil depth. So, the surface soil has more organic matters than deeper soil. More than 50 % of the area in the California counties contains <1 % organic matter. And more than 69 % of the New

Mexico counties < 1 % organic matter.

For counties in California, more than 75% of the total area had high quality of soils (Figure 4, Table 12). Some parts in the coast and northwestern areas had a low-quality index (about 20% of the total area), and only 4% t was assigned to moderate quality index. The low soil quality index on the coast and in the north can be related to the slope and the fine soil texture as these areas had very steep slopes and were dominated by fine textured soils which promote high drainage. Unlike counties in California, most of the New Mexico counties had a moderate SQI (66%) (Figure 5, Table 13). Only 5% of the total area had high quality soils, and about 26% of the area had low quality soils (Figure 5). Detailed maps of depth, drainage, organic matter, and slope for California and New Mexico are shown Appendix A and Appendix B, respectively.

Table 10: Influences of the sub-indexes and evaluation of the SQI in California counties:

Depth

Class	Descriptions	Depth (cm)	Area (sq mi)	% of total area
1	Deep	> 75	7663.3	54.5
2	Gentle	30 – 75	3164.03	22.5
3	Steep	15 – 30	933.1	6.6
4	Very steep	< 15	2285.1	16.2

Texture

class	Description	Texture	Weight	Area (sq mi)	% of total area
1	Good	L, SCL, SL, LS, CL	1	12631.6	89.9
2	Moderate	SiL, SiCL	1.2	811.3	5.7
3	Poor	C, SiC	1.6	391.8	2.7
4	Very poor	S	2	26.3	0.18

Drainage

Class	Drainage Description	Weight	Area (sq mi)	% of total area
1	Well drained	1	3861.8	27.49
2	Imperfectly drained	1.2	10114.86	72.01
3	Poorly drained	2	68.87	0.49

Table 10 (continued)

Slope

class	Description of slope	Slope (%)	Weight	Area (sq mi)	% of total area
1	Very gentle to flat	< 6	1	4307.2	30.6
2	Gentle	6 - 18	1.2	3118.7	22.2
3	Steep	18-35	1.5	883.4	6.2
4	Very Steep	≥ 35	2	5736.1	40.8

Organic matter

class	Description	OM (%)	Weight	Area (sq mi)	% of total area
1	Good	≥3	1	117.9	0.83
2	Moderate	2-3	1.2	727.3	5.1
3	Poor	1 - 2	1.5	6020	42.7
4	Very poor	<1	2	7181	51.0

Table 11: Influences of the sub-indexes and evaluation of the SQI in New Mexico counties studied: Depth, texture, Drainage, slope, and Organic matter.

Depth

Class	Descriptions	Depth (cm)	Area (sq mi)	% of total area
1	Deep	> 75	6571.5	63.5
2	Gentle	30 - 75	1130.7	10.9
4	Very steep	< 15	2645.9	25.5

Texture

class	Description	Texture	Weight	Area (sq mi)	% of total area
1	Good	L, SL, LS, CL	1	9841.09	95.09
2	Moderate	SiL, SiCL	1.2	265.42	2.56
3	Poor	C	1.6	57.22	0.55
4	Very poor	S	2	184.5	1.78

Drainage

Class	Drainage Description	Weight	Area (sq mi)	% of total area
1	Well drained	1	1385.99	13.39
2	Imperfectly drained	1.2	8960.256	86.58
3	Poorly drained	2	2.00	0.019

Table 11 (continued)

Slope

class	Description of slope	Slope (%)	Weight	Area (sq mi)	% of total area
1	Very gentle to flat	< 6	1	3743.6	36.1
2	Gentle	6 - 18	1.2	2277.1	22.0
3	Steep	18-35	1.5	1094.4	10.5
4	Very Steep	≥ 35	2	3233.0	31.2

Organic matter

class	Description	OM (%)	Weight	Area (sq mi)	% of total area
1	Good	≥3	1	2.40	0.023
2	Moderate	2-3	1.2	80.11	0.77
3	Poor	1 - 2	1.5	3115.02	30.10
4	Very poor	<1	2	7150.71	69.10

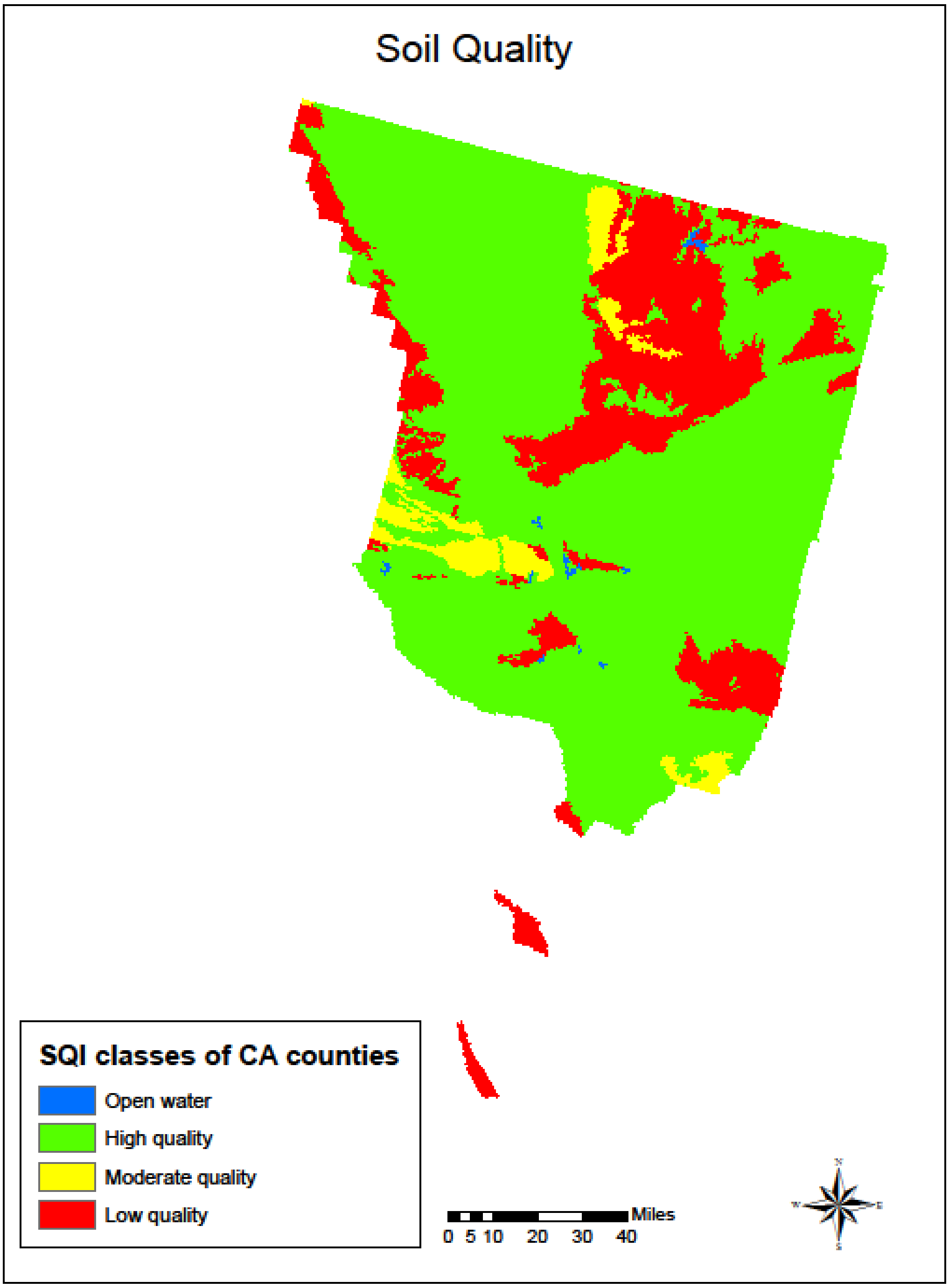

Fig. 4. Soil Quality Index (SQI) of California selected counties. See Tables 1 and 12 for details.

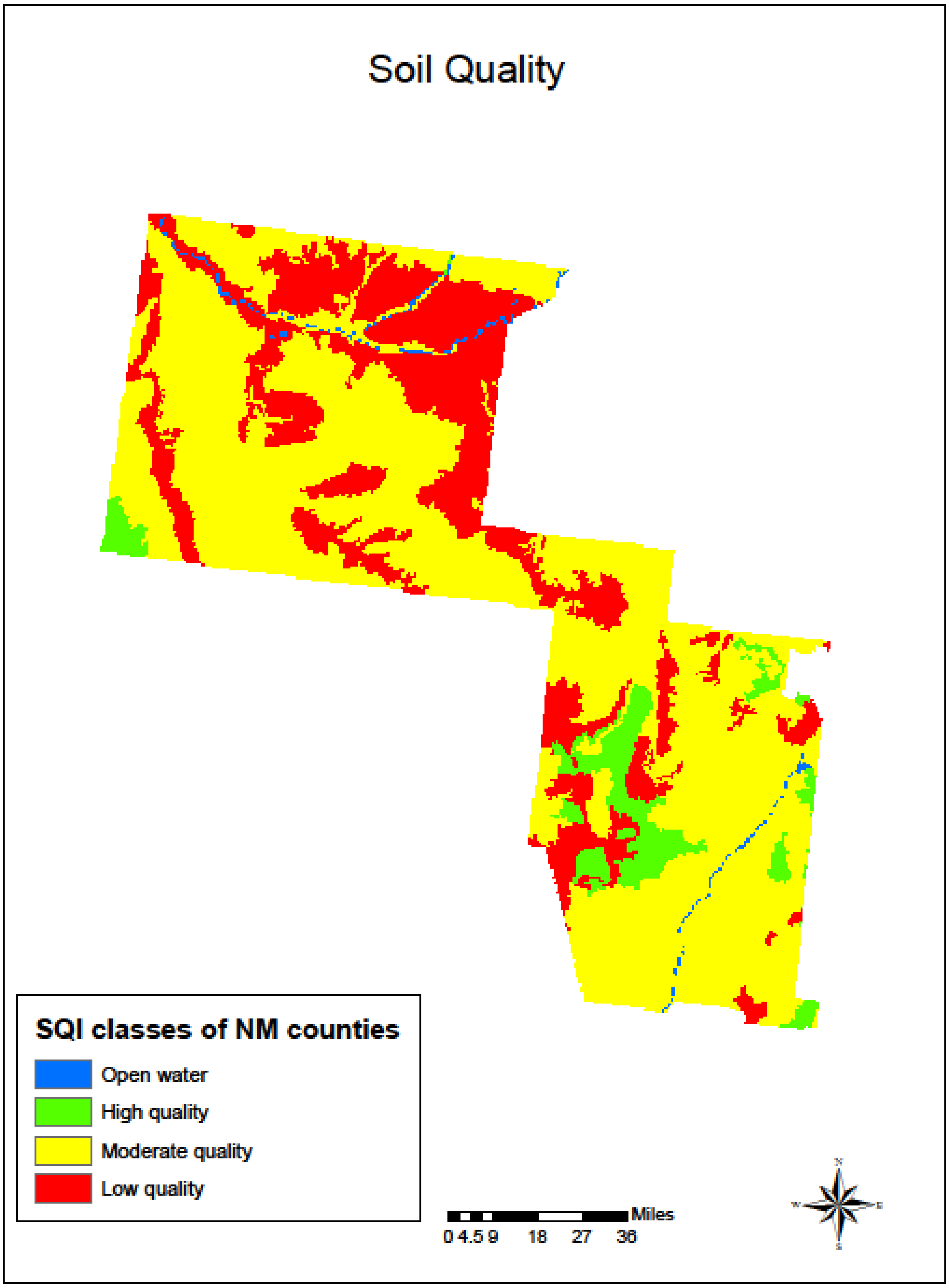

Fig. 5. Soil Quality Index (SQI) of New Mexico selected counties. See Tables 1 and 13 for details.

Table 12: Soil quality distribution in California counties

Class	Description	Range of SQI	Area (sq mi)	% of total area
1	High quality	<1.13	10643.87	75.8
2	Moderate Quality	1.13 – 1.45	576.77	4.10
3	Low quality	>1.46	2824.9	20.1

Table 13: Soil quality distribution in New Mexico counties

Class	Description	Range of SQI	Area (sq mi)	% of total area
1	High quality	<1.13	608.2	5.8
2	Moderate Quality	1.13 – 1.45	6960.6	66.7
3	Low quality	>1.46	2779.2	26.6

Climate Quality Index (CQI)

The CQI was evaluated based on three sub-indices: rainfall, aspect and aridity using climatic and geomorphological data According to Kosmas et al. (1999), the average annual rainfall is a measure of the availability of water. And any Area that have a yearly average rainfall below the threshold of 280 mm, are particularly vulnerable to desertification.

The average annual rainfall in the California counties is between 67 and 1376 mm (Table 14). Moreover, ~ 48% of the area has an average annual rainfall of <280 mm, while approximately 52% of the area is > 280 mm of annual rainfall. Similarly, most of the areas in New Mexico counties (72.3%) have an annual rainfall < 280 mm (Table 15). Related to rainfall is aridity which integrates rainfall and temperature (Trabucco & Zomer, 2018). Low rainfall and high temperature lead to reductions in soil moisture and available water for the growth and development of vegetation. The aridity index ranged between 0.0236 – 0.5557 in California Counties and between 0.1005 – 0.6842. In New Mexico counties

The Aspect factor was derived from the DEM of the catchment by using GIS. The slope aspect classified based on this method as N, NE, NW, W, and flat areas faces = 1 while, S, SE, SW, E =2. According to Kosmas et al. (1999), slopes exposed to south and west generally have a higher amount of solar energy and are characterized by a smaller absorbency than those exposed to North and to East, with resulting slower vegetative growth and higher erosion rates.

Figures 6 and 7 show the resulting climatic quality index map for the study areas in California and New Mexico. For California, it was clear that a great part of the total area was characterized by moderate climate quality (56 %). About 43% of the total area was characterized by low quality index and just 0.003 % of the area was high quality. Unlike counties in California, most of the study area in New Mexico was characterized by low climate quality (74 %). More than 25 % of the area was characterized by moderate climate quality and around 0.8% had high climate quality. This is can be explained by the fact that New Mexico receives very low annual rainfall (Appendix A, Figure A-5). Based on these results, CQI in both study areas suggests that climactic conditions can potentially have an important impact on desertification in these areas.

Tables 14 and 15 show classes and corresponding weights of precipitation in both study areas (California and New Mexico counties). Maps for aspect and precipitation slope for New Mexico and California are shown Appendix A and Appendix B, respectively.

Table 14: Influence of the sub-index rainfall in California selected counties

Class	Description	Rainfall (mm)	Weight	% of total area
1	High	>650	1	8.25
2	Moderate	280 - 650	1.5	43.2
3	Low	<280	2	48.5

Table 15: Influence of the sub-index rainfall in New Mexico selected counties

Class	Description	Rainfall (mm)	Weight	% of total area
1	High	>650	1	2.4
2	Moderate	280 - 650	1.5	25.3
3	Low	<280	2	72.3

Table 16: Areas of the three classes of climate quality in California selected counties

Class	Description	Range of CQI	Area (sq mi)	% of total area
1	High quality	< 1.15	0.517	0.003
2	Moderate quality	1.15 – 1.81	7398.51	56.023
3	Low quality	>1.81	5807.08	43.97

Table 17: Areas of the three classes of climate quality in New Mexico selected counties

Class	Description	Range of CQI	Area (sq mi)	% of total area
1	High quality	< 1.15	81.15	0.82
2	Moderate quality	1.15 – 1.81	2456.44	25.03
3	Low quality	>1.81	7273.34	74.13

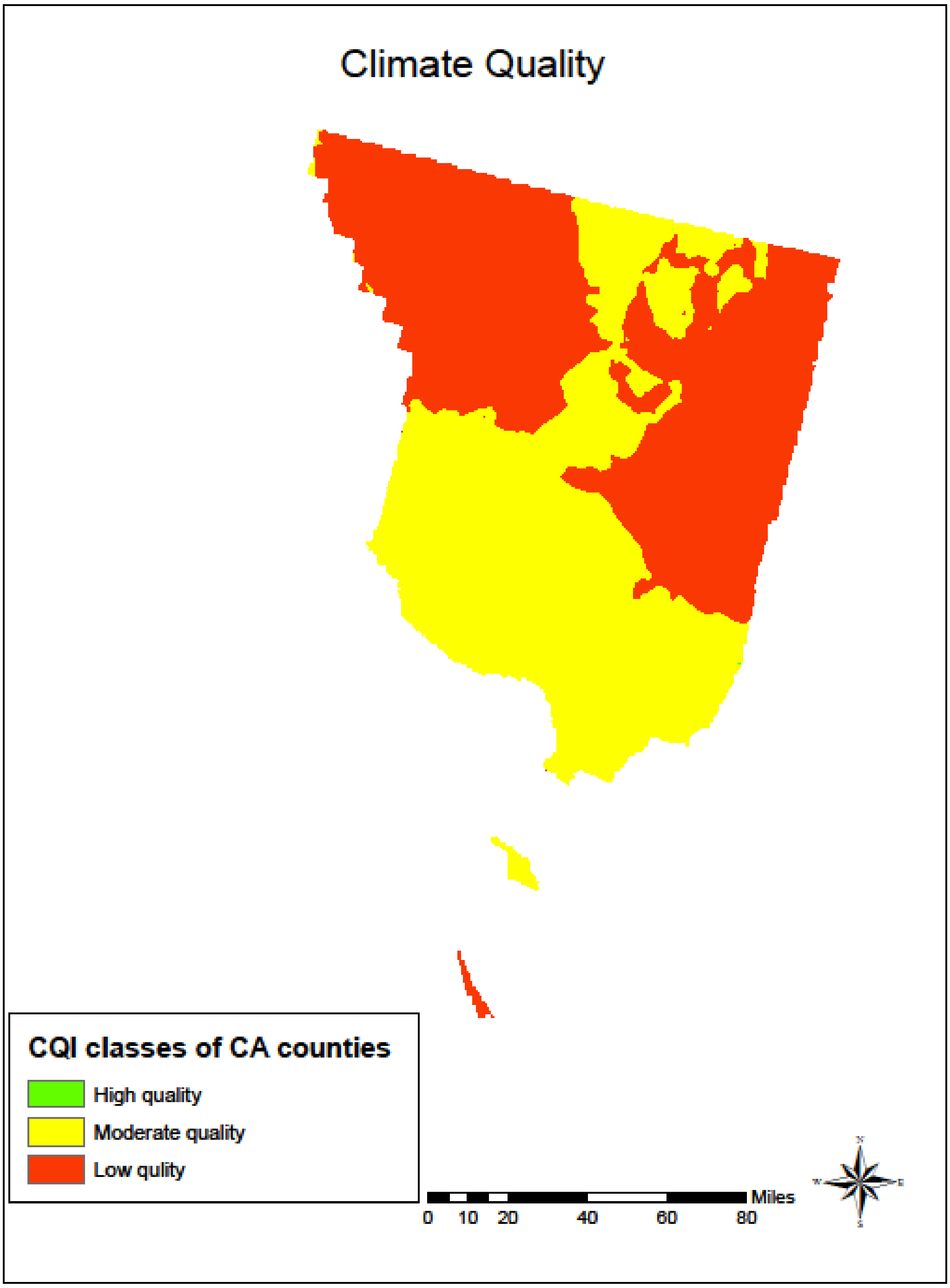

Fig.6. Climate Quality Index (CQI) of California counties. See Tables 5 and 16 for details.

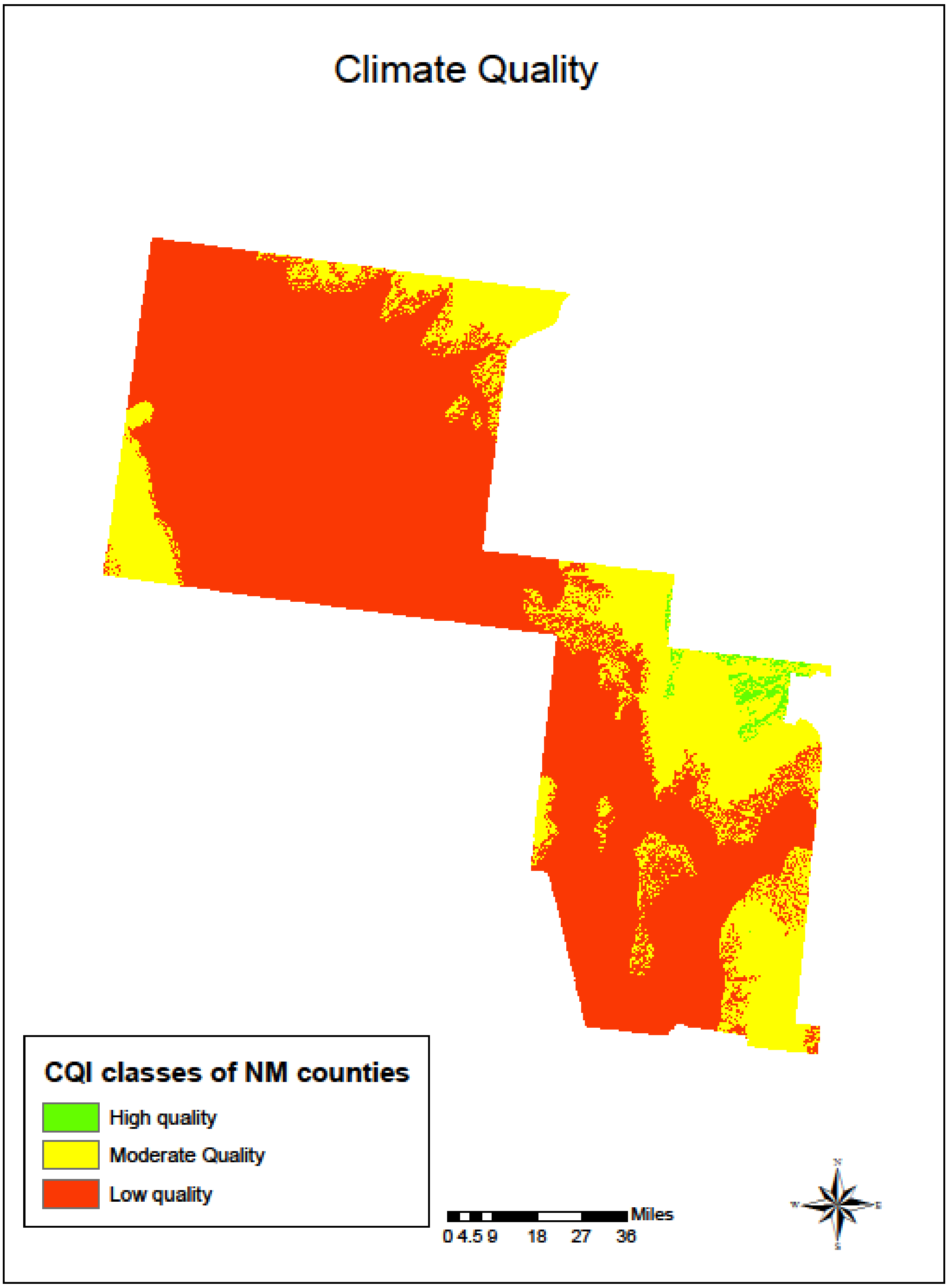

Fig 7. Climate Quality Index (CQI) of New Mexico counties. See Tables 5 and 17 for details.

Vegetation Quality Index (VQI)

The vegetation quality index was calculated by integrating fire risk, plant cover, drought resistance, and erosion protection using land cover maps for the study areas and vegetation data. The VQI in this study was classified based on the vegetation existing in each type of land cover (Table 18). The vegetation in both study areas included cropland, pasture, forest, shrub/scrub, herbaceous, and bare land. For the fire risk factors, I assumed bare land, developed area as a low fire risk type based on less vegetation whereas Hay/Pasture was classified as high fire risk covers. Fires can lead soil degradation due to changes in the soil physical properties, including changes in soil pore space which decreases the amount of water infiltration into the subsoil and increases surface runoff. Moreover, the reduction of vegetation cover is generally related to a reduction in soil protection from an erosion by rain and wind.

More than 2/3 of the study area in California was classified as having a high VQI and less than 1/3 was classified as moderate vegetation quality (Figures 8, Tables 19). On other hand, most (94.9 %) of the study area in New Mexico was classified as high vegetation quality and less than 5 % of the area was classified as moderate vegetation quality (Figure 9, Table 20) . Detailed maps of drought resistance, erosion protection, fire risk, and plant cover for New Mexico and California are given in Appendix A and Appendix B, respectively.

Table 18: Influence of sub-indexes and evaluation of the vegetation quality index (VQI)

Class	Description	Fire risk	Index
1	Low	Bare land, developed area, perennial snow/ ice, Woody wetland, Emergent Herbaceous wetland	1
2	Moderate	Deciduous forest, evergreen forests, mixed forest, Cultivated Crops	1.3
3	High	Shrub/Scrub, Herbaceous	1.6
4	Very High	Hay/Pasture	2
Class	Description	Erosion protection	Index
1	Very high	evergreen forests, mixed forest, Shrub/Scrub, Herbaceous	1
2	High	Hay/Pasture, Woody wetland, Emergent Herbaceous wetland	1.3
3	Moderate	Deciduous forest	1.6
4	low	perennial snow/ ice, Cultivated Crops	1.8
5	Very low	Bare land, Developed area,	2
Class	Description	Drought Resistance	Index
1	Very high	Perennial snow/ ice, evergreen forests, mixed forest, Shrub/Scrub, Herbaceous, Woody wetland, Emergent Herbaceous wetland.	1
2	High	Deciduous forest	1.2
3	Moderate	Cultivated Crops,	1.4
4	low	Hay/Pasture	1.7
5	Very low	Bare land, Developed area,	2

Table 18 (continued)

Class	Description	Plant cover	Type of vegetation	Index
1	High	>40%	Perennial snow/ ice, evergreen forests, mixed forest, Shrub/Scrub, Herbaceous, Woody wetland, Emergent Herbaceous wetland, Hay/Pasture	1
2	Low	10 - 40	Cultivated Crops	1.8
3	Very low	< 10 %	Bare land, Developed area,	2

Table 19: Areas of the two classes of vegetation quality in California selected counties

Class	Description	Range of VQI	Area (sq mi)	% of total area
1	High quality	1 – 1.6	10481.83	78.42
2	Moderate quality	1.7 - 3.7	2808.1	21.01

Table 20: Areas of the two classes of vegetation quality in New Mexico counties

Class	Description	Range of VQI	Area (sq mi)	% of total area
1	High quality	1 – 1.6	9902.72	94.93439
2	Moderate quality	1.7 - 3.7	502.429	4.816635

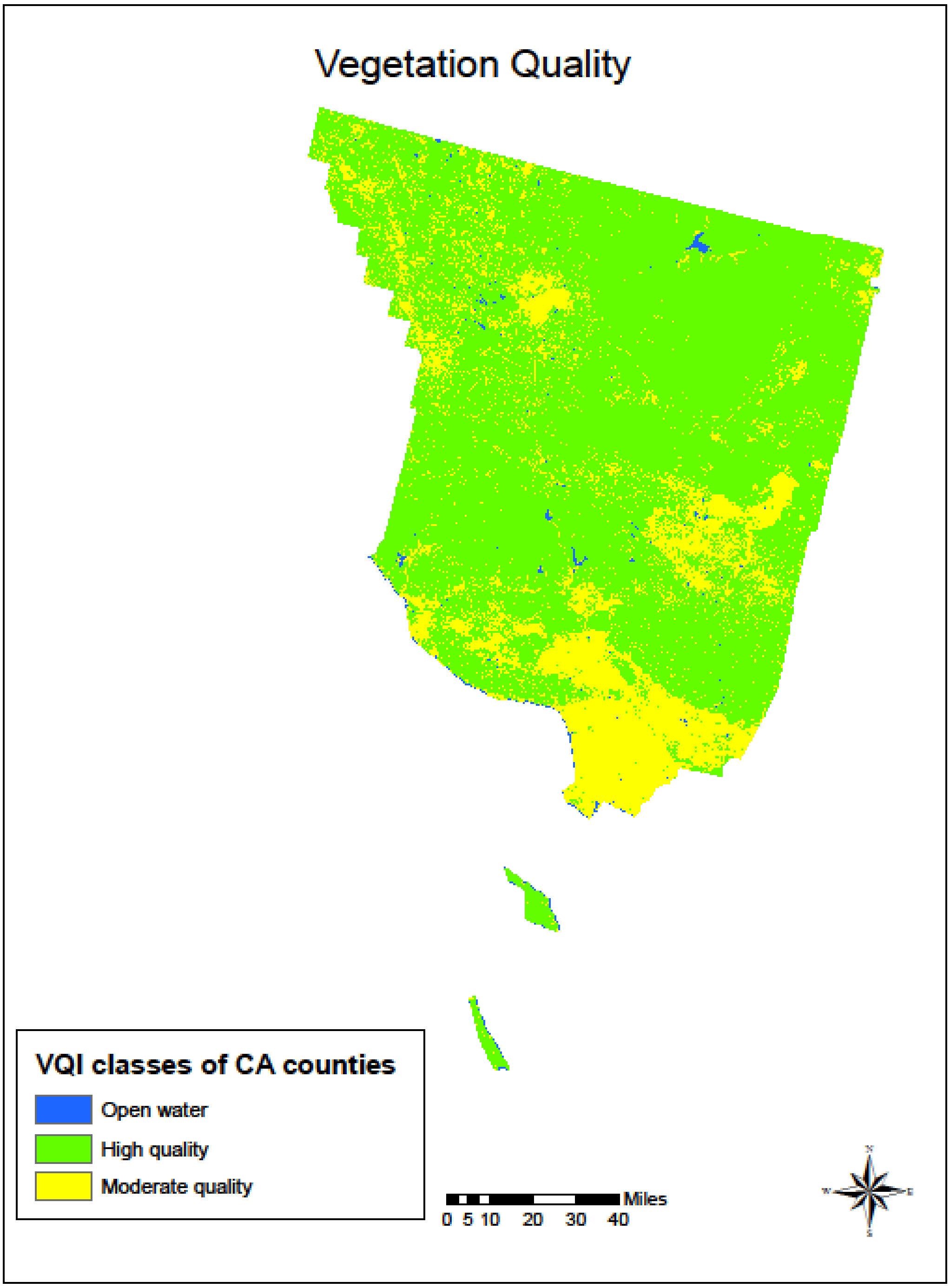

Fig 8. Vegetation Quality Index (VQI) of California counties. See Tables 18 and 19 for details.

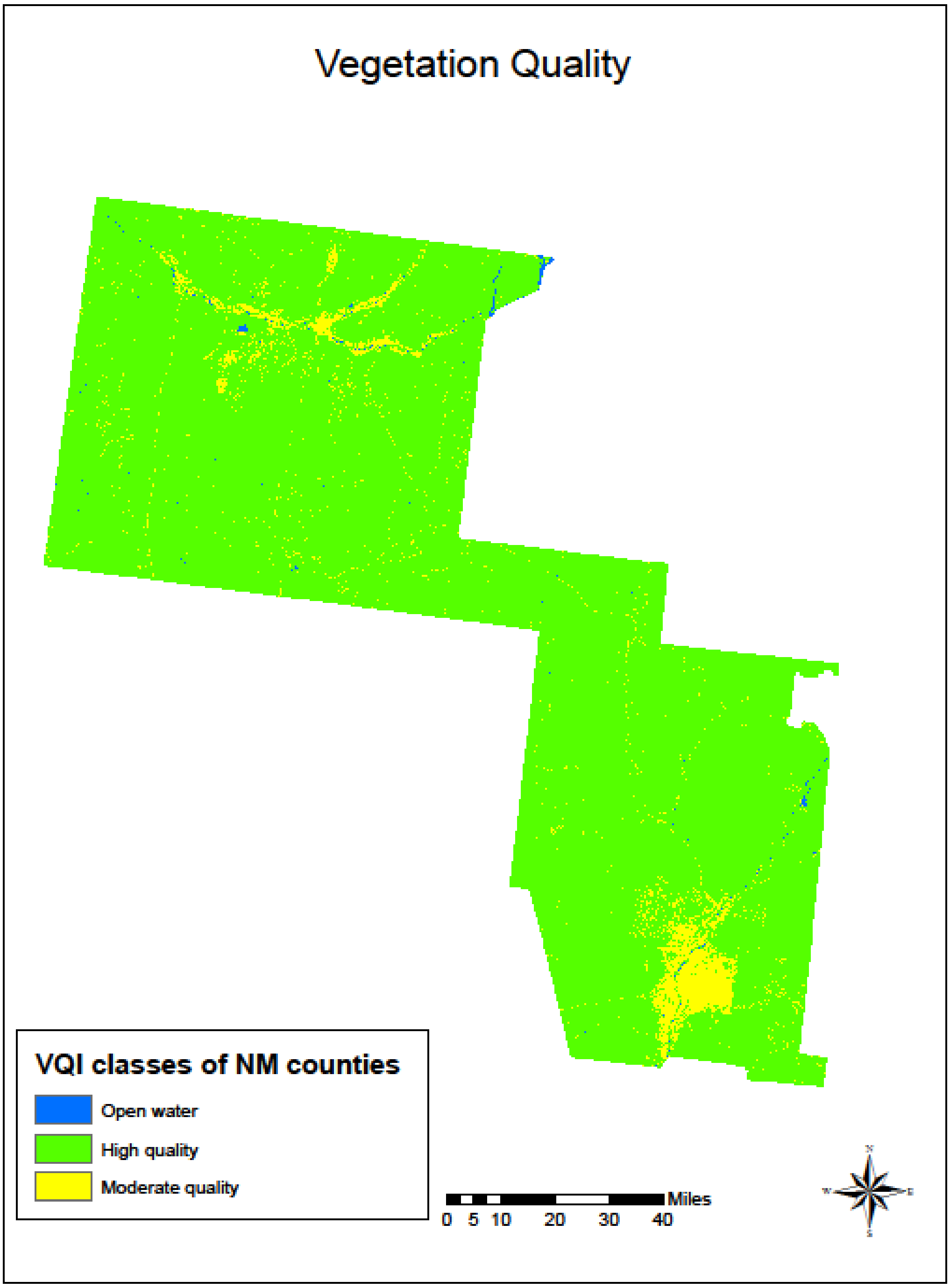

Fig 9. Vegetation Quality Index (VQI) of New Mexico counties. See Tables 18 and 20 for details.

Management Quality Index (MQI)

The MQI depends on land use (type and intensity) and policy. The intensity of land use was classified based on the types of land use including cropland, pasture, forest, shrub land, bare land and recreational and developed areas, and roads. An increase of the soil ‘‘stress’’ that resulted from Human pressure such as grazing, water supply, and intense agricultural activities lead to increases the sensitivity to desertification (Lamqadem, et al., 2018). For instance, there can be significant overgrazing in pasture areas which can particularly negatively affect soil conditions and increase the potential for desertification. For the study areas, three classes were considered based on protection that national and regional parks and forested sites can provide (high protection policy level, score 1), areas such as Developed, Medium Intensity, and Cultivated Crops (medium level, score 1.5), and areas with no protection (low level, score 2).

In California, 21.5 % of the California's study area was located in the high management quality class, 1.7 % was located in moderate management quality class and 76 % was located in low management quality class Figure 10, Table 21). the majority of the area of New Mexico counties were classified as having a low management quality class (81%), more than 16% of the area as high management quality class, and around 2% as moderate management quality class (Figure 11, Table 22). Detailed maps for land use intensity and policy enforcement for New Mexico and California are shown Appendix A and Appendix B, respectively

Table 21: Areas of the three classes of management quality in California selected counties

Class	Value	Description	Area (sq mi)	% of total area
1	1 – 1.25	High	2874.12	21.51
2	1.26 – 1.50	Moderate	240.2	1.79
3	>1.51	Low	10175.77	76.18

Table 22: Areas of the three classes of management quality in New Mexico selected counties

Class	Value	Description	Area (sq mi)	% of total area
1	1 – 1.25	High	1748.11	16.75
2	1.26 – 1.50	Moderate	204.76	1.96
3	>1.51	Low	8452.05	81.02

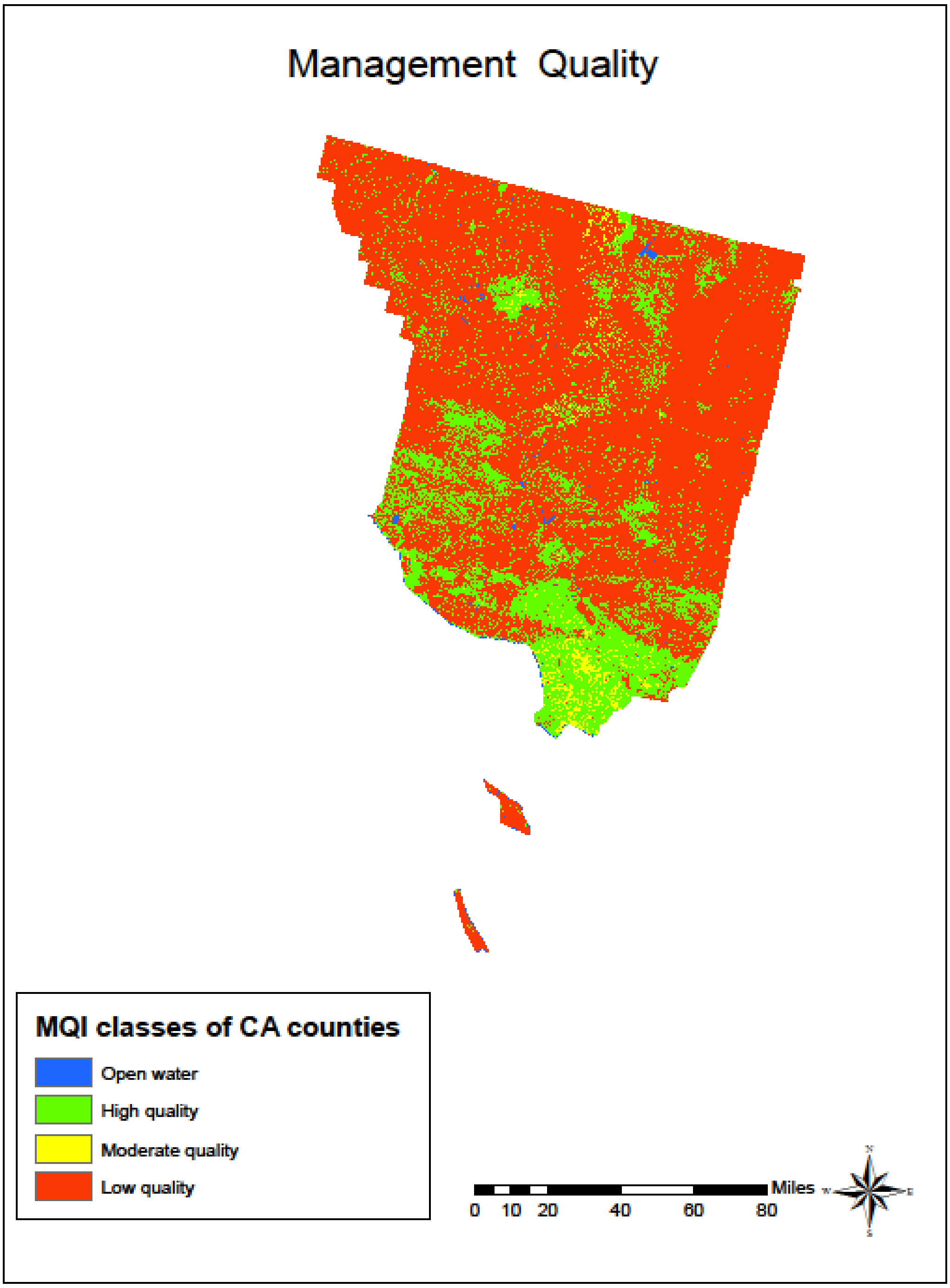

Fig 10. Management Quality Index (MQI) of California counties. See Tables 7 and 21 for details.

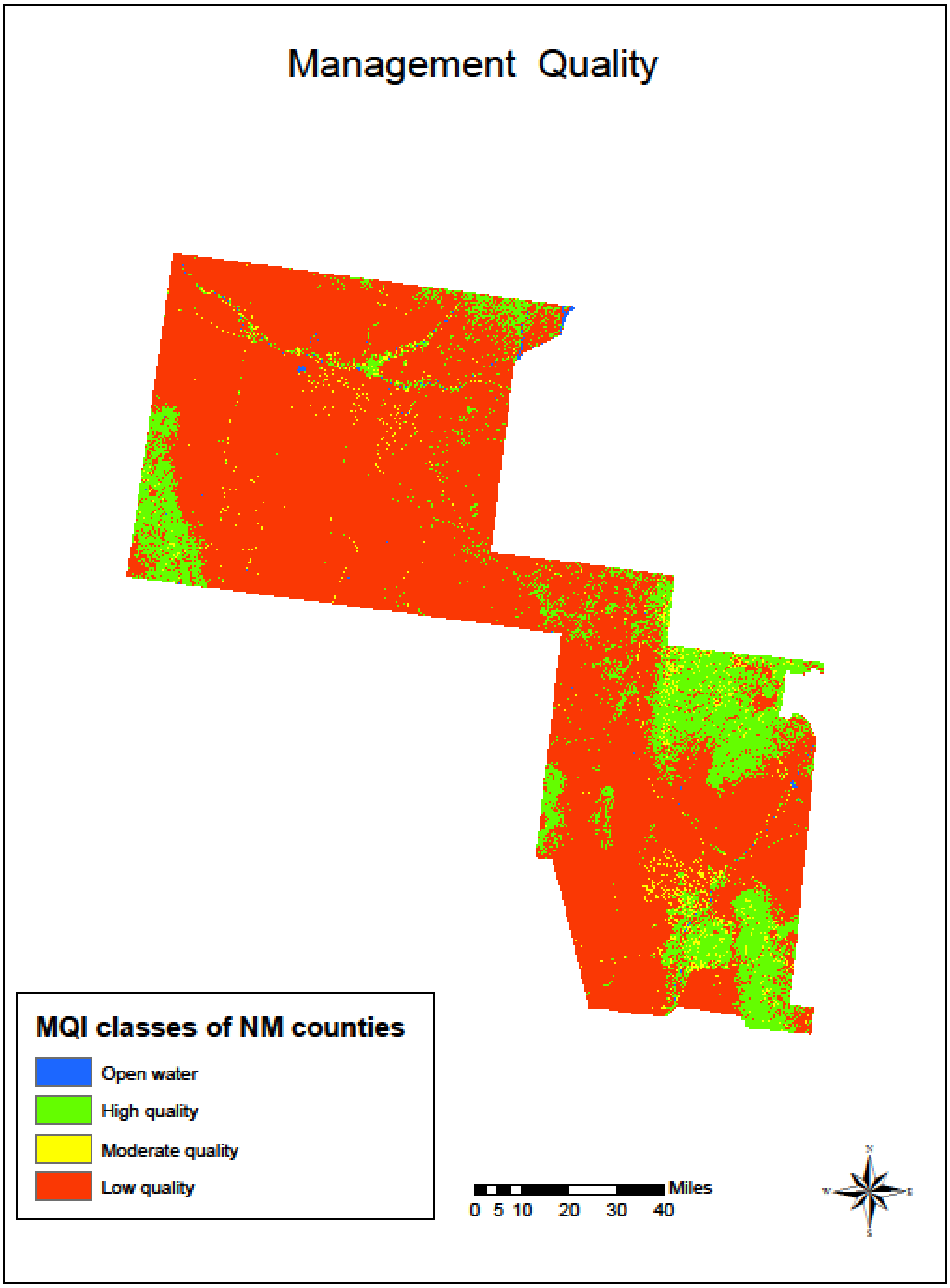

Fig 11. Management Quality Index (MQI) of New Mexico counties. See Tables 7 and 22 for details.

Environmental Sensitivity Areas Index (ESAI)

Calculation of the ESAI indicates that large areas of both the California and New Mexico study areas are very vulnerable to desertification due to several factors (Figures 12 & 13). Only very small areas 3.15 % (415.4 sq mi) of the California study area and 0.54% (52.97 sq mi) of the New Mexico study area were classified as not prone to desertification. These areas had very low values of several of the factors that are critical to desertification including low negative impacts of natural environmental conditions and low human activities. The non-threatened areas are nearly flat, have deep soil s that are well drained. Potential class (low sensitivity) covers 2.04% (269.87 sq mi) of California's counties and 2.01% (196.6 sq mi) of New Mexico's counties. This class where a land use mismanagement could create serious issues. The fragile class was divided into three sub-classes, F1, F2, and F3. The entire fragile class covers 11.5 % (1527.3 sq mi) and 13.7% (1286.9 sq mi) of CA and NM counties, respectively. Fragile areas are where any negative changes in human activities and natural conditions can result in desertification. However, the largest areas in both study areas are classified as critical with a high sensitivity for desertification. It is divided into three sub-classes including C1, C2, and C3. Due to the high impact of several factors that increase the desertification process such as aridity index, precipitation, fire risk, and land use in California counties, while in New Mexico the critical factors were organic matters, aridity index, precipitation, and land use, this class covers more than 82% (10913.84 sq mi) of California's study area and more than 83.3% (8135.18 sq mi) of New Mexico's study area (Tables 23 & 24).

Table 23: Ranges and description of sensitivity to desertification in California counties

Class	Range	Description	Area (sq mi)	% of total area
1	≤ 1.17	Non-affected	415.43	3.15
2	1.18 – 1.22	Potential affected	269.87	2.04
3	1.23 – 1.37	Fragile	1527.31	11.58
4	≥ 1.38	Critical	10913.84	82.77

Table 24: Ranges and description of sensitivity to desertification areas in New Mexico counties.

Class	Range	Description	Area (sq mi)	% of total area
1	≤ 1.17	Non-affected	52.97	0.54
2	1.18 – 1.22	Potential affected	196.69	2.01
3	1.23 – 1.37	Fragile	1286.91	13.17
4	≥ 1.38	Critical	8135.18	83.31

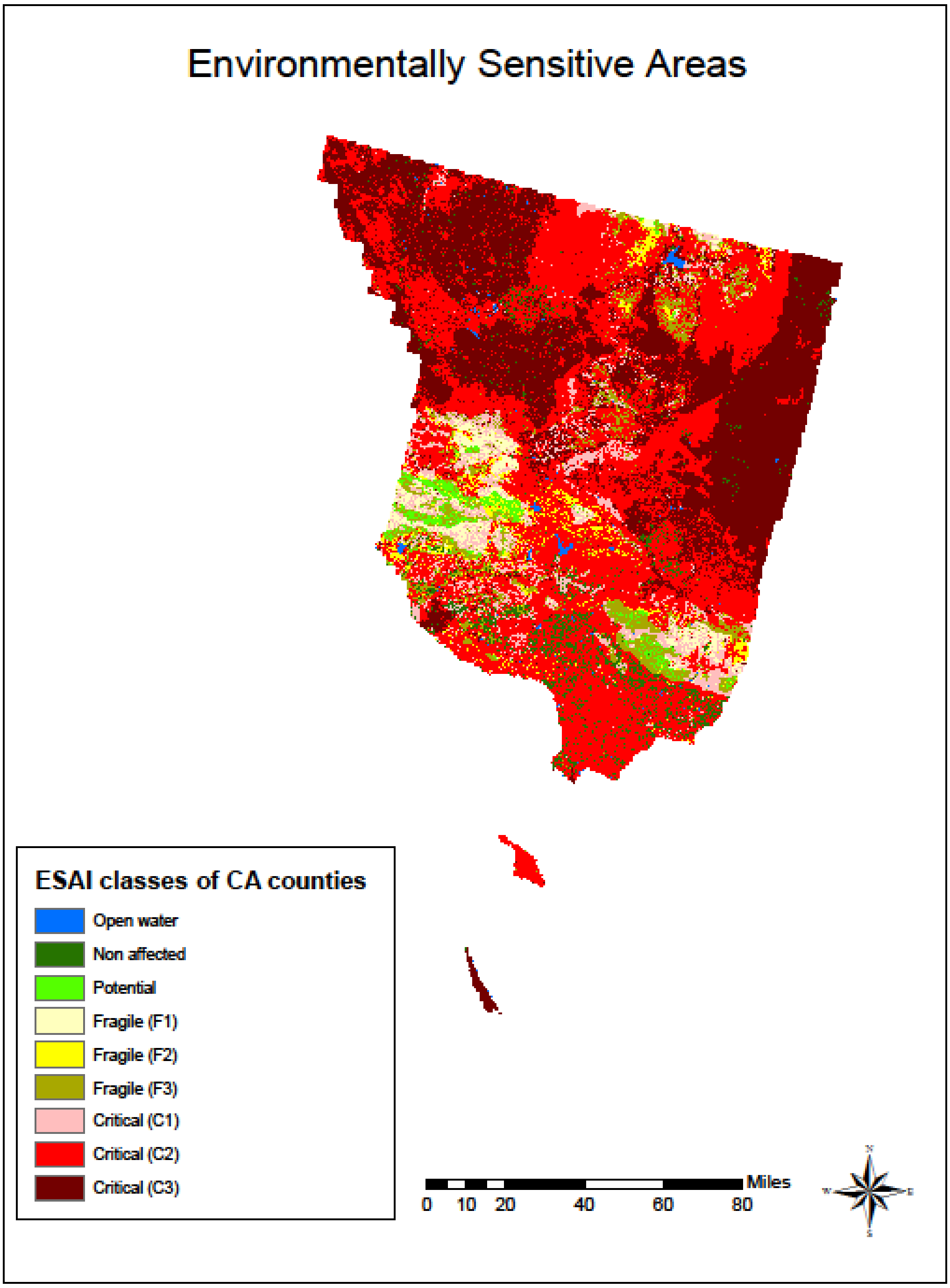

Fig 12. Environmental sensitivity to desertification (ESAI) in California counties. See Table 9 for details.

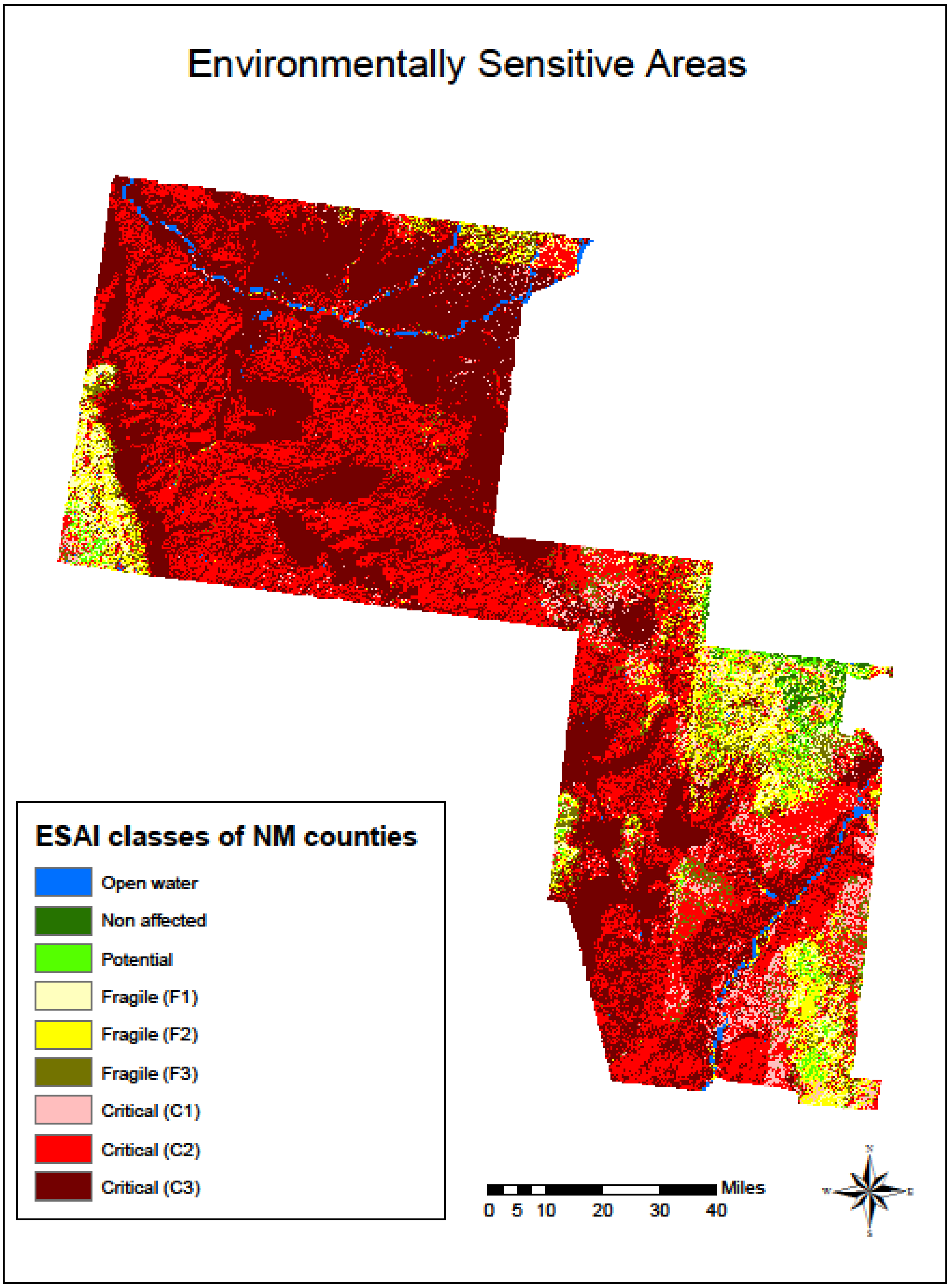

Fig 13. Environmental sensitivity to desertification (ESAI) in New Mexico counties. See Table 9 for details.

Conclusions

Desertification is a serious issue caused by human and natural factors. This change in many areas of the globe must be addressed and action plans and immediate steps are required to tackle the situation. All the nations across the globe have to come out with solutions to protect the fertile land from becoming barren desert not useful for agriculture as well as having impacts in terms of negative feedbacks on climatic changes (Bouhata & Kalla, 2014). It is not the problem of any specific continent or country, it is a global issue affecting each and every habitat in this world (Lamqadem, et al., 2018). The assessment of vulnerability to desertification is significant to plan relevant actions such as policy and land use plan, and also to improve the management and use of natural resources.

In this study, the MEDALUS method and GIS tools were used to investigate the risk of desertification in several New Mexico (Bernalillo, San Juan, and Sandoval) and California counties (Ventura, Los Angeles, and Kern). GIS is useful and valuable tool to retrieve, store, manipulate large amount of data, and other functions such as spatial analysis and classification. It provides huge time savings, precision and reliability.

In this study, both study areas are highly sensitive to desertification, as more than 80% of the study areas were classes as critical in term of desertification potential). Poorly vegetated urban areas, overgrazing, human activities, overexploitation natural resources, poor soils, and lower rainfall can contribute to higher levels of desertification risk. Based on the results, the primary factor indices that appear to be affecting environmental sensitivity to desertification within the study areas are the management, vegetation and climate indices in the California study area and the soil, management and climate indices in the New Mexico study area.

In attempt to identify the major indices that lead to desertification, two previous studies have been compared to this study. In the first study in the Oases of Middle Draa Valley, Morocco conducted by Lamqadem et al., 2018, the results showed that climate indices, characterized by low precipitation and high temperatures, and management indices, characterized by high human pressure, are mainly the sources of desertification in the oases located southeast of Morocco. The other study in southwestern Romania, showed that management indices due to high agricultural pressures sub-indicator and vegetation indices characterized by low vegetation cover are the primary factors of area desertification (Pravalie et al., 2017).

It is obvious that management quality index is the common factor for desertification in the areas mentioned above, which means that better management practices would lead to less desertification. The others quality indices vary from an area to another due to the difference of local conditions.

One of the main of difficulties that I encountered while using MEDALUS model is lack of some data that some of data are not available. For instance, the number of animals to determine if there is overgrazing or not in the study area for land use analysis. Also, Irrigation frequency in farming area. So, I made assumption based on the information available about the overgrazing and vegetables that grow in both states. In addition, the recent evapotranspiration data available is from 1970 to 2000 which is used to obtain aridity index data.

My suggestion to improve the model and get more accurate results is including more parameters that affect desertification such as the integration of soil salinity as a sub-indicator for deriving soil quality index (SQI). In addition, MEDALUS approach can be enhanced by adding water quality index that focuses on ground water quality. Good examples of sub-indicators for water quality index that I recommend to be considered for future studies are groundwater recharge, water salinity, and depth of the groundwater table. Since the data is time-dependent, more recent data is recommended for new studies.

CHAPTER IV

REFERENCES

Adeel, Z., Safriel, U., Niemeijer, D., & White, R. (2005). Ecosystems and human well-being: Desertification Synthesis. Washington, DC: World Resources Institute.

Afifi, A., Darwish, K. and Youssef, R. (2014). Geospatial information and indicators for mapping land sensitivity to degradation in Siwa Oasis, Egypt. sci-African journal of scientific issues, 2 (9) (23116188), pp.430-441.

Bot, A., & Benites, J. (2005). The importance of soil organic matter: Key to drought-resistant soil and sustained food and production. Rome: Food and Agriculture Organization of the United Nations.

Boudjemline, F., & Semar, A. (2018). Assessment and mapping of desertification sensitivity with MEDALUS model and GIS - Case study: Basin of Hodna, Algeria. Journal of Water and Land Devolpment, 36 (1), 17-26.

Bouhata Rabah, Kalla Mahdi (2014). 'Mapping of environmental vulnerability of desertification by adaptation of the MEDAULUS Method in the Endoreic area of Gadaine'. Geographia Technica, 9(2), pp. 1-8.

Canora, F., D'Angella, A., & Aiello, A. (2015). Quantitative assessment of the sensitivity to desertification in the Bradano River basin (Basilicata, southern Italy). Journal of maps, 11(5), 745-759.

Capozzi, Di Palma, De Paola, Giugni, Iavazzo, Topa, Giordano. (2018). Assessing desertification in sub-Saharan peri-urban areas: Case study applications in Burkina Faso and Senegal. Journal of Geochemical Exploration,190, 281-291.

Desertification. (1997, October 29). Retrieved February 10, 2019, from https://pubs.usgs.gov/gip/deserts/desertification/

Dregne, H. E. (1986). DESERTIFICATION OF ARID LANDS. Retrieved February 10, 2019, from http://www.ciesin.org/docs/002-193/002-193.html

Dutta Srimoyee, Chaudhuri Gargi (2015). 'Evaluating environmental sensitivity of arid and semiarid regions in northeastern Rajasthan, India'. Geographical Review, 105 (4), pp. 441-461.

Environment and Sustainable Development, EUR 18882, 87p.

Frattaruolo Francesco, Pennetta Luigi, Piccarreta Marco (2008). 'Desertification vulnerability map of Tavoliere, Apulia'. Journal of maps, pp. 117-125

Frattaruolo, F., Pennetta, L., & Piccarreta, M. (2009). Desertification Vulnerability Map of Tavoliere, Apulia (Southern Italy). Journal of Maps, 5(1), 117–125. https://doi.org/10.4113/jom.2009.1050.

Kadovic Ratko, Bohajar Yousef, Perovic Veljko, Simic Snezana, Todosijevic Mirjana, Tosic Sonja, Andelic Milosav, Mladan Dragan, Dovezenski Una (2016). 'Land sensitivity analysis of degradation using MEDALUS model'. Archives of Environmental Protection, 42(4), pp.114-124

Kosmas, Costas & Ferrara, Agostino & Briassouli, Helen & Imeson, Anton. (1999). Methodology for mapping Environmentally Sensitive Areas (ESAs) to desertification.

Lahlaoi Hicham, Rhinane Hassan, Hilali Atika, Lahssini Said, Moukrim Said (2017). 'Desertification Assessment using MEDALUS Model in Watershed Oued El Maleh, Morocco'. Geosciences, 7(50), pp. 1-16.

Lamqadem Atman, Pradhan Biswajeet, Saber Hafid, Rahimi Abdelmejid (2018). ‘Desertification sensitivity analysis using MEDALUS Model and GIS’. Sensors, 18, pp. 2-19.

Lamqadem, A. A., Pradhan, B., Saber, H., & Rahimi, A. (2018). Desertification Sensitivity Analysis Using MEDALUS Model and GIS: A Case Study of the Oases of Middle Draa Valley, Morocco. Sesors (14248220), 18 (7), 2230. Https. //doi-org.unh-proxy01.newhaven.edu/10.3390/s18072230.

Momirovic Natalija, Kadovic Ratko, Perovic Veljko, Marjanovic Milos, Baumgertel Aleksandar (2018). ‘Spatial assessment of the areas sensitive to degradation in the rural area of the municipality Cukarica’. International Soil and Water Conservation Research.

Paola, Ducci, Giugni (2013). ‘Desertification and erosion sensitivity’. Environ Earth Sci, 70, pp. 2179-2190.

Paola, F., Ducci, D., & Giugni, M. (2013). Desertification and erosion sensitivity. A case study in southern Italy: The Tucano River catchment. Environmental Earth Sciences, 70(5), 2179-2190.

Pravalie Remus, Savulescu Ionut, Patriche Cristian, Dumitrascu Monica, & Bandoc Georgeta. (2017). ‘Spatial assessment of land degradation sensitive areas in southwestern Romania using modified MEDALUS method’. Cetana, 153, pp. 114-130.

Sepher, Hassanli, Ekhtesasi, Jamali (2007). ‘Quantitative assessment of desertification in south of Iran using MEDALUS method’. Environ Monit Assess, 134, pp. 243- 254.

Sobhani Ameneh, Asgari Hamid, Noura Nader, Ownegh Majid, Sakieh Yousef (2017). ‘Application of land-use management scenarios to mitigate desertification risk in northern Iran’. Environmental Earth Sciences 76(680), pp. 607-622

Soil Drainage. (2005). Retrieved February 25, 2019, from https://www.sciencedirect.com/topics/earth-and-planetary-sciences/soil-drainage

Trabucco, A., and Zomer, R.J. 2018. Global Aridity Index and Potential Evapotranspiration (ETO) Climate Database v2. CGLAR-CSI Consortium for Spatial Information (CGLAR-CSI). Published online, available from the CGLAR-CST GeoPortal at https://cgiarcsi.community

Appendices

These appendices contain maps of 14 parameters in each appendix. Appendix (A) shows the California (CA) counties studied maps, while appendix (B) has the New Mexico (NM) counties studied maps. In order to determine the desertification sensitivity in both study areas I used these parameters with MEDALUS method. These parameters are aridity index, slope aspect, precipitation, land use intensity, policy enforcement, soil depth, soil drainage, organic matter, slope, soil surface texture, drought resistance, erosion protection, fire risk, and plant cover.

Appendix (A)

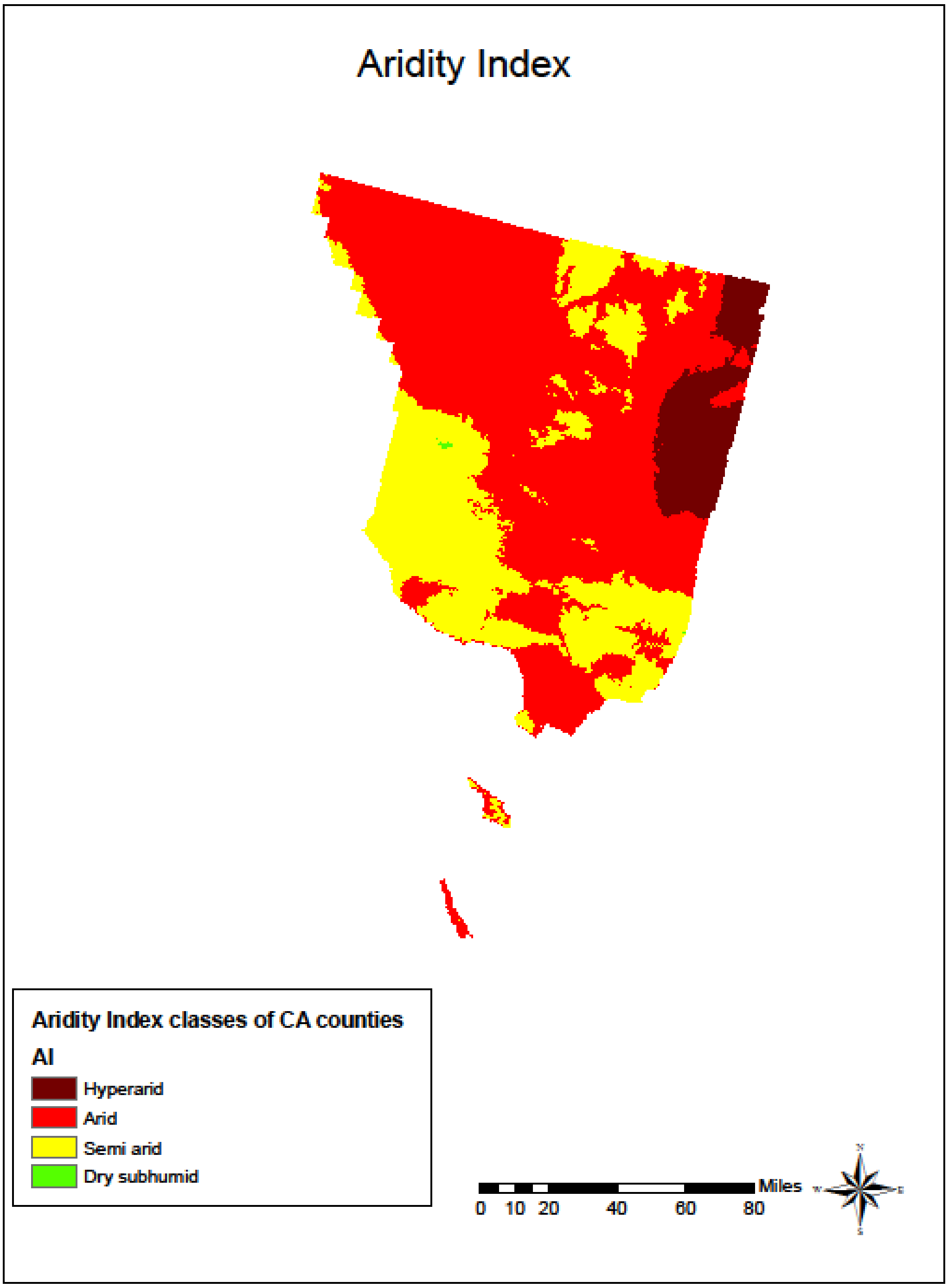

Figure1: Spatial distribution of the aridity index for the California (CA) counties studied. See Table 5 for details.

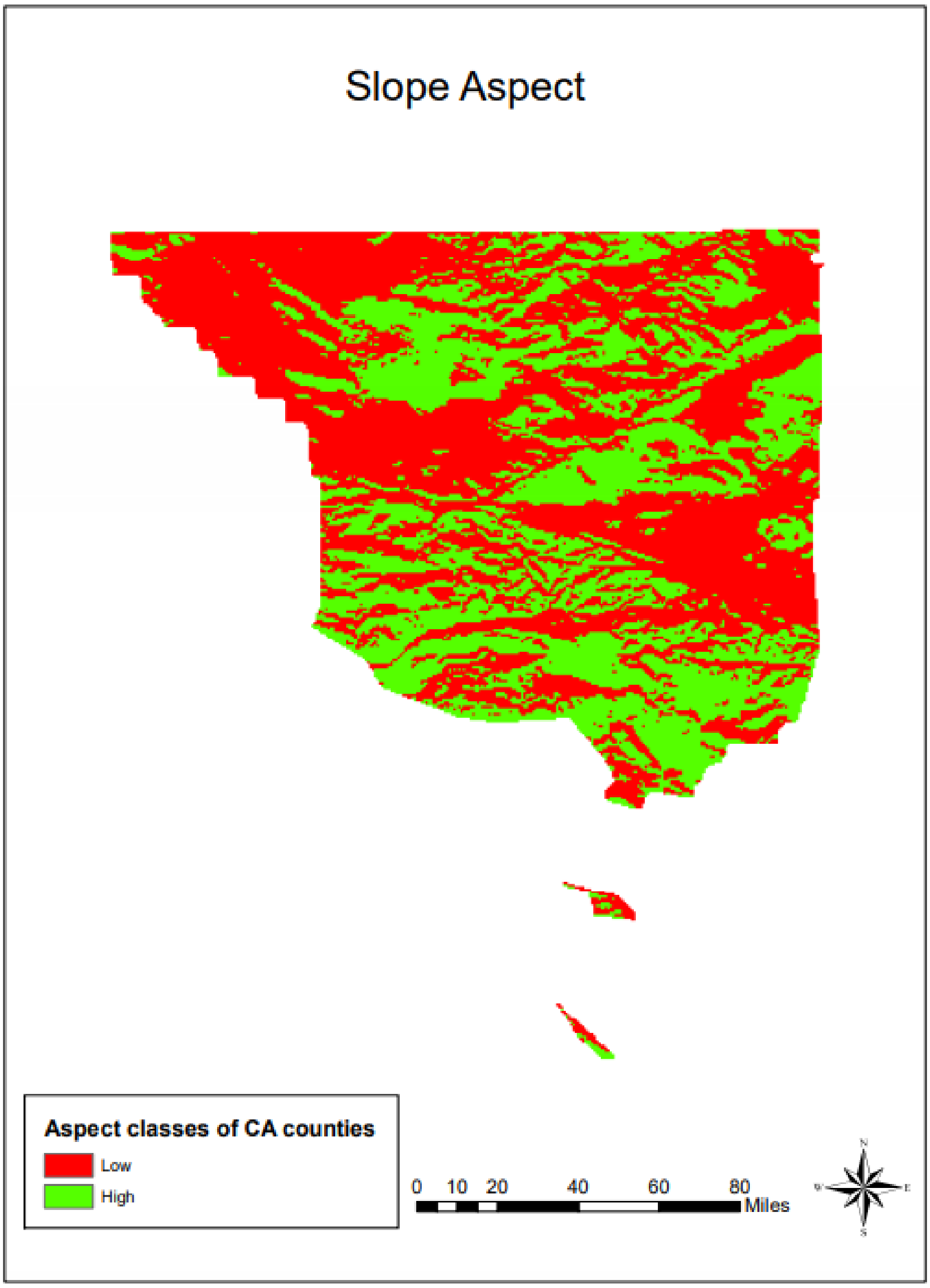

Figure 2: Spatial distribution of the slope aspect for the California (CA) counties studied. See Table 5 for details.

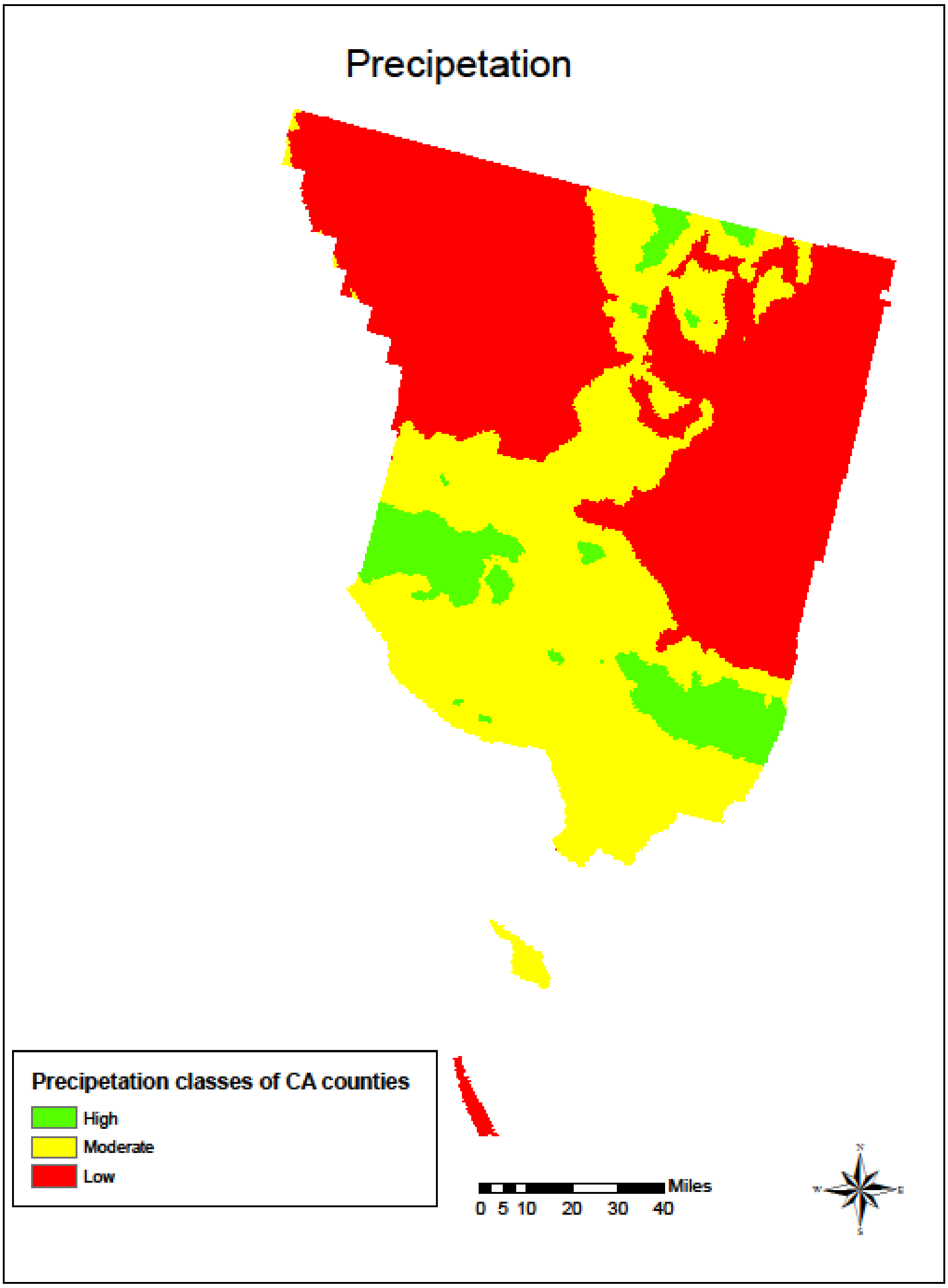

Figure 3: Spatial distribution of the precipitation for the California (CA) counties studied. See Table 14 for details.

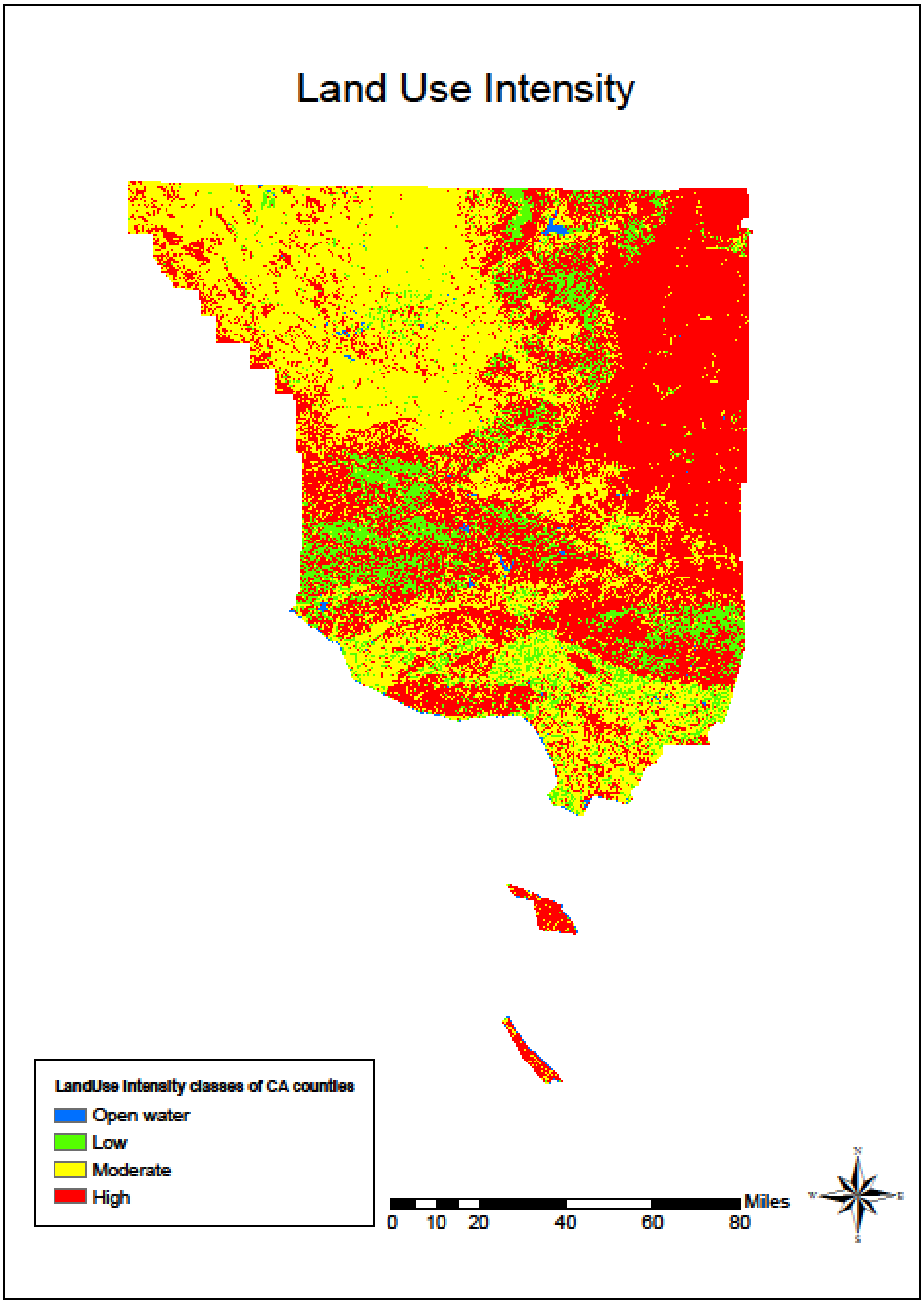

Figure 4: Spatial distribution of the land use intensity for the California (CA) counties studies. See Table 7 for details.

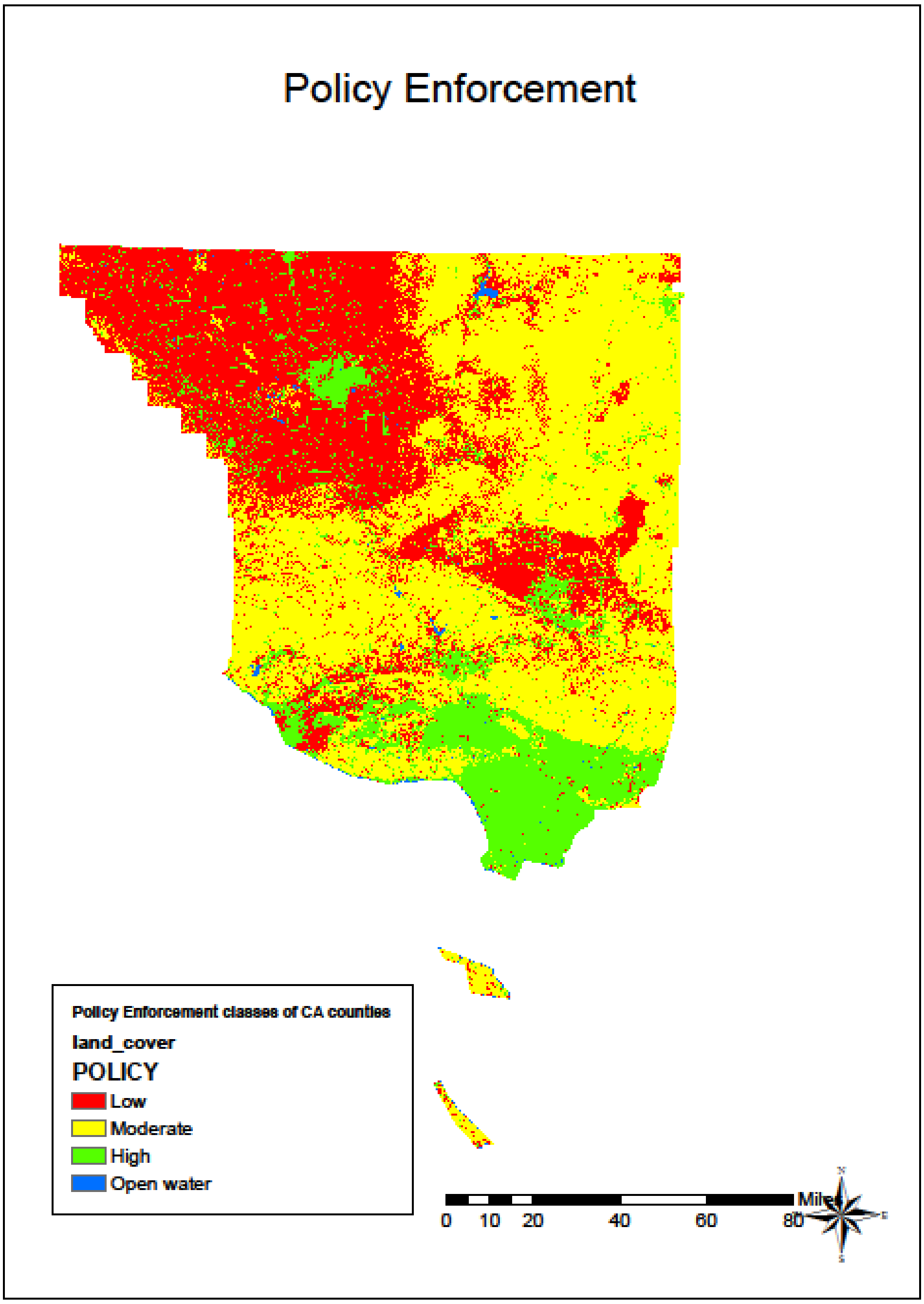

Figure 5: Spatial distribution of the policy enforcement for the California (CA) counties studies. See Table 7 for details.

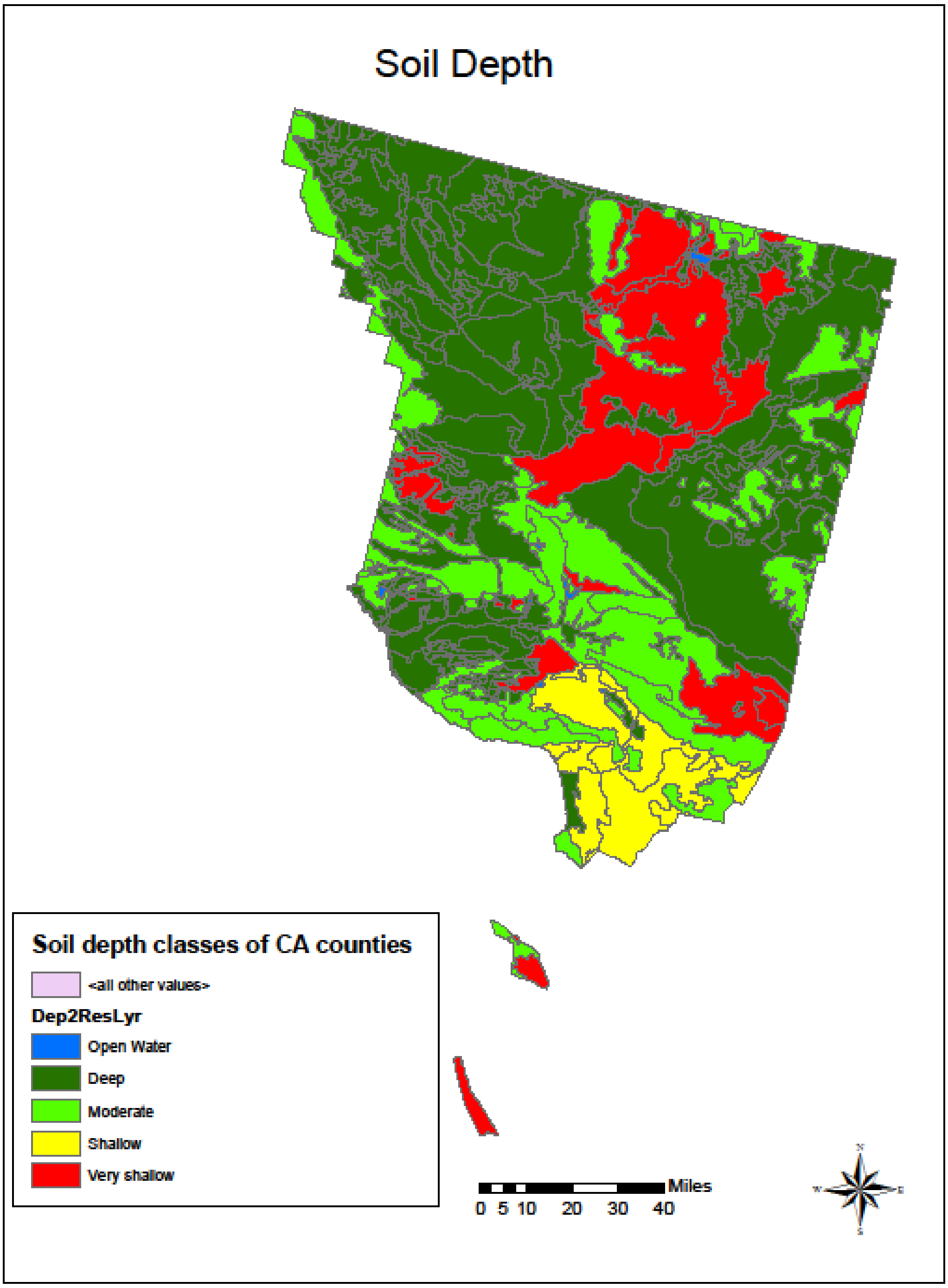

Figure 6: Spatial distribution of the soil depth for the California (CA) counties studies. See Table 10 for details.

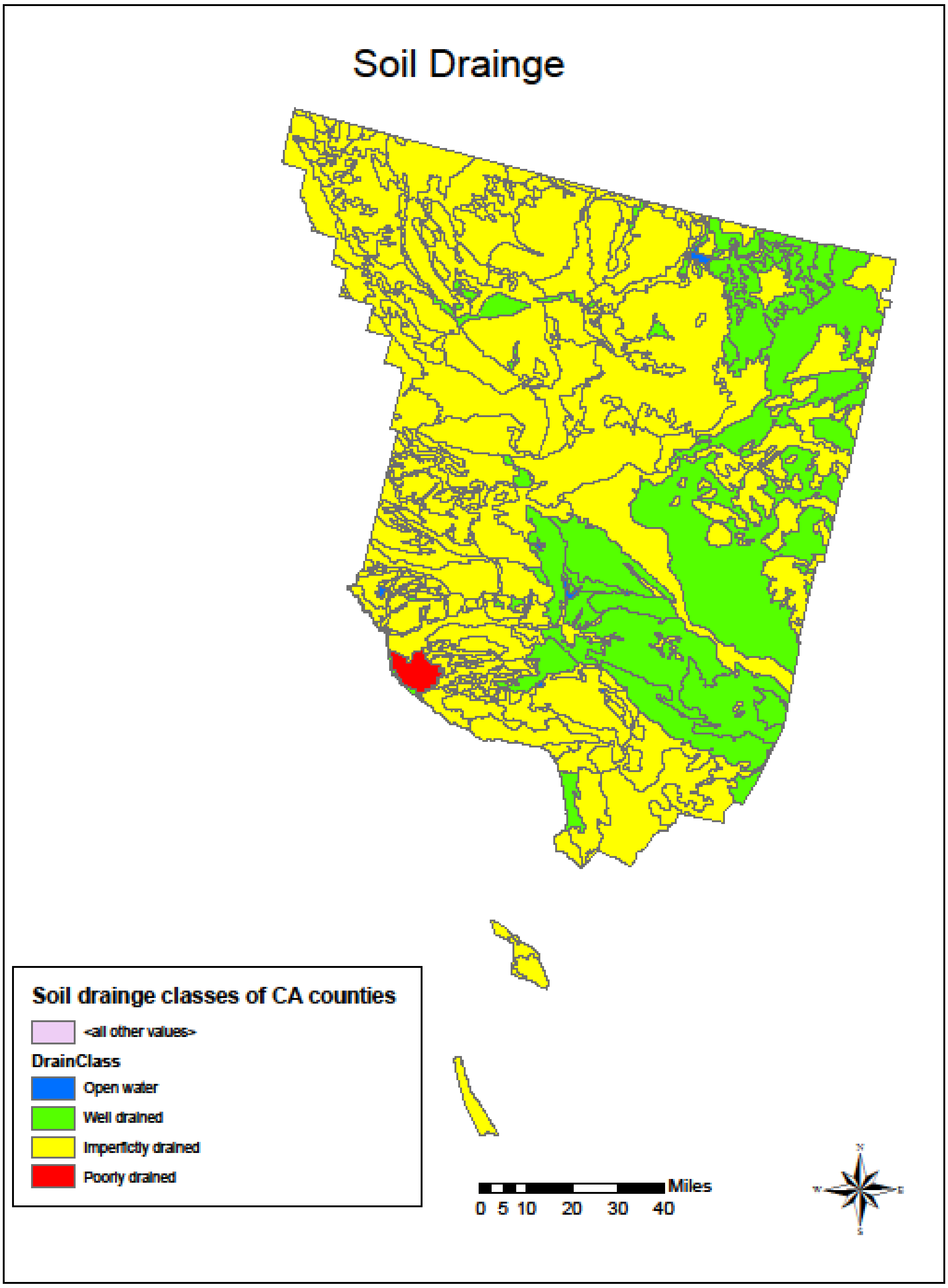

Figure 7: Spatial distribution of the soil drainage for the California (CA) counties studies. See Table 10 for details.

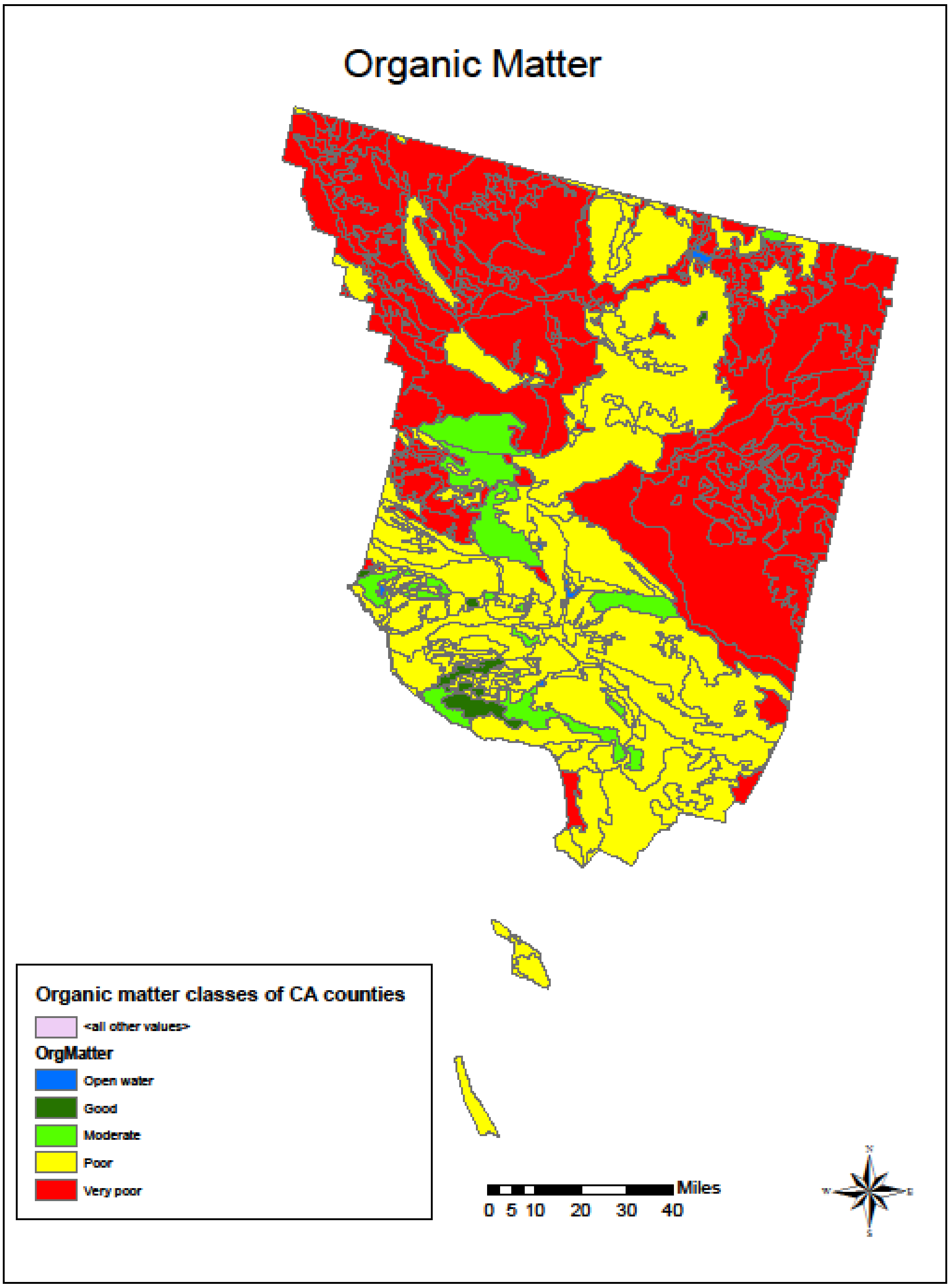

Figure 8: Spatial distribution of the organic matter for the California (CA) counties studies. See Table 10 for details.

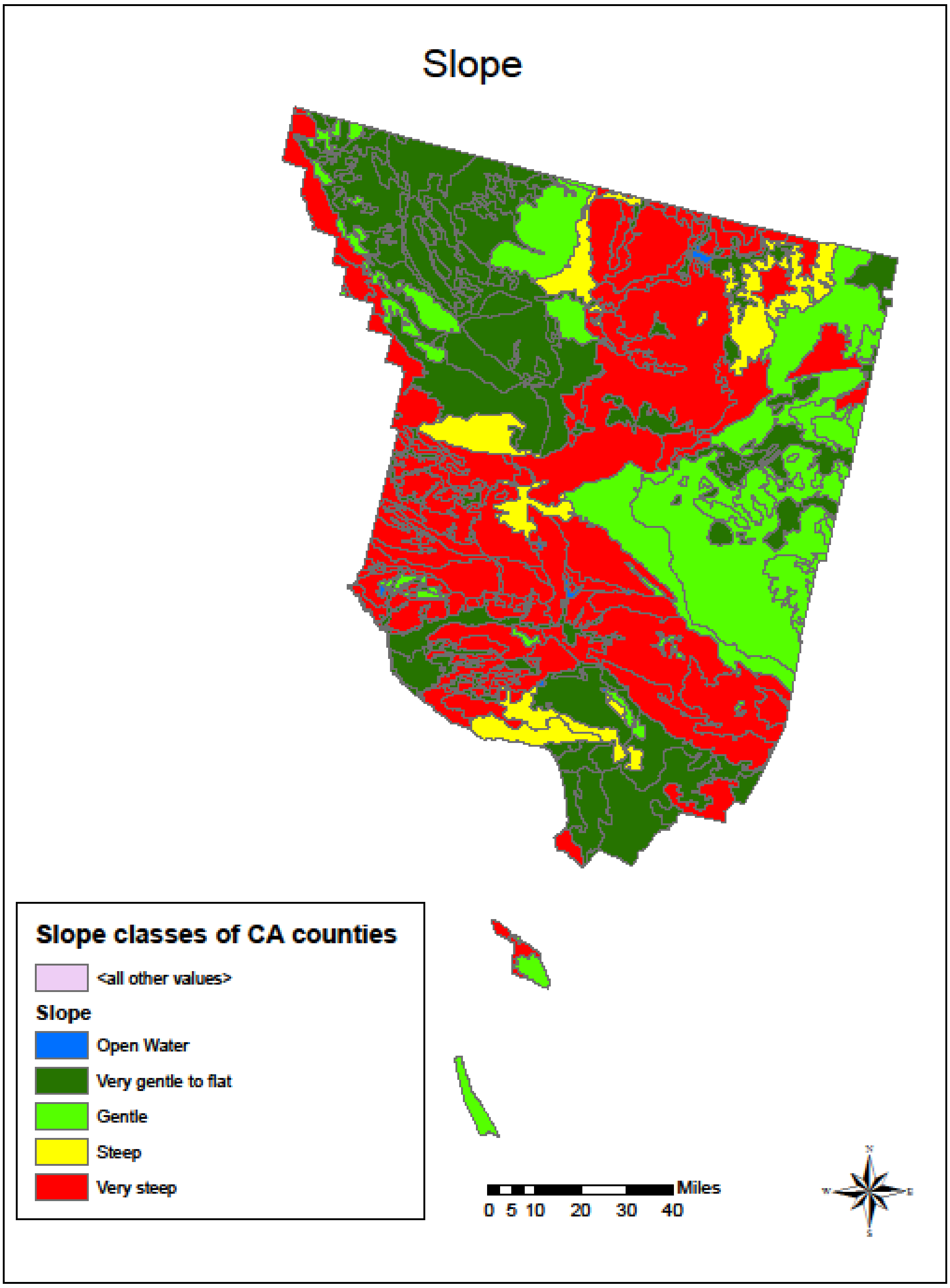

Figure 9: Spatial distribution of the slope for the California (CA) counties studies. See Table 10 for details.

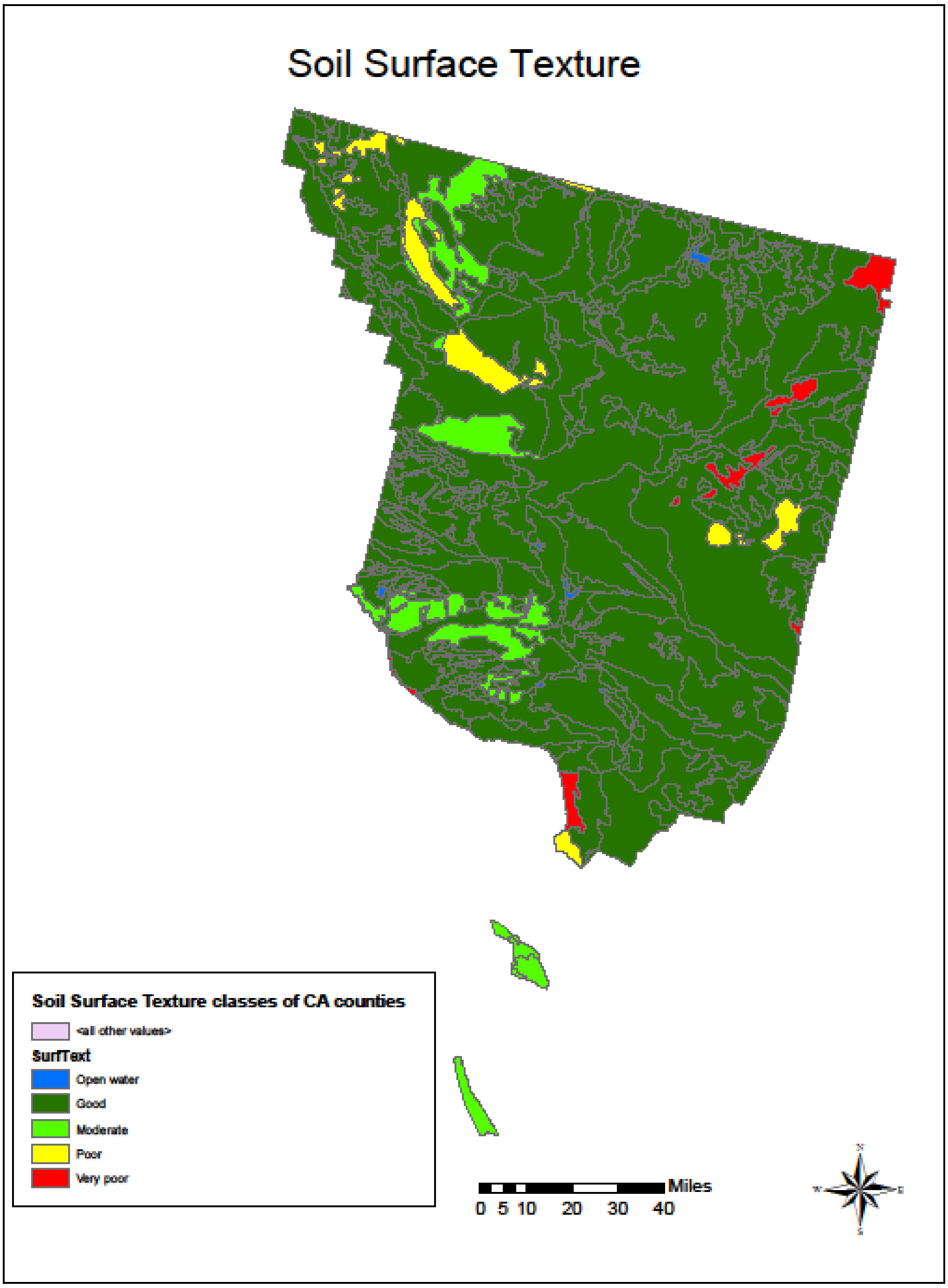

Figure 10: Spatial distribution of the soil surface texture for the California (CA) counties studies. See Table 10 for details.

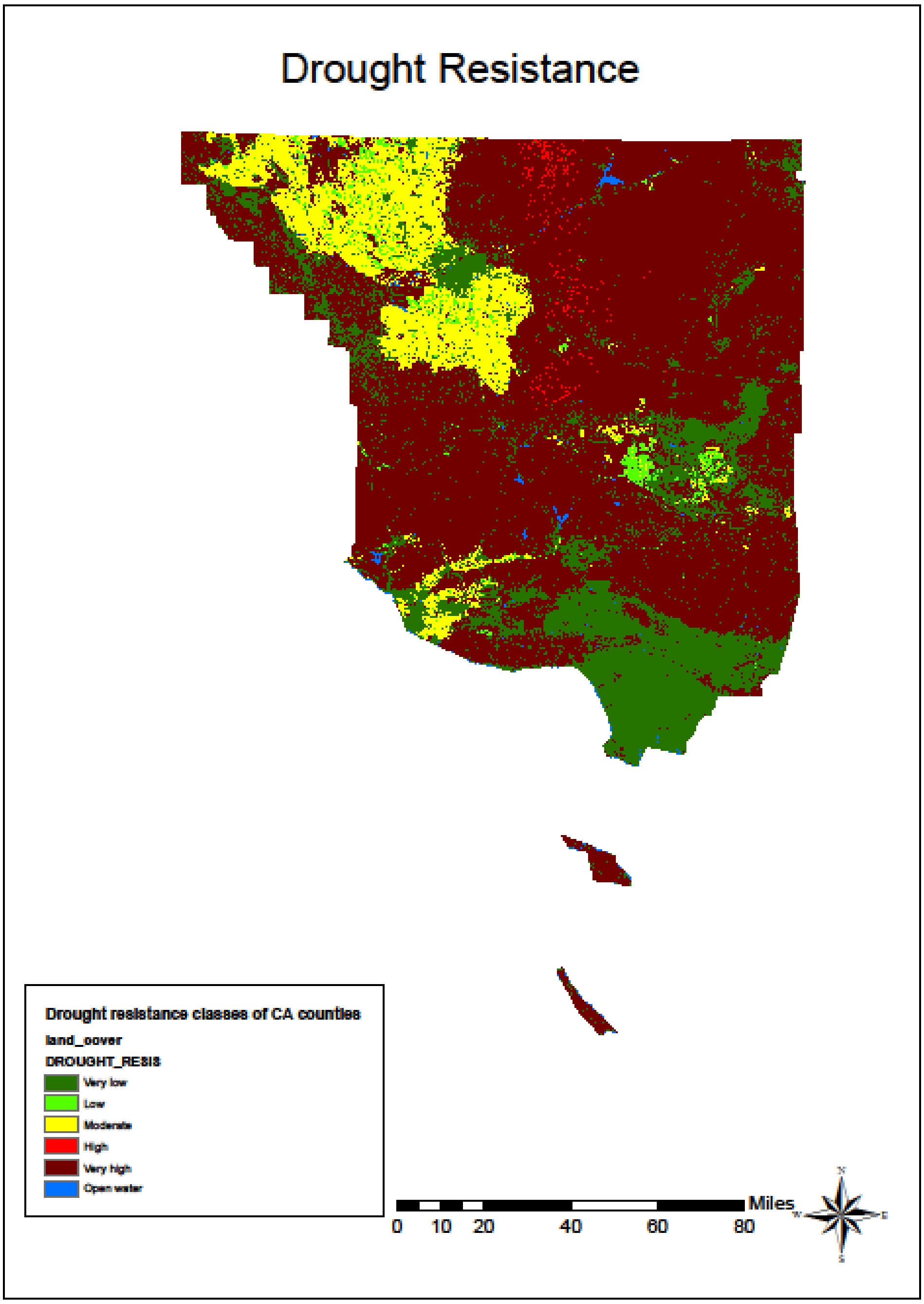

Figure 11: Spatial distribution of the Drought resistance for the California (CA) counties studies. See Table 18 for details.

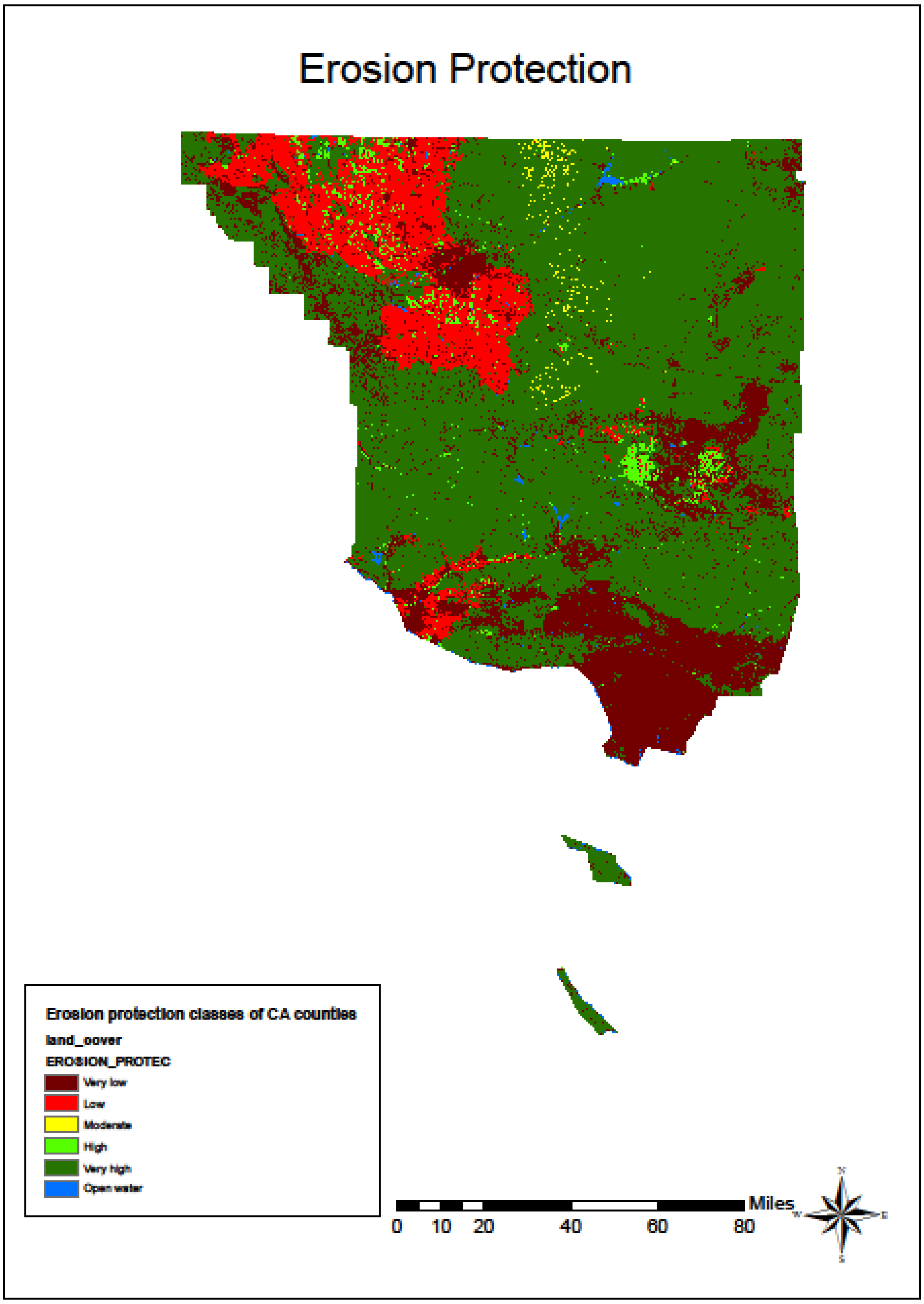

Figure 12: Spatial distribution of the erosion protection for the California (CA) counties studies. See Table 18 for details.

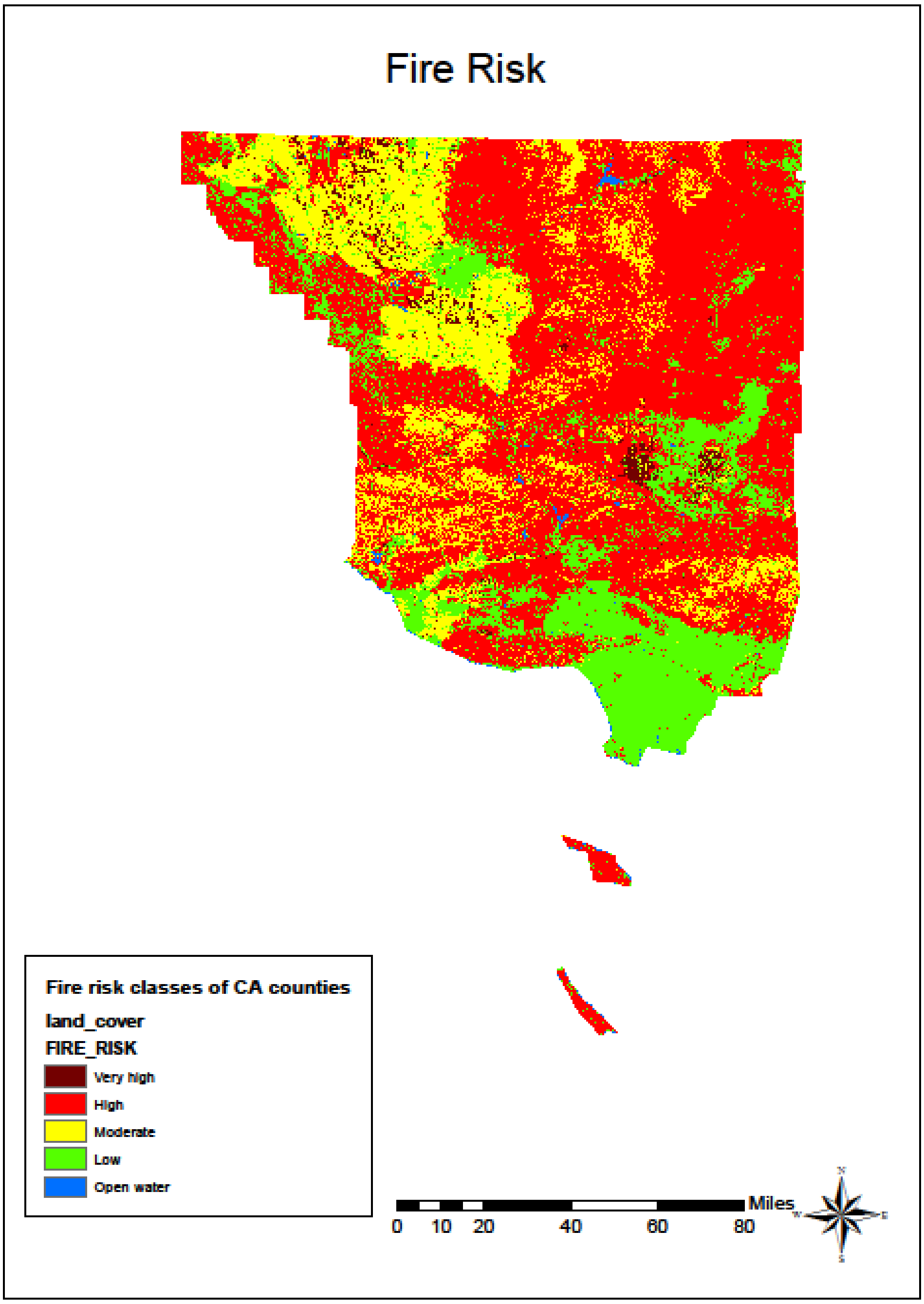

Figure 13: Spatial distribution of the fire risk for the California (CA) counties studies. See Table 18 for details.

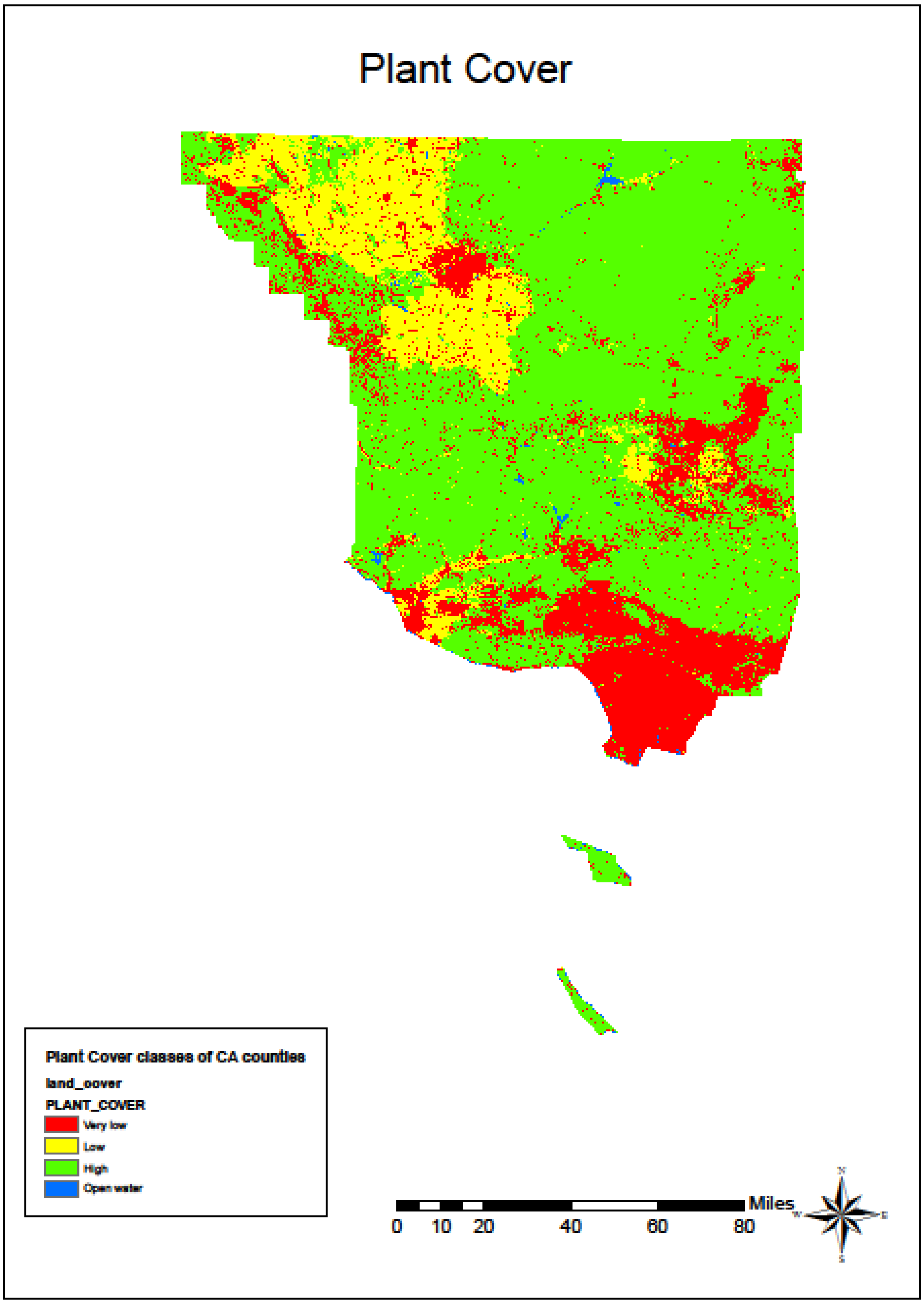

Figure 14: Spatial distribution of the plant cover for the California (CA) counties studies. See Table 18 for details.

Appendix B

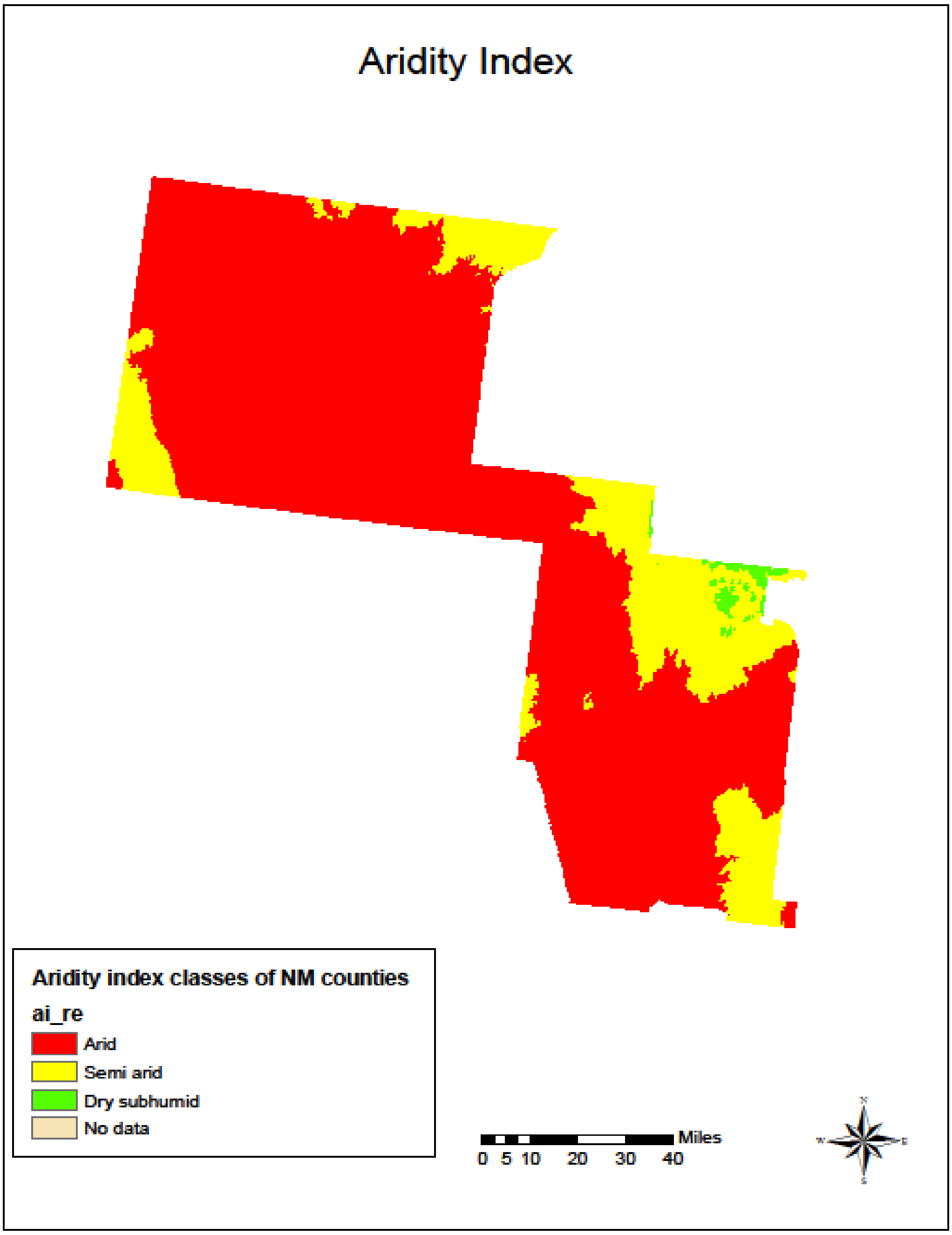

Figure1: Spatial distribution of the aridity index for the New Mexico (NM) counties studied. See Table 5 for details.

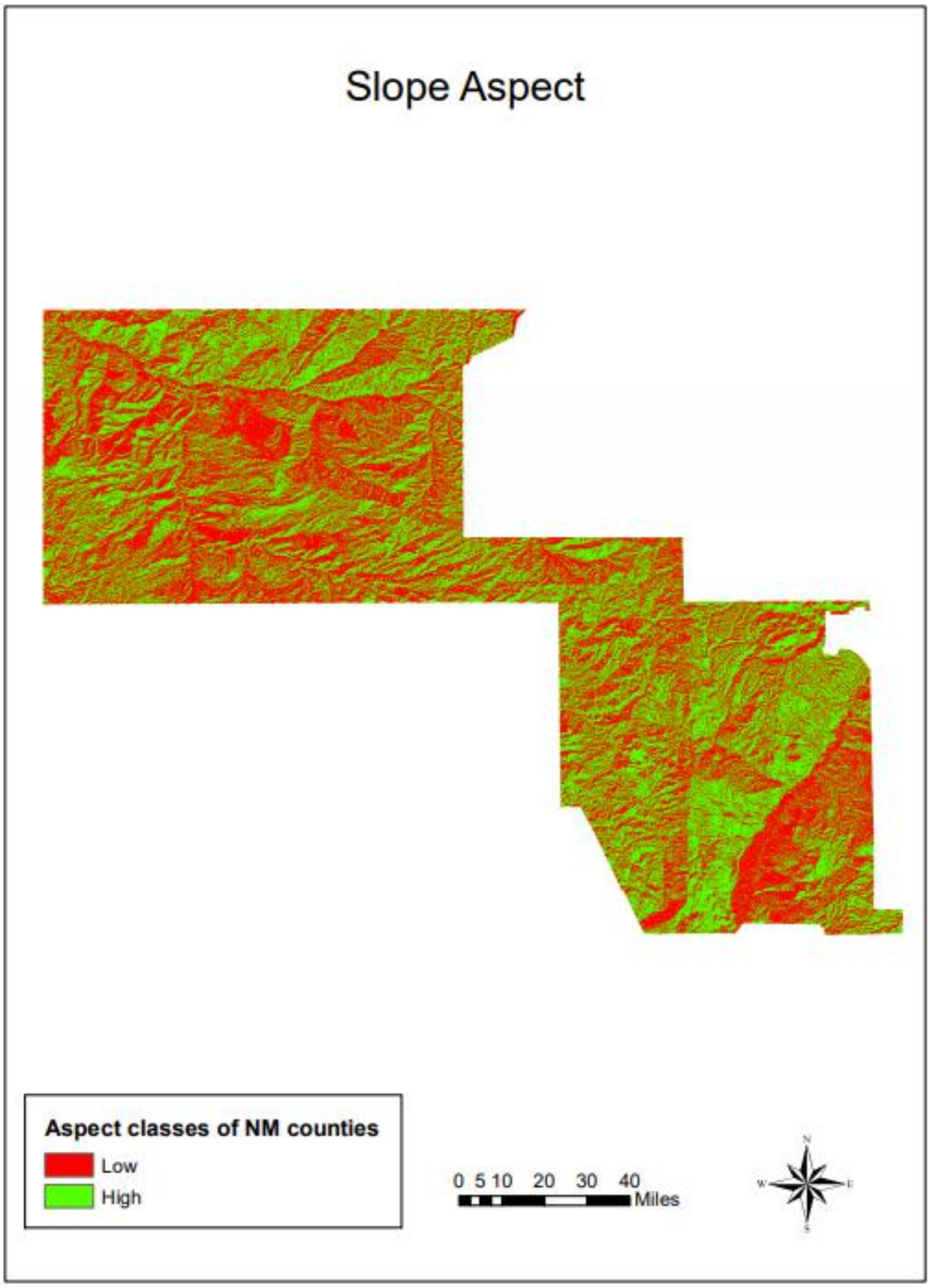

Figure 2: Spatial distribution of the slope aspect for the New Mexico (NM) counties studied. See Table 5 for details.

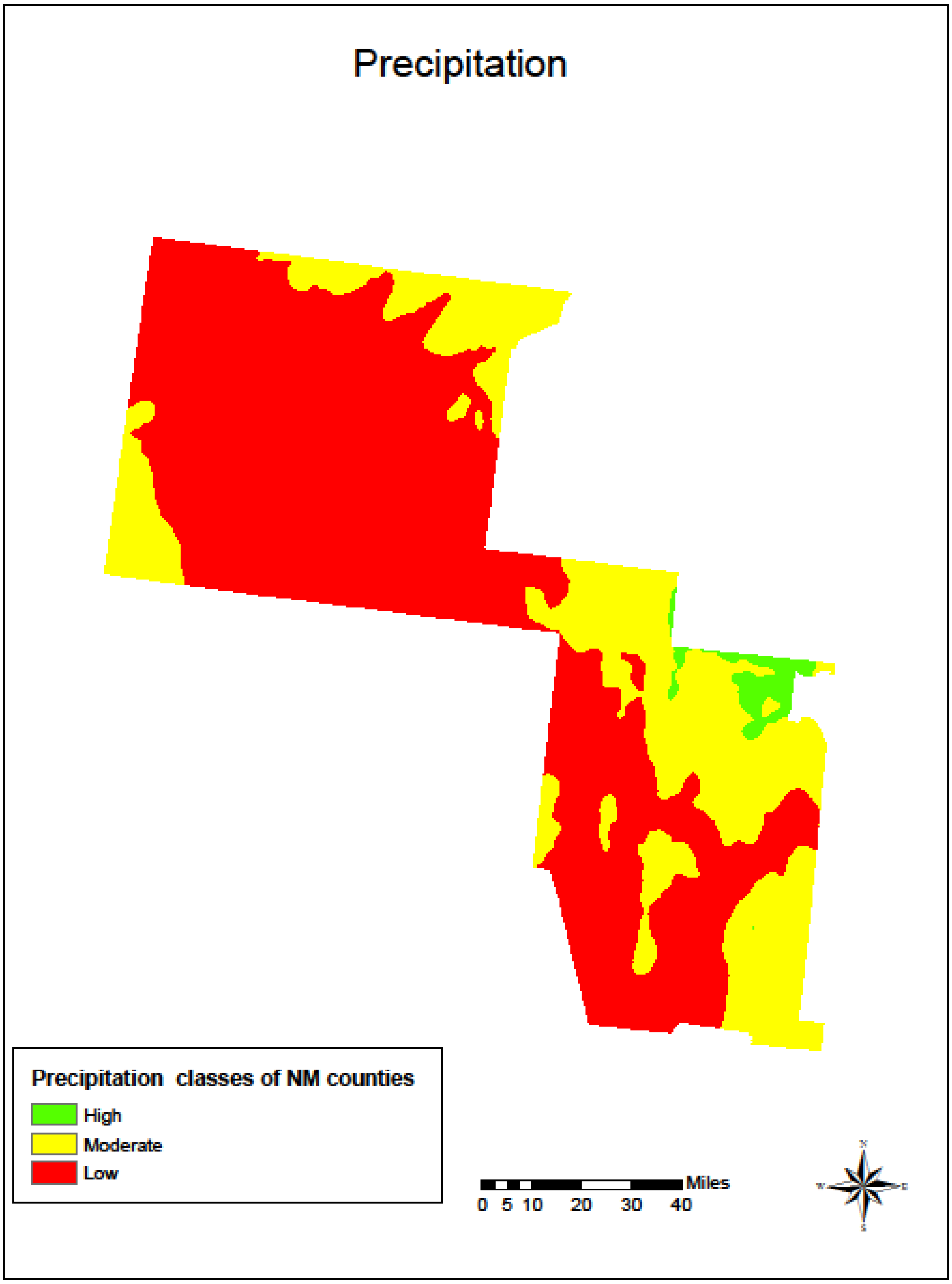

Figure 3: Spatial distribution of the precipitation for the New Mexico (NM) counties studied. See Table 15 for details.

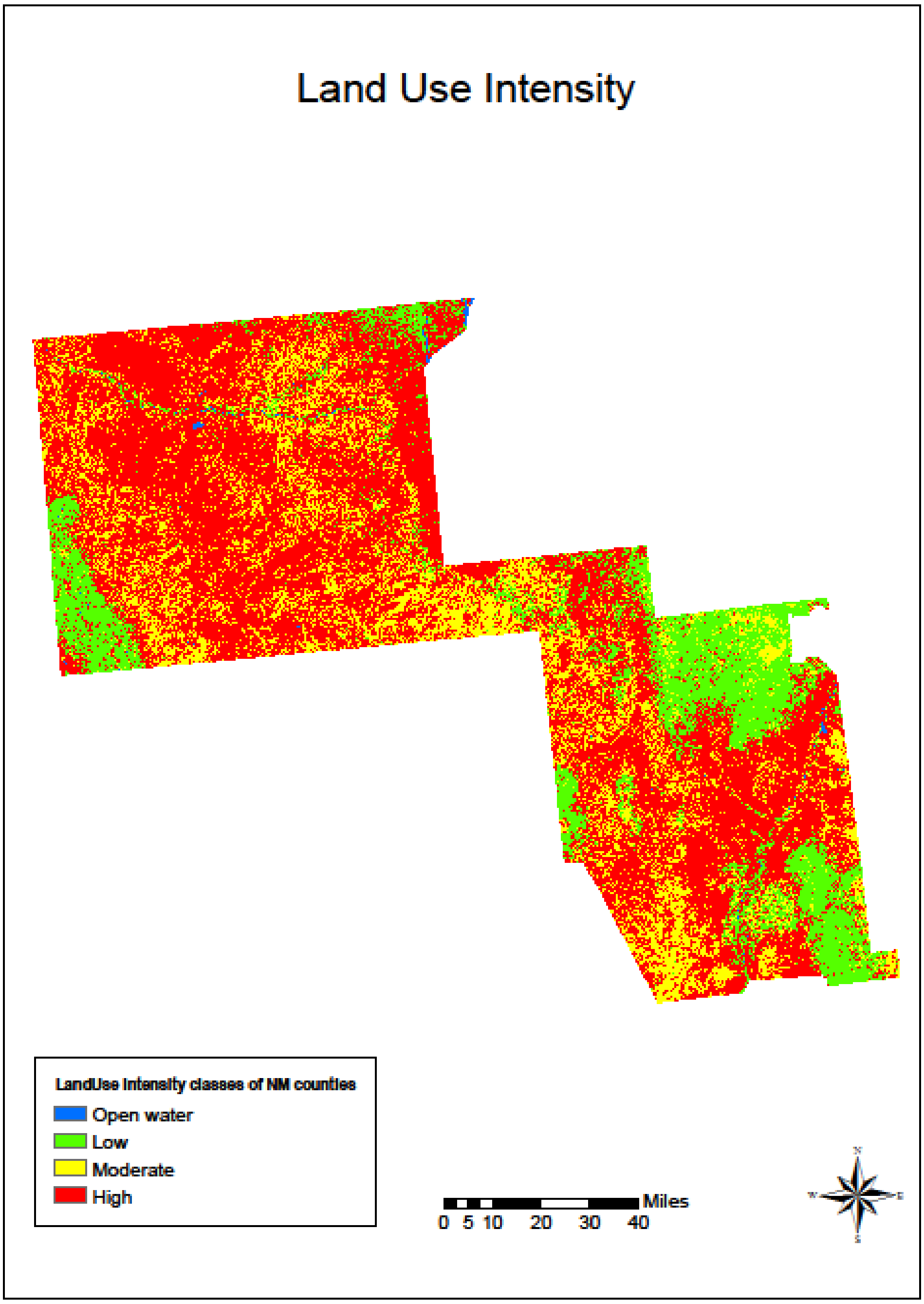

Figure 4: Spatial distribution of the land use intensity for the New Mexico (NM) counties studies. See Table 7 for details.

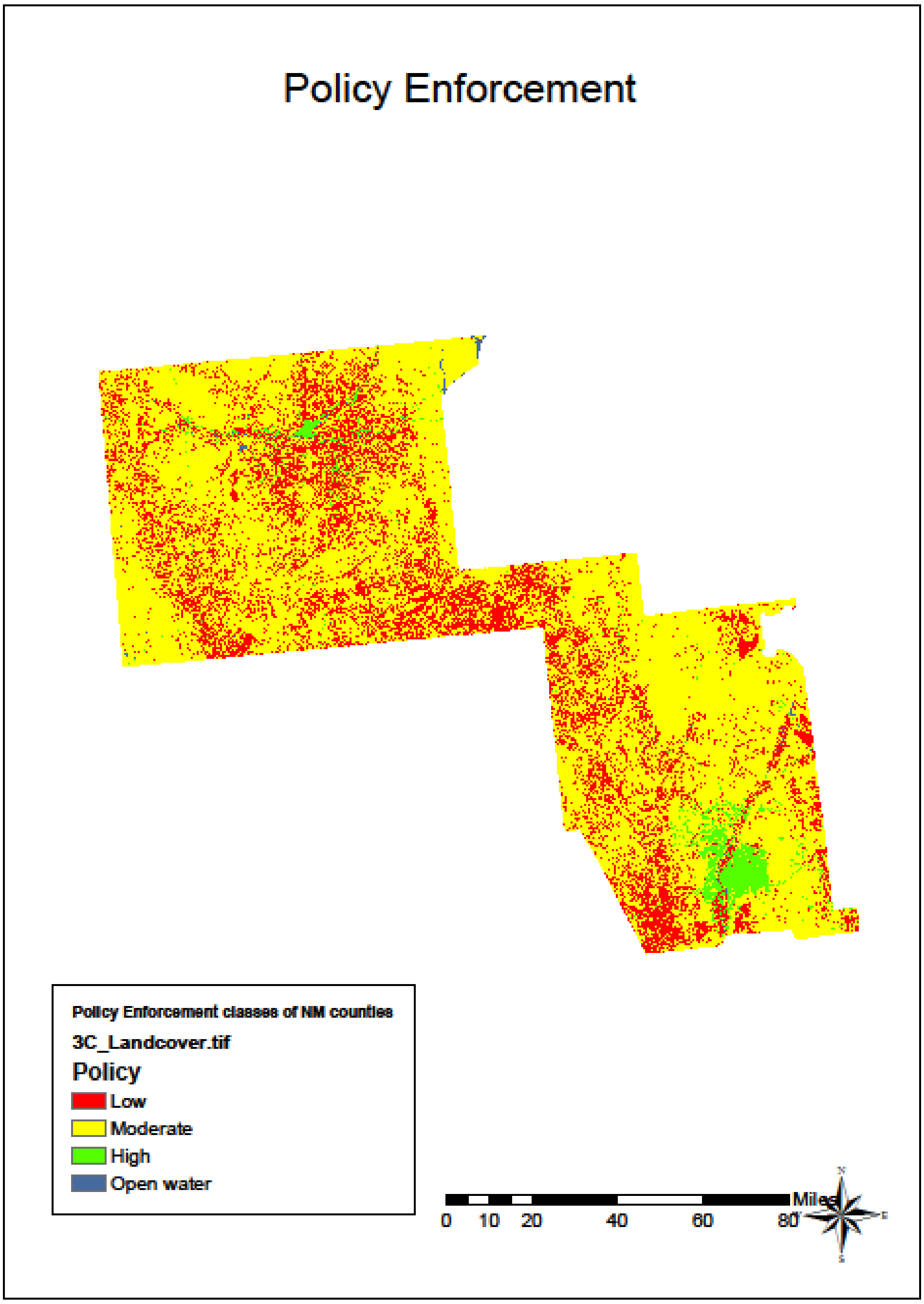

Figure 5: Spatial distribution of the policy enforcement for the New Mexico (NM) counties studies. See Table 7 for details.

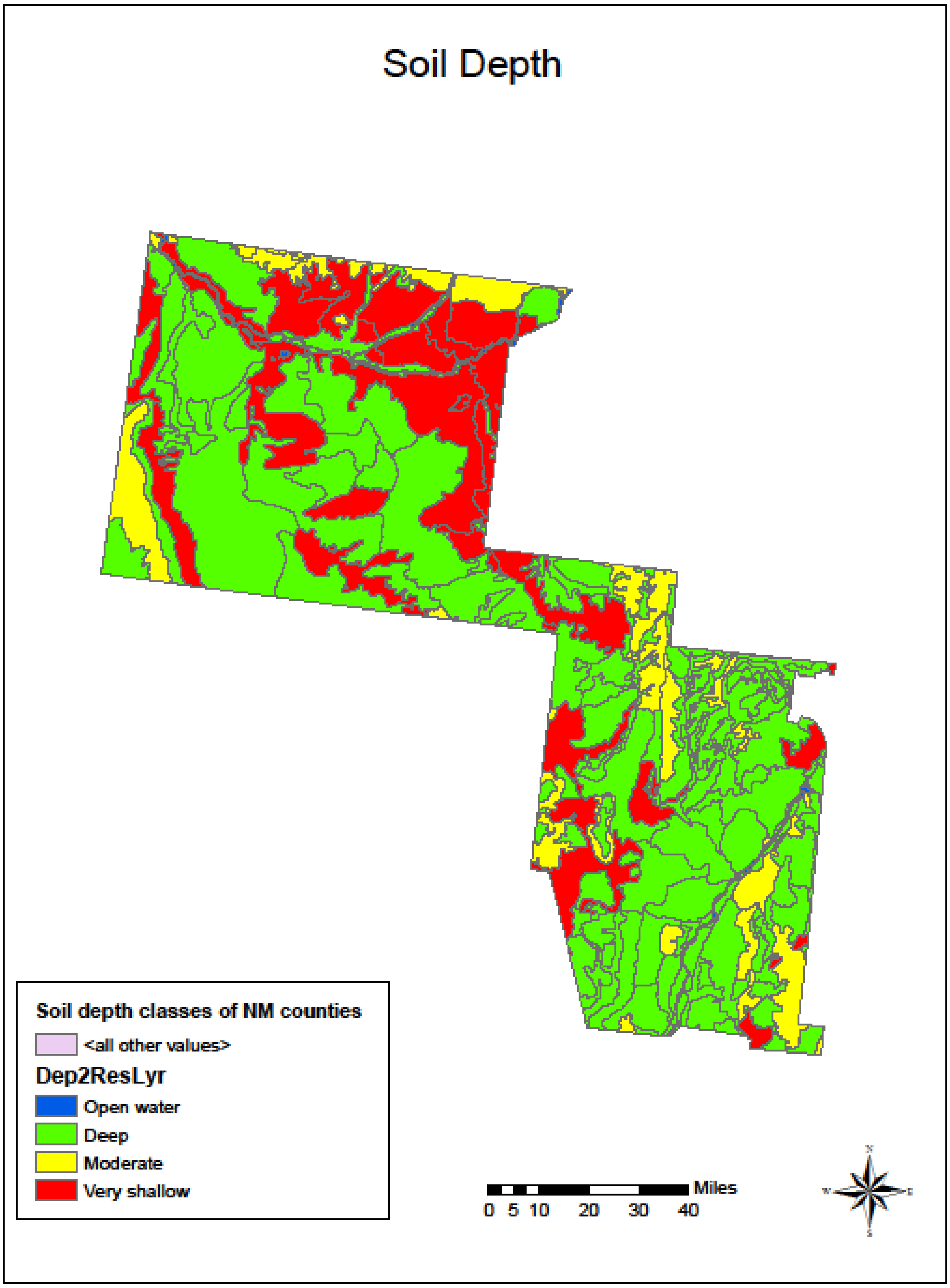

Figure 6: Spatial distribution of the soil depth for the New Mexico (NM) counties studies. See Table 11 for details.

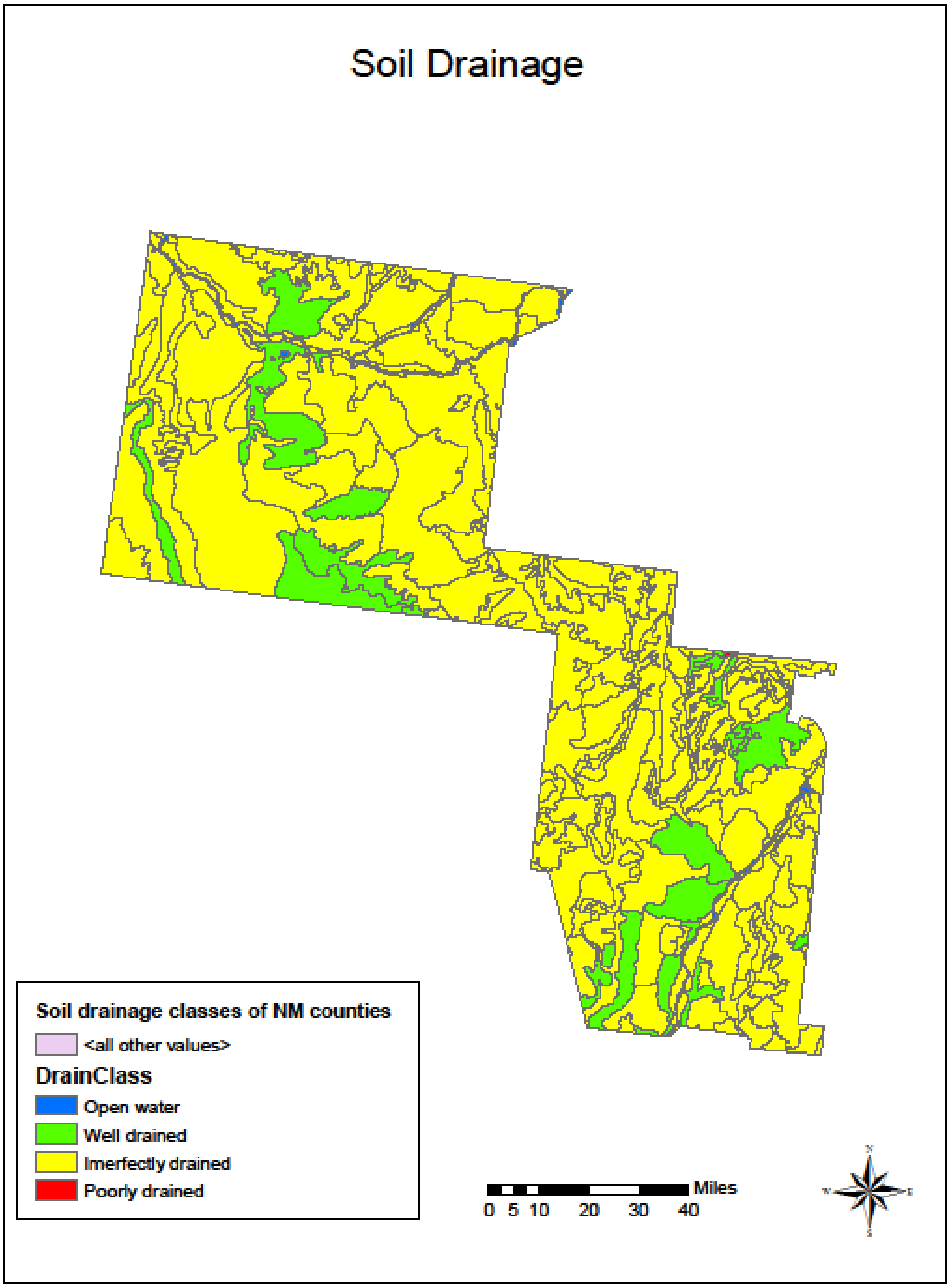

Figure 7: Spatial distribution of the soil drainage for the New Mexico (NM) counties studies. . See Table 11 for details.

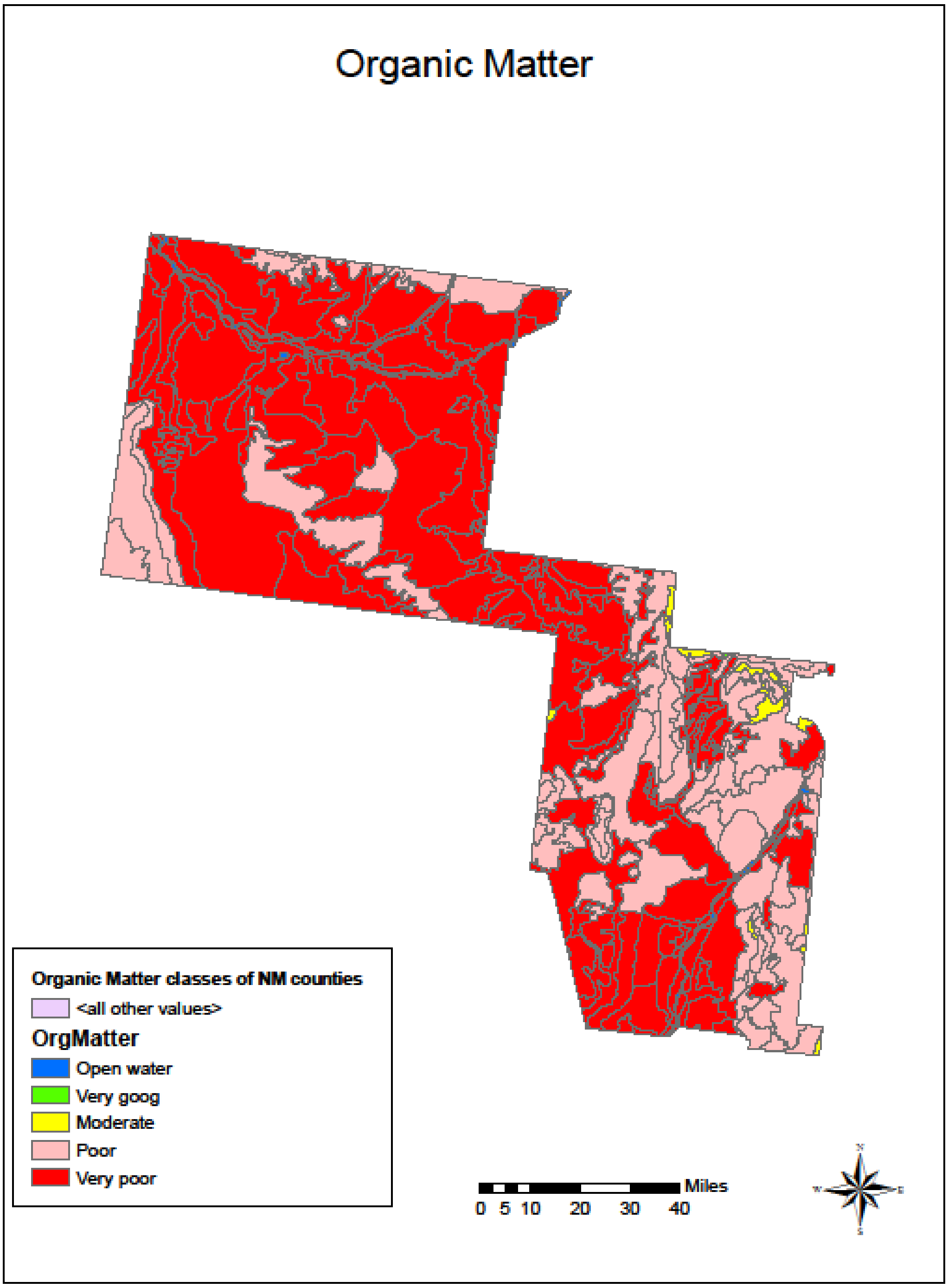

Figure 8: Spatial distribution of the Organic matter for the New Mexico (NM) counties studies.

See Table 11 for details.

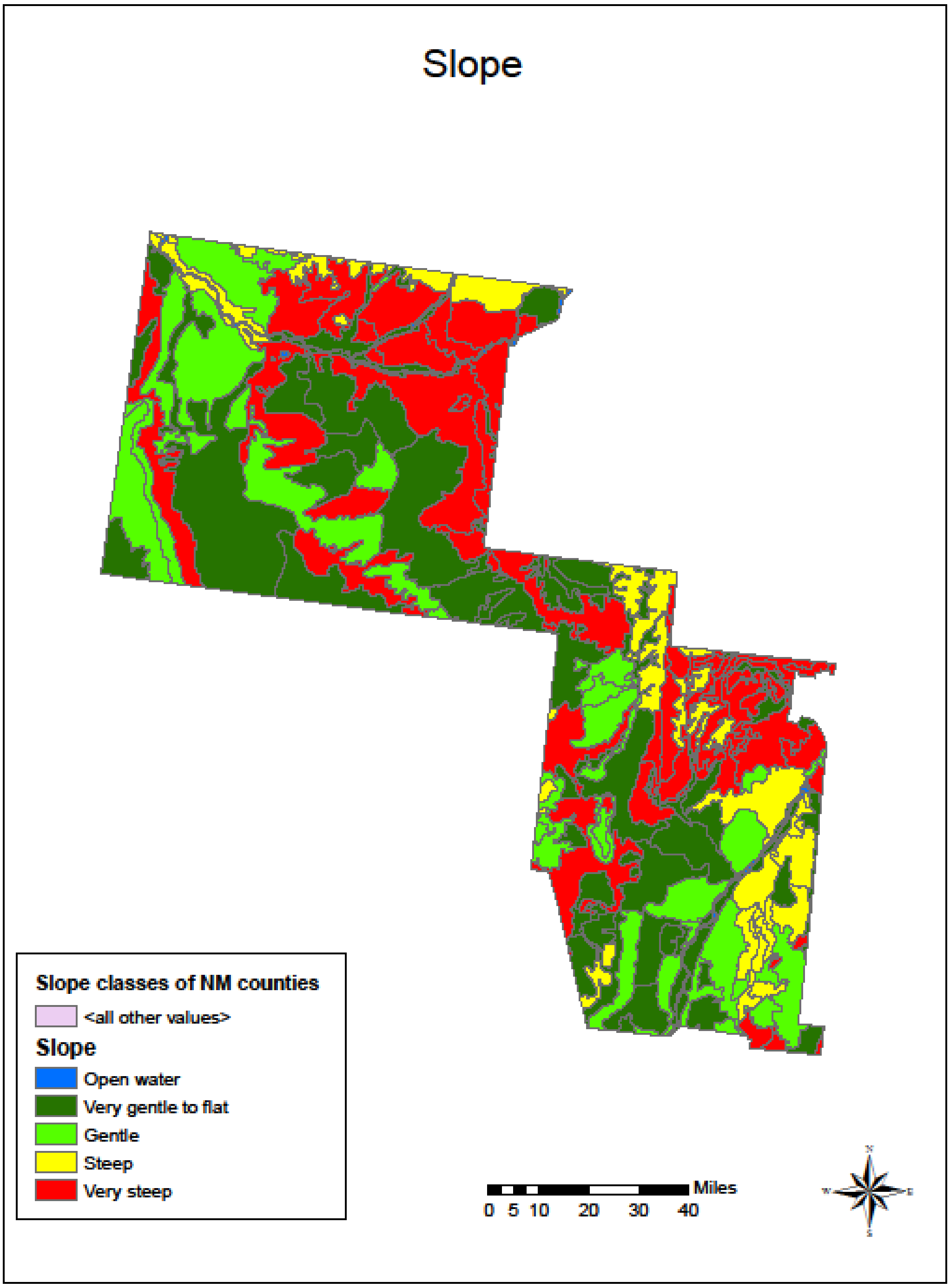

Figure 9: Spatial distribution of the slope for the New Mexico (NM) counties studies. See Table 11 for details.

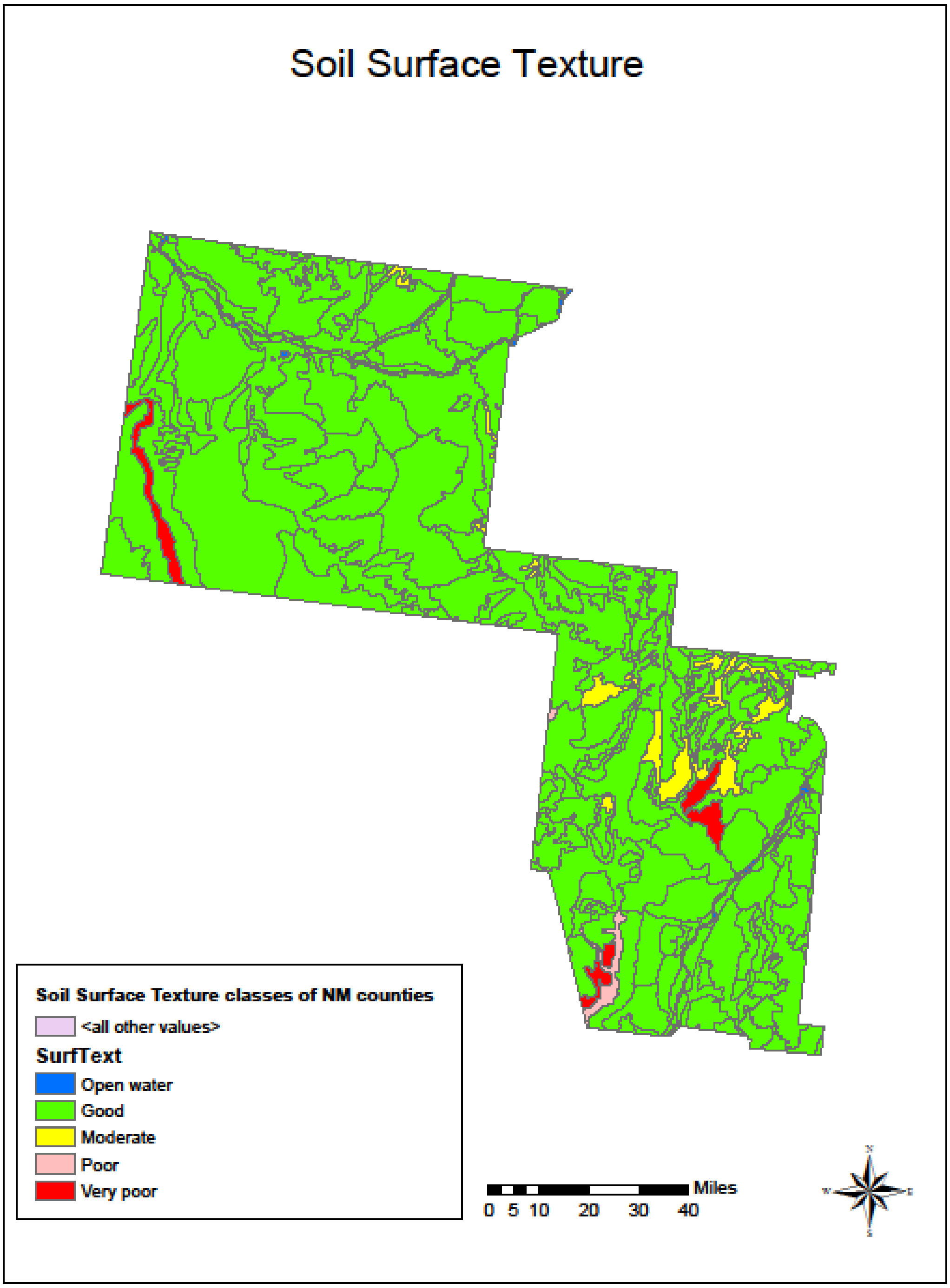

Figure 10: Spatial distribution of the soil surface texture for the New Mexico (NM) counties studies. See Table 11 for details.

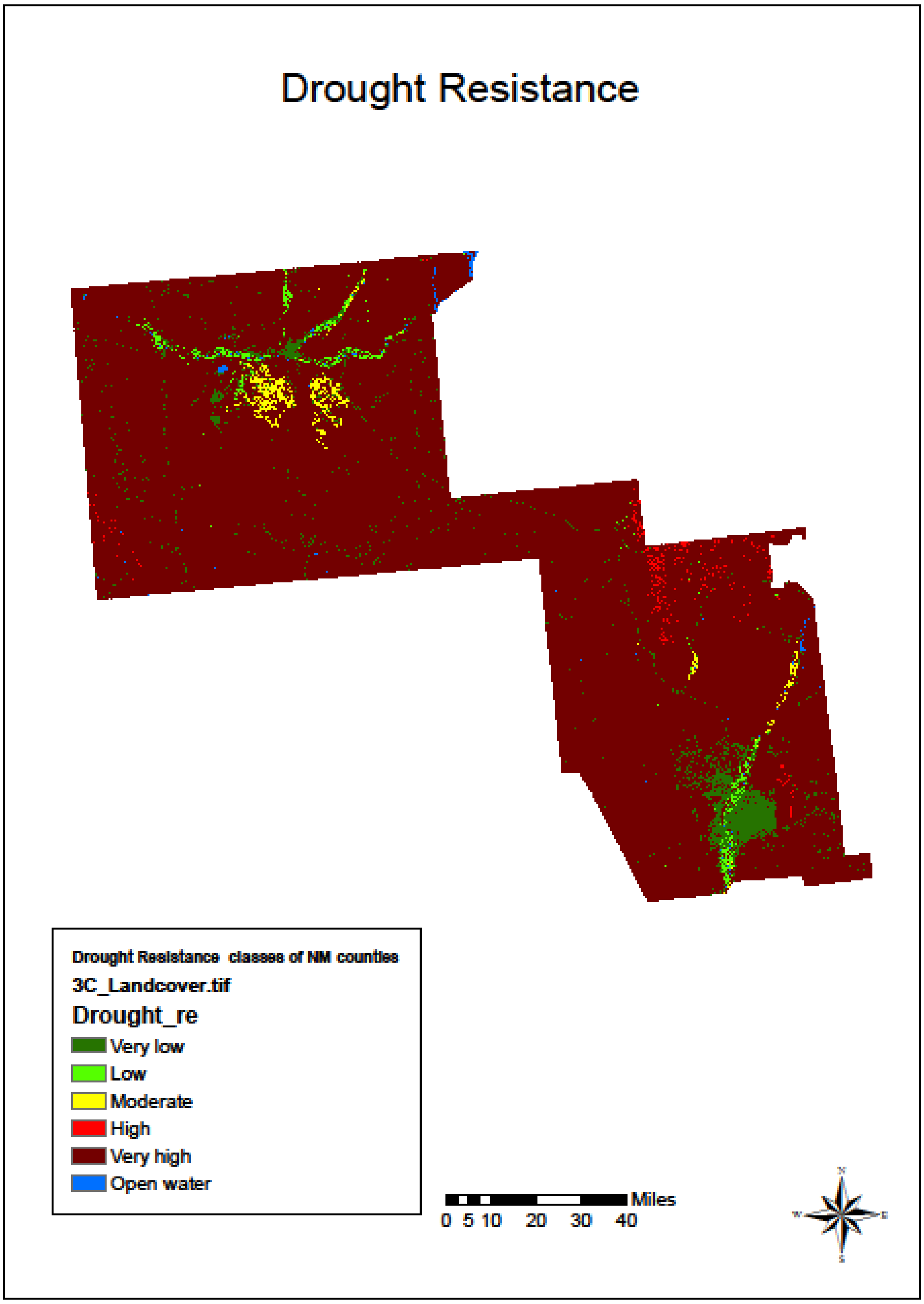

Figure 11: Spatial distribution of the Drought resistance for the New Mexico (NM) counties studies. See Table 11 for details.

Figure 12: Spatial distribution of the erosion protection for the New Mexico (NM) counties studies. See Table 18 for details.

Figure 13: Spatial distribution of the fire risk for the New Mexico (NM) counties studies. See Table 18 for details.

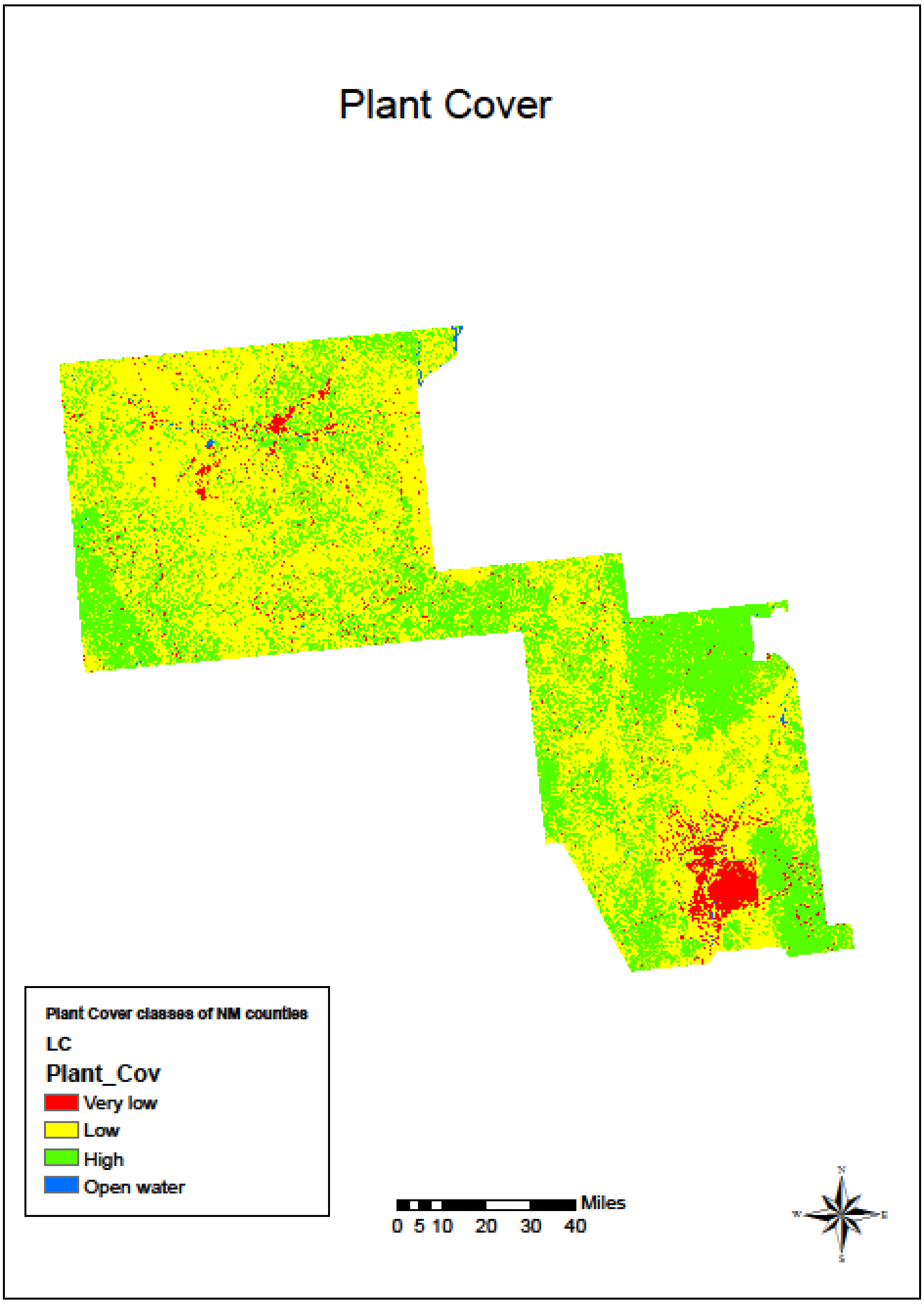

Figure 14: Spatial distribution of the plant cover for the New Mexico (NM) counties studies. See Table 18 for details.