June 2022

Assessing Environmental Sensitivity in San Diego County, California, for Bird Species of Special Concern

Eda Okan Kilic
University of South Florida

Assessing Environmental Sensitivity in San Diego County, California, for Bird Species of Special Concern

by

Eda Okan Kilic

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science Degree in Environmental Science and Policy
Department of Geosciences
College of Arts and Sciences
University of South Florida

Major Professor: Joni Downs Firat, Ph.D.
Philip Van Beynen, Ph.D.
Sarah Sheffield, Ph.D.

Date of Approval:
June 23, 2022

Keywords: desertification risk, land degradation, environmentally sensitive area, MEDALUS

DEDICATION

This study is dedicated to my son, Salih Sahin Kilic. You have made me stronger, better, and more fulfilled than I could have ever imagined. I love you to the moon and back.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my deep and sincere gratitude to my advisor Dr. Joni Downs Firat for her continuous support of my research and study, for her motivation and patience. Her guidance assisted me in all the time of research and writing of this thesis. Therefore, I am very proud to have her as my advisor.

I would like to thank my committee members, Dr. Philip Van Beynen, and Dr. Sarah Sheffield, for their warm encouragement, advice, and insightful comments.

I would also like to express my deepest gratitude to my parents, Salih Zeki Okan and Nalan Okan, for their prayers, caring, and sacrifices for educating and preparing me for my future. I am eternally grateful to both for their endless love and support, instilling in me the value of perseverance. I love you both and I appreciate everything that you have done for me Also, I express my thanks to my sisters, Selda Okan Unutmaz and Nisagul Okan, and my nephew Ulas, for their love and for always being there for me. I also would like to express my gratitude to my friend Barchinai Dzhuraeva.

I would also like to give special thanks to my beloved husband, Mehmet Kilic, for his moral support. This study would certainly not have been possible without my husband who encouraged, challenged, supported, and loved me. All I know is that he kept me going and with his care and faith in me, it has become possible for me to reach this stage.

Last but not the least, I owe a great debt to the Republic of Turkey, and the Ministry of National Education for giving me this opportunity and providing me with financial support.

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ABSTRACT

It is widely recognized that desertification constitutes one of the biggest environmental problems on Earth. Desertification negatively impacts the future of humans and other living things all over the globe. Therefore, the assessment of desertification is essential to both monitor and combat desertification. A number of models are routinely applied to assess desertification. The MEDALUS model is one of the most popular approaches, identifying desertification risk based on an environmentally sensitive area index (ESAI) that integrates climate, vegetation, soils, groundwater, and socio-economic factors to obtain an overall rating. The goal of this study was to measure potential impacts of desertification on bird species of special concern in San Diego County, California. First, the ESAI was applied to the county using a geographic information system (GIS). Second, the resulting ESAI was overlaid to the ranges of first priority seven taxa of bird species of special concern. The results illustrated that the area has high desertification risk. In addition, seven taxa of bird species of special concern may be under desertification stress. Changes in land use and a decrease in the vegetation cover resulting from human activities the major factors of the desertification process.

CHAPTER ONE

INTRODUCTION

Desertification, characterized by land degradation in arid, semi-arid, and dry sub-humid regions, is one of the major environmental and socio-economic problems on a global scale (IPCC, 2019). It affects large drylands around the world. Approximately 40% of the terrestrial Earth's surface is covered by drylands; in other words, desertification affects at least 30% of the global population (The world's Dry Areas, 2021). Although desertification is considered a serious problem worldwide, there is no single cause of desertification. Factors related to desertification can be indirect (population density and growth, socio-economic drivers) or direct (land use, land management, and climate-related processes) (Sterk, et al., 2016).

Desertification is a process of vigorous ecological destruction, often characterized by an alteration of the natural water resources in an area. This may cause a reduction in the usefulness of areas for wildlife. As a result of that, coping with the threat of desertification can be difficult for native wildlife in the area. Additionally, in the desertification process, population alteration (decrease or increase) of some animal species and permanent destruction of flora and wildlife can be witnessed (Fekadu, et al., 2020).

Over the years, several methods and approaches improved to synthesis desertification and land degradation (Bridges and Oldeman, 1999; Bai et al., 2008; Van Lynden et al.). The MEDALUS environmentally sensitive area index (ESAI) methodology is one of the greatest approaches among other models (Kosmas, C., et al., 1999). In this methodology, environmentally sensitive areas, in other words vulnerable areas to desertification, are determined using numerous indexes. The ESAI combines soil quality, climate quality, vegetation quality, socio-economic quality, and groundwater quality parameters to compute an overall index of desertification risk.

This study used the ESAI to map areas of environmental sensitivity to desertification in San Diego County, California, to assess potential risk to seven first priority taxa of bird species of special concern. Specifically, twenty-one parameters belonging to those five parameters are employed in the ESAI equation to produce desertification risk and sensitivity of seven first priority taxa of bird species of special concern maps. These maps will benefit to estimate the desertification sensitivity and assess the most important factors affecting desertification in San Diego County, California, in particular for at-risk bird species.

CHAPTER TWO

LITERATURE REVIEW

2.1 Desertification

2.1.1 Overview

About one-sixth of the world's population, 70 percent of all drylands, and one-quarter of the world's total land area are affected by desertification, which is one of the most alarming processes of environmental degradation. One of the biggest effects of desertification is widespread poverty. In addition to this, the degradation of 3.3 billion hectares of pastures with low animal and human carrying capacity, the decrease in soil fertility and structure in rainfed cropland areas by approximately 47 percent, and in irrigated cropland at 30 percent, are other effects of desertification (Declaration, 1992).

The term *desertification* was first used by a French biologist working on grasslands in arid southern Tunisia (Houérou, 2002). The actual definition of "*desertification*" is a controversial issue. It has different definitions and concepts. The main factors or processes changes (involved or excluded) according to the authors' perspective; therefore, several definitions of desertification have been used in some academic research. In the paper by Verstraete (1986), for example, it is mentioned that some authors are maybe more concerned about overgrazing by livestock than wildlife overgrazing. Likewise, while soil erosion, grazing, tree cutting, bad agricultural practices are considered the most critical desertification processes, waterlogging, salinization, drought, and termites are less admitted.

Even though there is an ambiguous definition of desertification, the UN, affirmed definitions of desertification presented at United Nations Convention to Combat Desertification (UNCOD) in 1977 are used by a majority. In 1990, the experts demanded a new definition of desertification to perform the plan of action to combat desertification and to obtain a more reliable and accurate global understanding of desertification. (Helldén, 1991). The UNEP describes desertification as land degradation in arid, semi-arid, and dry sub-humid areas that stem most from adverse human impact (UNEP, 1991). However, a commonly adopted description of desertification, stated in Chapter 12 from Agenda 21 of the United Nations Conference on Environment and Development (ICCD/COP, 2007) by the United Nations Convention to Combat Desertification (UNCCD), is 'land degradation in arid, semi-arid, and dry sub-humid areas arise from diverse factors, with the inclusion of climatic variations and human activities' (Akbari, et al., 2020).

2.1.1.1 Land degradation and Aridity

Land degradation is turning out to be one of the most prominent environmental problems, because if land degradation occurs in the drylands, it often creates desert or desert-like conditions. Land degradation is affecting developing countries as well as developed countries, including those in North America, Australia, and Southern Europe (Bajocco, et al., 2012). Globally, approximately 1.5 billion people depend on degraded areas directly, which is 24% of the land (UNDDD, n.d.).

Land degradation results from changes in land use or processes arising from human activities and habitation patterns in rain-fed cropland, irrigated cropland, range, pasture, forest, or woodlands, which results in a loss or decrease in their biological or economic productivity and complexity (UNCCD, 1992). Preference of land degradation terms widens the focus to include natural resources, such as climate, water, landforms, and vegetation. Widely accepted direct drivers of land degradation under broad categories are climatic, overgrazing of rangeland, over-cultivation of cropland, waterlogging and salinization of irrigated land, deforestation, pollution, and industrial causes (Stocking, et al., 2000).

Although low precipitation is a prominent feature of aridity, the efficiency of precipitation is of greater importance. Whilst high efficiency means low temperatures and high humidity (i.e., low evapotranspiration), low efficiency means high temperatures with low humidity (i.e., high evapotranspiration). An aridity index is commonly used to measure precipitation efficiency (Tolba, et al., 2008). The UNEP Atlas of Desertification (1992) presents the index of aridity as rainfall (mm)/ potential evapotranspiration to express the aridity or dryness of a climatic zone. Drylands are classified into four classes and zones:

- Extremely arid zones- aridity index is less than 0.05-the average annual rainfall below 60–100 mm this is inadequate for dryland farming or livestock grazing.
- Arid zones- aridity index is between 0.05 – 0.2- 200 mm. in winter rainfall territories, 300 mm in summer rainfall territories and possible livestock grazing.
- Semi-arid zones-aridity index is between 0.2 – 0.5 500 mm. in winter rainfall territories, 800 mm in summer rainfall territories and possible cultivation of drought-resistant crops
- Dry sub-humid zones-aridity index is between 0.5 – 0.65- in one (or more) rainy seasons precipitation in the range from 600 mm to 1200 mm. Water scarcity can be either seasonal or occasional

Considering these classification boundaries, drylands occupy 41.3% of the world's terrestrial areas: 6.6 % is extremely arid, 10.6 % arid, 15.2 % semi-arid, and 8.7 % dry sub-humid (UNDDD, n.d; Mainguet, 1994).

2.1.1.2 Global distribution of areas affected by desertification

Approximately 41% of the Earth's land surface is covered by drylands, corresponding to about 35% of the world's population. The population of over 2 billion people living in developing countries is supported by 90% of drylands (MEA, 2005). The main reasons for the desertification in Asia, Africa, and Australia are the extension of infrastructure for cropland irrigation and pasture development (reservoirs, dams, canals, boreholes, and pump stations) and water-related infrastructure (Niamir-Fuller, 1999). The growing human settlements and the accompanying need for increased food production and food security are the ground for building irrigation infrastructure in Asia and Africa. In addition, the extraction of wood (firewood, pole wood, charcoal) from forests and woodlands is another determinant concerning desertification (Geist, et al., 2004).

In China, desertification was evaluated first during the mid-1980s nationwide. The most spectacular outcome of desertification in China is a widespread increase in desert-like sand cover caused by wind erosion (Sneath, 1998). According to Chinese Committee for Implementing UN Convention to Combat Desertification (CCICCD) the total desertification in China is 2.622 million km2. 607×10^3, 205×10^3, 363×10^3, 233×10^3, and 214×10^3 km^2 of this desertification area is formed by wind erosion water erosion, frozen and melting processes, soil salinization, and degradation by other driving factors, respectively (Yang, et al., 2005).

Drylands in Africa cover the rough one-third of the world's drylands and consist of 1959 million ha or 66 percent of the continent together with hyper-arid deserts. One-third of this area is hyper arid desert (672 million ha) that are uninhabited without counting tiny oases and two-thirds of 1287 million ha is composed of arid, semiarid, and dry subhumid areas. Desertification in Africa affects 73% of agriculturally used drylands moderately or highly; irrigated cropland (18% of the total area), rainfed cropland (61% of the total area), and rangeland (74% of the total area) (UNEP, 1992a).

Australia is roughly 85% dryland and has no extremely arid climatic zone. 60% of Australia's total area is used for agriculture, 90% of which is grazing, and 10% is cultivated land (Dregne, 2002). According to a study conducted by Commonwealth/State collaborative; 3,356,000 km2 of land in use in the drylands about 1,850,000km2 need degradation control and almost 1,000,000km2 rangelands be afflicted with vegetation degradation. while vegetation and water and wind erosion constitute around 900,000 km2, 4,200 km2 are affected by dryland salinity and thirty-eight thousand km2 are scalded (Woods, 1984).

Twelve countries, 3 in North America and 9 in Central America, are covered by drylands. The arid area (7.6 mi km2) corresponds to almost one-third of the total area. The semi-arid area covers 4.8 mil km2 of the total area or approximately 3% of the earth's surface. 2.8 mil km2 of the semi-arid region is located within the US (United States) territory and mostly in the western part, while 0.8 mil km2 is in Mexico. Canada also has the high percentage of dry sub-humid areas that is about 1.4 mil km2 (14%). Dryland in south America covers 5.1 mil km2 and semi-arid areas 2.4 mil km2 of the total area (18 mil km2). In the European continent, 1.7 mil km2 of the total area (10-mil km2) is exposed to aridity. Spain has the largest drylands area which is the 70% of the country’s area (Prăvălie, 2016).

2.1.2 Causes of Desertification

2.1.2.1 Anthropogenic Factors

Human actions are one of the leading causes of desertification which are overgrazing, over cultivation, deforestation, and salinization on irrigated cropland. Human-induced desertification is caused by the increasing population density that triggers intense land use and pressure on natural resources (Patel, 2021). Deforestation leads to a reduction in vegetation cover and causes land degradation, one of the results of population growth and increase. With the growing population, the food supplies are being expanded by shifting forest areas into annual or permanent crops. Also, in some developing countries forests are cut to provide wood fuels for local populations' domestic cooking and heating demand (Allen and Barnes, 1985). The disappearance of many trees contributes considerably to land degradation and the deterioration of soil fertility (Anjum, et al., 2010).

Unsustainable agricultural practices also cause desertification because they include extensive and dense cropping of agricultural areas and overabundant use of fertilizers and pesticides (Ghrefat, n.d.). In arid regions, overgrazing is one other major cause of desertification. Especially, overgrazing is most widespread in areas socio-economic feasibility depends largely on animal husbandry. Grazing in arid regions reduces ground cover, productivity, and litter accumulation and destroys the topsoil structure which results in rising in soil crusting, lowering infiltration, increasing soil erosion, and generating a decline in soil fertility (Milchunas and Lauenroth,1993; Lavado, et al., 1996). Unmaintainable water management practices which are poor and inefficient irrigation practices and overexploitation of groundwater increase the salt concentration in the depleted aquifers lead to the desertification problem (Katyal and Vlek, 2000; Ghrefat, n.d.). For instance, in Nigeria, lack of insufficient information and skills about planning and managing the irrigation system has caused waterlogging and salinization causing irrigated farmlands to turn into desert conditions (Olagunju, 2015).

2.1.2.2 Natural Factors

Natural events can also be the cause and contribute to desertification other than human causes. Temperature, precipitation, wind, vegetation, and composition of surface materials are natural causes of desertification. Temperature and precipitation are found to be most significant in these natural causes because both have an impact on wind, vegetation, and composition of surface materials. In fact, rising temperature and decreased precipitation aggravate desiccation, cannot improve vegetation and reverse desertification (Xue-Yong et al., 2002). According to a study conducted by Luoand Peng (2004) on all the factors that were relevant to desertification, precipitation is found to be the most important factor. Increase in variability in rainfall and climate conditions and long-lasting droughts boost the aridity by greatly affecting desertification. For instance, in Southern Africa annual rainfall 1.5% decreased over the last quarter of 20^{th} century (Geist and Lambin, 2004). Furthermore, most importantly, climate change and global warming have a significant impact on rainfall patterns consequently contributing to desertification. Both can result in natural disasters like floods and droughts. Particularly, overgrazing in terrestrials be affected by drought can cause a reduction in vegetation cover due to lack of water. This leads to being soil bare and vulnerable to wind or water erosion (McSweeney, 2020). However, desertification contributes to climate change. Since desertification provokes vegetation and soil losses, it reduces carbon sequestration. Because of this, the carbon released from drylands to the atmosphere is assessed at 300 million tons (Zafar, A. et al., 2005).

2.1.3 Impacts of desertification

2.1.3.1 Environmental impacts

Desertification can cause some physical consequences like sand, dust storms and flooding resulting from insufficient drainage and poor irrigation system. These environmental factors can result in the removal of necessary soil nutrients and topsoil for crop production and loss of vegetation cover that has a crucial duty to remove carbon dioxide from the atmosphere. In India, for example, every year 2.5 million hectares turn into wasteland, and in Asia sandstorms harm and cause destruction in environment because of deforestation (UN,2003).

Wild species, domestic animals and agricultural crops and people are also adversely affected by desertification. According to Bullock and Le Houérou (1994), many plant and animal species are prone to be endangered due to desertification (Bullock and Houerou, 1996). In Nigeria, large number of animal and plant species which are important for human being are threatened (Olagunju, 2015). Deterioration of natural resources resulted in complete desert conditions in Sudan and desertification destroying most of the wildlife animals. Seasonal vegetation could not provide animals with convenient living conditions in Sudan. The absence of gazelles outside the protected natural sites in Sudan is the result of this situation (Eltoum, et al., 2015). Migratory species are especially vulnerable to land degradation. They depend on several habitats to accomplish long non-stop journeys. Because of habitat changes their migration pattern can change so with the limited energy finalizing long journey can be impossible.

In addition, the alteration of the periodic biologic events and behaviors (changes in their reproduction timing, mating, feeding etc.) of animals is an ecological response to desertification (Olagunju, 2015). For example, the Desert locust population, whose population increased with the drought period of 1986 in Sudan, is an example of this. The increasing population of desert locusts grounded considerable damage to the vegetation (Eltoum, et al., 2015).

2.1.3.2 Socio-Economic impacts

Desertification is not only an environmental issue influencing fauna and flora but also triggering humanitarian and economic crises. In arable lands loss of soil structure and cohesion, soil crusting, soil compaction, and soil erosion are the consequences of desertification deterioration of soil quality, reduces agricultural productivity and affects food security indirectly. Governments allocate considerable budgets that could have been used for other developmental projects on recovering the effects of desertification (Olagunju, 2015). The annual cost of combating land degradation and the annual income foregone in the areas affected by desertification is estimated by The World Bank estimates US$ 2.4 billion a year and US$ 42 billion each year respectively (Ghrefat, n.d.). Desertification in China causes US$2-3 billion annually directly and twice as much as indirectly (Zha and Gao,1997). While the loss resulting from land degradation, in some developing countries, comprises 1–17% of the gross national product, it is 10% in some tropical regions (Ghrefat, n.d.).

Migration is another socioeconomic result of desertification. People living in areas threatened by desertification are forced to move elsewhere to seek for employment and economic activities like farming, grazing, and fishing because of the absence of productive agricultural and animal practices in the rural areas (Oladipo, 1993). For instance, in Nigeria, herders living in the north towns migrate to south villages or neighboring countries having more rainfall due to aridity (NEST,1991). In Mexico, 70 percent of land under desertification risk this situation causes average 800,000 Mexicans to leave their homes every year (Kofi, 2003).

2.2 Mapping desertification and land degradation risk.

2.2.1 Overview

To date, many approaches and methods have been developed to identify degraded and deserted lands. Especially in 1996, the necessity and demand on measuring land degradation and desertification process rose after the International Convention on Desertification of the United Nations had taken effect (Anh, et al., n.d.).

Creating a desertification map to observe the desertification status is essential to preparing mitigation plans to combat desertification. For the sustainable development of countries where land degradation and desertification pose a problem or create a great potential, it is significant to understand the different factors (such as climate resources and the risk of climate-related or climate- induced natural disasters) (Sivakumar and Ndiang' Ui, 2007). In addition, observing and detecting the factors on desertification on a national scale is critical in order to combat land degradation and desertification with the participation of the state, local organizations, landowners, and the public (Mutlu et al., 2013).

2.2.2 Methods Used in Desertification Mapping

Global assessment of soil degradation (GLASOD,) which is the first estimation of the state of human-induced soil degradation, was published in 1991 (Bridges and Oldeman, 1999). The aim of GLASOD is “strengthening the awareness of policy-makers and decision -makers on the dangers resulting from inappropriate land and soil management and leading to a basis for the establishment of priorities for action programs.” To map the human-induced soil degradation, a large group of soil scientists was asked their opinions about soil degradation in particular geographic regions. However, it was not achievable to ask all national soil scientists to create their own maps. Therefore, soil degradation maps were prepared in 21 regions. The final map of GLASOD was given the best approximation of the global status of soil degradation (Oldeman et al., 1990). The GLASOD maps provide basic data on chemical, physical and erosional degradation density, and distribution worldwide. Ever since the map was produced in 1990, maps for individual countries have been requested; however, it was not possible to get this detailed information from the map or make extrapolations from existing data (Bridges and Oldeman, 1999). However, Lal (2003) assessed the extent of various types of soil degradation globally and their distribution as a continental level by adapting GLASOD data and information obtained from Oldeman along with FAO.

With the advent of remote sensing and geographical information system, remote sensing (RS) technology and GIS application have been used in all other global assessments of desertification (Zdruliet al., 2017). RS data enables to enhance the spatial representation of degraded lands on a global level and the process of land degradation. However, a major challenge for this approach is to discriminate between naturally low productivity areas -sparse vegetation and degraded areas by human impact. In most cases satellite data are just available since the 1980s, so changes can be observed for a short time frame (Gibbs and Salmon, 2015).

The Global Assessment of Land Degradation and Improvement (GLADA) is a following study of GLASOD. GLADA uses RS to detect areas where significant biological change is taking place, show possible hot spots of land degradation and bright spots of land improvement on a global scale (Bai et al., 2008). In this methodology net primary productivity (NPP), rainfall use efficiency (RUE), aridity index, rainfall variability, and erosion risk were used as main indicators. For the period 1981- 2006 satellite measurement of the normalized difference vegetation index is utilized as a proxy for NPP (Bai et al., 2011). Satellite-based assessments may capture recent or continuing degradation by measuring changes in productivity, however, they cannot get the full picture of all degraded lands (lands degraded long ago) (Gibbs and Salmon, 2015). Besides satellite data may have a problem distinguishing area between degraded and non-degraded grasslands and be limited by potentially biophysical conditions like seasonality in drylands and environmental trends) (Wessels et al., 2012).

Like GLADA, the Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD) (1997), was also follow up study of GLASOD and covered only human-induced soil degradation (Kniivila, 2004). The different soil degradation types included were water erosion, wind erosion, chemical deterioration, and physical deterioration inventoried by ASSOD. However, it has been indicated to have important limitations. Firstly, it ignored some significant components such as vegetation and biodiversity, second it could not be used in periodic quantitative monitoring over time due to expert-based assessment. Lastly the assessments were not spatially explicit (Lakshmi and Bolten, 2019).

In 1999, the European Commission (EC) presented the MEDALUS model which has been found many advantages compared to other models. In this model, GIS is used to compute necessary data and produce required indices and maps according to available algorithms. The MEDALUS model was developed for and applied to several parts of the Mediterranean region to identify the areas that are sensitive areas (prospectively threatened by land degradation and desertification). Thanks to its simplicity, flexibility, and rapid implementation it has proven a popular method worldwide (Kosmas et al., 1999; Prăvălie et al., 2017). In Mediterranean countries like Greece, Spain and Italy, non-Mediterranean countries of Europe as well as Nile Delta region, this method ensure accurate and appropriate results for monitoring desertification sensitivity (Abuzaid and Abdelatif, 2022).

The MEDALUS method determines environmentally sensitive areas via the Environmental Sensitive Area Index (ESAI) (Kosmas et al., 1999). The methodology involves organizing biophysical and anthropogenic indicators and processed as thematic layers overlapped by means of Geographic Information Systems (GIS) (Prăvălie, et al., 2017). Several variable indicators (soil quality, environmental quality, climatic quality, socio-economic quality, groundwater quality) can be implemented through ESAI. With the help of this index, it is possible to understand and acquire information about which parameter causes desertification risk at each spatial location (Ait Lamqadem et al., 2018). Moreover, the MEDALUS approach allows the studies to make a change in variables and indexes to state the desertification sensitivity which allows managing the study according to the availability of data for the specific area. For instance, the study conducted in Greece, for ESA (Environmentally Sensitive Areas) index three parameters for climate quality, four parameters for vegetation, six parameters for soil quality, and for management quality two parameters have used (Morianou, et al., 2018). On the other hand, in the north Nile delta region, seven indicators climate quality index (four parameters), Soil quality index (six parameters), Geomorphological Quality Index (four parameters), Vegetation Quality index (four parameters), Water Quality Index (two parameters), Management Quality Index (two parameters), Anthropic Quality Index (two parameters) (Prăvălie, et al., 2020). when layers are used, as the ESAI weights equally each index. Also, it does the same thing when computing each index by giving equal weight to each parameter (Symeonakis, et al., 2016).

CHAPTER THREE

GOALS AND OBJECTIVES

The main goal of this work is to identify the areas that are most responsive to desertification in a part of the San Diego steppe and to quantitatively determine the key factors that contribute to desertification risk for bird species of special concern through MEDALUS Environmental Sensitive Area Index (ESAI). The objectives include:

(1) To adapt and apply the MEDALUS ESAI method to map sensitivity and vulnerability to desertification in San Diego County, California.

(2) To use the ESAI to evaluate potential desertification risks to bird species of special concern in the county.

Research questions include: Which areas of the county are at high risk of desertification according to the MEDALUS Environmental Sensitive Area Index (ESAI)? Which factors contribute most to high ESAI values? Which bird species of special concern may be most impacted by desertification?

CHAPTER FOUR

METHODS

4.1 Study Area

San Diego is one of the largest cities in California with a close border to Mexico in the southernmost part of the state (Figure 1). San Diego County comprises urban and rural areas, including coastal beachfronts, mountains, and deserts. The region covers 4,300 square miles, with 70 miles of beach along the Pacific Ocean. The geographic coordinates of San Diego County are Latitude: 32° 42' 56.6496" N, Longitude: -117° 9' 39.9132" W. It has a boundary of Imperial County to the East, the Pacific Ocean to the West, Orange and Riverside Counties to the North, and Mexico to the South (County of San Diego, n.d.).

San Diego is the second-most densely populated county among the 58 counties of California. It is the fifth largest county in the United States with a population of more than 3.3 million residents. According to the 2019 U.S. Census, the total population for San Diego County is 3,3388,330 with a median age of 36.4. While 19.7% of the population is under 18 years old 13.4% of the population belongs to 65 and over (U.S. Census Bureau, 2019).

San Diego County has a diversity of climates and land, including coastal plains, inland valleys, mountain, and deserts. In addition, The Cleveland National Forest covers a large part of the interior of the county. According to Köppen climate classification, while in the northern part of San Diego Mediterranean climate is seen, the southern and eastern parts have warm steppe climates. In San Diego the climate is characterized by dry summers and warm winters. While precipitation and temperature are lower in the western portions of the county, temperature and precipitation are higher in the east and central regions. The county's desert region in the east. The average annual rainfall in coastal areas is 250 mm, at the mountain peaks over 800 mm, and in the low desert area often it is less than 150 mm. San Diego County receives most precipitation fall from November to March (85%) though rain fall totals are not extreme. The average temperature in San Diego is 16.7 C/ 62.1 F. Between microclimates and short distances in the county temperatures and temperature ranges can change (Mosase, et al., 2019; Climate-Data.Org, n.d.)

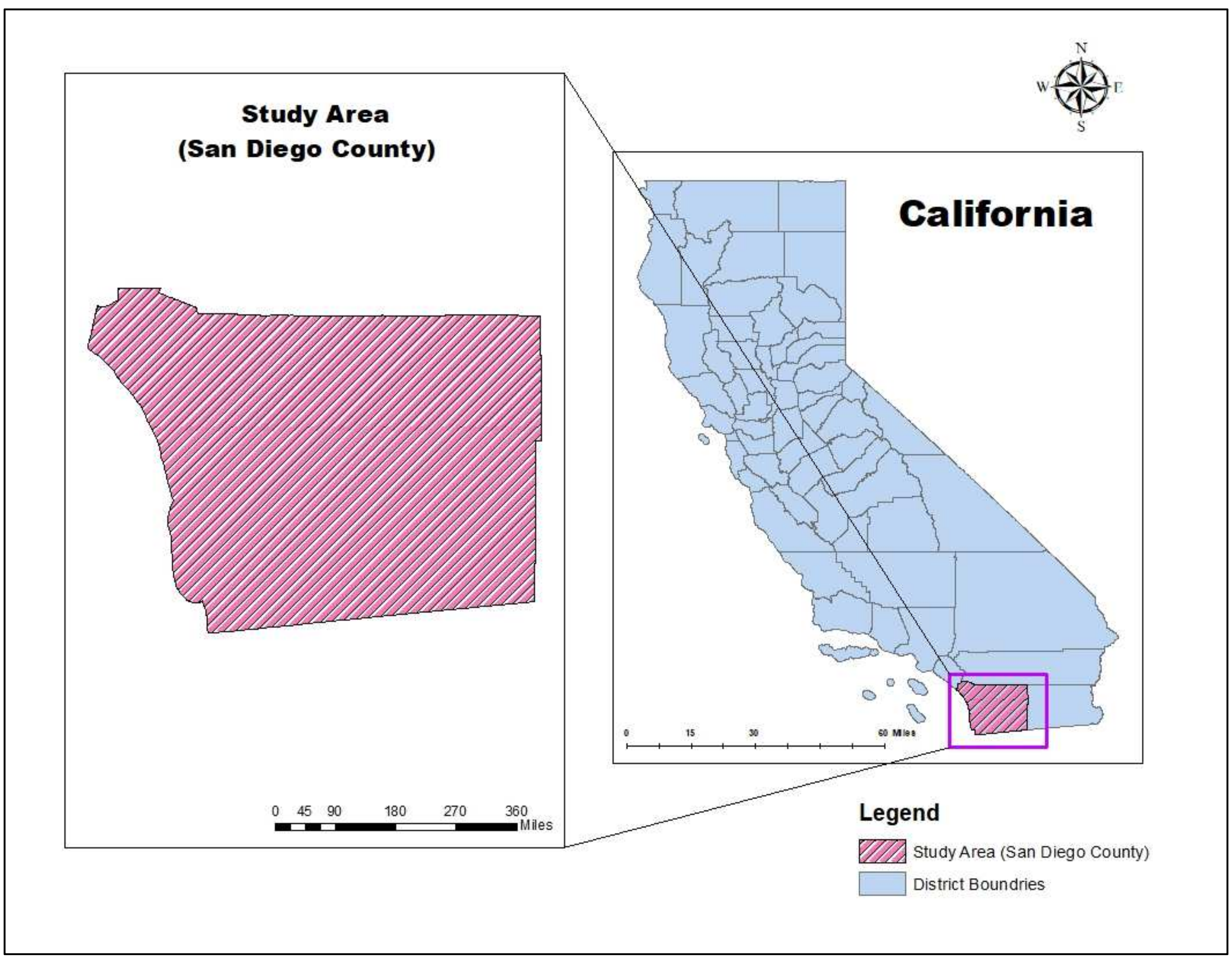

Figure 1. San Diego County, CA.

San Diego’s economy is over economic growth and unemployment of California and the U.S. averages throughout the last several years. The gross domestic product of San Diego is one of the largest in California. Based on data from the Bureau of Economic Analysis San Diego County accounted for more than $222.3 billion, or 7.9 percent of California's GDP (Gross Domestic Product) in 2019. San Diego’s economy is primarily made up of three major sectors: defense, tourism, and innovation (County of San Diego, n.d.). Agriculture also is an important contributor to the economy, with the county supporting over 200 different agricultural crops (Sandag, 2011).

4.2 Data Collection

To conduct this study, GIS layers are required for each parameter in the model. Parent material, texture, soil dept, water erosion, Sodium absorption ratio and electrical conductivity data as well as the necessary data (Na, Mg, and Ca) to calculate Sodium absorption ratio were gathered from California Soil Resource Lab. Slope and Aspect data computed from digital elevation model (DEM) which received from SANDAG. The needed data for water table depth, rainfall as well as aridity acquired from USGS, PRISM Climate Group and CGIARCSI, respectively. Population density, population growth rate, old age, education level was taken from United States Census Bureau and grazing data from HARVARD Data verse. Necessary data to estimate Vegetation quality downloaded from the Multi-Resolution Land Characteristics (MRLC) Consortium.

4.3 Methodology

The methodological approach used in this thesis for analyzing and mapping the sensitivity to desertification is based on Kosmas et al. (1999), focusing on the identification of

Environmentally Sensitive Areas (ESAs) to desertification through use of the ESAI. Twenty-one layers (Table 1- Table 5) of five main environmental quality indices concerned with climate, vegetation, soil, groundwater, and socio-economic characteristics of the land estimated (Figure 2). For the final ESAI calculation, appropriate weights for individual parameters of each indicator's quantitative (VQI, CQI, GQI, SosQI, SQI) indicator were classified from the least sensitive (1) to the most sensitive (2), based on (Kosmas et al., 1999a), DESERTLINKS, 2004 and Sepehr et al., 2007; (Tables 1-6).

The ESAI determined by the equation (Kosmas et al. 1999):

(ESAI) = (VQI * CQI * GQI * SosQI * SQI)1/5

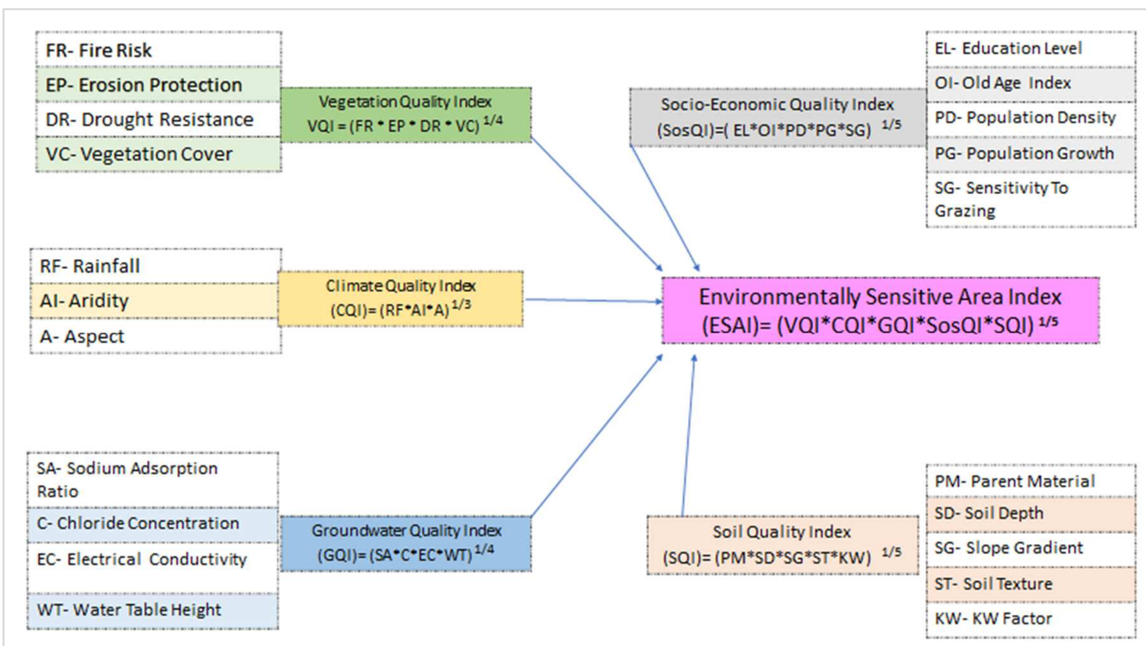

Figure 2. Flowchart of the methodological framework (ESAI)

In the equation, VQI corresponds to the Vegetation quality index, CQI is the climate quality index, GQI is the groundwater quality index, SosQI is the socio-economic quality index and SQI is the soil quality index. The socio-economic quality index is measured based on several factors old age, education level, population density, population growth and grazing sensitivity. The old-age parameter was calculated as (inhabitants >65)/ (inhabitants <5) while education level was (inhabitants >20 that are secondary education leavers)/ (inhabitants >20). Soil quality index was calculated via parent material, soil depth, slope gradient, soil texture and Kw factor. For the calculation of the Soil Quality index, instead of the water erosion parameter in the classification scheme from Kosmos, soil erodibility factor (KW) was used due to the absence of data. It represents both the soil's susceptibility to erosion and the runoff rate. Furthermore, the calculation of Groundwater Quality index was acquired by the utilize of the Water table depth, Sodium Adsorption ratio, chloride concentration, electric conductivity. Water table depth represents average water depth over the years 2016-2020. The vegetation quality index is estimated by using fire risk, erosion protection, drought resistance, and vegetation cover data while rainfall, aridity, and aspect are used for the climate quality index. Rainfall data signifies average rainfall over the years 2016-2020. Additionally, for plant cover Fractional Vegetative Cover formalization that is FVC=NDVI-NDVImin / NDVImax -NDVImin was applied based on NDVI (Gu et al.,2009). NDVI (A normalized difference vegetation index) is the instantaneous satellite observation value. NDVImin is the minimum value of NDVI that are bare or non-vegetated areas on remote sensing images, and NDVImax is the value of max NDVI that is entirely covered by vegetation (Zou et al., 2022). This formula estimates the total percentage of the study area vegetated. The classes depend on the paper ‘Monitoring Sensitivity to Land Degradation and Desertification with the Environmentally Sensitive Area Index’ and were derived from their analysis of Lesvos Island. For these five main parameters needed data of the study area were collected and inputted into a geographic information system (GIS). GIS software and MEDALUS method integrated as a decision-making tool.

As demonstrated in Figure 2 each index consists of several parameters that combined to get a quality indicator applying the general formula:

Quality indicator = $(\text{parameter}^{1} * \text{parameter}^{2} * \text{parameter}^{3} \ldots\ldots\ldots * \text{parameter}^{n})^{1/n}$

Where n is the number of parameters

According to the equation, each quality results classified into three qualitative classes between 1 to 2 and categorized as very high, moderate, or low according to the classification scheme shown in Table 6 by Sepehr (2007). The score breakdowns for each index reflect their respective contributions to the overall ESAI rating. It means the higher the weighting, the higher the sensitivity of the land to degradation. The ESAI values reclassified into non-affected, not very sensitive, sensitive, and very sensitive classes according to Table 7.

Table 1: Climate quality classification scheme and scores from Kosmas (1999b).

Climate Quality		
Parameter/ source/ date	**Classes**	**Score**
Rainfall https://prism.oregonstate.edu/ (2016-2020).	>650	1
	280-650	1.5
	<280	2
Aridity= Precipitation/PET https://cgiarcsi.community/data/global-aridity-and-pet-database/ (2019).	>0.65	1
	0.5-0.65	1.5
	<0.5	2
Aspect https://databasin.org/datasets/78ac54fabd594db5a39f6629514752c0/ (2000).	N,NE,NW,Plain(%5)	1
	S, SE, SW	2

Table 2. Soil quality classification scheme and scores from Kosmos (1999b).

Soil Quality		
Parameter/ source/ date	**Classes**	**Score**
Parent Material https://databasin.org/datasets/14a47cc5b56240c5840ac432a2466266/ (2017).	Shale, schist, basic, ultra-basic, conglomerates,	1
	unconsolidated, clays and marl (with natural vegetation)	
	Limestone, marble, granite, rhyolite, ignibrite,,gneiss	1.7
	siltstone,sandstone and solomyte.	
	Marl, pyroclastics	2
Texture https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	LSCL, SL, LS, and CL	1
	SC,SiL and SiCL	1.2
	Si, C and SiC	1.6
	S	2
Soil Depth https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	>75	1
	30-75	1.2
	15-30	1.6
	<15	2
Kw Factor https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	<0.0001	1
	0.0001-0.0087	1.2
	0.0087-0.026	1.5
	0.026-0.07	1.7
	>0.07	2
Slope gradient https://databasin.org/datasets/78ac54fabd594db5a39f6629514752c0/ (2000).	<6	1
	6- 18	1.2
	18-35	1.5
	>35	2

Table 3. Socio-economic quality classification scheme and scores from DESERTLINKS (2004).

Socio-economic Quality		
Parameter/ source/ date	**Classes**	**Score**
Population Density (people per km) https://www.census.gov/ (2020).	<25	1
	25-50	1.2
	50-100	1.4
	100-200	1.6
	200-400	1.8
	>400	2
Population Growth rate (%) https://www.census.gov/ (2020).	<2	1
	2-4	1.2
	4-6	1.4
	6-8	1.6
	8-10	1.8
	>10	2
Old age https://www.census.gov/ (2020).	<200	1
	200-400	1.3
	400-500	1.6
	>500	2
Education Level (%) https://www.census.gov/ (2020).	>35	1
	30-35	1.2
	25-30	1.4
	20-25	1.6
	15-20	1.8
	<15	2
Sensitivity to grazing (sheep and goats per km) https://dataverse.harvard.edu/ (2010).	<0.0066	1
	0.0066-0.13	1.3
	0.013-0.019	1.6
	>0.019	2

Table 4. Groundwater quality classification scheme and scores from Sepehr et al. (2007).

Groundwater Quality		
Parameter /source/date	**Classes**	**Score**
Water table depth (m) https://www.usgs.gov/ (2016-2020).	>3.15	1
	2.85-3.15	1.5
	<2.85	2
Sodium adsorption ratio (SAR) https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	<10	1
	10-18	1.3
	18-26	1.6
	>26	2
Chloride concentration(mg/l) https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	<250	1
	250-500	1.2
	500-1500	1.5
	1500-3000	1.7
	>3000	2
Electric conductivity https://casoilresource.lawr.ucdavis.edu/soil-properties/download.php (2020).	<250	1
	250-750	1.2
	750-2250	1.5
	2250-5000	1.7
	5000	2

Table 5. Vegetation quality classification scheme and scores from Kosmos (1999b).

Vegetation Quality		
Parameter/source/date	**Classes**	**Score**
Drought resistance https://www.mrlc.gov/ (2019)	Evergreen forests (except coniferous)	1
	mixed Mediterranean maquis- evergreen forest (with Q. ilex)	
	bedrock and bure soil.	
	Conifer forests, deciduous forests, and olives	1.2
	Almonds, orchards, and vines	1.4

Table 5 (Continued).

Drought resistance https://www.mrlc.gov/ (2019)	Prennial grasslands, pastures and shrublands	1.7
	Annual crops (annual grassland, cereals, maize, and sunflower)	2
	horticulture and very low vegetated.	
Erosion protection https://www.mrlc.gov/ (2019)	Evergreen forests (except coniferous)	1
	mixed Mediterranean maquis- evergreen forest (with Q. ilex)	
	bedrock.	
	Mediterranean /Macquis, conifer forests	1.3
	prennial grasslands, pastures, olives, and shrubs.	
	Deciduous forests (oak and mixed).	1.6
	Almonds and orchards	1.8
	Vines, horticulture, annual crops,	2
	very low vegetatedand bare soils.	
Fire risk https://www.mrlc.gov/ (2019)	Bare soils,bedrock,almonds,orchards,vines	1
	olives,irrigated annual crops and horticulture.	
	Prennial grasslanfs, deciduos forests (oak and mixed)	1.3
	mixed mediterranean maquis-evergreen forests (with Q.ilex)	
	very low vegetated and shrublands.	
	Mediterranean maquis	1.6
	Pines and other conifer forests.	2
Plant cover (%) https://www.mrlc.gov/ (2019).	>40	1
	10-40	1.8
	<10	2

Geographic Information System (GIS) software, ArcGIS 10.7, used to integrate and analyze all geographic data the spatial distribution of the factor layers. With overlay command layers merged, in fact the single database created from all data. With the geometric mean of the soil, climate, vegetation, groundwater, socio-economic parameters the risk index assessed. Based on the results (combination of the different MEDALUS factors) for each quality index desertification sensitivity map generated in ArcGIS 10.7. Maps have the same resolution which is 800x800m.

Table 6. Five quality indices according to scheme suggested by Sepehr (2007)

Quality index	Sensitivity class	Score
Climate Quality Index	Low	1
	Moderate	1.1-1.5
	High	1.6-2
Vegetation Quality Index	Low	<1.13
	Moderate	1.13-1.38
	High	>1.38
Soil Quality Index	Low	<1.13
	Moderate	1.13-1.45
	High	>1.46
Groundwater Quality Index	Low	1
	Moderate	1-1.4
	High	>1.4
Socio-economic Quality Index	Low	1-1.3
	Moderate	1.3-1.5
	High	>1.5

Table 7. ESA Index Value Ranges

Class	Description	Range
1	Non-affected	1.0-1.22
2	Not very sensitive	1.23-1.30
3	Sensitive	1.31-1.40
4	Very sensitive	1.41-2.0

Moreover, for bird species of special concern (the first Priority Seven Taxa shown in Table 8) that can easily become endangered, threatened, or extirpated because of specialized habitat needs or limits or other factors, five quality indices ranges determined for their spatial ranges. For each quality index, how much percentage of each bird species' range correspond to each sensitivity class examined. Additionally, according to the ESAI, the percentage of the species' ranges located in non-affected, not the very sensitive, sensitive, and very sensitive areas calculated and represented via created maps in GIS software.

Table 8. San Diego Bird Species of Special Concern (First Priority Seven Taxa)

Scientific Name	**Common Name**
Campylorhynchus Brunneicapillus	Cactus Wren
Toxostoma Lecontei	Le Conte'S Thrasher
Piranga Rubra	Summer Tanager
Pipilo Maculatus	Spotted Towhee
Melospiza Melodia	Song Sparrow
Lanius Ludovicianus	Loggerhead Shrike
Agelaius tricolor	Tricolored Blackbird

The results provide information about the environmental conditions in each species' spatial range and indicate how sensitive they may be to desertification conditions. For example, if a species is only currently found in non-affected areas, then future desertification in those areas may result in the extirpation of that species from those areas. If a species' range covers more sensitive areas, we can explore the sensitivity classes for the environmental factors are most associated with the species ranges.

CHAPTER FIVE

RESULTS

MEDALUS methodology was employed through ESAI to measure the sensitivity of land cover to desertification. ESAI is calculated by using the five-quality indices: Soil Quality Index (SQI), Climate Quality Index (CQI), Vegetation Quality Index (VQI), Socio-economic Quality Index, Groundwater Quality Index, and Soil Quality Index. For each quality index, several indicators impacting desertification are utilized and weighted to detect the spatial distribution of desertification sensitivity of land. To create a map of desertification-sensitive areas the geometric mean of the five quality index maps was utilized. Quality indexes were classified into three sensitivity classes low, moderate, and high. Consequently, for each quality index, the percentage of the covered area was estimated and mapped according to sensitivity classes (Table 9).

5.1. Climate Quality Index (CQI)

CQI was calculated by the combination of three sub-indicators which are rainfall, aridity, and aspect. The percentage of scored areas as a 1 and 2 is almost equal; 43.89 % of the area has a north and west aspect while 56.10% is south and east. The average annual rainfall in the San Diego County is between 7 and 64 mm. The area of 100% of the area has a low average annual rainfall which is <280mm. Aridity (precipitation/evapotranspiration) is also a climate phenomenon triggered by the amount of rainfall. Low rainfall takes leads to high aridity. Aridity index values for San Diego County range from 0.033 to 0.045 which indicates the climate is quite dry. Overall, areas with the lowest climatic quality index are observed in the western part of San Diego County. Approximately 39% of the study area is categorized as low, 56% moderate CQI, and 6% high CQI. CQI map demonstrates low, moderate, and high sensitivity of climate index areas was generated by overlaying analysis of three indicators rainfall, aspect, and aridity in Figure 3.

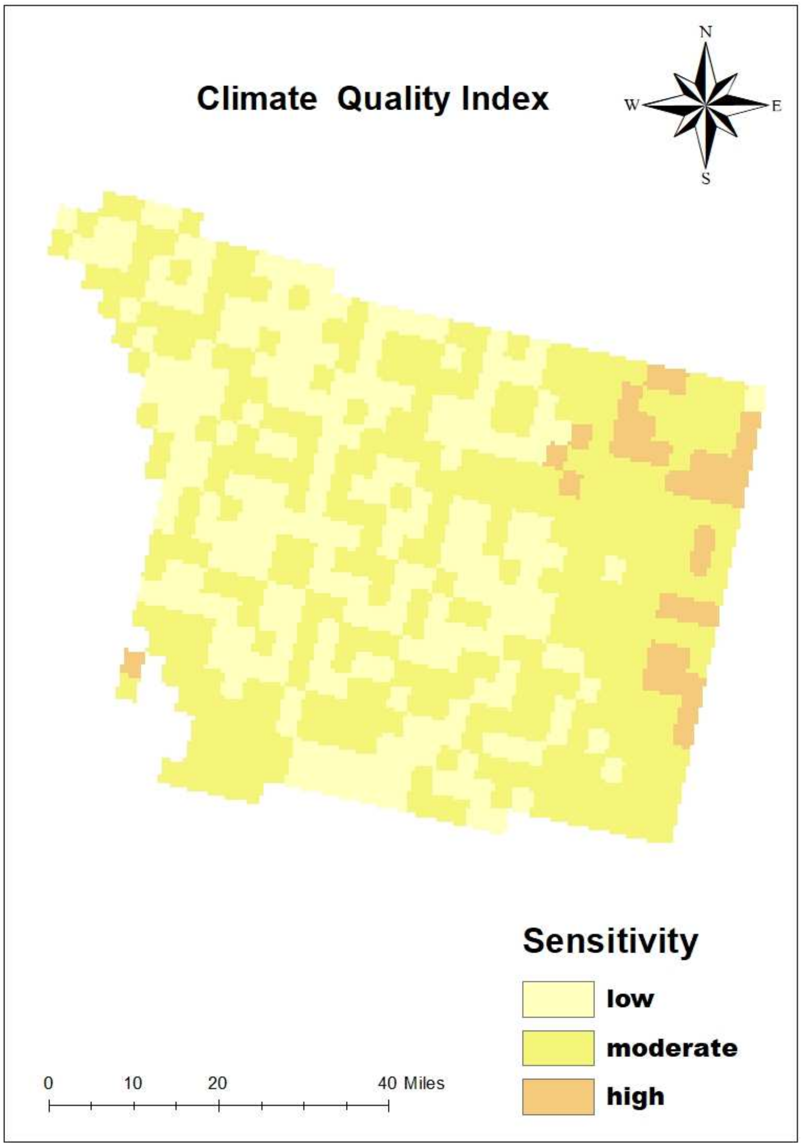

Figure 3. Climate Quality Index Map of San Diego County

5.2. Soil Quality Index (SQI)

By overlaying five soil characteristics that are slope, soil depth, parent material, soil texture, and kw factor, a soil quality index was acquired. About 58% of San Diego County is classified under a 6% slope, and 0.04% is over 35%. Soil depth in San Diego County varies from 4 cm to 200 cm. About 61% of soil is classified as over 75 cm while approximately 4% has under 15 cm depth. Soil is less deep in the middle of San Diego County by contrast to the west and east part. Parent materials such as unconsolidated deposits, shale, schist, basic, and conglomerates compose almost 29% of soil, while 4.8% is marl and pyroclastic in the San Diego area. Referencing soil texture, the northeast part has sand, north loamy sand, west part loam soil type and, however; the area largely is sandy loam. Around 92% of the study are in San Diego County is in the high quality and 4% low-quality degree class of soil texture. Furthermore, according to kw factor indices, the west part of San Diego County (mostly populated areas) demonstrates the highest soil erosion risk. Kw factor ranges from 0.02 to 0.55. Created map of SQI is generated by overlay analysis of five indicators shown in figure 2. Approximately 76% of the study area is classified with moderate SQI, 22% low, and 2% high SQI. While the Soil Quality index is more concentrated in the southern part of the county around Mexican border, high SQI appeared in the rest of the county distributed as small spots (Figure 4).

5.3. Vegetation Quality Index (VQI)

Based on Kosmas et al. (1999), Vegetation Quality Index was assessed via four sub-indices: drought resistance, erosion protection, fire risk, and plant cover. In terms of vegetation quality index, the areas with low drought resistance, high fire risk, and low ratio vegetation cover are identified as highly sensitive to desertification. The VQI in this study was classified based on the vegetation data and land cover map. According to vegetation classes, all parameters are weighted and scored from 1 to 2 which means a high score of high vegetation risk. The reduction in plant covers is mostly connected to a decline in soil protection from erosion. For drought resilience, evergreen forests (except coniferous), mixed Mediterranean maquis evergreen forest (with Q. ilex) bedrock, and bare soil are less resistant to desertification covering 15.72%. Conifer forests, deciduous forests, and olives cover 0.001%, almond, orchards and vines, perennial grassland, pastures, and shrublands cover 64% and annual crops (annual grassland, cereals, maize, and sunflower), horticulture and very low vegetated areas cover 20.25% of the area. Erosion is less possible in the forests mixed Mediterranean maquis evergreen forest (with *Q. ilex*), and bedrock which covers 4.98% of the San Diego County. Mediterranean Maquis, conifer forests, perennial grasslands, pastures, olives, and shrubs cover 64%, Deciduous forests (oak and mixed) cover 0.001%, horticulture, annual crops, very low vegetated and bare soils cover 30.99% of the land. On the other hand, the risk of the fire is low in bare soils, bedrock, almonds, orchards, vines, olives, irrigated annual crops that cover 32% of the county and horticulture Perennial grasslands, pastures, cereals, annual grasslands, deciduous forests (oak and mixed), mixed Mediterranean maquis evergreen forests (with Q ilex), very low vegetated and shrublands which has higher fire risk cover 68.14% of the area. The plant cover ratio (as a percentage) is one of the quality parameters for the climate quality index. Over 40 % of the area was scored 1 due to low desertification risk, between 10 and 40% is 1.8 and under 10% was 2. In San Diego County, 83% of the area has high vegetation quality index mostly seen western part of the area (high populated area) and less than 5% of the area was classified as low vegetation quality while 12% of the area was classified as moderate vegetation quality was located east, northeast, and southeast part of the county shown in Figure 5.

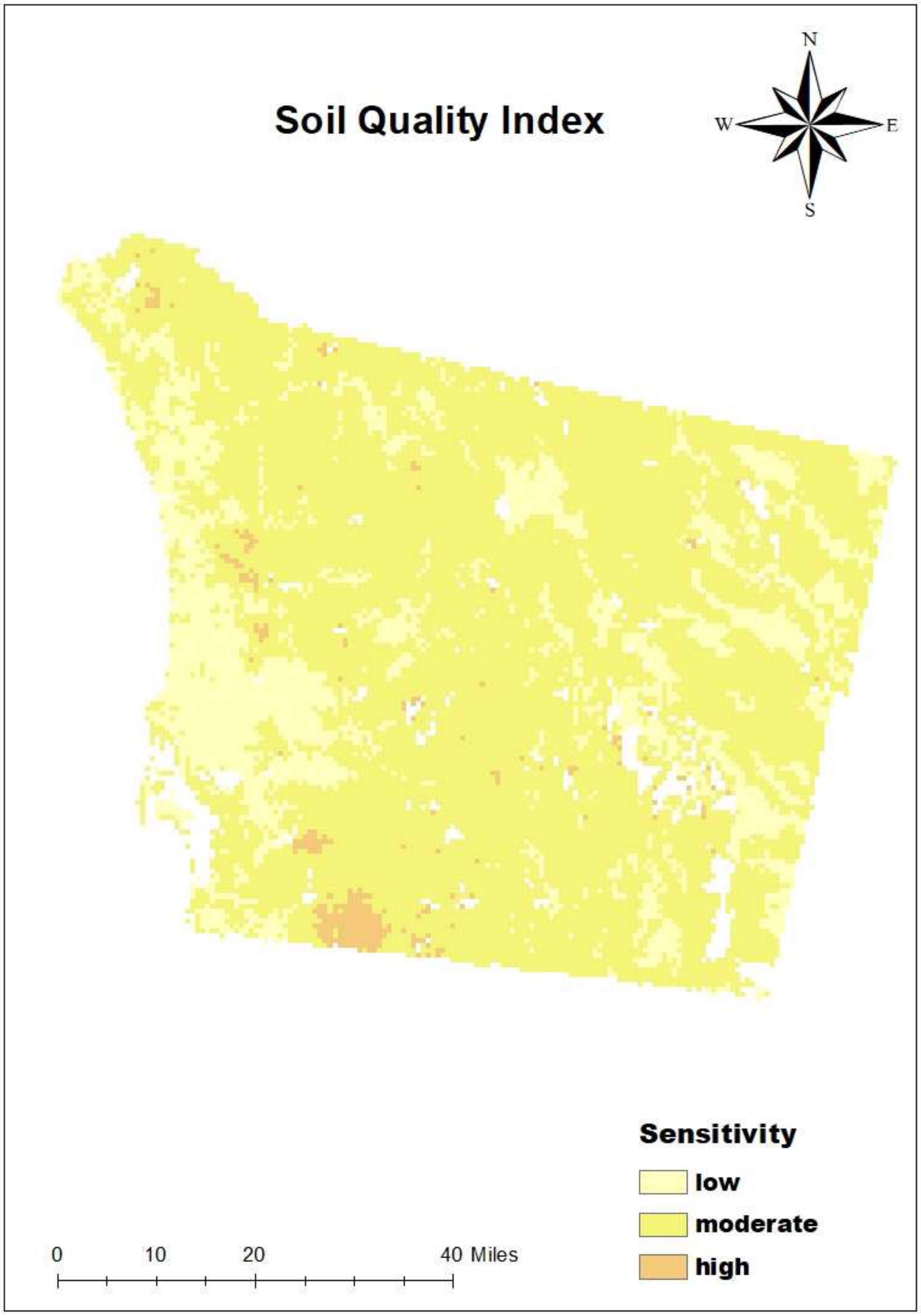

Figure 4. Soil Quality Index Map of San Diego County

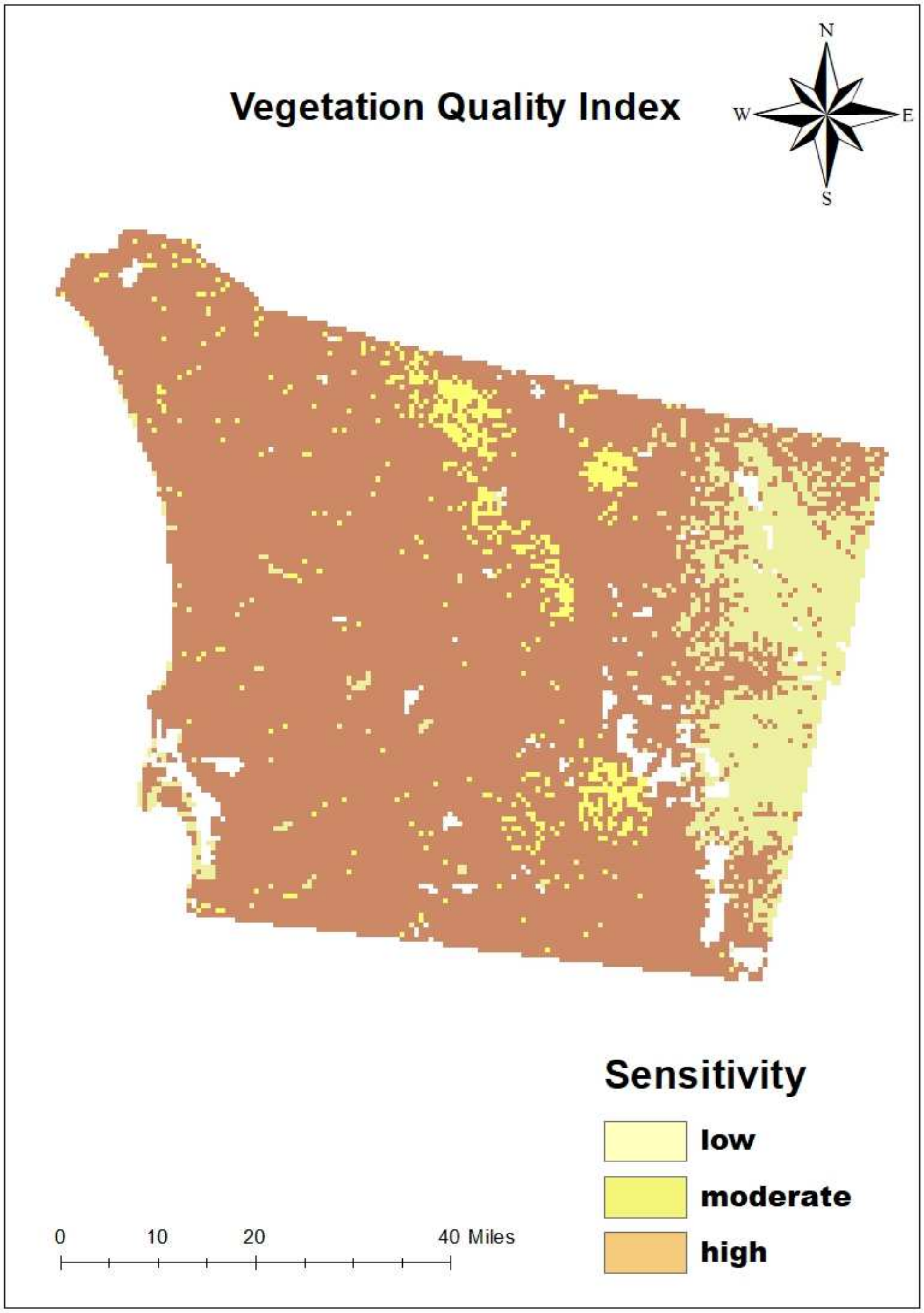

Figure 5. Vegetation Quality Index Map of San Diego County

5.4. Groundwater Quality Index (GQI)

Groundwater Quality Index is composed of four indices: water table depth, sodium adsorption ratio, chloride concentration, and electrical conductivity. While the sodium adsorption ratio in San Diego County was classified as 0.5% low and 96.7% high, the chloride concentration is 75.73% low and 4.3% high. Regarding electric conductivity 0.7% of the area is classified as high whilst roughly 70% is low. For water table depth 99.8% was classified with a low score of 1 and 0.02% is high with a score of 2. Overall, 55.2% of the San Diego area had a low groundwater quality index, and less than 1% of the area located east and southeast part of the county has high groundwater quality index (Figure 6).

5.5. Socio-economic Quality Index (SosQI)

SosQI was calculated by the combination of five sub-indicators which were population density, population growth rate, old age, education level, and sensitivity to grazing. Population density under 25 people per km^2 is 59.99 %, between (25-50) 7.31%, between (50-100) 8.11%, between (100-200) 6.79 %, between (200-400) 3.51%, and over 400 people per km2 is 14.26 % The population is mostly located in the west part of San Diego County along the seaside. Education level is calculated by the ratio of the population over the age of 20 who have leaved secondary education to the population over the age of 20. This ratio for San Diego County is 35 1.3%, between (30-35) 1%, between (25-30) 0.9%, between (20-25) 17.58%, between (15-20) 30.22% and under 15 is 48.83%. Furthermore, the calculation of old age is acquired by dividing the population over 65 by the population under 5 years old. This ratio for San Diego County under 200 is 6.31%, between (200-400) is 3.55 %, between (400-500) is 6.44%, and over 500 is 83.67%. As regards grazing sensitivity, from the west part to the east part grazing sensitivity demonstrates a low pattern. The highest grazing sensitivity was observed in the southwest part which is 2.02% whilst the lowest sensitivity to grazing was seen northeast part at 14,18%. Overall, 48.63% area of San Diego was calculated as a low (east of the county) while 5.47% is high (mostly observed west) socio-economic quality index indicated in Figure 7.

Table 9. All Quality index values for San Diego County

	VQI	**CQI**	**GQI**	**SosQI**	**SQI**
low	4.11	38.76	55.42	48.63	22.4
moderate	12.48	55.72	44.17	45.89	75.81
high	83.39	5.5	0.39	5.47	1.77

5.6. Environmentally Sensitive Area Index

According to the environmentally sensitive area index, 0.5% of the San Diego County is not affected and 0.8% is not very sensitive to desertification. These areas are mostly located northwest, northeast, and southeast parts shown in Figure 8. On the other hand, desertification risk is very high across the county; 2% is sensitive and 96.57% is very sensitive (Table 10).

Table 10. ESA Index for San Diego County

	Non-affected	**Not very Sensitive**	**Sensitive**	**Very Sensitive**
ESAI	0.52	0.79	2.1	96.57

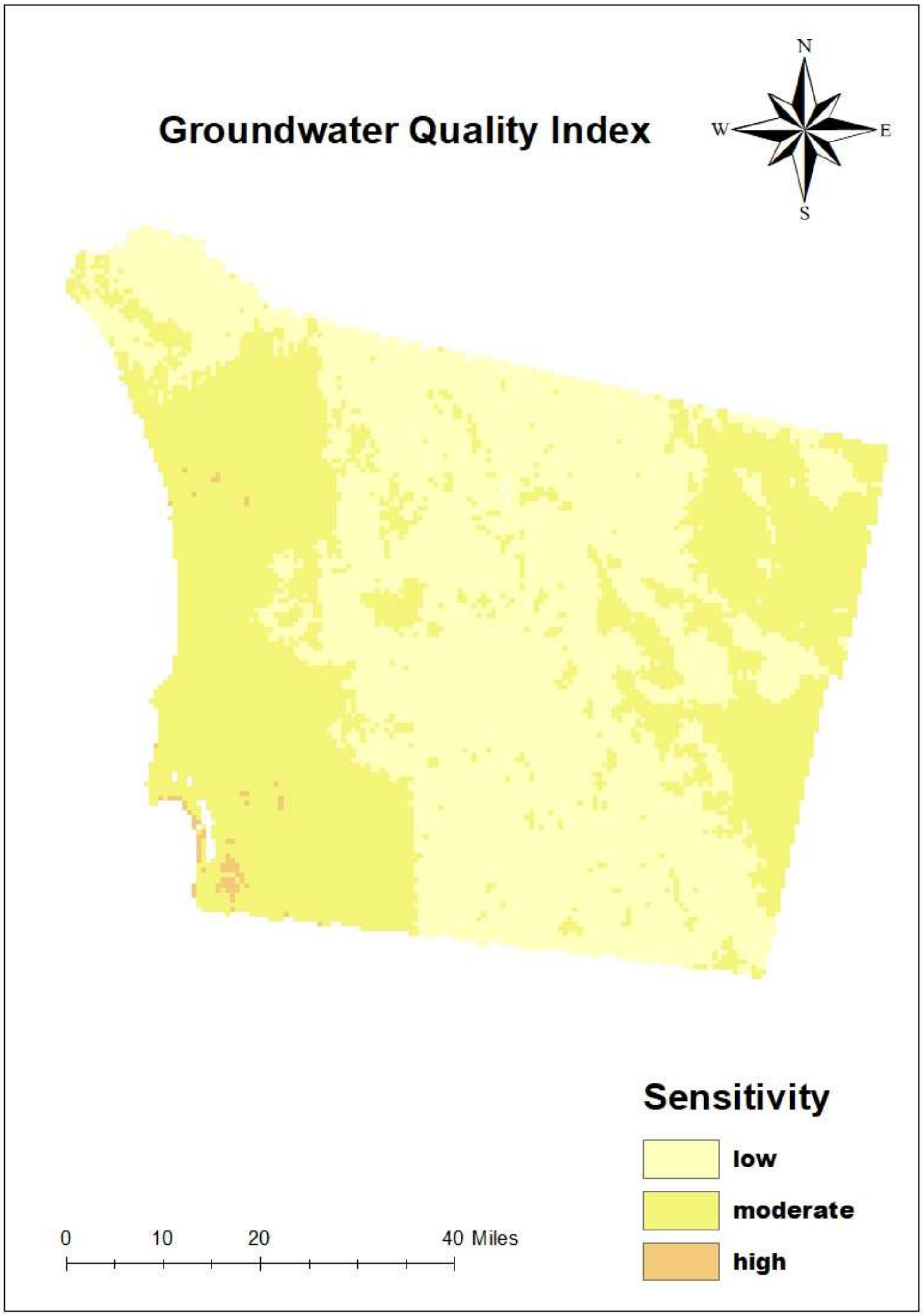

Figure 6. Groundwater Quality Index Map of San Diego County

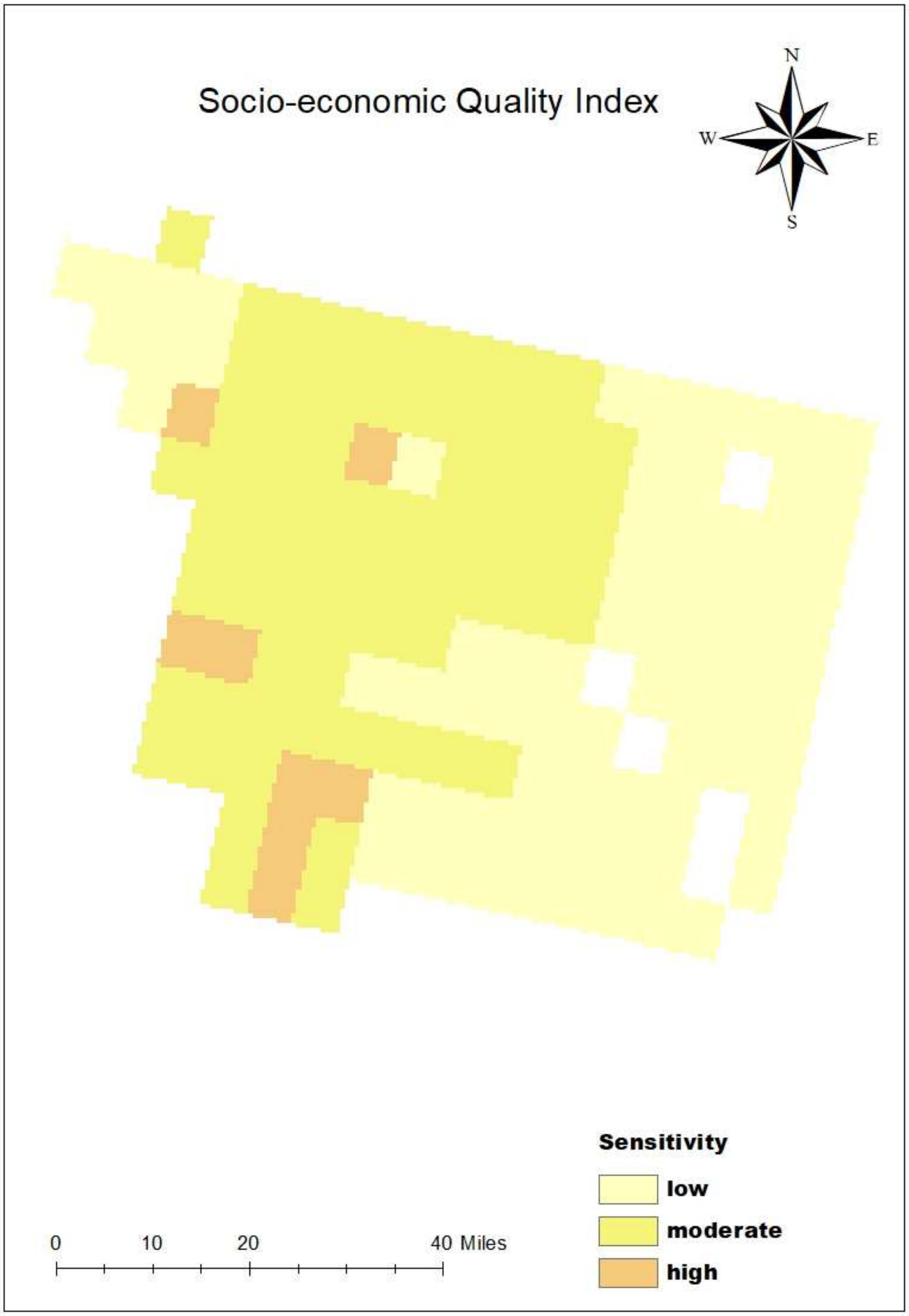

Figure 7. Socio-economic Quality Index Map of San Diego County.

Figure 8. Environmentally Sensitive Area Index Map of San Diego County

5.7. All Quality Indexes and ESAI for Bird Species of special concern in San Diego County

Over 95% of the area was found very sensitive for all seven taxa of bird species of special concern in San Diego County based on the environmentally sensitive area Index. In contrast, approximately 1 % of the area is not affected. Le Conte's Thrasher has the highest Environmentally sensitive area index with 99.19 (Table 11). Compared to Le Conte's Thrasher, Tricolored Blackbird has the lowest ESAI index with 95.80% (Table 12).

Table 11. ESA Index for Seven Taxa of Bird Species of Special Concern

	Non-affected	**Not very Sensitive**	**Sensitive**	**Very Sensitive**
Tricolored Blackbird	0.66	0.98	2.55	95.8
Song Sparrow	0.52	0.79	2.07	96.6
Cactus Wren	0.22	0.57	0.72	98.47
Le Conte's Thrasher	0.08	0.2	0.51	99.19
Loggerhead Shrike	0.52	0.79	2.07	96.6
Spotted Towhee	0.58	0.9	2.3	96.2
Summer Tanager	0.9	0	0.9	98.19

Table 12. All Quality Indexes for Seven taxa of Bird Species of Special Concern

Tricolored Blackbird	SosQI	SQI	WQI	CQI	VQI
low	32.16	20.76	60.14	49.19	5.51
moderate	60.48	77.03	39.33	50.56	0.73
high	7.35	2.19	0.52	0.23	93.75
Song Sparrow	SosQI	SQI	WQI	CQI	VQI
low	48.65	22.46	55.51	38.56	4.13
moderate	45.85	75.77	44.05	55.91	12.15
high	5.48	1.76	0.42	5.52	83.7
Cactus Wren	SosQI	SQI	WQI	CQI	VQI
low	38.03	26.63	44.1	40.3	1.78
moderate	53.94	71.08	55.32	53.58	12.68
high	8.01	2.27	0.56	6.11	85.53
Summer Tanager	SosQI	SQI	WQI	CQI	VQI
low	25.11	36.87	48.29		3.96

Table 12 (Continued).

moderate	74.88	62.41	51.7	100	3.96
high		0.7			92.06
Le Conte's Thrasher	SosQI	SQI	WQI	CQI	VQI
low	97.27	27.06	43.73	8.47	0.16
moderate	2.72	72.29	56.26	70.92	45.12
high		0.63		20.6	54.7
Loggerhead Shrike	SosQI	SQI	WQI	CQI	VQI
low	48.65	22.46	55.72	38.56	4.13
moderate	45.85	75.77	43.88	55.91	12.15
high	5.48	1.76	0.38	5.52	83.7
Spotted Towhee	SosQI	SQI	WQI	CQI	VQI
low	41.2	19.73	61.66	43.47	4.68
moderate	52.69	78.44	37.9	54.98	3.84
high	6.09	1.81	0.43	1.53	91.46

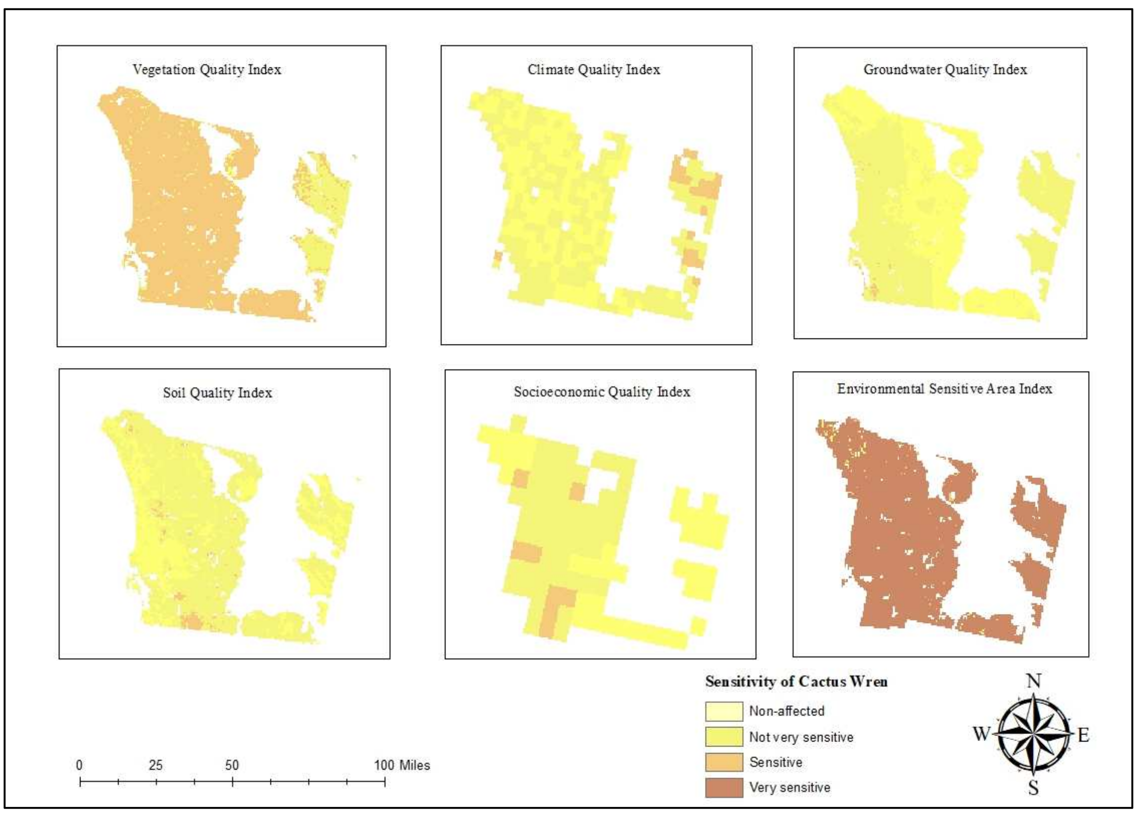

Figure 9. Sensitivity Map of All Quality Indexes and ESAI for Cactus Wren

Figure 10. Sensitivity Map of All Quality Indexes and ESAI for Loggerhead Shrike

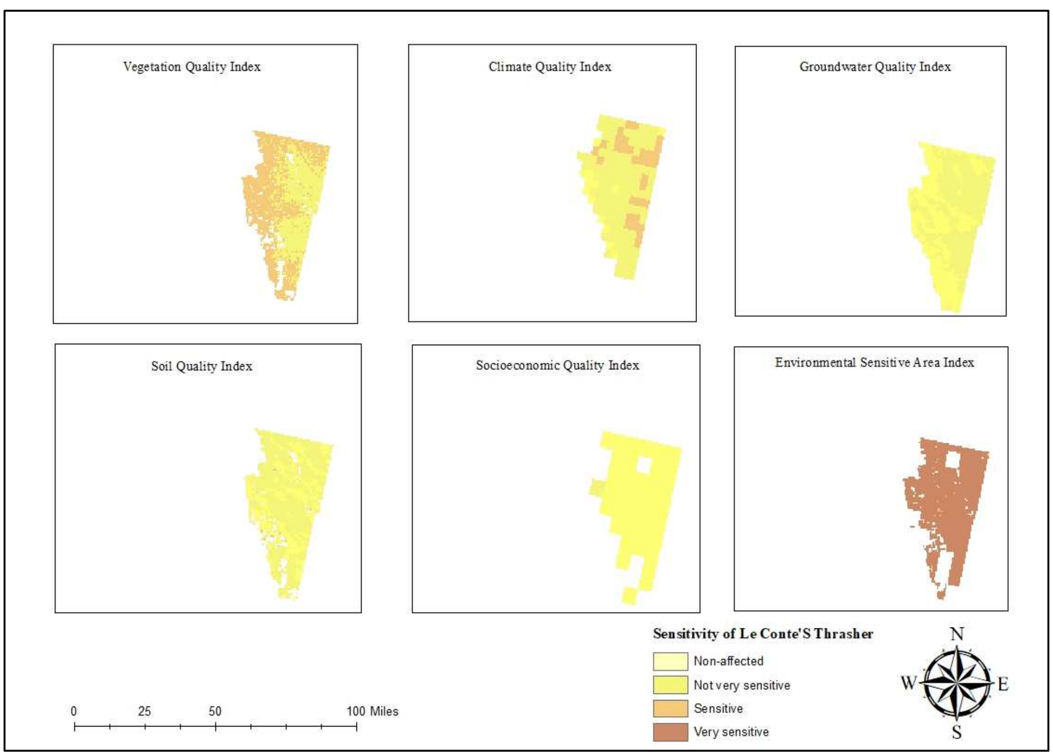

Figure 11. Sensitivity Map of All Quality Indexes and ESAI for Le Conte's Trasher

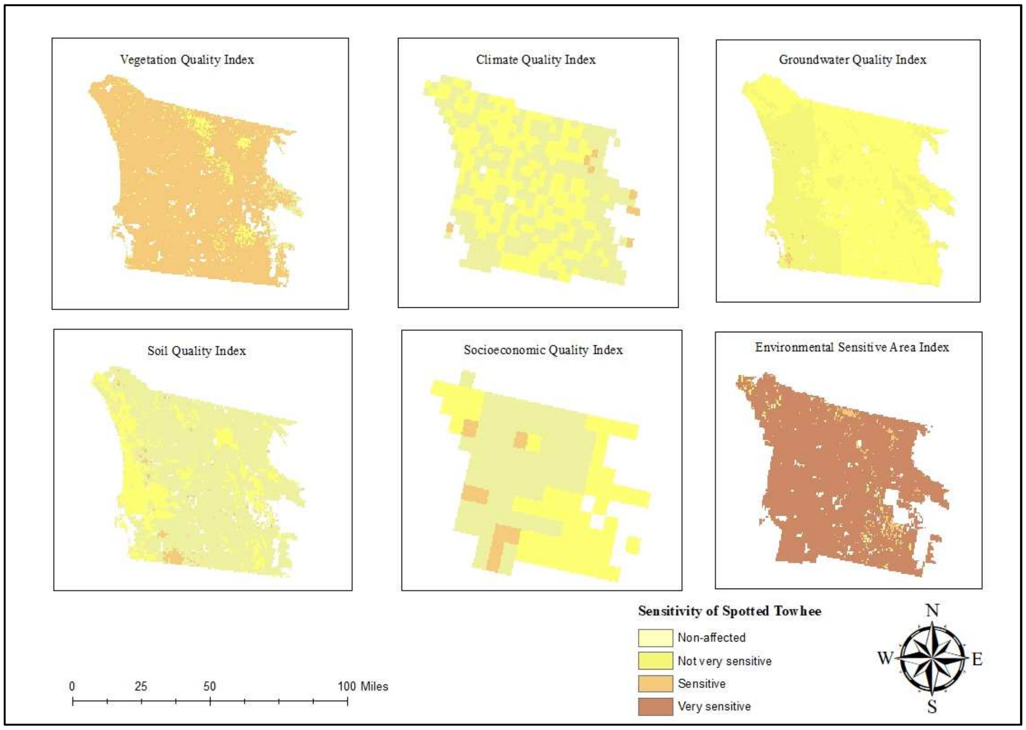

Figure 12. Sensitivity Map of All Quality Indexes and ESAI for Spotted Towhee

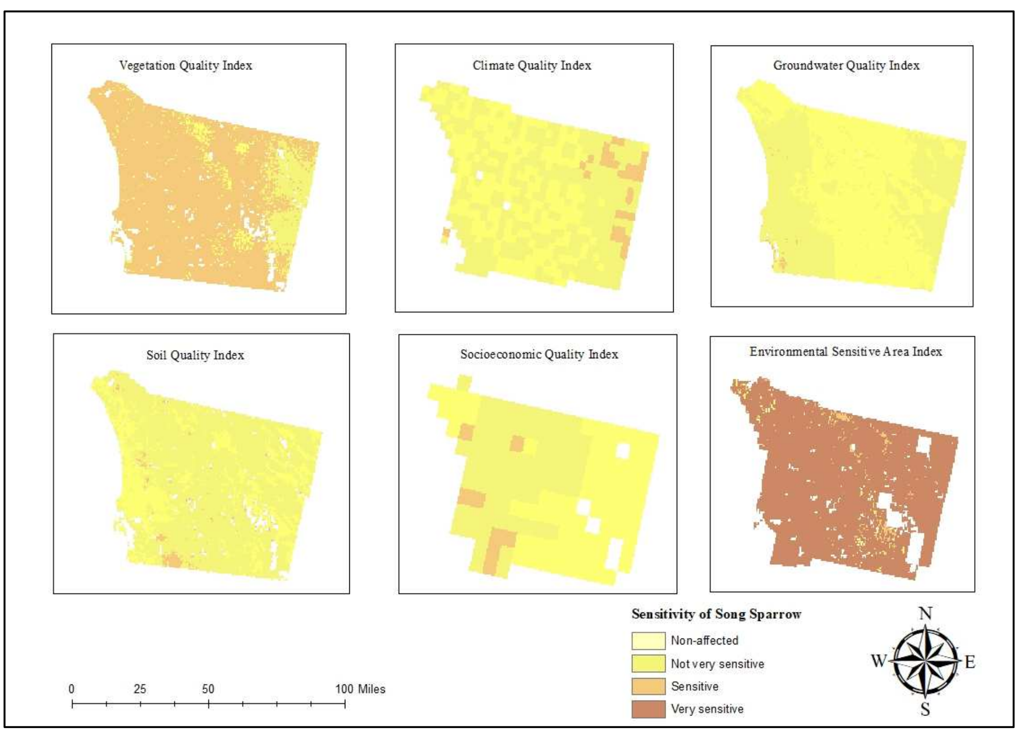

Figure 13. Sensitivity Map of All Quality Indexes and ESAI for Song Sparrow

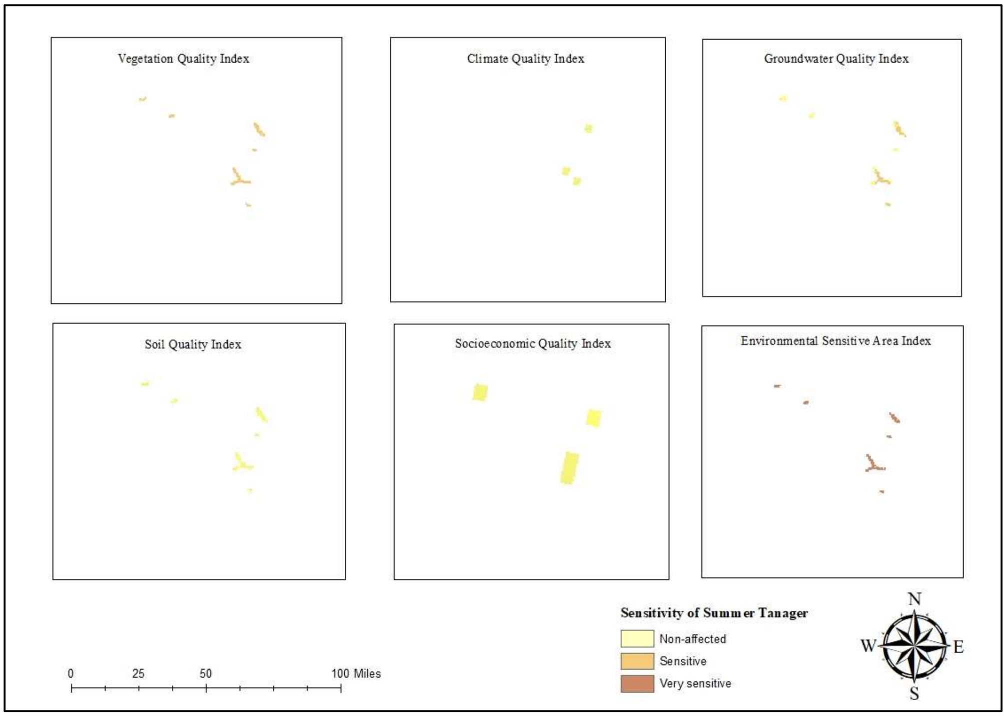

Figure 14. Sensitivity Map of All Quality Indexes and ESAI for Summer Tanager

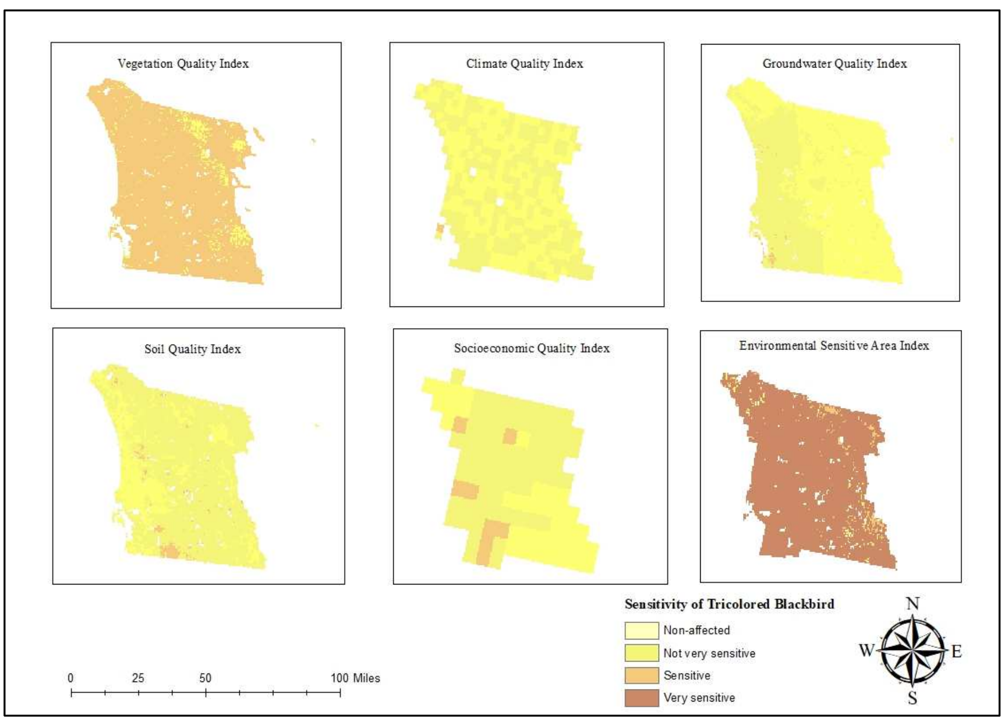

Figure 15. Sensitivity Map of All Quality Indexes and ESAI for Summer Tanager

CHAPTER SIX

DISCUSSION

6.1. Environmentally Sensitive Area Index

A significant part of San Diego County has been ascertained very sensitive to desertification risk. Non-effected areas are not very sensitive, and sensitive areas cover limited terrain. Natural indices like climate, vegetation, soil, and groundwater quality indexes were observed most effective indicators for environmental sensitivity. It is revealed that vegetation quality indexes had the largest impact on desertification sensitivity, thus very sensitive class for ESAI is mostly caused by the vegetation quality index. Following that, groundwater quality index is also found key threat to desertification. Classified areas with moderate and high groundwater sensitivity represent high sensitivity to desertification. Urban areas appear highly sensitive towards to desertification compared to low populated and intense territories. Increases in any of the indexes in the near future could further increase the risk of desertification in the San Diego region.

6.2. Climate Quality Index

The geographical aspect is the class of climatic sub-indicators having an influence on direct climate so desertification. North and west aspects are considered the areas having low desertification risk compared to south and east because north-facing aspects (west, north, northeast, northwest, and plain aspect) are more likely to get less sunlight and evapotranspiration, soil tends to be wet and moisture. On the other hand, the south, east, southeast, and southwest are mostly dry due to more exposition to solar radiation. Rainfall is another climatic indicator that has a large impact on desertification. Less reliable and variable rainfall causes drought and the loss of natural vegetation. As a result of a reduction in vegetation cover, rain cannot be absorbed by the soil, and soil exposes to solar radiation causing the soil to suffer the loss of moisture and crack. This indicates that soil disrupts its structure and fertility consequently resulting in desertification (Ait Lamqadem et al., 2018). Aridity is caused when water losses exceed water inputs. This means that if evaporation and transpiration (evapotranspiration) are higher than precipitation, aridity has a high possibility to occur (Adamo, et al.,2006). According to climate quality index results, rainfall indices had the highest influence on desertification compared to aspect and aridity indices, leading to high ESAI values in the east and western parts of the county.

6.3. Soil Quality Index

With reference to slope gradient, it has a huge effect on water run-off and soil sediment loss and is influenced by rainfall. There is a direct proportion between soil erosion and slope gradient. Deep soils have more potential to preserve water necessary for the preservation and widespread of vegetation. Also, for the root system of plants, deep soils are essential (University of Minnesota, 2018). Depth gives plant roots more room which helps soil to protect and keep its structure. Therefore, the soil erosion potential reduces in deeper soils. On the contrary, in places where the soil depth is low, the risk of soil erosion increases. The type of parent material is a determining factor in soil depth and soil erosion. Depending on which parent material they originated from, the reaction of vegetation, soil erosion, and desertification may vary. Some parent materials like consolidated (limestone, sandstone, etc.) are eroded and shallow soil that provide restricted effective rooting depth. Not only soil conditions but desertification sensitivity is also concerned with soil depth (Kosmas, 2003). In terms of soil absorbency and the risk of erosion, soil texture is another factor having an impact on desertification. Soil texture impacts soil drainage, the capacity of soil to hold water as well as soil erosion. Wind erosion is a major problem when sandy soils are used for agriculture in drylands. Furthermore, soils having a high amount of silt tend to crust formation. This causes surface water runoff and sediment loss. Created soil quality map indicates that kw factor and parent material had a considerable effect on soil quality index so desertification. In San Diego County, Kw factor led to high sensitivity in the inland south-central region and moderate sensitivity through much of the south plus coastal regions.

6.4. Vegetation Quality Index

Several forests such as evergreen ones store more carbon in the living and dead plant material, so they have more drought resistance and erosion protection. Unlike forests lands occupied with horticulture and annual crops are less drought-resistant and have erosion protection. Moreover, erosion protection is associated with the root system of trees, the leaf form, and the vegetation cover of land (University of Minnesota, 2018). Vegetation increases filtration thereby reducing soil erosion and runoff. The breakdown of soil aggregates is reduced thanks to vegetation because vegetation decreases the impact of raindrops on the soil surface. Vegetation types such as evergreen forest, deciduous forest, pasture, and land use as well as plant cover (%) indices are extremely important to decrease the desertification risk. In San Diego

County, drought resistance led to high sensitivity through much of the western and central regions and low in the east

6.5. Groundwater Quality Index

The sodium adsorption ratio is Na concentration divided by the square root of one-half of the Ca + Mg concentration. Salts include potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), and sodium (Na^+). The accumulation of these salts in the soil causes salinization and sodification which are physiological threats to land degradation and desertification. Electric conductivity/ Salinity is a prevalent land degradation process around the world. Moreover, water table-level rise drive salts to the surface and cause salinization in dry to sub-humid climates. (Schofield and Kirkby 2003). Accumulation of soluble salts in the arable land layers poisons the plant and increases the osmotic pressure on the vegetation resulting in loss of vegetation cover and acceleration of desertification risk (Luo et al., 2017; Pedrotti, 2015; Gkiougkis et al., 2015). The acquired map on groundwater quality index exhibits that electric conductivity is the one more effective index among others while water depth is the least. Chloride and SAR indices showed an equal pattern and influence on the groundwater quality index map, with low sensitivity in the central region, moderate in east and west, and only high near the city of San Diego County.

6.6. Socio-economic Quality Index

An uncontrolled and unplanned increase in the population may put environmental resources under pressure. High population growth, high density in populated areas, and inadequate land-use activities expand land degradation and desertification (Behnke, 2008). Also overgrazing in pasture areas adversely impacts soil conditions and increases the potential for desertification. In this study area, the socio-economic quality index mostly depends on population dynamics (Population density, education level) and human pressure (sensitivity to grazing). On the other hand, old age shows less relation to a socio-economic quality index and impact on desertification risk. Overall, higher sensitivity areas occurred in urban areas, because of higher population densities, low vegetative cover, and higher temperatures.

6.7. Desertification Risk on Bird Species of special concern in San Diego County

Globally, many bird species have experienced population declines because of land degradation leading to habitat loss, change in resource availability, and corruption of dispersal pathways and biotic interaction (Fusco, J., et al., 2021). The results of the ESAI show that most of San Diego County is very sensitive to desertification. Because San Diego County is home to seven bird species of special concern, considerations of how they might be affected by desertification or future land degradation are key to their conservation, particularly if they are either not adapted or cannot adapt to desert-like conditions.

Our results showed that the ranges of Le Conte's Thrasher and Cactus Wren intersected the most with very sensitive areas. This suggests that they are either adapted to or can tolerate some desert-like conditions. The Le Conte's Thrasher and Cactus Wren are both adapted to desert climates but rely on shrub-scrub habitat for nesting (Cornell Lab of Ornithology, 2019). This observation is consistent with our findings, where both are largely found in very sensitive areas with moderate to high vegetation sensitivity consistent with low to sparse canopy coverage, more so than the other species in the study. However, notably, Le Conte's Thrasher is largely found in areas with a low SosQI, indicating it is found in isolated rural areas, while the Cactus

Wren can be found mostly with moderate SosQI scores indicating less association with human activities.

In contrast, the other five species are migratory birds that pass-through California and are not known as desert species. Though their ranges largely intersected very sensitive areas, greater portions of their ranges intersected with less sensitive areas than the two desert species. When examining the individual quality indices, some patterns emerge. First, their ranges intersected areas with high SosQI scores in higher percentages than their desert counterparts, indicating they are found in areas with higher human presence. Additionally, these species were more likely to occupy areas with low groundwater quality sensitivity. This is likely because these birds are commonly associated with wetter habitats, such as cotton-willow stands for the summer tanager, wetland habitats of the tricolored blackbird, streamsides and shrubby marshlands for the song sparrow, and grasslands/prairies for the loggerhead shrike and spotted towhee (Cornell Lab of Ornithology, 2019). This suggests these five species may be more sensitive to environmental degradation and desertification than Le Conte's Thrasher and Cactus Wren and, accordingly, may experience population declines if further land degradation or desertification occurs in the future, particularly if driven by changes in groundwater or vegetation quality.

Climate change, in particular, may drive further land degradation or desertification in San Diego County. Already, San Diego County has warmed more than other states during the last century because of rising temperatures resulting from climate change (EPA, 2016). Thus, San Diego County is expected to reveal changes in some variables directly or indirectly because of climate change. For example, rainfall would be one of the indices that may decrease over years resulting in stress on vegetation. This may increase pressure on groundwater because of the demand for irrigation. Likewise, increasing temperatures and reduced rainfall may increase future risks of catastrophic wildfires, which would further reduce vegetative cover which is limiting in many parts of the county. Any of these changes could negatively affect bird species in the county.

Therefore, protecting areas rated low to moderate sensitivity with ecosystem management can play an important role to decrease the desertification risk to bird species. Replanting vegetation where possible can be a major instrument for alleviation and prevention of desertification risk. For example, China has a successful plant-based technique for combating desertification in degraded areas. Furthermore, replanting also would be a viable strategy for the areas exposed to deforestation resulting from catastrophic wildfires, where forests are not regenerating naturally. With carefully selected vegetation (sand-loving species) and suitable techniques, restoration projects can be successful (Heshmati, 2013). Additionally, since shrublands and grasslands used by these birds are sensitive to grazing (Cornell Lab of Ornithology, 2019), limiting or minimizing grazing may be another useful conservation strategy.

6.8. Future Work

MEDALUS methodology may be enhanced by adding different quality indicators like management quality index and sub-indices such as conservation practices -policy-, and cropland intensity and according to condition of area. Furthermore, adding wind data as a sub-indicator might be important measure of climate quality index. For Climate Quality index indices aspect may not represent climate quality in flat areas instead measuring solar radiation might be helpful to have more accurate results. In addition, for future studies, MEDALUS methodology can be applied to various animal and plant habitats especially endangered and threatened species to take measures before getting disappear. Furthermore, with the help of observations on changes in ESAI maps over time LULC and climate change projections can be studied.

6.9. Limitations

This study has a few possible limitations. A variety of data was needed to complete this study. Although most are current and updated, some are noncurrent. For example, parent material is dated 2017, and sensitivity to grazing 2010. Furthermore, some data in the original scheme by Kosmos 1999 was not able to be found. For water erosion data, the Kw factor soil credibility factor was used. Grazing sensitivity data used for the calculation of socio-economic quality index only includes sheep and goats. Because of cattle has pressure on grazing including cattle as a measurement may be more precise for assess the grazing sensitivity, our study could be biased. In addition, Some layers were not high resolution. For example, rainfall data is recorded at a 4-km resolution. However, even though all-quality index and ESAI maps are resampled with the same resolution in ArcGIS 10.7 software some appear not high quality. Therefore, acquiring fine-scale data might be helpful in having high-quality maps for quality indexes. For instance, in this study having fine-scale data for SosQI can improve the precision of the SosQI map. Lastly, ESAI has calculated the geometric mean of VQI, CQI, GQI, SosQI, and SQI. This means each index (VQI, CQI, GQI, SosQI, and SQI) is weighted equally and considered that all have an equal impact on desertification. However, some quality indexes may contribute more, less, or equal to ESAI. In our study area, for example, the vegetation quality index may have more control over desertification sensitivity compared to others. It was not enough literature about how the classification schemes of the quality indexes for the calculation of ESAI were derived. Analysis relied on species range maps, which can sometimes be very broad-scale and lack precision. Using finer scale data, such as home range data for individual animals, might be enable a more refined analysis.

CHAPTER SEVEN

CONCLUSION

Desertification is a degradation process of soil in arid ecologies which endangers the sustainability of natural resources. Degradation can be resulted from natural and human-induced. The study was conducted to develop a GIS-based model for the quantitative assessment of ESAs to desertification in San Diego County. In arid and semi-arid areas, GIS is a precise and reliable tool to store, retrieve and manage a huge amount of data required to map the desertification risk. The model depended on generating an environmental sensitivity area index by assembling 21 layers to be integrated with the five indices (Climate, Soil, Socio-economic, Vegetation, Groundwater) used in the MEDALUS model.

Current work provides desertification sensitivity maps by the utilization of MEDALUS methodology for five quality indexes for seven taxa of special concern od bird species in San Diego County. The result demonstrated that there is a high desertification intensity in the area and seven taxa bird species are under the risk of desertification pressure. Moreover, climate, vegetation qualities, and socio-economic quality are significant indicators affecting the desertification process. Arid climate and change in land use and plant cover are the major grounds of the desertification process. Furthermore, human activities considerably trigger the desertification process.

In the study area, resultant ESAI and bird species maps of the area will be beneficial as a decision-making tool, particularly in the vulnerable areas for seven taxa bird species of special concern as well as combatting the desertification fact. These maps may provide useful information for developing land management strategies, such as groundwater protection, vegetation restoration or grazing allocation.

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