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ANALYSIS AND ASSESSMENT OF LAND USE / LAND COVER IMPACT ON HUMAN AND NATURAL ECOSYSTEMS IN THE SALTON SEA WATERSHED, 2013 - 2021

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A Thesis
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Environmental Sciences

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by
Diego Ismael Ramirez
December 2023

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Approved by:

Dr. Jennifer Alford, Committee Chair, Geography and Environmental Studies

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ABSTRACT

This study represents an interdisciplinary analysis of the changing landscape of the Salton Sea Watershed from 2013 to 2021, focusing on land use land cover (LULC) category changes, climatic variations, and socioeconomic factors. The findings of this research show a shift in land cover categories, portrayed by the changes of natural landscapes and vegetative areas into rapidly increasing urbanized expansion and increased impervious surfaces. These changes pose concerns about increased temperature in the region, a decrease in overall water availability and groundwater infiltration, and an increase in pollution. The study explores 10 sub-watersheds within the Salton Sea Watershed basin, focusing on the changes of LULC categories and overall temperature in the region, as well as exposing the steady decline of water in the Salton Sea sub-watershed which show a trend that could exacerbate issues regarding water and air quality that would affect nearby human and ecological environments. As the landscape of this region continues to change, primarily with reduction of vegetation and the expansion of impervious surfaces, it is important to continue growing and implementing watershed management policies to reduce further environmental and public health impacts.

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Thank you, Dr. Jennifer Alford, for not giving up on me and helping me swim. To my committee, Dr. Beyersdorf and Dr. Xu, for having to deal with my many emails and questions.

To my parents, that without your unconditional love, support, and sacrifices since the beginning, none of this would have been possible. To my brother, for always being there for support, for never letting me get down and give up, and for the constant reminder of how close I always was to finishing. To my cousin, for helping me push myself to do more. To my friends in the I.E and L.A. for always being supportive and celebrating milestones with me. And to my dog, for always easing my stresses.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Across the globe, local and regional landscapes have been converted from their natural state to ones altered by human activities, driven by needs including agricultural and developed (i.e., urban, suburban) landscapes (McFarlane et al., 2013). Southern California is a major example of a region that continues to experience rapid and spatially diverse landscape changes. Coupled with extreme weather and environmental hazards associated with climatic changes, these landscapes are increasingly challenged with predicting and protecting valuable human and environmental resources (Bachelet et al., 2016, Soulard et al., 2013, Gao et al., 2022, Smith et al., 2023). Landscape changes includes intensive urbanization across coastal, inland, and desert communities. These changes are characterized by the development of industrial, residential, commercial, and resort buildings that increase impervious surface and roadways as well as natural resource consumption (i.e., water, energy), simultaneously reducing the quality of both public and environmental health (Moanga, et al., 2018; Vicuna and Dracup, 2007). Climatic based changes in the Southern California region includes two decades of extensive drought with short-lived, but intensive rainfall events (i.e., atmospheric rivers) creating unpredictable hazardous weather and conditions (Dong, et al., 2019; MacDonald, 2007). Following a Mediterranean climate of wet and dry seasonal patterns, the summer and fall seasons typically experience wildfires in both rural and urban areas that ultimately destroy infrastructure, development, habitats, and water resources. In contrast, the winter and spring season often face atmospheric rivers that produce heavy and snowfall in short durations, collectively leading to mudslides, debris flows, and other related hazards (Dong, et al., 2019; Ullrich, et al., 2018).

The extensive droughts over the past several decades has reduced the availability of local and regional water resources, bringing with it a reduction of water in surface and groundwater features as well as water allocation from Northern California and the Colorado River Basin (Sun, et al., 2022; Castle, et al., 2014). During this same period, Southern California experienced landscape conversions, primarily characterized as natural and agricultural, and transitioning into extensive impervious surfaces, created by urban and suburban development. These development patterns include extensive residential neighborhoods, commercial stores, roadways, and public services (i.e., hospitals, schools, government complexes) (Coleman et al., 2005). Collectively, these impervious surfaces – which are artificial surfaces that do not allow water to pass through into the ground – reduce the ability for stormwater to infiltrate into the natural surfaces often leading to flashflood and other water hazard events. In addition, these impervious surfaces can increase temperatures and impact air and water quality locally and across a region (Sabouri, et al., 2013).

The Salton Sea Watershed, which includes the Coachella Valley, is known for its distinctive landscape that is characterized by its unique ecosystem, a combination of chaparral and desert. Over time, this area has seen a transformation from natural desert chaparral landscape to an expansive land for agricultural use, and as of most recently to urban and suburban development because of the growing tourist and recreational quarters, with expansions ranging from drive-in theaters to vacation and casino resorts. The aim of this study focuses on temporal and spatial changes that specific land use categories have overgone, due to the growing urbanization in the area. Additionally, this study seeks to identify solutions in reducing impacts from the increase of impervious surfaces (i.e., roadways, buildings) and address the broader issue of how changes in landscape can exacerbate climate change conditions, reduce the quantity and quality of natural resources, and affect water runoff draining into the Salton Sea.

Literature Review

Impervious Surfaces and Climate Change in Desert Regions

Climate change is one of the most pressing environmental matters the world faces, one with the potential to have negative impacts on ecosystems and human communities all over the world. Effects of climate change, specifically in desert regions, can lead to several shifts in vegetation patterns as it did in China (Zeng et al., 2020), as well as bring an increase in temperature and changes in precipitation, which is associated to drought as seen in a study for the Chihuahuan Desert in Mexico (Kandakji, et al., 2021),

Urbanization and developmental growth often occur in desert landscapes, mostly due to its vast open space to build and low financial costs, which in turn supports the increase of impervious surfaces across the landscape. The increase of impervious surfaces can lead to a decrease of water quality, such as increased volume of combined sewer overflows (Salerno et al., 2018). Additionally, an increase in impervious, impenetrable surfaces in a desert ecosystem, can affect the quantity of water that is available for the community in the area due to the reduced infiltration of groundwater, which prevents aquifers to recharge (Brabec et al., 2000). Over an extended period, this can have serious impacts on a community. The quality of the water can also be affected by increasing pollution transport, where in a desert landscape with already minimal water availability, a high percentage of pollutants in the water can be damaging to the community (Kim et al., 2016).

Urbanization and urban expansion, as important as it is to accommodate a growing population, the process also carries local, regional, and global impacts on climatic changes in land use and significantly affects near-surface air temperatures and winds, which in succession impacts air quality and becomes a hazard for human health (Zhang et al., 2022, Grossman-Clarke et al, 2010). Studies performed in Southeast China demonstrate that the mean surface temperature has increased by 0.05°C per decade due to urbanization (Cui and Shi, 2012). Additionally, in the same study, the difference between four climate factors – annual mean temperature, relative humidity, wind speed, and annual hot days – between urban and rural areas have been increasing significantly since the 1980 (Cui and Shi, 2012).

This process of urbanization carries negative impacts on the atmosphere and water qualities in major populated cities. Studies in Shanghai show that water quality has degraded rapidly due to urbanization and the water quality classification is explained by industrial land area (Ren et al., 2003). Pollutants derived from urbanization can also lead to both short and long-term health effects, especially for people with existing health conditions, such as asthma, heart disease, and lung disease (Cui and Shi, 2012). Urbanization expansion has become a serious public health concern and in Asian countries, a correlation was found between growing urbanization and increase in coronary heart disease (Khoo et al., 2003). Another study associates the increase of motor vehicle pollution due to urbanization, as the number of patients treated have increased from 5.4 person times per year to 9.1 person times per year, in the span of 10 year (Ye et al., 2000). Lastly, urbanization leads to local climatic change specifically higher temperatures, forming what is known as an urban heat island effect (Tam et al., 2015).

Heat Island Effect

Urbanization can cause an increase in surface temperature, known as an urban heat island (Kumar et al. 2012). Urban heat islands (UHI) occur with an increase of urban development and infrastructure, causing the warming temperatures of land surfaces which can be noticeable during summer nights (Karakus, 2015). The two main indicators of UHI are air temperature and land surface temperature (LST), with the latter being easily obtainable through remote sensing imagery, such as Landsat TM/EMT+ and thermal imagery to analyze changes in Land Use Land Cover (LULC) that contributes to UHI (Karakus, 2019). The relationship between LST and land use/land cover (LULC) has been highlighted in numerous UHI analyses, indicating that UHI is significantly influenced by this relationship (Weng, Lu, & Schubring, 2004). The expansion of synthetic surfaces is an indicator of centralized human activities that contribute to rising surface temperatures on Earth (Su, Gu, & Yang, 2010).

A study done in Tehran also utilized Landsat TM imagery to generate LST, normalized difference vegetation index (NDVI), and LULC maps, which were then analyzed to identify the impact of population density and land use on UHI development (Bokaie et al. 2016). Results in this study showed that airports, industrial factories, and densely populated residential areas were more affected by urban heat island. Additionally, proximity of populated residential areas to high urban heat island zones increased the risk of respiratory and heart diseases, most noticeable among children and elderly (Bokaie et al. 2016). The study also revealed that areas with natural covers, particularly those with vegetation and green spaces, had the lowest temperatures, while bare lands and asphalt-paved surfaces had the highest temperatures, as well as having a negative correlation between NDVI and LST, showing that areas with less green have a higher average land surface temperature (Bokaie et al. 2016). This issue does not only impact the environment, but also the economics and social well-being of communities.

Most urban communities are in areas that are susceptible to the effects of climate change, such as along coasts where residents and economics assets are at risk. Climate change can affect the physical and emotional health of individuals, issues that include access to water and food, health issues and displacements (Gasper et al. 2011). Past research has shown that environmental stressors that are related to climate change have an impact on the health of residents, with heat and disease transmission being the highest hazards among the urban cities due to the urban heat island effect. (Gasper et al. 2011).

Southern California deserts are not immune to these impacts, in fact they may be the most vulnerable to the effects. A study done by Bachelet et al. (2016), highlights the vulnerability of Southern California's desert region to climate change and how that can affect ecosystems and communities alike. Such impacts in communities can be represented by an increase in wildfires, where they are seen more frequent and much more intense and pose a greater thread to natural ecosystems and biodiversity. Decreased water availability, which is already scarce in the desert regions of Southern California, is only found more at danger with the steady increase of warmer climate, endangering communities, wild habitats and agricultural production, which in turn can endanger market economic loses and an increase of prices to the consumer, endangering food security for the lower income communities. Lastly, as warmer temperature approach the water restricted regions, the demand for such will increase and the supply could be in danger.

Land Use and Land Cover

Land use and land cover (LULC) change has become an important environmental issue that carries significant implications for biodiversity, ecosystem circulation, and human health. Studies have highlighted the importance of the global environmental consequences of LULC change, with effects on water availability, biodiversity, and climate (Bachelet et al., 2016). LULC analysis is also important because this type of geospatial analysis is pivotal in understanding the patterns of anthropogenic actives on Earth's surface and how these change over time, specifically with respect to climate change. The information obtained through this analysis can provide a set of guides for planning and management, which can have positive impacts toward natural resources, the environment, biodiversity and even communities (Zope, et al., 2016; Konduru, et al., 2023)

As observed in the study done by Soulard and Wilson (2015), LULC plays an important role in relation to water resource management, especially when dealing with a desert region adjacent to a saline, endorheic lake such as the Salton Sea, where climate change and decrease in water inflow directly impact the volume of the lake, thus affecting nearby communities. Water resource management in Southern California is an issue because agricultural production heavily relies on irrigation. LULC changes can be identified in regions that can aid decision for water resource management, and identify which areas suffer from urbanization, which creates impervious surfaces that reduce infiltration and recharge of groundwater (Soulard and Wilson, 2015)

Moreover, LULC classification is fundamental while using GIS applications, which involves classifying different terrains and land cover types, such as croplands, forests, and urban areas. LULC classification needs to be accurate as it is essential for environmental monitoring and analyzing as well as land use planning (Rwanga and Ndambuki, 2017). The GIS application aids in obtaining a precise delineation of the LULC in each area, allowing for the area to be analyzed in detail and to calculate different environmental and land-based trends. These applications can be further used to explore the rate of urbanization and industrial growth as well as the decline of natural vegetative landscape in each area, which can highlight the most needed areas to policy makers and management officials (Homer et al., 2020).

A crucial theme regarding LULC changes is how the use of land for agriculture, urbanization and additional human activities have created an impact on the environment, including climate change, biodiversity loss and water scarcity (Roy et al., 2022). The conversion of forest and grasslands to urban area and croplands change the natural balance of the environment, affecting the hydrological cycles, soil erosion and carbon sequestration, and although these changes vary globally, they all share the same outcome of acquiring natural resources for immediate human needs (Foley et al. 2005), all changes carrying with them implications to human health. A few present issues are those of global environmental consequences land use change impacts such as deforestation, urbanization, and the heat island effect.

In addition to the issues listed above, land use practices have been significant to changing the carbon cycle since 1850, as about 35 percent of anthropogenic carbon dioxide emission come directly from land use (Ahearn at al., 2005). Being the largest consumer of water resources using about 85 percent of global use, agriculture can deplete water resources, reduce the flow of rivers, and increase water pollution and chemical runoff (Foley et al. 2005). In a study conducted in Ethiopia, forest disturbance and LULC show an impact on the hydrologic cycle, water quality, and streamflow dynamics. The need for cultivated lands has negatively impacted the presence of vegetation, promoting soil erosion, changing the hydrologic cycle balance in the area (Regasa et al. 2021). Similarly, to Foley, in this article, agriculture has a role in the increasing soil erosion in Ethiopia where the massive expansions of farm plots, overgrazing and encroachment of farmsteads into vegetated lands have led to environmental changes, which in turn affect the water balance (Regasa et al. 2021).

Similarly, the change of native vegetation to agricultural land and urbanization has been the main factor in the decline of forest cover and decreasing water quality in Brazil, which raises concerns regarding Amazons deforestation (de Mello et al. 2020). Anthropogenic activities and LULC have a significant impact on water quality in places like Brazil, which have intensified in the past years. LULC changes of natural vegetation to human based landscapes alters runoff, infiltration, and evapotranspiration, affecting streamflow and toxic loads to water bodies (de Mello et al. 2020). In Brazil, agriculture represents about 6.4 percent of anthropogenic land use and plays a significant role in the Brazilian economy, but also contributes the most to water quality degradation (Martinelli et al. 2010). In Brazil, increases in toxic pollutant loads in water bodies are associated with agricultural lands, as well as being the primary source for phosphorus nitrogen, ammonia, and several fertilizers and pesticides (for which the country is one of the largest consumers of and is often detected in freshwater, groundwater and drinking water), posing hazardous threats to aquatic ecosystems and groundwater contamination (Taniwake et al. 2017; de Mello et al. 2020)

Additional studies have also found that groups within cities, based on gender, age, race, and socioeconomic status have an unequal burden of climate change. For example, women are often more vulnerable due to limited access to resources following a disaster (Gasper et al. 2011). The urban poor also become vulnerable due to limited assets, low income, and restricted availability to resources such as insurance following damages related to climate change (Ruth et al. 2009). Low-income communities have a greater impact damage due to their high population/space area (crowded communities), poor infrastructure and lack of open green land (Bartlett, 2008).

Within the communities of middle to low-income population, children are the ones more at risk, due to several factors such as still developing immune systems (Bartlett, 2008). In a study done by Vardoulakis et al., 2014, it was concluded that both younger children and elderly pose an elevated risk of suffering heat-related illnesses and deaths. Additionally, climate change can increase the risk of other environmental hazards, such as air pollution which lead to respiratory illnesses (Gao, et al., 2022).

Climate Change and Environmental Health

Climate change is different all over the world and affects communities and ecosystems differently, from impacting physiology of fauna to becoming a growing environmental health hazard for people. As previously stated, climate change is one of the pressing environmental and developmental challenges of the current generation, and although these impacts appear worldwide, it is mostly impacting middle and low-income communities (Bartlett, 2008). The impact of climate change includes changes of temperature, changes in precipitation, circulation pattern shifts, droughts, wind stability, and are of great concern for public health (Alahmad, et al., 2023). The rising temperatures exacerbate certain parameters of air pollution, which includes ozone and particulate matter (Watson et al., 2005). Elevated levels of ozone are associated with respiratory conditions that can lead or worsen symptoms for illnesses like asthma. Additionally, in recent decades there has been a notable rise in respiratory illnesses and even allergic conditions in areas where high levels of ozone are found. Asthma, for example has increased up to three times in the 20th century, with studies linking association with climate change factors having direct and indirect effects on communities (Sampath, et al., 2023).

Increased climatic factors such as the ones mentioned above also have a significant role in increasing the frequency and number of aerosols. One example would be in highly vegetated region in Malaysia and Indonesia in 1998, where climate change contributed to the forest fires that resulted in an exponential increase of atmospheric aerosol levels, combined with a greater amount of greenhouse gas emissions that were responsible for over 260 deaths from respiratory diseases; an increase of 30 percent hospital outpatient attendance and a 70 percent increase of patients with worsened symptoms of respiratory infections (Watson et al., 2005).

The main force of land use change is the increase of human population, through the expansion of settlements, higher demand of energy, agricultural intensification, deforestation, overuse of natural resources and alterations of natural landscapes (Kobayashi et al., 2020; Lambin et al., 2003; Shao et al., 2006). The alteration of land use initiates a chain of effects and has an impact on climate change through the release of emissions, land and air interactions, hydrological changes, ecosystems impacts and loss of biodiversity (Roy et al., 2022). Additionally, changes in the natural land will accelerate climate change, urbanization will increase hazards like air pollution, water quality and environmental hazards (Cullis et al., 2019).

Salton Sea

Located in the southeastern region of California – adjacent to the study site of the Coachella Valley – the Salton Sea lies as a close basin, inland terminal lake, which means that water can enter the lake, but does not flow out (as noted in Figure 1). Ever since its inception, the lakes' water level is maintained by agricultural runoff from regions in the Coachella Valley (Jones and Fleck, 2020). In contrast to many other lakes, where agriculture water usage results in reduction in inflows and shoreline exposure, the Salton Sea has an opposite effect (Gao, et al., 2011). As a direct result of a 1990s-2000s policy decision where it reduced available water for agriculture, runoff and inflows to the lake have diminished, and with evaporation surpassing inflow rates, the lake started shrinking (Cohen, 2014).

Even though there has been extensive research on the correlation between shrinking lakes and air pollution, according to Johnston et al., 2019 there has not been extensive research on direct health effects of wind-blown dust associated with exposed shoreline from shrinking lakes, which include respiratory and other health problems. Although it is within reason to postulate that increasing air pollution would result in increased public health costs and increase in hospitalization within a community, further research would be required. And although only a portion of the Salton Sea area is presently exposed, the rate at which it is exposed has increased since 2006, increasing the potential for air quality issues (King at al., 2011).

In the Salton Sea, the main channels that transport agricultural runoff to the lake originate from the Alamo and New Rivers which contain industrial contaminants and agricultural pesticides (De Vlaming, et al., 2004). For decades, this has affected water quality and therefore has impacted fish and birds in the region, mostly by the presence of organochlorines, pesticides, and toxic metals (Johnston, et al., 2019). As the lake dies up, the toxic substances that are present in the playa, which is a flat and dry lowest area of a desert basin, have the potential to become airborne as dust particles, making them susceptible for inhalation exposure (Kelly and Fussell, 2012). As seen in similar previous encounters at Owens Lake, dust particles in such a large-scale dust event can carry a variety of organic and inorganic components that can vary over time and location (Kelly and Fussell, 2012).

Previous studies have suggested that the presence of multiple contaminants in the Salton Sea sediment are being carried by dust emissions and may be inhaled by nearby residents in the Imperial Valley and Coachella Valley regions, which indicate additional risks to respiratory health linked to the exposure of toxins being carried by dust particle that can contribute to respiratory hospital admissions in children (Ostro, et al., 2009), and impaired lung function and increased blood pressure in adults (Johnston, et al., 2019).

As children’s lung and immune systems continue to develop during childhood, they happen to be more susceptible to the effects of air pollutants. Young children have shown to have a higher deposition of particles (Johnston, et al., 2019). Aside from the negative effects of particulate matter, children are also at risk for long term health effects from exposure to dust borne contaminants, and early life lung damage can increase the possibility of a long-term disease, so the increase in ambient particulate matter around the Salton Sea may have an impact on long term lung health (Chen, et al., 2015; Johnston, et al., 2019).

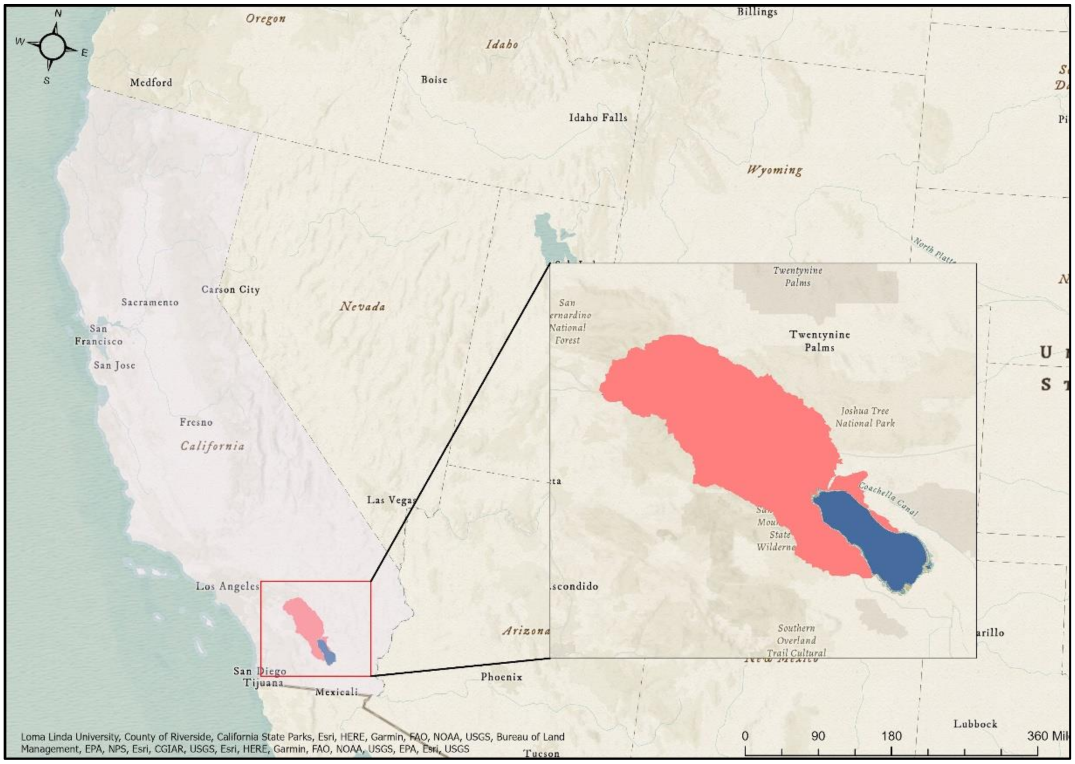


Figure 1. Map of the Salton Sea Watershed (ArcGIS)

Study Site

The Salton Sea Watershed and Coachella Valley Region

California is located on the west coast of the country, with diverse geography that contains a variety of landscapes including mountains, forests, deserts, and coastlines. The climate in the state is known to have wet and cold winters, and very dry and hot temperatures in the summer season (US Climate Data, 2023).

The Salton Sea Watershed – located in Southern California and segmented into eleven distinct sub-watersheds (as noted in Figure 2) – is an example of a region that has undergone significant land use change over the past century. The valley has historically been used for agriculture and natural resource extraction, but in recent years has become a popular destination for tourism and residential development (Sneed et al., 2014). This has led to the change of agricultural lands and natural habitats, and an increase in impervious surfaces and water consumption.

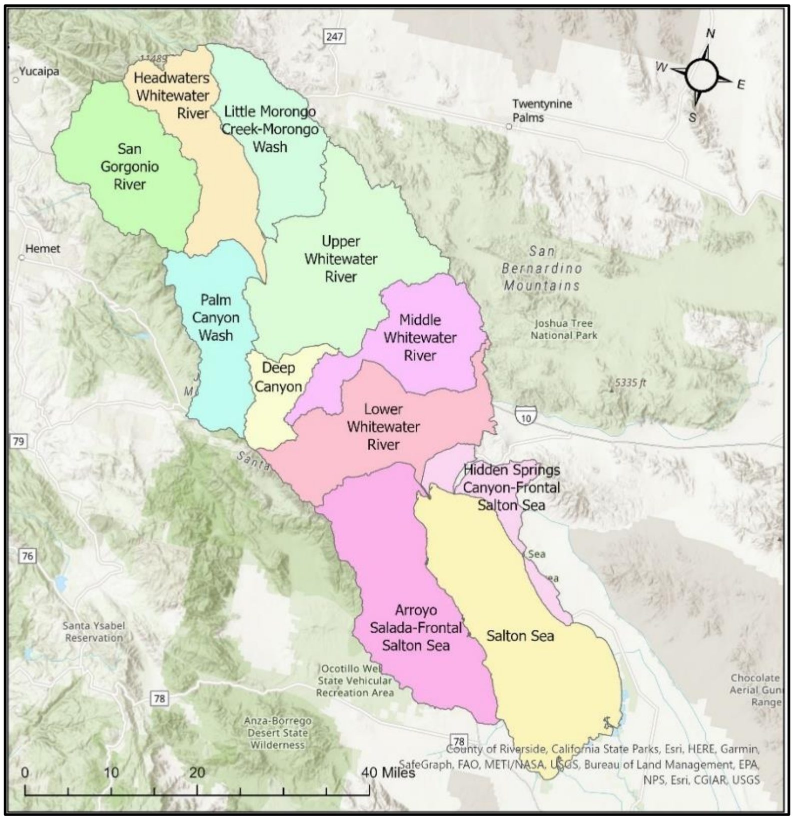


Figure 2. Study site of the Salton Sea Watershed (ArcGIS, MRLC, 2021)

Within the Salton Sea Watershed, the Coachella Valley is a 65-mile-long valley located in Southern California, adjacent to the Salton Sea. The valley covers 1036 square kilometers and includes the cities of Palm Springs, Cathedral City, Palm Desert, La Quinta, Coachella, Thermal, and Mecca (Sneed, et al., 2014). The valley is surrounded by mountains on three sides, which primarily drain into the Whitewater River and eventually discharge into the Salton Sea (Sneed, et al., 2014). Located in the southern region of Riverside County, in conjunction with the northern region of Imperial County, the Salton Sea is a body of water created accidentally in the 1905, due to a human error. The formation of the Sea emerged when water transported from the Colorado River from a poorly constructed irrigation system overflowed the canal and started filling the Salton Trough for a period of 17 months. In 1907, once the water stopped flowing into the basin, the Salton Sea sat at an elevation of -59 meters Mean Sea Level and had a surface area of 1,347 square kilometers (Setmire, et al., 2000). During this uncontrolled period of diversion, the level of the sea rose to cover more than 1,294 square kilometers and was more than 244 meters deep. However, over the following decade, the water level has receded 17 meters (Hely, et al., 1966).

Today, the Salton Sea is fed primarily by agricultural runoff from the northwest and southeast of the lake, as well as inflow from the Alamo and New Rivers in the southeast and Whitewater River in the northwest. Along with a 17-mile man-made extension for the lower valley, the Whitewater River collects stormwater runoff, agricultural return flows, and municipal and dish farm discharges, which all make up an average total surface discharge of less than 9 million cubic meters/year which is about 32 million cubic meters/year less than in 1957 (District, 2018). The weather in the Coachella Valley is arid, with an average annual rainfall less than 80 mm and a temperature range from 50°C in the summer and 0°C in the winter (Sneed, et al., 2014). The Coachella Valley has a unique desert ecosystem, which is home to a variety of plant and animal species, including the iconic Joshua Tree (National Park Service, 2023). However, this region is also impacted by urbanization, agriculture, and climate change, which have all contributed to changes in land use and land cover (Barrett, et al., 2013).

LULC have been a major concern in California, particularly in urban areas where development has led to the loss of natural habitats. The Coachella Valley has experienced significant LULC changes over the past few decades, with an increase in urbanization and agriculture leading to the conversion of natural habitats to developed land (Barrett, et al., 2013). These changes have impacted the ecological functioning of the region, including changes in water availability, air quality, and habitat fragmentation (Barrett, et al., 2013).

Study Objectives

The focus to this study is to further understand the distinct types of land use in the Coachella Valley Region, how they have changed over time, and how these changes impact environmental and socio-economic conditions.

The first objective is to gain a comprehensive understanding of the distinct types of land use in the region, including identification and characterization of numerous land uses: agricultural, urban, suburban, and shrub/scrub. Accurate classification of the regions land use can help comprehend the environmental and societal impacts.

The second objective is to determine changes in land use over time, including analyzing the LULC trends, such as the amount of land used for agriculture and urban development. Understanding the land use changes over time can help identify patterns that can inform future land use policies and decisions.

The third objective focuses on understanding where the biggest changes in land use take place across the region and within a given sub-watershed and how they impact auxiliary environmental and socio-economic conditions. This includes examining how changes in land use affect air and water quality, and natural habitats. Additionally, it involves analyzing how the land use changes affect socio-economic conditions, such as income levels, public health risks, and access to services. By identifying where the largest changes occur, it can help make better decisions to mitigate impacts and promote sustainable development as well as increase health awareness.

CHAPTER TWO

METHODS

Data Collection

Land Use and Land Cover Data

To determine the types and extent to which Land Use and Land Cover (LULC) has changed over time in the Coachella Valley, the Multi-Resolution Land Characteristics Consortium (MRLC) platform, specifically the National Land Cover Data (NLCD) (CONUS) dataset will be assessed (MRLC, 2023). The NLCD dataset is fundamental to the analysis of LULC as the dataset offers historical perspective, helping understand the initial state of land in the study area. The dataset, which is developed under the MRLC, provides a full classification of 21 hierarchical LULC classes at 30-meter spatial resolution (Wolter et al., 2006). A 30-meter resolution represents the size of a pixel on the surface of the area that measures 30-by-30 meters, which compared to other LULC resolutions is broad. This resolution represents a general classification of the area, which allows to capture a mix of different landscape categories (De Geeter et al., 2023). Such NLCD datasets support assessments of spatial changes in ecosystems and biodiversity, and aid in developing land management policies (Homer et al., 2012). The dataset was obtained for multiple years: 2013, 2016, 2019, and 2021. Each dataset includes a comprehensive legend that associated distinct land cover categories with their corresponding color pixel.

Each pixel in the dataset corresponds to a particular land cover classification legend, which when the pixels picked up by satellite are applied to remote sensing techniques, these pixels are labeled based on land cover, creating a mosaic of easier-to-identify land cover categories on the image (Kang et al., 2021). Figure 3 below represents the different LULC categories explored in this study.

NLCD Land Cover Classification Legend

11 Open Water
12 Perennial Ice/ Snow
21 Developed, Open Space
22 Developed, Low Intensity
23 Developed, Medium Intensity
24 Developed, High Intensity
31 Barren Land (Rock/Sand/Clay)
41 Deciduous Forest
42 Evergreen Forest
43 Mixed Forest
51 Dwarf Scrub*
52 Shrub/Scrub
71 Grassland/Herbaceous
72 Sedge/Herbaceous*
73 Lichens*
74 Moss*
81 Pasture/Hay
82 Cultivated Crops
90 Woody Wetlands
95 Emergent Herbaceous Wetlands

* Alaska only

Figure 3. NLCD Land Cover Classification Legend. (MRLC, 2021)

Hydrological Unit Code

Moreover, an additional important geospatial dataset was obtained from the United States Geological Survey (USGS). This dataset consists of a shapefile delineating hydrologic unit code 10 (HCU10), which will be used to identify the different hydrologic units within the study site of the Coachella Valley to work both as a holistic site and as individuals to determine which watershed had the most impact to change.

The hydrological unit framework provided from U.S. Geological Survey (USGS, 2023) is a hierarchal framework that displays drainage hydrography, and hydrological unit codes, or HUC (Seaber, et al., 1987). This framework splits HUCs at six hierarchical levels, which are defined by code length and level names (e.g., 2-digit [regions], 4-digit [subregions], 6-digit [basins], 8-digit [subbasins], 10-digit [watersheds], and 12-digit [sub watersheds]) (Seaber et al., 1987). In this study, 10-digit HCU will be utilized as seen fit. Moreover, HUCs play a significant role in watershed delineation, as they can accurately identify different watersheds, at the level 5, 10-digit unit code of a specific region (Omernik et al., 2017).

Geospatial Processing.

Similarly, to Ahearn et al (2005), Desktop ArcGIS 10.8.2 software will be used to determine a relative composition of land use in the Coachella Valley Region and its 10-digit hydrologic unit sub-basins, including the delineation of each catchment. This study will utilize cataloging units, the smallest-scale hydrologic units within the USGS hydrologic unit code (HUC) system, as a foundational framework for conducting watershed analysis and characterization. By employing cataloging units, a standardized hierarchical classification system, we can systematically delineate and study individual watersheds and sub-watersheds in the target region. The unique eight-digit codes assigned to each cataloging unit will serve as reliable identifiers for referencing and organizing hydrological data, including streamflow records, water quality parameters, and land use information (Omerkik et al., 2017, Sale et al., 2011).

Once each individual 10-digit HUCs has been delineated and separated from the holistic unit framework from USGS, a raster clipping technique is used in ArcGIS to clip the NLCD LULC data to the HUCs to identify which land use category is present within each 10-digit HUC watershed within the Coachella Valley study site. This information will provide information on percentage amount of LULC category present in the watersheds but will also identify which watersheds contain the most impervious surfaces/developed areas and provide information about the LULC changes in each watershed throughout the years selected.

For each individual watershed and year raster clip, the process involved accessing and transferring the attribute table data from ArcGIS into Excel. The main part of this analysis will be to calculate the size of each land attribute in hectares, and the difference throughout the years (Wolter et al., 2006).

Quantitative Analysis and Area Calculation

An essential segment of this study is to quantify the distinct land cover attribute of the watershed throughout the years. To discover the size of each attribute, a calculation was completed. Since each pixel on the map is 30-by-30 meters, square meters were utilized to convert it to hectares (Wolter et al., 2006). The conversion factor is 10,000 square meters in a hectare. By multiplying the number of pixels for each land attribute by this factor, the actual size of land type was obtained in hectares. After this was completed, each land type was added for each watershed to get the total of the overall watershed. Calculation shown below:

1. *30 x 30 = 900 (size of pixels)*
2. $\frac{900\, x\, N}{10{,}000}$, *where N is the number of pixels for each land type.*

Percentage Calculation and Analysis.

After all the area calculations were completed for each watershed and year, the next step is to understand how much of each land type there is in each area. For every year, the area of each land cover is divided by the total size of the watershed area and then multiplied by 100 to obtain a percentage. To make sure the calculations were accurate, the addition of all the percentages of each land type was calculated and made sure it added to 100 percent. Below is the equation.

1. $\frac{Total\ area\ watershed\ land\ type}{total\ area\ of\ watershed}\ x\ 100$

This analysis of percentage data is important to comprehend the changing LULC dynamics in each watershed over time. The percentages provide a clear indication of how different land cover types changed the overall composition of the area, aiding the understanding into the changes that have been undergoing in the Coachella Valley region and how that can affect the Salton Sea

Ancillary Data

Temperature and Precipitation. Temperature data provide insights into the thermal conditions of the study area, which can influence LULC patterns. By analyzing temperature records, it is possible to identify potential correlations between temperature variations and specific land cover changes (Ullah, et al., 2023). For example, rising temperatures may affect agricultural practices, leading to shifts in crop types or changes in irrigation methods. To access temperature data for the Coachella Valley, the National Centers for Environmental Information (NCEI) Climate Data Online (NOAA, 2023) portal is a valuable resource. The NCEI provides historical climate data, including temperature records, which allows it to examine long-term temperature trends and their impact on LULC changes (Longman et al., 2018). Data is being gathered by the Palm Springs station as this location is the most consistent and contains the most up to date metrics.

Precipitation data are essential for assessing the water availability and hydrological characteristics of the study area. Changes in precipitation patterns can significantly impact land use and vegetation dynamics. By examining precipitation records, the study aims to identify relationships between rainfall variations and LULC changes, such as the expansion of irrigated agricultural areas or the effects of drought on natural vegetation (Rodriguez et al., 1997).

Graphs were created using both Microsoft Excel and Microsoft Power BI with the obtained data to provide a clear visual insight into the fluctuations in thermal conditions and rainfall patterns within the study area. Power BI was used as it offers the ability to create easily comparable data visuals at a much faster rate.

Air Quality Data

For this study, air quality data was retrieved from the Environmental Protection Agency (EPA) Air Data Quality monitors, which are well-regarded sources of environmental information available on the EPA website (Environmental Protection Agency, 2023). The specific focus was on monitoring two crucial air pollutants, the mass of particulate matter smaller than 2.5 µm (known as $PM_{2.5}$) and ozone (O_3), due to their importance in evaluating air quality and their potential impacts on human health and the environment. The selection of monitoring sites played a critical role, and the sites chosen were based on data availability for the designated years (2013, 2016, 2019, and 2021) and their relevance to the Coachella Valley area. This site includes the centrally located Palm Springs monitoring site within the Salton Sea Watershed which provided data from a different geographical perspective for comparative analysis, as shown on Figure 4. It is important to note that not all monitoring sites had data available for every year of interest.

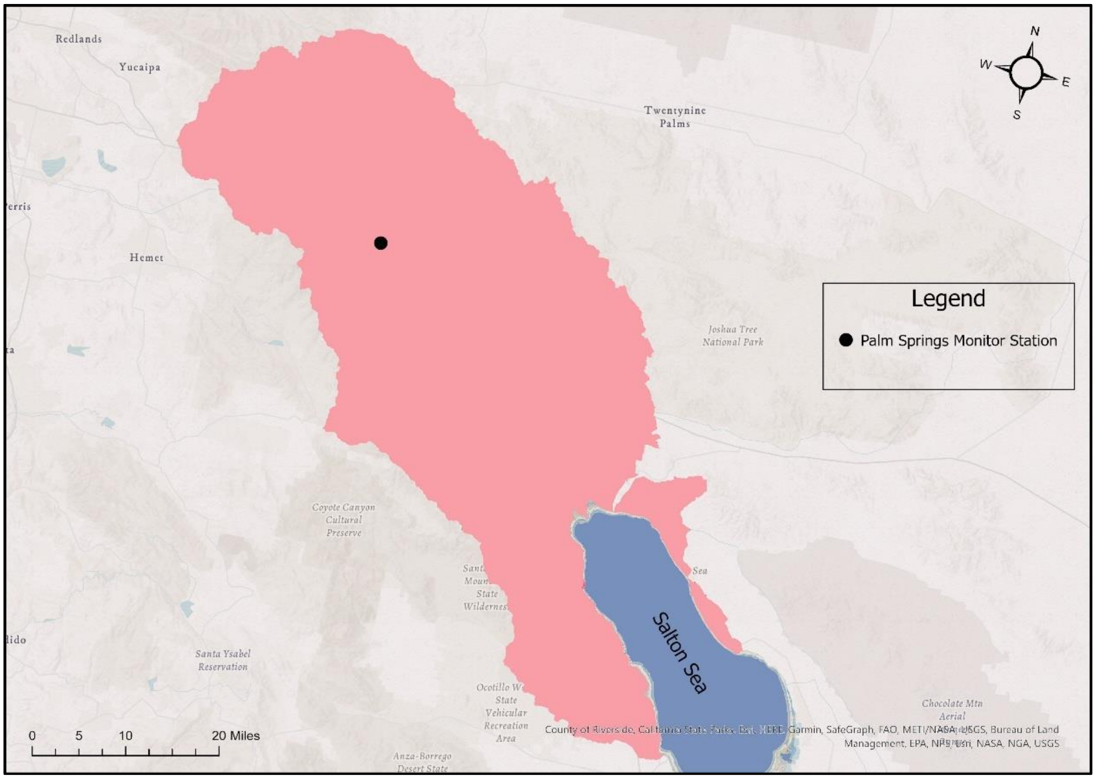


Figure 4. Map of The Salton Sea Watershed highlighting Palm Springs Monitoring Station (ArcGIS)

Population Factor, 2010 – 2020

The population section of this study relies on data sourced from the United States Census Bureau online database, which provides data such as population, social demographics, housing, educative and economic for specifics regions. The U.S Census Bureau uses census to calculate statistics based on geographic locations and is regularly used in studies to for analysis (Smith et al., 2023). For this study, population metrics from 11 major cities located within the Salton Sea Watershed are obtained from 2010 and 2020: Cathedral City, Coachella, Desert

Hot Springs, Desert Palms, Indio, La Quinta, Mecca, Palm Desert, Palm Springs, Rancho Mirage, and Thousand Palms.

While census data and HUC 10-digit watershed boundaries delineated for this analysis do not align, and falls beyond the scope of this study, the census data serves as a general informatic overview of the population in the area to help gain insight on the implications this can have on land category changes and urbanization within the study area of the Coachella Valley.

CHAPTER THREE

RESULTS

This study observed land use and land cover (LULC) changes within the Salton Sea watershed to determine the extent and types of land changes taking place from 2013 to 2021. Results highlight that drastic land conversions from vegetative cover to impervious surfaces occurred across the watershed. This decline could potentially be attributed to factors such as rising temperatures, altered precipitation patterns, or land-use practices. On the contrary, the development category demonstrated a contrasting increasing trend. The steady rise in development, encompassing urbanization and infrastructure expansion, indicates a shift in land use toward a built environment. Increases in impervious surfaces impact air, water, and soil resources by increasing surface temperatures, reducing water infiltration, and increasing roadways and electrical uses that create emissions. Another primary observation was that the Salton Sea itself was also reduced in the amount of surface water this landscape feature represents. Each of these observations suggests that not only is the landscape draining to the Salton Sea potentially increasing pollution inputs during storm flow event, but the Salton Sea itself may become more polluted as water levels recede.

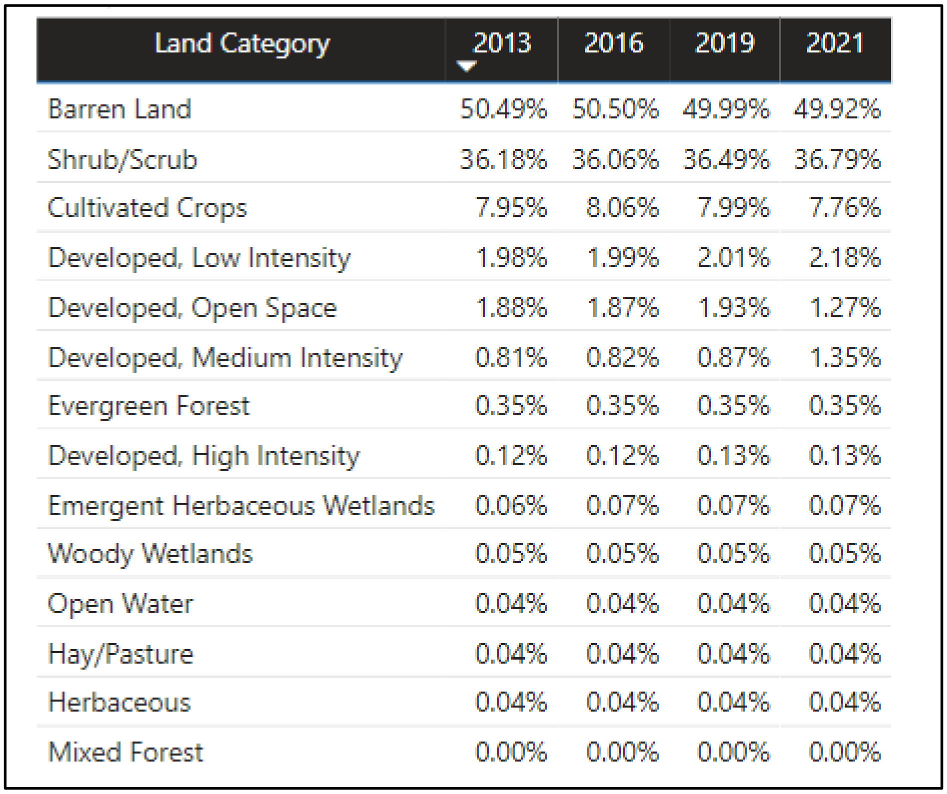
Watershed Landscape Changes

Watersheds play a pivotal role in shaping ecosystems and environmental health, making it crucial to understand where and the extent to which LULC changes occur within the Salton Sea Watershed it its sub-watersheds. Such an assessment positions itself to support the identification of adaptive watershed management strategies that jointly reduce human and climatic impacts to public-environmental health and natural resources. Through this investigation, we gain valuable insights into the evolving landscape, the land-use practices, and the ecological implications of landscape changes for sub-watershed within the Salton Sea watershed basin. To better understand the landscape changes on Figures 4-14, please refer to Figure 3, the NLCD Land Cover Classification Legend.

Arroyo Salada Sub-Watershed

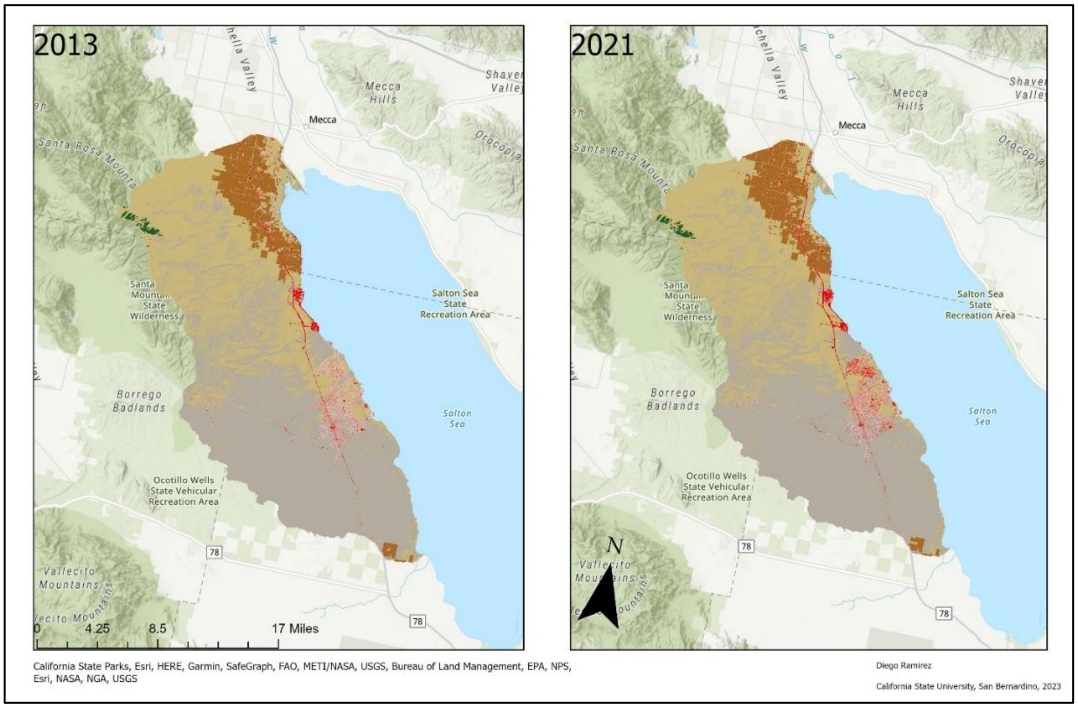
In 2013, the Arroyo Salada Sub-Watershed was primarily characterized by barren land (50 %) followed by shrub/scrub land (36 %) (Table 1). Both represented the dominant land types for this sub-watershed during the study period; however, barren land slightly decreased over time and shrub/scrub slightly increased. Developed, medium intensity represented the largest increases in LULC (+67 %) for the Arroyo Salada Sub-Watershed with developed, open space represented the largest decreases by LULC type (-32 %).

Table 1. Percentage of Land Categories in the Arroyo Salada



Land Category	2013	2016	2019	2021
Barren Land	50.49%	50.50%	49.99%	49.92%
Shrub/Scrub	36.18%	36.06%	36.49%	36.79%
Cultivated Crops	7.95%	8.06%	7.99%	7.76%
Developed, Low Intensity	1.98%	1.99%	2.01%	2.18%
Developed, Open Space	1.88%	1.87%	1.93%	1.27%
Developed, Medium Intensity	0.81%	0.82%	0.87%	1.35%
Evergreen Forest	0.35%	0.35%	0.35%	0.35%
Developed, High Intensity	0.12%	0.12%	0.13%	0.13%
Emergent Herbaceous Wetlands	0.06%	0.07%	0.07%	0.07%
Woody Wetlands	0.05%	0.05%	0.05%	0.05%
Open Water	0.04%	0.04%	0.04%	0.04%
Hay/Pasture	0.04%	0.04%	0.04%	0.04%
Herbaceous	0.04%	0.04%	0.04%	0.04%
Mixed Forest	0.00%	0.00%	0.00%	0.00%

Figure 5 displays the change in land categories for the years 2013 and 2021. The largest increase in medium intensity development, where impervious surfaces account for 50%-79% of total cover in an area mixed with constructed material and vegetation, is in the center northeast region of the sub-watershed, nearby the border of the Salton Sea Lake. Coincidently, this area is also where the largest decreasing category of developed open space, which impervious surfaces cover 20 % of the total mixed area, is also located.



California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, Esri, NASA, NGA, USGS

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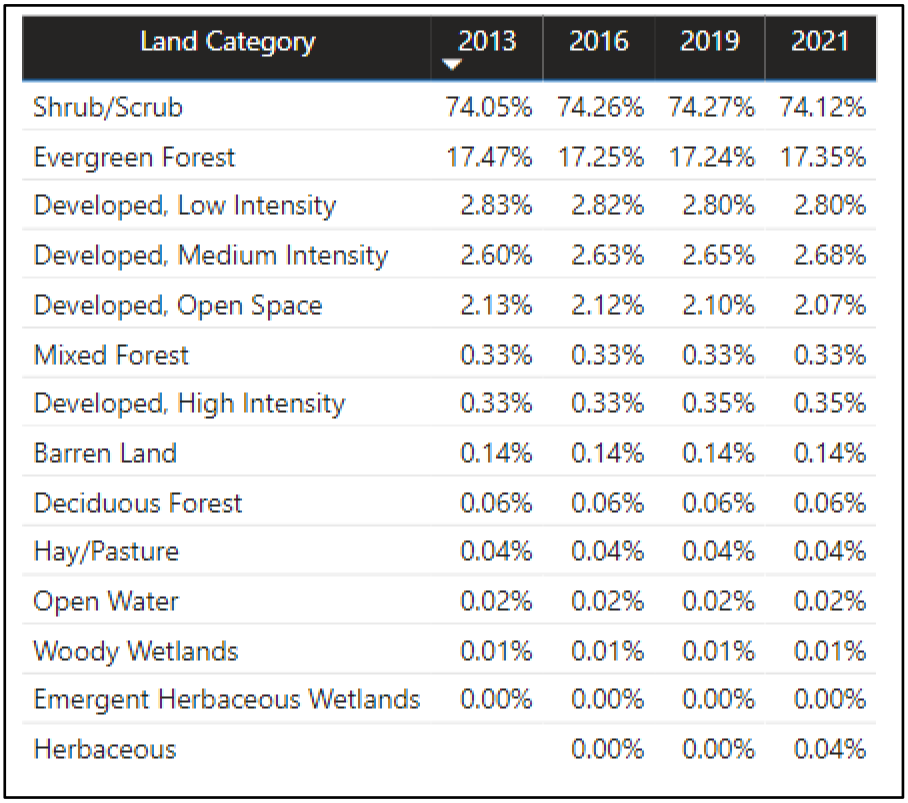
California State University, San Bernardino, 2023

Figure 5. Arroyo Salada Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Deep Canyon Sub-Watershed.

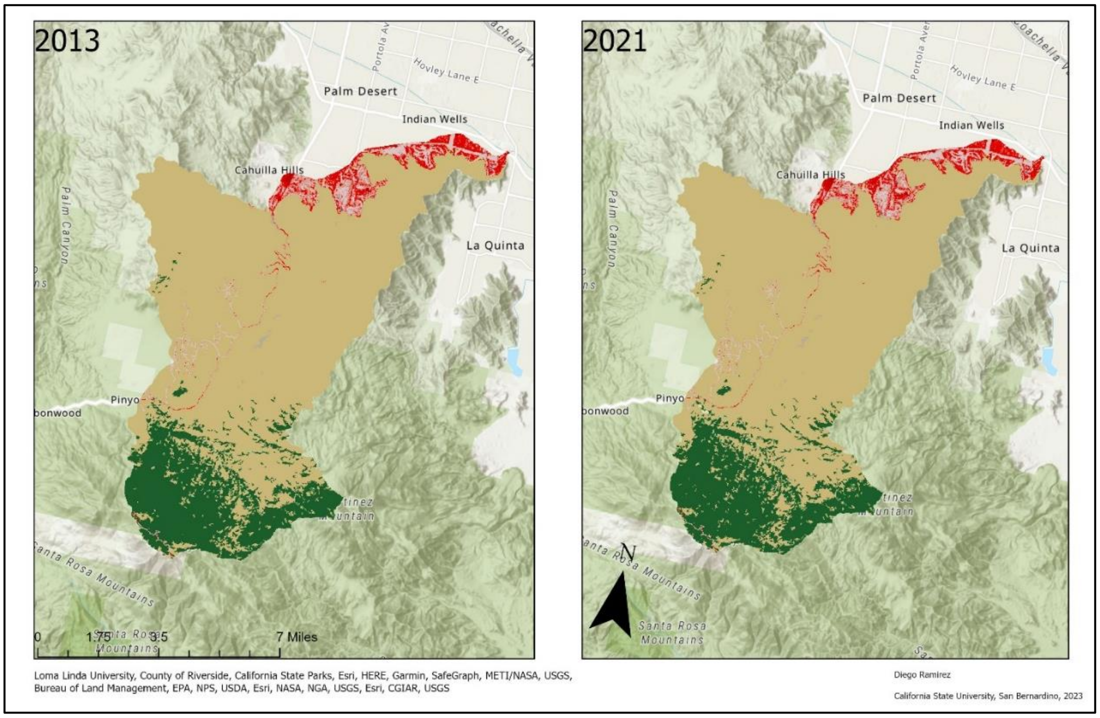
In 2013, the Deep Canyon Sub-Watershed was primarily characterized by shrub/scrub (75 %) followed by evergreen forest (17 %) (Table 2). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub slightly increased over time. Developed, medium intensity represented the largest increases in LULC (+3 %) for the Deep Canyon Sub-Watershed while evergreen forest represented the largest decreases by LULC type (-6 %).

Table 2. Percentage of Land Categories in the Deep Canyon



Land Category	2013	2016	2019	2021
Shrub/Scrub	74.05%	74.26%	74.27%	74.12%
Evergreen Forest	17.47%	17.25%	17.24%	17.35%
Developed, Low Intensity	2.83%	2.82%	2.80%	2.80%
Developed, Medium Intensity	2.60%	2.63%	2.65%	2.68%
Developed, Open Space	2.13%	2.12%	2.10%	2.07%
Mixed Forest	0.33%	0.33%	0.33%	0.33%
Developed, High Intensity	0.33%	0.33%	0.35%	0.35%
Barren Land	0.14%	0.14%	0.14%	0.14%
Deciduous Forest	0.06%	0.06%	0.06%	0.06%
Hay/Pasture	0.04%	0.04%	0.04%	0.04%
Open Water	0.02%	0.02%	0.02%	0.02%
Woody Wetlands	0.01%	0.01%	0.01%	0.01%
Emergent Herbaceous Wetlands	0.00%	0.00%	0.00%	0.00%
Herbaceous		0.00%	0.00%	0.04%

Figure 6 displays the change in land categories for the years 2013 and 2021. The largest increase in medium intensity development, where impervious surfaces account for 50%-79% of total cover in an area mixed with constructed material and vegetation, is in the northeast region of the sub-watershed closest to the Palm Desert, Indian Wells location. At the southwest region of the sub-watershed near the Santa Rosa Mountains, the evergreen forest category, or areas dominated by 5+ meter tall trees and greater than 20 % of total vegetation forest, saw the most decrease by LULC type.



Loma Linda University, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, Esri, NASA, NGA, USGS, Esri, CGIAR, USGS

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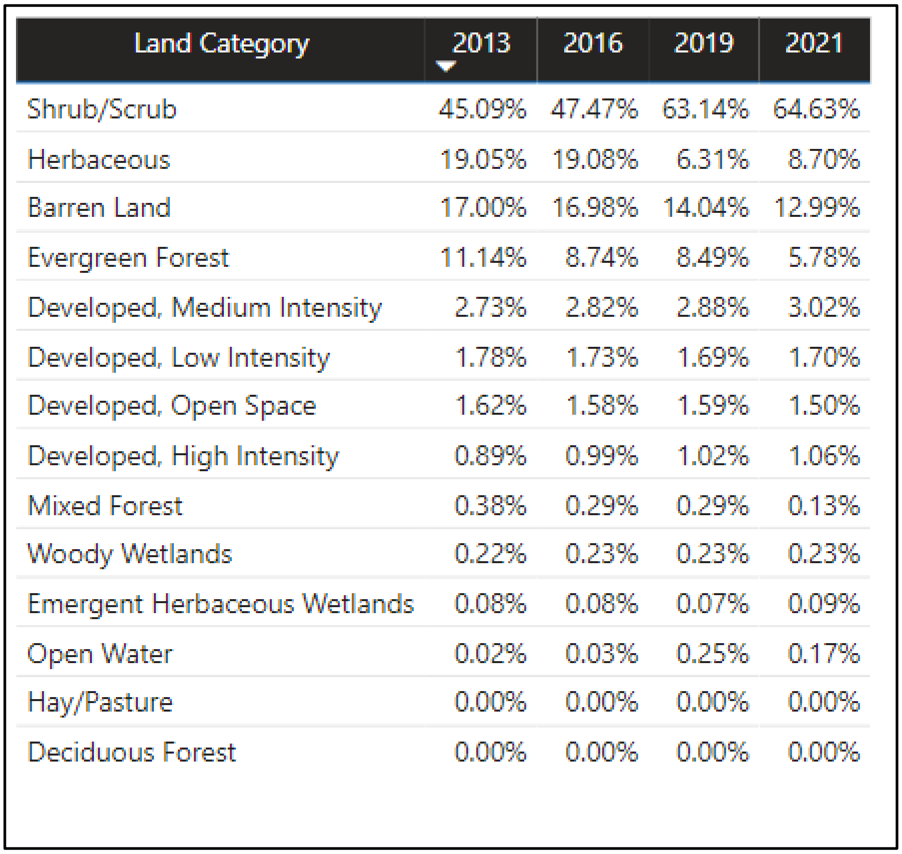
Figure 6. Deep Canyon Sub-Watershed Map. (ArcGIS, MRLC, 2021)

<u>Headwaters Whitewater Rivers Sub-Watershed.</u>

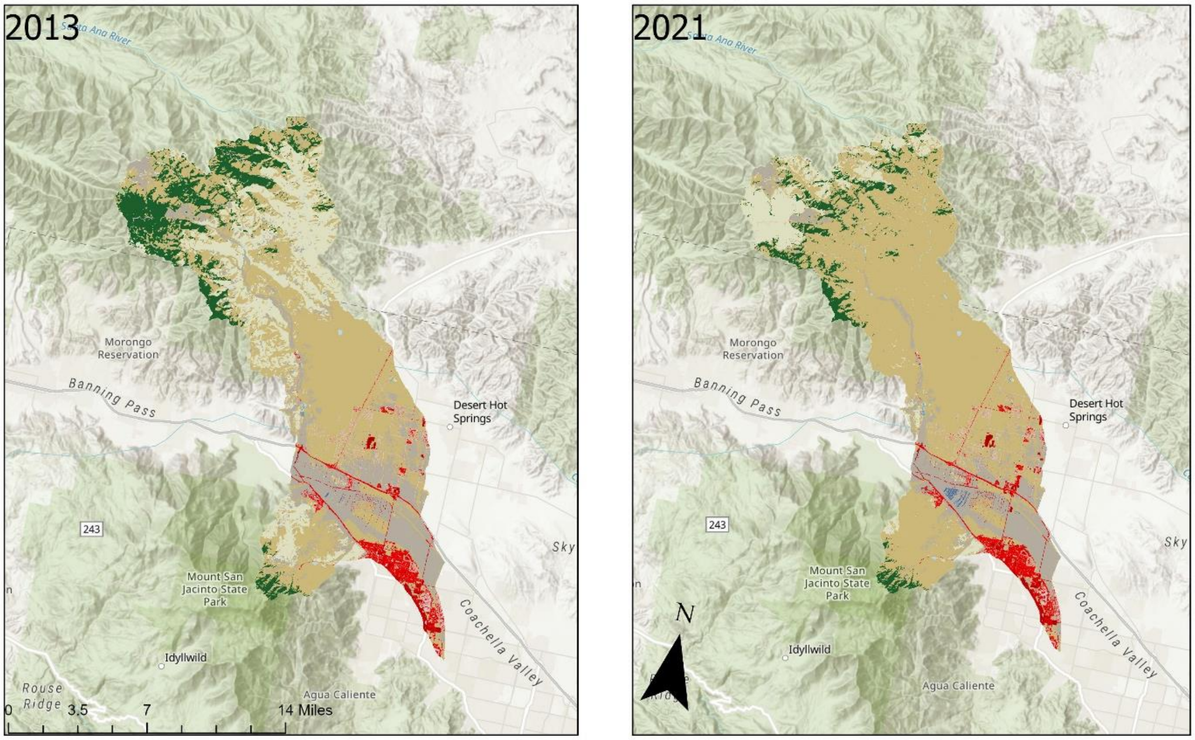
In 2013, the Headwaters Whitewater Rivers Sub-Watershed was primarily characterized by shrub/scrub (45 %) followed by herbaceous (19 %) (Table 3). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub increased over time. Shrub/scrub represented a significant increase in LULC (+43 %) for the Headwaters Whitewater Rivers Sub-Watershed, while herbaceous represented the largest decreases by LULC type (-54 %).

Table 3. Percentage of Land Categories in the Headwaters



Land Category	2013	2016	2019	2021
Shrub/Scrub	45.09%	47.47%	63.14%	64.63%
Herbaceous	19.05%	19.08%	6.31%	8.70%
Barren Land	17.00%	16.98%	14.04%	12.99%
Evergreen Forest	11.14%	8.74%	8.49%	5.78%
Developed, Medium Intensity	2.73%	2.82%	2.88%	3.02%
Developed, Low Intensity	1.78%	1.73%	1.69%	1.70%
Developed, Open Space	1.62%	1.58%	1.59%	1.50%
Developed, High Intensity	0.89%	0.99%	1.02%	1.06%
Mixed Forest	0.38%	0.29%	0.29%	0.13%
Woody Wetlands	0.22%	0.23%	0.23%	0.23%
Emergent Herbaceous Wetlands	0.08%	0.08%	0.07%	0.09%
Open Water	0.02%	0.03%	0.25%	0.17%
Hay/Pasture	0.00%	0.00%	0.00%	0.00%
Deciduous Forest	0.00%	0.00%	0.00%	0.00%

Figure 7 displays the change in land categories for the years 2013 and 2021. The largest increase in the open water category, areas of open water where there is generally less than 25 % cover of vegetation or soil, is in the center southwest region of the sub-watershed by where Banning Pass cuts through. Both the north and south areas of the delineated sub-watershed saw a combined decrease in herbaceous LULC type, areas with 80 % or more of herbaceous vegetation, and evergreen forest, 5+ meter tall trees covering more than 20 percent of the area.



Esri, NASA, NGA, USGS, Loma Linda University, UC Riverside, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS

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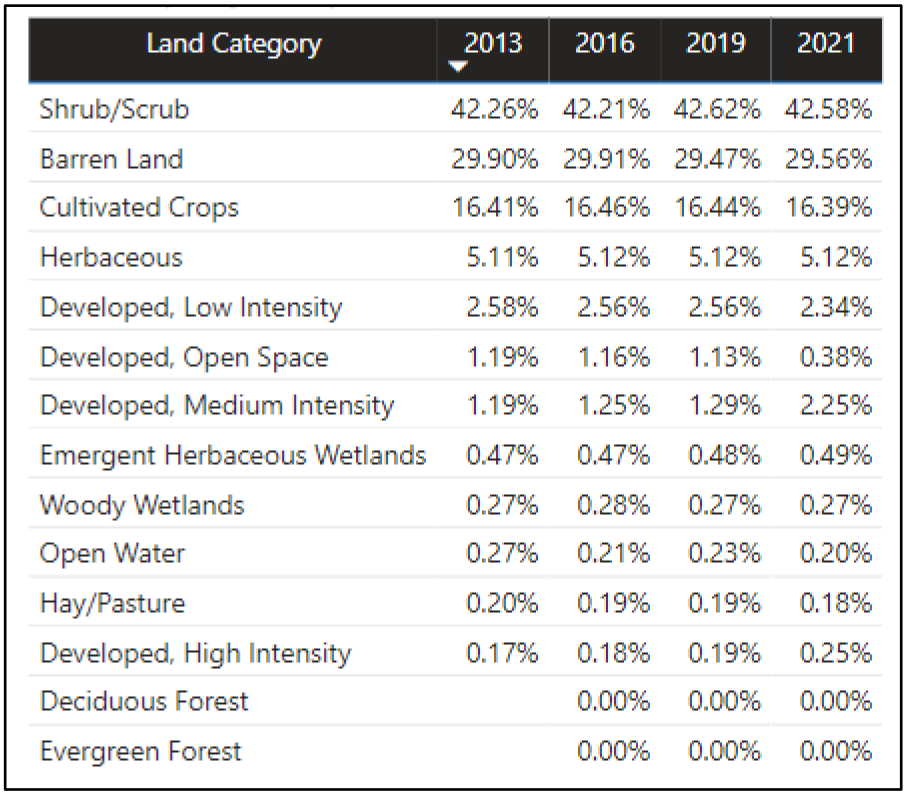
Figure 7. Headwater Whitewater River Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Hidden Springs Canyon Sub-Watershed.

In 2013, the Hidden Springs Canyon Sub-Watershed was primarily characterized by shrub/scrub (42 %) followed by barren land (30 %) (Table 4). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub slightly increased over time while barren land decreased. Developed, medium intensity represented the largest increases in LULC (+90 %) for the Hidden Springs Canyon Sub-Watershed while developed – open space represented the largest decreases by LULC type (-68 %).

Table 4. Percentage of Land Categories in the Hidden Springs Canyon



Land Category	2013	2016	2019	2021
Shrub/Scrub	42.26%	42.21%	42.62%	42.58%
Barren Land	29.90%	29.91%	29.47%	29.56%
Cultivated Crops	16.41%	16.46%	16.44%	16.39%
Herbaceous	5.11%	5.12%	5.12%	5.12%
Developed, Low Intensity	2.58%	2.56%	2.56%	2.34%
Developed, Open Space	1.19%	1.16%	1.13%	0.38%
Developed, Medium Intensity	1.19%	1.25%	1.29%	2.25%
Emergent Herbaceous Wetlands	0.47%	0.47%	0.48%	0.49%
Woody Wetlands	0.27%	0.28%	0.27%	0.27%
Open Water	0.27%	0.21%	0.23%	0.20%
Hay/Pasture	0.20%	0.19%	0.19%	0.18%
Developed, High Intensity	0.17%	0.18%	0.19%	0.25%
Deciduous Forest		0.00%	0.00%	0.00%
Evergreen Forest		0.00%	0.00%	0.00%

Figure 8 displays the change in land categories for the years 2013 and 2021. The largest increase in the medium intensity development, where impervious surfaces account for 50%-79% of total cover in an area mixed with constructed material and vegetation, is in the center east region of the sub-watershed which faces the Salton Sea, north of the recreation area stated on Figure 6. This area is also the where the open space change, where impervious surfaces cover less than 20 %, mostly occurred.

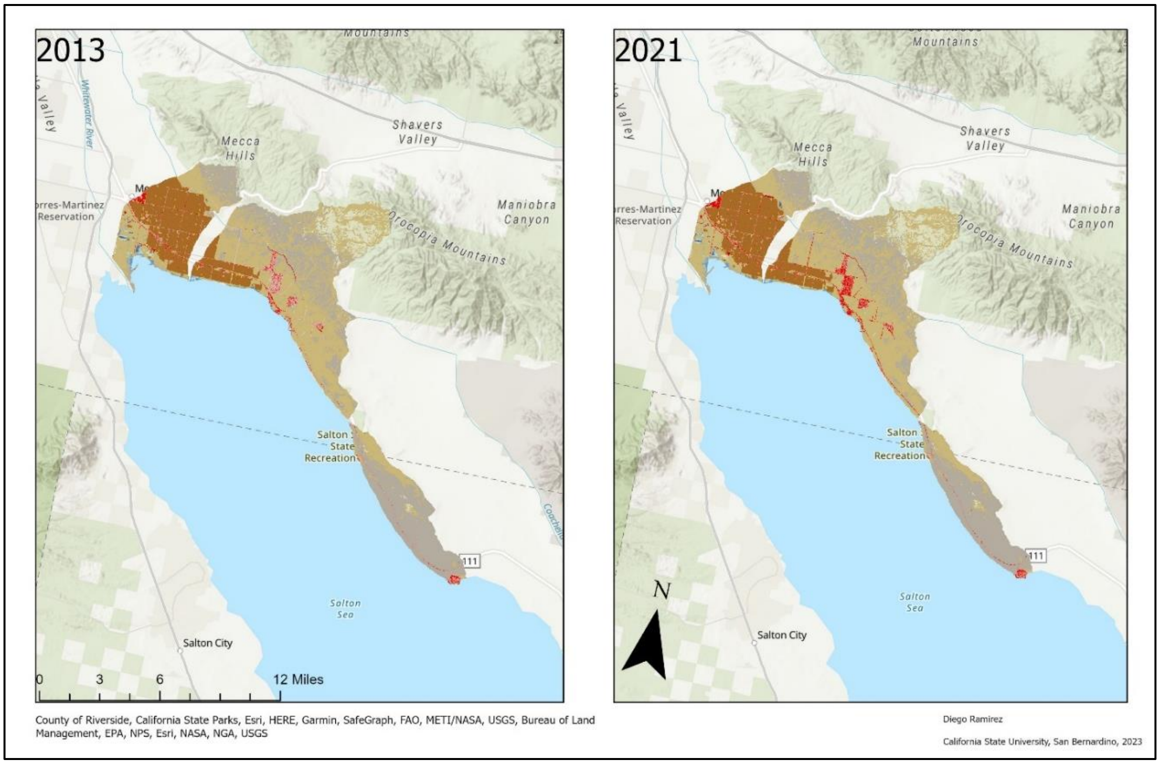
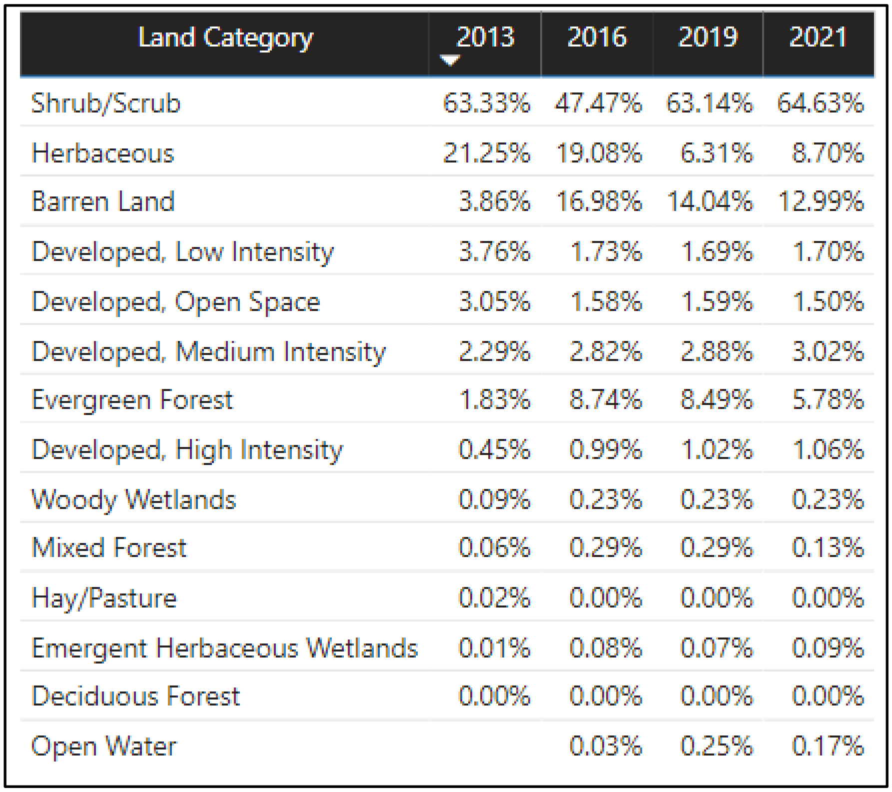


Figure 8. Hidden Springs Canyon Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Little Morongo Sub-Watershed.

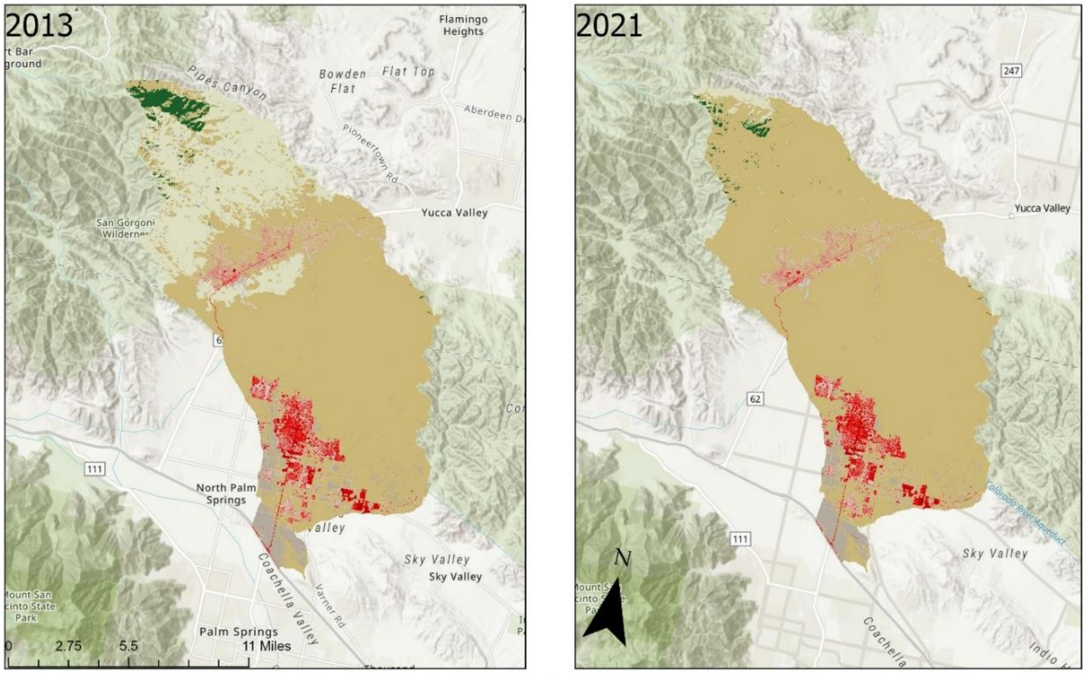
In 2013, the Little Morongo Sub-Watershed was primarily characterized by shrub/scrub (63 %) followed by herbaceous (21 %) (Table 5). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub slightly increased over time while herbaceous decreased. Barren land represented the largest increases in LULC (+236 %) for the Little Morongo Sub-Watershed while herbaceous represented the largest decreases by LULC type (-59 %).

Table 5. Percentage of Land Categories in Little Morongo



Land Category	2013	2016	2019	2021
Shrub/Scrub	63.33%	47.47%	63.14%	64.63%
Herbaceous	21.25%	19.08%	6.31%	8.70%
Barren Land	3.86%	16.98%	14.04%	12.99%
Developed, Low Intensity	3.76%	1.73%	1.69%	1.70%
Developed, Open Space	3.05%	1.58%	1.59%	1.50%
Developed, Medium Intensity	2.29%	2.82%	2.88%	3.02%
Evergreen Forest	1.83%	8.74%	8.49%	5.78%
Developed, High Intensity	0.45%	0.99%	1.02%	1.06%
Woody Wetlands	0.09%	0.23%	0.23%	0.23%
Mixed Forest	0.06%	0.29%	0.29%	0.13%
Hay/Pasture	0.02%	0.00%	0.00%	0.00%
Emergent Herbaceous Wetlands	0.01%	0.08%	0.07%	0.09%
Deciduous Forest	0.00%	0.00%	0.00%	0.00%
Open Water		0.03%	0.25%	0.17%

Figure 9 displays the change in land categories for the years 2013 and 2021. The largest increase in the shrub/scrub category, which are areas dominated by shrubs and usually greater than 20 % of total vegetation, is found throughout the northern region of the sub-watershed, which makes up the edge of the San Gorgonio mountains. This area is also the where the decrease of herbaceous, where 80 % of the total vegetation is composed of herbaceous vegetation, is located, and only mostly remains on the northeast region.



Loma Linda University, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, Esri, NASA, NGA, USGS, Esri, CGIAR, USGS, Loma Linda University, County

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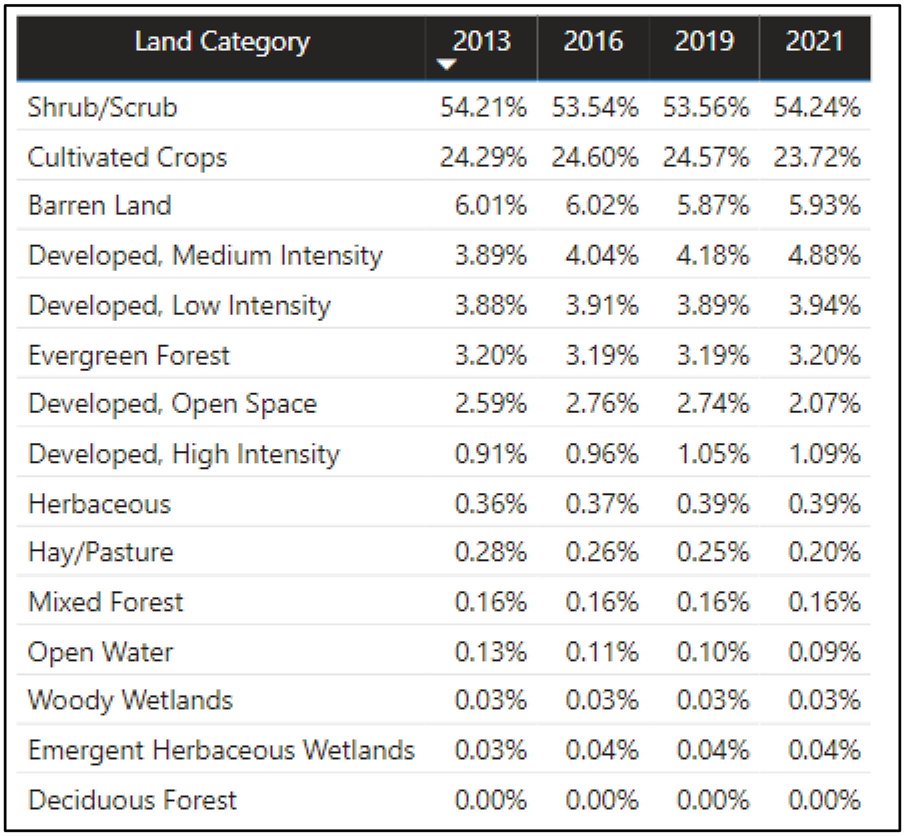
Figure 9. Little Morongo Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Lower Whitewater Rivers Sub-Watershed.

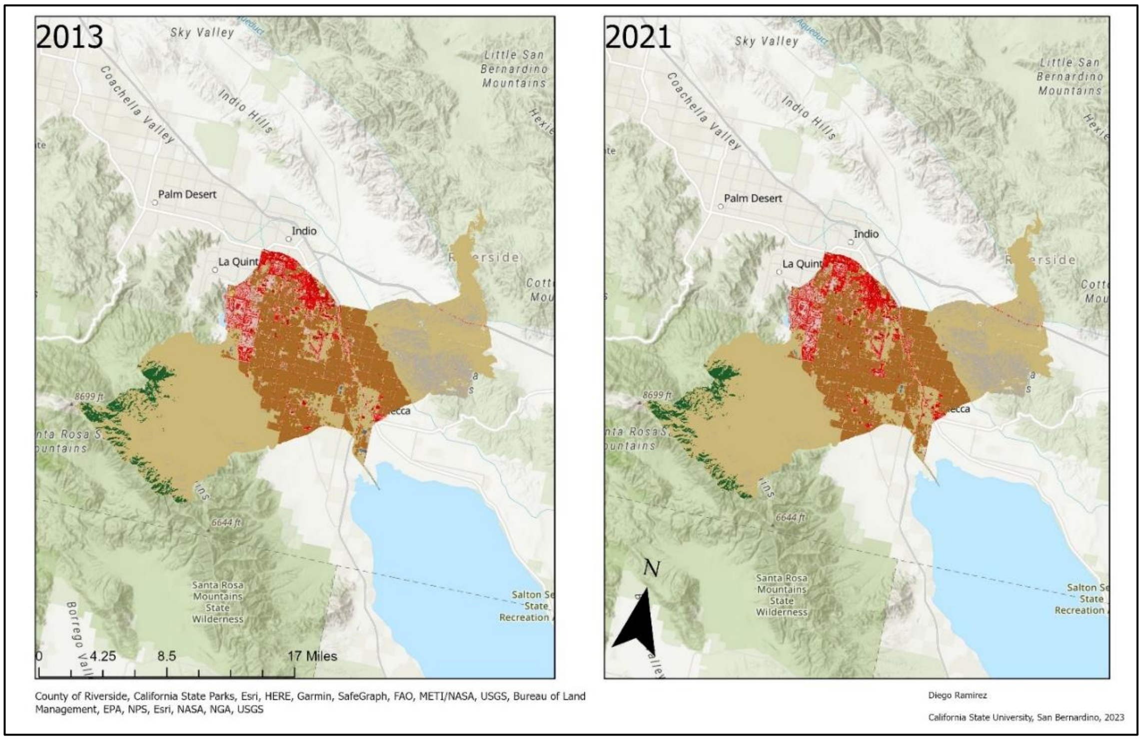
In 2013, the Lower Whitewater River Sub-Watershed was primarily characterized by shrub/scrub (54 %) followed by cultivated crops (24 %) (Table 6). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub slightly increased over time while cultivated crops decreased. Developed – medium intensity represented the largest increases in LULC (+25 %) for the Lower Whitewater River Sub-Watershed while open water represented the largest decreases by LULC type (-31 %).

Table 6. Percentage of Land Categories in the Lower Whitewater



Land Category	2013	2016	2019	2021
Shrub/Scrub	54.21%	53.54%	53.56%	54.24%
Cultivated Crops	24.29%	24.60%	24.57%	23.72%
Barren Land	6.01%	6.02%	5.87%	5.93%
Developed, Medium Intensity	3.89%	4.04%	4.18%	4.88%
Developed, Low Intensity	3.88%	3.91%	3.89%	3.94%
Evergreen Forest	3.20%	3.19%	3.19%	3.20%
Developed, Open Space	2.59%	2.76%	2.74%	2.07%
Developed, High Intensity	0.91%	0.96%	1.05%	1.09%
Herbaceous	0.36%	0.37%	0.39%	0.39%
Hay/Pasture	0.28%	0.26%	0.25%	0.20%
Mixed Forest	0.16%	0.16%	0.16%	0.16%
Open Water	0.13%	0.11%	0.10%	0.09%
Woody Wetlands	0.03%	0.03%	0.03%	0.03%
Emergent Herbaceous Wetlands	0.03%	0.04%	0.04%	0.04%
Deciduous Forest	0.00%	0.00%	0.00%	0.00%

Figure 10 displays the change in land categories for the years 2013 and 2021. The largest increase the medium intensity development, where impervious surfaces account for 50%-79% of total cover in an area mixed with constructed material and vegetation, is found mostly the northern region of the sub-watershed, closest to La Quinta and Indio. Meanwhile the area that saw the most decrease in a LULC category, open water, is in the south region of the sub-watershed, bordering the Salton Sea.



County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, Esri, NASA, NGA, USGS

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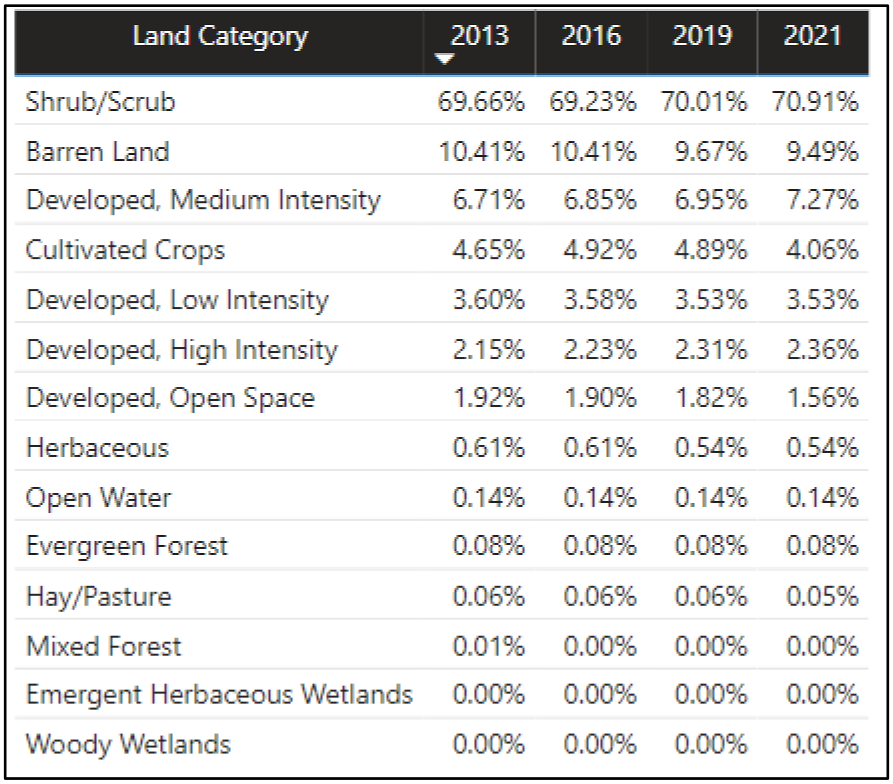
Figure 10. Lower Whitewater River Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Middle Whitewater Rivers Sub-Watershed.

In 2013, the Middle Whitewater River Sub-Watershed was primarily characterized by shrub/scrub (69 %) followed by barren land (10 %) (Table 7). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub slightly increased over time while barren land slightly decreased. Developed–high intensity represented the largest increases in LULC (+10 %) for the Middle Whitewater River Sub-Watershed while cultivated crops represented the largest decreases by LULC type (-12 %).

Table 7. Percentage of Land Categories in the Middle Whitewater



Land Category	2013	2016	2019	2021
Shrub/Scrub	69.66%	69.23%	70.01%	70.91%
Barren Land	10.41%	10.41%	9.67%	9.49%
Developed, Medium Intensity	6.71%	6.85%	6.95%	7.27%
Cultivated Crops	4.65%	4.92%	4.89%	4.06%
Developed, Low Intensity	3.60%	3.58%	3.53%	3.53%
Developed, High Intensity	2.15%	2.23%	2.31%	2.36%
Developed, Open Space	1.92%	1.90%	1.82%	1.56%
Herbaceous	0.61%	0.61%	0.54%	0.54%
Open Water	0.14%	0.14%	0.14%	0.14%
Evergreen Forest	0.08%	0.08%	0.08%	0.08%
Hay/Pasture	0.06%	0.06%	0.06%	0.05%
Mixed Forest	0.01%	0.00%	0.00%	0.00%
Emergent Herbaceous Wetlands	0.00%	0.00%	0.00%	0.00%
Woody Wetlands	0.00%	0.00%	0.00%	0.00%

Figure 11 displays the change in land categories for the years 2013 and 2021. The largest increase in the high intensity development category, where impervious surfaces account for 80-100% – due to it being a highly developed area – is found the central region of the sub-watershed, closest to Palm Desert. Similarly, the cultivated crops LULC type, where crop vegetation makes up more than 20 % of the total vegetation in the area, is in the center region of the sub-watershed as it often gets replaced by impervious surfaces.

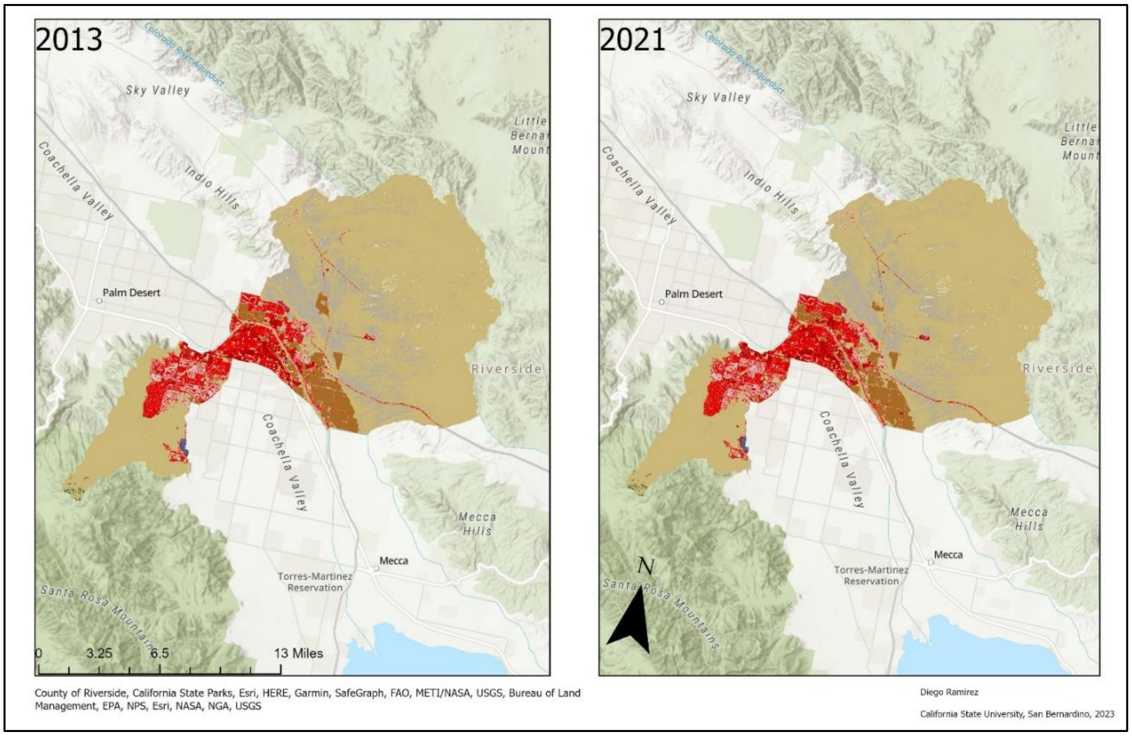
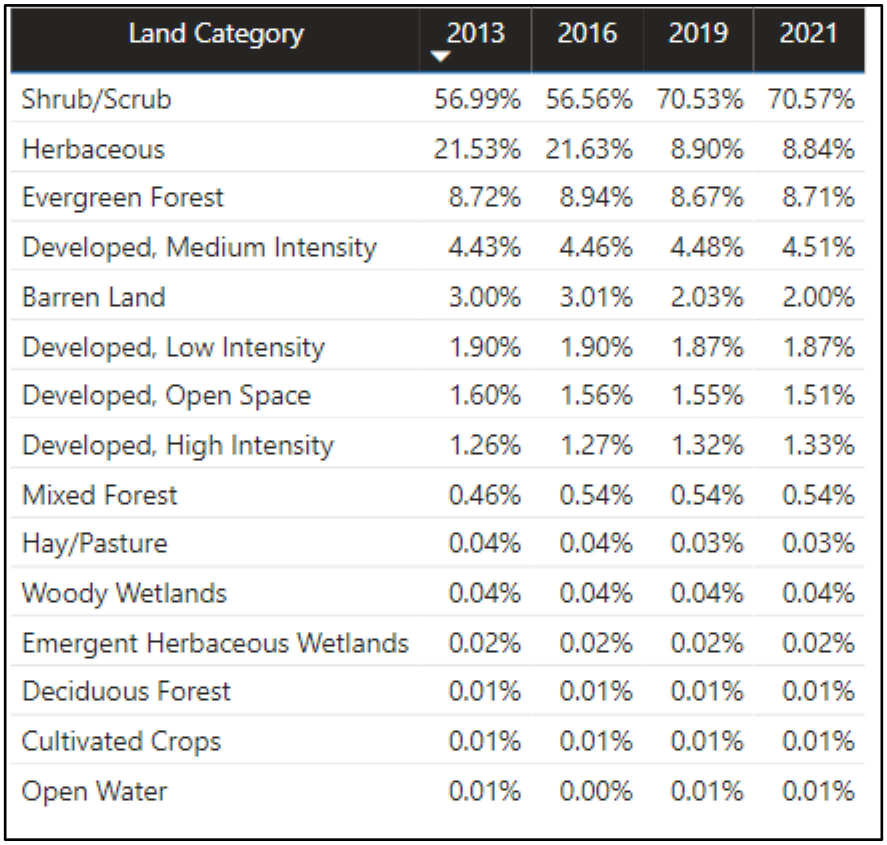


Figure 11. Middle Whitewater River Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Palm Canyon Sub-Watershed

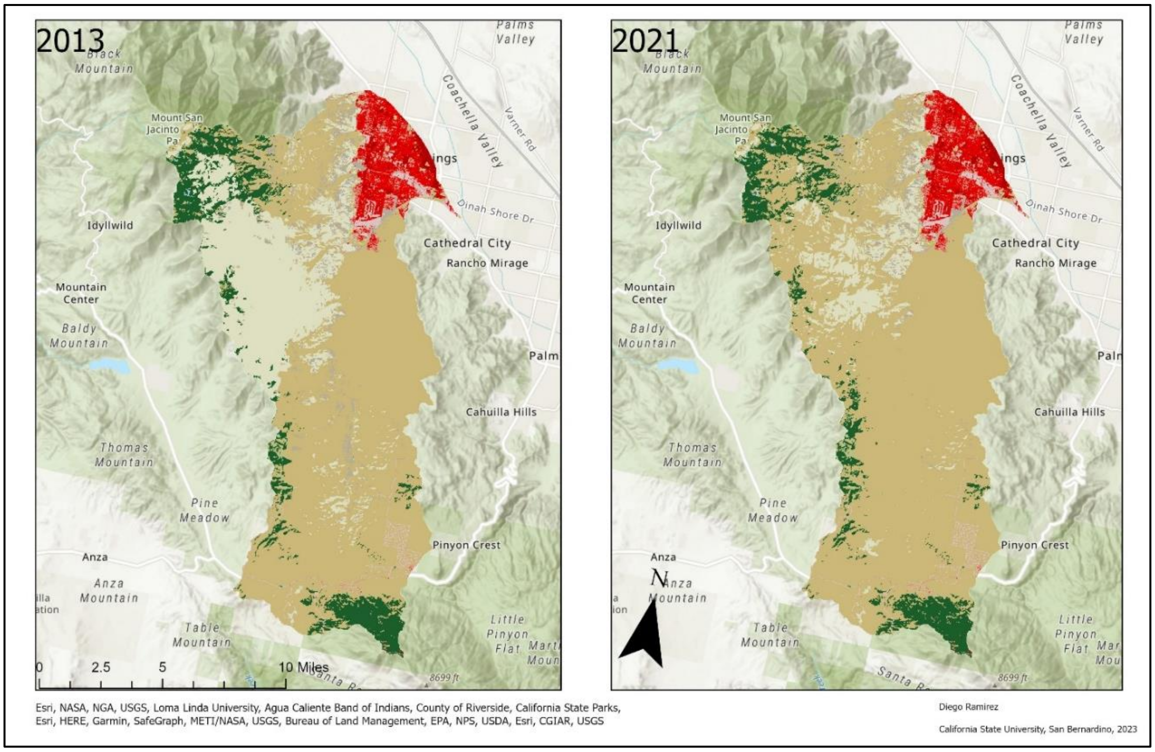
In 2013, the Palm Canyon Sub-Watershed was primarily characterized by shrub/scrub (57 %) followed by herbaceous (21 %) (Table 8). Both represented the dominant land types for this sub-watershed during the study period, however, shrub/scrub increased over time while herbaceous decreased. Shrub/scrub represented the largest increases in LULC (+24 %) for the Palm Canyon Sub-Watershed while herbaceous represented the largest decreases by LULC type (-59 %).

Table 8. Percentage of Land Categories in the Palm Canyon Watershed



Land Category	2013	2016	2019	2021
Shrub/Scrub	56.99%	56.56%	70.53%	70.57%
Herbaceous	21.53%	21.63%	8.90%	8.84%
Evergreen Forest	8.72%	8.94%	8.67%	8.71%
Developed, Medium Intensity	4.43%	4.46%	4.48%	4.51%
Barren Land	3.00%	3.01%	2.03%	2.00%
Developed, Low Intensity	1.90%	1.90%	1.87%	1.87%
Developed, Open Space	1.60%	1.56%	1.55%	1.51%
Developed, High Intensity	1.26%	1.27%	1.32%	1.33%
Mixed Forest	0.46%	0.54%	0.54%	0.54%
Hay/Pasture	0.04%	0.04%	0.03%	0.03%
Woody Wetlands	0.04%	0.04%	0.04%	0.04%
Emergent Herbaceous Wetlands	0.02%	0.02%	0.02%	0.02%
Deciduous Forest	0.01%	0.01%	0.01%	0.01%
Cultivated Crops	0.01%	0.01%	0.01%	0.01%
Open Water	0.01%	0.00%	0.01%	0.01%

Figure 12 displays the change in land categories for the years 2013 and 2021. The largest increase the shrub/scrub category, which are areas dominated by shrubs and usually greater than 20 % of total vegetation, is found the west region of the sub-watershed, which faces Idyllwild. Similarly, the herbaceous LULC type, where 80 % of the total vegetation is composed of herbaceous vegetation, also is found in the west region of the sub-watershed, mostly replacing the shrub/scrub type.



Esri, NASA, NGA, USGS, Loma Linda University, Agua Caliente Band of Indians, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, Esri, CGIAR, USGS

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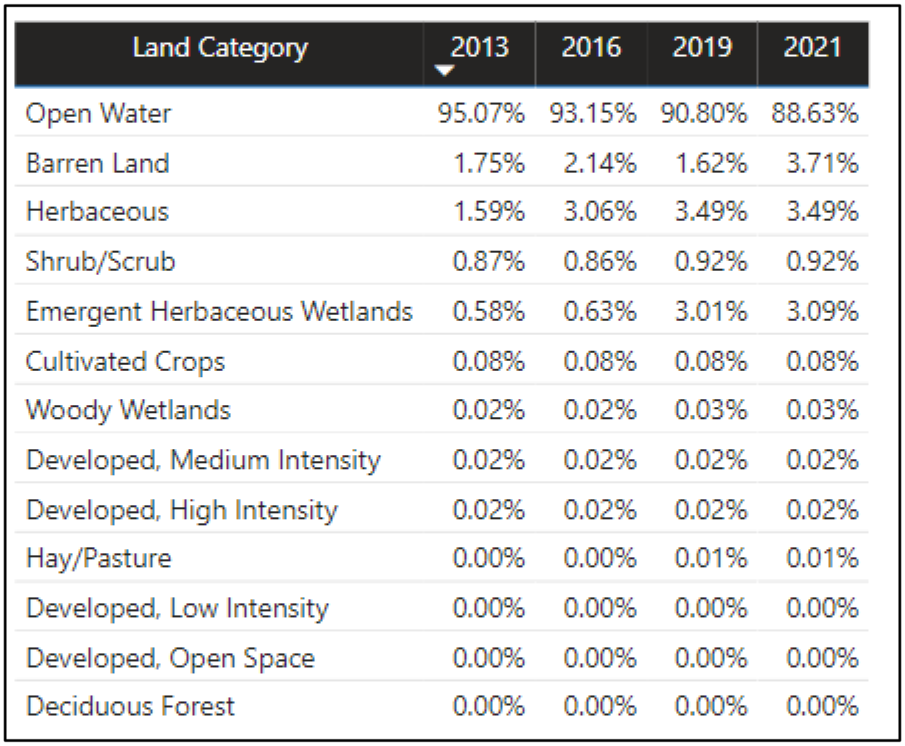
California State University, San Bernardino, 2023

Figure 12. Palm Canyon Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Salton Sea Sub-Basin

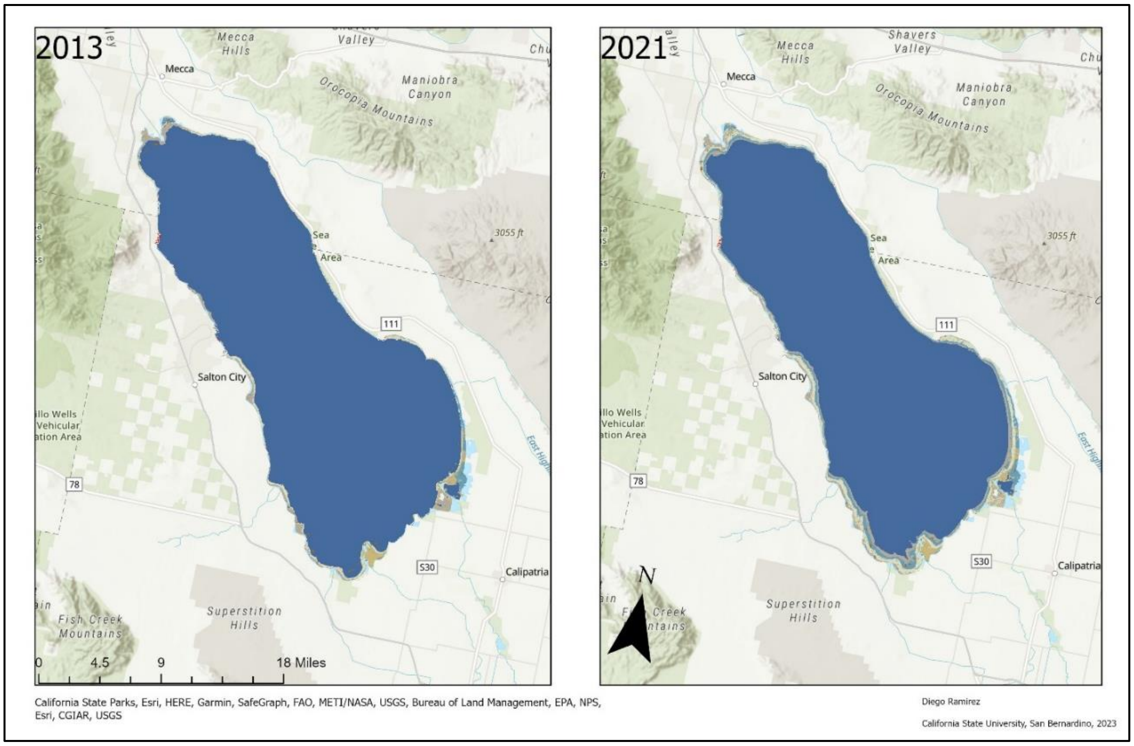
In 2013, the Salton Sea Sub-Basin was primarily characterized by open water (95 %) followed by barren land (2 %) (Table 9). Both represented the dominant land types for this sub-watershed during the study period, however, open water slightly decreased over time while barren land slightly increased. Emergent herbaceous wetlands represented the largest increases in LULC (+432 %) for the Salton Sea Sub-Basin while open water represented the mist significant decreases by LULC type (-7 %).

Table 9. Percentage of Land Categories in the Salton Sea



Land Category	2013	2016	2019	2021
Open Water	95.07%	93.15%	90.80%	88.63%
Barren Land	1.75%	2.14%	1.62%	3.71%
Herbaceous	1.59%	3.06%	3.49%	3.49%
Shrub/Scrub	0.87%	0.86%	0.92%	0.92%
Emergent Herbaceous Wetlands	0.58%	0.63%	3.01%	3.09%
Cultivated Crops	0.08%	0.08%	0.08%	0.08%
Woody Wetlands	0.02%	0.02%	0.03%	0.03%
Developed, Medium Intensity	0.02%	0.02%	0.02%	0.02%
Developed, High Intensity	0.02%	0.02%	0.02%	0.02%
Hay/Pasture	0.00%	0.00%	0.01%	0.01%
Developed, Low Intensity	0.00%	0.00%	0.00%	0.00%
Developed, Open Space	0.00%	0.00%	0.00%	0.00%
Deciduous Forest	0.00%	0.00%	0.00%	0.00%

Figure 13 displays the change in land categories for the years 2013 and 2021. The largest increase the emergent herbaceous wetlands category, which are areas where perennial herbaceous vegetation accounts for more than 80 % of vegetative cover and the soil is periodically saturated with water, is located around the edges of the Salton Sea itself, most in the northern end closest to Mecca, and southern end closest to the S30 side of the lake. Similarly, the open water LULC type, decrease is found in the areas of increased herbaceous wetlands and this open water recedes to expose the soil.



California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, Esri, CGIAR, USGS

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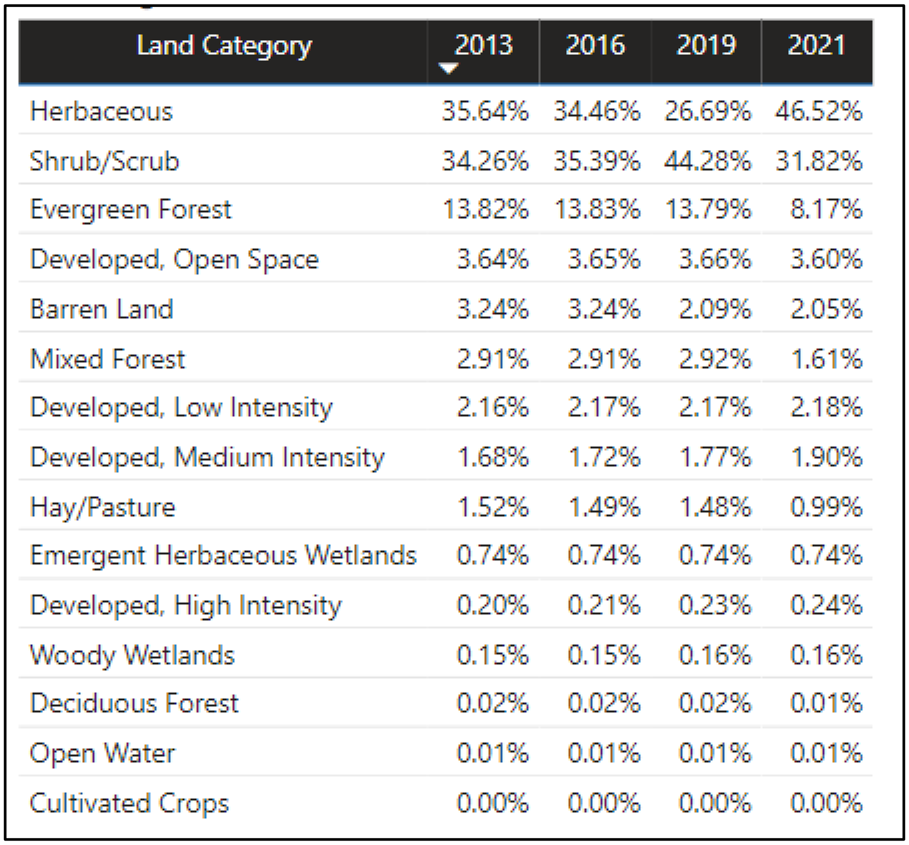
Figure 13. Salton Sea Sub-Basin Map. (ArcGIS, MRLC, 2021)

San Gorgonio Sub-Watershed

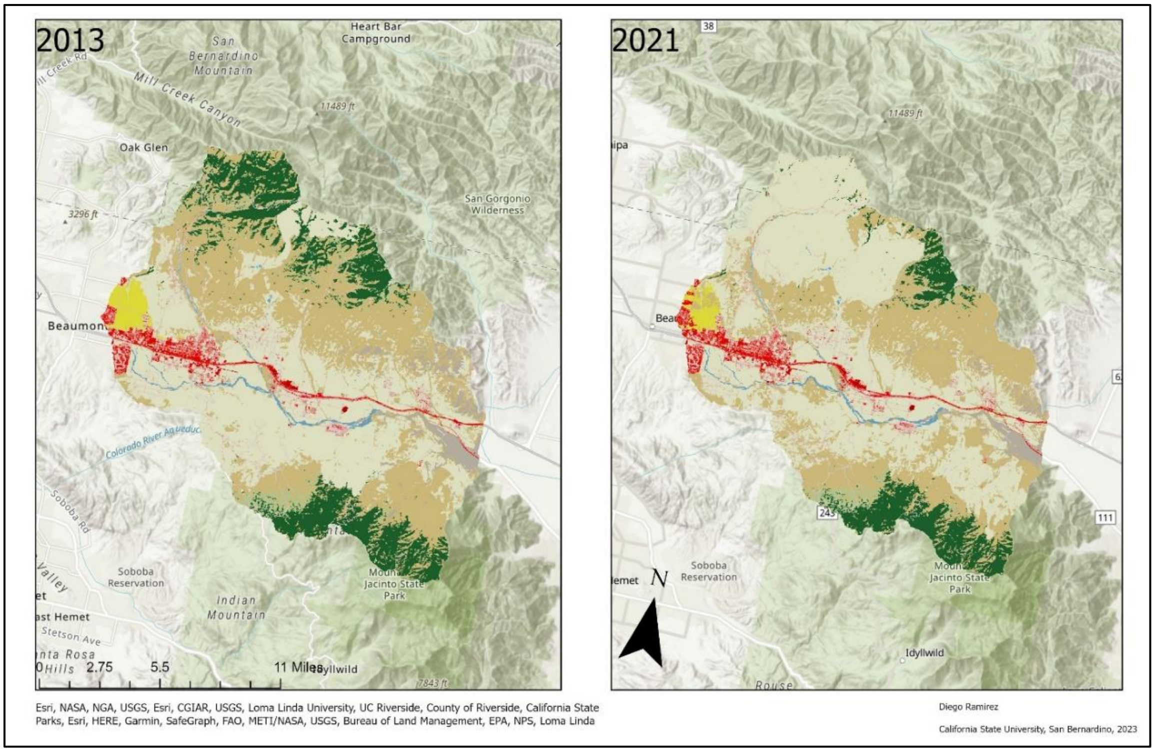
In 2013, the San Gorgonio Sub-Watershed was primarily characterized by herbaceous (36 %) followed by shrub/scrub (34 %) (Table 10). Both represented the dominant land types for this sub-watershed during the study period, however, herbaceous slightly increased over time while shrub/scrub fluctuated but ultimately slightly decreased. Emergent herbaceous wetlands represented the largest increases in LULC (+432 %) for the San Gorgonio Sub-Watershed while open water represented the mist significant decreases by LULC type (-7 %).

Table 10. Percentage of Land Categories in the San Gorgonio



Land Category	2013	2016	2019	2021
Herbaceous	35.64%	34.46%	26.69%	46.52%
Shrub/Scrub	34.26%	35.39%	44.28%	31.82%
Evergreen Forest	13.82%	13.83%	13.79%	8.17%
Developed, Open Space	3.64%	3.65%	3.66%	3.60%
Barren Land	3.24%	3.24%	2.09%	2.05%
Mixed Forest	2.91%	2.91%	2.92%	1.61%
Developed, Low Intensity	2.16%	2.17%	2.17%	2.18%
Developed, Medium Intensity	1.68%	1.72%	1.77%	1.90%
Hay/Pasture	1.52%	1.49%	1.48%	0.99%
Emergent Herbaceous Wetlands	0.74%	0.74%	0.74%	0.74%
Developed, High Intensity	0.20%	0.21%	0.23%	0.24%
Woody Wetlands	0.15%	0.15%	0.16%	0.16%
Deciduous Forest	0.02%	0.02%	0.02%	0.01%
Open Water	0.01%	0.01%	0.01%	0.01%
Cultivated Crops	0.00%	0.00%	0.00%	0.00%

Figure 14 displays the change in land categories for the years 2013 and 2021. The largest increase, herbaceous LULC type, where 80 % of the total vegetation is composed of herbaceous vegetation is in the northern end of the sub-watershed, near Oak Glen. Similarly, the evergreen forest LULC type decrease is found in the same area.



Esri, NASA, NGA, USGS, Esri, CGIAR, USGS, Loma Linda University, UC Riverside, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, Loma Linda

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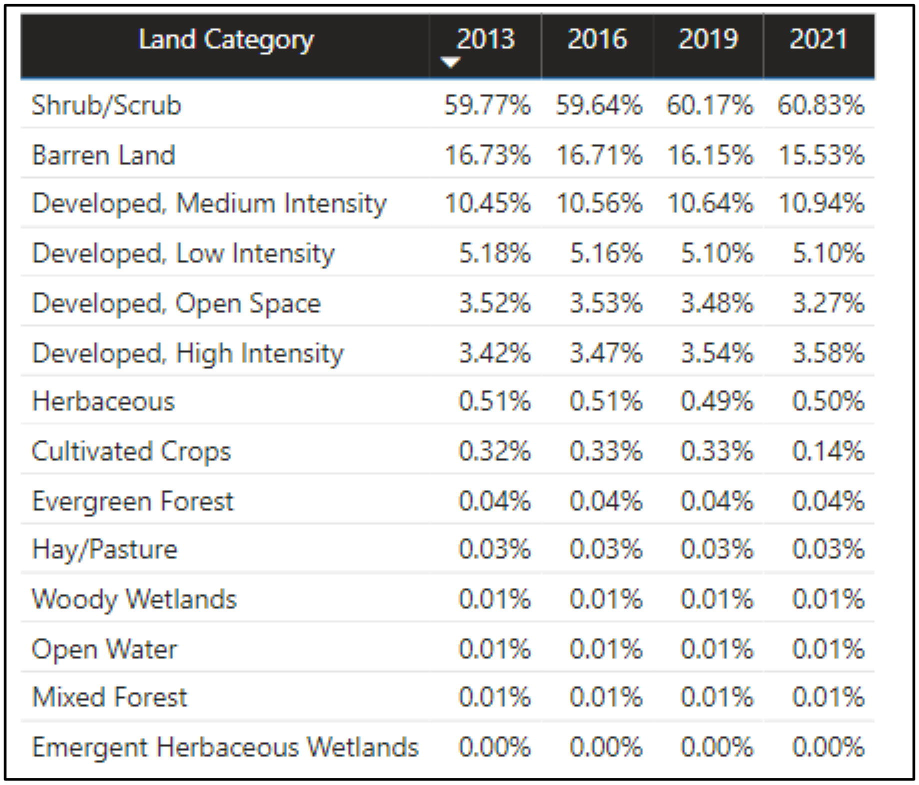
Figure 14. San Gorgonio Sub-Watershed Map. (ArcGIS, MRLC, 2021)

Upper Whitewater Rivers Sub-Watershed

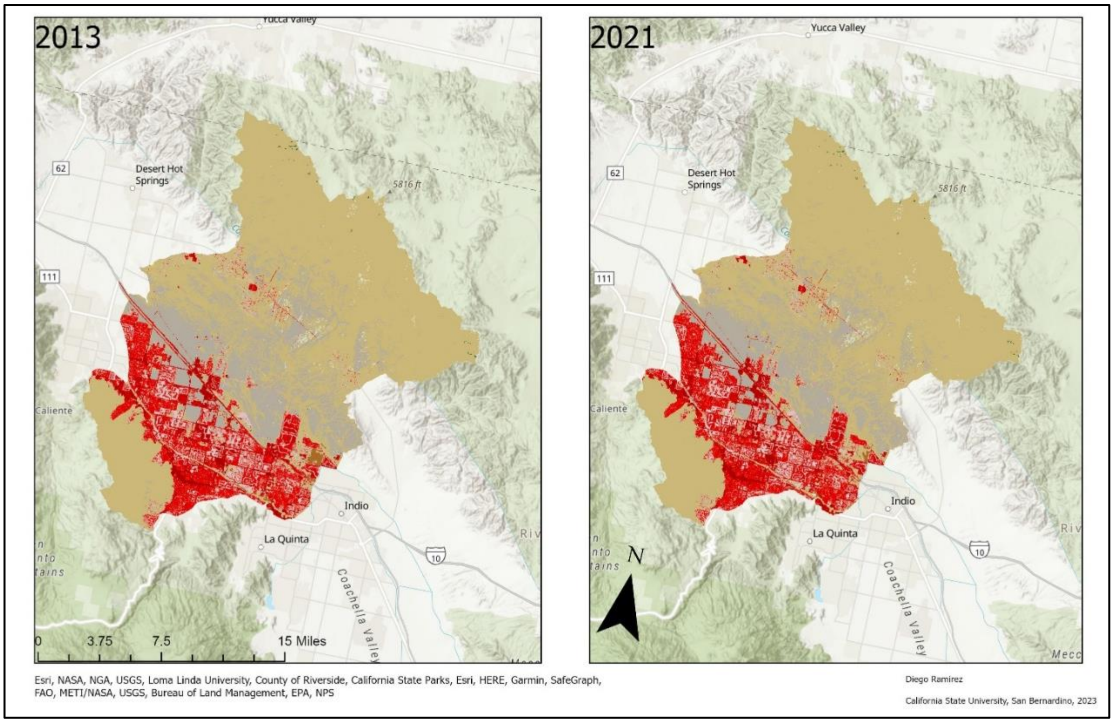
In 2013, the Upper Whitewater Rivers Sub-Watershed was primarily characterized by shrub/scrub (60 %) followed by barren land (17 %) (Table 11). Both represented the dominant land types for this sub-watershed during the study period, however, herbaceous slightly increased over time while barren land slightly decreased. Developed-high intensity represented the largest increases in LULC (+4 %) for the Upper Whitewater Rivers Sub-Watershed while barren land represented the mist significant decreases by LULC type (-7 %).

Table 11. Percentage of Land Categories in the Upper Whitewater Rivers



Land Category	2013	2016	2019	2021
Shrub/Scrub	59.77%	59.64%	60.17%	60.83%
Barren Land	16.73%	16.71%	16.15%	15.53%
Developed, Medium Intensity	10.45%	10.56%	10.64%	10.94%
Developed, Low Intensity	5.18%	5.16%	5.10%	5.10%
Developed, Open Space	3.52%	3.53%	3.48%	3.27%
Developed, High Intensity	3.42%	3.47%	3.54%	3.58%
Herbaceous	0.51%	0.51%	0.49%	0.50%
Cultivated Crops	0.32%	0.33%	0.33%	0.14%
Evergreen Forest	0.04%	0.04%	0.04%	0.04%
Hay/Pasture	0.03%	0.03%	0.03%	0.03%
Woody Wetlands	0.01%	0.01%	0.01%	0.01%
Open Water	0.01%	0.01%	0.01%	0.01%
Mixed Forest	0.01%	0.01%	0.01%	0.01%
Emergent Herbaceous Wetlands	0.00%	0.00%	0.00%	0.00%

Figure 15 displays the change in land categories for the years 2013 and 2021. The increase in the high intensity development category, where impervious surfaces account for 80-100% – due to it being a highly developed area – is in the southeast region of the sub-watershed where most of the population resides near La Quinta. Similarly, the barren land LULC type decrease is in the same general area.



Esri, NASA, NGA, USGS, Loma Linda University, County of Riverside, California State Parks, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS

Diego Ramirez
California State University, San Bernardino, 2023

Figure 15. Upper Whitewater Rivers Sub-Watershed Map (ArcGIS, MRLC, 2021)

Overall temporal trends and land category changes for the region during the period of the study shows that one leading trend is the increase in medium intensity development, indicating and suggesting the constant increase in urbanization and development and human footprint, which in turn exacerbates the expansion of impervious surfaces. Interestingly, the most dominant vegetation category, shrub/scrub, has continued to slightly increase during the time of the study, implying that even though population seems to be growing, and impervious surfaces keep expanding, this natural landscape continues to also expand. Biggest and perhaps just as important as increasing impervious surfaces, is the decreasing open water category within the Salton Sea Sub-Basin. This only solidifies the theory that an increase in urbanization could perhaps be a main reason as to why runoff water no longer reaches the lake, helping it stay full and in turn keeping the pollutants at bay.

Temperature

In this study, temperature data from the Palm Springs station is obtained as daily high temperature for the year and then calculated to obtain a monthly average temperature metric, and in 2013 the average annual temperature for the study area was 24°C. On average during the spring months, the monthly average temperature is of 29°C, a temperature of 32°C in the summer, with some days reaching temperatures above 37°C. The monthly average temperate was 24°C in the fall, and the winter months average temperature is of 13°C with some days as low as 7°C. Figure 16 shows an increasing trend of temperature with each corresponding month. Winter months are seen as the coldest month in the figure while summer and early fall months are seen toward the end of the graph, representing the hotter months of the year.

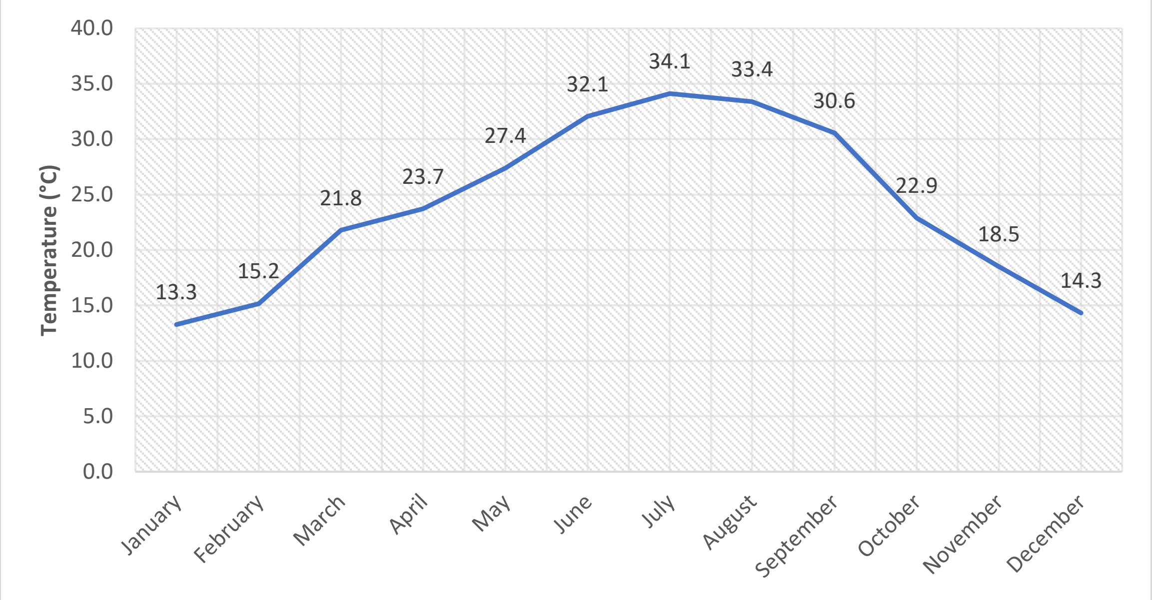


Figure 16. Average Temperature by Month in The Salton Sea Watershed in 2013. (NCEI CDO)

In 2016 the average annual temperature for the study area was 25°C. On average during the spring months, the monthly average temperature is of 23°C, a temperature of 33°C in the summer, with some days reaching temperatures above 37°C. The monthly average temperate was 24°C in the fall, and the winter months' average temperature is of 16°C with some days as low as 9°C. Figure 17 shows an increasing trend of temperature with each corresponding month. Winter months are seen as the coldest month in the figure while summer and early fall months are seen toward the end of the graph, representing the warmer months of the year.

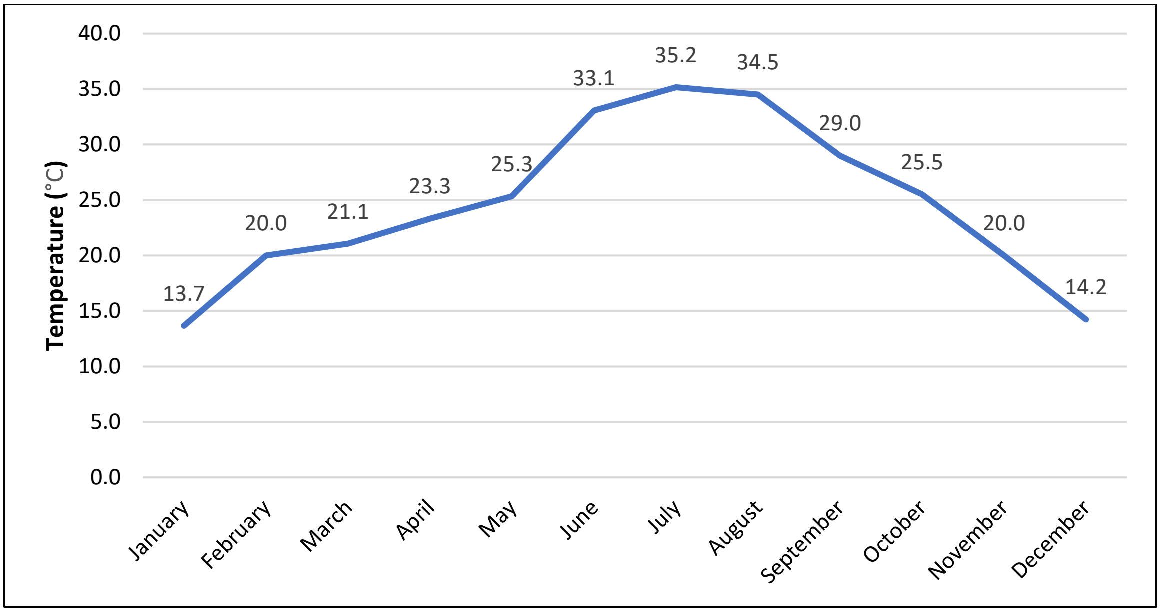


Figure 17. Average Temperature by Month in The Salton Sea Watershed in 2016. (NCEI CDO)

In 2019 the average annual temperature for the study area was 23°C. On average during the spring months, the monthly average temperature is of 22°C, a temperature of 33°C in the summer, with some days reaching temperatures above 37°C. The monthly average temperate was 25°C in the fall, and the winter months average temperature is of 13°C with some days as low as 9°C. Figure 18 shows an increasing trend of temperature with each corresponding month. Winter months are seen as the coldest month in the figure while summer and early fall months are seen toward the end of the graph, representing the warmer months of the year.

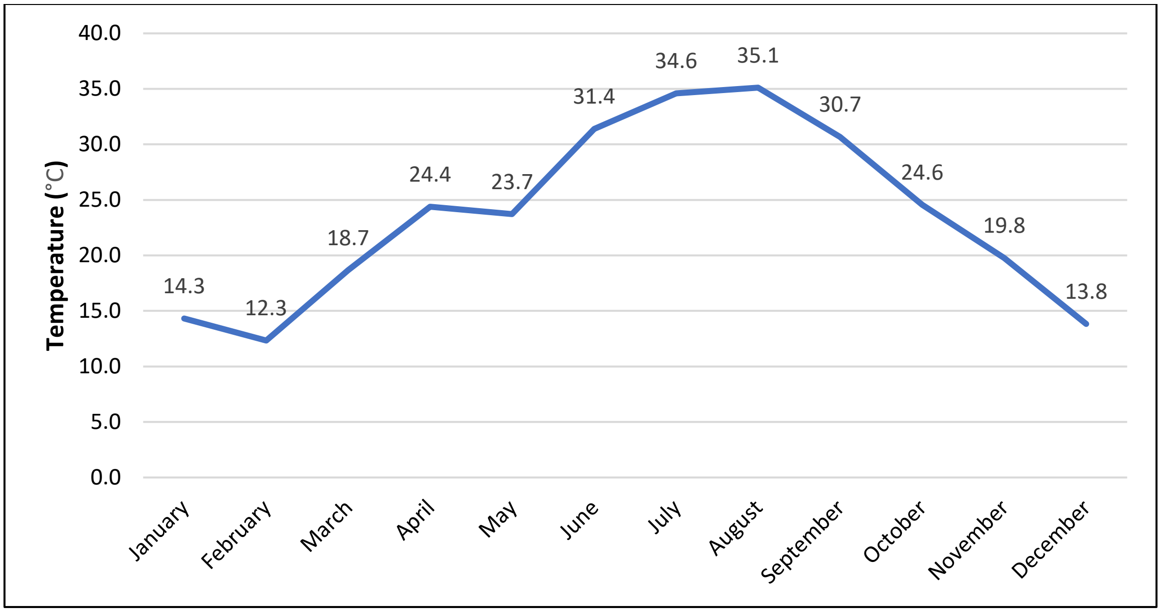


Figure 18. Average Temperature by Month in The Salton Sea Watershed in 2019. (NCEI CDO)

In 2021 the average annual temperature for the study area was 25°C. On average during the spring months, the monthly average temperature is of 23°C, a temperature of 35°C in the summer, with some days reaching temperatures above 40°C. The monthly average temperate was 26°C in the fall, and the winter months average temperature is of 16°C with some days as low as 11°C. Figure 19 shows an increasing trend of temperature with each corresponding month. Winter months are seen as the coldest month in the figure while summer and early fall months are seen toward the end of the graph, representing the warmer months of the year.

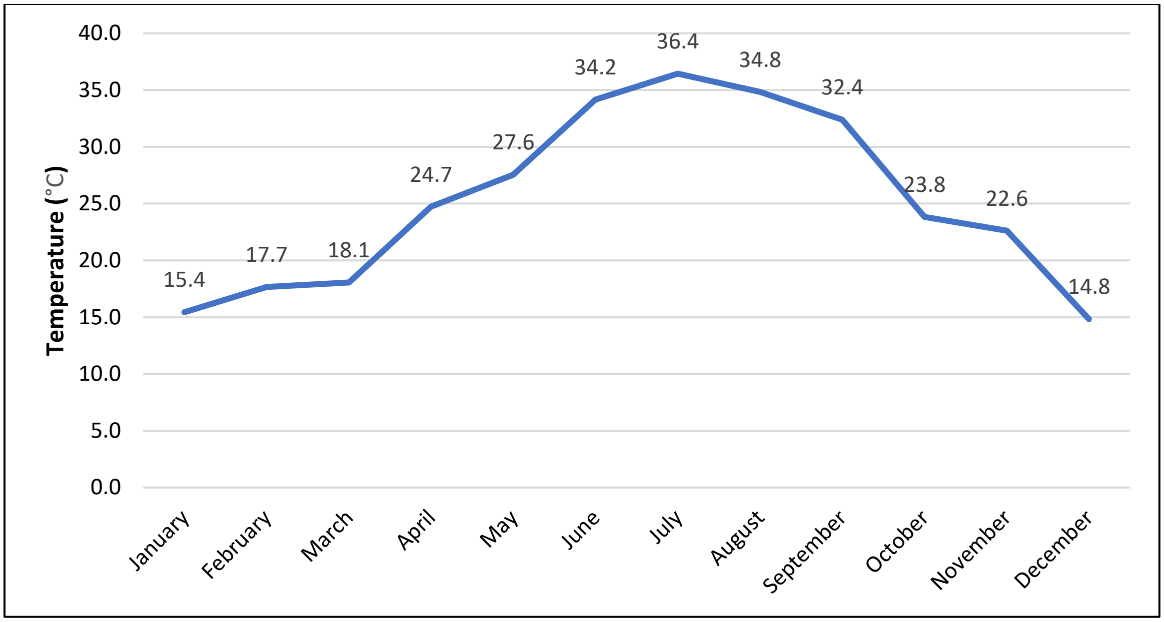


Figure 19. Average Temperature by Month in The Salton Sea Watershed in 2021. (NCEI CDO)

Comparing 2013 and 2021, the Salton Sea Watershed region saw an increasing trend of temperature. For the coldest month of both years, December, the temperature increased from 14.0°C to 14.8°C, resulting in an increase of 0.8°C. For the hotter month of the years, July, temperature increased from 34°C to 36.4°C, resulting in an increase of 2.4°C. Overall, for each month and seasons, 2021 resulted in warmer temperatures than 2013 in the Salton Sea Watershed region (Figure 20). Additionally, Table 12 shows the average temperature for all the years of this study, broken down by months, to better give a more direct comparison between the years.

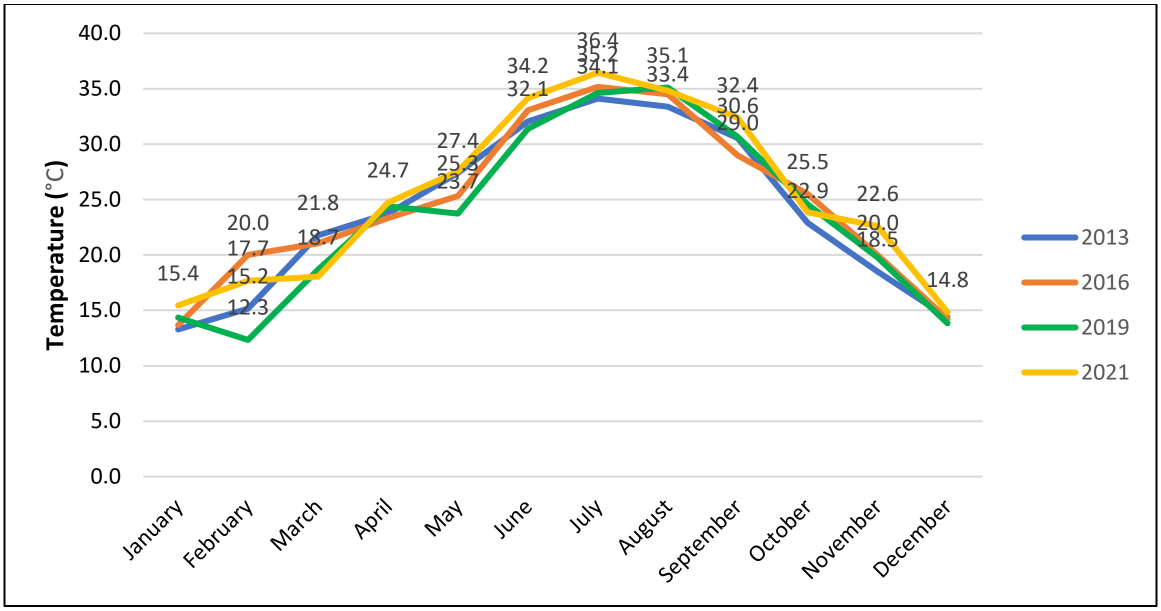
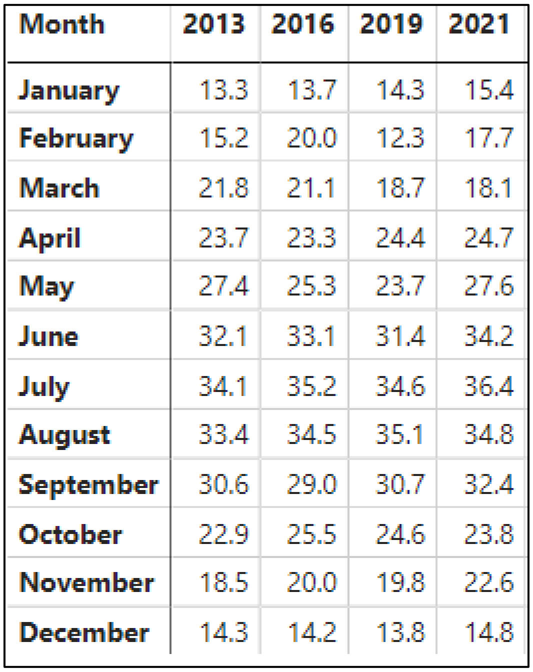


Figure 20. Average Temperature by Month in The Salton Sea Watershed per Year. (NCEI CDO)

Table 12. Monthly Average Temperature Data per Year



Month	2013	2016	2019	2021
January	13.3	13.7	14.3	15.4
February	15.2	20.0	12.3	17.7
March	21.8	21.1	18.7	18.1
April	23.7	23.3	24.4	24.7
May	27.4	25.3	23.7	27.6
June	32.1	33.1	31.4	34.2
July	34.1	35.2	34.6	36.4
August	33.4	34.5	35.1	34.8
September	30.6	29.0	30.7	32.4
October	22.9	25.5	24.6	23.8
November	18.5	20.0	19.8	22.6
December	14.3	14.2	13.8	14.8

Precipitation

In 2013, the study area experienced an average annual precipitation level of 1.16 centimeters. Analyzing monthly precipitation records, we found that the lowest monthly precipitation occurred in April, December, June, and May, registering 0 centimeters of rain. Conversely, the highest monthly precipitation was observed in July, reaching 2.39 cm. The average rainfall for the spring this year was of 0.10 cm, the summer had 0.88 cm making it the wettest season of the year, fall had 0.21 cm and the winter had 0.78cm. Figure 21 shows the cumulative monthly precipitation data, highlighting July with the highest precipitation values.

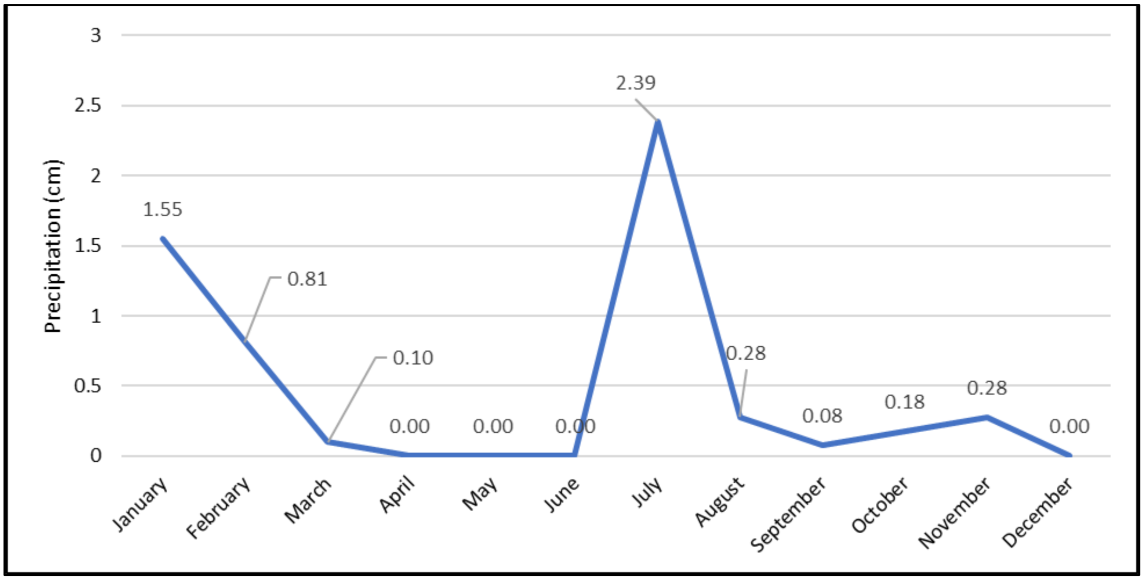


Figure 21. Precipitation by Month in The Salton Sea Watershed in 2013. (NCEI CDO)

In 2016, the study area experienced an average annual precipitation level of 1.09 centimeters. Analyzing monthly precipitation records, we found that the lowest monthly precipitation occurred in August, February, July, and June, registering 0 centimeters of rain. Conversely, the highest monthly precipitation was observed in January, reaching 5.75 centimeters. The average rainfall for the spring this year was of 0.15 cm, the summer had 0.0 cm, fall had 1.02 cm and the winter had 3.18 cm, making it the wettest season of the year. Figure 22 highlights the average monthly precipitation data for 2016.

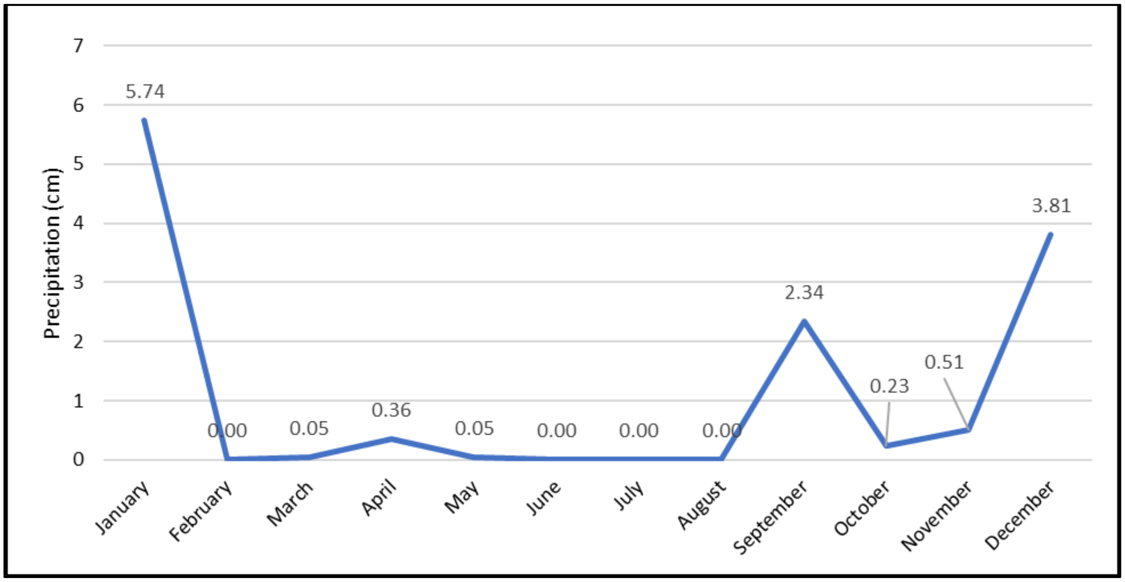


Figure 22. Precipitation by Month in The Salton Sea Watershed in 2016. (NCEI CDO)

In 2019, the study area experienced an average annual precipitation level of 2.0 centimeters. Analyzing monthly precipitation records, we found that the lowest monthly precipitation occurred in April, August, July, June, and October, registering 0 centimeters of rain. Conversely, the highest monthly precipitation was observed in February, reaching 11.2 centimeters. The average rainfall for the spring this year was of 0.44 cm, the summer had 0.0 cm, fall had 1.5 cm and the winter had 6.1 cm, making it the wettest season of the year. Figure 23 highlights the average monthly precipitation data for 2019.

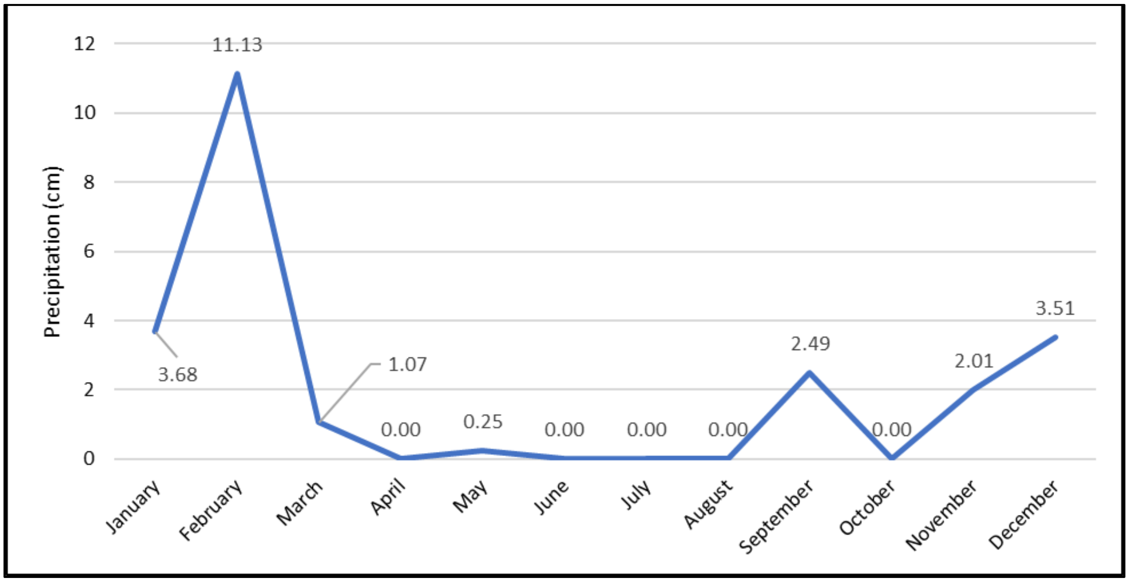


Figure 23. Average Precipitation by Month in The Salton Sea Watershed in 2019. (NCEI CDO)

In 2021, the study area experienced an average annual precipitation level of 0.53 centimeters. Analyzing monthly precipitation records, we found that the lowest monthly precipitation occurred in April, August, February, May, and November, registering 0 centimeters of rain. Conversely, the highest monthly precipitation was observed in

December, reaching 3.28 centimeters. The average rainfall for the spring this year was of 0.04 cm, the summer had 0.48 cm, fall had 0.11 cm and the winter had 3.7 cm, making it the wettest season of the year. Figure 24 shows the average monthly precipitation data for 2021. Additionally, Table 13 shows the average precipitation for all the years of this study, broken down by months, to better give a more direct comparison between the years, including a total for each year. 2013 displayed an annual rainfall of 5.66 cm (the least of the study), 2016 had 13.08 in, 2019 had 24.13 cm (most of the study), and 2021 had 6.53 cm. Figure 25 displays a comparison graph of the monthly average precipitation for each year.

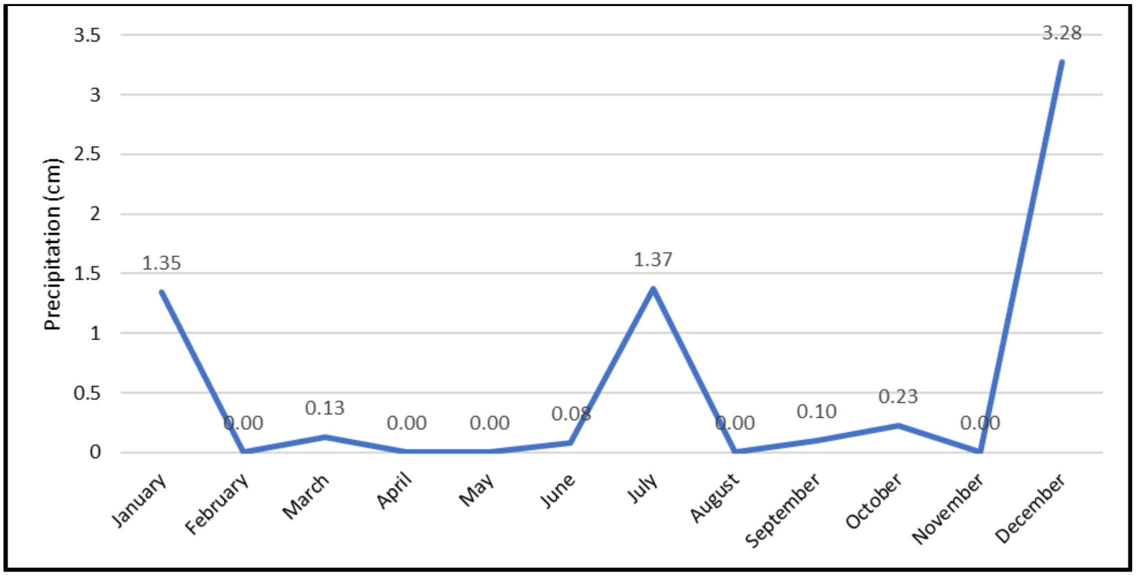


Figure 24. Average Precipitation by Month in The Salton Sea Watershed in 2021. (NCEI CDO)

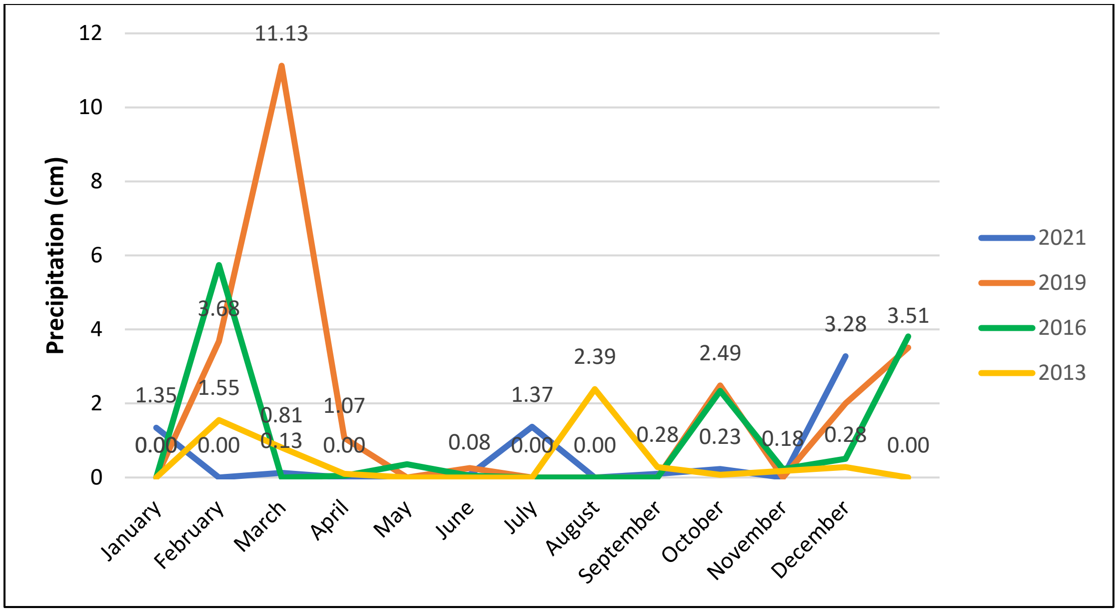
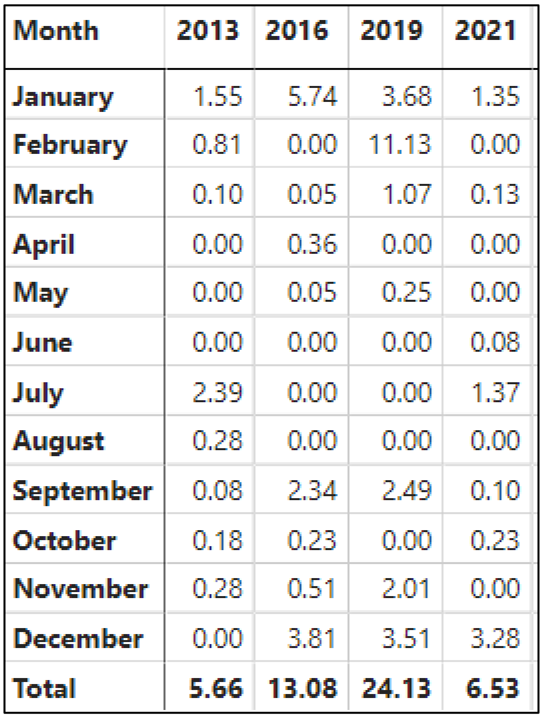


Figure 25. Monthly Average Precipitation by Year. (NCEI CDO)

Table 13. Monthly Average Precipitation Data per Year.



Month	2013	2016	2019	2021
January	1.55	5.74	3.68	1.35
February	0.81	0.00	11.13	0.00
March	0.10	0.05	1.07	0.13
April	0.00	0.36	0.00	0.00
May	0.00	0.05	0.25	0.00
June	0.00	0.00	0.00	0.08
July	2.39	0.00	0.00	1.37
August	0.28	0.00	0.00	0.00
September	0.08	2.34	2.49	0.10
October	0.18	0.23	0.00	0.23
November	0.28	0.51	2.01	0.00
December	0.00	3.81	3.51	3.28
Total	**5.66**	**13.08**	**24.13**	**6.53**

Ozone

In the years of the study area, 2013, 2016, 2019, and 2021, the investigation into ground-level ozone concentrations within the study area revealed compelling insights into the yearly variations and patterns of this atmospheric component. These findings interpret the dynamic nature of ozone concentrations, with distinct high and low points discerned throughout the year. Notably, the months of June and July stood out with the highest recorded ozone concentration across all studies, reaching levels of up to 0.104 parts per million (ppm). This spike in ozone levels not only shows that there is a seasonal trend but can also be linked to increased temperature and sunlight. Conversely, the end months of the year, January and December exhibited the lowest ozone concentrations, often registering as low as 0.024 ppm. The contrast between these months highlights the influence of seasonality and climatic factors which influence the relationship between environmental conditions and air quality in the study area. Figures 26 and 27 showcase the temporal differences between ozone level concentrations from 2013 to 2021 in the area, highlighting that 2021 overall average annual ozone concentrations are lower than of 2013. Additionally, Table 14 shows the average ozone for all the years of this study, broken down by months, to better give a more direct comparison between the years, highlighting 2013 ozone concentrations to be the highest at 1.69 ppm, followed by a decrease in 2016 and 2019 with ozone levels at 1.54 ppm and 1.57 ppm, and showing an increase in 2021 with levels of 1.57 ppm. Table 15 shows the average of ozone during the summer months. Here we can see that the average of ozone concentrations during those months decreased throughout the study period, showing the summer of

2013 displaying ozone concentration levels of 2.12 ppm, 2016 with 2.08 ppm, 2019 with 1.52 ppm and 2021 with 1.99 ppm.

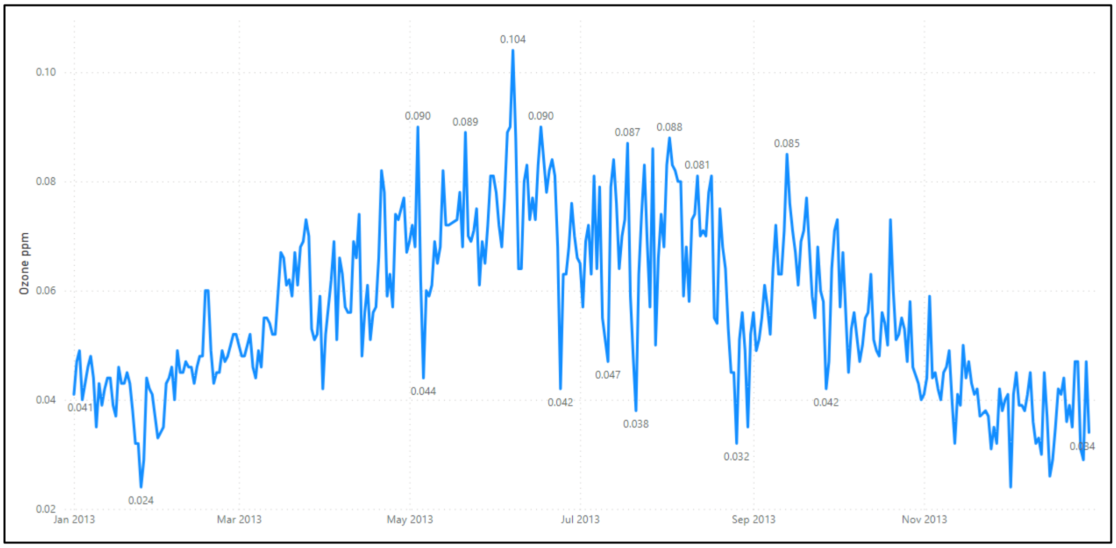


Figure 26. Monthly Ozone Average Obtained by Monitor in Palm Springs, 2013. (EPA)

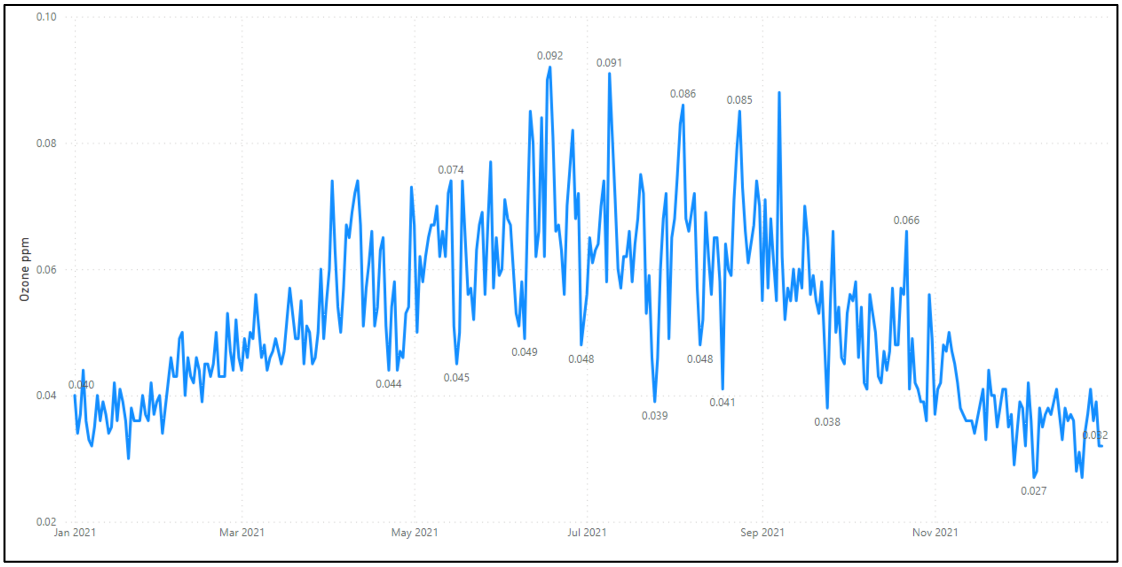
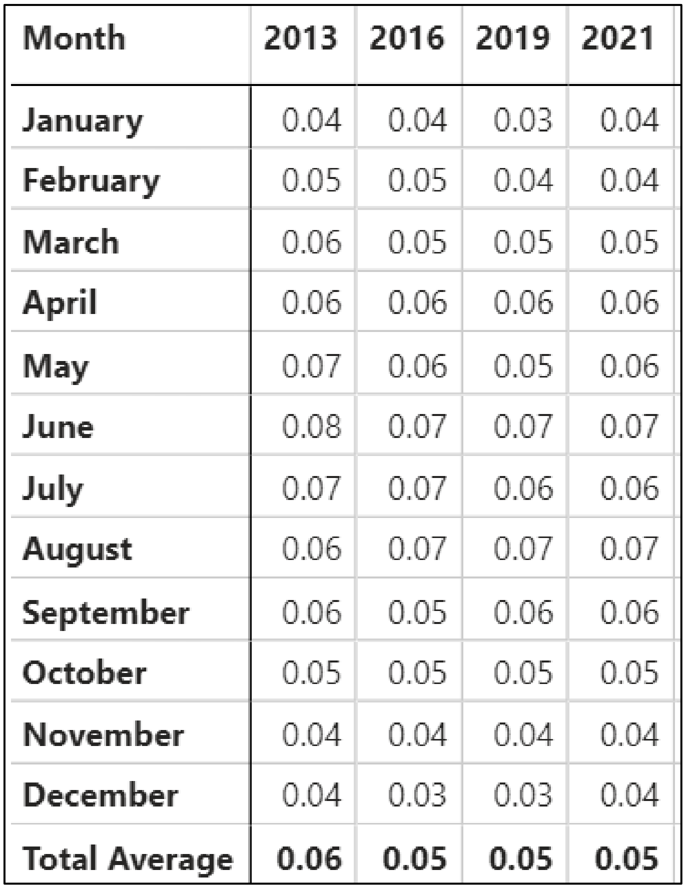


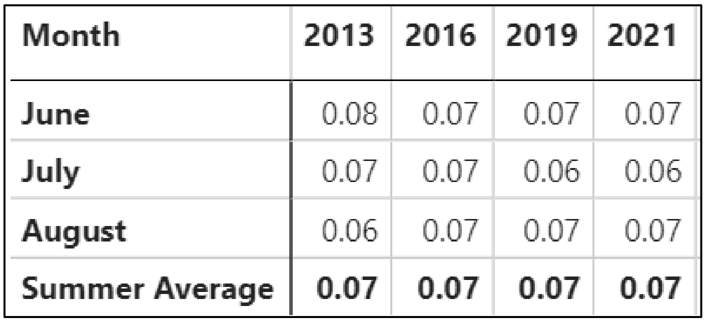
Figure 27. Monthly Ozone Average Obtained by Monitor in Palm Springs, 2021. (EPA)

Table 14. Monthly Average Ozone Data per Year



Month	2013	2016	2019	2021
January	0.04	0.04	0.03	0.04
February	0.05	0.05	0.04	0.04
March	0.06	0.05	0.05	0.05
April	0.06	0.06	0.06	0.06
May	0.07	0.06	0.05	0.06
June	0.08	0.07	0.07	0.07
July	0.07	0.07	0.06	0.06
August	0.06	0.07	0.07	0.07
September	0.06	0.05	0.06	0.06
October	0.05	0.05	0.05	0.05
November	0.04	0.04	0.04	0.04
December	0.04	0.03	0.03	0.04
Total Average	**0.06**	**0.05**	**0.05**	**0.05**

Table 15. Summer Ozone Average



Month	2013	2016	2019	2021
June	0.08	0.07	0.07	0.07
July	0.07	0.07	0.06	0.06
August	0.06	0.07	0.07	0.07
Summer Average	**0.07**	**0.07**	**0.07**	**0.07**

Particulate Matter 2.5

In this study, an analysis of $PM_{2.5}$ (mass of particulate matter with a diameter of 2.5 micrometers or less) concentration in the Palm Spring area was conducted for the years which this study focuses in: 2013, 2016, 2019, and 2021.

The analysis for the given years shows an increasing trend in the warmer summer months and decrease concentration in the colder earlier and later months of the year. However, it is important to note that the concentration levels and sporadic peaks within months vary from year to year, possibly due to seasonal and meteorological variations that occur every year. However, a total increasing concentration is seen as time passes by with more double-digit results showing in 2021 than in 2013.

$PM_{2.5}$ concentrations over the years in this study experience common fluctuations where there are noticeable variations levels that periodically and seasonally increase and decrease throughout the year. All four years show lowest concentrations of $PM_{2.5}$ in March, while the highest concentrations all occur in different months for each year. 2013 saw February and September as those months with highest concentrations levels, August, and September in 2016, January and July in 2019, and August and July in 2021. Figures 28 and 29 show the daily concentration levels of $PM_{2.5}$ for the years 2013 and 2021.

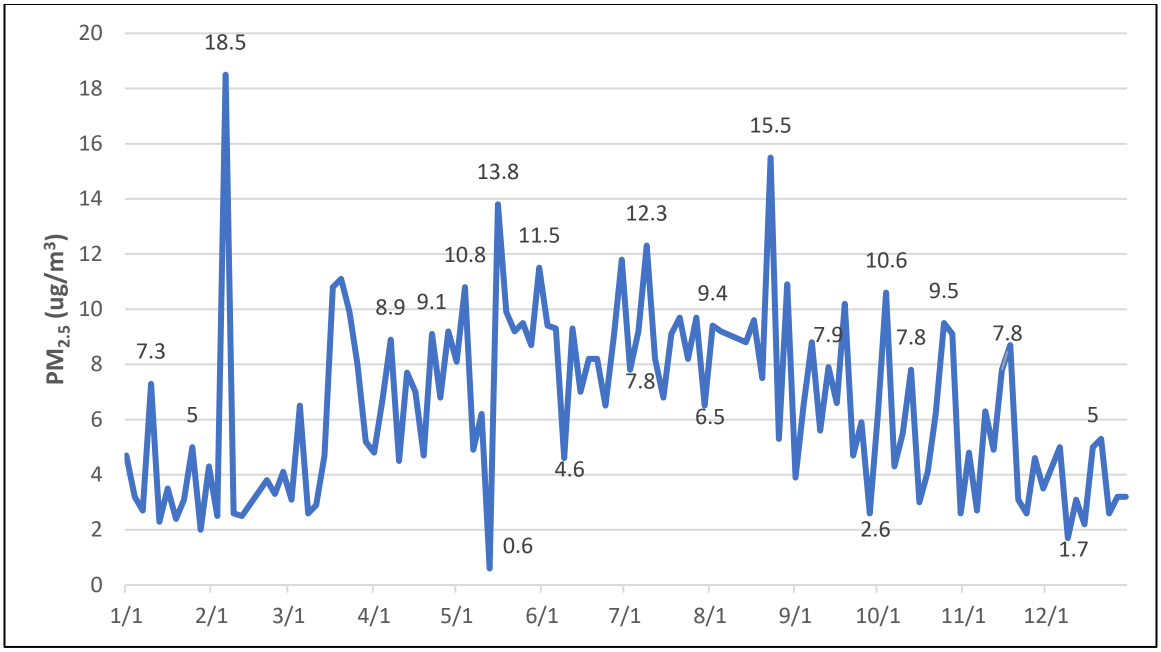


Figure 28. Daily PM2.5 Average Obtained by Monitor in Palm Springs, 2013. (EPA)

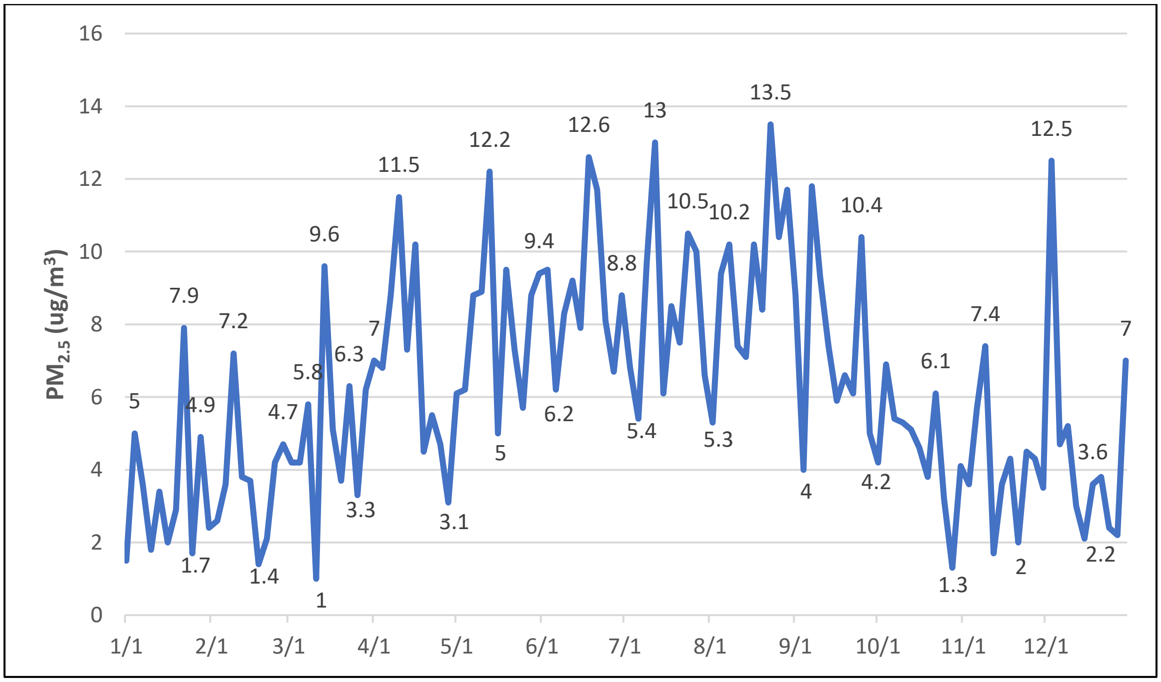
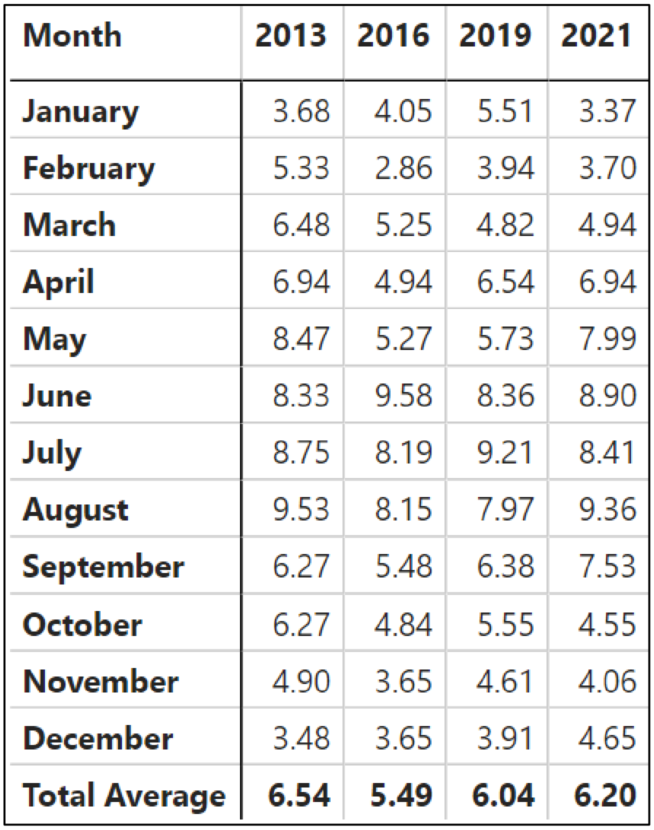


Figure 29. Daily PM2.5 Average Obtained by Monitor in Palm Springs, 2021. (EPA)

In 2013, the highest $PM_{2.5}$ concentrations were seen in February and September with values of 18.5 µm/m³and 15.5 µm/m³ respectively, and lowest concentration in May with 0.6 µm/m³. In 2016, the highest $PM_{2.5}$ concentrations were seen in August and September with values of 12.8 µm/m³ and 14.7 µm/m³ respectively, and lowest concentration in February with 1.2 µm/m³. In 2019, the highest $PM_{2.5}$ concentrations were seen in January and July with values of 14.2 µm/m³ and 15.5 µm/m³ respectively, although May and November also showed high concentrations of 11.5 µm/m³ and 12.4 µm/m³. The lowest concentration was in March with 1.0 µm/m³. In 2021, the highest $PM_{2.5}$ concentrations were seen in August and July with values of 13.5 µm/m³ and 13.0 µm/m³ respectively, although most of the year showed concentrations higher than 10.0 µm/m³. The lowest concentration was in March with 1.0 µm/m³. Table 16 displays the information in a tabular way, which helps easily identify that from 2016 to 2021, $PM_{2.5}$ values have been increasing. It is curious to see that 2013 displays the highest concentration of $PM_{2.5}$, followed by a drastic decrease in 2016.

Table 16. PM2.5 Monthly Average per Year.



Month	2013	2016	2019	2021
January	3.68	4.05	5.51	3.37
February	5.33	2.86	3.94	3.70
March	6.48	5.25	4.82	4.94
April	6.94	4.94	6.54	6.94
May	8.47	5.27	5.73	7.99
June	8.33	9.58	8.36	8.90
July	8.75	8.19	9.21	8.41
August	9.53	8.15	7.97	9.36
September	6.27	5.48	6.38	7.53
October	6.27	4.84	5.55	4.55
November	4.90	3.65	4.61	4.06
December	3.48	3.65	3.91	4.65
Total Average	**6.54**	**5.49**	**6.04**	**6.20**

U.S. Census Bureau

Population data from the U.S. Census Bureau was obtained for the available cities that are within the study site of the Salton Sea Watershed, as seen on Figure 30. Those major cities are Cathedral City, Coachella, Desert Hot Springs, Desert Palms, Indio, La Quinta, Mecca, Palm Desert. Palm Springs, Rancho Mirage, and Thousand Palms. The major cities that are missing on this census tracks are those of Thermal and Indian Wells.

The population census data for the major cities within the Salton Sea Watershed were only available for the years 2010 and 2020, and since that covers at least three of the years focused on this study, the population metrics were seen holistically as the range.

As seen on Table 17, in 2010 the city of Indio recorded the most population with 76,036 people and the city of Desert Palms recorded the least population with 6,957 people. This stayed consistent for 2020 as Indio had the most population at 89,137 people and Desert Palms had the least population at 6,686 people. In addition, Desert Hot Springs is the city that saw the greatest increase in population between 2010 and 2020 with a 25% increase in population, and the most decreasing population is both Desert Palms and Mecca with a 4% decrease in population.

Overall, excluding the missing cities of Thermal and Indian Wells which according to the U.S Census Bureau have a population of less than 5,000, the census region registered a total of 364,809 people in 2010 and 388,250 people in 2020, calculation a difference of 234,441 people and a 46% increase in the population.

Table 17. Population Census Data for City in 2010 and 2021.

Cities	2010	2020	Difference	Percent Change
Cathedral City	51200	51493	293	1%
Coachella	40704	41941	1237	3%
Desert Hot Springs	25938	32512	6574	25%
Desert Palms	6957	6686	-271	-4%
Indio	76036	89137	13101	17%
La Quinta	37467	37558	91	0%
Mecca	8577	8219	-358	-4%
Palm Desert	48445	51163	2718	6%
Palm Springs	44552	44575	23	0%
Rancho Mirage	17218	16999	-219	-1%
Thousand Palms	7715	7967	252	3%
Total	**364809**	**388250**	**23441**	**6.4%**

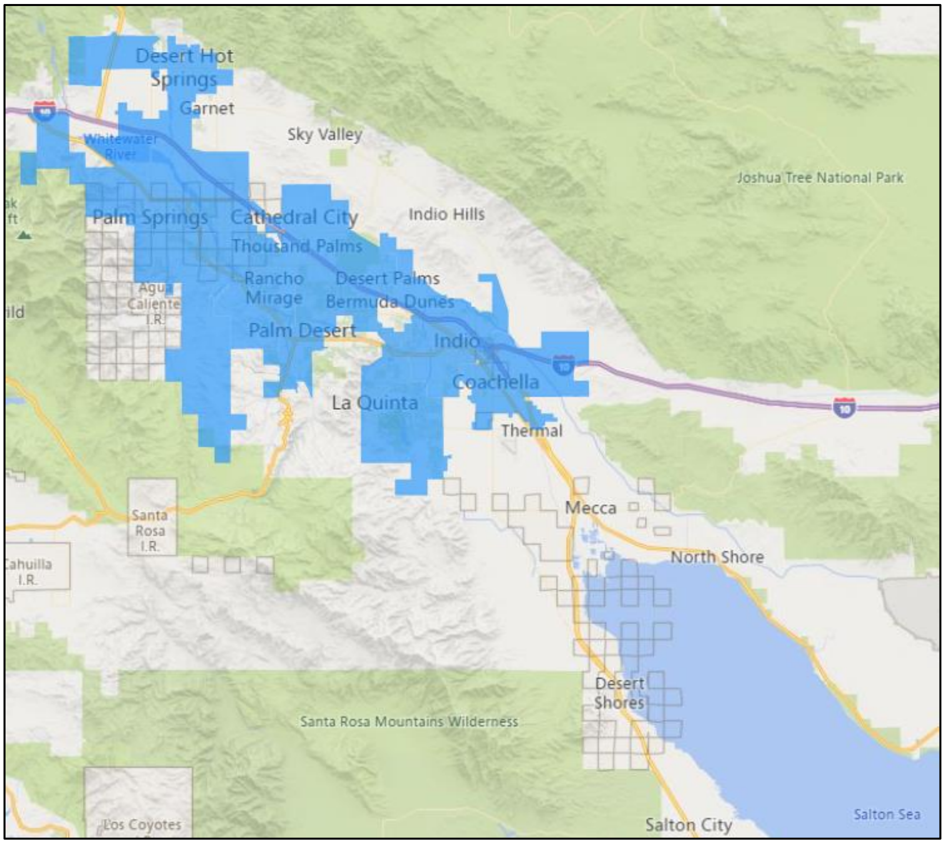


Figure 30. Census Map, 2010 – 2021

CHAPTER FOUR

SUMMARY AND DISCUSSION

The findings from the Salton Sea Watershed analysis highlight the significant changes occurring in this region. Urbanization and development are steadily changing the landscape, with a holistic increase in medium developed category trend visible from several populated sub-watershed. This transformation, driven by population growth and economic expansion, requires a thoughtful approach to sustainable land use that demonstrates a balance between development and conservation efforts. Additionally, shifts in vegetation cover and water bodies are evident, reflecting the complicated relationship of factors like climate change and water resource management practices. These changes carry substantial consequences for local ecosystems, biodiversity, and the overall long-term well-being of the watersheds.

Watershed LULC Results

One of the central aspects of this study revolves around the examination of Land Use and Land Cover (LULC) dynamics within the Coachella Valley and its associated watersheds. The LULC data obtained from multiple years (2013, 2016, 2019, and 2021) provides crucial insights into how the landscape has evolved over time. Each sub-watershed within the Salton Sea Watershed experienced a change in landscape, with the most noticeable trend of land changing from an agricultural/natural landscape to urbanization and impervious surfaces based LULC category. The Little Morong Sub-Watershed experiences the most significant increasing changes in land categories, as it increased 236 % in the barren land category, followed by the Hidden Springs Canyon Sub-Watershed with a 90 % change in the developed, medium intensity category. Hidden Springs Canyon Sub-Watershed also experienced the most significant decreasing change with 68 % in the developed – open space LULC category, followed by Lower Whitewater Rivers Sub-Watershed which experienced a 31 % decreasing trend of open water.

Urbanization and Development

One prominent trend that emerges across several watersheds is the increasing dominance of urban and developed land categories. This shift is evident in watersheds such as Arroyo Salada, Headwaters Whitewater Rivers, Hidden Springs Canyon, Lower Whitewater Rivers, Middle Whitewater Rivers, and Palm Canyon. In these areas, we observe significant growth in the Developed, Medium Intensity and Developed, High Intensity categories. This pattern underscores the ongoing urbanization of the Coachella Valley.

The causes of this urbanization trend are multilayered. Population growth, economic development, and land-use policies that encourage infrastructure expansion all contribute to the transformation of natural landscapes into built environments (Ahearn et al., 2005). However, this urbanization comes with challenges, including potential impacts on water resources, wildlife habitats, and overall environmental sustainability (Cullis et al., 2019). Balancing development with conservation efforts is a critical consideration for the future of these watersheds.

Changes in Vegetation

Another common thread in watershed changes is alterations in vegetation categories. Watersheds like Headwaters Whitewater Rivers, Little Morongo, Palm Canyon, and Upper Whitewater Rivers have experienced shifts in vegetation cover. While some areas have seen increases in the Shrub/Scrub category, others have witnessed declines in herbaceous or deciduous forest cover (Dong et al., 2019).

These changes in vegetation can be linked to several factors, including climate change, water availability, and human activities. Shifts in vegetation patterns can impact local ecosystems, wildlife, and overall biodiversity (Soulard & Wilson, 2013). Sustainable land management practices, habitat restoration, and climate resilience strategies are essential for preserving the ecological health of these watersheds.

Water Bodies and Wetlands

Changes in water bodies and wetlands are noticeable in watersheds like Deep Canyon, Headwaters Whitewater Rivers, Little Morongo, and The Salton Sea itself. Open Water and Emergent Herbaceous Wetlands categories have seen significant fluctuations, which may reflect alterations in water management practices, regional climate variations, and ecological restoration efforts (Reclamation, U.S., 2020).

The decline in water levels in the Salton Sea is of particular concern, given its ecological significance and status as an important habitat for migratory birds (Lyons et al., 2018). Understanding and addressing the factors contributing to this decline, such as changes in water inflow and agricultural runoff, is crucial for the long-term health of this unique ecosystem.

Declining Vegetated Categories: A Changing Landscape

Over the selected years (2013, 2016, 2019, and 2021), a prominent and concerning trend has emerged within the Coachella Valley—the consistent decline of vegetated categories in the region's land use and land cover (LULC). This trend signifies a significant transformation of the natural landscape and raises vital questions about the environmental factors driving these changes.

Temperature and Precipitation Patterns

Temperature and precipitation patterns play pivotal roles in driving environmental changes in the Coachella Valley. Over time, the region has witnessed variability in both temperature and precipitation levels. The observed increase in average annual temperatures, as indicated in the data from 2013 to 2021, holds profound implications for the valley's ecosystems, water resources, and overall livability.

During 2013, the study area recorded an average annual temperature of 24°C, serving as a baseline for subsequent temperature assessments. A closer look at monthly temperature records revealed that January marked the lowest monthly temperature at 13°C, while July recorded the highest monthly temperature, soaring to 34°C. By 2021, the average annual temperature had risen to 25°C, signifying a notable increase of approximately 2°C from 2013. This upward temperature trend aligns with broader climate change patterns and carries implications for both vegetation and the respiratory health of Coachella Valley residents (Bachelet et al., 2016).

Air Quality and Health Considerations

Ground-level ozone concentrations and particulate matter ($PM_{2.5}$) levels serve as crucial indicators of air quality and have substantial health implications for residents. High ozone levels can present significant health risks and may be linked to environmental factors such as temperature, air circulation, and local emissions (Ostro et al., 2009).

The data on ground-level ozone concentrations reveals that months like June and July consistently experience the highest recorded ozone concentrations, reaching levels of up to 0.104 ppm. This is particularly concerning as ground-level ozone is a well-known respiratory irritant. The rising temperatures in the Salton Sea Watershed intensify the chemical reactions responsible for ozone formation, with volatile organic compounds (VOCs) and nitrogen oxides (NO_x) emitted by human activities, such as vehicle emissions and industrial processes, interacting more readily in the presence of sunlight to form ground-level ozone. However, it is observed that the ozone concentration levels during the summer months decrease throughout the study period, and this can be associated with the phenomenon known as ozone suppression, where ozone levels stop rising with temperature (Steiner, et al., 2010).

Prolonged exposure to elevated ozone concentrations, especially during the summer months, can have severe health effects, including asthma exacerbation and other respiratory difficulties. Vulnerable communities, such as those with lower socioeconomic status or limited access to healthcare, may disproportionately bear the effect of these health impacts.

Population Impacts

The population growth documented in the U.S. Census Bureau online database reflects the changing demographic landscape of the Salton Sea Watershed. As the years have passed in the last decade. the population has increased, implying a growth of urbanizations especially in the major cities of Desert Hot Springs, Indio, and Palm Desert where the most increase in population percent change is observed, 25%, 17% and 6% respectively. Addressing these challenges requires a holistic approach that includes targeted healthcare interventions, workforce development, and social support systems (Xu et al., 2020).

The Salton Sea Watershed are undergoing dynamic changes influenced by a range of environmental, social, and economic factors. Urbanization and development are transforming the landscape, while shifts in vegetation and water bodies require careful management and conservation efforts. Rising temperatures and fluctuations in precipitation patterns present additional challenges, as do air quality concerns and associated health impacts (Sun et al., 2022).

Recommended Watershed Management Strategies

The Coachella Valley's continued growth and urbanization necessitate sustainable land use planning that integrates conservation with development (Bachelet et al., 2016). Drawing inspiration from successful models in similar contexts, the region can establish growth boundaries and implement zoning regulations that prioritize environmental conservation and protection. This approach can help strike a balance between urban development and the preservation of critical natural landscapes, including sensitive habitats and wildlife corridors. Furthermore, adopting land-use policies that promote mixed land-use planning, green infrastructure, and compact urban design can reduce sprawl and its associated environmental impacts (Boeing et al., 2022). Moreover, the agriculture sector could implement drip irrigation, soil monitoring and overall best agricultural practices to reduce water demand without losing productivity, as preserving natural wetlands and recharging aquifers is pivotal for the ecological ecosystem (Olaoye et al., 2021). Lastly, addressing the rapid expansion of urbanization and industrialization is important to combat the effects of urban heat islands and impervious surfaces. Green infrastructures like green roofs, could help in decreasing the surface temperature in urban communities, and aid in conserving natural landscapes (Mohamed Irfeey et al., 2023).

Efficient Water Resource Management and Conservation

Water scarcity and quality are prominent concerns in the Salton Sea Watershed. To address these challenges, the region can draw inspiration from effective water resource management practices. Implementing rainwater harvesting systems, wastewater treatment, and sustainable irrigation practices can help alleviate water stress and promote water conservation (Zope et al., 2016). Additionally, adopting water-efficient landscaping and agriculture practices can reduce water demand while maintaining agricultural productivity. The

Coachella Valley can explore partnerships with regional stakeholders to develop and implement comprehensive water management strategies that include water recycling, aquifer recharge, and the preservation of natural wetlands (Berthet et al., 2021). Such strategies can enhance water availability and quality while safeguarding the region's ecosystems and by prioritizing sustainable land use planning and efficient water resource management, the Salton Sea Watershed can address the unified challenges of urbanization and water scarcity (Courtney et al., 2019).

Additionally, the region may benefit from an implementation of bioretention areas to aid the water management. Bioretention areas include features like swales and rain gardens that help manage stormwater runoff and help groundwater recharge (Baek et al., 2019). This usage of bioretention can also aid in improving water quality by reducing pollution runoff, adding benefits to the community with access to the water (Lammers et al., 2022).

CHAPTER FIVE

CONCLUSION

The findings of this study show the layered environmental landscape that occurs within the Salton Sea Watershed from 2013 to 2021. The LULC category types of changes reveal a shift in the region, portrayed by the transformation of vegetative cover that would cover over 70 % of an area to a growing urbanized environment full of expanding impervious surfaces that prevents water from becoming groundwater and ultimately affecting water quality and quantity of the region. These changes have an impact on the local communities and environment, increasing the concern of hotter temperatures, increased and more common urban heat island, reduced water infiltration and higher pollutant-based health hazards. Moreover, the declining water levels in the Salton Sea sub-basin show a negative trend which could increase water quality issues and decrease environmental ecological habitats.

Additionally, the study aims to highlight different climatic change trends that are observed during the time period. Holistically, an increase in temperature in the area as well as the LULC changes of overall increased impervious surfaces in the area represent a correlation that dictates a relationship between urbanization and climate. Similarly, the fluctuating precipitation trends could also play a pivotal role regarding the already limited water scarcity the area poses. The study also recognized population information derived from the U.S. Census Bureau, highlighting separate population percentage changes as well as a holistic area population percent change, implying the ongoing urbanization and population growth, and combined with increased temperatures, increased lakebed exposure; this leading for a possible link to the increase respiratory cases to be explored further.

Fundamentally, these findings represent a blueprint of the relationship between anthropogenic activities, climate changes, and environmental effects within the Salton Sea Watershed, highlighting the importance of environmental management practices and policy implementation to mitigate and ensure both the community and the environment's health.

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