Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2016, Volume 5, Issue 6, pp. 1747-1754
ISSN 2320 - 0243, Crossref: 10.23953/cloud.ijarsg.57

Research Article **Open Access**

Mapping Changes in Desert Pavement Surfaces of the Lower Colorado Desert of Southern California using Landsat Time Series Analysis

Christopher Potter

NASA Ames Research Center, United States

Publication Date: 9 June 2016

DOI: https://doi.org/10.23953/cloud.ijarsg.57

Abstract Potential disturbance of desert soils from renewable energy development in southern California is receiving increasing attention due to potential impacts on air quality and greenhouse gas emissions. This study was designed to quantify and map, for the first time, changes in desert pavement surface area using 20 years of Landsat satellite image data across the Lower Colorado Desert. Landsat-derived maps of geomorphic surface classes from 1990 to 2014 for the Lower Colorado Desert area showed that a relatively stable area of around 1920 km^2 was covered by well-developed desert pavements prior to 2014. Based on 2014 Landsat imagery, coverage of well-developed pavements within solar energy development boundaries of the Lower Colorado Desert area totaled to 421 km^2, the majority of which (>82%) were located in eastern Riverside County. If disturbed as a result of construction activities, these desert pavements could become a source of dust from exposure of the underlying fine particle layer.
Keywords *Landsat; Desert Pavements; Solar Energy Development; Lower Colorado Desert; DRECP*

1. Introduction

A desert pavement is an arid land surface that is covered with closely packed, interlocking angular or rounded rock fragments of pebble and cobble size (Cooke and Warren, 1973). A notable feature of desert pavements is the development of the so-called "vesicular A" (or Av) soil horizon just below the surface of pebbles, gravels, and small stones that form the ground surface of desert pavement. The Av layer consists of dust-sized wind-deposited particles underneath the pavement. Most of the particulate matter consists of very fine silt and fine sand. The fine-textured layer of particulates at the top of the soil profile contrasts notably with the underlying soil layer.

One theory for the formation of desert pavements is based on the shrink/swell properties of the clay underneath the surface stones and gravel. Trapped by slowing wind speed due to surface roughness, dust particles land on the surface and subsequently work their way down between surface gravels. The physical shrinking and swelling processes of clay stemming from drying and wetting result in lifting a gravel layer to the surface and form a desert pavement. Shrinking and swelling are also most likely the cause of air trapped in the clay-rich layer creating disconnected air "vesicles" or air pockets in the Av layer (Yonovitz and Drohan, 2009).

Av horizons are characterized by an abundance of vesicular pores. Vesicular horizons are of interest to ecologists and hydrologists because they regulate the distribution of water by reducing infiltration rates and increasing water retention near the soil surface (Young et al., 2004). Fine clay particulates once weakly cemented to each other in the Av horizon contribute to stabilizing arid land surfaces (McFadden et al., 1998). At the same time, the gravel fragments above interlock and secure the underlying dust that may have been accumulating for millennia (Sweeney and Mason, 2013).

In a study of dust emissions from different Mojave Desert soil surfaces (including dry washes, dunes, playa margins, distal alluvial fans, and pavements), Sweeney et al. (2011) found that undisturbed desert pavements were the lowest emitters of dust, due to tightly-packed gravel that armors the surface and prohibits fine soil particles from being entrained by wind. However, if the Av horizon protected by pavements is partially exposed due to major mechanical disturbance, then these fine soils can become among the highest emitters of dust in desert landscapes (Bacon et al., 2011).

Renewable energy in newly proposed Development Focus Areas (DFAs) of southern California is receiving increasing attention due to potential impacts on air quality and greenhouse gas emissions. To mitigate and monitor the impacts of solar facility construction projects, the Desert Renewable Energy Conservation Plan (DRECP, 2010) has become a major component of the State of California Renewables Portfolio Standard. The DRECP is intended to provide effective environmental protections and natural resource conservation of desert ecosystems as appropriate development of renewable energy projects advances in southern California. The DRECP covers parts of seven California counties: Imperial, Inyo, Kern, Los Angeles, Riverside, San Bernardino, and San Diego. Approximately 91,000 km^2 of federal and non-federal California desert land are part of the DRECP Area. By the end of 2016, the Final DRECP Environment Impact Statement (EIS) will be completed for public lands under agency jurisdictions within the DRECP area. The objective of this remote sensing data analysis for southern California deserts was to quantify and characterize, for the first time, changes desert pavement surface area using 20 years of Landsat satellite image data across the Lower Colorado Desert region (Figure 1).

2. Study Area

The area of interest for this Landsat data study of desert pavements within the southern DRECP region was the Lower Colorado Desert of California (Figure 1). This area is bounded on the west by the Laguna, Santa Rosa, and San Jacinto mountain ranges, on the east by the California-Arizona state line, on the north by the gradual transition to the Mojave Desert, and on the south by the California-Mexico border (Marks, 1950). Low annual rainfall (50 – 300 mm) and high temperatures (reaching 45^{o}C in the summer) make this area one of the most arid in North America. Vegetation communities in the Colorado Desert have been classified into seven basic types: creosote bush scrub, cactus scrub, saltbush scrub, alkali sink, microphyll woodland, psammaophytic scrub, and palm oasis (Schoenherr and Burk, 2007).

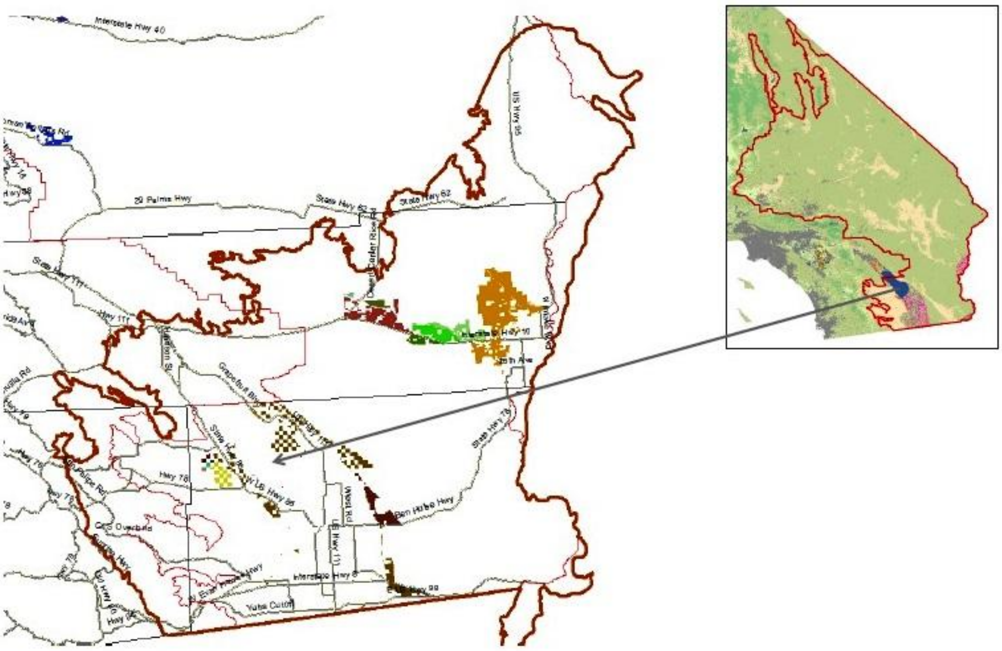


Figure 1: *Map of the Lower Colorado Desert (brown line) and DRECP (red line) study area, with Development Focus Areas (DFAs) in other shaded polygon outlines. Smaller map in the right panel shows vegetation cover types for the entire DRECP area from the USDA CropScape map of 2014 (available online at nassgeodata.gmu.edu/CropScape/), with shrublands in light green, barren sand dunes in tan, developed urban areas in grey, croplands in magenta, and open water in blue*

3. Methods

3.1. Satellite Imagery

For this study, near cloud-free imagery from the Landsat sensor was selected from the United States Geological Survey (USGS) Earth Explorer data portal (available online at earthexplorer.usgs.gov). Landsat scenes from path/row 39/37 were acquired between July and September of each year, well after the peak flowering period in the Lower Colorado Desert growing season (Schoenherr and Burk, 2007). All images used in this study were geometrically registered (UTM Zone 10) using terrain correction algorithms (Level 1T) applied by the USGS EROS Data Center.

For the Landsat 4-5 Thematic Mapper (TM) images acquired between 1985 and 2011, 30-m resolution surface reflectance data were generated from the Landsat Ecosystem Disturbance Adaptive Processing System (Masek et al., 2006). Moderate Resolution Imaging Spectroradiometer (MODIS) atmospheric correction routines were applied to Level-1 TM data products. Water vapor, ozone, geopotential height, aerosol optical thickness, and digital elevation are input with Landsat data to the Second Simulation of a Satellite Signal in the Solar Spectrum (6S) radiative transfer models to generate top of atmosphere (TOA) reflectance, surface reflectance, brightness temperature, and masks for clouds, cloud shadows, adjacent clouds, land, snow, ice, and water. Landsat 8 (after 2012) surface reflectance products were generated from the L8SR algorithm, a method that uses the scene center for the sun angle calculation and then hard-codes the view zenith angle to 0. The solar zenith and view zenith angles are used for calculations as part of the atmospheric correction.

3.2. Desert Pavement Detection

Beratan and Anderson (1998) developed an approach to map alluvial geomorphic surfaces in California. Visible bands and the near infrared (NIR) band of Landsat TM images were used to compose a new spectral space, which provided information about the composition and topography of desert surfaces. This spectral space can be classified as young, intermediate, or old in terms of stages of development. This methodology was successfully applied to mapping in the southern Whipple Mountains portion of the Mojave Desert in California.

Landsat image processing was carried out using the Environment for Visualizing Images software package (ENVI version 5.1, Research Systems, Inc.). A combination of processing techniques was required to delineate compositional differences between the three major geomorphic surfaces. Of primary interest in this study were surfaces covered by well-developed desert pavements and rock varnishes (Stage 2 surfaces). According to Beratan and Anderson (1998), Stage 2 surfaces display spectra that are strongly modified by the reflection spectrum of rock varnish. Such varnishes decrease surface reflectance and albedo, and result in a steep positive slope in between Landsat bands 1 and 5 due to a strong suppression of short wavelength radiance by the presence of oxidized transition metals (mainly Fe and Mg). In contrast, Stage 1 active washes are more commonly dominated by sand (quartz and feldspar crystals), which results in an increased reflectance (higher albedo) in all Landsat bands (Beratan and Anderson, 1998).

Figure 2 shows the image processing flowchart and definitions of surface classifications from Beratan and Anderson (1998) applied for the present study. Before applying these image analysis steps, pixels with non-pavement land cover features were masked out (e.g., vegetation, roads, and river channels, based on the United States Department of Agriculture (USDA) national land cover map of 2014; Figure 1).

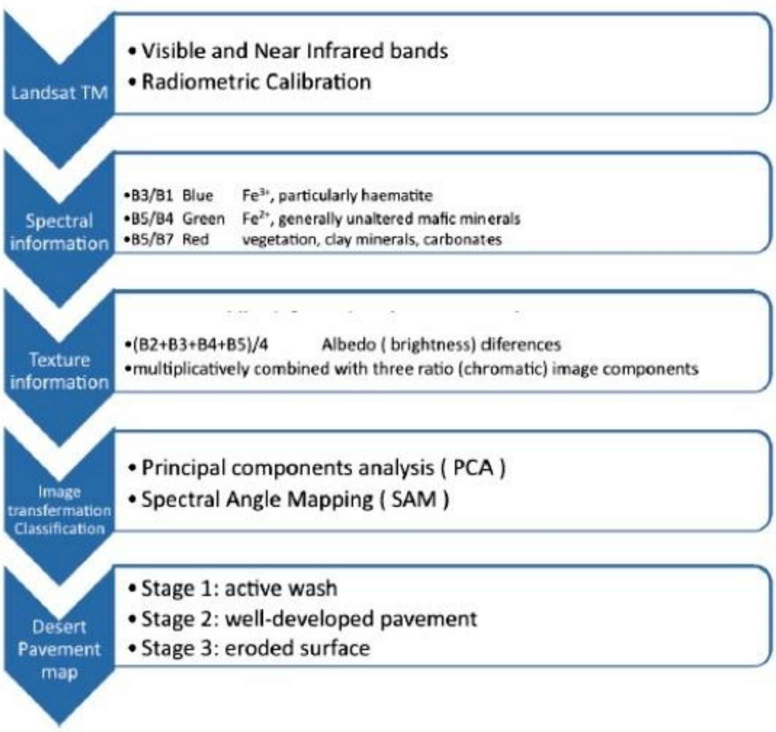


Figure 2: *Image processing flowchart of desert pavements based on the four-component methodology from Beratan and Anderson (1998)*

Spectral Angle Mapper (SAM) is a spectral classification in the ENVI software application that uses an n-D angle to match pixels to reference spectra (Kruse et al., 1993). The algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands. Endmember spectra used by the SAM were specified by Beratan and Anderson (1998) in their Figure 5. SAM compares the angle between the endmember spectrum vector and each pixel vector in n-D space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified.

A clustering approach was used to further divide the areas as Stages 1 and 3 of desert pavement development. Stage 1 included young alluvial fan deposits with active channels and depositional fan surfaces. This stage of development is identified by the presence of distinct bar and swale topography. Stage 3 included old alluvial fan deposits that have been highly dissected, leaving virtually no trace of the original fan surface.

4. Results and Discussion

Landsat-derived maps of geomorphic surface classes from 1990 to 2014 for the southern DRCEP Colorado Desert area (Figure 3) showed that a relatively stable area of around 1920 km^2 was covered by Stage 2 well-developed pavements prior to 2014. Between 2010 and 2014 image dates, the Stage 2 well-developed pavements fraction evidently increased in area by 10% (to 2145 km^2), whereas the Stage 3 fraction decreased in area by 10% (Figure 4). The majority of this recent area change between Stage 3 and Stage 2 surface classes was detected in the Granite Mountain and Palen Valley washes of eastern Riverside County (Figure 5).

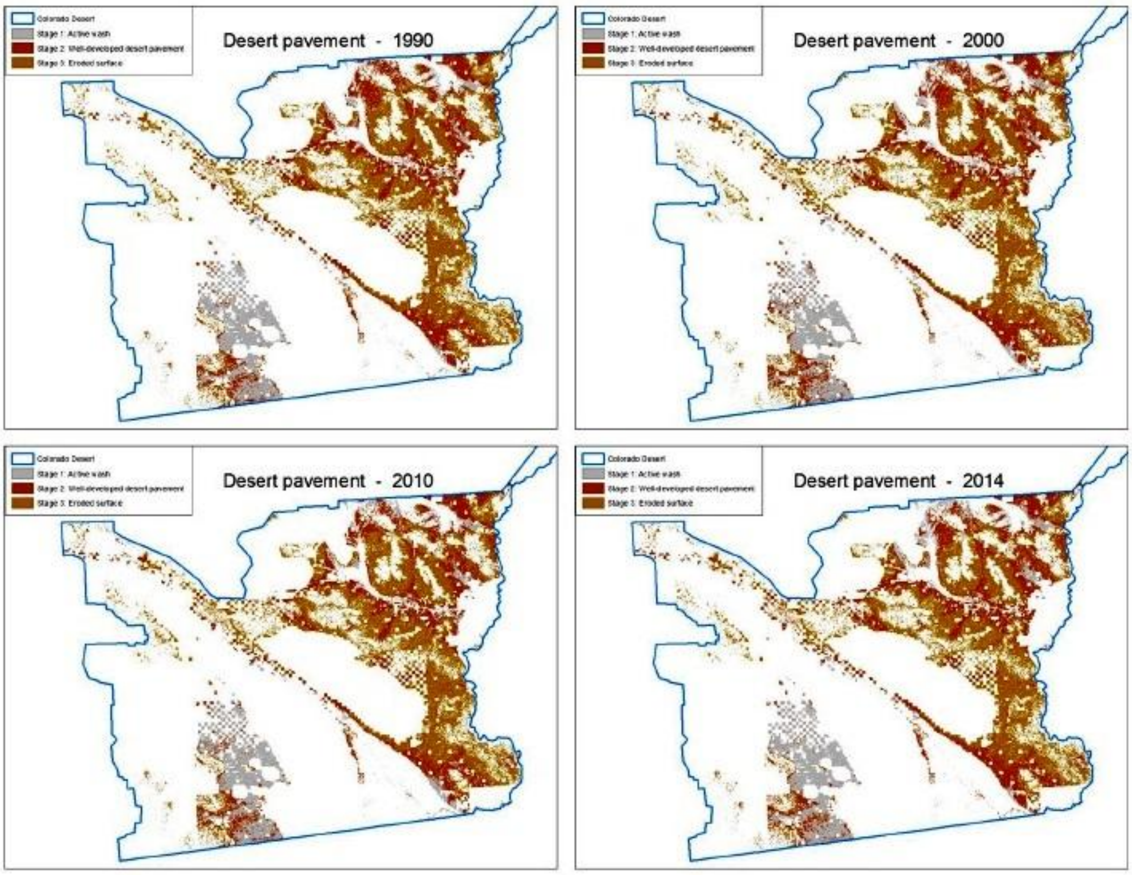
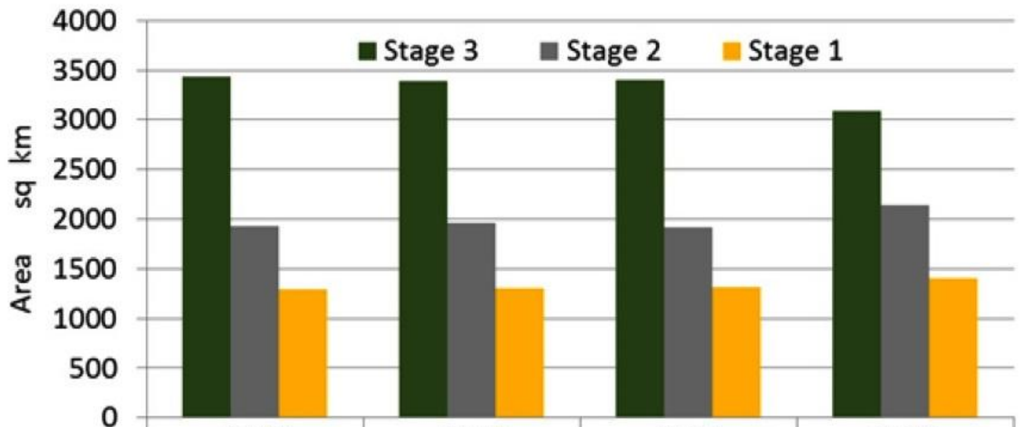


Figure 3: *Landsat-derived maps of geomorphic surface classes in southern DRCEP Lower Colorado Desert area*



	1990	2000	2010	2014
Stage 3	3433.97	3386.08	3404.15	3092.04
Stage 2	1921.90	1958.40	1921.46	2144.83
Stage 1	1291.76	1304.09	1315.12	1407.74

Figure 4: *Changes in Landsat-derived geomorphic surface classes in the southern DRCEP Lower Colorado Desert area*

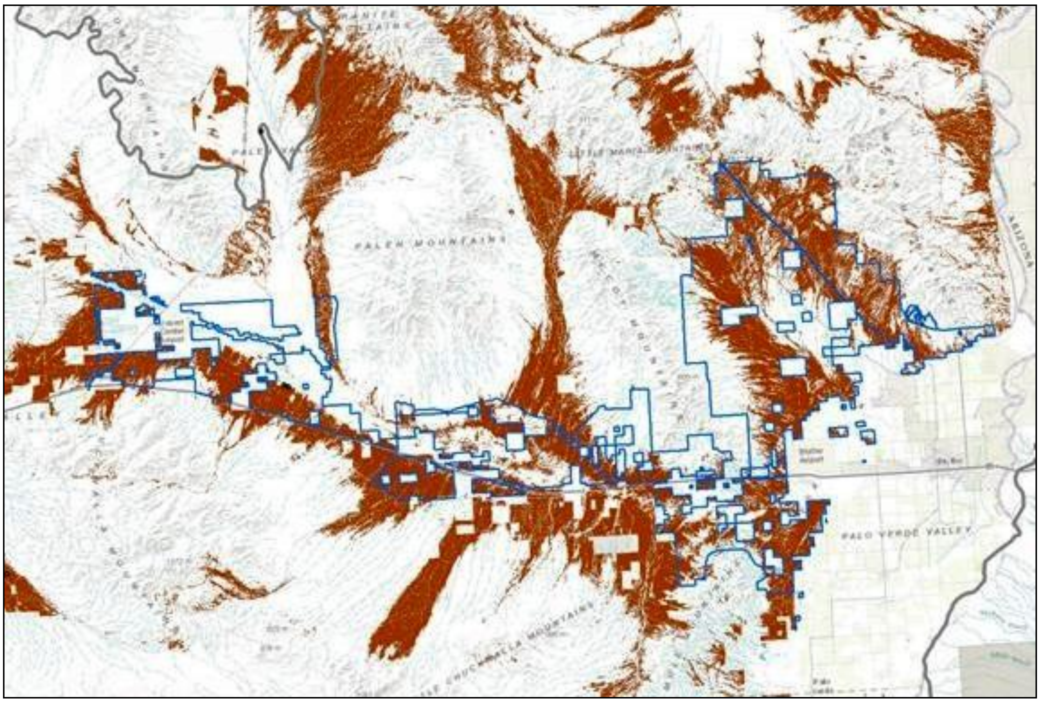


Figure 5: *Landsat-derived coverage of Stage 2 well-developed pavements in 2014 for Riverside County areas of the Lower Colorado Desert (outlined in gray), with DFA boundaries outlined in blue*

Generally speaking, increases detected in Stage 2 well-developed pavements may conceivably result from prior confusion in the satellite image classification process with Stage 3 eroded surfaces. According to Beratan and Anderson (1998), Stage 3 surfaces display the greatest relief, the presence of gullies and shadows, and strong linear features among pixels. These properties of Stage 3 eroded surfaces could contribute to misclassification errors into the other two geomorphic classes.

With reference to other transition types, it is conceivable that Stage 2 well-developed pavements could transition into Stage 1 active washes or into Stage 3 eroded surfaces, and that Stage 3 eroded surfaces could transition into Stage 1 active washes, or vise-versa. It is not easily conceivable, however, that Stage 1 active washes could transition into Stage 2 well-developed pavements in less than 25 years.

Based on 2014 Landsat imagery, coverage of Stage 2 well-developed pavements within DFA boundaries of the DRCEP Colorado Desert area totaled to 421 km^2, the majority of which (> 82% or 347 km^2) were located in eastern Riverside County (Figure 5). About 217 km^2 of Stage 2 well-developed pavements were located in the DFA zones in washes of the eastern McCoy Mountains alone (as listed in Table 1). Within DFAs of Imperial County east of the Salton Sea, namely those in the Pope, Alamo River, and German Diggins Wash drainages, 51 km^2 were covered by Stage 2 well-developed pavements, based on 2014 Landsat imagery. If disturbed as a result of construction activities within these DFAs, these desert pavements could become a source of dust and surface erosion from exposure of the underlying fine particle layer.

Table 1: *Coverage areas greater than 1 km^2 of Stage 2 well-developed pavements in 2014 within individual drainage basins (delineated by Seaber et al., 1987) of DFAs of eastern Riverside County*

Predominant Drainage	km^2
Aztec Mines	20.5
Ford Well	17.6
Lower Big Wash	58.8
Eagle Creek	3.6
McCoy Wash	217.2
Hopkins Well	28.1

5. Conclusions

Disturbance to the desert pavement surfaces could “unlock” the stabilizing surface and readily generate fugitive dust and surface erosion from a dry, exposed Av layer. Ecological destabilization and human health problems with the increase in airborne particulate matter are adverse impacts that the DRECP seeks to avoid. Site hydrology may also change as soils may become more permeable for water, at least initially after disturbance. The multiple connections of dust in the environment to performance of solar facilities make management of disturbances to desert pavements critical to sustaining original energy production goals. Solar energy project developers can benefit from the satellite mage mapping of locations of desert pavements in advance, so that the design of project footprints excludes desert pavements at the start.

Acknowledgements

The author is grateful to James Weigand (BLM, Sacramento, CA) for continual guidance in all aspects of this work. Satellite image processing and application of mathematical algorithms for soil map product figures and plots in this report was carried out primarily by Shuang Li of California State University Monterey Bay.

References

Bacon, S.N., McDonald, E.V., Amit, R., Enzel, Y. and Crouvi, O. *Total Suspended Particulate Matter Emissions at High Friction Velocities from Desert Landforms.* Journal of Geophysical Research. 2011. 116; F03019.

Beratan, K.K. and Anderson, R. *The Use of Landsat Thematic Mapper Data for Mapping and Correlation of Quaternary Geomorphic Surfaces in the Southern Whipple Mountains, California,* International Journal of Remote Sensing. 1998. 19 (12) 2345-2359.s.

Cooke, R.U. and Warren, A., 1973: *Geomorphology in Deserts*. London: B.T. Batsford Ltd. 120.

DRECP, 2010: Recommendations of Independent Science Advisors for The California Desert Renewable Energy Conservation Plan (DRECP) prepared for Renewable Energy Action Team.

Lentile, L., Holden, A., Smith, A., Falkowski, M., Hudak, A., Morgan, P., et al. *Remote Sensing Techniques to Assess Active Fire Characteristics and Post-Fire Effects*. International Journal of Wildland Fire. 2006. 15; 319-345.

Kruse, F.A., Lefkoff, A.B., Boardman, J.B., Heidebrecht, K.B., Shapiro, A.T., Barloon, P.J. and Goetz, A.F.H. *The Spectral Image Processing System (SIPS) - Interactive Visualization and Analysis of Imaging Spectrometer Data.* Remote Sensing of Environment. 1993. 44; 145-163.

Marks, J.B. *Vegetation and Soil Relations in the Lower Colorado Desert*. Ecology. 1950. 31; 176-193.

Masek, J.G., Vermote, E.F., Saleous, N., Wolfe, R., Hall, F.G., Huemmrich, F., Gao, F., Kutler, J. and Lim, T.K. *A Landsat Surface Reflectance Data Set for North America, 1990-2000.* Geoscience and Remote Sensing Letters. 2006. 3, 68-72.

McFadden, L.D., McDonald, E.V., Wells, S.G., Anderson, K., Quade, J. and Forman, S.L. *The Vesicular Layer and Carbonate Collars of Desert Soils and Pavements: Formation, Age and Relation to Climate Change.* Geomorphology. 1998. 24; 101-145.

Schoenherr, A.A. and Burk, J.H., 2007: *Colorado Desert Vegetation*. In: Barbour, M.G., Keeler-Wolf, T. and Schoenherr, A.A. (Eds.), Terrestrial Vegetation of California, 3rd ed. Berkeley, California: University of California Press. 657-682, 712.

Seaber, P.R., Kapinos, F.P. and Knapp, G.L., 1987: Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294. 63.

Sweeney, M.R., McDonald, E.V. and Etyemezian, V. *Quantifying Dust Emissions from Desert Landforms, Eastern Mojave Desert, USA.* Geomorphology. 2011. 135 (1-2) 21-34.

Sweeney, M.R. and Mason, J.A. *Mechanisms of Dust Emission from Pleistocene Loess Deposits, Nebraska, USA.* Journal of Geophysical Research - Earth Surface. 2013. 118; 1460-1471.

Yonovitz, M. and Drohan, P.J. *Pore Morphology Characteristics of Vesicular Horizons in Undisturbed and Disturbed Arid Soils; Implications for Arid Land Management.* Soil Use Management. 2009. 25; 293-302.

Young, M.H., McDonald, E.V., Caldwell, T.G., Benner, S.G. and Meadows, D.G. *Hydraulic Properties of a Desert Soil Chronosequence in the Mojave Desert, USA.* Vadose Zone J. 2004. 3; 956-963.