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Remote Sensing Analysis Of Hydrological Functionality Of Playa Wetlands Using Landsat TM/ETM+ Data

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REMOTE SENSING ANALYSIS OF HYDROLOGICAL FUNCTIONALITY OF PLAYA WETLANDS USING LANDSAT TM/ETM+ DATA

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A Thesis Presented to the Graduate Faculty
of the Fort Hays State University in
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the Degree of Master of Science

by

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ABSTRACT

A playa wetland's ability to retain moisture and water has the greatest influence on the ecological and hydrological functionality of the playa. In this project, Landsat TM/ETM+ satellite imagery was analyzed to determine whether it could be used to detect hydrological functionality of playa wetlands based on their temporal ability to retain soil moisture and water. The project consisted of a ground truth study in which soil moisture, water content, and vegetation data was gathered from the area and related to the satellite imagery pixel values. With this data, a maximum likelihood classifier was created using the mean pixel values and standard deviations of each ground truth wetness category, creating a threshold of values for each wetness category. Based on the results of this study, it was determined from the final analysis that with the correct weather conditions, and accurate rainfall data; Landsat TM/ETM+ band 5 data is capable of detecting a temporal difference in moisture and water presence between undisturbed, disturbed, and altered playa wetlands.

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INTRODUCTION

Motivation for Research

Across the Central High Plains of North America are small, shallow, clay lined depressions that have naturally formed on the landscape and are referred to as playa wetlands. These playas frequently are dry, and in the event of heavy rainfall are flooded and can retain water for as long as just a few days to over a year; much longer than their surrounding native upland/grassland soils (Smith, 2003). Since these playas hold water for a longer period of time than their surrounding environment, they frequently transform from their dry phase, into vibrant wetland environments which support and host an even larger variety of animals than the surrounding semi-arid environment. All playas have an unpredictable hydroperiod, which is essential to their maintenance of such high biodiversity (Haukos and Smith, 2003). The term hydroperiod refers to the length of time in which the playa wetland is inundated with water (Luo et al., 1997). Playas serve as important recharge sources to the High Plains Ogallala Aquifer and also are critical for surface drainage. During wet and dry states, they provide important habitat for many different species of animals, including: migrating waterfowl, shorebirds, and a variety of mammals, amphibians, reptiles and invertebrates (Haukos and Smith 2003, Osterkamp and Wood, 1987).

Functions and services of playa wetlands are dependent mostly upon hydrological functions, and those hydrological functions of playas are mostly impacted by accelerated accumulation of sedimentation over the top of the expansive clay layer which is characteristic to all High Plains playas (Smith et al, 2011). Characteristics of a fully functional and natural playa are affected by several properties of the surrounding land within the watershed. The variable characteristics playa watersheds include such as soil porosity and vegetation cover are dependent upon the uses of the surrounding watershed, and in turn, affect the functionality, sedimentation, and potential for restoration of the playas (Smith et al. 2011, Tsai et al. 2007). Different uses of land within playa watersheds can affect their hydrology and hydroperiod (Luo et al. 1997). The more a playa and its watershed have been altered and disturbed, the more additional sediments it receives, and the less hydrologically functional it becomes (Smith et al. 2011). The purpose of this research project is to test the capability of Landsat Thematic Mapper and Enhanced Thematic Mapper Plus (Landsat TM/ETM+) data in detecting hydrological functionality of playa wetlands by monitoring the temporal presence of soil moisture and water content.

Landowners have altered the slope and landscape of their land to fill in, drain, or prevent the playas from being inundated which can kill crops. Other causes for the alteration of playas and their landscapes are for storage of irrigation water, feedlot runoff, or treated wastewater; and sometimes they are altered by road construction and urban development (Haukos and Smith, 2003). The High Plains is one of the most intensely cultivated regions of the Western Hemisphere, and playas are severely impacted by a number of agricultural practices (Smith et al. 2011). Watersheds that are plowed or overgrazed can increase runoff into the playas which in turn increases sedimentation, and decreases the length of the playa’s hydroperiod. The ability of a playa wetland to hold water is affected by all these uses and characteristics of surrounding watersheds, and the ecological and hyrological functionality of a playa is dependent upon that ability to hold water (Luo et al, 1997).

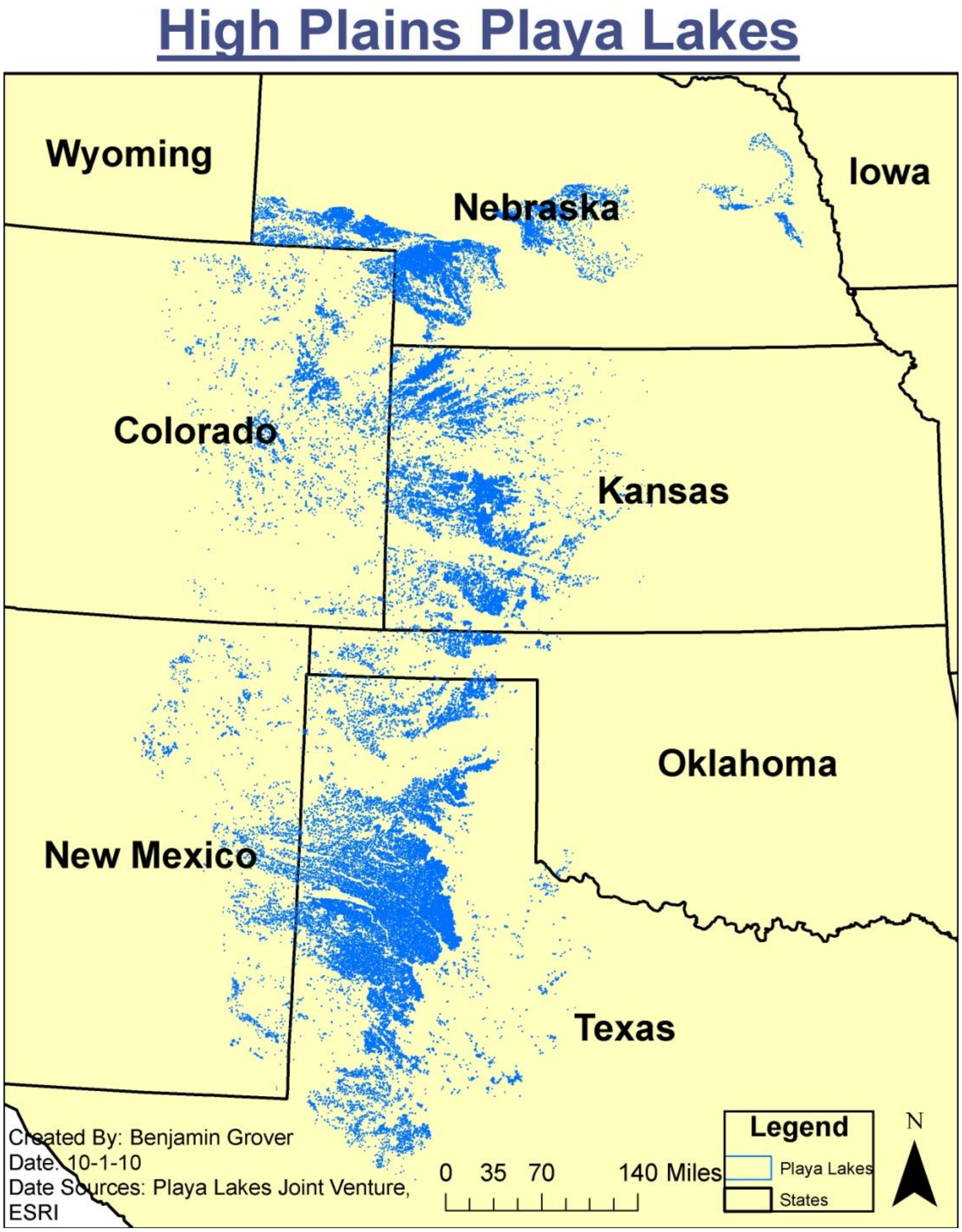
For the purpose of this study, playa condition is defined based on the alteration and disturbance of the playas and their surrounding watershed. A playa that has had the landscape around it or within it altered in some way for the purpose of draining or preventing it from receiving runoff is considered an “altered” playa. Alterations such as terraces, dams, or excavation fall into this playa category. Playas that have only been cultivated and farmed with no other landscape alterations are considered “disturbed”, and playas located in pasture or native grasslands with no alterations or disturbances are considered “undisturbed”.

Because of the large numbers of playa wetlands across the High Plains region of the U.S., a process for determining a playa’s potential for conservation remotely would help save the time and money of conservationists looking to identify playas that still can hydrologically function and/or have a functioning unbroken clay layer. Remote sensing data from both the Landsat Thematic Mapper (TM) Satellite, and Enhanced Thematic Mapper Plus (ETM+) Satellite were used to identify the functionality of playas in western Kansas by monitoring their soil moisture content over time. I hypothesized that the soil moisture within playas that are unaltered and undisturbed will be detected for a longer period of time than disturbed playas, and disturbed playas longer than altered playas. The process will allow state and federal conservation program professionals to remotely determine the functioning status of thousands of playa wetlands, and make it possible to target playas with the greatest potential for conservation as ecologically and hydrologically functional wetlands.

Introduction to Playa Wetlands

Descriptions of playa wetlands vary because the ecology, hydrology, and geology vary greatly across different geographic regions of the world (Smith, 2003). There are many theories about the processes involved in the formation of playas, but most scientists agree that the playas in the High Plains of America are shallow depression recharge wetlands that are formed through a combination of wind, wave, and dissolution processes, with each wetland existing in its own watershed (Smith 2003, Osterkamp and Wood 1987, Gustavson et al. 1995, Reeves and Reeves 1996). These wetlands receive water through precipitation and runoff only, and the water is lost through evaporation, transpiration, and percolation (Haukos and Smith, 2003). Most playas in the Great Plains region exist in semi-arid short-grass prairie, while some also exist further east in the mixed-grass prairie (Smith, 2003). A precise count of all the playas in the Great Plains is non-existent, but the number is estimated to exceed 25,000 for the Southern Great Plains (Haukos and Smith 2003, Tsai et al. 2007). For the entire High Plains area including Texas, New Mexico, Oklahoma, Nebraska, Wyoming, Kansas, and Colorado this number is estimated to be 60,000 (“Playa Lakes Joint Venture”, no date)(Figure 1), and there are estimated to be at least 22,000 playa wetlands in Kansas alone (Bowen et al., 2010).

Figure 1: Map of High Plains playas. This map displays the distribution of playa lakes across the High Plains region of the US.



In a playa wetland, the entire floral and faunal population can change within only a few days (Smith, 2003). Early spring thunderstorms can occur over playas and its surrounding watershed, which often results in the playa basin being flooded with 0.5

meters of water or more (Smith, 2003). Aquatic plants begin to germinate within a few days; and aquatic invertebrates such as clam shrimp, as well as toads and frogs all begin to emerge (Smith, 2003). Shorebirds arrive to feed on the invertebrates, waterfowl passing through during migration stop at these playa wetlands and also feed on the abundant food present, and occasionally duck pairs nest near or on the playa wetlands (Smith, 2003).

The playa wetlands' dynamic, unpredictable hydroperiods are essential to the maintenance of their biodiversity (Haukos and Smith, 2003). Playa wetlands require flooding events to remain as key areas of rich biodiversity (Smith, 2003). Playas very frequently dry out, and this stage, though generally not considered to be as important as the wet stage, is also important in that it keeps them healthy and functional (Smith, 2003). While the playas are dry, this stage allows for the decomposition of organic materials, and also allows a different community of plants and animals to emerge that prefer the openness of the dry cracked clays and short grasses, increasing the diversity of life in the playa and surrounding prairies (Smith, 2003). Also, while playas are dry and their clay layer shrinks and cracks this opens passageways through the semi-impermeable clay layer in which rain waters can pass through and recharge the aquifer below during the early stages of the playa's next flood event. After the clay has been exposed to water long enough, the clay particles swell up, and expand, and seal off the cracks keeping the water from infiltrating quickly (Hovorka, 1997).

Cultivated land lacking vegetation very often does not catch or absorb excessive runoff water, which increases the runoff into playas during heavy rainfall events (Tsai et al., 2007). Additional sediments carried by this excessive runoff fills the playa bottoms with eroded silt from the cultivated and bare surrounding soils to the point that they cannot hold water for as long, and in some cases to a point that they cannot hold water at all (Luo et al., 1997; Smith, 2003). When a playa is affected by accelerated sedimentation, playa becomes shallower, spreading the water out over a larger area, which makes the water more vulnerable to evaporation, and shallow soil infiltration (Smith, 2003). These seemingly subtle changes to the playas hydroperiod can drastically affect plants and animals that depend on the playas (Smith, 2003; Jurik et al., 1994; Gleason et al., 2003). One of the main threats to playa wetlands is culturally accelerated sedimentation from the cultivation of the surrounding watersheds (Luo et al., 1997), thus restoration of these watersheds, and easement of the remaining unaltered playas is important to the conservation of these unique wetlands (Smith, 2003; Luo et al., 1997).

LITERATURE REVIEW

Playa Wetlands

Since approximately the mid-1950's, studies have been conducted concerning playas and their impacts on aquifer recharge, floral and faunal diversity, and cultural practices such as agriculture and irrigation.

For the purpose of aquifer recharge, Cox et al. (1965) investigated the effectiveness of the alteration of playa wetlands to recharge the High Plains Aquifer. The researchers altered the playas to attempt to use the standing water for irrigation and aquifer recharge (Cox et al., 1965). Some landowners placed pumps in the centers of playas to pump the water from the playas to irrigate their crops (Cox et al., 1965). This alteration of the playas was a success by making use of the water, but for unknown reasons, many of these playa irrigation pumps were abandoned (Cox et al., 1965). In attempts to recharge the High Plains Aquifer, other experiments were done using playas to capture water, and pumps were then used to force the water into the ground through gravel columns (Cox et al., 1965). Cox et al. (1965) found that while this technique was successful at first, the process quickly lost effectiveness due to clay particles and sediments clogging the pores in the gravel, and most recharge wells were abandoned in a short time.

It was found that despite the many studies of playas in relation to wildlife and agriculture, playas have received little study focusing on their ecological structure and function as wetland ecosystems (Bolen et al., 1989). Bolen et al. (1989) concluded that because of this lack of knowledge on functionality, additional research should be conducted in the context of ecosystem structure and function to help allow the integration of playa ecosystems with other, more thoroughly investigated wetlands.

Haukos and Smith (2003) describe the importance of playas to the maintenance of biodiversity. However, many playas have been negatively impacted by unnatural events and processes influenced by human activity; for example: culturally accelerated sedimentation, pit excavation, road construction, industrial and municipal wastewater, feedlot runoff, urban development, overgrazing, and deliberate filling of the playas (Haukos and Smith, 2003). Agricultural cultivation contributes greatly to the degradation of playa hydrological functionality (Haukos and Smith, 2003). Haukos and Smith's study concluded by suggesting the implementation of a variety of conservation and protection programs aimed at the local, state and federal levels (Haukos and Smith, 2003).

A study completed by Tsai et al (2007), examined influences of land use on water loss rates and hydroperiods of playas in the Southern High Plains of the United States. His study concluded that land use, percent of playa vegetation cover, and soil texture zone were all important factors explaining water loss rate; while starting water level and land use were important in explaining hydroperiod (Tsai et al., 2007). Land use and cultivation around playas increased suspended sediment in run-off water flowing into the playas, which built up in the playa bottom over time, eventually filling them up, and decreasing the volume of the playa (Tsai et al., 2007). This process increased the water surface area and evaporation of the water, and possibly infiltration as well, thus shortening the hydroperiod of the playas (Tsai et al., 2007).

These studies show how our understanding of playa functionality and their ecological importance has changed since the 1960s. Altering playa landscapes to pump water from playas for irrigation use and prevent evaporation loss is now understood to negatively impact the playa and the ecological and hydrological function of the wetland and grassland ecosystems. Playas have long been misunderstood, but after realizing their importance to aquifer recharge, and their role in animal habitat, playas have been studied more closely. It is now known that accelerated sedimentation, and farming of playas and their watersheds damages them as functioning wetlands and efforts are being made to restore them, and protect them from disappearing.

Remote Sensing of Soil Moisture

There are many techniques used to monitor and detect soil moisture, most of which provide point values rather than values over an entire area, and require direct contact with the area of study. These techniques include but are not limited to tensiometry, neutron probes, gravimetric soil sample analysis, soil lysimeters, and soil electrical resistance (Wheeler and Duncan, 1984). Because these techniques provide only point specific data, and require samples or measurements to be taken at the site, the ability to remotely gather soil moisture values for an entire area can be advantageous (Shih and Jordan, 1992). Remote sensing provides a unique capability for direct observation of the Earth's surface. This is useful because it enables scientists to acquire spatial soil moisture values for a large area without ever having to visit the area of study (Njoku and Entekhabi, 1996). Other advantages presented by remote sensing are cost and safety. Many remote sensing data archives are readily available, and free of charge for use by anyone. And by not having to visit distant locations to gather data, one can save on cost and possibilities of getting hurt during field work and travel are eliminated.

There are many different types of remote sensing technologies in existence that are capable of detecting soil moisture. Some of the more commonly used consist of microwave data, Synthetic Aperture Radar (SAR) data, and multispectral data bands including thermal infrared, near infrared, and middle infrared. Different types of remote sensing techniques have limitations in the determination of ‘true’ soil moisture; while all have different advantages over others as well (Foody, 1991).

Microwave measurements have the advantage of being mostly unaffected by cloud cover and variable surface solar illumination. However, accurate soil moisture estimates are limited to regions that have either bare soil, or small amounts of vegetation cover (Njoku and Entekhabi, 1996). One other drawback of the use of microwave data for soil moisture detection is poor resolution. Since over 80% of playa wetlands in the High Plains region are less than .02 km^2 in area, and less than 2% are over .1 km^2, a sensor resolution of 10-20km (Bowen et al., 2010; Njoku and Entekhabi, 1996) is not high enough resolution. Major factors that affect the appearance of soil characteristics in microwave data include soil moisture, surface roughness, soil and vegetation temperature, and vegetation type and water content (Njoku and Entekhabi, 1996). To retrieve soil moisture data from brightness and temperature observations, there are corrections needed to adjust for errors (Njoku and Entekhabi, 1996).

A study done in Poland used both SAR data and Landsat TM imagery in conjunction to detect soil moisture (Hejmanowska and Mularz, 2000). Landsat data was used to create land-use and land-cover categories, and also the thermal band was used for thermal inertia modeling and soil-moisture detection of bare soils, which was compared to *in situ* temperature measurements (Hejmanowska and Mularz, 2000). A similar study completed in Arizona determined that SAR and optical data could be used together for monitoring vegetation growth and surface soil moisture conditions (Moran et al., 2000).

Multispectral SPOT satellite data were used for a study in France to model soil moisture-reflectance relationships (Muller and Decamps, 2000). This study concluded that because direct observation of soils is only possible in the absence of vegetation, the effective remote sensing of soil moisture is limited to a few days per year (Muller and Decamps, 2000). Results suggested a positive relationship between soil moisture measured in the field, and the reflectance data observed in the SPOT images (Muller and Decamps, 2000). Muller and Decamps (2000) also found that the impact of soil moisture on reflectance could be higher than differences in reflectance due to the different soil categories used.

In a study by Shih and Jordan (1993), Landsat thermal-IR data and land use maps were used together in detecting soil moisture differences. They found that surface-temperature data from Landsat TM thermal-IR imagery is a useful technique in assessing soil moisture conditions (Shih and Jordan, 1993). The thermal-IR response in the satellite imagery was inversely related to the soil moisture conditions based on qualitative ground truth observations made by the researchers. In a separate study, Shih and Jordan (1992) used Landsat middle-IR reflectance data in detecting surface soil moisture content. The middle-IR response was compared to surface soil-moisture conditions, also based on qualitative ground observations made during visits to the study areas (Shih and Jordan, 1992). Shih and Jordan (1992) determined that Landsat TM middle-IR data have significant potential in detecting surface soil moisture conditions.

In Montana, Landsat TM imagery was used with a tasseled cap transformation to create brightness, greenness, and wetness axes that correspond to the physical characteristics of vegetation (Baker et al., 2007). These brightness, greenness, and wetness components can account for more than 97% of the spectral variability present in a given Landsat scene (Baker et al., 2007). Tasseled cap transformations have been used effectively to isolate wet sites on a landscape and improve distinctions between moist and aged vegetation (Baker et al., 2007).

All spectral domains have their own limitations and advantages, and none are used regularly to predict soil moisture (Muller and Decamps, 2000). When determining which remote sensing instrument is best for a particular analysis there are numerous factors to consider. These factors include the required spatial and temporal resolution, the limitations and advantages of the sensor and platform for the intended purpose, and the data availability. Landsat Thematic Mapper, and Thematic Mapper Plus multi-spectral imagery was ultimately decided upon for use in this project due to the availability, spectral resolution, and 16 day (8 day combined) orbital intervals (Jensen, 2007).

DATA AND METHODOLOGY

Objective

The objective of this project was to determine if Landsat TM/ETM+ satellite imagery could be used to monitor soil moisture within playa wetlands, and in turn distinguish between functioning and non-functioning playa wetlands, based on the ability of the playas to hold water or soil moisture. A series of ground truth visits was carried out to assist in determining the most suitable band for detecting soil moisture differences. The ground truth visits were followed by several analyses of playa wetlands from varying categories of functionality to determine if differences in temporal patterns of moisture content could be detected. The data used in the study consisted of Playa Lakes Joint Venture's (PLJV) probable playa GIS layer, a Kansas land coverage file from the Data Access Support Center (DASC), and monthly total precipitation data from the Weather Data Library of the Kansas State University (KSU) Agronomy Department.

Ground Truth

Ground truth spectral control data was acquired by observation of a KDWPT (Kansas Department of Wildlife, Parks and Tourism) managed wetland called Heron Playa, located at coordinates 37º 47' 20" north, and 99º 46' 16" west (Spearville, Ford County, Kansas, Figure 2), using Landsat TM/ETM+ multi-spectral data, in combination with physical visits to the playa. The ground truth portion of the study allowed correlation between the pixel values of the satellite imagery with observed and confirmed degrees of moisture/water content and vegetation cover in the playa. Physical visits to Heron Playa were made every 8 to 16 days when Landsat was scheduled to collect data for the area. On days that were cloudy or overcast, visits were not carried out. During the summer of the ground truth, Heron Playa consisted of two different types of vegetation cover. In the bottom or central region of the playa, sparse vegetation cover consisting mostly of sunflowers and other tall, sparsely foliated plants covered the area, leaving much of the bare ground visible through the vegetation (Figure 3). In the outer edges of the area, short dense grasses covered the ground, making the bare ground not visible from above (Figure 4). Moisture conditions of the playa were divided into three categories: Dry, Mud, and Water. If the ground was dry on the surface still showing mud cracks, it was categorized as dry. If the soil was wet, with no standing water, it was categorized as mud, and if there was standing water covering the ground, it was categorized as water. Upon each visit, observations of both the wetness and vegetation conditions were made, and the area was photographed. After the ground truth process was complete, a total of 6 days of usable ground truth data were acquired over a period of 68 days from August 15, 2011 until October 18, 2011. In early September, before the third ground truth visit that resulted in usable data, KDWPT began flooding Heron Playa, and the wetland's transition from dry to wet was observed and correlated with the acquired Landsat satellite data.

Figure 2: Location of Ground Truth Study Area - Heron Playa, Ford County, KS.

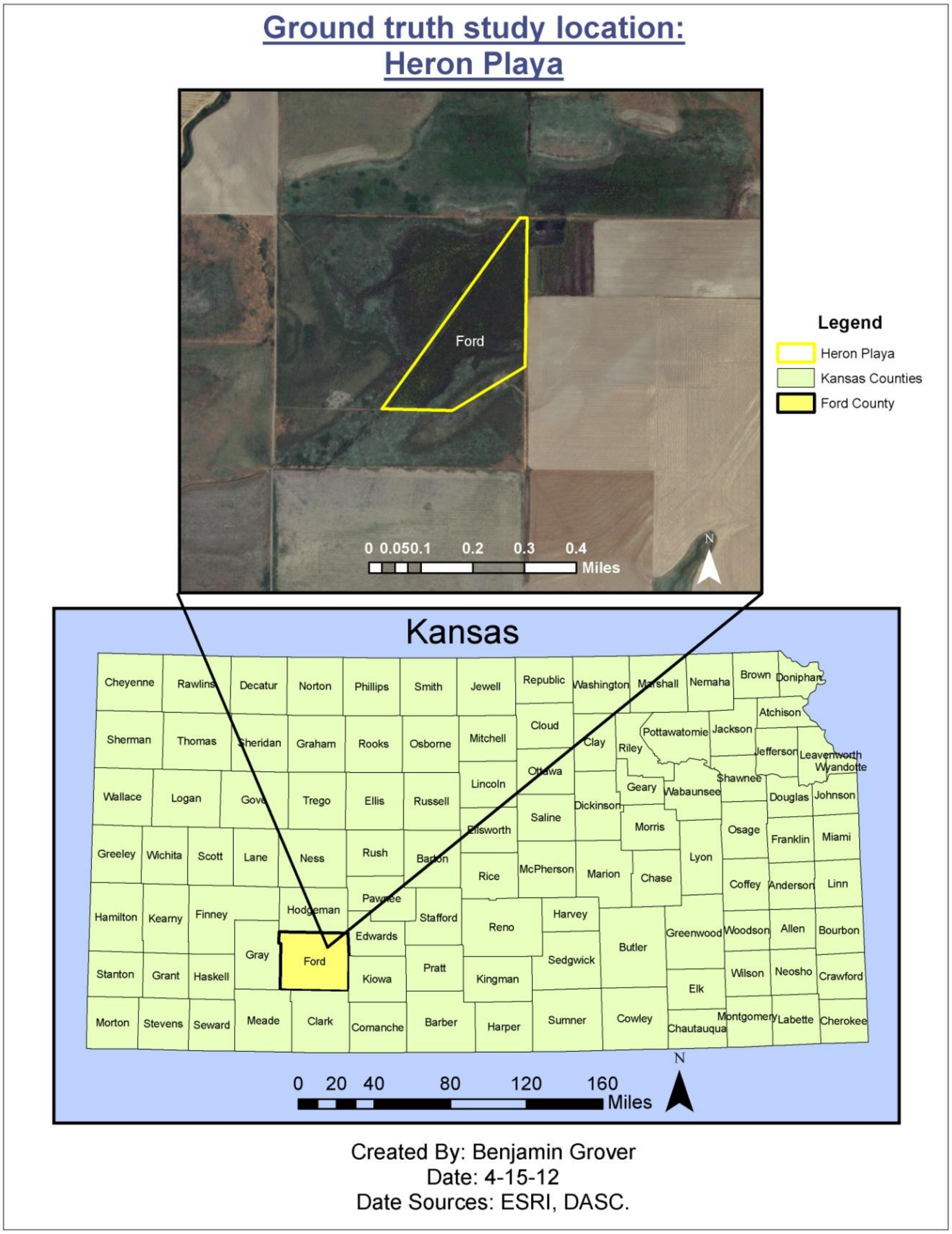


Figure 3: Heron Playa dense photo. Heron Playa’s densely vegetated ground cover with bare ground not visible.

Figure 4: Heron Playa sparse photo. Heron Playa’s sparsely vegetated ground cover with bare ground visible.

Preliminary Analysis of Landsat Bands

After the ground truth data were collected, a series of preliminary tests and analyses were performed to determine the most suitable band(s) for detecting changes in soil moisture and water coverage. Based on the findings of Quinn (2001), Landsat Infrared bands 4, 5, and 7 were initially selected for a preliminary analysis. Quinn (2001) stated that these three infrared bands were most suitable for detecting water and vegetation differences. Color composite images displaying bands 4, 5, and 7 with the colors blue, green, and red respectively, were then created using ENVI Image Analysis software for each Landsat scene acquired throughout the ground truth period (Figure 6).

Further preliminary analyses of the ground truth data consisted of creating change detection images of the three infrared bands (4,5 and 7) from the collected Landsat data using the band math function through the ENVI Image Analysis software (Figure 7). These images show day to day pixel value changes, with darker pixels indicating increases in soil moisture and decreases in pixel values, and lighter pixels indicating decreases in soil moisture and increases in pixel values. There are areas of data in these images that are not usable due to a sensor error with the Landsat 7 ETM+ sensor. The Scan Line Corrector (SLC) has stopped working on the ETM+ sensor, and therefore creates gaps in each scene, appearing as wedges that increase in width from the center to the outside edge of the scene (Maxwell et. al., 2007). In this SLC-off mode, the ETM+ still acquires approximately 75% of the data for any given scene (Maxwell et al., 2007). These scenes consisted of image dates 8-23, 9-24, and 10-10 of Figure 6, and therefore affected the output of each change detection image created in Figure 7 using any of those three ETM+ images. All areas in each change detection image that do not consist of any gaps from the original three ETM+ images are usable, error free data.

Following the change detection analysis, a comparison of the pixel value means of the four wetness categories for all seven visible and infrared bands was carried out. This analysis was based on a series of graphs constructed for each band. Each band's graph displayed the temporal variation of the wetness category means (dry dense, dry sparse, mud sparse, and water sparse) over the six days of observation (Figure 8). These graphs show the separation of the means for each ground truth category within each Landsat band, as well as the variability of the four wetness category's mean reflectance from the six days of the ground truth period.

From the same data, a table with the categories and band means with each day averaged together was created (Table 1), along with a graph displaying the category means, and the standard deviations as error bars (Figure 9). The graph in Figure 9 showed the averaged wetness category means for all six days of observation together for all seven Landsat bands. The overall standard deviations for each wetness category and each band are displayed in the graph as error bars (Figure 9). This graph was created to further exhibit the severability of each wetness category's average mean pixel value, and the overlap of each category's average standard deviations for each band.

Following the series of graph analyses of the ground truth data, a non-parametric statistics test was performed on the band 5 data called the Kruskall and Wallis Test (Table 2). Using this test, the means of each category for all six days were compared to each other. By using this test, the mean ranks of pixel values from the four wetness categories are compared for difference, and the four samples of data are either determined to be from the same population of values, or to not all be drawn from the same population (McGrew and Monroe, 2000). The reason for the use of this test is due to the very small sample sizes. The Kruskall-Wallis test is best fit for comparison of three or more sample populations, with atleast one sample population having a population of less than five (McGrew and Monroe, 2000).

In addition to the Kruskall and Wallis test, a series of Wilcoxon Rank Sum tests were completed, which compared each of the four ground truth categories to each other with the band 5 data only. The Wilcoxon Rank Sum test compares the mean pixel values of each wetness category to each of the other wetness categories. This test is used to determine exactly how statistically different each categories mean is from the others (Table 3) (McGrew and Monroe, 2000). Before making any determinations based on the P-values generated with the Wilcoxon Rank Sum tests, a multiple comparison correction was required to be made for the alpha value. Using an original overall alpha of 0.05 (95% Confidence Interval), that alpha value of 0.05 was divided by 6 (n: the total number of comparisons) to determine the new corrected alpha value. This gave a new significance level of 0.0085 for each of the individual comparisons. Using the original alpha of .05, and the corrected significance level of 0.0085, none of the individual comparisons showed a significant difference. By increasing the alpha value from 0.05 (a 95% Confidence Interval) to 0.1 (a 90% Confidence Interval), and running the correction formula on this new value, a new corrected significance level of 0.0174 was then acquired to be used for the individual comparisons. The use of the Wilcoxon Rank Sum tests was most suitable for this situation because it is also a non-parametric test, meaning it does not assume normality in the data sets, and is suitable for comparing just two sample populations of smaller sizes (McGrew and Monroe, 2000).

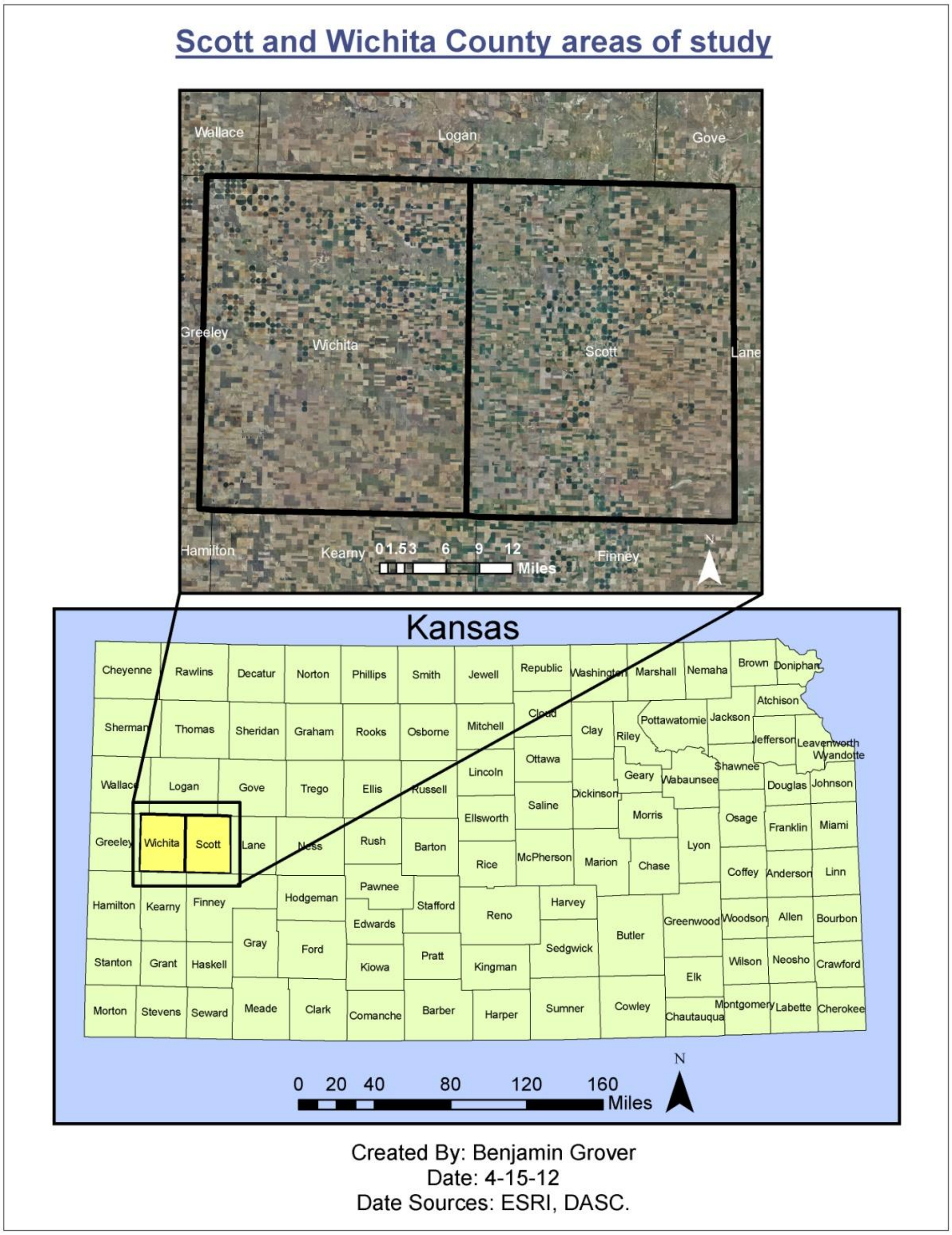
After completing the statistical analyses of the band 5 data, a maximum likelihood classifier was created using Microsoft Office Excel, and the band 5 ground truth data. When creating the classifier, the means of each category, and the respective standard deviations were used to determine a threshold of minimum and maximum values for each wetness category (Table 4). Each category's standard deviation was subtracted and added from its respective category mean to determine a minimum and maximum value for each ground truth category. First, absolute values of the difference between each wetness category's mean and a random pixel value were determined based on the wetness category's standard deviation. A second formula was then created to determine the smallest of the four wetness categories absolute difference values. The wetness category with the smallest absolute difference value was then determined to be the most likely category to match the pixel value. This series of functions was carried out for each pixel value entered into the classifier, and resulted in a column of text data stating the most likely wetness category for each entered band 5 pixel value. This Excel-based maximum likelihood classifier was then used to analyze playas using historical Landsat data, and precipitation data to monitor temporal variations in their moisture presence.

Prior to completing the final analysis, a confusion matrix table was completed based on the ground truth data and a band 5 classification of the ground truth study area (Table 5). This table was used to demonstrate the accuracy of the maximum likelihood classifier created with the ground truth data, against the actual recorded ground truth data (Lewis and Brown, 2001).

Analysis of Playa Wetland Functionality

After finishing the ground truth portion of the project, the maximum likelihood classifier created using the ground truth data was used to test the ability of the Landsat data to detect temporal differences in soil moisture presence in three playa wetland categories following heavy rainfall events. The period for monitoring of these playas was determined based on historical rainfall data acquired from the Weather Data Library of KSU's Agronomy Department. The three playa wetland categories were based on degrees of alteration and disturbance of the playa and the watersheds. These categories of alteration and disturbance were determined based on land cover and human induced modification of the wetlands, and their surrounding landscapes. Playas classified as 'Undisturbed' were located in uncultivated pasture areas with native grassland or CRP ground cover, without roads cut through the playa soil, or terracing surrounding the watershed of the playa. 'Altered' playas were located on tilled land, with terracing surrounding the wetland, and/or with a road cut through the playa soil. The third category called 'Disturbed', consisted of playa wetlands located on land that was cultivated, but had with roads cut through the playa's perimeter and no terracing surrounding the playa and its watershed. This process of selecting playas for these three categories was completed using the PLJV's Probable Playa GIS database layer, NAIP aerial photography, and a Kansas landcover GIS database acquired from the Data Access and Support Center website. After creating the maximum likelihood classifier, months of high rainfall in 2001 were randomly selected from the precipitation data for both Wichita and Scott Counties in Western Kansas. After selecting the months for analysis, all available archival Landsat TM/ETM+ data was downloaded for the area following the rainfall event from May of 2001 through October 2001, and playa wetlands from the three alteration/disturbance categories were selected in close proximity of each other within the county. Pixel values from within each of the selected playas were then extracted from each of the archival Landsat scenes using ENVI, and were entered into the maximum likelihood classifier in Excel to determine the most likely wetness category (Dry Dense, Dry Sparse, Mud Sparse and Water Sparse) for each pixel. Using the results from the classifier, tables were created to display the percentage of pixels in each wetness category within each of the three alteration/disturbance categories for all days the playas were observed. The amounts of moisture present within the three playa alteration categories were compared to the monthly rainfall totals to see if the playas with no disturbances or alterations were able to hold more water for a longer period of time in comparison to the altered and disturbed playas. This process was completed for a total of five times. The first three analyses were refered to as the small scale analyses (Figure, as they only consisted of a total of three playas, one per each alteration/disturbance category. The first two groups were located in Scott County, KS, and were monitored from May through October of 2001. The third set was located in Wichita County, KS and was monitored over the same period using the same Landsat data. Following the small scale analyses, a series of two large scale analyses were completed. It was decided that only selecting one playa for each category in each analysis (as in the small scale analysis) was too small of a sample size to pair with county wide, monthly average rainfall data. According to Russell and Garbrecht (2000), monthly precipitation in the Southern Great Plains of the US has such high spatial variability, it is not reliable to use for localized applications. Since the precipitation data was only readily available at the county level, the two mass analyses were carried out. In the two mass analyses, two rain events were analyzed with larger sample sizes, both again in Scott and Wichita Counties (Figure 5). A total of fifteen playas were selected for each of the three playa categories within the two counties, which gave a total sample size of forty five playas for each of the two mass analyses.

Figure 5: Scott and Wichita County Areas of Study. The final two mass analyses completed using the maximum likelihood classifier were completed within both Scott and Wichita Counties, in western Kansas.



Scott and Wichita County areas of study

Created By: Benjamin Grover
Date: 4-15-12
Date Sources: ESRI, DASC.

RESULTS AND CONCLUSIONS

Analysis of Landsat bands

In the two preliminary analyses of the ground truth data, there were observable changes in the study area's appearance as the soil moisture and water presence increased over the period of observation (Figures 3 and 4). The changes observed showed pixels transforming from lighter to dark colors as moisture and water presence increased in the wetland. This preliminary analysis indicates that at least one of the three infrared bands of Landsat used in these color composite images was detecting the changes in the soil moisture of Heron Playa upon being filled with water.

Figure 6. Landsat TM/ETM+ Infrared Bands 4, 5, and 7 Color Composite Images – Infrared bands assigned to colors Blue, Green, and Red respectively; showing the change in appearance of the study area throughout the ground truth period from August 15, 2011 through October 18, 2011. As moisture increased, pixels transformed from light to dark colored pixels.

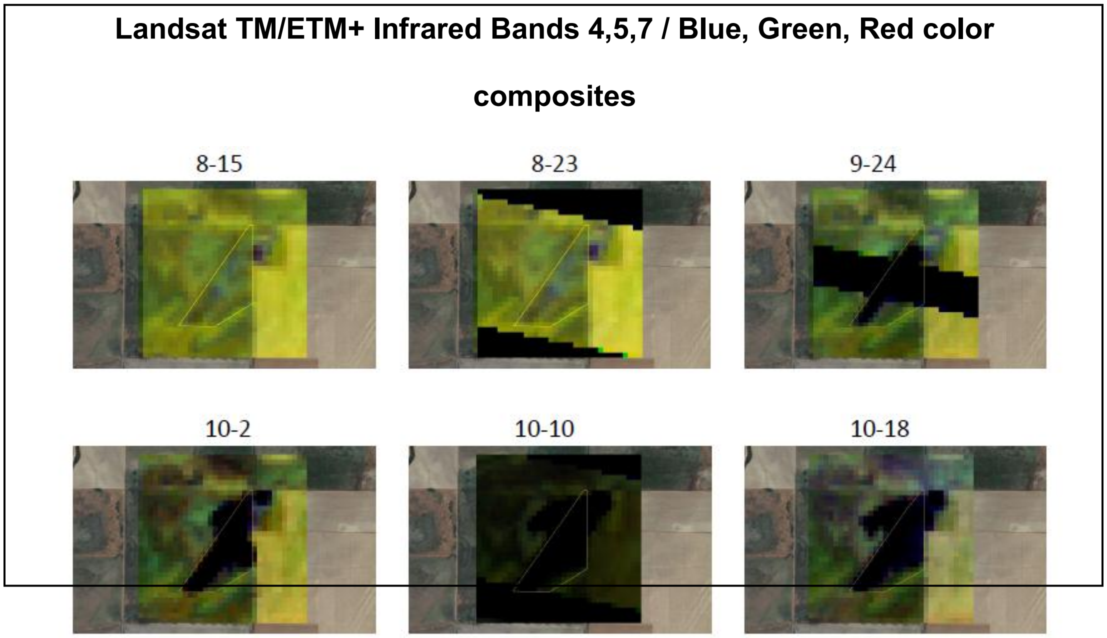
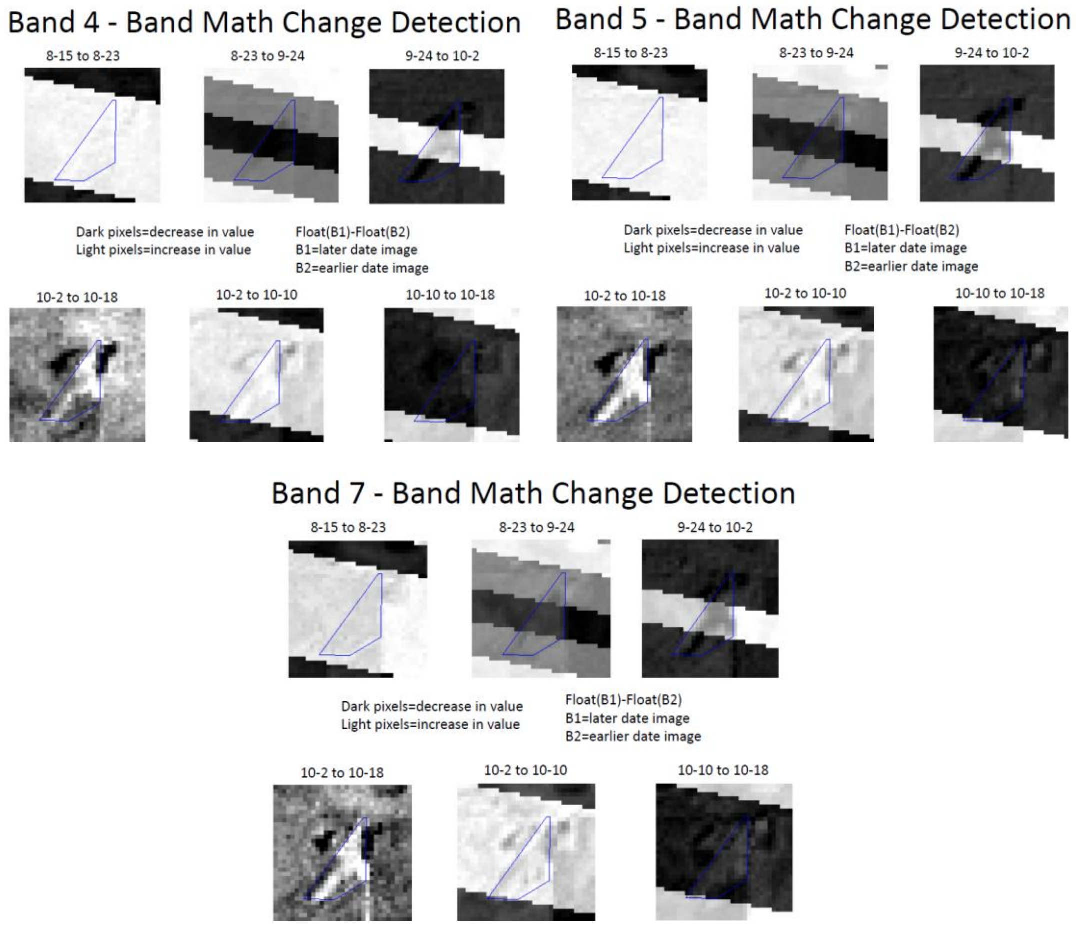


Figure 7: Change Detection For Bands 4, 5 and 7. Change detection images showed the darkening of pixel values as the soil moisture and water cover spread out within the study area from day to day starting in September.



Based on the data in the graphs of Figure 8 and Figure 9, band 5 was determined to have the best combination of both separation between wetness category means, and low temporal variability of each category’s mean; thus it was determined to be most suitable for distinguishing between wet and dry pixel values. Results from the Kruskall-Wallis test indicate that at least one of the four wetness categories sample of daily pixel means is from a statistically different population of values than the others (Test statistic: 10.61, degrees of freedom: 3, p-value: 0.014; Table 2). Following the Kruskall-Wallis test, a series of Wilcoxon Rank Sum tests was completed to compare each of the individual wetness categories (Table 3). Using the original alpha of .05, and the correction significance level of .0085, none of the individual comparisons showed a significant difference. By increasing my alpha value from .05 to .1 (a 90% Confidence Interval), and running the correction formula on this value, a significance level of .0174 was acquired for each individual comparison. When an alpha of 0.01 was used, the results showed that the Dry Dense and Water Sparse categories were significantly different from each other (Test statistic: 2.56, p-value: .011; Table 3).

Figure 8: Wetness Category Severability and Temporal Variation Graphs - Line graphs for each Landsat band display the variation and severability of the mean pixel values for each ground truth category across all six days.

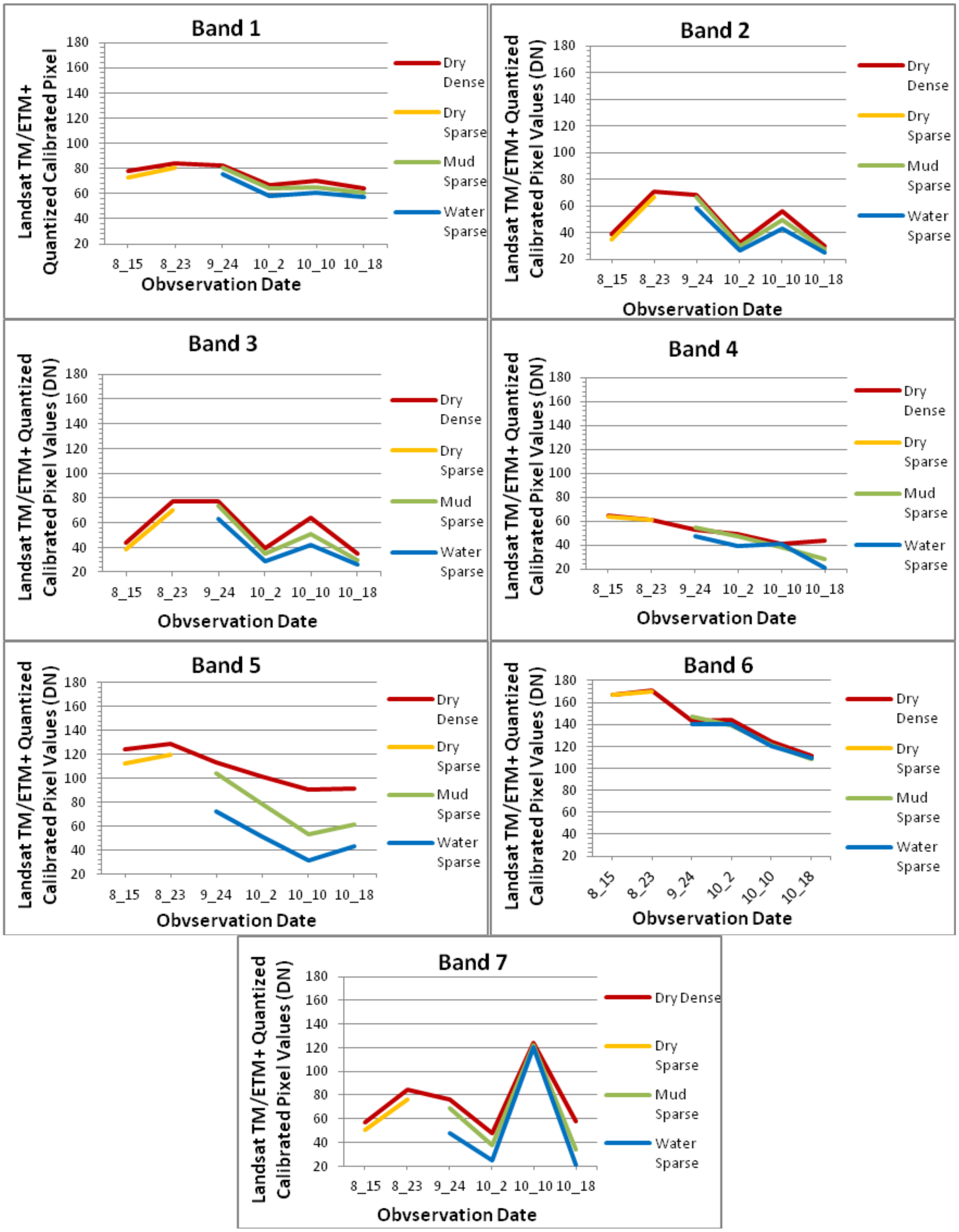


Table 1. Average Means and Average Standard Deviations of All Bands and Ground Truth Categories. The selected band (band 5) for the final analysis is highlighted in grey.

		Dry Dense		**Dry Sparse**		**Mud Sparse**		**Water Sparse**	
		Average Mean	**Average Standard Deviation**	**Average Mean**	**Average Standard Deviation**	**Average mean**	**Average Standard Deviation**	**Average mean**	**Average Standard Deviation**
Landsat TM/ETM+ Band	**B1**	74.18	1.92	76.73	1.46	67.70	3.24	62.72	1.71
	B2	49.31	1.39	50.55	1.34	43.31	2.45	38.20	1.50
	B3	56.30	2.06	54.16	1.95	47.13	3.33	40.00	2.18
	B4	52.05	1.68	62.33	2.56	42.19	2.11	37.21	2.21
	B5	108.42	6.06	116.16	3.34	74.49	9.41	49.71	7.78
	B6	143.55	1.44	168.37	0.64	129.06	1.83	127.66	1.53
	B7	74.63	4.06	63.55	2.71	65.62	6.88	53.43	4.52

Figure 9. Average Means and Average Standard Deviations for Each Wetness Category and Each Landsat Band.

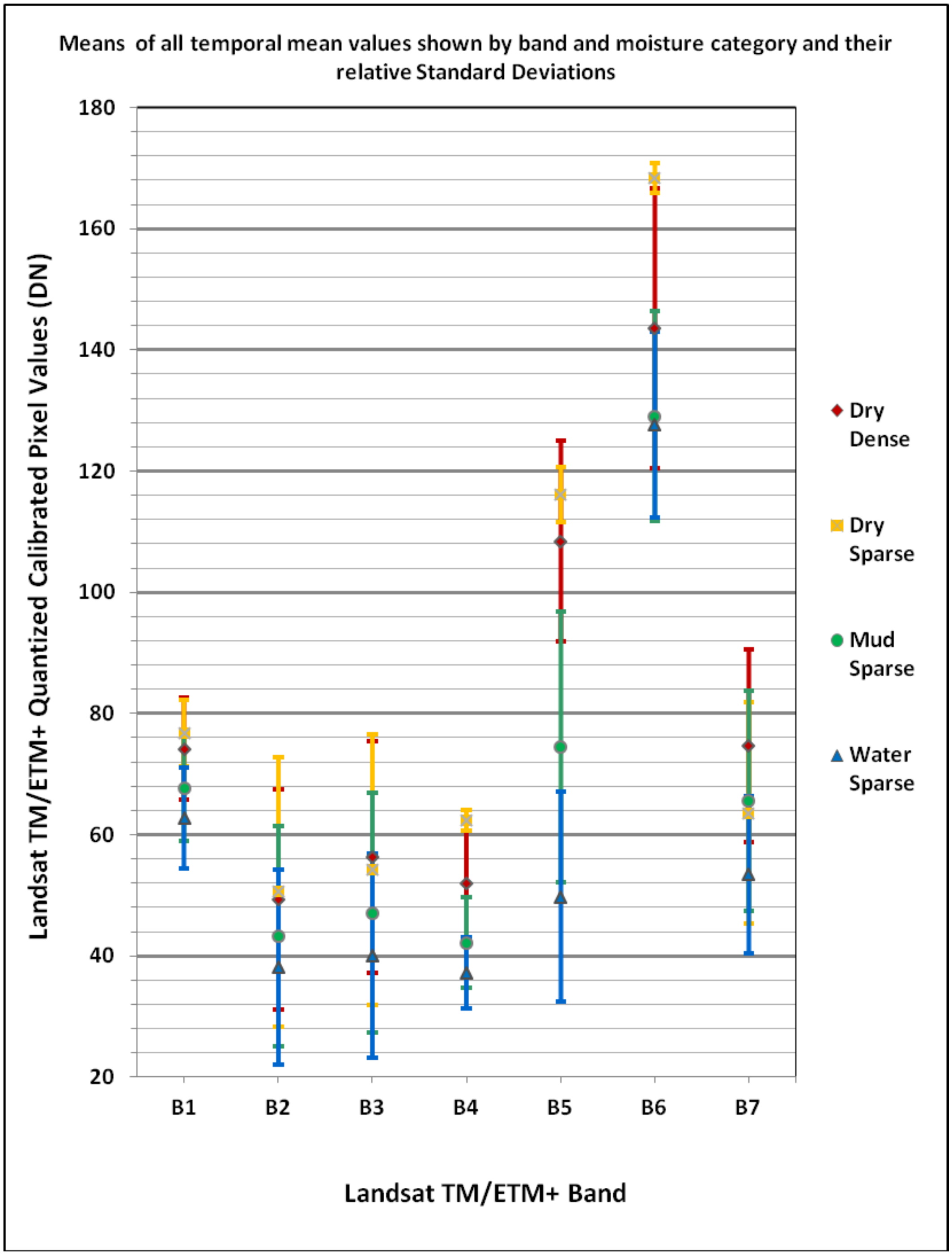


Table 2. Kruskall-Wallis Non-Parametric Test. Using only band 5 data, the mean ranks of pixel values from the four wetness categories are compared for difference, and the four samples of data are either determined to be from the same population of values, or to not all be drawn from the same population (McGrew and Monroe, 2000).

Kruskall-Wallis Non-Parametric Test

B5

	DD Rank	**Dry Dense**	**DS Rank**	**Dry Sparse**	**MS Rank**	**Mud Sparse**	**WS Rank**	**Water Sparse**
8_15	**15**	**125**	**12**	**113**	no data	no data	no data	no data
8_23	**16**	**129**	**14**	**119**	no data	no data	no data	no data
9_24	**13**	**114**	no data	no data	**11**	**104**	**6**	**72.4**
10_2	**10**	**102**	no data	no data	**7**	**78.6**	**3**	**51.7**
10_10	**9**	**90.3**	no data	no data	**4**	**53.6**	**1**	**31.2**
10_18	**8**	**91.2**	no data	no data	**5**	**61.5**	**2**	**43.5**
Rank Sums:	**71**	no data	**26**	no data	**27**	no data	**12**	no data
Mean Ranks	**11.8**	no data	**13**	no data	**6.75**	no data	**3**	no data

H=10.61	Null Hypothesis (Ho) = atleast one of the samples is from a different population
Chi^2=10.61	Alternative Hypothesis (Ha) = populations from which the 4 samples have been drawn are NOT all identical
df=4-1=3	
p=0.014	P < .05 - Meaning the null hypothesis (Ho) is rejected, and the alternative hypothesis (Ha) is accepted, so atleast one sample population out of the four is significantly different from the other sample populations

Table 3. Wilcoxon Rank Sum Tests. Compares each of the four ground truth category's daily means, to determine how statistically different each category is from the others using band 5 data.

Wilcoxon Rank Sum Tests		
Hypothesis	**Category Comparison**	**P-Value**
Ho: mean DD is equal to mean DS	Dry Dense and Dry Sparse:	0.74
Ho: mean DD is equal to mean MS	Dry Dense and Mud Sparse:	0.31
Ho: mean DD is equal to mean WS	Dry Dense and Water Sparse:	0.011
Ho: mean DS is equal to mean MS	Dry Sparse and Mud Sparse:	0.064
Ho: mean DS is equal to mean WS	Dry Sparse and Water Sparse:	0.064
Ho: mean MS is equal to mean WS	Mud Sparse and Water Sparse:	0.084
Ha: Sample1 is significantly different than Sample2	P < .0085 = Ha true, Ho false P > .0085 = Ho true, Ha false	Alpha .05 / 6 = .0085
Ho: Sample1 is **NOT** significantly different than Sample2	P < .0174 = Ha true, Ho false P > .0174 = Ha true, Ho false	Alpha .1 / 6 = .0174

After selecting band 5 for use in the analysis, the confusion matrix was created to compare the accuracy of the maximum likelihood classifier against the actual ground truth data collected from which it was created (Table 5). The numbers in the table showed that the overall accuracy of the classifier was about 68.6%. This level of accuracy was considered sufficient based on a study completed that also observed wetland differences using remote sensing. The study concluded that an agreement level of 65% or better between ground truth data and classifier/image interpretation constitutes that the validation by interpretation approach is reliable (Grenier et al., 2007). Through further interpretation of the confusion matrix table, it was hypothesized that the lower accuracies observed in the Mud Sparse categories were due to the different vegetation covers either hiding the actual wet ground cover, or increasing moisture response from high moisture content in the vegetation.

Table 4. Computer Assigned Category Thresholds. Thresholds were determined by adding and subtracting the standard deviation of each wetness category from the respective categories mean value to determine a minimum and maximum value for each ground truth category.

Computer Assigned Category Thresholds			
Dry Dense	**Dry Sparse**	**Mud Sparse**	**Water Sparse**
108+/-16.6	**116+/-4.59**	**74.5+/-22.4**	**49.7 +/- 17.3**
Min: 91.9	**Min: 112**	**Min: 52.1**	**Min: 32.4**
Max: 125	**Max: 121**	**Max: 96.9**	**Max: 67.0**

Table 5. Confusion Matrix Table of Computer Assigned Maximum Likelihood Cover Types. Tests the maximum likelihood classifier created using the ground truth data against its own ground truth data (Lewis and Brown, 2001).

		Computer Assigned Maximum Likelihood Cover Types					
		Dry Sparse	**Dry Dense**	**Mud Sparse**	**Water Sparse**	**Total**	**Producer Accuracy**
Actual Ground Truth Cover Types	**Dry Sparse**	15	29	0	0	44	65.9%
	Dry Dense	4	99	28	0	131	75.6%
	Mud Sparse	2	11	58	30	101	57.4%
	Water Sparse	0	0	18	74	92	80.4%
	Total	21	139	104	104	**Overall Accuracy: 68.6%**	
	User Accuracy	71.4%	71.2%	55.8%	71.2%		

Small scale analysis of playa wetlands

After comparing the three small scale sets of playas with their respective rain events, there were no visible relationships, patterns or consistencies observed (Figure 10, Figure 11, Figure 12). There was only one occurrence out of the three analyses in which the undisturbed playa held more water than the altered and disturbed playa categories following a high rainfall month as hypothesized. This occurrence was in Scott County Set 2, on dates 5/6 and 8/26 of 2001 (Figure 11). In the small scale analyses, there were too many inconsistencies between the monthly rainfall data and moisture coverage of the playa samples to make a definitive observation of whether it was possible to determine hydrological functionality of playas based on temporal soil moisture and water presence.

Figure 10: Scott County Analysis Set 1, soil moisture percentages present in all three playa categories (Altered, Disturbed, and Undisturbed), compared to the corresponding monthly rainfall data.

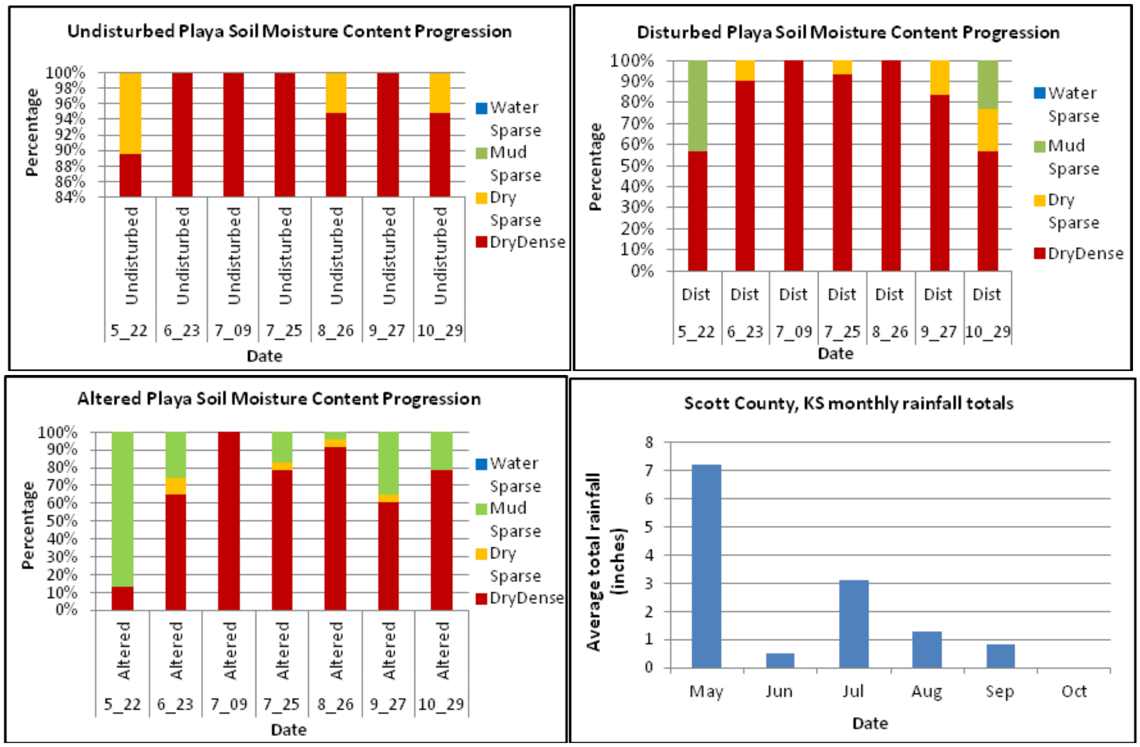


Figure 11: Scott County Analysis Set 2, soil moisture percentages present in all three playa categories (Altered, Disturbed, and Undisturbed), compared to the corresponding monthly rainfall data.

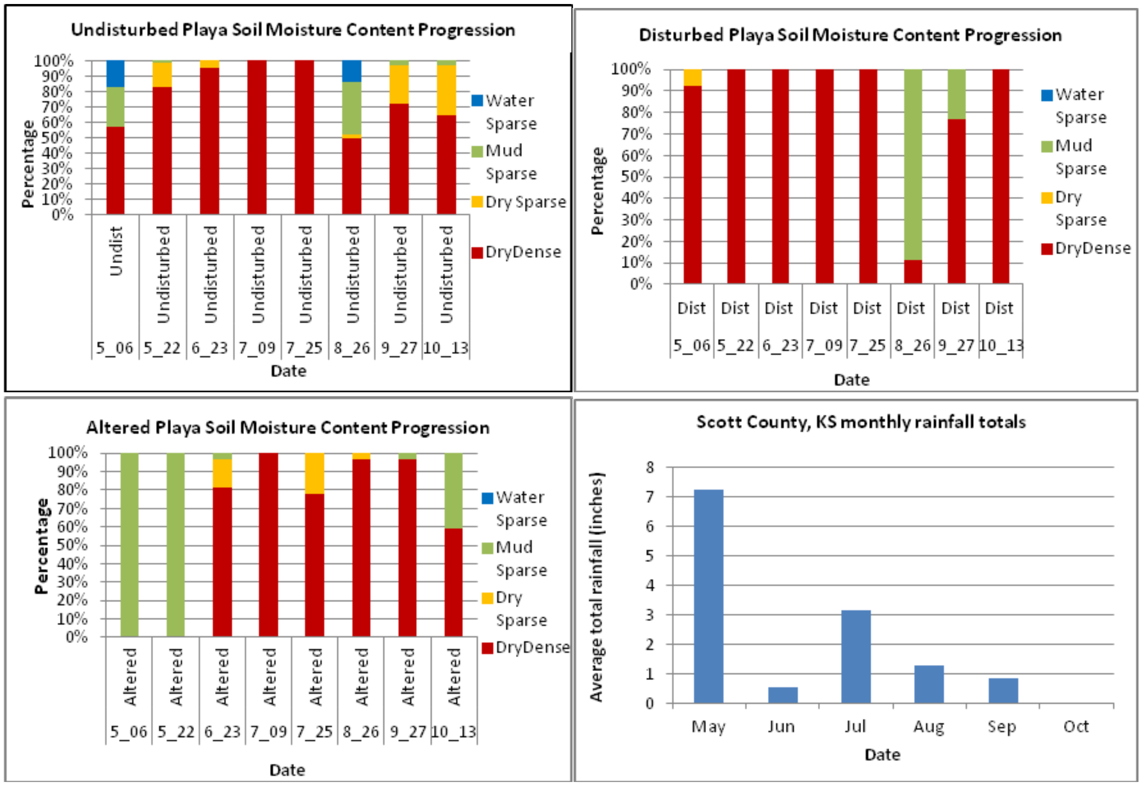
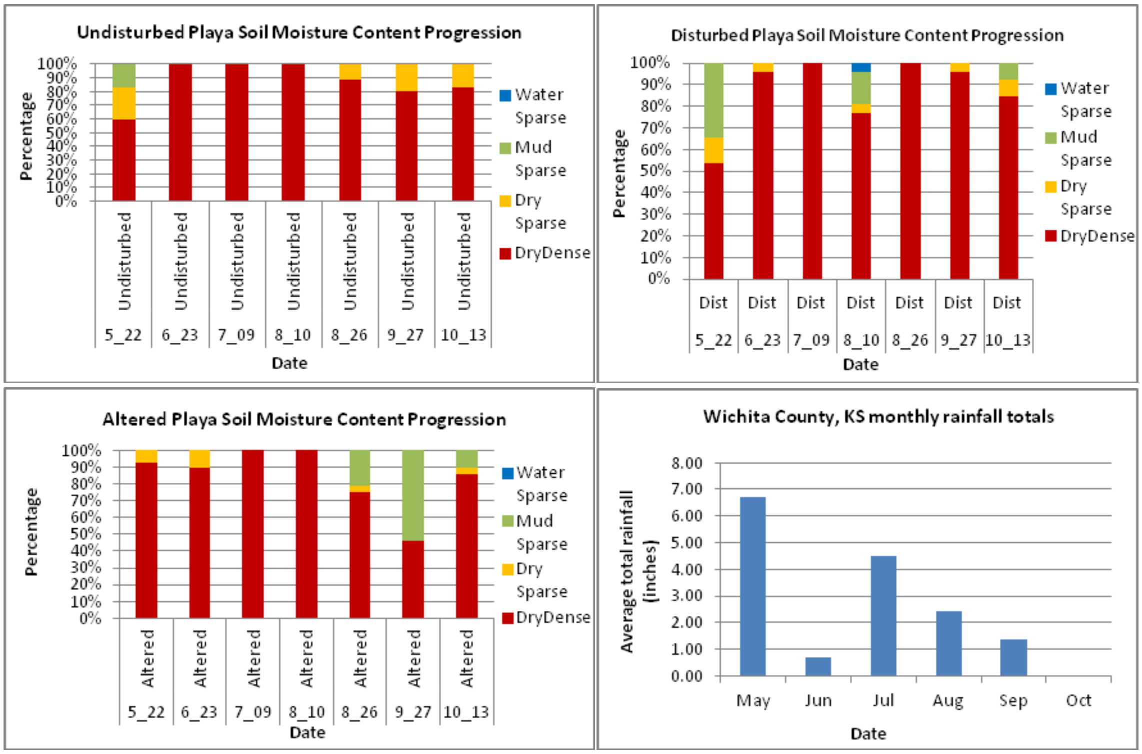


Figure 12: Wichita County Analysis Set 1, soil moisture percentages present in all three playa categories (Altered, Disturbed, and Undisturbed), compared to the corresponding monthly rainfall data.



Undisturbed Playa Soil Moisture Content Progression

Disturbed Playa Soil Moisture Content Progression

Altered Playa Soil Moisture Content Progression

Wichita County, KS monthly rainfall totals

Large scale analysis of playa wetlands

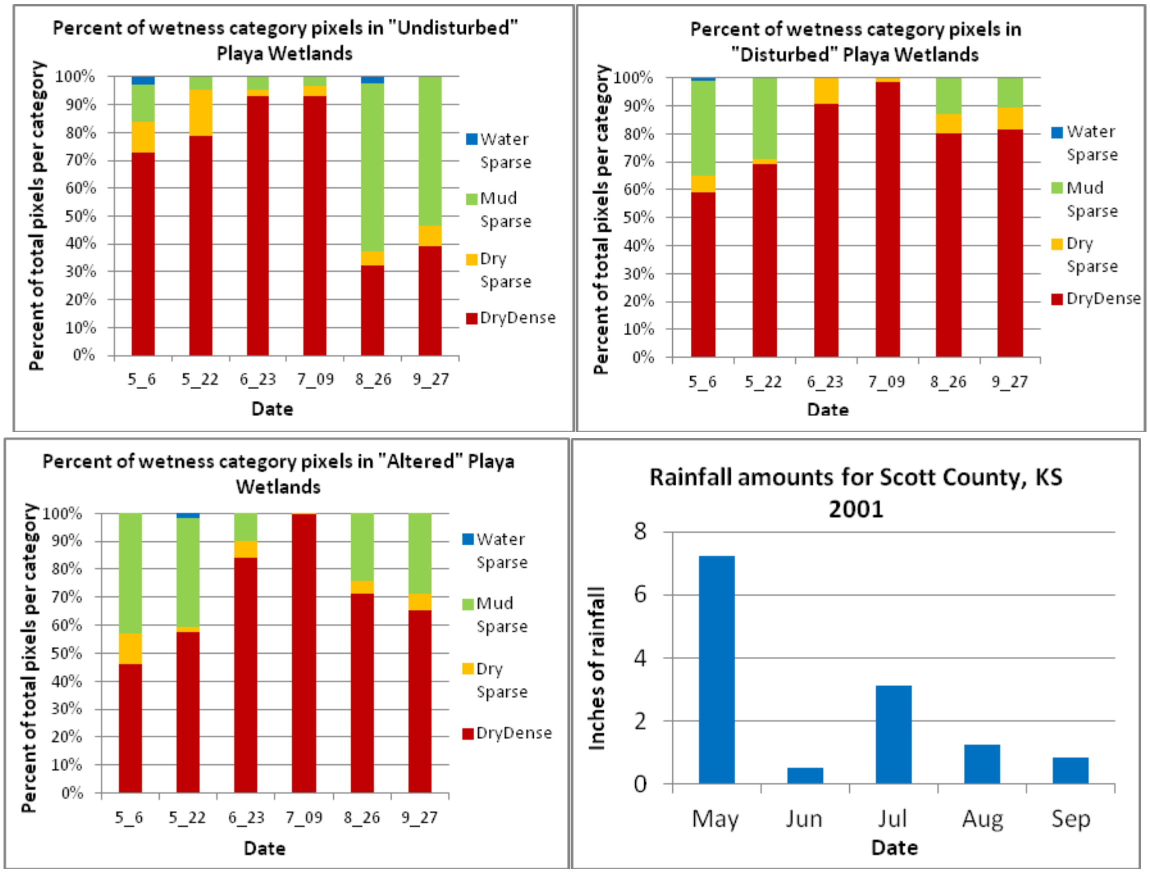
After the analysis of the graphs and tables created for the mass analyses of playas within both Scott County (Table 6 and Figure 13) and Wichita County (Table 7 and Figure 14), there was a noticeable consistency with the data across all three playa categories in relation to the precipitation data. Based on the percentages of the pixels per wetness category shown in the tables and graphs, it was observed that following the first heavy rainfall event in both the analyses, the undisturbed playas did not retain as much water and moisture as the other two disturbed and altered categories. For both analyses, the corresponding rainfall data showed two significant rainfall events in both sets.

Following the first large rainfall event, and prior to the second, the undisturbed playas consisted of an average of 95% Dry category pixels, while the altered and disturbed playas held an average of only 80% Dry category pixels. Following the second large rainfall month in July, the undisturbed playa categories in both mass analysis sets had a larger number of water pixels held than those in the altered and disturbed categories. After the second rain event in July, the undisturbed playas consisted of an average of 53% water and mud pixels, while the altered and disturbed playas only held an average of 24% water and mud pixels.

Table 6: Wichita County Mass Playa Analysis: Percentage of Pixels per Category - Table shows the written percentages of pixels from each wetness category for all three playa alteration/disturbance categories for the Scott County mass analyses.

	Scott County mass playa analysis: Percentage of pixels per category					
	Undist					
	5_6	5_22	6_23	7_09	8_26	9_27
DryDense	73%	79%	93%	93%	32%	39%
Dry Sparse	11%	17%	2%	4%	5%	8%
Mud Sparse	14%	5%	5%	3%	61%	53%
Water Sparse	3%	0%	0%	0%	2%	0%
	Disturbed					
	5_6	5_22	6_23	7_09	8_26	9_27
DryDense	59%	69%	91%	99%	80%	82%
Dry Sparse	6%	2%	9%	1%	7%	8%
Mud Sparse	34%	29%	0%	0%	13%	10%
Water Sparse	1%	0%	0%	0%	0%	0%
	Altered					
	5_6	5_22	6_23	7_09	8_26	9_27
DryDense	46%	57%	84%	100%	71%	65%
Dry Sparse	11%	2%	6%	0%	4%	6%
Mud Sparse	43%	39%	10%	0%	24%	29%
Water Sparse	0%	2%	0%	0%	0%	0%
	May		**Jun**	**Jul**	**Aug**	**Sep**
Rainfall (in.)	7.22		0.52	3.12	1.26	0.83

Figure 13: Scott County Mass Analysis. Soil moisture percentages present in all three playa categories (Altered, Disturbed, and Undisturbed), compared to the corresponding monthly rainfall data.



Percent of wetness category pixels in "Undisturbed" Playa Wetlands

Percent of wetness category pixels in "Disturbed" Playa Wetlands

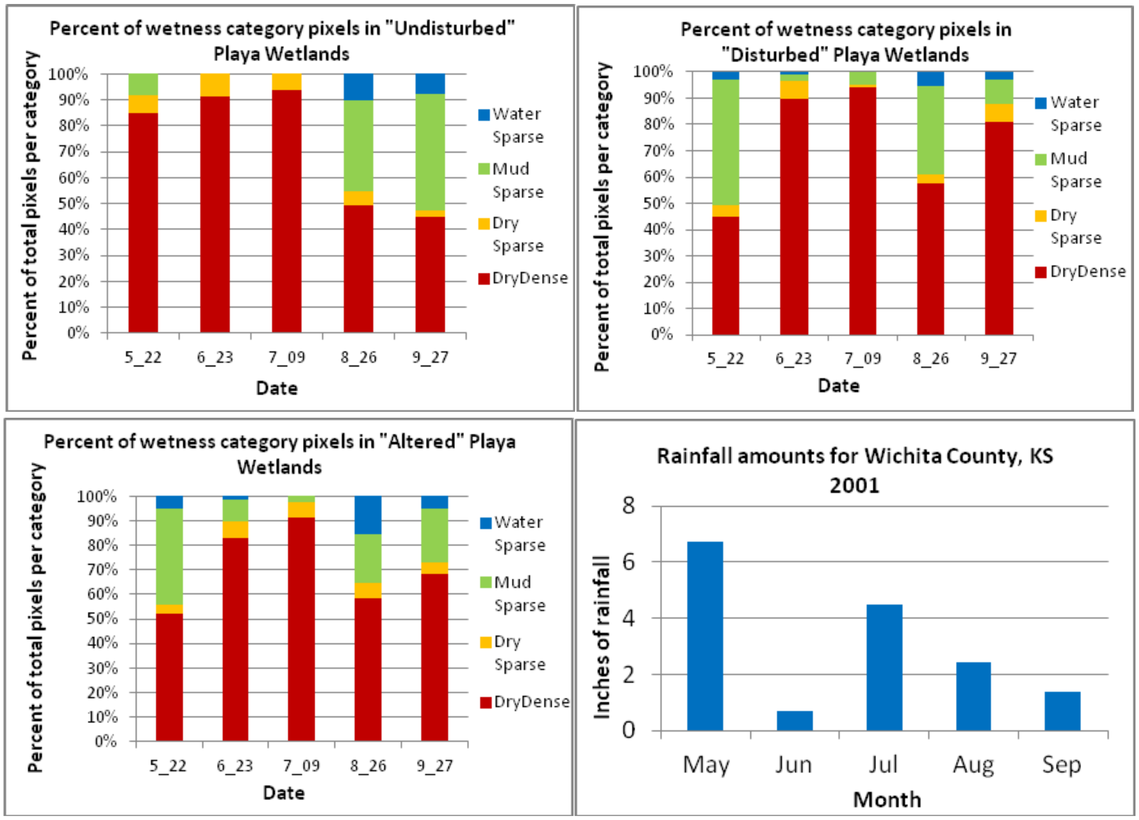
Percent of wetness category pixels in "Altered" Playa Wetlands

Rainfall amounts for Scott County, KS 2001

Table 7: Scott County Mass Playa Analysis: Percentage of Pixels per Category - Table shows the written percentages of pixels from each wetness category for all three playa alteration/disturbance categories for the Wichita County mass analyses.

	Wichita County mass playa analysis: Percentage of pixels per category				
	Undisturbed				
	5_22	**6_23**	**7_09**	**8_26**	**9_27**
DryDense	84.9%	91.1%	93.8%	49.3%	44.9%
Dry Sparse	6.7%	8.9%	6.2%	5.3%	2.7%
Mud Sparse	8.4%	0.0%	0.0%	35.1%	44.4%
Water Sparse	0.0%	0.0%	0.0%	10.2%	8.0%
	Disturbed				
	5_22	**6_23**	**7_09**	**8_26**	**9_27**
DryDense	44.7%	89.7%	94.3%	57.4%	80.9%
Dry Sparse	4.6%	6.7%	0.7%	3.5%	6.7%
Mud Sparse	47.9%	2.5%	5.0%	33.7%	9.6%
Water Sparse	2.8%	1.1%	0.0%	5.3%	2.8%
	Altered				
	5_22	**6_23**	**7_09**	**8_26**	**9_27**
DryDense	52.0%	83.0%	91.3%	58.5%	68.1%
Dry Sparse	3.9%	6.6%	6.1%	6.1%	4.8%
Mud Sparse	38.9%	9.2%	2.6%	20.1%	22.3%
Water Sparse	5.2%	1.3%	0.0%	15.3%	4.8%
	May	**Jun**	**Jul**	**Aug**	**Sep**
Rainfall (in.)	6.73	0.71	4.48	2.43	1.37

Figure 14: Wichita County Mass Analysis. Soil moisture percentages present in all three playa categories (Altered, Disturbed, and Undisturbed), compared to the corresponding monthly rainfall data.



DISCUSSION

After observation of the results for the mass analyses of playas in Wichita and Scott Counties, a consistent pattern was observed between the two sets that seemed to demonstrate a characteristic known of playa wetlands and their clay layer. To summarize the results of the final analyses, it was determined that by using large enough sample sizes of playa wetlands, covering a large enough area within the county being studied and paired with accurate precipitation data, undisturbed playa wetlands beginning with dry and cracked clay bottoms do not accumulate as much water following a first rainfall as altered and disturbed playas. But, on occasions when a second significant rainfall follows a first, the undisturbed playas held a significantly larger percentage of mud and water than the altered and disturbed playas. Playa wetlands in natural settings possess a clayey floor, which swells when wet, and shrinks and cracks when it is dry. This characteristic allows first rainfalls following a dry season to infiltrate and percolate through this clay layer (Luo et al., 1997). The cracks, being as wide as five inches and several feet deep as observed during the ground truth session of this study, can allow much of the first fallen rain and run-off to percolate through the clay layer and into the ground to the water table (EPA, 2009), not allowing much water accumulation on the playa's surface until after these clay layers have been exposed to enough moisture to become swollen to sealed these cracks and become impermeable (EPA, 2009). In observation of the two mass analyses, this characteristic was present in both the Scott and Wichita County playa sets. The analyses corresponding rainfall data showed two significant rainfall events in both sets. Following the first rainfall event, and prior to the second, the undisturbed playas accumulated a lower average percentage of Mud and Water pixels than the altered and disturbed playas. This was hypothesized to be due to the undisturbed playa's intact, but dry and cracked clay floors allowing this first rain event to percolate through the surface quickly. Following the second heavy rainfall events in July, the undisturbed playas held a much higher average percentage of mud and water over the two days following than the altered and disturbed playas; which is also hypothesized to be due to the clay layers, except after having become saturated and expanded from the first rainfall event, they allow much more accumulation of moisture and water on the surface. Based on these observations and using this technique and process, it is considered possible to detect and differentiate between functioning and non-functioning playa wetlands based on temporal presence of soil moisture and water content by using Landsat TM/ETM+ band 5 infrared data.

The first sets of the final analyses consisting of the small localized sample sizes did not correspond well with the county wide average precipitation data. This was hypothesized to be due to the spatial variability of monthly rainfall in the Southern Great Plains. In the Southern Great Plains region, monthly precipitation data varies too much spatially to be relied on for local applications or analyses (Russell and Garbrecht, 2000). For this reason, the second set of final analyses consisted of the total of 45 playas within each county, to cover a larger area of the county, and provide a better representation of playas to be compared to the county level precipitation data.

It is therefore concluded that with proper precipitation data for the area, and under the proper circumstances (that being dry conditions prior to the first observed rainfall event, and two different and significant rainfall events within the analysis period) this process is a significant step towards remotely detecting hydrological functionality of playa wetlands. The process being completed with free Landsat satellite data, Kansas landcover GIS data, probable playa GIS data, and county level precipitation data makes it possible for anyone properly educated with a GIS and remote sensing degree, and any cost budget to utilize the method. It could be most useful to conservationists looking for possible locations for placement of habitat easements or habitat restoration projects. Aside from randomly selecting and visiting the playas themselves, many biologists or habitat and wildlife conservationists have no other means of selecting these more potentially restorable wetlands. The management and restoration of these playa wetlands has become a higher priority of both wildlife, and ground water focused environmental groups in the last thirty years. Groups such as the Playa Lakes Joint Venture, and United States Department of Agriculture are currently active in preserving privately owned playa wetlands and offer various programs promoting the conservation and restoration of the playas (Smith et al., 2011). Programs such as the Wetlands Reserve Program (WRP) and the Conservation Reserve Program (CRP) promote the restoration of wetlands by seeding the areas back to grassland, and in the case of the WRP, sediment removal is even allowed to help with the restoration of wetland hydrology (Smith et al., 2011). The restoration of these wetlands to their original native condition is beneficial to both our future water supply, and future wildlife populations, particularly waterfowl; and likely will continue to be considered an important issue in the future.

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