LAND USE/ LAND COVER CHANGE DETECTION AND ANALYSIS

OF THE UPPER GUADALUPE RIVER, CENTRAL TEXAS

by

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TABLE OF CONTENTS

List of Figures:

List of Tables:

ABSTRACT

The study was conducted to detect the land use/ cover changes in the upper Guadalupe River basin, located in central Texas over an analysis period from 1987 to 2017. Surface water bodies, vegetation, urban areas and agricultural land forms were studied for the change detection. Satellite images obtained from the USGS website, were processed and classified using ERDAS Imagine software. Based on the classified images, changes were detected for 10-year intervals. Results showed a clear decline in water bodies and most riparian vegetation due to rapid urbanization and the expansion of agricultural lands; however, the changes were mostly contributed by the growth of structural developments, causing loss of 14% of the total studied water bodies. These changes could be attributed to population increase, influences of larger nearby cities and the availability of water for drinking and irrigation. While water and urbanization showed graduality in their change, vegetation and agriculture changes were very rapid. Improved management relative to land use/ land cover changes may reduce their impacts on riparian corridors and water resources. However, before generalizing solutions to the problem, further research would need to be done to identify direct impacts from the results of this study.

CHAPTER ONE

Background:

Landcover generally refers to the biophysical material on the earth's surface such as forest, grasslands, water bodies while land use usually refers to the land with human intervention in it to an extent where it changes the previous condition of the land to a different form such as urban and industrialized areas, parks, roads etc. (Siewe 2007).

Land is considered as one of the most powerful resources but human actions are altering the terrestrial environment at an unprecedented rate and spatial scales (Turner, Meyer, and Skole. 1994). Global land use/ cover changes are the impacts of small scale regional or local changes. Due to insufficient and inadequate researches, it has become really important to distinguish the underlying factors of this effect. Land use/ cover change detection indicates this altercation of lands from different times and help to understand the rate of change at present and predict for the future.

Change detection using remote sensing techniques is a widely accepted method of monitoring the earth's well-being (Van Oort 2007). The concept is to identify the change in pixel values from two or more different times and assign the new value to the designated land form. Like mentioned above, it is of great importance to know such changes and how they contribute globally (Morawits et al. 2006), through monitoring the biophysical and anthropogenic features on the ground (Turner, Meyer and Skole. 1994).

The use of remote sensing techniques for change detection is increasing because of improved data quality, less time consuming for land cover/ use classification and ease of mapping land cover/ use features. This analysis takes into consideration the spatial, spectral, temporal, and radiometric resolutions of the images which enhances the accuracy of classification thus the results. It also enables the user to focus easily on the details that need to be studied.

Problem Statement:

The population of central Texas is growing rapidly. This increasing population is triggering other forms of growth in the form of structural developments including urbanization, industrialization, and transportation networks etc. The upper Guadalupe River Basin area is experiencing effects of the growth in recent years. It is evident from observations made from the historical images from Google Earth that vast portions of the area are currently converting from one type of land cover to another based on their usage, for example once forested land is now a fully developed urban area or agricultural land. The rapid population growth and land use conversions are putting pressure on the water resources as well, showing a decrease in the water bodies for the study area.

To understand the impacts of population growth and land use/ cover changes, it is very important to identify where the changes are most prevalent and what types of land use/ cover changes are occurring. This research will provide an insight into the land cover changes caused by the rapid growth and its impacts on the quantity of water bodies and riparian vegetated areas which will enable planners to come up with feasible solutions to negative impacts.

Objectives of the Study:

As many of the changes have been observed quite recently, the time- period is very important for change analysis. The study will focus on the land use/ cover changes occurring from 1987 to 2017, dividing it into 3 temporal divisions with 10-years intervals (1987- 1997, 1997- 2007, 2007- 2017) within the following three counties: Kerr, Kendal, and Comal which covers about 98% of the study area (upper Guadalupe River Basin). This temporal framework will make it easier to understand how changes are occurring before and after a specific year of observation, with the same time interval. Also, this will allow observations and inferences to the reasons for the land use/ land cover changes.

In general, the objectives of the research are to analyze, detect, and prepare maps of land use/ cover changes within the study area for the last 30 years and provide guidance to planners to come up with possible solutions of the negative impacts on water and riparian vegetation in future. In doing so, this study aims to narrow down the changes into 4 specific categories (water, agriculture, built-up/ urban and forest/ vegetation) that will explain the most occurring transitions. This change/ comparison will be shown in percentage and per hectare change.

Study Area:

The Guadalupe River is one of the most important spring- fed rivers of Texas. It is considered an asset to the state because of its natural beauty which attracts many tourists every year. While it serves as a recreational site for local to international visitors and is a primary water resource supply for the people living here, a strong management system is required by the Upper Guadalupe River Authority (UGRA). But due to recent rapid growth within this area, the natural setting is experiencing changes. This increasing population and agricultural lands are also likely affecting other factors of water withdrawal, intensive use of lands, and many more.

The study area covers about 37,09,538 sq. meters starting from the Canyon Lake to the very upstream end of the North Fork Guadalupe River which is situated in the Kerr county. More than ten thousand smaller tributary streams drain the area making it into a complex river system. Each stream based on its elevation, length and connectivity represents a unique environment. These characteristics also create a situation suitability for agricultural expansion because of the fertile soil and easy access to water for irrigation. This portion of the river is divided into thirtysix sub-watersheds (Figure 1). As mentioned earlier, major portions of the study area fall within three counties: Kerr, Kendall, and Comal. Small portions of it also fall within Blanco, Bandera and Gillespie Counties. Almost half of the sub-watersheds fall within Kerr County.

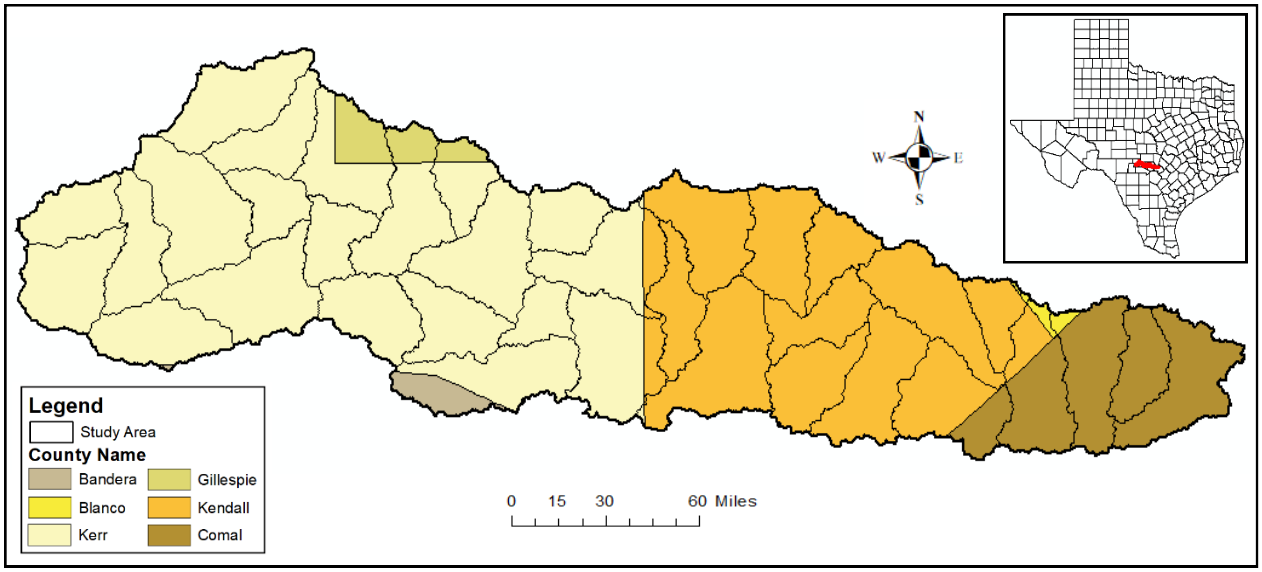


Figure 1: Counties and sub-watersheds within the study area (Upper Guadalupe River Basin)

Observations from the recent historical images on Google Earth, show that most of the developments (highways, urban areas) have occurred around the water resources. Specifically, significant clusters are evident around the Canyon Lake, Kerrville Ponding Lake, Lake Old Ingram and Lake New Ingram. Also, some can be seen surrounding the Center Point Lake. Another reason for the development around the Canyon Lake is assumed to be the influence of other major cities like San Antonio, New Braunfels, San Marcos which are situated very close to it.

Most of the land covers in the north-eastern part of the study area show forest or riparian vegetation. According to the Google Earth and satellite images observed, most of these areas are in Bandera and Real Counties. And that is why these two counties represent a very dense and riparian vegetation type. There are also some patches of barren lands found in some places and they are quite large in extent. Much of the agricultural lands are situated in the eastern, central and northern parts of the study area basically around streams because of the availability of water from the river for irrigation. In general, this area has been chosen for this study because of the very well visibility of rapid land use/ cover changes. Also this study area could be one of the best examples to study the negative impacts on the quantity of water bodies and riparian vegetation due to the increase of urban and agricultural lands. These are the reasons for selecting it as the study area and land use categories to detect the changes.

CHAPTER TWO

Literature Review:

This section of the paper is divided into two bodies of literature based on the problem statement of the research. The first body will focus on discussing potential reasons and rates of human induced developments (roads, buildings, agricultural lands etc.) in land use/ cover change in Texas as reported in previous studies. The second body of literature will describe the current and future negative impacts of these developments on water resources. Water issues will be covered in both bodies of literatures to explain how its decline in quantity can trigger other forms of land transitions. The final section of this chapter will focus on the physical degradation of the upper Guadalupe River basin.

Agricultural Activities and Structural Developments behind Land Use/ Cover Change in Texas

Land use and cover are usually concerned about the type and quantification of land transitions. Some common land transitions are from water to urban, forest to urban, water to agriculture, forest to agriculture etc. The major difference between these land cover types is some are natural and some are human induced which are considered to have a negative impact on the natural ones. For example: water and forest are taken as natural land covers while agriculture and urban areas are human made. Debate may occur as water and vegetation can be both natural and artificial, which makes it quite difficult to differentiate which one will have negative or positive impacts. In this research, the major concern is to quantify the increase and/or decrease of the different land uses and land covers and to uncover the underlying reasons for these changes with the hope that this understanding will lead to solutions for effective management of resources in future.

Land is considered as one of the most valuable resources to man especially when occupied by water and vegetation covers. Overpopulation is one of the problems that people all over the world are fighting to overcome with. The increasing number of people need lands to inhabit and so different landforms are being transformed and developed into urban centers. Alig, Kline, and Lichtenstein 2004 report that there was 34% increase in the developed areas in the United States during 1982- 1997, the southern region being the largest development center. These developments are predominantly replacing agricultural and forested lands. A study mentioned that the area of forest cover replaced by urban areas in the United States between the years 2001 and 2006 shows a clear regression on the size and density of forest (Clement, Chi, and Ho 2015). In fact according to LaGro and DeGloria, most of these urban lands come from the removal of forest lands (LaGro and DeGloria, 1992).

In this study area, Kerr, Kendall and Comal Counties are experiencing urbanization, mostly Comal County (observed from Google Earth). Kerr County has experienced expansion of urban areas and could be considered as the most developed amongst the three counties, 60% of its people live in the urban areas and the number is increasing (Texas Association of Counties). Kendall County is the least developed in terms of structures but advanced in agricultural production as most of its population lives in rural areas (Texas Association of Counties). Socio-economic drivers like education, and occupational opportunities may be behind the human impacts in these counties.

A land use/ cover change study analyzed the relationship between the land use change factors and developments of highways in Austin, Texas from 1978- 2008 (Huang 2010) which can support the reasons of urban expansion. The author in this study used historical data on the transportation developments that have been overlayed with Landsat land classification. It helped in identifying the impacts of transportation accessibility and neighborhoods on the likelihood of land use/ cover changes. But one thing it did not consider is the influence of nearby developed cities which can be the case for Comal County. It is situated quite close to San Marcos, New Braunfels and Austin. Besides, fast growing population and their average density, job opportunities, urban employment are some of the factors associated with the county level of urbanization (Goldsmith, 1990). It would be useful to observe similar factors within the study area to come up with potential factors.

The natural land covers are affected the most in the development of urban areas. Structural simplification of vegetation has negative impacts in many areas (McKinney 2008). Landscaping and maintenance of residential and commercial areas typically involve removal of shrubs and increase in grasses (Marzluff and Ewing 2001) which hinders the growth of vegetation. Timber harvesting can be considered as one of this densely vegetated area. Though harvested for commercial purpose but these trees can protect the land from floods or soil loosening most of the time of a year. The rate of harvesting has decreased upto 19% with urban expansions in the south central United States till 2000 (Munn et al. 2001). Urban expansion regimes can alter the plant productivities. This might happen because sometimes the forest management restrictions are applied beyond the developed areas.

Another land use/ cover change analysis in Texas studied the Maverick County urban developments from 1992- 2001 and showed an increase in urbanization while decrease in agricultural lands (Muhlestein 2008). The temporal observation of this literature is only 10 years for land use change which was effective for Maverick County but not necessarily that might be the case for other counties like Kendall. As the study area includes three counties, a dynamicity is expected to show in results. For example: The Mission-Aransas coastal region in Texas showed about one- fourth change in land use from 1990 to 2010, the increase of built environment was 71% while it was 75% along the coast (Guneralp et al. 2013).

The agricultural croplands are playing a vital role in decreasing forested areas. Several case studies between the time-frame in 1980-2005 show that, croplands were abandoned for forest regrowth in the eastern part of United States while the opposite occurred in the west, which created a balance for the central region to stay stable in 1909-2002 (Ramankutty, Heller, and Rhemtulla 2010). The abandonment might have worked for some regions like eastern Texas where there was a clear regression in forest upto 1980 but recovered in 1990 (Hung 2004). Another study on land use/ cover change detection in San Antonio, Texas shows that during 1985- 2003 almost 3% of the forested areas have converted into active croplands and another 9% into fallow lands (Owojori 2005). The expansion of croplands in Texas in 1997 is almost 145 per 1000 km^2 which is one of the extreme cases where agriculture expanded upto 20 adjacent counties (Waisanen and Bliss 2002). While water bodies and forests are being replaced by agriculture and urban lands, the urban areas are advancing in this competition in some regions, evidenced in the second body of literature. According to the future projection the urban expansion will be the cause for loosing almost 2.5% cropland by 2030 (Bren 2016).

Other than forest cover, water resources in Texas are also experiencing major decline. In fact, these resources play the major role in protecting forest cover by maintaining a suitable environment. So any disturbances in water resources affect other forms of land uses/ covers. These disturbances might be caused by artificial developments like buildings, roads, agricultural lands etc. Over the last century in southern United States, only 18% of the total population lived in urban regions in 1900 which increased upto 72% in 2000 (U.S. Census). This increase indicates that more lands were needed to provide habitats for the rapidly increasing population and will continue to do that in future. These urban areas are mostly built along rivers because of its capacity to provide drinking water and transportation (Grischek et al. 2002). Studies are evident of the fact that this urbanization process has affected the river hydrology in many ways e.g. decline in the channelization of the headwater streams, loss of wetlands etc. (O'Driscoll et al. 2010). Other forms of structural developments like dams play their role in changing river hydrology. With the construction of dams, the connectivity networks between stream channels are restricted and therefore hinders the natural flow of the whole river basin. This hindrance furthers triggers the decreasing supply of necessary sediments which helps in growing vegetation near water resources.

The agricultural lands use both surface and groundwater for irrigation. The Houston Chronicle Article mentioned in 2012, that Texas should limit their agricultural water use (Wagner 2012). The main reason for developing croplands along river systems is due to the easy accessibility to water. After the highest peak of usage in 1975, it is again picking the height since 2005 approximately 10000000 ac-ft (Texas Water Development Board Report 347 & Irrigation Water Use Estimates). Typically 12% of the irrigated lands use surface water resources and 2% uses both surface and groundwater (Texas Water Development Board Report 347). When lands are plowed strongly, sometimes heavy rainfall transports the loose soils into the water bodies and creates unnecessary sedimentation (Bradbury and Van Metre 1997). Initial observations made from the google earth images within the study area also indicates several areas being sedimented and loosing their connectivity for freshwater flow. Situations and impacts of carrying sediments into the river system are discussed in the second body of literature.

Impacts of Agricultural Activities and Structural Developments on Water Resources in Texas

"It is widely recognized that water and forest are intricately linked"- (Nagy et al. 2011). The replacement of forest covers by agriculture and urban development poses challenges for better water management because the impacts of land use/ cover change on water is broad and complicated. The transformation of land by anthropogonic activities can alter the quantity and quality of water resources and lead to severe degradation (Guneralp et al. 2013). Close attention has always been given to the arid regions on the relationship between human and water due to the scarcity of water. But recent situations in Texas demand proper steps to be taken for conserving its water resources.

There are several negative impacts of structural developments on the watershed hydrology, physiography, groundwater recharge and stream geomorphology of a drainage basin. Sometimes historical land use practices can lead to the decline of water bodies. Till now, in many regions headwater streams are buried to accommodate urban growths which alters the base flow of rivers (Wenger et al. 2009) and increases the run-off. One of the major impacts of urbanization in central Texas is that, they are making streams more intermittent than other areas, decreasing the water flow in hillslope watersheds therefore drier (Sung 2010).

If the urban growth increases, more problematic situations like flooding will begin to occur within the study area. Flooding is a regular problem in Houston because this is one of the most fastest growing new cities in Texas. A study shows that concrete increased the frequency of flooding 21% between 1984- 1994, 39% in 1994- 2000 and 114% between 2000- 2003 within the urbanized area of Houston (Khan 2005). One of the major reasons is the expanding impervious surface cover that increases the run-off and peak-flow resulting from floods. Increases in flooding are especially prominent in flood-prone areas. Small floods can increase upto 10 times due to urbanization and flood with a return period of 100 years can double in size by 30% if there are structural developments in the basin (Hollis 1975). Regions where wetlands are replaced by structural developments have low water drainage capacity and therefore suffer from floods with long duration.

Statistical results of a study on Texas counties explained the negative impacts of not having enough wetlands and more developed areas, "3.15 inches of rainfall in October 1997 caused approximately USD 15,000 of reported damage in De Witt County, where at the time only five wetland-altering permits had been granted. Four years later, when there were 17 wetland alteration permits, roughly the same amount of rainfall caused USD 150,000 of damage. Similarly, 1.5 inches of rainfall in April 1997 caused some USD 50,000 of reported damage in Wharton County, where 17 wetland alteration permits had been issued up until that point. Four years later, with 26 wetland development activities permitted, more or less the same amount of rainfall caused USD 100,000 of damage. Finally, a rainfall event of 0.09 inches in April 1997 caused USD 5,000 of property damage in Galveston County, where 546 wetland permits had been issued up until that point. In September 2000, the same amount of precipitation caused USD 100,000 of damage. At this time, 921 wetland permits had been issued" – Brody et al. 2007.

Porous pavements are extremely effective in infiltrating storm water run-off (Dietz 2007). On the other hand, impervious surfaces restrict the drainage of water into underground. The decline of groundwater recharge in Edwards Aquifer from 1986 – 2000 (Peschel 2005) is a result of increasing impervious surface cover. The recharge system of aquifers is natural though very poorly filtrated. As aquifers are recharged with water that seeps through fractures or cracks on the surface, construction of highways in the recharge zone might pollute the water and thus degrade the quality too (Barrett et al. 1995). While urban centers are the reason of impervious surface development, impervious surface regulations can sometimes trigger the urban sprawl too affecting water systems.

It is clear from the facts discussed above that urban expansion is the major reason behind impervious surface cover increase. But the alarming fact here is, these developments are mostly taking place in the regions of healthy vegetation. For example, over 80% of most central (downtown) urban areas are covered by pavement and buildings (Blair and Launer 1997), leaving less than 20% as vegetated area. A case study in the Williamson Creek sub-watershed in Texas showed that, deforestations occurred in large areas and then the remaining forests were fragmented where the limit of impervious surface is 15% (Sung, Yi, and Li 2013). Channels in a watershed with forested riparian vegetation are wider than non-forested riparian vegetation, while the effect of riparian vegetation varies with the level of urbanization (Hession et al. 2003).

Other than floods, urbanization affects the debris flow with rapid movement of soil, sediments and large wood to the down steep stream channels creating blockades in the connectivity (Jones et al. 2000). The rate of debris flow varies with the density of roads but decreases the chance of mid-slope river-road crossings (Jones et al. 2000). Not only do debris flows contribute to the materials flows down in the stream channels, but industrial and agricultural contaminants also multiply the effects of decrease and degradation of water bodies (Paul and Meyer 2001). In the pre-farming era, sediments that were carried out to river channels were around 100 tons/ sq-mi/ year but for agricultural lands that increases upto 300-800 tons/ sq-mi/ year (Wolman 1967). So this might indicate that the sediment yield will decline when these lands are converted into urban centers. But urban centers with construction sites yield almost 100,000 tons/ sq-mi/ year which will lead to further problematic situations (Wolman 1967). Studies infer that it takes one or two decades for a channel to re-stabilize but that varies from different urban growths, as the stabilization can take longer with a continuously growing urban center (Henshaw and Booth 2000).

Structural developments affect the hydrological cycle too. Water stress in western Texas has always been the highest amongst other regions in Texas since 1994 (Sun et al. 2008). Besides, regions with large urban centers have decreased precipitation failed to maintain minimum vegetation cover. Without much vegetation cover these urban lands decrease the evapotranspiration and therefore the rainfall. It leads to extreme weather conditions and therefore affects the water storage of rivers by altering the cycle. The hydrological changes can initiate long-term changes for the stream channels. Increasing discharge of water triggers channel expansion and incision of channels (Booth 1990). On the other hand carrying down excessive amount of sediments fill out the channels partially, narrowing them. These two alternating extreme situations create an unpredictable nature for streams which leads to their abnormal and unproportionate changes.

Land use/ cover changes can affect the streams most in shortening the lengths or loss of channels (Julian et al. 2015). These effects are evident in the river cross-section area where the size, shape and composition of the stream channels are most visible (Gregory 2006). Especially urbanization has been suspected as the major contributor in stream channel erosion because these urban areas yield so much sediments (Trimble 1997). Another case study in Thunderbird Lake in Oklahoma showed that 71 km of channels have been lost after overlaying 137 years of land use data and 70 years' stream channel length data and the most significant changes occurred around the urbanized areas (Julian et al. 2015). Though made on long-term temporal interval data but this study can be very useful in predicting the future for upper Guadalupe River in central Texas with short term changes also. By this time it is clearly known that carrying excessive amount of sediments have their own negative impacts on the river channels. To reach the final stage of stream shortening and steepening, the channels undergo several stages of transformation to balance the impacts. The first stage of bringing sediments seems very stable for the river for the time being but the next stages of detaching from the main river network and lagging deposits of bedload at tributary mouths show the real and final condition (Everitt 1993). There are other reasons of water resource decline than the ones discussed above, and the impacts count even more making the river systems vulnerable and endangered.

CHAPTER THREE

Methodology:

Overview

In this chapter, the methods and techniques adopted for image processing and classification will be discussed in greater detail. The methodology section is divided into three main sections: data acquisition and softwares, image processing and classification, accuracy assessment and change detection. The first stage of methodology will describe the sources, softwares and pre-requisites set for appropriate data collection. The second stage consists of image processing (image import, correction, mosaic and subset) which will demonstrate the steps followed to prepare the images for final classification. The final stage will address the accuracy assessment and post classification change detection within the study area.

Image and Data Acquisition

Both vector and raster data have been used in this study. The raster data/ satellite images have been downloaded from the United States Geological Survey's (USGS, 2018). As this research is focused on land use/ cover change, it was important to choose the time-frame carefully. Three things were considered in order to obtain the desired images- cloud cover, growing season and sensor type. Details are given below:

- ♠ Cloud cover: 10%- 30% cloud cover has been considered for both land and scene. More than 30% cloud cover for the desired period within the study area was affecting the images and could have affected the classification process even with haze reduction.
- ♠ Growing season: The times chosen for change detection were within February- May. But all of the images fall within March- April to maintain the same phenological cycle.

- Sensor type: Two sets of sensors have been considered for image acquisition- Landsat 4-5 Thematic Mapper Collection 1 Level 1 and Landsat 8 OLI (Operational Land Imager)/ TIRS (Thematic Infrared Sensor) Collection 1 Level 1 (Table 1).

Table 1: Temporal and sensor details of the images used in the research project

Year of Observation	Day and Month	Path and Row	Sensor Type
1987	9 April	Path: 27, Row: 39	Landsat 4-5 Thematic Mapper
	18 April	Path: 28, Row: 39	
1997	3 March	Path: 27, Row: 39	Landsat 4-5 Thematic Mapper
	28 March	Path: 28, Row: 39	
2007	8 March	Path: 27, Row: 39	Landsat 4-5 Thematic Mapper
	15 March	Path: 28, Row: 39	
2017	19 March	Path: 27, Row: 39	Landsat 8 OLI/ TIRS
	26 March	Path: 28, Row: 39	

The NHD (National Hydrography Dataset) Plus for the study area has been obtained from the Horizon Systems Corporation, the software developer and user support contractor of US EPA and USGS. These hydrological datasets are developed and maintained by the US EPA and USGS to make them available to the potential users. The shapefile that has been used in this project is a NHDPlus V2 shapefile which has better source data and additional components to enhance the utility (McKay et al. 2017). It is an integrated dataset of geospatial features from NHD, NED (National Elevation Dataset) and WBD (Water Boundary Dataset). But only the boundaries for the sub-watersheds have been used for this study area.

Softwares

Two softwares have been used to complete this project- ERDAS Imagine v16 and ArcGIS 10.5.1. (ESRI 2017). ArcGIS was used to customize the shapefile by dissolving other features/ boundaries and to keep the main boundary of the study area which was further used to clip from the images and prepare final maps with attributes on them for a better understanding and visualization. ERDAS Imagine has been used to perform the major tasks for this project which were image stacking, rectification, merging and subsetting, classification, accuracy assessment and analysis (post classification image comparison).

Image Processing

The next step after image acquisition was to process and prepare them for classification. This image processing can be described into four main steps based on their sequence of performing:

1. Image Stacking: Mentioned in Table 1, in total 8 images were acquired for four individual years (1987, 1997, 2007, 2017) with 2 images per year which have been stacked separately using the "Layer Stack" tool in ERDAS Imagine software. All the bands were combined in this way and were used to make different combinations for specific land cover/ use identification.

2. Image Rectification: Image rectification refers to the geometric and radiometric correction of the acquired images. But in this study only the radiometric correction has been performed as required. This is one of the pre-processing steps and should be done for multi-date images in order to adjust the images' pixel values.

Digital sensors usually record the electromagnetic radiations for each spectral band as DN values which depend on the radiometric resolution, and that is why the DN value ranges differently for different bands. Another reason behind radiometric correction is that the spectral signatures are not transferrable, also are image specific which depends on solar elevation, earth-sun distance. There are basically two major steps following the correction:

- Converting DN (Digital Number)/ BV (Brightness Value) to Radiance: The first step is to convert the DN values into radiance values. The basic equation for this calculation is:

$$L_\lambda = gain * Q_{cal} + bias$$

$$i.e.\ L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{cal\,max}}\right) Q_{cal} + LMIN_\lambda$$

Where, L_λ = spectral radiance at the sensor's aperture

$gain$ = RADIANCE_MULT_BAND_X (X= band number)

$bias$ = RADIANCE_ADD_BAND_X (X= band number)

Q_{cal} = the quantized calibrated pixel value in DN

$Q_{cal\,max}$ = the maximum quantized calibrated pixel value in DN = 255

$Q_{cal\,min}$ = the minimum quantized calibrated pixel value in DN = 1

$LMAX_\lambda$ = the spectral radiance that is scaled to $Q_{cal\,max}$

$LMIN_\lambda$ = the spectral radiance that is scaled to $Q_{cal\,min}$

All of these data were acquired from the image's metadata (filename .MTL) which comes with each image folder. The "Model Maker" tool from ERDAS Imagine has been used to perform the calculations which makes it easier and less time consuming.

- Converting Radiance to TOA (Top of Atmosphere) Reflectance: The second/ last step includes the previously converted images to convert their radiance values into reflectance. The basic equation for this calculation is different for Landsat 4-5 TM and Landsat 8 OLI/ TIRS images. The following equation is for Landsat 4-5 TM images:

$$\rho_\lambda = \frac{\Pi * L_\lambda * d^2}{ESUN_\lambda * cos\Theta_s}$$

where, ρ_λ = unitless planetary reflectance

Π = mathematical constant approximately equal to 3.14159

L_λ = spectral radiance at the sensor's aperture (obtained from the first step)

d^2 = earth-Sun distance in astronomical units

$ESUN$ = mean solar exo-atmospheric irradiances

Θ_s = solar zenith angle in degrees = 90- solar elevation

Here, the earth-sun distance (d^2) and solar-zenith angle (Θ) were acquired from the image's metadata again. The ESUN values were obtained from the USGS official website for those specific years. Another model was built from the "Model Maker" tool perform the calculations.

These models and equations were used only for Landsat 4-5 TM images. In both times, the calculation was performed for the bands separately, and then stacked together to make a composite image. It is to be mentioned that only the bands needed for the study have been calculated. For example, spatial resolution for the thermal bands were bigger than the others, e.g. Landsat 4-5 TM = 120 x 120m, Landsat 8 OLI/ TIRS = 100 x 100m. Also, the panchromatic band was removed from the Landsat 8 OLI/ TIRS image because the spatial resolution was less than usual (15 x 15 meters).

The basic equation to calculate TOA reflectance for Landsat 8 OLI/ TIRS is quite simple and similar to the one used for DN value conversion for Landsat 4-5 TM images.

ρ_λ = REFLECTANCE_MULT_BAND_X * pixel value in DN + REFLECTANCE_ADD_BAND_X

Where, ρ_λ = unitless planetary reflectance

X = individual bands of a particular image

As mentioned above, these steps are only required for multi-date images because of image comparison and change detection. The images were then prepared for the next pre-processing.

3. Image Mosaicing: Image mosaicing refers to the merging of two or more images together to make composite land use/ cover images. This pre-processing step is required for this project as the study area falls within the adjunction of two satellite images, which means the rows of the sensors were same but the paths were not (path 27 row 39, path 28 row 39). This process has been re-run for three more times to get all four merged images.

The "Mosaic" tool has been used for this task to select both the images. In order to blend the edges well "Weighted Seamline" and "Feathering" options were used in mosaicking them. A sample mosaiced image (Figure 2) has been shown below:

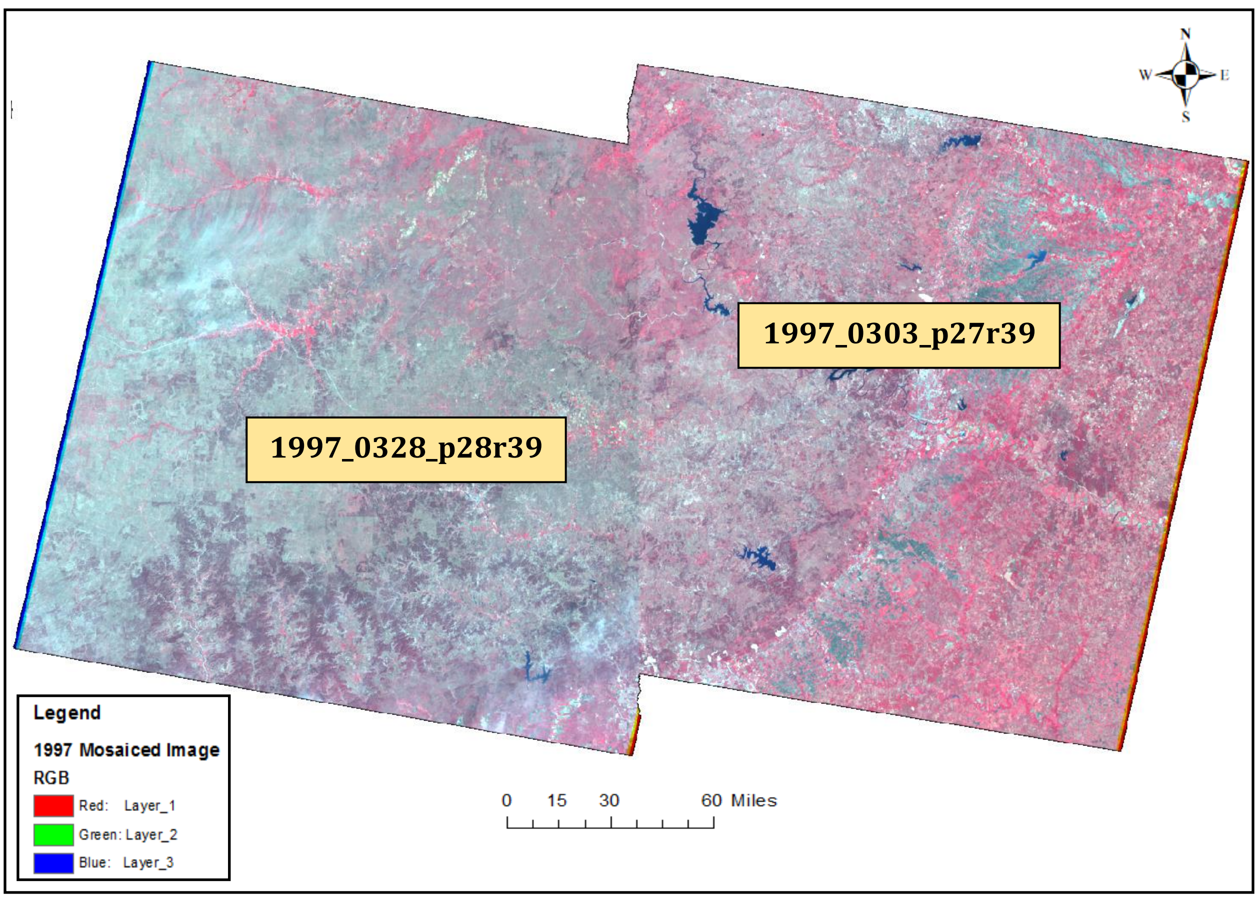


Figure 2: Mosaicked image for the year 1997 obtained from 3 March and 28 March images

The methodological structure of the study that has been developed to present the steps performed in order to reach the final results is given below (Figure 3):

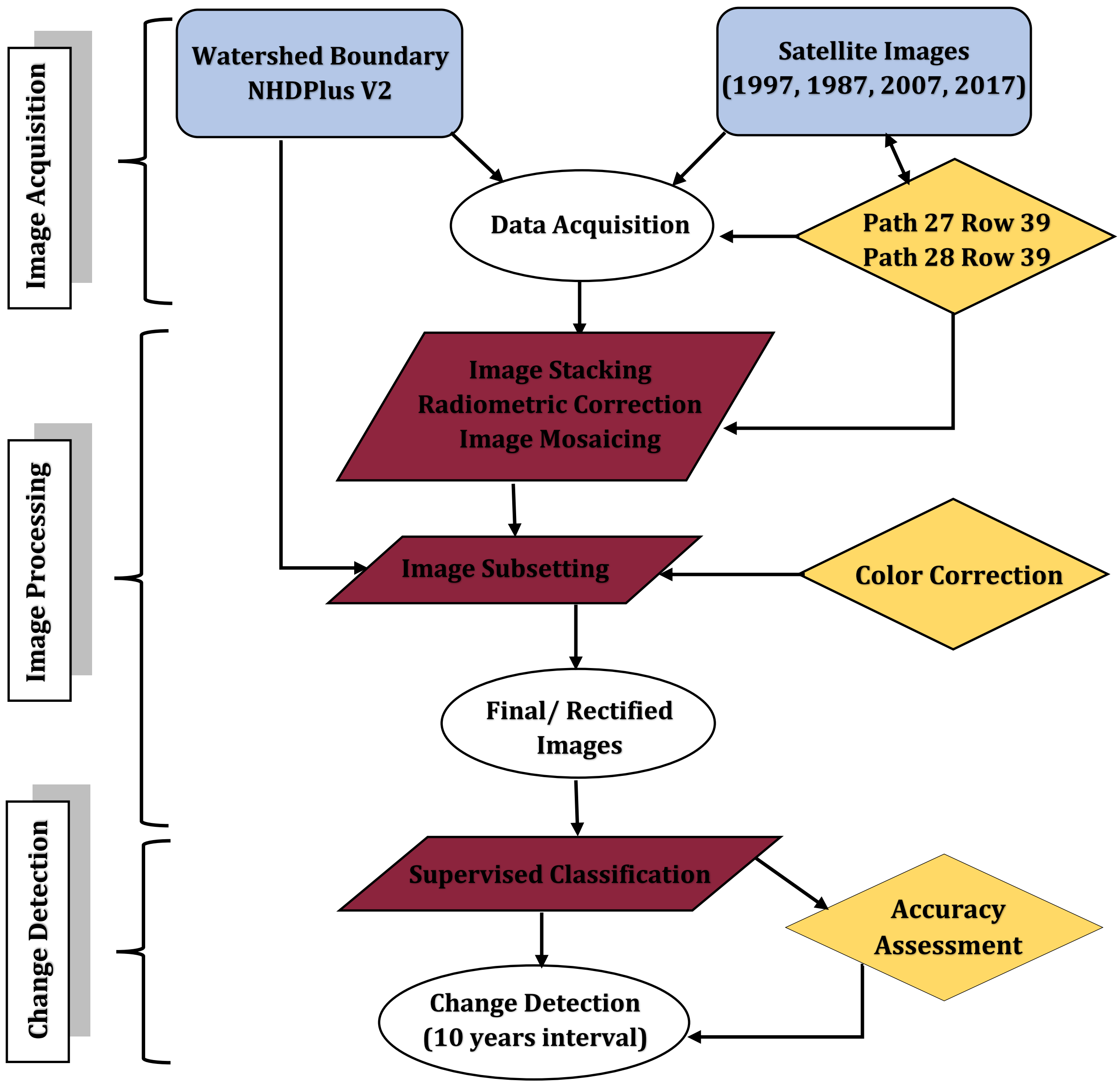


Figure 3: Methodological structure of the research project

4. Image Subsetting: The rectified images were subsetted from the shapefile to extract the study area from the mosaiced image. Subsetting is preferred than clipping only when the user intends to remove/ select some of the bands rather than all. The "Subset and Chip" tool has been used for this task. The process has been run for four times to get the final composite images from four different years. A sample subset image (Figure 4) has been shown below:

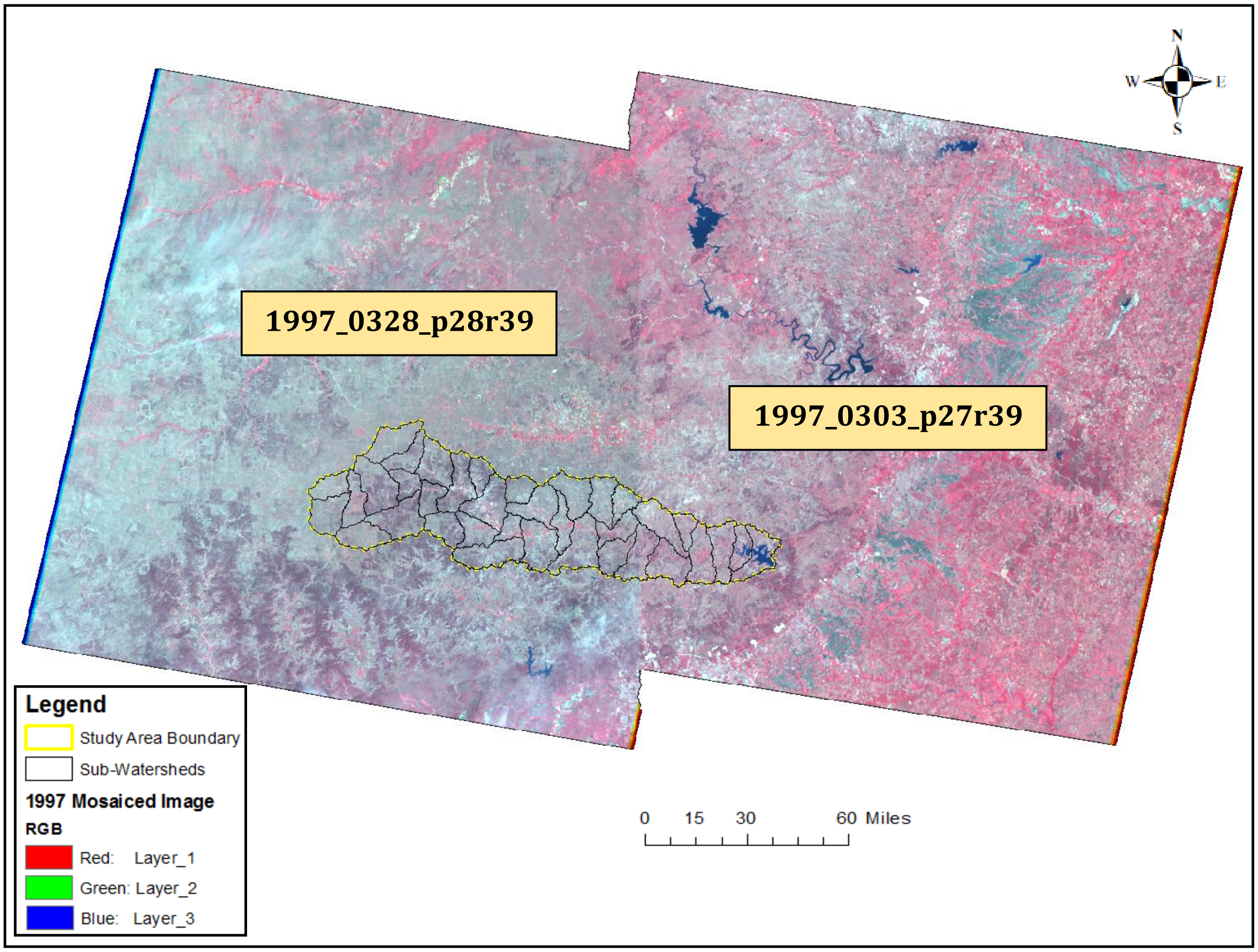


Figure 4: Study area located within the mosaiced image for 1997

The color of the subsetted images were very different from the original ones. The display colors are applied with a contrast stretch that is calculated from the image pixel statistics. Because there is a lot less pixels in the subset images, the calculated stretch values are much different than the original images. But that can be fixed by easily saving the breakpoints from the mosaiced images and then applying them to the subset ones, which was done in this case. This step is optional and completely depends on the user.

Image Classification

Image classification refers to the grouping of pixels with similar values as specific land cover/ use types. There are basically two different types of classification methods: supervised and unsupervised. In supervised classification method, the classification is done manually by the user based on his/ her knowledge, on the other hand the unsupervised classification is performed by the software itself but the parameters are set by the user sometimes. For this research, the supervised classification system has been used in order to classify the land cover/ use types. In terms of field information as ground truth data, the Google Earth Pro has been used throughout to identify the land cover/ use classes.

The first step in supervised classification was to group pixels as training sites and add them in the Signature Editor. The "Polygon" tool has been used to select pure pixels that represent only one type of land cover/ use. Pixels of similar values were selected from all over the study area to accurately classify the land cover/ use types. These training sites have been grouped together using the "Group" option and this AOI (Area of Interest) has been saved for further edit/ use. The signature editor has been used to record each training sites' pixel values separately. More than one signatures were merged into one and given the specific land cover/ use names to show in the final image. These editors were also saved in order to use them for future edition.

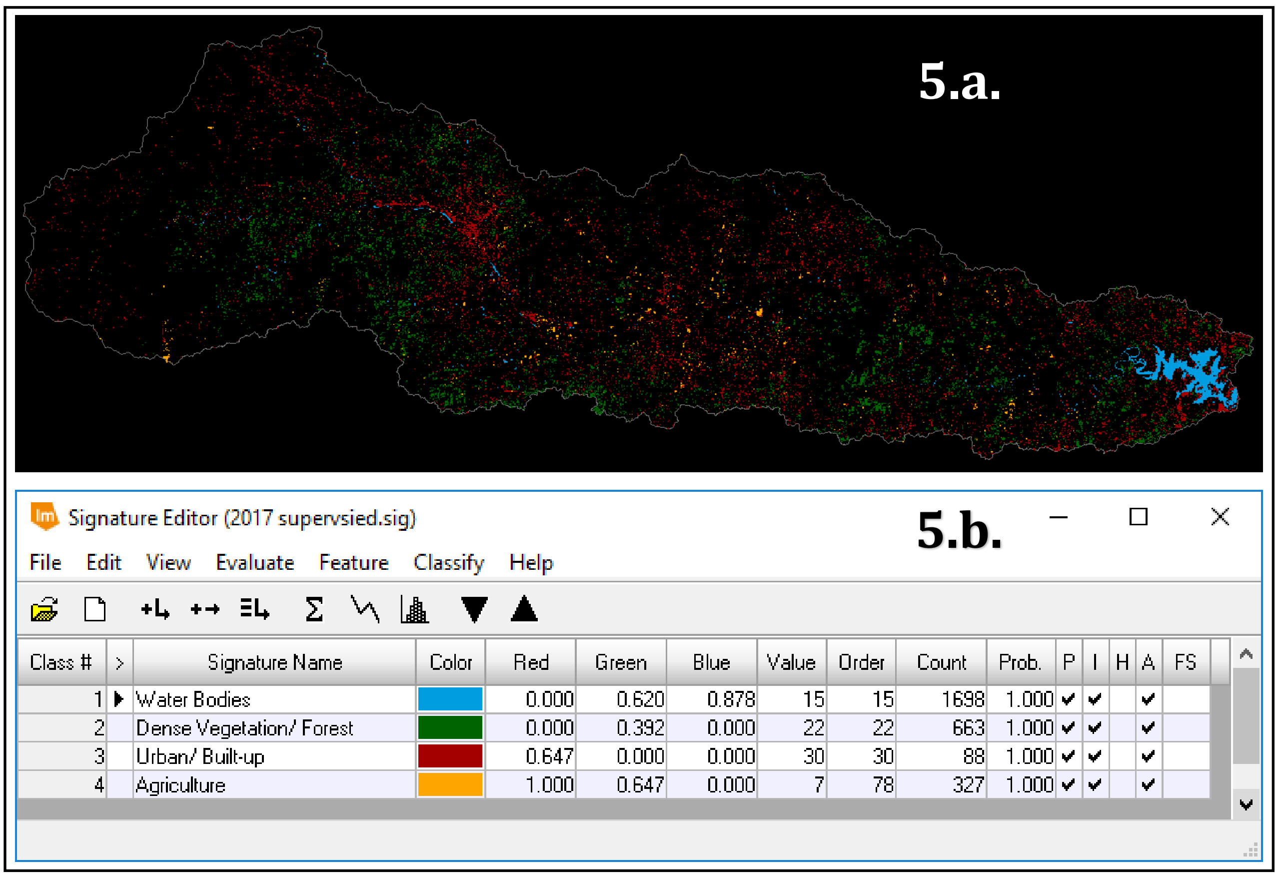
For each band the minimum requirement of pixels is 10 but the more the better. The process of collecting pixels had been run for several times until met with the minimum requirements. Additional pixels have also been collected because it increases the chance of accuracy in classifying land cover/ use types. The table (Table 2) below shows the total number of pixels collected for each land cover/ use types for each year:

Table 2: Total number of pixels collected for land cover/ use classes

Year of Observation → / Land Cover/Use Types ↓	1987	1997	2007	2017
Water Bodies	4948	6219	8325	1698
Vegetation	226	244	129	663
Agriculture	233	326	293	327
Urban/ Built-up	171	178	182	88

The final step in supervised classification is to merge all these pixel values/ signatures and customize the colors for better visualization. To do that, a new Signature Editor had been opened and signatures of different classes added. At this time the raw signatures were removed and only the merged ones were kept to save as the final legend. To get the final output, from the Supervised Classification option, the original image and final signature editor file were loaded. The parametric rule of "Maximum Likelihood" approach has been chosen for this. It is the most commonly used method in remote sensing for supervised classification. The algorithm for this approach works in a way where each pixel value is compared with the training pixels and then assigned to the one that matches most. After setting the parameters, the process was run and the classified images have been saved for change detection analysis.

For this research project, four land cover/ use classes have been identified to have more influences in reaching the research goals. These are: water bodies, vegetation/ forest, agriculture and urban/ built-up areas (Figure 5b). With these four major land use/ cover classes, an additional land cover/ use class has been classified during the classification process titled “Others” instead of classifying each and every landform in the field. This class was created to keep the user classes pure and not to mix with any other types of landforms. Therefore it has not been analyzed in the results. It also indicates that the conversions that took place involving this user class has also not been considered in order to keep the focus on the four most prevalent land use/ cover classes. Because of this the sum of columns in cross-tabulation matrices for each class is not equal to 100%. Details will be discussed in the analysis part of this research.



Class #	>	Signature Name	Color	Red	Green	Blue	Value	Order	Count	Prob.	P	I	H	A	FS
1	▶	Water Bodies		0.000	0.620	0.878	15	15	1698	1.000	✔	✔		✔	
2		Dense Vegetation/ Forest		0.000	0.392	0.000	22	22	663	1.000	✔	✔		✔	
3		Urban/ Built-up		0.647	0.000	0.000	30	30	88	1.000	✔	✔		✔	
4		Agriculture		1.000	0.647	0.000	7	78	327	1.000	✔	✔		✔	

Figure 5: a) Classified image of 2017 with supervised classification method, b) Signature editor associated with the classified image

Accuracy Assessment

Accuracy assessment is one of the most important parts of a research in order to evaluate the applied classification methods and their outcomes. The assessment has been done using the ERDAS Imagine's accuracy assessment tool which allows the user to set specific parameters. The stratified random sampling method has been chosen to be the best fit for this supervised classification. For each classified image, 300 points were added with a minimum of 50 points for each land use/ cover class which were distributed on the images. These points are added randomly and without looking at the images. The output matrix showed an average accuracy of 80.60% which was enough to permit it for further analysis. This evaluation is based on one's own classification and the matrix is generated by the software.

Table 3: Image Classification Accuracy Assessment (Producer, User and Kappa Index)

1987 Image Classification Accuracy				
Users Classes	**Water Bodies**	**Vegetation**	**Agriculture**	**Urban-Built-up**
Producers Accuracy	97.87%	79.59%	98.04%	81.08%
Users Accuracy	92.00%	78.00%	100%	60.00%
Conditional Kappa Index	0.9017	0.7269	1.0000	0.5312
Overall Kappa Accuracy	0.7529			
Overall Accuracy	79.76%			
1997 Image Classification Accuracy				
Producers Accuracy	96.08%	85.45%	94.34%	69.01%
Users Accuracy	98.00%	94.00%	100%	98.00%

Conditional Kappa Index	0.9759	0.9265	1.0000	0.9738
Overall Kappa Accuracy	0.8480			
Overall Accuracy	87.33%			
2007 Image Classification Accuracy				
Producers Accuracy	93.88%	80.65%	100%	92.68%
Users Accuracy	92.00%	100%	100%	76.00%
Conditional Kappa Index	0.9044	1.0000	1.0000	0.7220
Overall Kappa Accuracy	0.8760			
Overall Accuracy	89.67%			
2017 Image Classification Accuracy				
Producers Accuracy	86.67%	58.23%	86.67%	63.04%
Users Accuracy	78.00%	92.00%	52.00%	58.00%
Conditional Kappa Index	0.7440	0.8938	0.4703	0.5095
Overall Kappa Accuracy	0.5944			
Overall Accuracy	65.63%			

Change Detection

The post-classification change detection method is usually performed on two classified images using the “Matrix Union” tool in ERDAS Imagine. One of the advantages of this method is that it allows separately classified images to be compared, minimizing the problems with atmospheric correction and sensor (Siewe 2003). As proposed in the study, the change has been detected for the last 30 years starting from 1987-2017 with 10 years of temporal interval. But three additional changes (1987-2007, 1987-2017, 1997-2017) were also shown to compare the changes internally. The output images are shown in a gradual color of black and white but can be customized in order to show the land use/ cover changing pattern. A change detection matrix or cross-tabulation table was generated, which was summarized showing the change in percentage and per hectare area. The final analysis has been done based on this matrix and classified images.

CHAPTER FOUR

Analysis and Results:

This chapter will present the change detection results and the analysis performed on the classified images. The changes will be discussed in two phases, the first phase will discuss changes with 10 years of temporal interval to show the gradual changes and the second phase will represent maps with more than 10 years of change to show areas of more intense change. Each land use/cover type will also be compared individually. This comparison will also be analyzed and shown with cross-tabulation matrix to validate the outputs. This matrix will show the conversion of each land use/ cover types to one another in both percentage and total area in hectare change.

Change Detection with 10-year Intervals

The first phase of change detection includes the analysis of results with 10 years of temporal interval for each land use/ cover type. As mentioned before, the study area has been divided into four major land use/ cover types. Changes will be detected following these starting from 1987 till 2017. This comparison can be made in two ways, one is the change detections in the same regions from one to another, and the other will indicate changes within the same year but different regions. In this way, the maps will be able to analyze and state the gradual changes occurred within the study area.

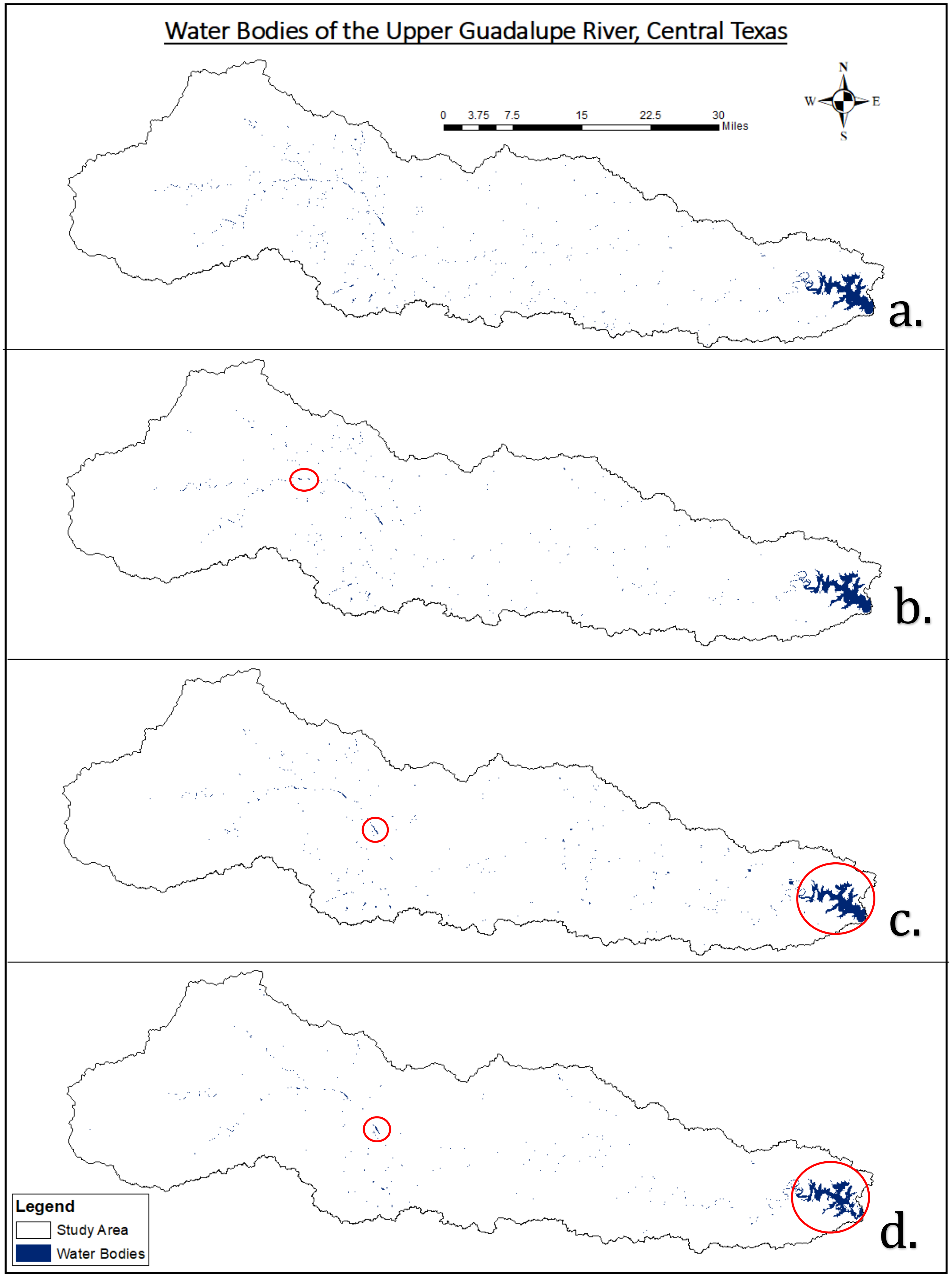


Figure 6: Water bodies within the study area in 1987 (a), 1997 (b), 2007 (c) and 2017 (d)

Water Bodies:

A lot of water bodies can be observed throughout the whole area, especially in the Kerr and Kendall Counties (Figure 6a.). But in 1997, many have disappeared and some of the stream channels started to become discontinuous in the Kerr County (Figure 6b.). The reason behind this discontinuity shows sedimentation or drying out of channels, observed from the Google Earth. Overall, the southern part of the area seems to have a lot less water bodies in 1997 (Figure 6b.) compared to 1987 (Figure 6a.). Changes have not occurred much in the Comal County surrounding the Canyon Lake. Though the Kerrville Ponding Lake was still unchanged and unaffected till 1997 but the Lake Old and New Ingram show a change in their volume and size (marked areas in Figure 6b.).

A significant decrease in water bodies is observed in 2007 (Figure 6c.) which probably started a few years before that. The stream channels became more discontinuous and some of the large lakes have been affected by that time. Among them there is Kerrville Lake and Canyon Lake which had already become smaller in size (marked areas in Figure 6c.).

The changes are more acute in 2017 (Figure 6d.) where most of the smaller water bodies dispersed all over the area have disappeared and major lakes have decreased even more (following the circles in Figure 6c.). The severity of changes seems to have occurred after 2007 when larger water bodies started getting affected along with the small ones.

From an overview of the changes detected on the maps, it is quite clear that the upper western and southern parts of the study area show a great loss of stream networks. Specially the connectivity network from the Canyon Lake till the Kerrville Lake has suffered a severe decrement of water and left trails of bare lands along the way.

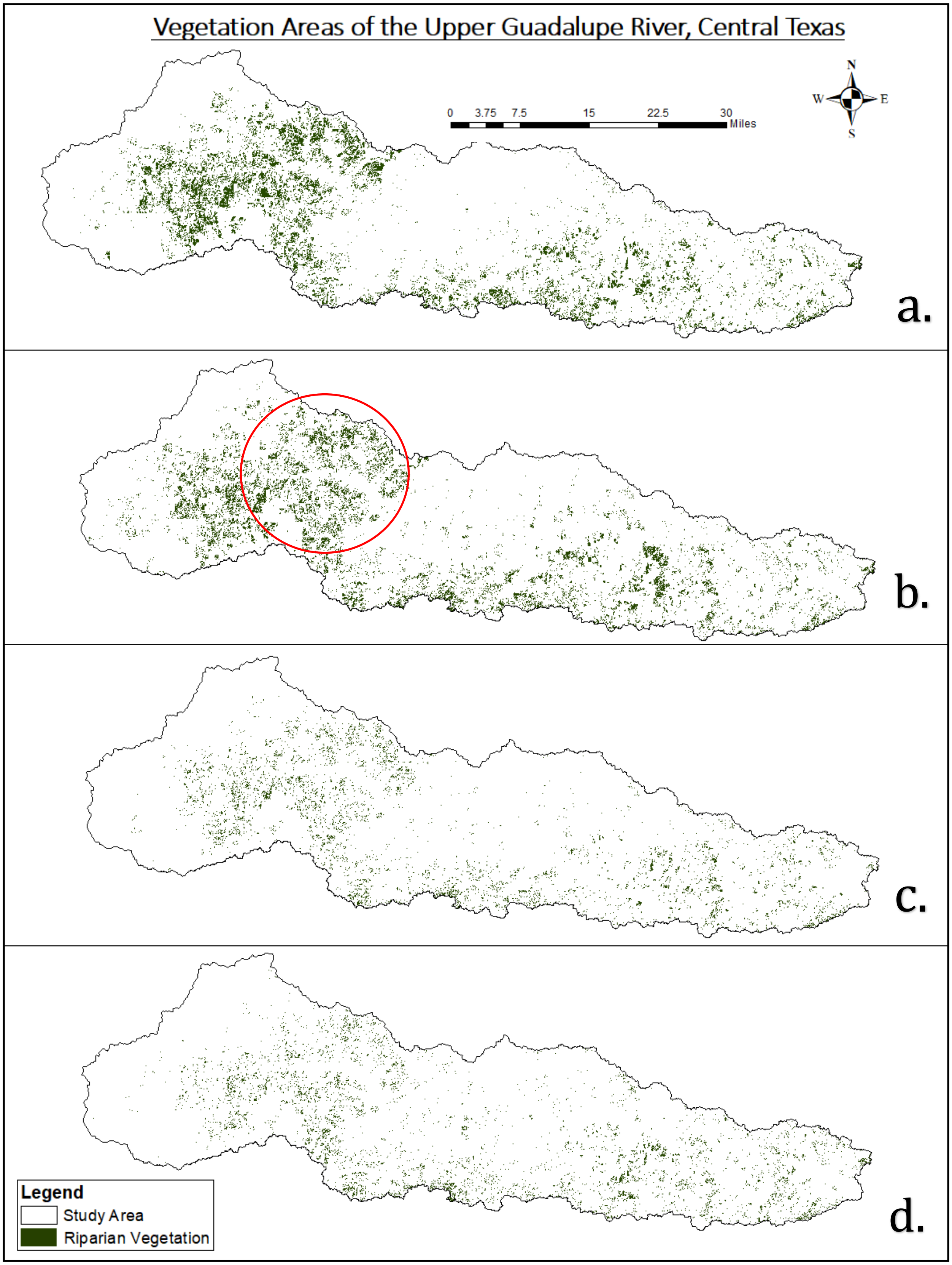


Figure 7: Vegetation within the study area in 1987 (a), 1997 (b), 2007 (c), 2017 (d)

Vegetation:

Almost 90% of the total vegetation occurs within the Kerr County, therefore any loss in Kerr County would have a large impact on the overall decline of the vegetated areas in the study area. The majority of the rest of the change in vegetation occurs within Kendall and Comal Counties surrounding Canyon Lake. An overview of the changes detected in the study area shows a general decline in the riparian vegetation specifically within the Kerr County (Figure 7d.). Significant changes have not been observed within the first 10 years of the time-frame (1987-1997) except some loss of vegetation in the north-western portion of the study area (marked areas in Figure 7b.).

There is a major decrease in the riparian vegetation during 1997-2007 and almost most of them occurred within the Kerr County (Figure 7c.). According to Clement, Chi and Ho (2005), United States experienced its largest regression in forest within 2001- 2006 and an evidence is shown in Figure 7c. From a close observation, it can be estimated that the whole study area has lost about 50% of its natural vegetation. The Kendall County has also suffered a great loss in this regard, the volume has decreased to a large extent in the southern region of the study area. But surprisingly not enough changes can be detected around the Canyon Lake in 1987-2017.

Further major declination in vegetation is not observed in 2017 compared to 2007 (Figure 7d.). In fact, the central regions have developed some new but scattered vegetation, also surrounding the Canyon Lake.

From an overall comparison of the results, a major line can be drawn in between 1997 and 2007. Until 2007, the change was really detectable and greater in percentage. Then again, the rate of decrease became steady till 2017 (Figure 7d.). Some new growths seemed to occur probably due to the better management system.

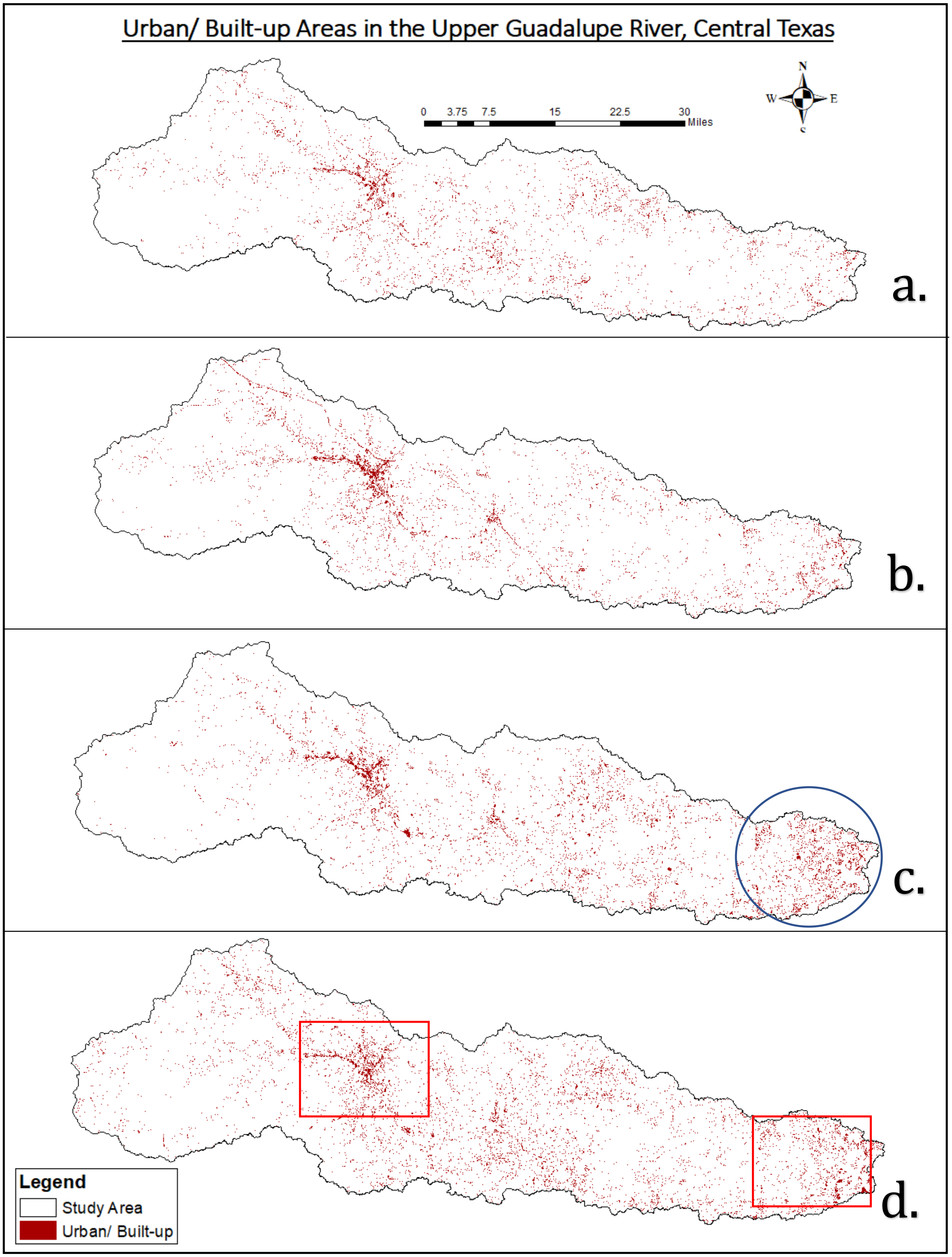


Figure 8: Urban/built-up areas in the study area in 1987 (a), 1997 (b), 2007 (c), 2017 (d)

Urban/ Built-up:

Clustered developments are observed in the Kerrville and Ingram Cities (Figure 8a.). These infrastructural developments include buildings, roads, dams, parking lots and some construction sites near urban zones. It became denser after 10 years, in 1997 and the transportation networks were more developed with time (Figure 8b.). A small cluster started to develop in the center of the study area which is the Comfort City of Kendall County. Other than the expansion of these cities, no significant changes are observed in 1997.

According to the map in 2007, the Kerrville and Ingram Cities have not expanded further than before but more developments have been observed in the Kendall and Comal Counties. Most of Comal County's built-up areas are around the Canyon Lake (marked in Figure 8c.) and was assumed to have grown more in 2017.

The map of 2017 shows the recent developments in the study area (Figure 8d.). Compared with the urban area in 2007, significant increase is observed. Though the density of clusters has become less than before but they have extended greatly (marked in Figure 8d). This means that the cities or densely populated areas are decentralizing and dwelling in other areas nearby especially near the water bodies.

In general, the upper Guadalupe River area is experiencing more developments in the recent years and also expanding towards the boundary of our study area. Other than the Kerr County, central region of the Kendall County and the whole Comal County seem to have some kind of developments, not necessarily only buildings but transportation networks are also playing a vital part in this. The most important finding about this land use type is that these urban developments are following the trails of water bodies which actually validates one of the major assumptions of this research project.

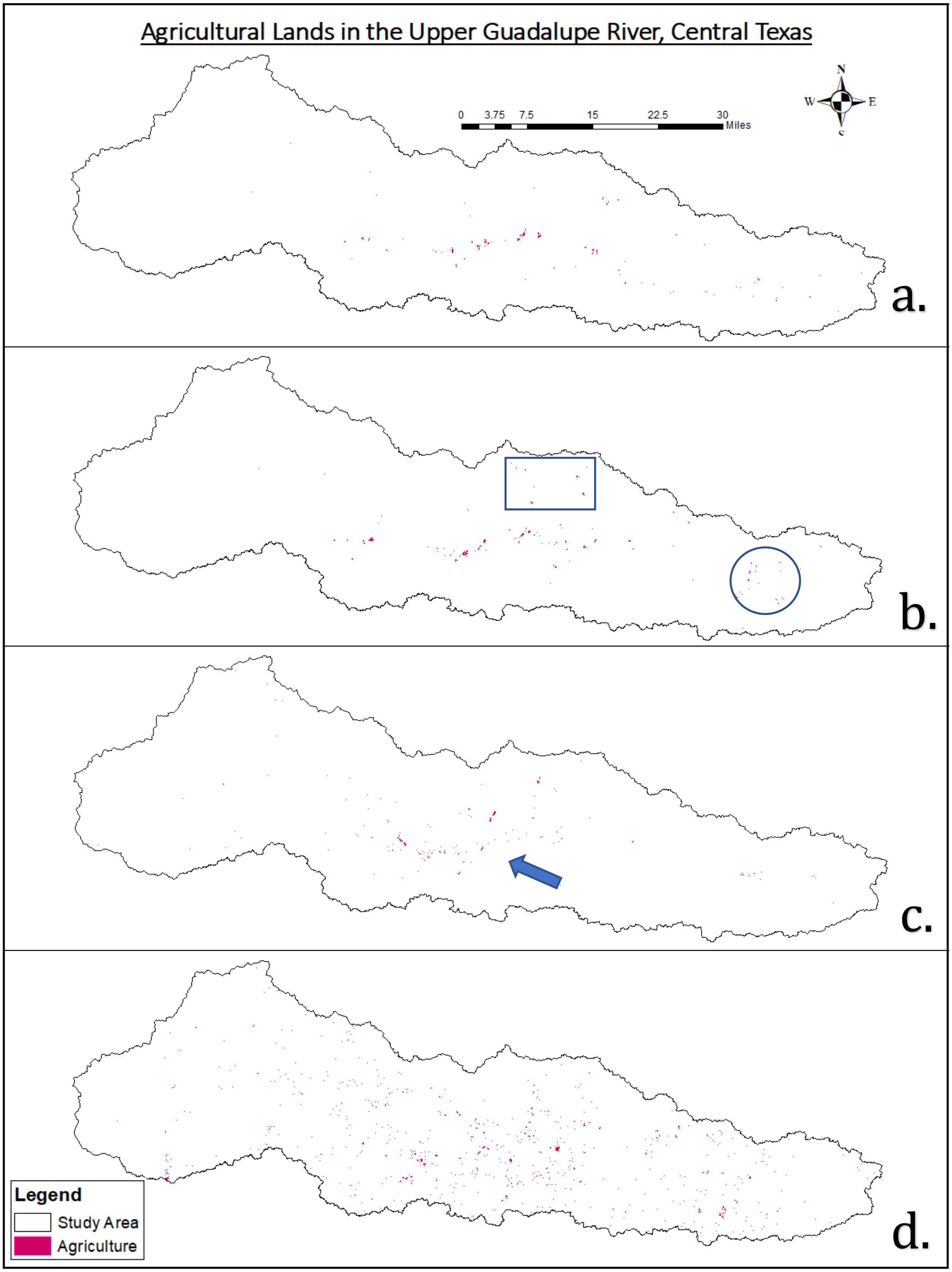


Figure 9: Agricultural lands within the study area in 1987 (a), 1997 (b), 2007 (c), 2017 (d)

Agriculture:

The agricultural lands in the 1987 map, mostly occurred within the Kendall County (Figure 9a.). These lands have been developed beside the stream channels from Canyon Lake to the Kerrville Ponding Lake for accessibility to water. However, there were none in the upper western part of the study area or in the Kerr County.

The agriculture did not grow quite significantly (Figure 9b. and 9c.) in 1997 and 2007. Historical studies in 1909-2002 says that, during 1985-2005 many agricultural activities were abandoned in the southern United States (Ramankutty, Heller, and Rhemtulla 2010). That explains the agricultural stability within the study area till 2007. Some lands have expanded towards the northern edge of the Kendall County and surrounding the Canyon Lake (marked in Figure 9b.), whereas most of the lands in 2007 have clustered in the center of the study area.

On the other hand, the map of 2017 shows a different scenario with a rapid areal increase in the agricultural lands (Figure 9d.). So, there is a sharp line drawn between 2007 and 2017 where most of the agricultural activities occurred and expanded greatly.

Cross-tabulation Matrix Change Detection with 10-year Intervals:

So far in this research, the maps have detected the changes in land use/ cover types from year to year, but they did not show the conversion from one type to another. The cross-tabulation matrices will display changes from one year to another and also how one land cover/ use changed or remain unchanged during these years. The numbers in the table represent decadal land cover conversion. This research focuses on the changes that can have negative impacts on the study area to fulfil the aims of the study. Typically, the conversions that will be emphasized for analysis are from- water to urban and/ or agriculture, vegetation to urban and/ or agriculture and some changes that are more significant. The tables are given below:

Table 4: Change detection cross-tabulation matrix of 1987- 1997 in the study area

1987 → 1997 ↓	Water	Vegetation	Agriculture	Urban
Water	83.97%	0.38%	0.05%	0.29%
	3891.15 ha	121.05 ha	0.18 ha	23.58 ha
Vegetation	2.14%	61.37%	0.66%	0.01%
	99.09 ha	19496.2 ha	2.25 ha	0.54 ha
Agriculture	0.00%	0.00%	15.17%	0.02%
	0 ha	0.27 ha	51.39 ha	1.53 ha
Urban	3.27%	0.34%	0.29%	48.42%
	151.56 ha	108.72 ha	0.99 ha	3988.17 ha

The diagonal cells indicate "no change" where the rest of the cells indicate "change". These individual cells might differ in percentages as shown in the maps before because they reflect the calculation performed including all the land use/ cover classes classified by the user. This means that this calculation involves the "Others" class also which has been mentioned in the methods section. For example: according to table 4, only 48.42% urban areas have remained urban in 1997 from 1987 which means the rest has been converted. This conversion includes water, vegetation, agriculture and everything else ("others"). As the focus will remain on the changes of our four observational classes, the calculation of change of "Others" class has been ignored. This also explains the varying sum of column percentages.

Almost 3.27% (151.56ha) of the surface water resources have been converted into urban areas in 1997 from 1987 (Table 4). But no water bodies have been transformed into agricultural lands (evident in Figure 9b.) where no agricultural expansion was discovered. Apart from water, very negligible percentage of riparian vegetation has been converted into agriculture and urban lands.

Table 5: Change detection cross-tabulation matrix of 1997-2007 in the study area

1997 → / 2007 ↓	Water	Vegetation	Agriculture	Urban
Water	79.85% 3309.75 ha	0.08% 23.31 ha	0.09% 0.45 ha	0.48% 46.62 ha
Vegetation	0.01% 0.54 ha	32.48% 9734.94 ha	0.20% 0.99 ha	0.00% 0.18 ha
Agriculture	0.01% 0.45 ha	0.00% 1.35 ha	7.43% 36.63 ha	0.01% 1.44 ha
Urban	13.47% 558.54 ha	0.88% 264.78 ha	1.57% 7.74 ha	43.31% 4231.98 ha

There are a few notable land use/ cover conversions from 1997-2007 (Table 5). One of the most significant conversions is from water to urban, such that 13.47% (558.54 ha) of water bodies have been built into either building or roads or other forms of developments. There are no significant changes into agriculture. Almost no vegetation has been transformed into agriculture and only 0.88% into urban areas. Almost 2% conversion of agricultural lands into urban areas explain the development of larger cities (Table 5, Figure 8c.).

Table 6: Change detection cross-tabulation matrix of 2007- 2017 in the study area

2007 → / 2017 ↓	Water	Vegetation	Agriculture	Urban
Water	72.99%	0.00%	0.02%	4.54%
	2706.12 ha	0.09 ha	0.09 ha	548.46 ha
Vegetation	0.92%	43.71%	0.09%	0.17%
	34.02 ha	5284.91 ha	0.36 ha	21.06 ha
Agriculture	0.18%	0.37%	11.28%	0.39%
	6.66 ha	44.28 ha	46.53 ha	46.55 ha
Urban	3.43%	0.74%	3.06%	39.33%
	127.08 ha	90.02 ha	12.6 ha	4753.35 ha

The rapid conversion of water into urban areas decreased but is still more than other conversions with 3.43% (127.08 ha) change (Table 6). Though the conversion of water bodies into agriculture has been increasing but still in a very small percentage compared from 1997 and 2007. On the other hand, dense vegetated areas turning into agriculture and urban areas have increased but in a negligible amount. One significant change is that almost 5% urban area transformed into water but what is not known is whether it is natural or human altered change but most likely is artificial or at least human influenced.

Change Detection Greater than 10-year Intervals:

The second phase of change detection will emphasize on the intensity of changes of the study area and will refer to the same maps shown above for the analysis.

Water bodies:

The water resources have decreased to a great extent from 1987 to 2017 (Figure 6). Roughly estimated, half of the total water bodies have disappeared, but the rate of decline has been equal in every 10 years and that can be confirmed from the comparison of 1987-2007 (Figure 6a. and 6c.) or 1997-2017 (Figure 6b. and 6d.) maps. According to the cross-tabulation matrix of 1987-2007 (20 years) almost 16% of these water bodies have been converted into urban areas.

Vegetation:

The changes detected for this land cover type are not as uniform as for the water bodies. A sharp decline is observed between the year of 1997 and 2007 (Figure 7b. and 7c.). The major decrease may have started after 2000 where almost 50% of the vegetation disappeared but then stayed static for the next 10 years upto 2017. The effect of this is shown in the maps from 1987-2007 (Figure 7a. and 7c.), 1997-2017 (Figure 7b. and 7d.) and 1987-2017 (Figure 7a. and 7d.) which actually show a rapid negative change in the riparian vegetation area of the study region.

Urban/built-up Areas:

The urban areas started developing quite evenly and in 1997 the first major identifiable cluster was observed with developed transportation systems (Figure 8b.). The built-up areas started growing eventually every 10 years with the same rate. So, the areal extension almost doubled in 2017 from 1987 (Figure 8d. and 8a.).

Agricultural lands:

The agricultural lands show a clear division of growth from 2007 to 2017 (Figure 9c. and 9d.) which indicates that the intensity has increased almost three times in the the past 5-7 years and expanded evenly throughout the study area.

CHAPTER FIVE

Discussions:

The following discussion will only focus on the larger, continuous changes in the land use/ cover maps from 1987 and 2017.

The majority of the vegetation cover in the study area is basically riparian and thus will be discussed using the description. According to Hession et al (2003), stream channels with riparian vegetation are wider than the ones without. This suggests that with the declining water bodies the vegetation cover will also start decreasing. The change detection results support this general trend for all sequences of years, thus only 1987-2017 maps will be used in this chapter to avoid the redundancy in discussions (Figure 10).

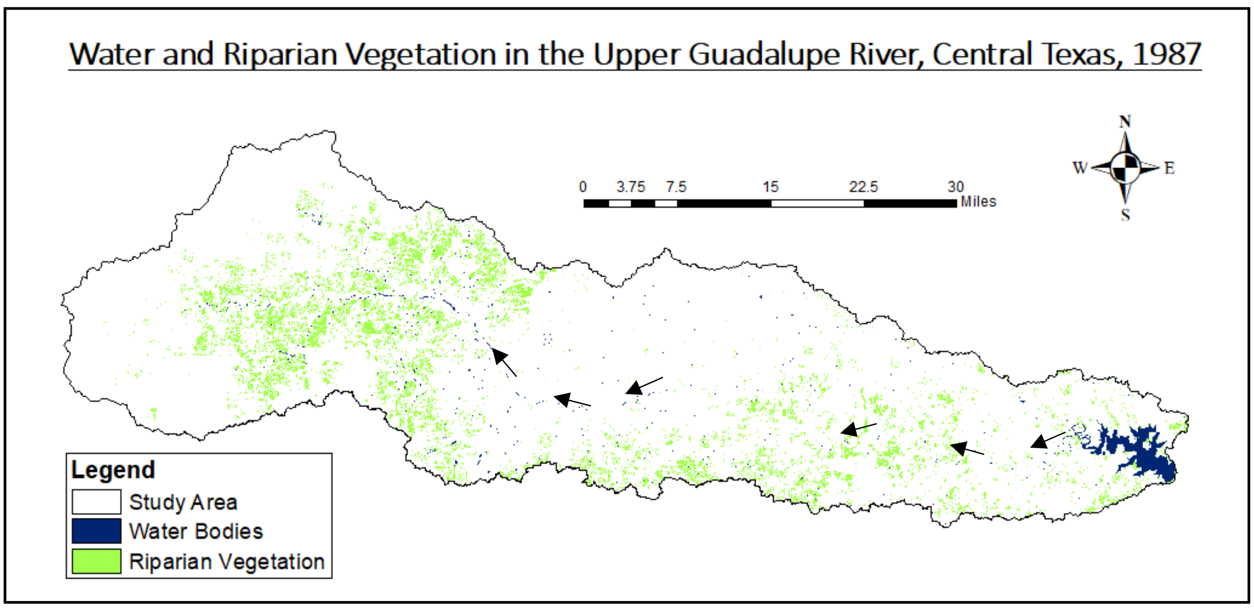


Figure 10: Water bodies and vegetation within the study area in 1987 (arrows showing track of the riparian vegetation changes)

Figure 10 shows that 90% of the vegetation cover is around the stream channel networks in the Kerr County. The rest of the vegetation appears along the longest stream network connecting from the Canyon Lake to the Kerrville Ponding Lake (pointed in figure 10) and around the Canyon Lake area. An interesting inquiry to follow up on is whether the decline in water bodies affect this vegetation cover or not (Figure 11).

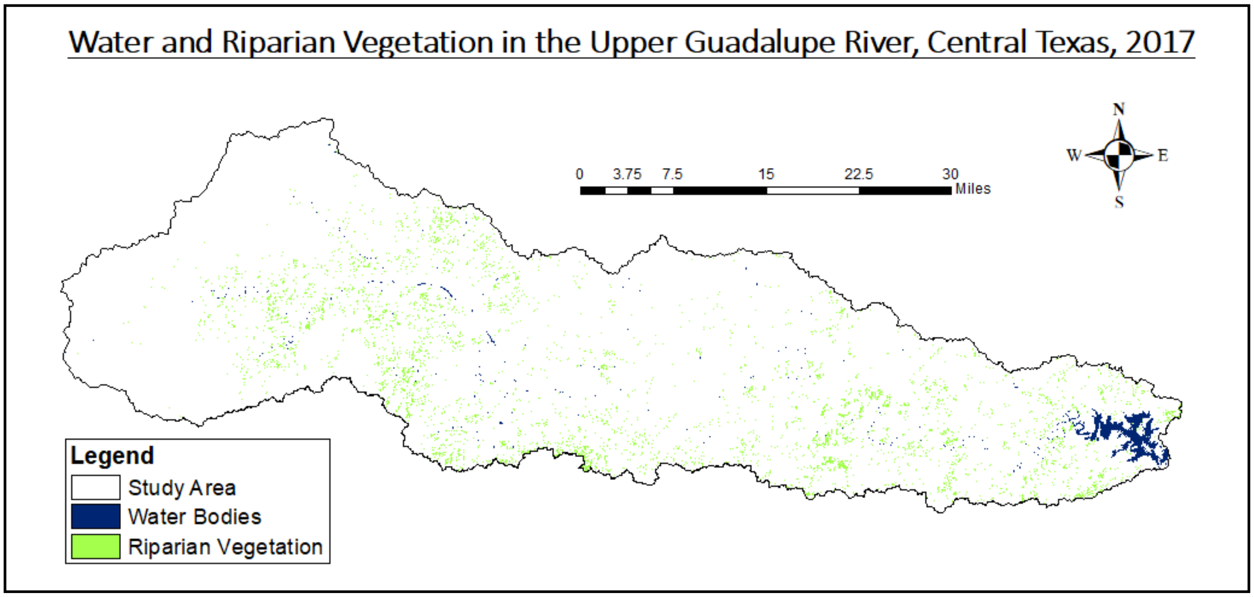


Figure 11: Water bodies and vegetation within the study area in 2017

Both of these land cover types have shown a reciprocal relationship where the vegetation decreases with the decrease in water bodies. This is most evident in Kerr County and the central region of the study area where nearly 80% of the water bodies have declined in sync with reduced vegetation cover. Therefore, we can be predict that further reductions in water bodies will be accompanied by loss of riparian vegetation.

An important next step is to find the underlying reason for disappearing water bodies. Mentioned in the problem statement of this research that central Texas is growing really fast in population and infrastructure developments. These developments are replacing natural land covers and altering surface water. According to U.S. Census, the population of southern Texas has increased from 18% to 72% in the last century. This huge amount of population is triggering the development of urban centers and theses centers are developed along water for drinking water and better transportation (Grischek et al. 2002). The following maps show the change in water, vegetation and urban areas from 1987 to 2017:

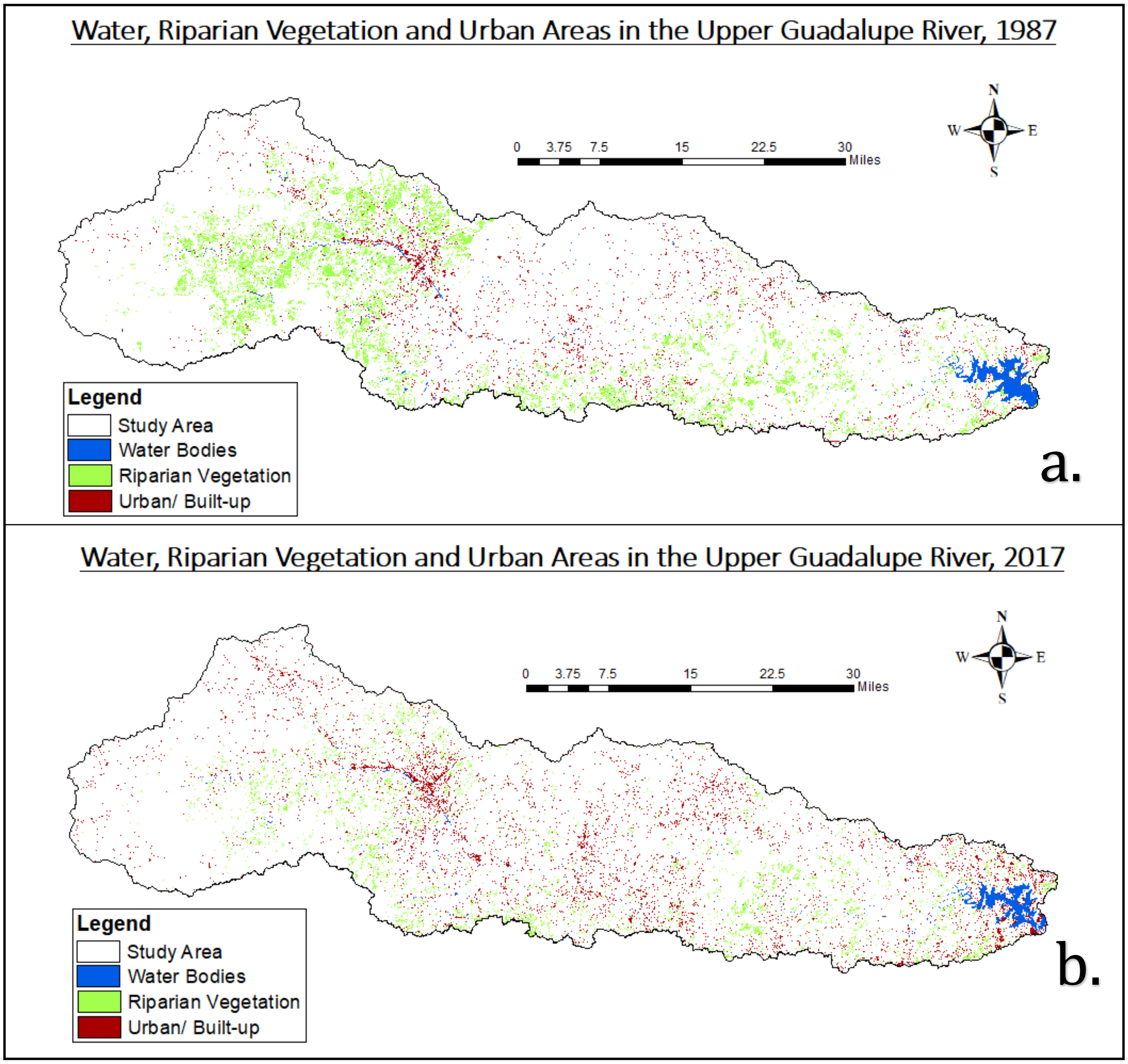


Figure 12: Water bodies, vegetation and developed regions of the study area in 1987 (a), and in 2017 (b)

There is an expansion of bigger urban centers in the Kerr County, with developed transportation networks around (Figure 12a.). From close observations it can be seen that structural developments occurred mostly in the vegetated area. Another cluster is spotted around the Canyon Lake area (Figure 8d. and Figure 12b.).

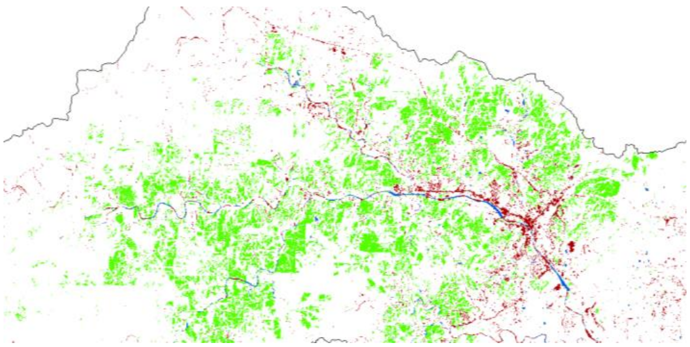


Figure 13a: Kerrville City in 1987

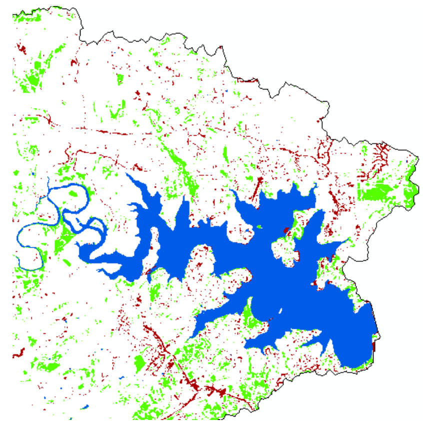


Figure 14a: Canyon Lake in 1987

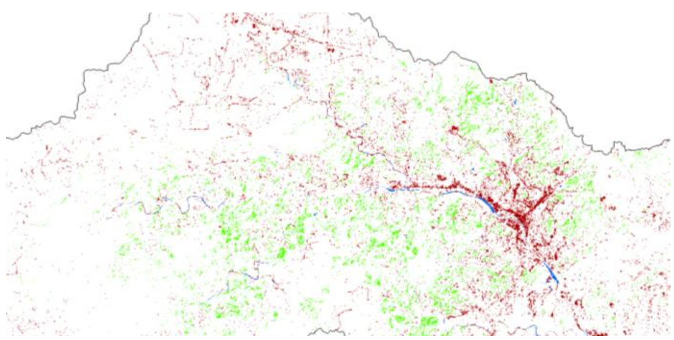


Figure 13b: Kerrville City in 2017

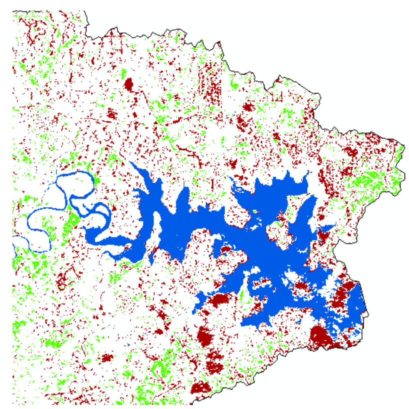


Figure 14a: Canyon Lake in 2017

Figure 13 and 14: Comparison of the same land cover/ use types from 1987 to 2017 within the study area

The riparian and other vegetation cover started disappearing as urban centers started developing (Figure 13a. and 13b.). The impact of this urbanization on water resources is quite significant (Figure 14a. and 14d.). The Canyon Lake has narrowed down in the last 30 years possibly due to sedimentation, reduced water surface and drought, however a specific analysis looking at these factors would be necessary to pinpoint a cause in the changes to Canyon Lake. Drought may be a major factor resulting the reduction of surface water bodies within the study area. Another possible factor could be the increase of impervious surface cover and its influence on ground water depletion.

The agricultural lands also play a vital role in depletion of water bodies through the use of surface and ground water irrigation sources. According to the Texas Water Development Board, 12% of the irrigated lands in Texas use surface water and 2% use both surface and groundwater. The increase in agriculture could be putting pressure on the water resources (Figure 15).

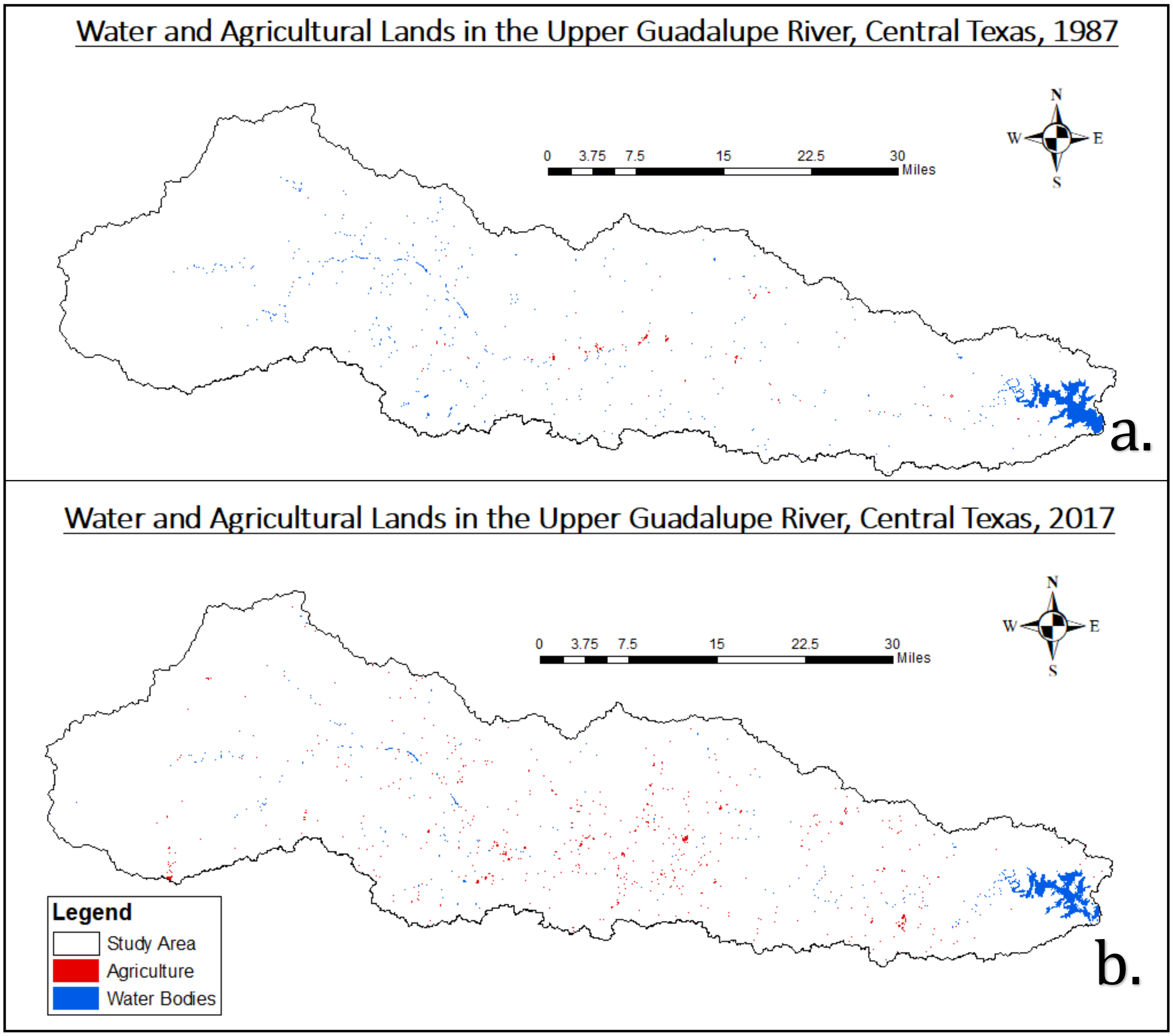


Figure 15: Water bodies and agricultural lands in the study area in 1987 (a) and 2017(b)

Majority of the active agricultural lands developed in 1987 were around surface water resources and in 2017 that expanded throughout the whole study area, although the greatest change is concentrated toward the center of the study area (Figure 15a. and 15b.). In addition to increasing the pressure on surface and groundwater resources, this can also add chemical, soil and wooden residues of croplands which can degrade the water quality.

The most significant factor to be considered in decreasing surface water for Texas is drought conditions. Hydrologically isolated this state has experienced a record-breaking drought in 2011 due to long term extreme dry conditions starting from November 2000- January 2012 (Long et al. 2013). The reduction in water storage was as low as 50% than the usual, during this event (Scanlon, Duncan, and Reedy 2013). According to the U.S. drought monitor report, the areal extent of the most extreme drought prone regions has increased from 9.59% in 2010 to 43.07% in 2011 and the upper Guadalupe River area falls within it (Gammon 2011). Along with the impervious surface and irrigation systems these exceptional cases trigger the depletion in water storage levels thus in disappearing surface water (Figure 11, 12b, 13b and 14b). The future water demand estimated at this point is 22 million-acre feet a year which is 20% more than it is today (Henry 2011). The loss of riparian vegetation in absence of water, yields large volume of sediments influenced by droughts making the landscape more vulnerable (Allen et al. 2010).

Limitations of the Study:

- The intention of this study was to use the most updated data for better results. The temporal intervals demanded to use Landsat 4-5 TM for 1987 and 1997, Landsat 7 ETM for 2007 and Landsat 8 OLI/TIRS for 2017. But Landsat 7 images could not be used because of the line stripped and gap of pixels. Instead the Landsat 4-5 TM images were used for 2007 too.

- The study area falls within the adjunction of two different paths of Landsat sensors, path 28 row 39 and path 27 row 39. It creates a time gap (7-10 days) in obtaining the images for the whole study area. The best option was to get the most closely dated images in order to maintain the same phenological cycle.
- The post classification change detection depends highly on the accuracy of the classification performed on the images for comparison. Also, it shows only the conversion of the land uses, not the modifications.
- One of the biggest limitations is that this research failed to distinguish the specific land cover/ use types. For example: water bodies include all surface water resources whether natural or artificial. The same goes for the vegetation also, rooftop urban vegetation might be included into the vegetation category.

Conclusion:

This research attempted to identify the growing intensity of artificial developments which are replacing the natural land covers. It also intended to find out about every possible reasons behind this replacement. It hoped that with the result it will be easier to project the future growth rate, the areal extent of the altered land use/ covers that can have negative impacts on people. For example: urbanization and urban sprawls are projected to increase in the coming century which will physically alter the water systems. Therefore, proper management systems and required measurements are necessary to install. Besides this study can contribute to the literature and future researches. Interested researchers can add dimensions to this study by looking at the research objective from different angles and contribute with their knowledge identifying the gaps.

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