2011

Temporal changes in quality of life and environment in New Orleans after Hurricane Katrina

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TEMPORAL CHANGES IN QUALITY OF LIFE AND ENVIRONMENT IN NEW ORLEANS AFTER HURRICANE KATRINA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in
The Department of Environmental Sciences

By
Danielle Johanna LaRock
B.A., University of Virginia, 2009
August 2011

DEDICATION

I would like to dedicate this thesis to my dad. Thank you for always being there for me, for always helping me to realize all the good I have in life, and for always helping me to persevere, and never quit.

ACKNOWLEDGEMENTS

This research could not have been accomplished if not for the help of several people and agencies. I would like to acknowledge the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) for funding this research (award numbers: M09AC15619, M09AC15620). I am very grateful to have had Dr. Nina Lam as my faculty advisor and mentor. She has always been available to help, despite her busy schedule. She is an amazing teacher and has taught me many important and useful skills during my time at LSU. I have learned so much from her expertise and am very thankful for the many great opportunities she has given me. I would also like to thank Mr. DeWitt Braud and Dr. Crystal Johnson for serving on my thesis committee. They were both always willing to assist me with work related to my thesis. Mr. Braud is a fantastic teacher who gave me a clear understanding of how to use ERDAS Imagine software. Dr. Johnson has also helped me immensely with writing, including submitting a grant proposal. I would also like to thank Mr. Hampton Peele with the Louisiana Geological Survey for taking the time to help me download DOQQ files. I was also extremely lucky to have a brilliantly smart and kind office mate, Helbert Arenas, a PhD candidate in the LSU Department of Geography. Over the past two years, he has answered literally hundreds of questions I have had and has always devised a solution to any problem. Jennifer Lentz, a PhD candidate in the LSU Department of Oceanography, has also been full of encouragement and enormously helpful with her impeccable GIS and remote sensing notes. I also cannot forget to acknowledge the support from my family and friends during my graduate career.

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ABSTRACT

Understanding and assessing the spatial and temporal changes of quality of life and environment of a community is critical to its sustainable development, especially after a disaster strikes. This study explores an approach that integrates remote sensing with socioeconomic data to assess the temporal changes in quality of life and environment (QOL) using Orleans Parish as an example. Hurricane Katrina, which struck New Orleans in 2005, has had vast implications economically, socially, and environmentally for this city and the surrounding area. Empirically quantifying these concepts will help to rebuild the city more sustainably.

This study investigated change in environmental quality pre- and post-Katrina using Landsat-TM imagery. Environmental quality was measured by means of vegetation productivity as an indicator, using the Normalized Difference Vegetation Index (NDVI) and Tasseled Cap Index (T-cap) of greenness, wetness, and brightness derived from the Landsat images. Factor analysis was employed to create a QOL index at the zip code level that incorporated both environmental (vegetation, flood depth) and socioeconomic variables. The factor analysis yielded four factors with 95.3% of the variance explained. A weighted QOL index was created that included seven variables from the four factors: NDVI, median household income, population density, housing density, median home value, educational attainment, and flood depth. Validation of the QOL indices with households receiving mail post-Katrina resulted in correlations of 0.546 and 0.510 for the pre- and post-Katrina QOL indices, respectively.

The QOL index maps demonstrated spatial contiguity pre- and post-Katrina. Areas that exhibited high QOL included Downtown, Uptown, Garden District, West Bank, and Lakefront. Low QOL was found in New Orleans East, Lower Ninth Ward, and Central Business District. Four years after Katrina, much of the city experienced a decrease in QOL. Zip codes with high wealth tended to maintain or even increase their high QOL, such as in Uptown and the Garden District. This study suggests that higher values of income, education, home value, and vegetation contribute to higher QOL and increase resilience to natural disturbances. These QOL indices link human and natural systems and provide an effective means for comparing changes in a region after a disaster.

CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Hurricane Katrina was one of the strongest storms to impact the coast of the United States during the last century (NOAA 2010; Wang & Xu 2010). Katrina made landfall as a strong Saffir-Simpson Category 3 on the border of Mississippi and Louisiana the morning of August 29, 2005 (Figure 1). Measurements at Grand Isle, LA showed wind speeds at landfall of approximately 125 mph (110 kts), with a central pressure of 920mb – the third lowest on record for a landfalling Atlantic storm in the U.S. (NOAA 2010). The storm surge was estimated at ~3-3.5 meters (~9.8-11.5 feet) near the city of New Orleans (Pardue et al. 2005). The strong winds, heavy rainfall, and large storm surge caused widespread devastation along the central Gulf Coast states and affected many communities, including the major port city of New Orleans, LA.

Hurricane Katrina is estimated to be the largest natural disaster ever to strike the United States (Costanza et al. 2006). The storm resulted in massive damage to property and loss of life. It is estimated that over 1,000 people died due to the storm (Brunkard et al. 2008; Lam et al. 2009). The total damage costs range from $80 billion to over $100 billion (University of South Carolina Hazards & Vulnerability Research Institute 2010; NOAA 2010). The loss of life and property damage was worsened due to breaching of the levees that separate New Orleans from Lake Pontchartrain and the Industrial Canal (NOAA 2010). Approximately 80% of the city of New Orleans was flooded due to the levee failures (Pardue et al. 2005; NOAA 2010). In some areas, flood depth exceeded 15 feet (LSU GIS Information Clearinghouse: CADGIS Lab 2005). The city was flooded for several days before dewatering operations began (Pardue et al. 2005). Additionally, there was widespread catastrophic wind damage that destroyed residential, commercial, and industrial buildings, as well as disabled critical infrastructure, such as electrical transmission, water, sewage services, and the city's floodwater removal pumps (Presley et al. 2006). It has taken years for communities to recover, and rebuilding efforts are still a work in progress.

1.2 Objectives and Hypothesis

Considering the devastating effects of this hurricane, it is important to understand its impacts on environmental quality and quality of life in New Orleans. Some areas of the city were completely

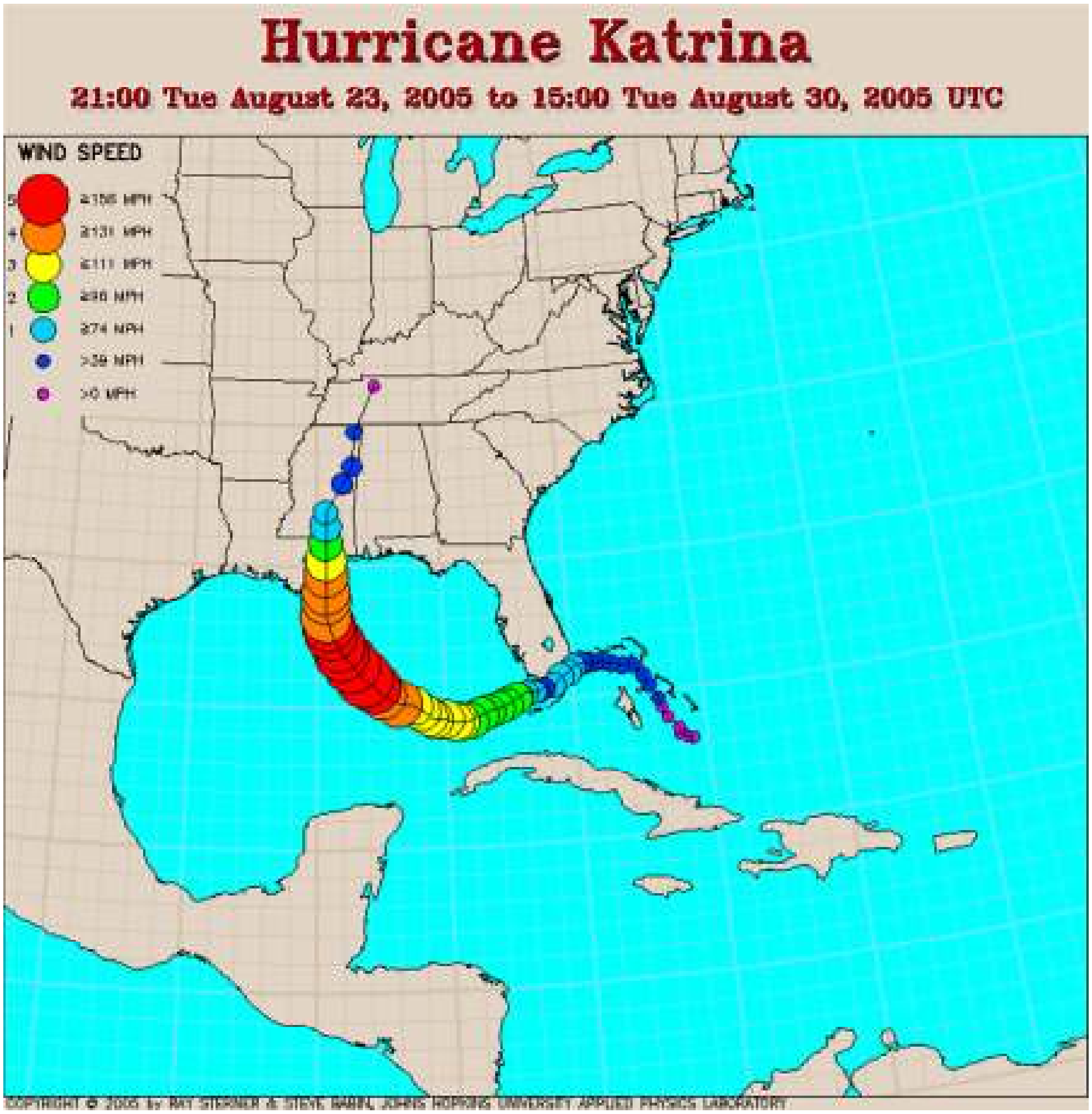

Figure 1: Track of Hurricane Katrina (NOAA 2010)

destroyed by the storm, leaving only house foundations and dead vegetation. In contrast, other areas of the city fared much better, largely due to their higher elevation. As the city is being rebuilt, it would be useful for urban planners, policy makers, and community residents to know the quality of human life and the natural environment in order to make more informed decisions and allocate limited resources and funds appropriately.

This study looks into the question of how Hurricane Katrina affected both quality of life and environmental quality in New Orleans. In this study, vegetation health and biomass, gathered from remotely sensed images, act as an indicator of environmental quality. Vegetation and socioeconomic variables can be used to create a Quality of Life index (QOL index) that incorporates environment (Lang et al. 2007; Li & Weng 2007; Lo & Faber 1997). The main objectives of this study are:

1. To investigate the use of two vegetation indices (Normalized Difference Vegetation Index, *NDVI*; and Tasseled Cap index of greenness, brightness, and wetness, *T-cap*) for assessing vegetation health and biomass as an indicator for environmental quality in Orleans parish
2. To measure the quality of life (QOL) in Orleans Parish by creating an empirically derived QOL index that incorporates remote sensing data and socioeconomic data, using factor analysis and regression analysis
3. To estimate the change in QOL before and after the major disturbance of Hurricane Katrina with reference to the processes of urban redevelopment and repopulation

Background research on QOL and environmental quality suggest several relationships. Based on well-described correlations between the greenness of an urban space and the wealth of its inhabitants, it is hypothesized that remotely sensed vegetative productivity would be a significant positive indicator of and a main contributor to QOL (Lo & Faber 1997). It is also postulated that QOL in vulnerable urban areas is lower after a major natural disaster.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 Quality of Life and Environment

Improving quality of life and environment (shortened as QOL hereafter) has been a major policy goal of individuals, communities, the nation, and the world. However, defining QOL and measuring it is complicated (Costanza et al. 2007). There are many concepts related to QOL, such as livability, environmental quality, and sustainability. Often these terms are used interchangeably and overlap conceptually. However, there is neither a uniform conceptual framework nor a consensus on an appropriate indicator system (Kamp et al. 2003). This can be illustrated by the large variety of definitions of these key concepts, as found by the literature review conducted by Kamp et al. (2003).

Although there is no comprehensive definition of QOL, many researchers agree that QOL is manifested by social, economic, and environmental circumstances. The United Nations (2010) defines QOL as a "notion of human welfare (well-being) measured by social indicators rather than by 'quantitative' measures of income and production." It has also been established that socioeconomic conditions such as population density, income, poverty, employment, health, education, and housing characteristics contribute to QOL (Li and Weng 2007; Lo and Faber 1997; Costanza et al. 2007; Kamp et al. 2003). Environmental conditions, such as the amount of green vegetation in the urban environment, are also an essential part of QOL (Jensen et al. 2004; Lang et al. 2007; Fung & Siu 2000; Lo & Faber 1997; Kamp et al. 2003; Li & Weng 2007). Thus community, economic, and environmental conditions intersect to create QOL. A conceptual model of these three factors is depicted in Figure 2.

2.2 Remote Sensing and Spectral Vegetation Indices

Several studies have used vegetation productivity as an indicator for environmental quality (Lo & Faber 1997; Fung & Siu 2000; Li &Weng 2007; Jensen et al. 2004). One reason for this is that the presence of trees and other green vegetation in a city helps mitigate the urban heat island effect (Lang et al. 2007). Another reason is that greenery tends to be correlated with higher home values (Lo & Faber 1997) and is used by landscape architects to improve the appearance of outdoor space (Fung & Siu 2000; Lang et al. 2007). Both NDVI and T-cap are useful indices in remote sensing for evaluating vegetation health and biomass, and thus can be used as indicators of environmental quality.

Figure 2: Conceptual model of factors that contribute to community quality of life (Shafer et al. 2000)

NDVI is probably the most often used vegetation index to detect changes in green biomass due to seasons, human activities, and natural disturbances (Wang & Xu 2010). NDVI values range from -1 to +1, where negative values correspond to an absence of vegetation (Pettorelli et al. 2005). Typical NDVI values for cover types are shown in Table 1. Dense green-leaf vegetation has NDVI values around 0.5, medium green-leaf vegetation around 0.140, light green-leaf vegetation around 0.09, bare soil around 0.35, and water around -0.257 (Holben 1986). NDVI is calculated using a band ratio of the near-infrared band (Landsat-TM Band 4) and the visible red band (Landsat-TM Band 3) as follows (Pettorelli et al. 2005; Wang and Xu 2010):

$$\boldsymbol{NDVI} = \frac{TM4 - TM3}{TM4 + TM3}$$

The formula is based upon the phenomena of chlorophyll absorbing red solar electromagnetic energy and the mesophyll leaf structure scattering near-infrared solar electromagnetic energy (Myneni et al. 1995). The relationship between NDVI and vegetation health and productivity is well established. The association between NDVI and the fraction of absorbed photosynthetic active radiation intercepted has been confirmed both theoretically and empirically (Sellers et al. 1992; Asrar et al. 1984).

Tasseled Cap (T-cap) transformation is a linear transformation of Landsat data that projects soil and vegetation information into a single place in multispectral data space in which the major spectral components of an agricultural scene are displayed in two dimensions. Initially defined for Landsat Multispectral Scanner (MSS) data, subsequent research has extended the concept to the six non-thermal bands of Landsat Thematic Mapper (TM). The coefficients are calculated by means of an iterative procedure that can be applied to as many bands as available (Campbell 2002). T-cap index of brightness (TCB), greenness (TCG), and wetness (TCW) are three of the six bands calculated from the Landsat-TM bands. The T-cap indices are able to measure presence and density of green vegetation, overall reflectance, and soil moisture content (Wang & Xu 2010).

Vegetation indices have been used in hurricane disturbance ecological studies. Bianchette et al. (2009) studied the effects of Hurricane Ivan on a coastal ecosystem in Alabama by computing the NDVI from pre- and post-hurricane images and creating a difference image to determine the extent and degree

Table 1: Typical NDVI values for various cover types (Holben 1986)

Cover Type	Red	NIR	NDVI
Dense green-leaf vegetation	0.050	0.150	0.500
Medium green-leaf vegetation	0.080	0.110	0.140
Light green-leaf vegetation	0.100	0.120	0.090
Bare soil	0.269	0.283	0.025
Clouds (opaque)	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

of damage. Wang and Xu (2010) compared the performance of four change detection algorithms with six vegetation indices derived from pre-and post-hurricane imagery to select an optimal remote sensing technique for identifying forestlands disturbed by Hurricane Katrina. They found that the T-cap index of wetness outperformed the other indices owing to its maximum sensitivity to forest modification. Another study used data from the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) 14 satellite and NDVI to assess natural disturbances in Puerto Rico resulting from Hurricane Georges (Ayala-Silva & Twumasi 2004).

2.3 Integration of Remote Sensing and Socioeconomic Data

Integration of remotely sensed and socioeconomic data has been used to assess environmental quality. A study in Hong Kong integrated mean NDVI values at the Tertiary Panning Unity level (basic units for census in Hong Kong) with census and land cover data for four dates from 1987 to 1995. It found that NDVI values were positively correlated to woodland and tall scrubland, and inversely related to high-density urban areas and high level of crowding. This assessment helped to reveal the effects of the urban expansion process on environmental quality (Fung & Siu 2000).

Remotely sensed vegetation indices and social perceptions have also been used to gauge prevalence and importance of green spaces in urban areas. A study conducted in Phoenix, Arizona and Salzburg, Austria used NDVI, object-based image analysis, and subjective social data (via interviews on importance of various green structures) to monitor urban green development. A Weighted Green Index was created, which combined the occurrence and distribution of relevant green structure types with the results of relative importance of these types in the eyes of the citizens. They argue that this type of collectively weighted indicator could help increase public acceptance of spatial-decision making (Lang et al. 2007).

Urban quality of life has also been studied in other cities. A study conducted in Terre Haute, Indiana, examined the urban quality of life by assessing the relationship between observed socioeconomic conditions and urban forest amenities. The paper observed the relationship between urban leaf area and a population density parameter with median income and median housing value. Results indicated positive

correlations between urban leaf area, population density, and their interaction with median income and median housing value. They found that leaf area and density statistically accounted for the observed variance in median income and median housing value. Therefore, the authors argue that these variables could be used to study observed quality of life metrics (Jensen et al. 2004).

Correlations have been shown to be high between remotely sensed environmental variables and socioeconomic variables. Lo and Faber (1997) correlated NDVI values, land use, and surface temperature with socioeconomic variables to assess the quality of life of Athens-Clarke County, Georgia. They found that NDVI had a high positive correlation with per capita income, median home values, and education attainment. Thus, they argued that NDVI provided a QOL measure by giving both environmental and socioeconomic implications. Their results showed that satellite image data can complement census data in providing QOL assessment with an environmental perspective (Lo & Faber 1997).

Remote sensing and socioeconomic data has also been combined to create a Quality of Life index (QOL index). Li and Weng (2007) integrated environmental (greenness, impervious surface, and temperature) with several socioeconomic variables to derive indicators of quality of life. Using factor analysis, they identified three aspects of quality of life: material welfare, environmental conditions, and crowdedness. A synthetic QOL index was computed and mapped based on weighted factor scores of these three factors. These studies indicate the importance and usefulness of interdisciplinary methods in analyzing environmental quality and quality of life.

This study will build on these approaches and concepts. This analysis serves to develop an integrated index to examine the QOL and environment in New Orleans after Hurricane Katrina. It aims to provide important insights on QOL after a major natural disaster and find the best indicators for sustainable development.

2.4 Study Area

New Orleans is a city located in southeastern Louisiana. Orleans Parish is surrounded by Lake Pontchartrain to the north, the Mississippi River to the south, and wetlands of the Lake Pontchartrain estuarine system to the west and east (Figures 3 and 4) (Presley et al. 2006). The city is also connected to Lake Pontchartrain and Brenton Sound via the Industrial Canal and the Mississippi River Gulf Outlet

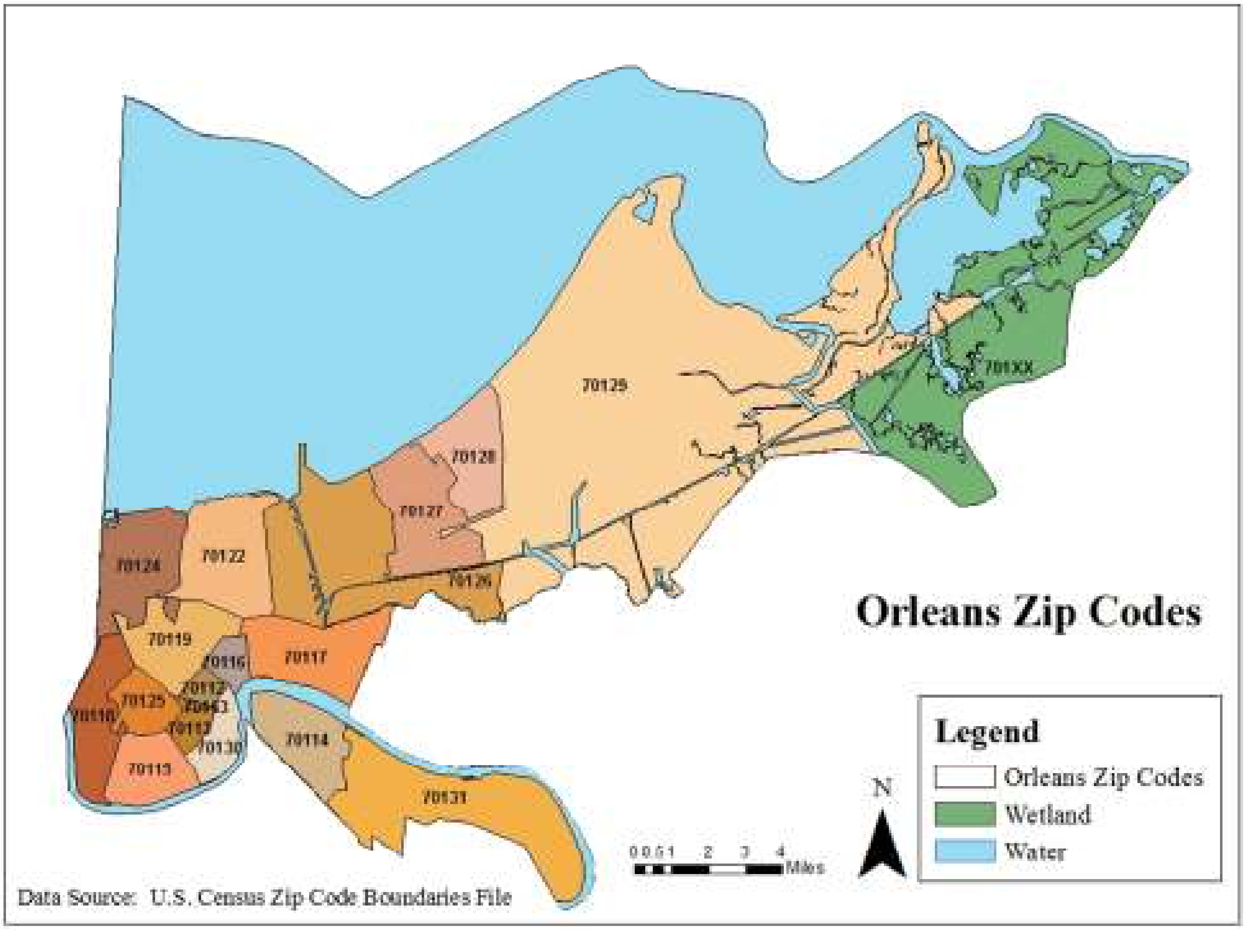

Figure 3: New Orleans zip codes (U.S. Census 2000)

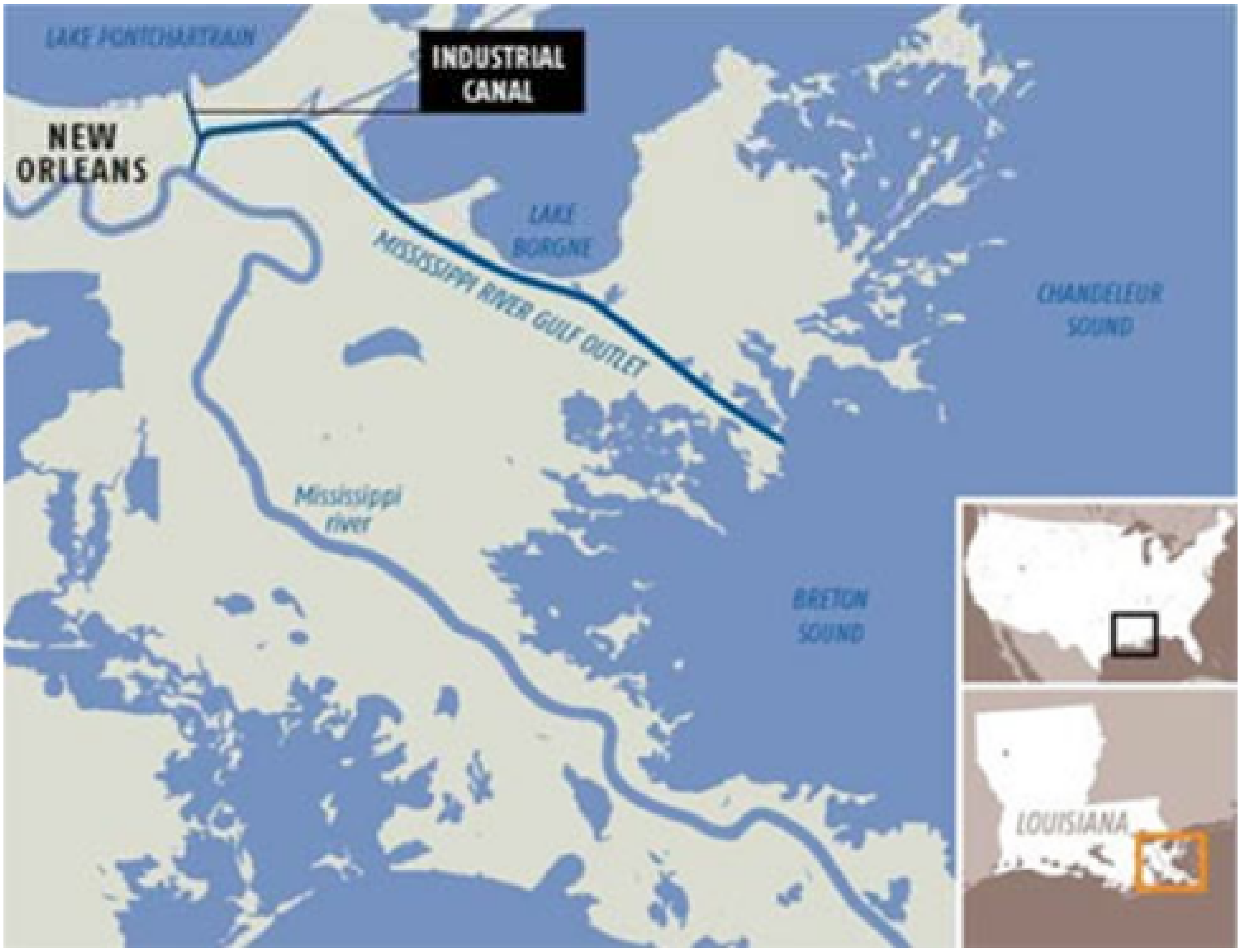

Figure 4: New Orleans in relation to surrounding water bodies (U.S. Army Corps of Engineers 2011)

(Figure 4). Most of New Orleans is currently 2-15 feet (0.6-5m) below sea level, due to natural and anthropogenically enhanced subsidence from compaction of clay soils and oxidation of organic matter (Costanza, Mitsch, & Day 2006). According to the United States Census Bureau, Orleans Parish has a total area of 350.2 mi^2 (907km^2), of which 180.56 mi^2 (467.6 km^2) is land. In 2000, the total population was 484,674 (U.S. Census Bureau 2004).

Zip codes were chosen as the unit of scale in this study for several reasons. Zip codes were selected to observe differences in QOL spatially throughout the city. This unit of scale was neither too broad nor too detailed. The socioeconomic variables related to QOL were also available at this level, but are not available at more detailed levels such as the census block level. This unit of scale is also germane to another study on resilience in the Gulf of Mexico region, which is creating a resilience index at the county and zip code level (Lam & Reams publication forthcoming). Therefore, zip codes could allow synergy between these two related studies. To provide some reference for the areas the zip codes represent, a map of the New Orleans neighborhoods is also provided (Figure 5).

Figure 5: New Orleans neighborhoods (Greater New Orleans Community Data Center 2010)

Chapter 3: Remote Sensing Analysis of Environmental Quality Changes

3.1 Methods

3.1.1 Image Selection and Preparation

Landsat-TM 5 Images were acquired from the United States Geological Survey (USGS) Earth Resource Observation Systems Data Center. Two images were selected, one from pre-Katrina (June 19, 2005) and one from post-Katrina (June 30, 2009). These images were selected because they were cloud free in the study area and both from the same month. The post-Katrina image was chosen to be several years after Katrina to measure the long-term changes in environmental quality. Both images were subset to the study area. Reflectance was calculated using a reflectance model with solar elevation and acquisition date so that values could be directly compared over time (Figures 6 and 7).

3.1.2 Vegetation Indices

Vegetation indices were calculated for pre- and post-Katrina images. The Normalized Difference Vegetation Index (NDVI) was calculated for both reflectance images. The NDVI was calculated using the band ratio of near-infrared (TM Band 4) to the visible red band (TM Band 3) as follows:

$$\boldsymbol{NDVI} = \frac{TM4 - TM3}{TM4 + TM3}$$

A Tasseled Cap (T-cap) transformation was also run on both reflectance images to derive indices for the brightness, wetness, and greenness (Braud 2009).

3.1.3 Land Cover Classification

The land cover classification for both time periods was conducted using a hybrid method employing both supervised and unsupervised procedures (Figure 8). The same method was used on both the 2005 and 2009 images. The images were classified using 2005 and 2008 DOQQ's and a 2005 NOAA land cover classification as references (Louisiana State University Atlas 2005; NOAA 2007). The NOAA land cover classification was based on Landsat TM scenes from 11/05/2004 to 8/15/2005.

The land cover categories used in this analysis were selected from the NOAA 2005 land cover classified image. These classes were chosen because they represented a significant portion of the study area and were germane to the analysis. The land cover categories used were 1) water, 2) forested wetland,

Figure 6: Pre-Katrina (June 19, 2005) reflectance image; bands 1-5, 7

Figure 7: Post-Katrina (June 30, 2009) reflectance image; bands 1-5, 7

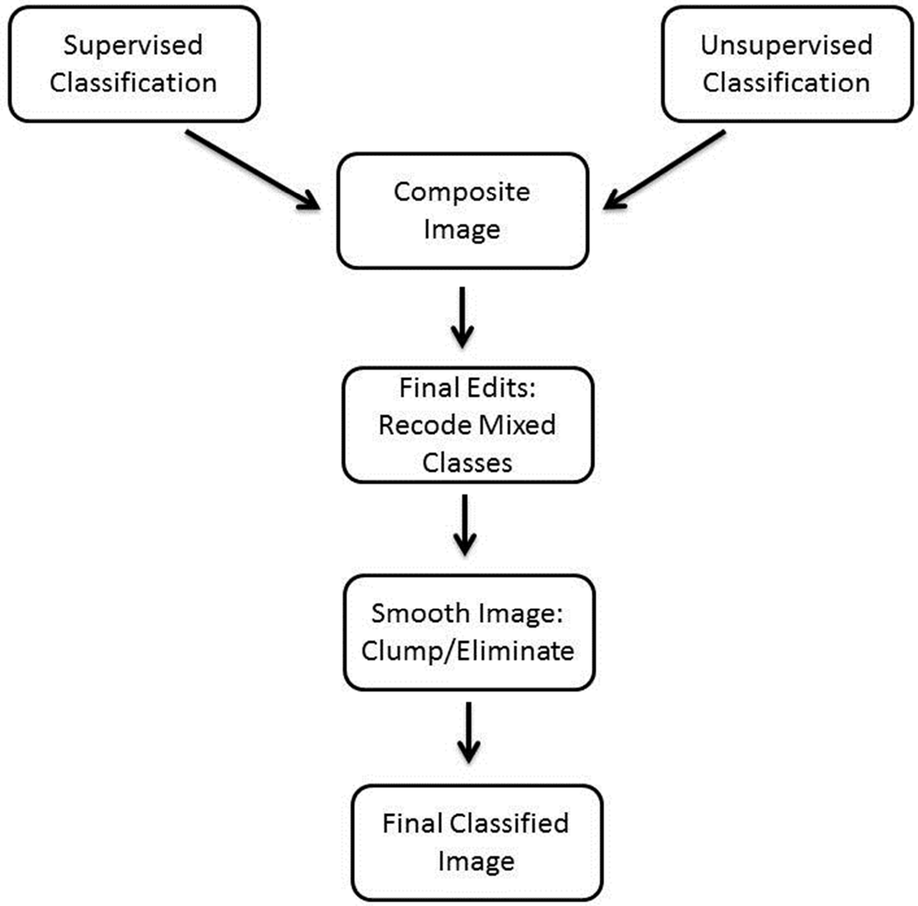

Figure 8: Land cover classification methods flow chart

3) nonforested wetland, 4) scrub/shrub wetland, 5) developed green space, and 6) low-mid intensity developed, and 7) high intensity developed.

In the supervised procedure, signatures were developed and evaluated for several land cover categories. Water, forested wetland, nonforested wetland, and scrub/shrub wetland were classified using supervised methodology and a Maximum Likelihood decision rule. A threshold was used to separate unclassified pixels, which were processed using the ISODATA unsupervised algorithm. The land cover categories identified in the unsupervised methodology were developed green space, low-mid intensity developed, and high intensity developed. A composite procedure was used to combine the supervised and unsupervised results using a spatial model to merge the images. A final edit was conducted to recode large obvious errors in the final classification. Clump and eliminate were run on the image to smooth the features and remove miscellaneous scattered pixels. An accuracy assessment using 256 randomly stratified points was then conducted on the final classified images using 2005 and 2008 DOQQ's as references to the pre-Katrina and post-Katrina classifications, respectively.

3.2 Results and Discussion

3.2.1 Vegetation Indices Analysis

NDVI and T-cap images were produced for 2005 and 2009 (Figures 9-12). For the NDVI images, lighter areas indicate higher NDVI values, and darker areas indicate lower NDVI values. For the T-cap images, red indicates the brightness component, green indicates the greenness component, and blue indicates the wetness component.

Difference images were developed from the NDVI and T-cap data by subtracting year 2005 values from year 2009 (Figures 13-16). Each layer of T-cap was analyzed separately to produce three difference images (one of brightness, one of greenness, and one of wetness). The T-cap greenness, brightness and wetness difference images are shown in Figures 14-16, respectively.

The NDVI and the T-cap greenness difference images were analyzed to help determine changes in vegetation. Lighter colored areas indicated an increase in NDVI or T-cap greenness from 2005 to 2009, and darker colored areas indicated a decrease in NDVI or T-cap greenness. Certain areas in both images experienced similar changes NDVI or T-cap greenness. The nonforested wetland in the northeast quadrant

Figure 9: Pre-Katrina (2005) NDVI image. Lighter areas indicate higher NDVI values.

Figure 10: Post-Katrina (2009) NDVI image. Lighter areas indicate higher NDVI values.

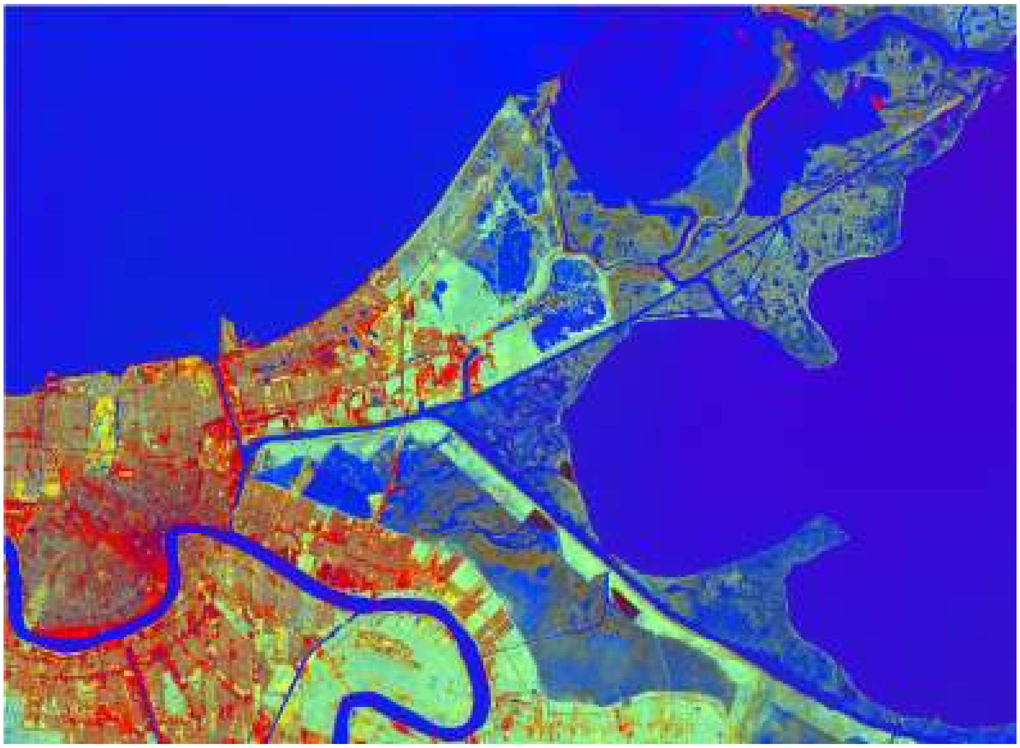

Figure 11: Pre-Katrina (2005) Tasseled Cap image. Green indicates greenness component, blue indicates wetness component, and red indicates brightness component.

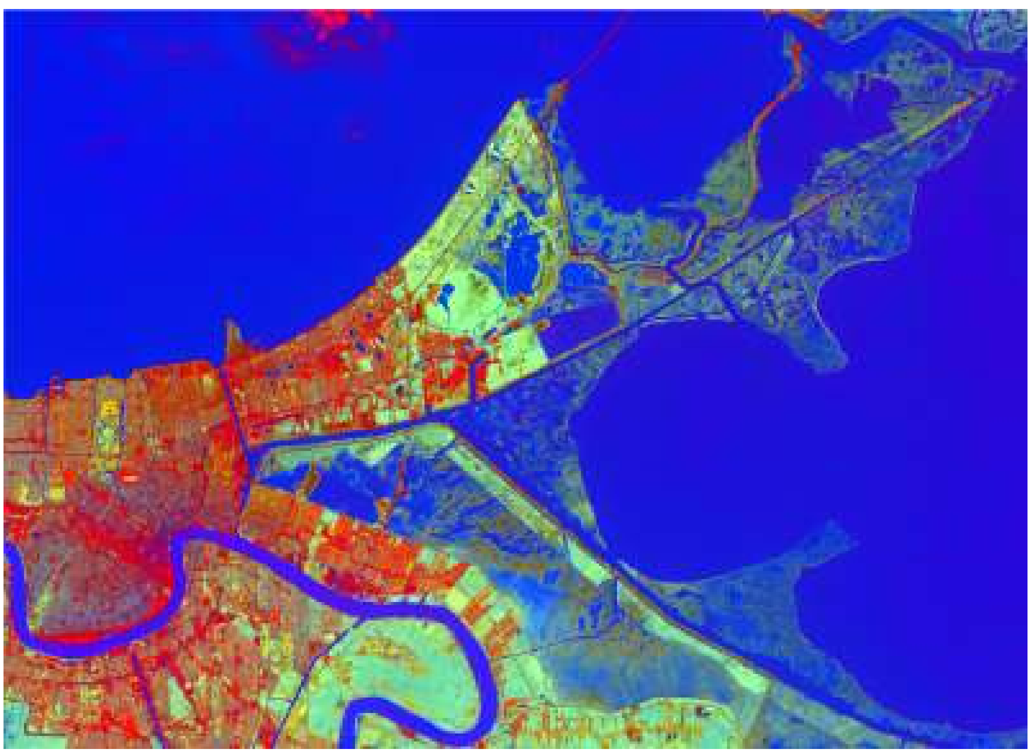

Figure 12: Post-Katrina (2009) Tasseled Cap image. Green indicates greenness component, blue indicates wetness component, and red indicates brightness component.

Figure 13: NDVI difference image (n= 2009-2005, where n is the difference of NDVI). Lighter areas indicate NDVI increase and darker areas indicate NDVI decrease after Katrina. Notable NDVI increases and decreases are circled in green and red, respectively.

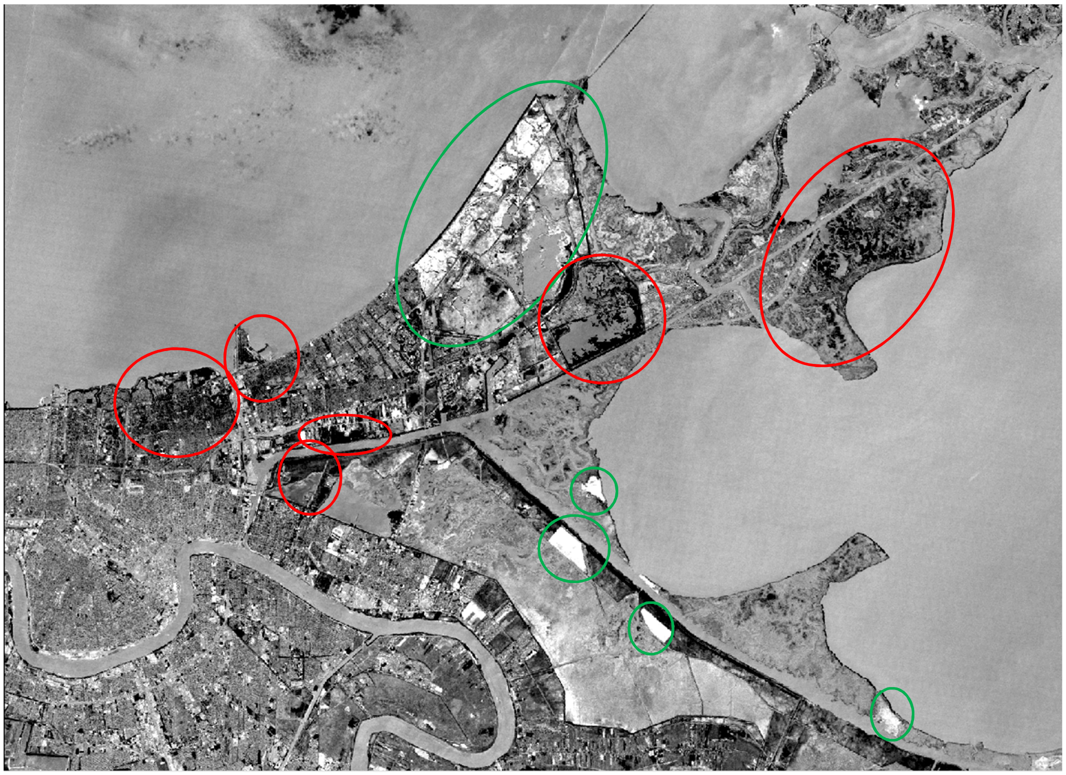

Figure 14: Tasseled Cap difference image for the greenness component (n= 2009-2005, where n is the difference of greenness). Lighter areas indicate an increase in greenness values and darker areas indicate a decrease in greenness values after Katrina. Notable T-cap greenness increases and decreases are circled in green and red, respectively

Figure 15: Tasseled Cap difference image for the brightness component (n= 2009-2005, where n is the difference of brightness). Lighter areas indicate higher brightness values and darker areas indicate lower brightness values after Katrina.

Figure 16: Tasseled Cap difference image for the wetness component (n= 2009-2005, where n is the difference of wetness). Lighter areas indicate higher wetness values and darker areas indicate lower wetness values after Katrina.

of the image experienced a decrease in NDVI and T-cap greenness from 2005 to 2009 (circled in red). Urban areas along Lake Pontchartrain also had lower NDVI and T-cap greenness values after Katrina (circled in red). Areas of scrub/shrub wetland along the Mississippi River Gulf Outlet and nonforested wetland along Lake Pontchartrain had increased NDVI and T-cap greenness from 2005 to 2009 (circled in green).

Increases of NDVI and T-cap in these areas indicate an improvement in vegetation productivity, biomass, and health post-Katrina, whereas decreases in NDVI or T-cap greenness indicate a decline. This would suggest that certain areas experienced improved environmental quality due to higher vegetation productivity, while other areas experienced a decline in environmental quality due to loss of vegetation biomass or deteriorating vegetation health. In order to further substantiate these results, a land cover analysis needed to be conducted.

3.2.2 Land Cover Analysis

The land cover classifications depict seven land cover categories, their areas in acres, and percent of the study area (Figures 17 and 18). The accuracy assessments indicated a 97.27% overall accuracy for the 2005 classification and a 99.61% overall accuracy for the 2009 classification (Tables 2 and 3). The high accuracies are due to the manual editing of misclassified pixels in the final edit.

A change detection analysis was conducted on the final classified images to observe changes in land cover. Land cover change was analyzed using a land cover change matrix (Table 4). Low-mid intensity developed and high intensity developed classes were combined into one class (urban) for the matrix analysis to reduce complexity and to more clearly examine changes in vegetation in developed areas. Changes from one land cover to another were calculated, as were changes in total area for each category from 2005 to 2009.

There were several significant changes between land cover categories from 2005 to 2009. According to the matrix, over 15% of forested wetland in 2005 changed to non-forested wetland in 2009. Nearly a quarter of scrub/shrub wetland in 2005 changed to nonforested wetland and another quarter to forested wetland. Over 29% of developed green space in 2005 changed to urban in 2009 and another 21% to forested wetland in 2009.

Class Name	Color	Area	Percent
Outside Study Area		0	0.00%
Water		263247	58.87%
Forested Wetland		24437	5.47%
Nonforested Wetland		65728.6	14.70%
Scrub/Shrub Wetland		5517.18	1.23%
Developed Green Space		6944.06	1.55%
Low-Mid Intensity Developed		67785.6	15.16%
High Intensity Developed		13481.1	3.01%

Figure 17: Pre-Katrina (2005) final land cover classification

Class Name	Color	Area	Percent
Outside study area		0	0.00%
Water		265618	59.40%
Forested Wetland		22893.1	5.12%
Nonforested Wetland		69714.4	15.59%
Scrub/shrub Wetland		5510.95	1.23%
Developed Green Space		8190.14	1.83%
Low Density Developed		55552.7	12.42%
High Density Developed		19660.4	4.40%

Figure 18: Post-Katrina (2009) final land cover classification

Table 2: Pre-Katrina (2005) land cover classification accuracy assessment

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Outside Study Area	0	0	0	---	---
Water	106	107	105	99.06%	98.13%
Forested Wetland	20	22	20	100.00%	90.91%
Non-forested Wetland	40	39	38	95.00%	97.44%
Shrub-scrub Wetland	18	16	16	88.89%	100.00%
Developed Green Space	15	15	14	93.33%	93.33%
Low-Mid Intensity Developed	38	38	37	97.37%	97.37%
High Intensity Developed	19	19	19	100.00%	100.00%
Totals	256	256	249		

Overall Classification Accuracy = 97.27%
Overall Kappa Statistics = 0.9641

Table 3: Post-Katrina (2009) land cover classification accuracy assessment

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Outside Study Area	0	0	0	---	---
Water	128	128	127	99.22%	99.22%
Forested Wetland	17	18	17	100.00%	94.44%
Non-forested Wetland	39	39	38	97.44%	97.44%
Shrub-scrub Wetland	10	10	10	100.00%	100.00%
Developed Green Space	13	11	11	84.62%	100.00%
Low-Mid Intensity Developed	36	33	32	88.89%	96.97%
High Intensity Developed	13	17	13	100.00%	76.47%
Totals	256	256	248		

Overall Classification Accuracy = 96.88%
Overall Kappa Statistics = 0.9552

Table 4: Land cover change matrix. Class areas are in acres. Percent indicates change from reference of Pre-Katrina (2005) image. Changes are based on land cover classifications. Low-mid intensity developed and high intensity developed classes were combined into "Urban" for clarity. Notable changes (>10%) between land covers are highlighted in yellow. Negative percentage values in the "Change" column indicate loss from 2005 in that category.

Land Cover Category in 2009	Land Cover Category in 2005							
	Water	**Forested Wetland**	**Nonforested Wetland**	**Scrub/Shrub Wetland**	**Developed Green Space**	**Urban**	**Total Acres (2009)**	**Change from 2005 to 2009**
Water	259,420	173	4,760	20	229	1,015	265,618	1%
	98.55%	0.71%	7.24%	0.37%	3.30%	1.25%		
Forested Wetland	49	16,848	1,320	1,316	1,504	1,855	22,893	-6%
	0.02%	68.95%	2.01%	23.86%	21.66%	2.28%		
Nonforested Wetland	3,336	3,780	57,373	1,356	298	3,572	69,714	6%
	1.27%	15.47%	87.29%	24.58%	4.29%	4.39%		
Scrub/Shrub Wetland	24	1,731	977	2,712	14	52	5,511	0%
	0.01%	7.08%	1.49%	49.16%	0.20%	0.06%		
Developed Green Space	82	934	457	19	2,868	3,830	8,190	18%
	0.03%	3.82%	0.70%	0.34%	41.31%	4.71%		
Urban	334	971	842	93	2,030	70,942	75,213	-7%
	0.13%	3.98%	1.28%	1.69%	29.23%	87.30%		
Total Acres (2005)	263,247	24,437	65,729	5,517	6,944	81,267		
Total Percent	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%		

Changes in total area for each land cover category from 2005 to 2009 were also calculated. There was a slight overall increase in water and nonforested wetland (1% and 6%, respectively) and a slight overall decrease in forested wetland and urban from 2005 to 2009 (-6% and -7%, respectively). There was a moderate overall increase in developed green space (18%) from 2005 to 2009. Scrub/shrub wetland experienced essentially no net change in total acres (0%) from 2005 to 2009.

Although these findings depict substantial changes in certain land covers in Orleans Parish after Katrina, these results could also be due in part to the complexity of the image. The land cover classifications serve as a generalization of land cover. Not every detail is accurately represented and many classes are mixed together among the image. Developed green space is scattered throughout the image in close proximity to urban areas and forested wetland. These intricacies could explain some of the changes from 2005 and 2009. However, these results still give a useful indication of these changes.

Changes in vegetation can serve as indicators of environmental quality. Since wetland loss in Louisiana is a major concern, a change analysis of land loss and land gain was conducted for the study area (Figure 19). Any land class that changed to water represented land loss. Vegetation gain/loss was also analyzed (Figure 20). Any vegetated class (wetland and developed green space) that changed to non-vegetation (developed or water) represented vegetation loss. Vegetation or land gain is shown in green and vegetation or land loss is shown in red. Results from these change detections are similar to those in the NDVI and T-cap change detections. The nonforested wetland in the northeast quadrant of the image experienced wetland loss. Areas of scrub/shrub wetland along the Mississippi River Gulf Outlet and nonforested wetland along Lake Pontchartrain gained wetland. Vegetation was also gained in developed green spaces of the study area, including within some parks and agricultural areas.

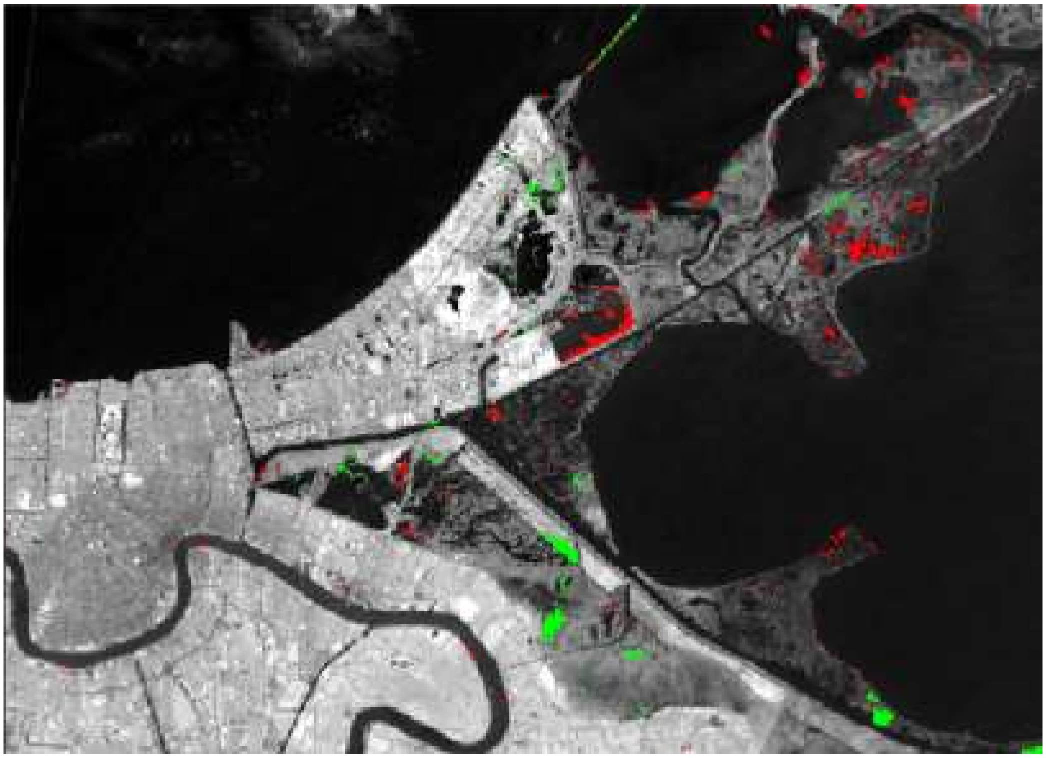

Figure 19: Land loss/gain map. Land loss is represented by any land class (wetland, developed, developed green space) changing to water. Green areas indicate land gain, red areas indicate land loss.

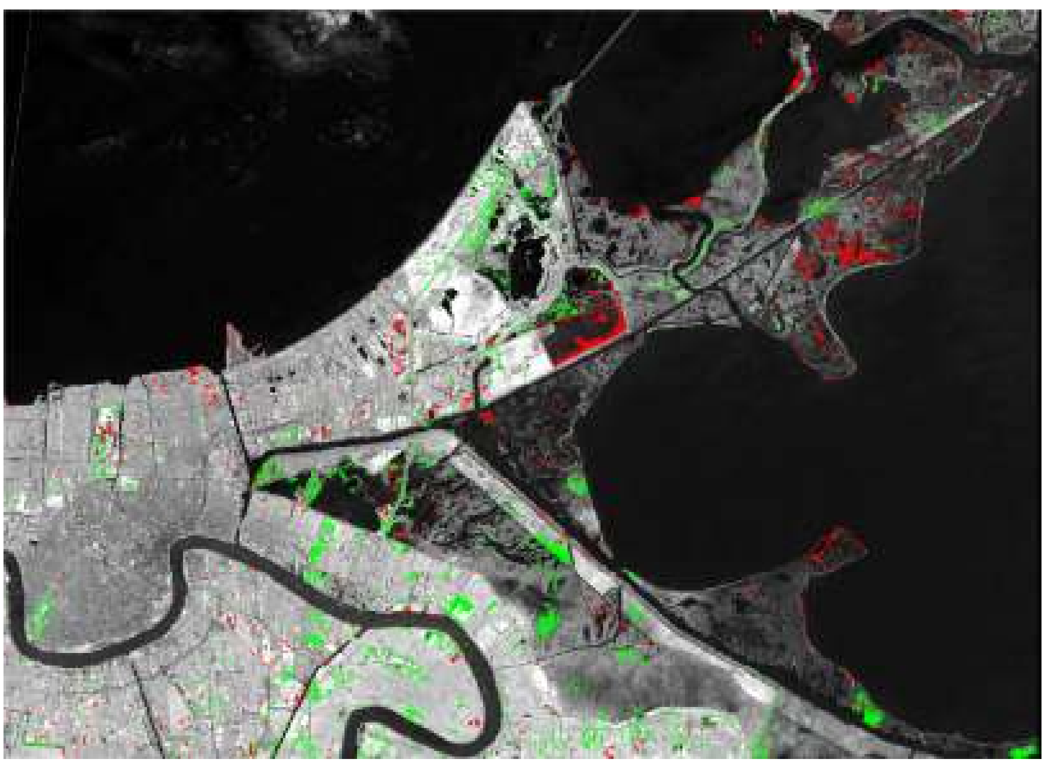

Figure 20: Vegetation Change map. Vegetation includes wetland and developed green space classes. Green areas indicate vegetation gain, red areas indicate vegetation loss.

CHAPTER 4: CREATION OF QUALITY OF LIFE INDEX

4.1 Methods

4.1.1 Integration of Data

Socioeconomic variables contributing to QOL were selected for this analysis based on the literature (Fung & Siu 2000; Lo & Faber 1997; Li & Weng 2007). Original data values can be found in Table 12 of the appendix. The socioeconomic data was gathered or derived from U.S. Census Bureau zip code tabulation area (ZCTA) data for year 2000 and included: 1) median household income, 2) per capita income, 3) housing density, 4) population density, 5) education level (as percent of the population over 25 with a bachelor's degree), 6) median home value, 7) percent of the population below poverty, and 8) percent unemployment.

In order to create the QOL index, the remote sensing data and socioeconomic data needed to be integrated. A descriptive, weighted QOL index model was developed using pre-Katrina data. To do this, several layers of data were input into the GIS:

- Zip code boundary files from the U.S. Census
- Pre-Katrina NDVI layers
- Pre-Katrina T-cap layers of brightness, wetness, and greenness
- Flood depth (September 2, 2005) (LSU GIS Information Clearinghouse: CADGIS Lab 2005)

Zip codes 70163 and 701XX were excluded from this analysis. 70163 is a small zip code (< 0.003 mi^2) in the Central Business District, which had many missing values (Table 12 in Appendix). Thus it was removed from analysis to avoid skewed results. 701XX is wetland with no population and therefore was not applicable to the QOL analysis (Figure 23).

The mean values for each zip code for NDVI, T-cap brightness, greenness, and wetness, and flood depth were derived from the GIS using zonal tabulation (Table 13 in Appendix). These mean values were input along with the socioeconomic zip code data into a factor analysis. A depiction of this integration method is shown in Figure 21.

4.1.2 Factor Analysis

QOL is a complex concept and is difficult to measure directly. However, there are many

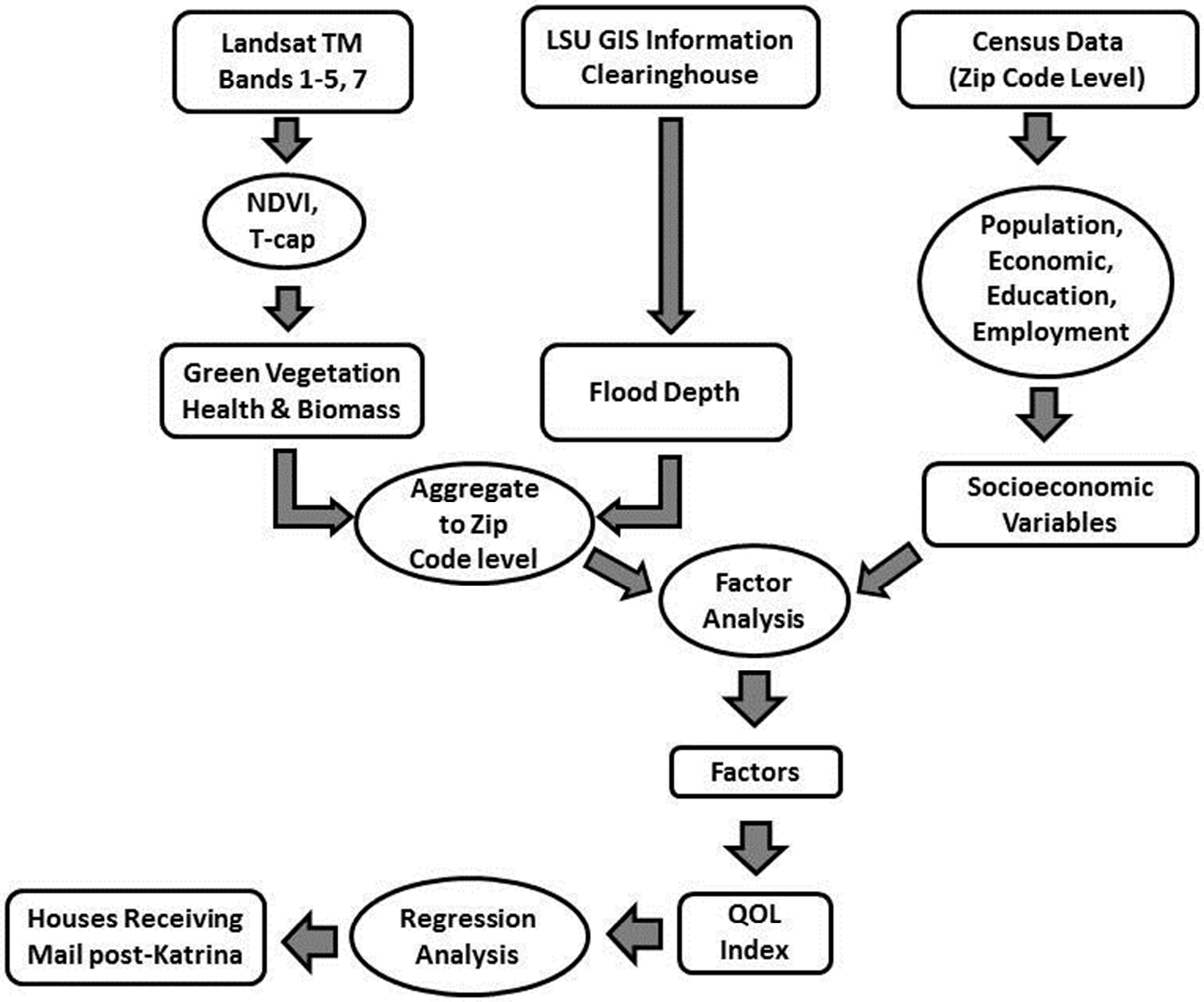

Figure 21: Flow chart of integration method

underlying constructs that can help explain and simplify this multifaceted phenomenon. Factor analysis is a statistical technique that can be used to identify a relatively small number of factors that explain observed correlations among variables. It is also helpful in reducing the number of variables that measure the underlying dimensions of QOL (Norusis 2003). In essence, factor analysis can help derive QOL.

The eight socioeconomic variables, mean NDVI and T-cap components' values, and flood depth values were analyzed in SPSS using the principal components analysis option under factor analysis. After factor extraction, varimax rotation was used to maximize the variance among factors and minimize the variance within factors. The goal was to find a small number of clearly defined factors that explained most of the variance. After several trials, all T-cap components were removed from the analysis, since brightness and wetness were creating an additional factor with a low eigenvalue, and the vegetation health (or greenness) was determined to be adequately represented by NDVI. After several additional trials, per capita income was also excluded since it was highly correlated with education level, and median household income adequately described earnings. Removing these variables from analysis helped reduce data redundancy. Flood depth was entered as negative values, to specify that no or little flooding contributed positively to QOL.

Initially the factors were extracted using eigenvalues over one. However, after examining the initial eigenvalues (Table 5) and the scree plot (Figure 22), it was determined that the first four factors had relatively high eigenvalues (above or near 1), and explained a large percent of the variance (95.3% after rotation). This means that these four factors can effectively describe the seven variables selected to represent QOL in New Orleans based on the literature.

Once the factors were selected, the top two positively loading variables for each factor in the rotated component matrix were chosen to represent the factor (Tables 6 and 7). Factor 1 was named "Sustainability" because it was described by NDVI and median household income. Factor 2 was named "Urbanization" because it was described by population density and housing density. Factor 3 was named "Wealth" because it was described by level of education and median home value. Factor 4 was named "Flooding" because it was described by only the flood depth variable. These factors and variables are shown in Table 7. The total variance explained was rescaled to equal 100% (instead of 95.3%). Once the

Table 5: Total variance explained

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.950	54.995	54.995	4.950	54.995	54.995	3.227	35.852	35.852
2	1.915	21.277	76.273	1.915	21.277	76.273	2.212	24.579	60.431
3	.980	10.893	87.166	.980	10.893	87.166	2.080	23.107	83.538
4	.732	8.131	95.297	.732	8.131	95.297	1.058	11.758	95.297
5	.225	2.503	97.799						
6	.103	1.145	98.944						
7	4.96E-02	.551	99.496						
8	3.55E-02	.394	99.890						
9	9.91E-03	.110	100.000						

Extraction Method: Principal Component Analysis.

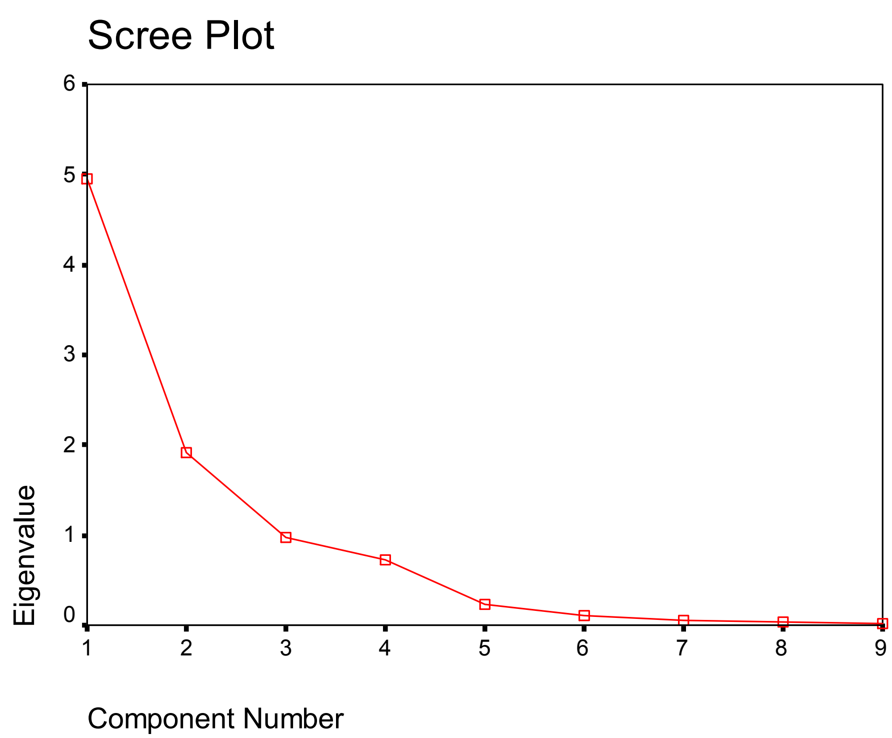

Figure 22: Scree plot

Table 6: Rotated component matrix

Rotated Component Matrix [a]

	Component			
	1	2	3	4
PCTPOV	-.924			
NDVI05	.871	-.412		
MEDINC	.784		.413	
PCTUNEMP	-.744		-.404	
POPDEN		.949		
HOUDEN		.934		
MEDHV			.990	
PCTEDU	.495		.845	
FLOOD				.982

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 5 iterations.

Table 7: Total variance explained, rescaled variance, and variable weights

Component	**Highest Loading Variables**	**% Original Variance Explained**	**% Rescaled Variance**	**Weight for each variable**
Sustainability	NDVI, MEDINC	35.869	37.624	18.812
Urbanization	POPDEN, HOUDEN	24.612	25.816	12.908
Wealth	MEDHV, PCTEDU	23.1	24.230	12.115
Flooding	FLOOD	11.754	12.329	12.329
		95.335	100.000	
		Total Original Variance Explained	Total Rescaled Variance	

rescaled variance was calculated for each factor, the weight for each representative variable was calculated (Table 7). The rescaled variances for factors 1, 2, and 3 were divided evenly between the two representative variables for each factor. For example, factor 1 had a rescaled variance of 37.624 which resulted in a weight of 18.812 for NDVI and median household income. Factor 4 was represented by one variable, flood depth, and thus this variable weight was 12.329, the same as the factor rescaled variance. It is important to note that these weights serve as important guidelines for contribution to QOL, but are not inferential.

An additive model was used to create the QOL index. The weighted variables were added since they contributed positively to QOL. The representative variables were normalized before being placed into the weighted, additive model to create the QOL index, using the formula below (Baker 2009):

Normalization Formula: (Equation 1)

$$V = (X - Xmin)/(Xmax - Xmin)$$

Where *X* = original variable, *Xmin* = minimum value of variable X, *Xmax* = maximum value of variable X, and *V* = normalized variable

QOL Additive Model: (Equation 2)

$$QOL = \sum_{i=1}^{n} ViWi$$

Where *n* = number of variables selected from significant factors, *Vi* = normalized variable value for zip code, and *Wi* = percentage of variance the variable explains

4.2 Results and Discussion

4.2.1 QOL Index

Once rescaling, normalizing, and weighting were completed, a final descriptive model of QOL for New Orleans' zip codes was determined. This model was used to calculate QOL for pre- and post-Katrina. The final model for the QOL index was:

QOL = (Equation 3)

$$18.812NDVI + 18.812MEDINC + 12.908POPDEN + 12.908HOUDEN + 12.115MEDHV + 12.115PCTEDU + 12.329FLOOD$$

QOL index values were determined for each zip code (Table 8). The index ranged from 0-1, with 1 being the highest QOL. The lowest QOL index scores pre-Katrina were observed in zip codes: 70112, 70117, 70113, 70129, and 70127. The highest QOL index scores pre-Katrina were observed in zip codes: 70118, 70116, 70130, 70115, 70124, and 70131. Zip code 70112 had the lowest QOL index value pre-Katrina at 0.28 and 70131 had the highest QOL index value at 0.65. The pre-Katrina QOL index values were mapped to examine the spatial attributes of the index (Figure 23).

Using the natural breaks method to divide the index values into three classes, it was found that the QOL index demonstrated spatial contiguity. Zip codes with the highest QOL were adjacent to one another as were the zip codes with the lowest QOL. Notable areas with high QOL were the zip codes bordering the Mississippi River, including Downtown, Uptown, the Garden District, and West Bank. Another area that exhibited a high QOL index value was the Lakefront area. Notable areas with low QOL were New Orleans East, the Lower Ninth Ward, and the Central Business District. Areas with moderate QOL were Mid-City, Treme, Broadmoor, Gentilly Terrace, and Algiers, as well as parts of New Orleans East.

The lowest QOL index scores were seen in the French Quarter, Central Business District, Lower Ninth Ward, and New Orleans East areas. Zip code 70112 coincides with parts of the Central Business District and French Quarter neighborhoods. This area sustained some flooding, but flood depth was low (1.99 feet) compared to what other parts of the city experienced. The reason the QOL index for 70112 was lowest was due mainly to low NDVI and low median income. This area is highly developed, contributing to its low NDVI value (0.165). Median household income in this zip code was very low, only $7,448 annually. Zip code 70117 coincides with the Lower Ninth Ward and Holy Cross neighborhoods. This area sustained a great deal of flooding (3.9 feet) and also had the lowest median home value of all the zip codes ($57,000). It also had low education level (only 7.4% of population over 25 with a bachelor's degree), and low median income ($19,567). Zip code 70113 coincides with the Central Business District, and had the lowest education level (4.2%) and second lowest median income ($12,048). Zip codes 70129, 70126, and 70127 coincide with the New Orleans East area. These zip codes were characterized by relatively low median household income (around $30,000), relatively low education level (between 10.7% and 14% with a bachelor's degree), and relatively high flood depths (between 3.6

Table 8: Pre-Katrina QOL index values for New Orleans zip codes. Some notable coinciding neighborhoods are included for reference. Lowest data values are highlighted in red; highest data values are highlighted in green

Zip Code	Pre-Katrina QOL Index	Level of QOL	Some Coinciding Neighborhoods	NDVI05	MEDINC99	HOUDEN00	POPDEN00	PCTEDU00	MEDHV00	FLOOD05
70112	0.28	Low	French Quarter/Central Business District	0.165035	7,448	3,428	6,810	9.6	111,400	-1.994696
70117	0.31	Low	Lower Ninth Ward/Holy Cross	0.320612	19,567	3,453	7,877	7.4	57,000	-3.878855
70113	0.33	Low	Central Business District	0.230123	12,048	4,844	9,612	4.2	63,500	-1.442119
70129	0.34	Low	New Orleans East	0.407837	31,439	73	209	10.7	82,900	-2.605682
70126	0.36	Low	New Orleans East	0.394659	30,627	1,073	2,747	14.0	75,200	-3.627659
70127	0.4	Moderate	New Orleans East	0.422551	30,954	1,773	4,518	13.3	84,000	-3.869809
70119	0.42	Moderate	Mid City	0.328231	21,297	4,305	10,137	9.9	78,200	-2.916523
70122	0.42	Moderate	Gentilly Terrace	0.428898	31,104	2,656	6,385	14.5	83,400	-4.853431
70125	0.44	Moderate	Broadmoor/Gert Town	0.317289	20,089	4,314	9,980	14.0	106,400	-3.657375
70114	0.46	Moderate	Algiers/U.S. Naval Base	0.451909	23,379	2,565	5,895	9.2	67,500	0
70128	0.46	Moderate	New Orleans East	0.455627	42,326	1,391	4,092	17.7	92,800	-4.995747
70118	0.53	High	Audubon	0.39995	28,006	3,579	7,870	20.7	112,100	-2.754755
70116	0.54	High	Treme/Laffitte/Marigny	0.272004	21,150	7,829	12,481	15.6	89,500	-1.608727
70130	0.55	High	Garden District/Central Business District	0.186557	26,387	4,439	6,927	21.6	179,700	-0.631325
70115	0.59	High	Uptown/Garden District	0.322398	27,094	5,484	10,525	19.7	147,100	-2.441756
70124	0.64	High	Lakefront	0.471145	51,684	1,833	3,663	28.1	182,400	-5.423113
70131	0.65	High	West Bank	0.568039	45,592	873	2,220	21.5	113,900	0

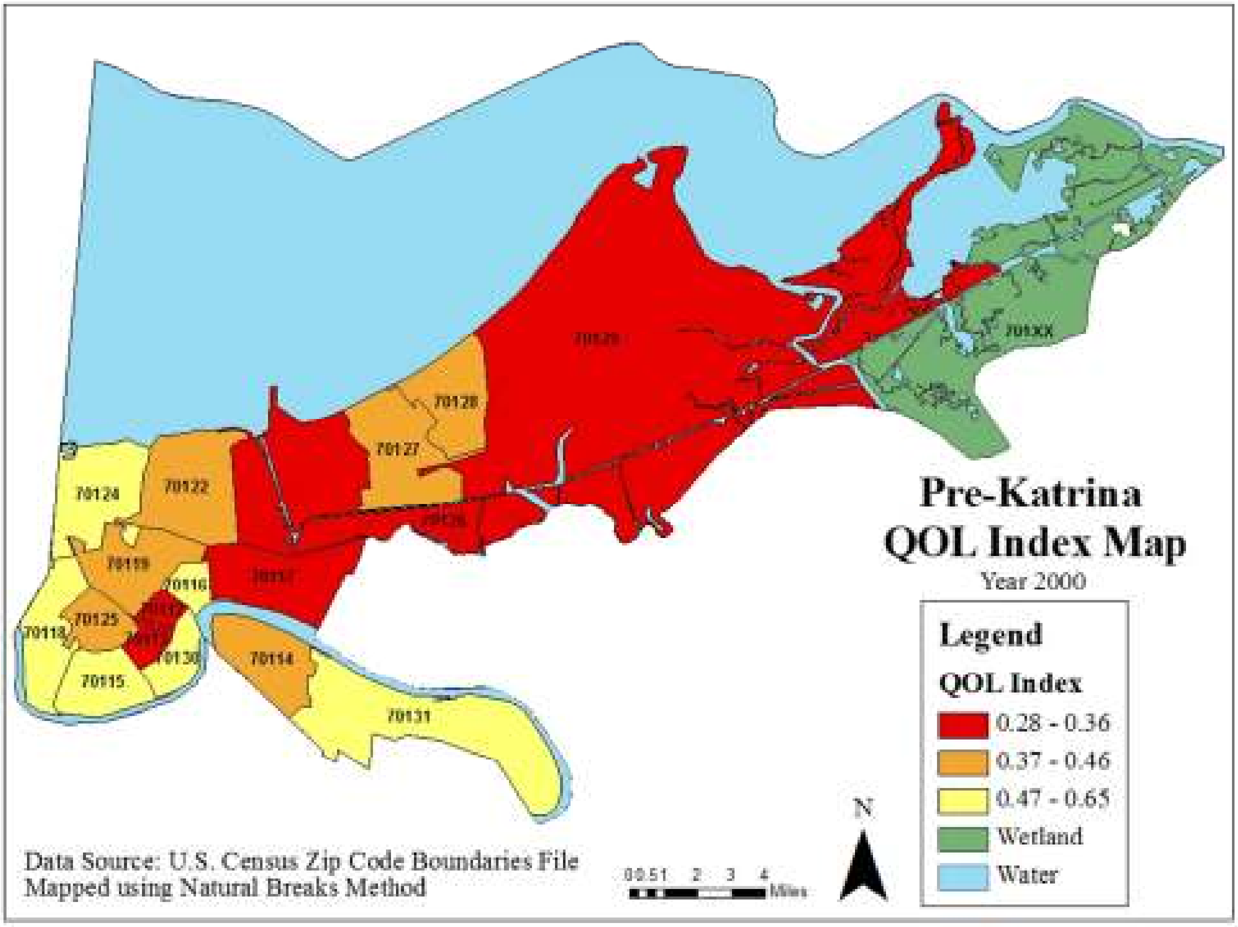

Figure 23: Pre-Katrina QOL index map for New Orleans zip codes. QOL index range is 0-1 with 1 being the highest QOL. Wetland and water classes were not included in this analysis.

and 3.9 feet). Zip code 70129 was also the largest zip code and had the lowest housing density (73 houses per mi^2) and population density (209 people per mi^2).

The highest QOL index scores were seen in the Audubon, Garden District, Uptown, Lakefront, and West Bank areas. Zip code 70131 coincides with the West Bank area. This area of the city sustained no flooding, contributing to its high QOL index score. It also had the highest NDVI (0.568) and second highest median income ($45,592). Additionally, this zip code had relatively high median home value ($113,900) and education level (21.5% of people over 25 had a bachelor's degree). Zip code 70124 has the second highest QOL score (0.64) and coincides with the Lakefront area. This high QOL is interesting because this area also sustained the greatest flood depth (average of 5.4 feet), which would decrease its QOL score. However, it also exhibited the highest median income ($51,684), highest education level (28.1%), highest median home value ($182,400), and second highest NDVI (0.47), all of which increased the QOL for this zip code.

These results lend to interesting speculations. Zip codes with high QOL were in areas that have tended to have high, stable economic conditions. QOL was also high in areas that did not flood. This makes sense since flood depth decreased the index score. However, one zip code (70124) in the Lakefront area experienced a great deal of flooding, but still exhibited a high QOL index value. This appears to be due to the high wealth and income in the area. High values for median income, education level, median home value, and NDVI appeared to contribute the most to high QOL. It is important to note that no one variable can explain QOL, which further emphasizes the need for this index.

4.2.2 Index Validation

To fully understand how QOL in Orleans Parish was affected by Hurricane Katrina, this QOL index needs to be validated and calculated for pre- and post-Katrina years. Households receiving mail by zip code in August 2006 was used as an indicator for population return after Katrina to verify the QOL index. Population return can be viewed as a gauge of recovery in the parish after the storm. A correlation analysis was run in SPSS between the QOL index and the households receiving mail in 2006 for each zip code. This resulted in a Pearson correlation of 0.546 with a 2-tailed significance of 0.023. Therefore, the QOL index is significantly correlated with households receiving mail in 2006 at the 0.05 level (2-tailed).

This validation suggests that the QOL index adequately measures aspects of QOL.

4.2.3 Temporal Changes in QOL

To see temporal changes in QOL it was also necessary to calculate QOL index values for each zip code post-Katrina. Socioeconomic data for 2009 at the zip code level was collected from city-data.com (http://city-data.com/city/New-Orleans-Louisiana.html, accessed May 23, 2011). The variables available for 2009 included: 1) median household income, 2) median home value, 3) housing density, and 4) population density. Educational attainment data values from 2000 were used due to lack of availability for year 2009. Mean flood depth after Katrina was the same as 2005 in the QOL index model. Mean NDVI values for each zip code post-Katrina were also input into the model.

Using the descriptive QOL index model (Equations 1, 2, and 3), QOL values were determined for each zip code post-Katrina (Tables 9 and 10). The lowest QOL index scores post-Katrina were observed in zip codes: 70117, 70126, 70129, 70113, 70112, 70127, and 70122, while the highest QOL was observed in zip codes: 70116, 70118, 70124, 70131, 70115, and 70130. Zip code 70117 had the lowest QOL index value post-Katrina at 0.25 and zip code 70130 had the highest at 0.6. The validation using households receiving mail in August 2008 resulted in a Pearson correlation of 0.510 with a 2-tailed significance of 0.037, showing similar accuracy to the pre-Katrina QOL index.

The post-Katrina QOL index values were mapped to examine the spatial distribution of the index (Figure 24). The post-Katrina QOL index also demonstrated spatial contiguity. Most zip codes had the same levels of QOL (high, moderate, or low) as in pre-Katrina. The zip codes bordering the Mississippi River, West Bank, and Lakefront had the highest QOL. The zip codes in New Orleans East, Lower Ninth Ward, and Central Business District had the lowest QOL. Only two zip codes (70122 and 70127) changed levels of QOL (from moderate to low) after Katrina (Table 10).

To further examine the changes in QOL after Katrina, a QOL index change map was created (Figure 25). Most zip codes demonstrated a decrease in QOL from 2000 to 2009. Four zip codes experienced an increase (+0.01 to +0.05) in QOL index value (70115, 70125, 70112, and 70130). Zip code 70130 had the highest increase of +0.05 from 2000 to 2009 (Table 9). This zip code corresponds to the Garden District and Central Business District, which also had the fourth highest QOL pre-Katrina.

Table 9: Pre- and Post-Katrina QOL index values for each zip code. The difference in QOL was calculated using the following formula: n = Post Katrina QOL – Pre Katrina QOL, where n is the difference in QOL

Zip Code	Pre-Katrina QOL Index	Post-Katrina QOL Index	Change in QOL	Difference
70112	0.28	0.31	Increase	0.03
70113	0.33	0.3	Decrease	-0.03
70114	0.46	0.43	Decrease	-0.03
70115	0.59	0.6	Increase	0.01
70116	0.54	0.51	Decrease	-0.03
70117	0.31	0.25	Decrease	-0.06
70118	0.53	0.52	Decrease	-0.01
70119	0.42	0.41	Decrease	-0.01
70122	0.42	0.32	Decrease	-0.1
70124	0.64	0.58	Decrease	-0.06
70125	0.44	0.46	Increase	0.02
70126	0.36	0.27	Decrease	-0.09
70127	0.4	0.31	Decrease	-0.09
70128	0.46	0.37	Decrease	-0.09
70129	0.34	0.27	Decrease	-0.07
70130	0.55	0.6	Increase	0.05
70131	0.65	0.58	Decrease	-0.07

Table 10: Post-Katrina QOL index values for New Orleans zip codes. Some notable coinciding neighborhoods are included for reference. Lowest data values are highlighted in red; highest data values are highlighted in green

Zip Code	Post-Katrina QOL Index	Level of QOL	Some Coinciding Neighborhoods	NDVI09	MEDINC09	HOUDEN09	POPDEN09	PCTEDU00	MEDHV09	FLOOD05
70117	0.25	Low	Lower Ninth Ward/Holy Cross	0.228969	23,004	3,453	9,207	7.4	129,773	-3.878855
70126	0.27	Low	New Orleans East	0.280229	34,279	1,073	3,057	14.0	139,959	-3.627659
70129	0.27	Low	New Orleans East	0.329701	34,168	73	226	10.7	131,875	-2.605682
70113	0.3	Low	Central Business District	0.172302	18,091	4,844	14,350	4.2	128,688	-1.442119
70112	0.31	Low	French Quarter/Central Business District	0.136106	12,284	3,428	11,166	9.6	268,077	-1.994696
70127	0.31	Low	New Orleans East	0.306113	33,981	1,773	4,931	13.3	145,453	-3.869809
70122	0.32	Low	Gentilly Terrace	0.282409	37,128	2,656	7,577	14.5	149,493	-4.853431
70128	0.37	Moderate	New Orleans East	0.348484	48,004	1,391	4,614	17.7	172,643	-4.995747
70119	0.41	Moderate	Mid City	0.254525	31,776	4,305	15,037	9.9	200,783	-2.916523
70114	0.43	Moderate	Algiers/U.S. Naval Base	0.370648	33,249	2,565	8,335	9.2	132,966	0
70125	0.46	Moderate	Broadmoor/Gert Town	0.239036	36,196	4,314	17,877	14.0	229,264	-3.657375
70116	0.51	High	Treme/Laffitte/Marigny	0.212056	33,013	7,829	19,370	15.6	131,722	-1.608727
70118	0.52	High	Audubon	0.325851	44,524	3,579	12,440	20.7	207,479	-2.754755
70124	0.58	High	Lakefront	0.355895	74,315	1,833	5,237	28.1	311,357	-5.423113
70131	0.58	High	West Bank	0.495355	51,483	873	2,493	21.5	184,781	0
70115	0.6	High	Uptown/Garden District	0.250684	44,184	5,484	17,064	19.7	316,754	-2.441756
70130	0.6	High	Garden District/Central Business District	0.150161	49,409	4,439	12,896	21.6	361,199	-0.631325

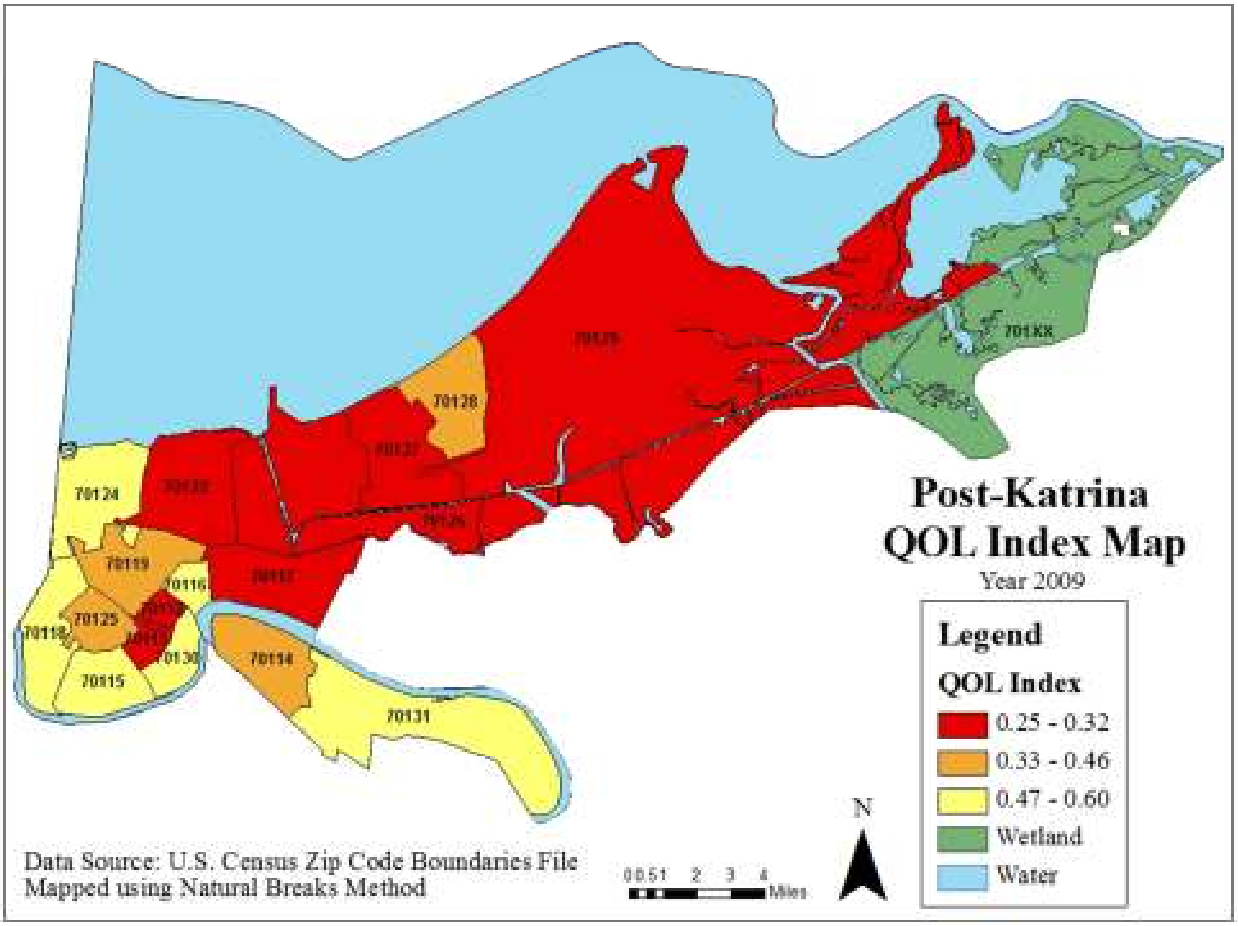

Figure 24: Post-Katrina QOL index map for New Orleans zip codes. QOL index range is 0-1 with 1 being the highest QOL. Wetland and water classes were not included in this analysis

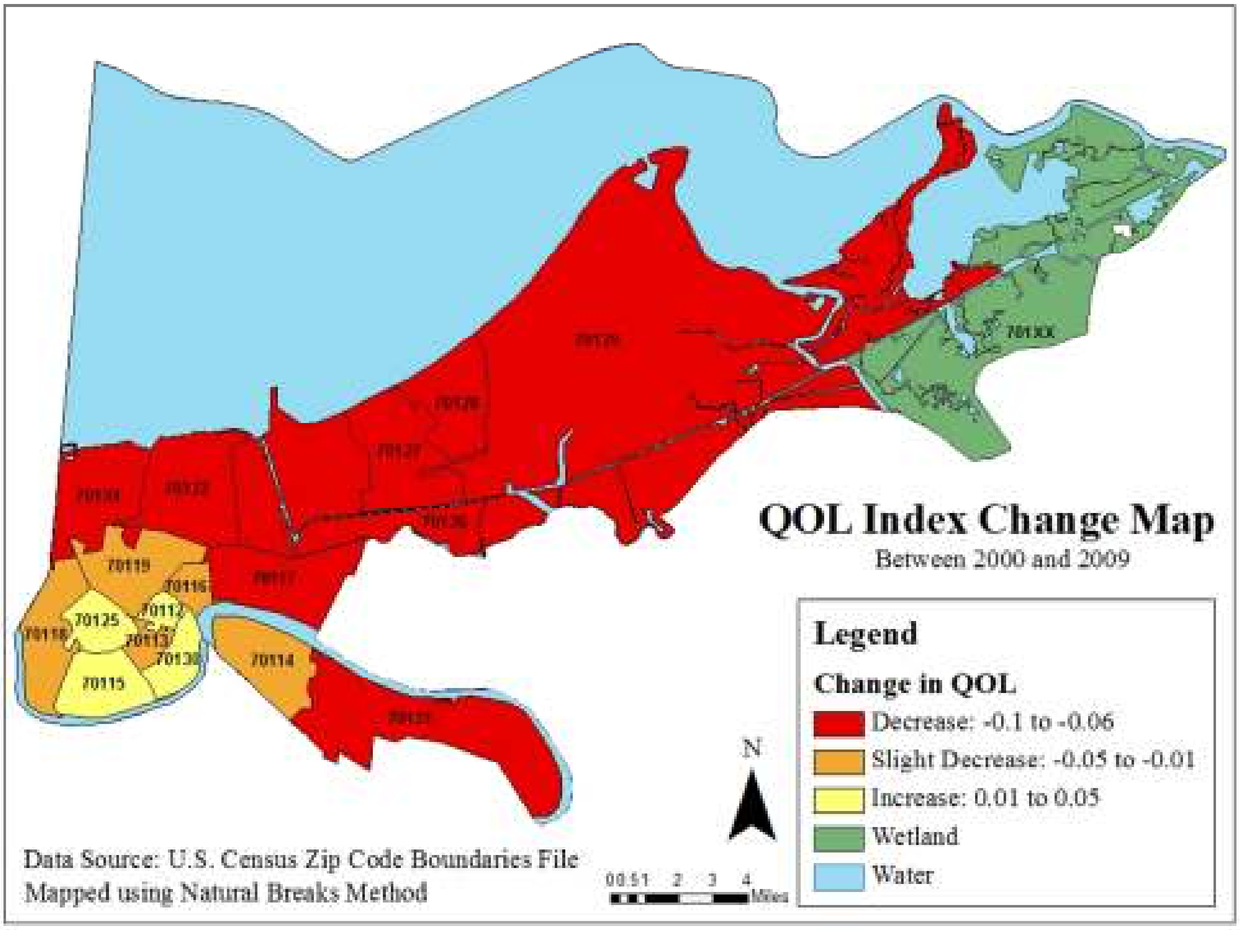

Figure 25: QOL index change map for New Orleans zip codes (n = Post Katrina QOL – Pre Katrina QOL, where n is the difference in QOL). Wetland and water classes were not included in this analysis

This spatiotemporal analysis of QOL suggests that Katrina negatively impacted QOL in New Orleans. Areas that were more vulnerable to flooding or had less wealth experienced a decrease in QOL. However, areas that exhibited higher QOL pre-Katrina, which had higher income, wealth, and NDVI values, tended to have a lesser extent of decrease in QOL or even had higher QOL index values four years after Katrina. These areas appear to be more resilient to the natural disaster. Based on these findings, the two research hypotheses stated on page 3 can be upheld. The first hypothesis was substantiated in that vegetation abundance in urban areas (NDVI values) was found to have a high loading in the factor analysis, contributing to high QOL. The second hypothesis that QOL in vulnerable urban areas (or low QOL areas pre-Katrina) decreased after Katrina can also be confirmed.

CHAPTER 5: CONCLUSIONS

5.1 Impact of Hurricane Katrina on QOL in New Orleans

This thesis has attempted to bring in the aspect of the natural environment and provide means for linking human and natural systems. The results of this integrated analysis indicate that Hurricane Katrina did impact QOL in New Orleans. Certain areas of the parish were more affected than others. From the standpoint of the natural environment, some wetland was lost on the fringes of the parish from 2005 to 2009. Continued wetland loss over time could make the city more vulnerable to future storm surges. Future flooding could negatively impact QOL in New Orleans. Areas of the city that experienced flooding from the storm tended to have lower QOL, whereas areas that experienced no flooding, such as West Bank, had higher QOL. However, income and wealth did help to counter the negative effects of flooding and increase QOL in those zip codes. Areas that had high NDVI also contributed to higher QOL. Four years after Katrina, much of the city experienced a decrease in QOL as indicated by the drop in QOL index values. However, areas of the city that had high income and wealth tended to maintain or even increase their high QOL, as was case in Uptown and the Garden District. This study suggests that higher values of income, wealth, and vegetation contribute to higher QOL and increase resilience to natural disturbances. These areas that had higher QOL pre-Katrina had the smallest decrease in QOL or increased in QOL. Conversely, areas that had lower QOL pre-Katrina had the largest decrease in QOL, suggesting a much more severe impact from the disaster or a lower adaptive capacity to rebound.

5.2 Uses of Index

This QOL index and model has many practical applications. QOL is important for city planning, and can help planners make informed decisions about development. Because the index includes NDVI, it emphasizes the importance of vegetation and how it can contribute to environmental quality and QOL in a community. Policy makers can also use the QOL index to distribute resources appropriately as well as make decisions and enact laws that could improve QOL. The QOL index would also be of great interest to homebuyers and businesses, since people would likely like to reside and do business in communities with high QOL. This QOL index could also be useful for hazard mitigation and economic stability, to understand which communities could be most vulnerable to natural disasters and economic disturbances.

The importance of this index can also be seen in light of the Mississippi River flood of 2011, which has affected and continues to affect many communities with a wide range of socioeconomic characteristics and surrounding environs. This study could be applied in other communities and the information generated by this research will make it possible to more clearly understand, and possibly even predict, the far-reaching consequences of the Mississippi River flood on residents of many affected states.

5.3 Future Research

Although this QOL index provides great insight on the quality of life and environment in New Orleans, it can be improved in several ways to broaden its applications. First, the QOL index could be further verified with other data that indicates QOL. Crime and/or health variables could serve as additional validation to this index. Correlating the index with other indicators of QOL will help to further determine its accuracy.

Another possible future research study would be to look at QOL at different scales. For instance, QOL could be examined at the county level. In the case of Katrina, QOL could be compared along the Gulf Coast in Louisiana, Mississippi, Alabama, and Florida. QOL and vegetation could also be examined at the census tract or block group level to get a more detailed view of QOL in neighborhoods.

It would also be useful to collect data from more time periods. Data from the 2010 U.S. Census would be very important to further research QOL. Additionally, examining QOL sooner (i.e. one year later) after Katrina could yield interesting temporal changes. The index could be calculated and validated for these time periods to determine if the index still adequately measures QOL. This would help to further determine if the QOL in New Orleans is sustainable over a period of years and after a natural disaster. Analyzing the change of QOL through time could depict a community's level of resilience. Thus, QOL measures could be linked to the resilience literature and offer understanding on indicators for sustainable development.

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APPENDIX: ORIGINAL DATA AND DEFINITIONS

Table 11: Variable Sources and Definitions

Year	Abbreviation	Variable	Source Definition	Source
2000	PCTUNEMP00	Unemployment	Unemployed Civilian Labor Force	U.S. Census 2000
1999	PCTPOV99	Poverty Level	Families below poverty level	U.S. Census 2000
2000	PCTEDU00	Education Level	Population 25 years and over with Bachelor's degree	U.S. Census 2000
1999	MEDINC99	Median Household Income	Median household income (dollars)	U.S. Census 2000
1999	PCINC99	Per Capita Income	Per capita income (dollars)	U.S. Census 2000
2000	MEDHV00	Median Home Value	Median value (dollars) for all Owner-Occupied Housing Units	U.S. Census 2000
2000	HOUDEN00	Housing Density	Total housing units/land area (square miles)	U.S. Census 2000
2000	POPDEN00	Population Density	Total population/land area (square miles)	U.S. Census 2000
2005	NDVI05	NDVI	Normalized Difference Vegetation Index	Landsat 5 TM Image
2005	BRIGHT05	T-cap Brightness	Tasseled Cap Index- Brightness Component	Landsat 5 TM Image
2005	GREEN05	T-cap Greenness	Tasseled Cap Index- Greenness Component	Landsat 5 TM Image
2005	WET05	T-cap Wetness	Tasseled Cap Index- Wetness Component	Landsat 5 TM Image
2005	FLOOD05	Flood depth	Flood depth (feet) post-Katrina on September 2, 2005	LSU GIS Clearinghouse, U.S. Army Corps of Engineers
2009	MEDINC09	Median Household Income	Median household income (dollars)	http://www.city-data.com/city/New-Orleans-Louisiana.html
2009	MEDHV09	Median Home Value	Estimated median house/condo value in 2009	http://www.city-data.com/city/New-Orleans-Louisiana.html
2009	HOUDEN09	Housing Density	Houses and condos/land area (square miles)	http://www.city-data.com/city/New-Orleans-Louisiana.html
2009	POPDEN09	Population Density	Estimated Population in 2009/land area (square miles)	http://www.city-data.com/city/New-Orleans-Louisiana.html
2009	NDVI09	NDVI	Normalized Difference Vegetation Index	Landsat 5 TM Image
2009	BRIGHT09	T-cap Brightness	Tasseled Cap Index- Brightness Component	Landsat 5 TM Image
2009	GREEN09	T-cap Greenness	Tasseled Cap Index- Greenness Component	Landsat 5 TM Image
2009	WET09	T-cap Wetness	Tasseled Cap Index- Wetness Component	Landsat 5 TM Image

Table 12: Original socioeconomic data

Zip Code	PCTUNEMP	PCTPOV	PCINC	PCTEDU	MEDINC	MEDHV	HOUDEN	POPDEN	MEDINC	MEDHV	HOUDEN	POPDEN
Year	**2000**	**1999**	**1999**	**2000**	**1999**	**2000**	**2000**	**2000**	**2009**	**2009**	**2009**	**2009**
Unit	*%*	*%*	*$*	*%*	*$*	*$*	*per sq. mi*	*per sq. mi*	*$*	*$*	*per sq. mi.*	*per sq. mi.*
70112	8.7	75.1	8,403	9.6	7,448	111,400	3,428	6,810	$12,284	$268,077	3,428	11,166
70113	10.0	45.3	8,327	4.2	12,048	63,500	4,844	9,612	$18,091	$128,688	4,844	14,350
70114	5.3	30.3	12,288	9.2	23,379	67,500	2,565	5,895	$33,249	$132,966	2,565	8,335
70115	5.2	24.4	22,672	19.7	27,094	147,100	5,484	10,525	$44,184	$316,754	5,484	17,064
70116	7.2	33.7	17,794	15.6	21,150	89,500	7,829	12,481	$33,013	$131,722	7,829	19,370
70117	6.8	34.0	10,595	7.4	19,567	57,000	3,453	7,877	$23,004	$129,773	3,453	9,207
70118	4.5	18.7	23,201	20.7	28,006	112,100	3,579	7,870	$44,524	$207,479	3,579	12,440
70119	5.1	29.2	13,885	9.9	21,297	78,200	4,305	10,137	$31,776	$200,783	4,305	15,037
70122	5.0	19.9	16,582	14.5	31,104	83,400	2,656	6,385	$37,128	$149,493	2,656	7,577
70124	1.3	3.6	36,292	28.1	51,684	182,400	1,833	3,663	$74,315	$311,357	1,833	5,237
70125	10.1	37.3	14,377	14.0	20,089	106,400	4,314	9,980	$36,196	$229,264	4,314	17,877
70126	4.8	18.8	14,146	14.0	30,627	75,200	1,073	2,747	$34,279	$139,959	1,073	3,057
70127	5.4	15.3	14,817	13.3	30,954	84,000	1,773	4,518	$33,981	$145,453	1,773	4,931
70128	4.9	14.2	17,174	17.7	42,326	92,800	1,391	4,092	$48,004	$172,643	1,391	4,614
70129	5.4	26.3	13,016	10.7	31,439	82,900	73	209	$34,168	$131,875	73	226
70130	5.8	33.5	25,809	21.6	26,387	179,700	4,439	6,927	$49,409	$361,199	4,439	12,896
70131	4.0	10.0	22,885	21.5	45,592	113,900	873	2,220	$51,483	$184,781	873	2,493
70163	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999
701XX	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999	-999

Table 13: Original vegetation, flood depth, and area data

Zip Code	NDVI	NDVI	FLOOD	BRIGHT	GREEN	WET	BRIGHT	GREEN	WET	AREA
Year	**2009**	**2005**	**2005**	**2005**	**2005**	**2005**	**2009**	**2009**	**2009**	
Unit	#	#	*Feet*	#	#	#	#	#	#	*sq. mi.*
70112	0.136106	0.165035	-1.994696	0.393069	-0.079751	-0.143012	0.387626	-0.086677	-0.126213	0.92
70113	0.172302	0.230123	-1.442119	0.381102	-0.059691	-0.140612	0.384026	-0.07648	-0.125551	1.07
70114	0.370648	0.451909	0	0.38566	0.021126	-0.127037	0.380881	-0.006994	-0.113689	4.82
70115	0.250684	0.322398	-2.441756	0.370054	-0.031594	-0.128274	0.362768	-0.050482	-0.10814	3.83
70116	0.212056	0.272004	-1.608727	0.339381	-0.040265	-0.114237	0.344198	-0.057184	-0.103923	1.34
70117	0.228969	0.320612	-3.878855	0.348261	-0.020767	-0.112328	0.355202	-0.048501	-0.11518	6.51
70118	0.325851	0.39995	-2.754755	0.360835	0.001667	-0.11899	0.35701	-0.021915	-0.10451	4.68
70119	0.254525	0.328231	-2.916523	0.378113	-0.025908	-0.131858	0.380707	-0.047991	-0.122525	4.95
70122	0.282409	0.428898	-4.853431	0.374822	0.013217	-0.124402	0.38601	-0.037995	-0.146528	7.29
70124	0.355895	0.471145	-5.423113	0.375442	0.030821	-0.119291	0.384004	-0.010499	-0.132631	6.27
70125	0.239036	0.317289	-3.657375	0.379688	-0.031438	-0.13775	0.380086	-0.054358	-0.124742	2.39
70126	0.280229	0.394659	-3.627659	0.359848	0.006429	-0.106675	0.362651	-0.034685	-0.121716	14.81
70127	0.306113	0.422551	-3.869809	0.379764	0.013195	-0.121459	0.394068	-0.029613	-0.138521	7.00
70128	0.348484	0.455627	-4.995747	0.384647	0.028616	-0.119878	0.386676	-0.012733	-0.132818	5.02
70129	0.329701	0.407837	-2.605682	0.272615	0.021099	-0.051348	0.28441	-0.003928	-0.061843	71.56
70130	0.150161	0.186557	-0.631325	0.398905	-0.074815	-0.14171	0.387582	-0.08252	-0.117164	2.15
70131	0.495355	0.568039	0	0.357225	0.069148	-0.090229	0.352862	0.040068	-0.079038	12.79
70163	0.136094	0.193508	-0.904512	0.323838	-0.060507	-0.082114	0.337537	-0.080291	-0.080768	0.00
701XX	0.225831	0.364411	0	0.250009	0.000901	-0.047016	0.239219	-0.034574	-0.041253	28.13

VITA

Danielle LaRock was born in Leesburg, Virginia, and grew up in the Washington, D.C., metro area. She initially attended Tulane University in New Orleans, Louisiana, in 2005, where she became passionate about environmental and social issues after witnessing the devastation of Hurricane Katrina. She spent her first semester of college at the University of Virginia, where she did all she could to learn about the impacts of the storm. She ended up transferring to UVA to complete her undergraduate studies, but Louisiana was never far from her mind or her heart. She graduated in 2009 from UVA and was given an amazing opportunity to work on her graduate studies at Louisiana State University. Her time at LSU was academically stimulating, rewarding, and positive. Thanks to wonderful teachers, loving family, encouraging friends, and a little bit of yoga, she will graduate with a Master of Science in August 2011. She has been accepted to the Presidential Management Fellows program, a flagship leadership developed program in the federal government for advanced degree candidates. She is looking forward to a career in public service where she can work with environmental science and policy and act as a liaison between science and the public to develop sustainable solutions to environmental problems.