A Mixed Method Multi-scale Analysis:
A Case Study on Extreme Heat in Phoenix, AZ

Darren Ruddell

School of Geographical Sciences
Arizona State University
Tempe AZ 85287-0104
(480) 965-6913
Fax:(480) 965-8313
darren.ruddell@asu.edu

A Mixed Method Multi-scale Analysis:

A Case Study on Extreme Heat in Phoenix, AZ

Abstract

Mixed method multi-scale analysis presents two distinct challenges: 1) investigations of various physical or social processes at multiple scales of analysis typically employ either a quantitative or qualitative framework; and 2) mixed method analyses (the integration of quantitative and qualitative techniques) often examines a single scale of analysis. A pressing challenge among studies of socio-ecological issues, however, is to examine a given process via the mixed method framework at multiple scales of analysis. This study aimed to address this gap in research by examining extreme heat in the Phoenix, AZ (USA) metropolitan area as a case study. Specifically, I employ the Weather Research and Forecast (WRF) climate model to simulate local environmental conditions while using self-reported perceptions on temperature from a social survey of local residents. Data were synthesized into a mixed method framework and analyzed at multiple scales of analysis (e.g., regional and neighborhood), which compared biophysical conditions (e.g., local temperature) with social perceptions of temperature at two spatial scales of analysis. Local media reports were also analyzed to determine if media coverage on extreme heat may have influenced local and/or regional perceptions. Research findings support utilizing the mixed method multi-scale research framework tested in this study.

Keywords: scale, mixed method, GIS, climate change, environmental perception

1 INTRODUCTION

Within the framework of hypothesis testing and developing theories and laws designed to procure truth, knowledge, and enhanced understanding are various methods for investigating biophysical and social processes. While biophysical scientists traditionally employ quantitative approaches (e.g., mathematical techniques, theorems, and proofs) to examine form and/or causal relations of a given system, social scientists often utilize qualitative methods (e.g., personal interviews, surveys, text analysis, among other techniques) to investigate how people experience and/or view the world (Johnston et al. 2000). Recently, however, scholars have integrated quantitative and qualitative approaches into a mixed method framework which has become an increasingly popular research technique in the scientific community (Boyd 2000; Thurmond 2001). For instance, scholars have utilized the mixed method framework to investigate a variety of complex research topics such as water resource management, quality of life (QoL), climate change, among other issues (Baker et al. 2003; Bolin et al. 2008; Costanza et al. 2007; Harlan et al. 2006). The argument for mixed methods is that studies employing exclusively quantitative or qualitative methods often present a limited picture of a given process; however, mixed method analyses provide a multidimensional perspective into various phenomena, and thereby, increases the ability to present truth, knowledge, and enhanced understanding (Dunning et al. 2008; Mitchell 1986; Shih 1998).

Mixed method analysis was initially used to validate a study's findings by using both quantitative and qualitative research methods (Shih 1998). Over time, the mixed method approach moved beyond a validation system (confirming research findings) to a framework that utilizes multiple methods to enhance the current understanding of a given process (comprehension) (Reichardt and Cook 1979; Tashakkori and Teddlie 1998). Confirmation is defined as the convergence of findings from two or more data sets which have been generated via general accepted approaches. Comprehension blends quantitative and qualitative research techniques to help provide a more inclusive understanding of a phenomenon. The assumption is that each research method is vulnerable to different weaknesses and/or biases, but the use of multiple methods seeks to counterbalance the shortcoming of any single strategy (Jick 1979; Thurmond 2001). While a quantitative analysis aims to provide hard, replicable, and reliable data, qualitative measures focus on richness, depth, and data validity (Shih 1998). Recent work by Dunning et al. (2008) examined issues of quality of life (QoL) via the *confirmation* and *comprehension* framework, and notable research findings included: 1) a lack of confirmation between quantitative and qualitative methods; 2) methodological challenges in operationalizing the mixed method framework; and 3) enriched comprehension (analyses identified two variables contributing to perceived QoL).

The confirmation/comprehension framework lends itself to examining socio-ecological issues since such studies require an investigation of both social and biophysical dimensions of a given problem. Socio-ecological issues refer to the coupled feedback between human decision-making (or behavioral patterns) and the associated impacts on the dynamic natural environment (Gimblett et al. 2001). Climate change represents a social-ecological issue whereby human development and the modification of the natural environment has resulted in increased anthropogenic heat into the environment contributing to rising global temperatures and urban heat islands (UHI) (IPCC 2001; Lowry 1967; Oke 1997). The modification of native landscapes into urban centers has transformed natural systems, which in turn, have resulted in warming temperatures, regionally and globally. While scholars routinely examine physical dimensions of climate change, public perceptions of climate change are relatively under-researched yet equally important for developing effective policy to adapt to or mitigate the impacts of climate change (Brazel et al. 2000; IPCC 2007; Leiserowitz 2005; Oke 1987).

Another mechanism to provide depth to an investigation is through multi-scale analysis. Scholars investigating socio-ecological issues, for instance, have recently focused on processes of variable spatial and temporal scales (Easterling and Polsky 2004). Current literature on scale-related issues highlights two distinct themes: first, research findings may communicate different (even conflicting) results when analyzing data at multiple scales of analysis. For instance, Imeson and Lavee’s (1998) study of soil erosion and climate change found that spatial and temporal scales do not exhibit a linear relationship, but vary based on local properties such as slope, patch, and/or landscape. The second theme on scale research is that studies utilizing mixed theoretical or methodological approaches have helped advance research on scale. Work by Bolin et al. (2008), for instance, juxtaposed environmental conflicts over water resources with local politics in Arizona. This study required a synthesis of socially defined political boundaries that were spatially mismatched with natural watershed boundaries. Scientists therefore are making new and valuable research contributions to research on scale by utilizing the mixed method framework.

Although research has benefited from mixed method analysis by confirming results and/or enhancing the comprehension of a given process, one limitation of mixed method research is the tendency to examine one scale of analysis. For instance, while Dunning et al. (2008) enhanced comprehension on QoL via the mixed method framework, the spatial scale of analysis (the city of Saskatoon, Saskatchewan) was constant. Employing mixed methods to a single scale of analysis (temporal or spatial) presents similar limitations to investigating a given process using a single methodology (e.g., quantitative or qualitative). Since studies examining processes at multiple scales of analysis via a single methodology have identified patterns of non-linearity, and investigations using the mixed method framework at a single scale have added richness to a study, it is likely that a mixed method multi-scale analysis will further enhance the present knowledge and understanding of a given process.

New research challenges (e.g., socio-ecological issues) often require new or alternative methods to better understand a given process. While quantitative or qualitative methodologies offer insight into various physical or social processes, this study aimed to evaluate the potential of enhancing the mixed method framework to analyze a multi-process issue (e.g., climate change) at multiple scales of analysis. Specifically, I test the confirmation/comprehension framework by analyzing biophysical and social measurements of temperature as one dimension of climate change at multiple scales of analysis (regional and neighborhood) among forty diverse Phoenix, AZ metropolitan neighborhoods. Analyses offer a comparison on the physical distribution of temperatures to public perceptions of temperature throughout selected neighborhoods. I also incorporate a text analysis to determine if public perceptions were influenced by local media sources. Confirmation and comprehension were assessed by comparing results of environmental conditions with public perceptions of temperature throughout the study area. The research question informing this study is: *1) Does analyzing extreme heat via a mixed method multi-scale research framework lend new insight into socio-ecological issues?*

2 CASE STUDY ON URBAN CLIMATE

2.1 Study Area

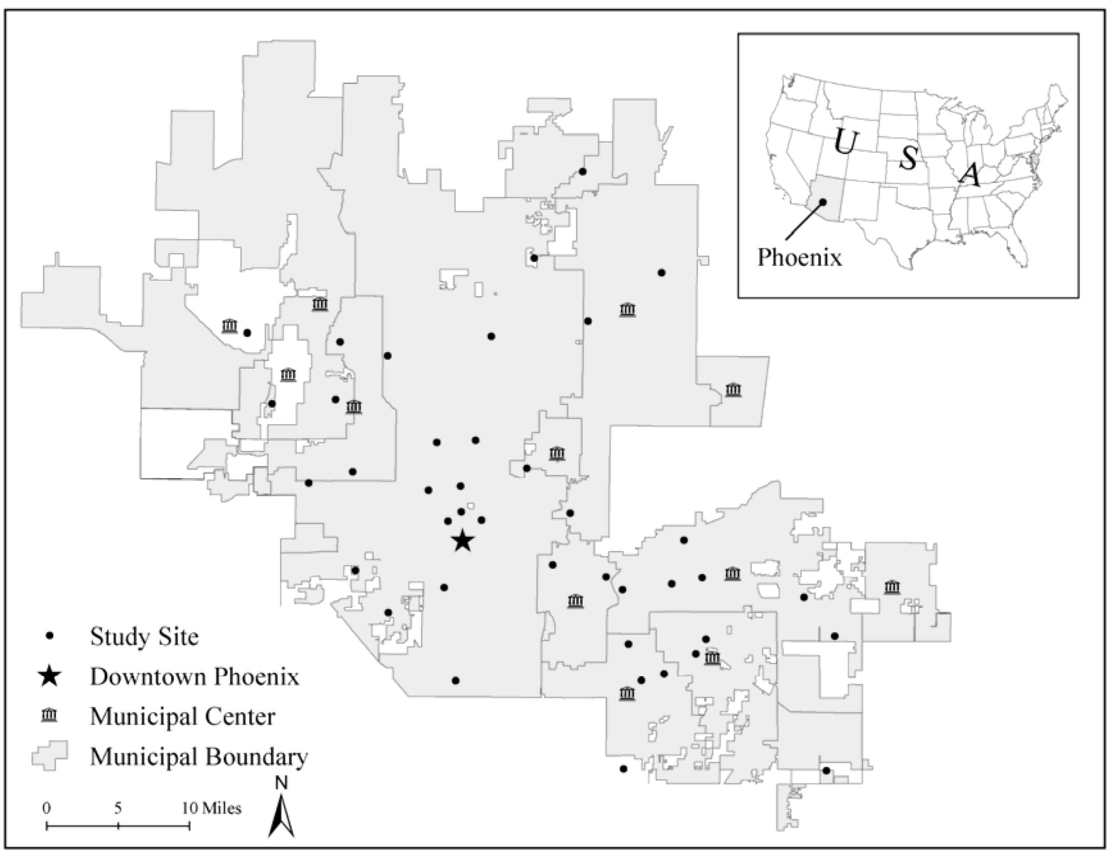
Encompassing over 1,800 square miles of the Sonoran Desert in central Arizona, the Phoenix metropolitan is home to over 65 percent of the state's 6.1 million residents (Figure 1)

(Census Bureau 2006). Metropolitan Phoenix is an ideal setting for studying physical and social dimensions of climate change because average annual temperatures have increased by more than 3^{o}C (or 5.4^{o}F) in Maricopa and Pinal counties over the 20th century (Brazel et al. 2003). Although the average annual regional temperature has risen steadily, temperatures in urban areas have increased by 4.2°C compared to an increase of 1.3°C in rural areas, representing a warming rate over three times higher in urban areas (Brazel et al. 2000). According to the National Weather Service, the average number of heat days is also on the rise in the Phoenix metropolitan area. High heat days, defined as local temperatures of 43.3°C (or 110°F) or higher, averaged ten days per summer between 1971 to 2000; however, the summer of 2005 recorded a record 24 heat days only to be surpassed in 2007 with 33 heat days.

The impacts of extreme temperature on human health and comfort are also expected to increase as the threshold of human tolerance to rising temperatures are crossed more frequently and for longer periods of time (Kalkstein and Green 1997). Although heat-related mortality already accounts for more deaths than all other weather-related events combined, human vulnerability to heat is expected to rise as the frequency, intensity, and duration of heat waves are projected to increase of over the next century (CDC 2005; Meehl and Tebaldi 2004). While Arizona led the nation in heat-related deaths from 1993-2002, this trend is likely to continue as temperatures are projected to increase the most in arid environments (IPCC 2007). Changes in physical climate (i.e., temperature) increasingly threaten human health and well-being which underscores the need to examine public perceptions of climate change in the region.

The present study further concentrates on 40 diverse Phoenix area neighborhoods under study as part of the 2006 Phoenix Area Social Survey (PASS) project. These neighborhoods offer insight into the spatial distribution of temperature variability throughout the region during a summer heat event, in addition to a survey of residents' perceptions of temperature. PASS employed a two-stage research design (Harlan et al. 2007). First, a systematic sample of 40 neighborhoods was selected from the 94 urban sites that are monitored by the Central Arizona-Project Long-Term Ecological Research CAP LTER project (Grimm and Redman 2004). Census data by block group were assembled for all 94 sites and classified by location (urban core, suburban, and fringe), median income, and ethnic composition. All types of neighborhoods in the Phoenix area were represented among the sample of 40. Second, a random sample of households within each neighborhood was selected to participate in a social survey, which is described in more detail below.

Figure 1: Metropolitan Phoenix, Arizona and PASS neighborhoods



2.2 Simulated Physical Conditions

This study utilized the meso-scale Weather Research and Forecast (WRF) climate model developed by the National Center for Atmospheric Research (NCAR) (Shamrock et al. 2005) to simulate environmental conditions throughout the Phoenix metropolitan area. Temperature variability was determined by employing WRF to simulate environmental conditions throughout the study area (Ruddell et al. 2009). Reporting 2m surface air temperature at a spatial resolution of 1km, the climate model calculated fine-scale temperatures throughout the study area by considering various input variables (e.g., air temperature, wind speed, horizontal and vertical advection, LULC). To accurately represent urban heterogeneity of LULC, we used remote sensing techniques as input data. Finally, as a surrogate for measuring the temperature in the Phoenix metropolitan area for the entire summer of 2005, I used a four-day heat wave (July 15-19, 2005) to measure temperature variability throughout the Phoenix metropolitan area for the summer of 2005 (Meehl and Tebaldi 2004).

2.3 Public Perceptions of Temperature

To investigate public perceptions of climate change, I analyzed self-reports of the 2006 Phoenix Area Social Survey (PASS), which asked respondents about their weather-related experiences and perceptions during the summer of 2005. In each of the 40 PASS neighborhoods, described above, 40 randomly selected households were recruited for participation in PASS until a minimum 50 percent response rate was achieved in each neighborhood. Overall survey response rate was 51% (n=808). Data were collected using a multi-modal approach (online, telephone, or personal interview). The survey was administered by the Institute for Social Science Research (ISSR) at Arizona State University from April 29 through September 27, 2006.

The following PASS question was analyzed to measure perceptions of climate change: 1) During the summer of 2005, do you think your neighborhood was a lot cooler, a little cooler, a little hotter, or a lot hotter than most other neighborhoods in the Valley or do you think it was about the same temperature as other neighborhoods? (herein referred to as Perceived Temperature). The term "Valley" is a local expression that refers to the Phoenix metropolitan area.

2.4 Media Coverage

A text analysis of media coverage on extreme heat for the summer of 2005 was conducted to determine if social perceptions were influenced by local media reports (Creswell 2003). The data were obtained from an academic keyword search of "heat advisory" and "heat warning". Three primary media sources (i.e., local reports, wires, and broadcasts) were identified via the Lexus-Nexus search engine, and results were narrowed to the state of Arizona. News reports were provided by the Arizona Department of Health Services (ADHS) which issues local and state-wide advisories for the National Weather Service (NWS). We also analyzed wire reports via the Associated Press State and Local Wire Media, and archived television coverage provided by Global Broadcasts.

2.5 Procedures

To evaluate the mixed method multi-scale research framework investigating physical and social dimensions of climate change in the Phoenix metropolitan area, data analyses were organized into four primary steps. The first phase of analysis examined physical differences in exposure to extreme heat via the WRF climate model which simulated local temperatures throughout the study area for the four-day period of July 15-19, 2005. Once the temperatures were calculated, GIS was used to map temperatures for the region as well as each of the forty neighborhoods in the study. The second phase of analysis was to calculate perceived temperature among survey respondents at two spatial scales of analysis (e.g., regional and neighborhood). Responses were analyzed collectively (e.g., the regional scale) and aggregated to the neighborhood scale (Census block group) then mapped in GIS.

The third step in the analysis employed the confirmation/comprehension framework. Integrating physical and social data sets, I tested confirmation of results via a chi-square test to compare the distribution of observed frequencies to expected frequencies at multiple scales of analysis (Dunning et al. 2008). Comprehension was determined by using a Pearson's product-moment correlation to measure the strength of association between physical and social variables at the regional and neighborhood scales. The fourth and final step of the analysis examined media coverage (e.g., heat advisories) on summer temperatures for the summer of 2005. A discourse analysis was used to investigate media attention on extreme heat, and focused on three characteristics of media coverage: 1) how the temperature is reported; 2) suggestions residents should follow; and 3) the spatial scale of the heat advisory. The text analysis aimed to ascertain whether or not media coverage on extreme heat influenced social perceptions.

3 RESULTS

3.1 Environmental Conditions: A Biophysical Multi-Scale Investigation

Regional and neighborhood temperatures were calculated by the meso-scale Weather and Research Forecast (WRF) climate model. WRF considered various global, regional, and local inputs for estimating surface air temperature at 2 meters above the ground with a spatial resolution of 1 km. Although this technique enables microscale temperature analyses, WRF output was also aggregated to reflect a regional temperature for the Phoenix metropolitan area for a four-day period in the summer of 2005.

Regional Climate Conditions

The data represent a four-day period for the summer of 2005, and report regional average temperatures for mean average, mean high, and mean low temperature (Table 3). Temperatures represent daily average temperatures for the metropolitan region, with the average high temperature for the four-day period at 45.66°C (or 114.2°F) while the low was 30.87°C (or 87.6°F) and the average was 38.29°C (or 100.9°F), respectively.

Table 3: Simulated Mean Average, High, and Low Regional Temperature for July 15-19, 2005.

Simulated Temperature	Temperature (Celsius)
Mean Average	38.29
Mean High	45.66
Mean Low	30.87

Neighborhood Climate Conditions

To investigate temperature variability within the urban area, the WRF climate model simulated local conditions at a spatial resolution of 1km. Table 4 provides empirical insight into local environmental conditions by reporting mean average, mean high, and mean low temperatures for each of the forty neighborhoods in the study area. The mean average temperature for the four-day period was 38.29°C; however, the range of temperatures among the forty neighborhoods reported a low of 34.65°C to 39.62°C in the warmest neighborhood, representing a difference of 4.97°C (or 8.9°F). Mean low temperature reported the greatest range (5.16°C or 9.3°F) among individual observations which is particularly significant since minimum temperatures often increase faster in urban areas compared to maximum temperatures (Karl et al. 1993). Results, therefore, indicate significant differences in exposure to summer-time temperatures among neighborhoods within the Phoenix metropolitan area for the summer of 2005.

Table 4: Descriptive Statistics on Simulated Temperatures for July 15-19 2005 at the Neighborhood Scale.

Simulated Temperature	Descriptive Statistics (Temp in Celsius)				
	Min	Max	Mean	SD	Range
Mean Average	34.65	39.62	38.29	1.08	4.97
Mean High	42.16	46.78	45.66	0.98	4.62
Mean Low	27.2	32.36	30.87	1.17	5.16

3.2 Perceived Temperatures: A Social Multi-Scale Investigation

Similar to the analysis of environmental conditions at multiple spatial scales, social perceptions also vary by scale of analysis. Analyses examined responses for perceived temperature of neighborhood relative to others at the regional and neighborhood scales, and results indicate varying perceptions of temperature throughout the Phoenix metropolitan area for the summer of 2005.

Regional Climate Perceptions

At the regional scale of analysis, the majority of survey respondents perceived temperature in their neighborhood was about the same compared to other Valley neighborhoods for the summer of 2005 (Table 5). Although most respondents (51.2 percent) reported that the temperature in their neighborhood was about the same as other Valley neighborhoods for the summer of 2005, about a quarter of respondents (24.6 percent) believed their neighborhood was either a little cooler or a lot cooler than other Valley neighborhoods. Similarly, just less than a quarter of respondents (24.1 percent) perceive their neighborhood as either a little hotter or a lot hotter than other metropolitan neighborhoods.

Table 5: Descriptive Statistics and Frequency of Survey Respondents on Perceived Temperature for Summer 2005.

Dependent Variable	Descriptive Statistics							
	N	Mean	SD	Lot Cooler	Little Cooler	Same	Little Hotter	Lot Hotter
Perceived Neighborhood Temp	767	3.04	0.870	2.3	22.3	51.2	17.5	6.6

Note: Perceived Temperature was measured on a 5-point scale. Responses ranged from 1: a lot cooler; to 5: a lot hotter.

Neighborhood Climate Perceptions

An analysis of survey responses aggregated at the neighborhood scale indicates varying degrees of perception for perceived temperature. For example, Table 6 shows the range of responses for perceived temperature aggregated among the forty neighborhoods. Although the mean response for perceived temperature is 3.04 (temperature in my neighborhood is about the same as the temperature in other Valley neighborhoods for the summer of 2005), perceptions range from 2.35 to 3.70, representing significantly different perceptions of temperature relative to other Valley neighborhoods. Respondents in some neighborhoods therefore perceive their local environment as either cooler or warmer compared to other metropolitan areas for the summer of 2005.

Table 6: Descriptive Statistics on Perceived Temperature for Summer 2005 at the Neighborhood Scale.

Respondent Perceptions	Descriptive Statistics				
	Min	Max	Mean	SD	Range
Perceived Temperature	2.35	3.70	3.04	0.31	1.35

3.3 Data Synthesis: A Mixed Method Multi-Scale Investigation

The third step in the analysis employed the confirmation/comprehension framework by synthesizing physical and social data on temperature at the regional and neighborhood scales of analysis. Although research findings fail to confirm results, comprehension is enriched. These conclusions require the mixed method approach to be performed at multiple scales of analysis.

Confirmation

A chi-square test was used for statistical confirmation to compare simulated temperature to social perceptions at the regional and neighborhood scales of analysis. Mean low neighborhood temperature served as the measure of environmental conditions and the temperature range (5.16°C) was divided into five classes to match the 5-point Likert scale at which residents reported perceived temperature for the summer of 2005. Tables 7-10 reflect the range of minimum temperature divided into equal intervals; however, the data were also analyzed using other methodological classifications (e.g., quantile, natural breaks, geometric interval, standard deviation). Analyses reported similar findings at the regional scale of analysis but results varied at the neighborhood scale.

Analyses at the regional scale reported significant differences (chi-square = 0.000) between environmental conditions and perceived temperature (Tables 7 and 8). For instance, perceived temperature exhibits a normal distribution while the distribution of environmental conditions is negatively skewed. The distribution of environmental conditions suggests that an overwhelming majority of respondents live in relatively warm local environments; however, the majority of respondents perceived the temperature in their neighborhood to be about the same as other metropolitan neighborhoods for the summer of 2005. Survey responses were then aggregated by neighborhood to compare perceived temperature with temperature at the neighborhood scale, and analyses showed modest differences between the two samples (chi-square = 0.321) (Tables 9 and 10). Again perceived temperature displayed a normal distribution while environmental conditions were negatively skewed. A one way analysis of variance (ANOVA) confirmed significant differences between data sets at the regional scale while reporting modest differences at the neighborhood scale (Table 11). When analyzing individual responses (e.g., the regional scale), results indicate that social perceptions of relative neighborhood temperature are not congruent with local environmental conditions. Most respondents feel they live in an average (or even cooler than average) neighborhood when, in fact, their neighborhoods are hotter than others. When responses are aggregated to the neighborhood level, however, perceived neighborhood temperature is more closely aligned with simulated conditions.

Table 7: Crosstabulation of Perceived Relative Neighborhood Temperature Compared to Simulated Temperature in Neighborhood at Regional Scale.

Class	Perceived Temp	Simulated Temp	Residual
1 (cooler)	18	41	-23
2 (a little cooler)	171	60	111
3 (ambient)	393	35	358
4 (a little hotter)	134	291	-157
5 (hotter)	51	340	-289

Table 8: Chi-square Results of Perceived Relative Neighborhood Temperature Compared to Simulated Temperature in Neighborhood at Regional Scale.

Test	N	Value	Significance
Pearson Chi-Square	767	75.8	0.000

Note: I also analyzed the range of mean low temperature using four other methodological classifications and found similar results. Quantile: r = 61.5; sig. = 0.000; Natural Breaks: r = 71.2; sig. = 0.000; Geometric Intervals: r = 78.6; sig. = 0.000; Standard Deviation: r = 81.6; sig. = 0.000.

Table 9: Crosstabulation of Perceived Relative Neighborhood Temperature Compared to Simulated Temperature in Neighborhood at Neighborhood Scale.

Class	Perceived Temp	Simulated Temp	Residual
1 (cooler)	3	2	1
2 (a little cooler)	8	3	5
3 (ambient)	16	2	14
4 (a little hotter)	7	15	-8
5 (hotter)	6	18	-12

Table 10: Chi-square Results of Perceived Relative Neighborhood Temperature Compared to Simulated Temperature in Neighborhood at Neighborhood Scale.

Test	N	Value	Significance
Pearson Chi-Square	40	18.1	0.321

Note: I found similar results for the range of mean low temperature using other methodological classifications. Quantile: r = 14.9; sig. = 0.535; Natural Breaks: r = 28.1; sig. = 0.031; Geometric Intervals: r = 27.3; sig. = 0.038; Standard Deviation: r = 20.5; sig. = 0.200.

Table 11: ANOVA Results of Perceived Relative Neighborhood Temperature Compared to Simulated Temperature in Neighborhood at Regional and Neighborhood Scales.

ANOVA	F	Significance
Regional Scale	10.9	0.000
Neighborhood Scale	3.8	0.011

Note: I also conducted a one way ANOVA using four other methodological classifications and found similar results. Results at the regional scale of analysis: Quantile: F = 9.1; sig. = 0.000; Natural Breaks: F = 9.5; sig. = 0.000; Geometric Intervals: F = 10.8; sig. = 0.000; Standard Deviation: F = 11; sig. = 0.000. Results at the neighborhood scale of analysis: Quantile: F = 3.2; sig. = 0.026; Natural Breaks: F = 2.9; sig. = 0.034; Geometric Intervals: F = 3.8; sig. = 0.011; Standard Deviation: F = 3.7; sig. = 0.013

Comprehension

Although the tests of confirmation indicate the two data sets are statistically different, the data were then examined for comprehension. A Pearson's *r* was used to test the strength of association between mean low neighborhood temperature and perceived temperature relative to others at the regional and neighborhood scales of analysis. Analyses report mixed levels of statistical significance between variable pairs (Table 12). For example, there is a relatively weak correlation between simulated temperature and social perceptions of temperature when analyzed at the regional scale ($r = 0.232$). Alternatively, social perceptions aggregated to the neighborhood scale report a strong correlation to environmental conditions ($r = 0.636$). Analyses show that survey responses aggregated to the neighborhood scale are congruent with local environmental conditions (respondents within a given neighborhood accurately perceived their neighborhood as relatively cooler or warmer); however, individual perceptions of temperature relative to others report a weak correlation with local temperature (individual respondents did not accurately perceive temperature in their neighborhood relative other others for the summer of 2005).

Table 12: Pearson's Correlation Results for Perceived Relative Temperature Compared to Simulated Temperature at the Regional and Neighborhood Scales of Analysis.

Pearson's Correlation	N	Pearson's *r*	Sig (2-tailed)
Regional Scale	767	0.232	0.000
Neighborhood Scale	40	0.636	0.000

3.4 Media Analysis

The final step of the analysis examined media coverage on summer temperatures for the summer of 2005 to determine whether the media may have influenced social perceptions on extreme heat throughout the Phoenix metropolitan area. A key word search of "heat advisory" and "heat warning" produced three primary media sources reporting on heat stress during the summer of 2005. Excerpts from news releases provided by the Arizona Department of Health and Services (ADHS) are presented in Table 13; the report by the Associated Press State and Local Wire is summarized in Table 14; and finally, Table 15 reflects excerpts of television broadcasts.

Table 13: News Release Excerpts from Arizona Department of Health and Services for Summer 2005.

Date	Press Title
June 16, 2005	Staying Healthy In Arizona's Deadly Summer Heat
-With daytime temperatures stuck in triple digits, Arizona summers turn dangerous and deadly; *-Last summer, 34 residents died as a direct result of excessive exposure to heat;*	
July 18, 2005	Health Department Urges Caution as Deadly Heat Grasps Arizona
-These are some of the hottest days of summer and people need to be diligent about staying indoors, wearing light clothing, and drinking water; *-Young children and the elderly are also at greater risk to suffer from heat-related illness;*	
August 29, 2005	Return Of Extreme Summer Heat Brings Deadly Dangers
-Temperatures over 110 degrees means taking special precautions to protect ourselves and our loved ones from the risk of heat-related illness and death. The best way to combat this is to stay hydrated and out of the sun; *-People who work outdoors are at especially high risk. People that have outdoor occupations need to take more breaks and get more of their work done in the early morning hours if possible.*	

Table 14: News Reports by the Associated Press State and Local Wire on Heat in Phoenix, AZ for Summer 2005.

Date	Press Title
May 24, 2005	Weather Service warns of problems associated with record heat
-The heat is on in the Phoenix metropolitan area and authorities are warning residents of possible health problems associated with record-setting temperatures; *-The National Weather Service has issued an excessive-heat warning for the past four days since Friday with another heat advisory for Wednesday;* *-Experts say a high of 109 degrees now is more dangerous than the same temperature in mid-July, when people's bodies have had a chance to acclimate to the heat.*	

Table 15: Excerpts from Global Broadcast on Heat in Phoenix, AZ for Summer 2005.

Date	News Provider
July 19, 2005	CBS
-Police say there were four more heat-related deaths today (Tuesday) raising the toll to twelve since the heat wave started Saturday; *-At least ten of those who have died were homeless and the other two were elderly women;* *-Heat advisories and warnings are in effect as the temperatures hover around 113 degrees.*	
July 20, 2005	Fox
-At least two-dozen deaths are being blamed on the extreme heat in Arizona; *-Officials say many of those who have died are illegal immigrants living in cramped quarters often without air.*	
August 5, 2005	ABC
-People who work outdoors are at especially high risk. People that have outdoor occupations need to take more breaks and get more of their work done in the early morning hours if possible.	

Analyses of the three media sources highlight some general trends. First, results indicate that heat advisories are applied at broad spatial scales, such as there is a heat advisory in Phoenix, Arizona from Saturday to Tuesday. Another trend is that the data communicate evidence of extreme heat and report outcomes of human health, e.g., *x* number of people have died as a direct result of excessive heat. A third finding is that the media source typically offers recommendations regarding individual decision-making, e.g., drink lots of water, stay in indoors or in the shade, wear light clothing. The message of the three media sources on extreme heat is consistent: use caution and be prepared. Although recent studies have found evidence of significant temperature variability within the same urban environment (Harlan et al. 2006; Ruddell et al. 2009), media reports are applied at broad (e.g., metropolitan) scales of analysis.

4 DISCUSSION AND CONCLUSION

This paper aimed to examine the effectiveness of a mixed method multi-scale research framework by investigating environmental conditions and public perceptions of temperature at regional and neighborhood scales of analysis in the Phoenix metropolitan area as a case study. Analyses utilized both quantitative (WRF) and qualitative (PASS; Media Coverage) methods for examining temperature, and both techniques observed differences based on spatial scale. For instance, WRF simulations showed variable levels of exposure in temperature between regional and neighborhood scales. Similarly, perceived temperature also varied by spatial scale whereby respondents in some neighborhoods perceived their local environment as either cooler or warmer compared to regional trends for the summer of 2005. First, I used a single methodology (e.g., quantitative, qualitative) to examine physical and social dimensions of temperature at multiple scales of analysis, and found variable results.

An important objective of this study, however, was to apply the confirmation/comprehension framework at multiple scales of analysis. Utilizing physical and social data on temperature, I tested for confirmation via a chi-square test and found significant differences between observed and expected frequencies at the regional scale and modest differences at the neighborhood scale of analysis. While analyses showed a lack of empirical congruence between the methodological approaches, comprehension was enriched. Pearson's *r* compared environmental conditions to social perceptions and reported varying strengths of association based on spatial scale. For instance, there was a relatively weak correlation between environmental conditions and social perceptions at the regional scale; however, the strength of association was much stronger when aggregated to the neighborhood level. This research finding is significant in two ways: first, it suggests there may be an optimal level of aggregation on which to report environmental perceptions. Aggregating survey responses minimizes outlying perceptions while providing an average for each group (in this case a neighborhood). While there was a significant amount of variability when analyzing individual survey responses, aggregating responses at too broad of a scale (e.g., by municipality) may conceal interesting differences between groups. The second way in which this finding is significant is that the mixed method multi-scale framework allowed me to identify this observation. It would not have been possible to compare social perceptions with environmental conditions at multiple scales without employing this approach. My contribution therefore is the introduction of the mixed method multi-scale research framework to help identify new and valuable research observations.

A review of the media analysis, however, may lend insight into social perceptions on extreme heat. The three sources of media coverage on extreme heat in the Phoenix metropolitan area for the summer of 2005 consistently reported on the broad regional scale of analysis. Although reports failed to specify where temperatures were the most or least intense within the Valley, the coverage on heat advisories may have influenced individual perceptions regarding neighborhood temperature. For instance, perceived neighborhood temperature reported a weak correlation with local environmental conditions when analyzing individual survey responses. While 51 percent of survey respondents believed their neighborhood was about the same temperature relative to others, simulated temperatures indicated that 82 percent of those interviewed lived in warm metropolitan neighborhoods. Thus, the general perception that a respondents' neighborhood temperature is about the same as other metropolitan neighborhoods may have been influenced by media coverage reporting on the regional scale of analysis. Since there is significant temperature variability within urban environments, local media sources (e.g., neighborhood newsletter) may want to begin reporting information and strategies on extreme heat at intraregional spatial scales (e.g., neighborhood).

This study aimed to contribute to research on scale by building upon existing methods to understand physical and/or social processes. Specifically, I tested the effectiveness of a mixed method multi-scale research framework by examining temperature as one dimension of climate change in the Phoenix, AZ metropolitan area for the summer of 2005. Although analyses reported a lack of confirmation between the quantitative and qualitative methods employed in this study, comprehension was enriched. The research finding which indicates social perceptions of environmental conditions are more accurate at finer spatial scales compared to broader scales of analysis was only visible via the mixed method multi-scale research framework that was introduced and tested in this study. Moreover, it would not have been possible to identify this observation using existing methodological approaches. This case study on temperature, therefore, validates the effectiveness of the mixed method multi-scale research framework. So in addition to enhancing comprehension on climate change and environment perception research, this study also contributes to understanding scale-related challenges.

REFERENCES

Baker, L. W., Brazel, A. J., Selover, N., Martin, C., McIntyre, N., Steiner, F. R., Nelson, A., & Musacchio, L. (2003). Urbanization and warming on Phoenix (Arizona, USA): impacts, feedbacks, and mitigation. *Urban Ecosystems*, 6, 183-203.

Bolin, B., Collins, T. & Darby, K. (2008). Fate of the verde: water, environmental conflict, and the politics of scale in Arizona's central highlands. *Geoforum*, 39, 1494-1511.

Boyd, C. O. (2000). Combining qualitative and quantitative approaches. In: P. L. Munhall & C. O. Boyd (Eds.) *Nursing Research: A Qualitative Perspective* (pp. 454-475). Boston: Jones & Bartlett.

Brazel, A., Selover, N., Vose, R., & Heisler, G. (2000). The tale of two climates—Baltimore and Phoenix urban LTER sites. *Climate Research*, 15, 123-135.

Brazel, A. (2003). Future climate in central Arizona: heat and the role of urbanization. Center for Environmental Studies, Arizona State University.

Census Bureau (2006). American Community Survey. Available at: www.census.gov.

Costanza, R., Fisher, B., Ali, S., Beer, C., Bond, L., Boumans, R., Danigelis, N. L., Dickinson, J., Elliott, C., Farley, J., Gayer, D. E., Glenn, L. M., Hudspeth, T., Mahoney, D., McCahill, L., McIntosh, B., Reed, B., Rizvi, S. A. T., Rizzo, D. M., Simpatico, T., & Snapp, R. (2007). Quality of life: an approach integrating opportunities, human needs, and subjective well-being. *Ecological Economics*, 61, 267-276.

Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Thousand Oaks: Sage.

Dunning, H., Williams, A., Abonyi, S., & Crooks, V. (2008). A mixed method approach to quality of life research: a case study approach. *Social Indicators Research*, 85, 145-158.

Easterling, W. E., & Polsky, C. (2004) Crossing the Divide: Linking Global and Local Scales in Human-Environment Systems. In: E. Sheppard and R. McMaster (Eds.) *Scale and Geographic Inquiry: Nature, Society, and Method* (pp. 66-85). Oxford: Blackwell.

Gimblett, H. R. (2001). *Integrating Geographic Information Systems and Agent-Based Modeling Techniques for Simulating Social and Ecological Processes*. Oxford: Oxford.

Grimm, N. B. & Redman, C. L. (2004). Approaches to the study of urban ecosystems: the case of Central Arizona – Phoenix. *Urban Ecosystems*, 7, 199-213.

Harlan, S. L., Budruk, M., Gustafson, A., Larson, K., Ruddell, D., Smith, V. K., Yabiku, S. T., Wutich, A. (2007). Phoenix Area Social Survey 2006 Highlights: Community and Environment in a Desert Metropolis. Central Arizona – Phoenix Long-Term Ecological Research Project, Contribution No. 4. Global Institute of Sustainability, Arizona State University.

Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*, 63, 2847-2863.

Imeson, A. C., & Lavee, H. (1998). Soil erosion and climate change: the transect approach and the influence of scale. *Geomorphology*, 23, 219-227.

(IPCC) Intergovernmental Panel on Climate Change (2007). Climate Change 2007: Synthesis Report. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf . Accessed 12/20/08.

(IPCC) Intergovernmental Panel on Climate Change. (2001). *Climate Change 2001: Impacts, adaptation, and vulnerability*. Report of Working Group II. United Nations Environment Program.

Jick, T. D. (1979). Mixing qualitative and quantitative methods: triangulation in action. *Administrative Science Quarterly*, 24, 602-611.

Johnston, R. J., Gregory, D., Pratt, G., & Watts, M. (Eds.) (2000). *The dictionary of human geography*. Massachusetts: Blackwell.

Kalkstein, L. S. & Green, J. S. (1997). An evaluation of climate/mortality relationships in large U.S. cities and the possible impacts of a climate change. *Environmental Health Perspectives*, 105, 84-93.

Karl, T. R., Jones, P. D., Knight, R. W., Kukla, G., Plummer, N., Razuvayev, V., Gallo, K. P., Lindseay, J., Charlson, R. J., & Peterson, T. C. (1993). A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. *American Meteorological Society*, 74, 1007-1023.

Leiserowitz, A. A. (2005). American risk perceptions: is climate change dangerous? *Risk Analysis*, 25, 1433-1442.

Lowry, W. (1967). The climate of cities. *Scientific American*, 217, 15-23.

Meehl, G. A., & Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, 305, 994-997.

Mitchell, E. S. (1986). Multiple triangulation: a methodology for nursing science. *Advances in Nursing Science*, 8, 18-26.

Oke, T. R. (1997). Part 4: The changing climatic environments: urban climates and global environmental change. In R. D. Thompson & A. Perry (Eds.), *Applied Climatology Principals and Practice* (pp. 273-287). London: Routledge.

Oke, T. R. (1987). Boundary Layer Climates. 2nd Edition. Cambridge: University Press. Olea, R. A. (1990) *Geostatistical Glossary and Multilingual Dictionary*. New York: Oxford University Press.

Reichardt, C. S., & Cook, T. D. (1979). Beyond qualitative versus quantitative methods. In: T. D. Cook & C. S. Reichardt (Eds.) *Qualitative and Quantitative Methods in Evaluation Research* (pp. 7-32). Beverly Hills: Sage.

Ruddell, D. M., Harlan, S. L., Grossman-Clarke, S., & Buyanteyev, A. (2009). Risk and exposure to extreme heat in microclimates of Phoenix, AZ. In P. Showalter & Y. Lu (Eds.), *Geospatial contributions to urban hazard and disaster analysis*. Springer.

Shamrock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Wang, W., & Powers, J. G. (2005). A Description of the Advanced Research WRF Version 2. NCAR Technical Note.

Shih, F. J. (1998). Triangulation in nursing research: issues of conceptual clarity and purpose. *Journal of Advanced Nursing*, 28, 631-641.

Tashakkori, A., & Teddlie, C. (1998). *Mixed Methodology: Combining Qualitative and Quantitative Approaches*. Thousand Oaks: Sage Publications.

Thurmond, V. A. (2001). The point of triangulation. *Journal of Nursing Scholarship*, 33, 253-258.