Adapting to climate variability: an analysis on the Southern Great Plains

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Introduction

It is the purpose of this paper to examine changes in climate throughout the Southern Great Plains with the purpose of mitigation and adaptation strategy development. Many ecoregions will be affected by climate change and it may create problems with sustainability of our economy and society. Four major ecoregions include agriculture, grassland, water, and forests.

Agriculture is extremely vulnerable to climate change due to its dependence on weather and the associated risk to severe events like drought and flooding. The estimated cost in 2011 from flooding in the upper Midwest was $2 billion. In 2009, the estimated cost of drought in the Great Plains was $5.3 billion (Walthall et al., 2012). However, a study by Brown and Rosenberg shows that the CO2-fertilization effect, where a rise in CO2 increases primary productivity. This can significantly help in reducing the negative impacts of climate change (1999). A large portion of the land cover in Kansas consists of cropland which is defined as "all areas with actively growing row crops and small grains, as well as harvested land, fallow land, and large, uniform areas of bare, plowed ground" (Figure 1). Cropland accounted for 48% of the land cover (Peterson et al., 2005). Since the majority of land in Kansas is cropland, it is important to find adaptation measures for the drier lands of the central and western portion of Kansas, which can be more prone to climatic impacts.

How rangeland management is adapted in the future may determine the degree with which climate change will have. Temperature and precipitation were analyzed to identify changes likely to take place in a rangeland environment. Although much of the Southern Great Plains is under cultivation, some regions are ill suited for such practices and have remain native rangeland. These rangelands are important for the production of animal products. To maintain the health of these ecosystems, changse in rangeland management practices will need to be made as changes take place in the environment.

In regards to water, this is another extremely important resource for all matters of life. It is an ecosystem service which many people depend on for recreational use and renewable energy. While climate change is partially responsible for what is happening to water resources, many of these changes are anthropogenically driven. Some examples are the exploitation of the Aral Sea. According to a study done by Joseph MacKay, the Aral Sea has lost more than half of its surface area, as well as three quarters of its volume since the 1960's (MacKay 17). Other repercussions of anthropogenic induced climate change include the damming of the Colorado River. Another result is the continued depletion of the Ogallala aquifer. Although these are anthropogenic changes, climate change in this realm of resources is heavily driven by anthropogenics due to practices in irrigation and wastewater management. With a tainted water system, the whole ecosystems is affected.

Forests are also affected by the change in climate. There are not a lot of adaptation measures geared towards forests in the Southern Great Plains. Forests, while not a large focal point in the Southern Great Plains, are still important. They provide cover for vegetation and can potentially take over the carefully cultivated prairie. Several studies have been done on how the changing climate is affecting forests. These studies use their climate change data to find adaptation measures. These efforts need to be backed by government law and policy. United

States has few laws regarding climate change. Policies from other countries will be researched and applied to the United States.

Objectives

We will be 1) analyzing climate data from Kansas to identify any trends in precipitation or temperature change and 2) researching policies and climate adaptations implemented in other countries, and 3) applying them to the Southern Great Plains. Other countries have implemented adaptations to climate change and we will perform a literature review to develop a list of strategies for the Southern Great Plains. We predict a change in precipitation and temperature and hypothesize that adaptations from other countries can be altered to suit the Southern Great Plains.

Methods

Study design

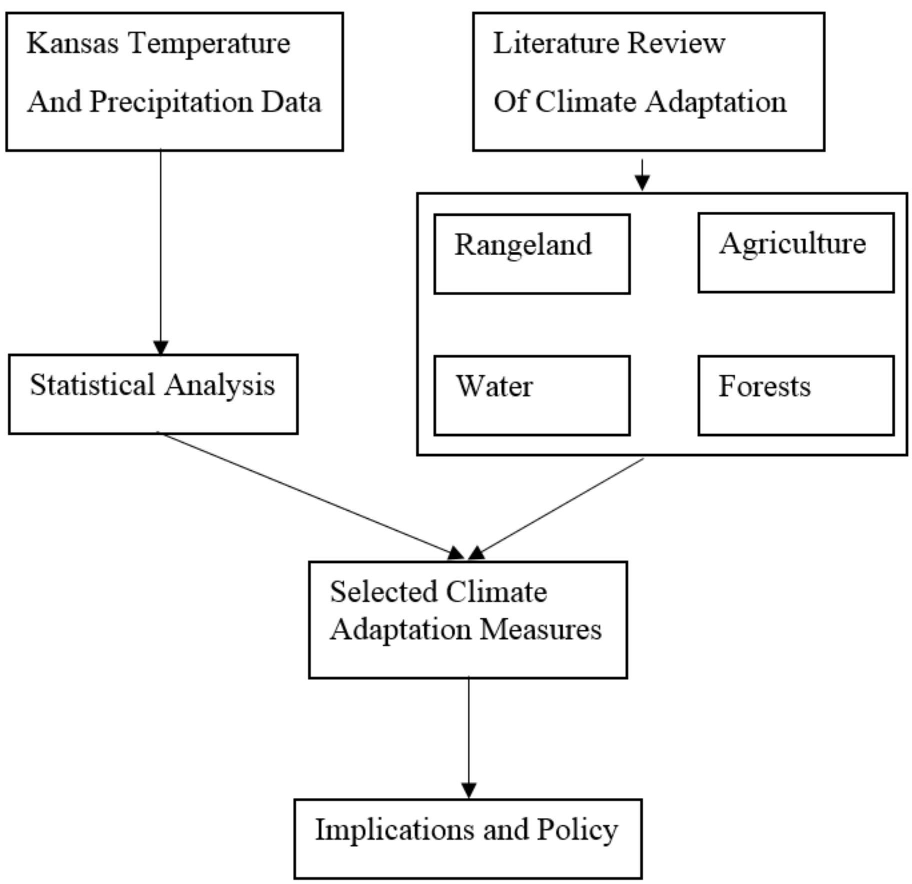


Figure 1: Flow chart describing the process our paper took for finding adaptation measures suitable for the Southern Great Plains region.

Study region and Data

The focus of our study is in the Southern Great Plains, which stretches from Eastern Colorado, through Kansas, Oklahoma, and the northern reaches of Texas.

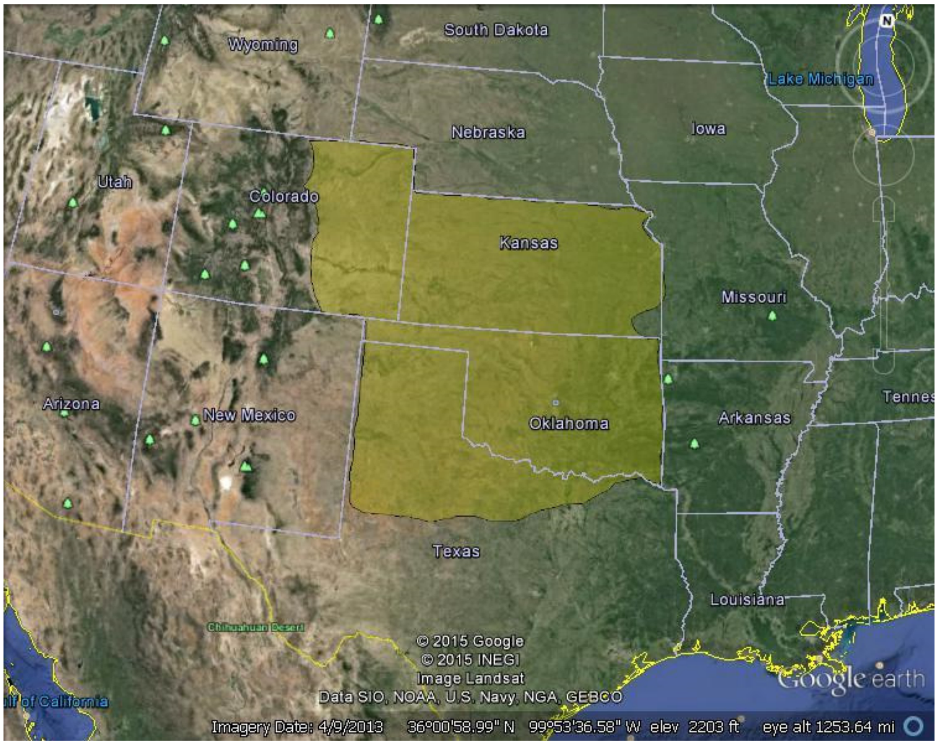


Figure 2: Southern Great Plains region of concern for climate adaptation (Anandhi et al., 2013)

Definitions

Adaptation: Adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation (Parry et al 2007, p869).

Vulnerability: Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (Parry et al 2007, p 883).

Mitigation: Mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases (Parry et al 2007, p 878).

Agriculture: Agriculture is the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products

Forests: Forests are defined as any stand of trees with an established undergrowth that surrounds a riparian area, prairie, or rangeland.

Rangeland: Rangeland is any natural grassland; grazed or ungrazed, regardless of the current land use. Rangeland in the Southern Great Plains includes tallgrass prairie, mixed grass prairie, shortgrass prairie and the gulf coast prairie.

Water: There are many components to look at which pertain to adaptability, quality, and water resource management. One of the components we delved into was above ground water. Above ground water pertains to water which is supplied by natural processes, such as precipitation or the recycling of water through cities and towns. Several examples that house above ground water are lakes, oceans, rivers, dams, and reservoirs. Another component that water resources entails is groundwater. Groundwater pertains to the precipitation that is seeped into the water table, and supplies underground water resources. Some examples of groundwater uses are agriculture and well water to supply households with this resource

Policy concerning climate change is defined by any policy that enforces laws regarding renewable and nonrenewable natural resources. These are mostly enforced at a national level, as well as international agreements between countries to enforce climate change policies.

Ecoregions

The Southern Great Plains was divided into four main ecoregions: forests, rangeland, agriculture, and water. This was done because climate change affects each of these regions in different ways and they represent the major ecoregions of the great plains. By identifying particular impacts in each of these regions, adaptation measures and policies can be implemented more effectively.

Literature Review

Peer-reviewed sources were researched in order to find adaptation measures for climate change that other countries have implemented, and, if applicable, identified as possibilities for mitigating climate change in the Southern Great Plains. A minimum of ten sources were researched for each ecoregion. Each adaptation was given a rating, high, medium, or low, for its applicability to the Southern Great Plains based on any observed change in climate.

Policy

Using the Kansas State University's Library Proquest Database, peer-reviewed scientific papers were found discussing climate change policy. All levels of government are included in the search.

Statistical Analysis and GIS

Many statistical methods are available for analyzing observed and predicted climate data (Hennemuth et al., 2013). In this study we will focus on trends within the data. The Mann-

Kendall test is a nonparametric test for detecting monotonic trends and lowers the impact outliers may have on the average (Mann, 1945; Kendall 1975). This test has been used to analyze rainfall and temperature trends (Kothyari and Singh, 1996) as well as climate variability in India (Kumar et al., 2008). McLeod et al. have thoroughly developed the methodology for the Mann-Kendall test in conjunction with hydrological data (1990). The assumptions in this test include: when no trend is present the measurements are independent and identically distributed, the observations over time are representative of the current conditions, and the sampling methods provide unbiased data. Data which is seasonally variable warrants the adjustment of the Mann-Kendall test in order to best fit a trend (Hirsch et al., 1982). If the data is serially correlated the test can still be performed but with decreased significance. Incorporating effective sample size can reduce the impact of serial correlation for hydrologic data (Yue and Wang, 2003). To calculate the Mann-Kendall test we will use program R. The calculated significant trends will be mapped using ArcGIS.

Also, using the averages for temperature and precipitation for 1900 and 2009, we will join and relate that information using the toolbox in ArcMap, which share a same attribute, in order for it to appear on a map.

Data collection

Data from 1900 to 2009 was collected from 23 weather stations(Figure 3) by the High Plains Regional Climate Center. Quality of the data and methods for collection is documented by Anandhi et al. (2013).

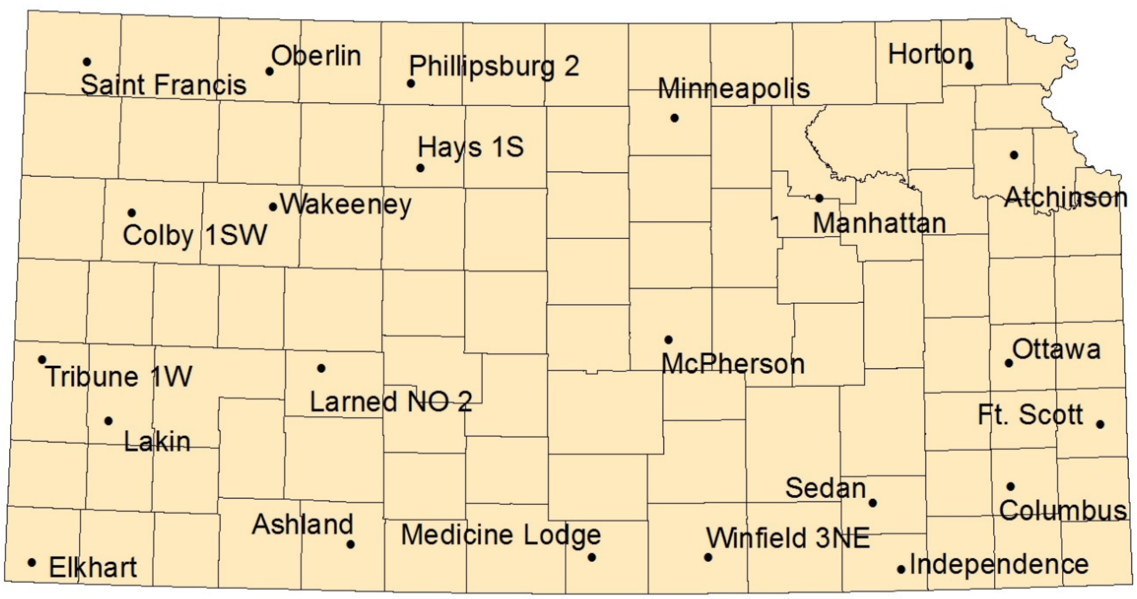
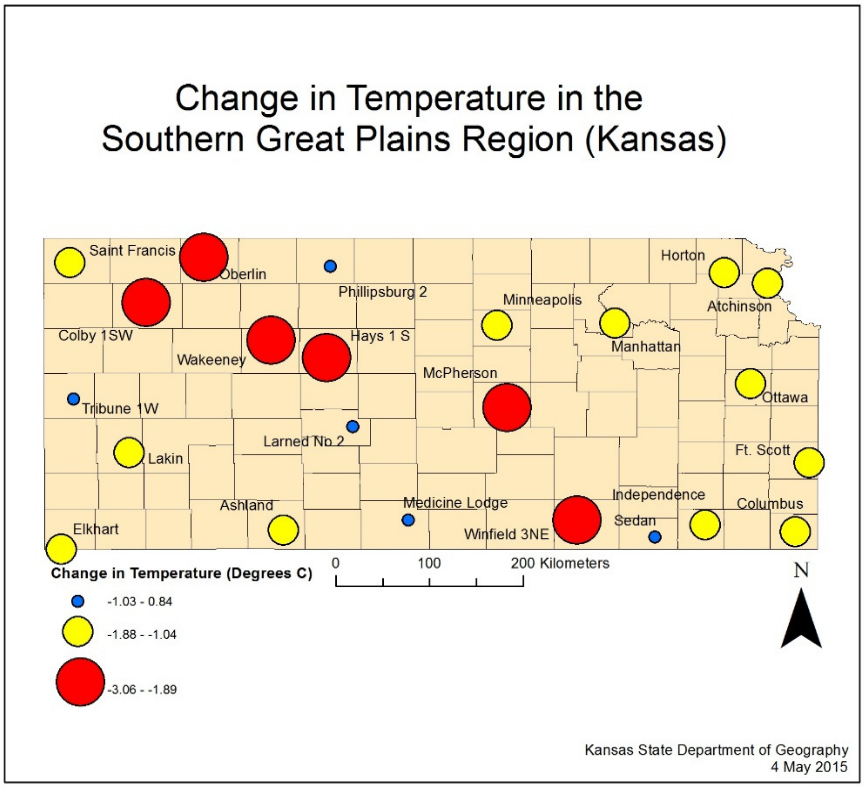


Figure 3: Map of weather stations

Mapping Data

In order to create a map, we need a geographical region in order to manipulate data for Kansas and the twenty-three weather stations. These stations measure temperature and precipitation. To create a map of Kansas, ArcMap 10.2 is the program which offers the best results for any map-based project. While a shapefile for Kansas is ideal, one outlining the United States is sufficient. In order to have Kansas as a standalone object, a definition query is performed, usually with “STATE_NAME = KANSAS” as the input value. After that is done, the values for the stations need to be assessed. Using another piece of software (I Googled a converter for degrees to decimals), we convert degrees, minutes, seconds into a decimal system from the excel spreadsheets that dictate where those stations are placed on the Kansas map (making sure to relate the map and values together with the “join and relate” tools). Using the “add (x, y) data” coordinates tool in ArcMap, input values will be placed from the excel spreadsheet which contains the newly created decimal coordinates. Points should now be located on the map. After there are points on the map, we need to export those points as shape features in order to manipulate them in any sort of fashion. In order to consolidate the data, we must place the data all on one new Excel spreadsheet which has data for one year average on precipitation and temperature for each of the twenty-three stations located in Kansas. After they are grouped, we need to join the spreadsheets with the points created in order for it to convey the data of precipitation and temperature. The plan is to perform this action for one in 1900 and 2009, the most present data, and place it on the map. In total, there will be 2 maps which will have this information encoded into ArcMap (it will document the difference in climate change for the years 1900 and 2009). For ease of readability, applying a color scheme will be helpful for these maps. We will provide proportional symbol maps, with a choropleth scheme, which will have three classes on it (varying degrees of color). The method of these maps will be natural breaks (Jenks), seeing as this is the standard for most maps. In order to provide more information about the region, labels will be included of the stations in order to see which station is located in what spot. For a more interactive simulation, I will combine the grouped precipitation maps together and the temperature maps together. I will also include a legend for each of the maps to indicate the severity of temperature and precipitation change, along with there standard cartographic ideologies. Those maps can be seen below:



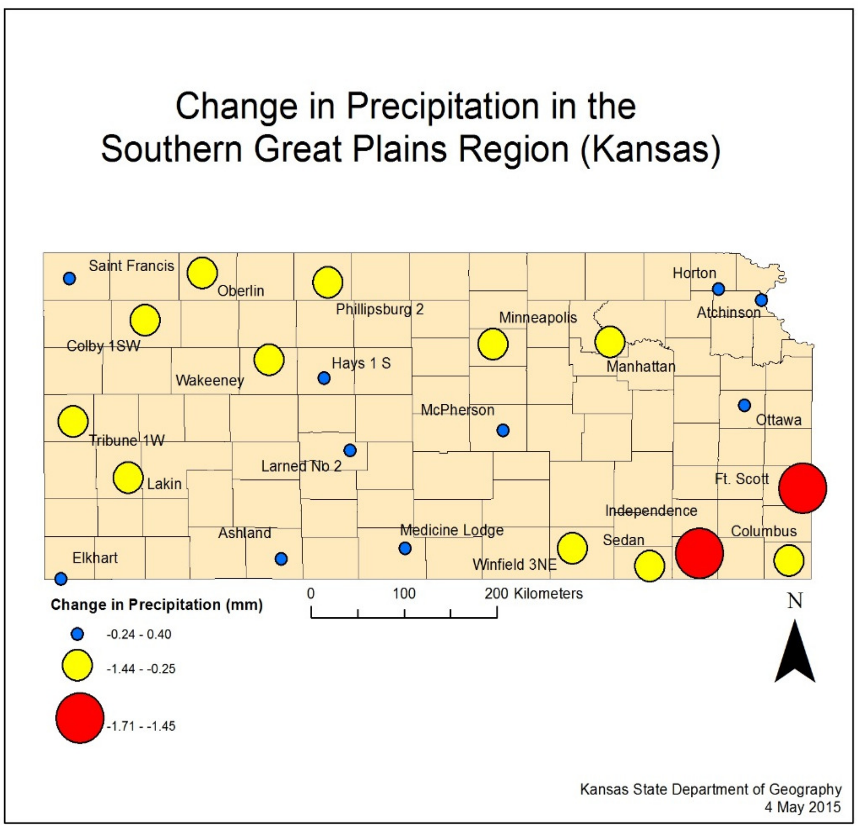


Figure 4: Change in average temperature and precipitation from the year 1900 and the year 2009.

Above the maps show a slightly distinct pattern in the west with the way it is grouped together. Most of the variability in climate is shown through the temperature. From the year 1900, and for the year 2009, we noticed a general decrease in temperature, as well as a general decrease in precipitation. Most of the weather stations in eastern Kansas are grouped which show moderate variability in temperature and precipitation. Like stated before, there is some geographical significance in regards to this area. **However, this only observes two years which are averaged together and the climate variability would be drastically different if there was, for example, a drought one year and high precipitation in the later year.** More data would need to be analyzed in order to captivate the spatial pattern that this is trying to convey.

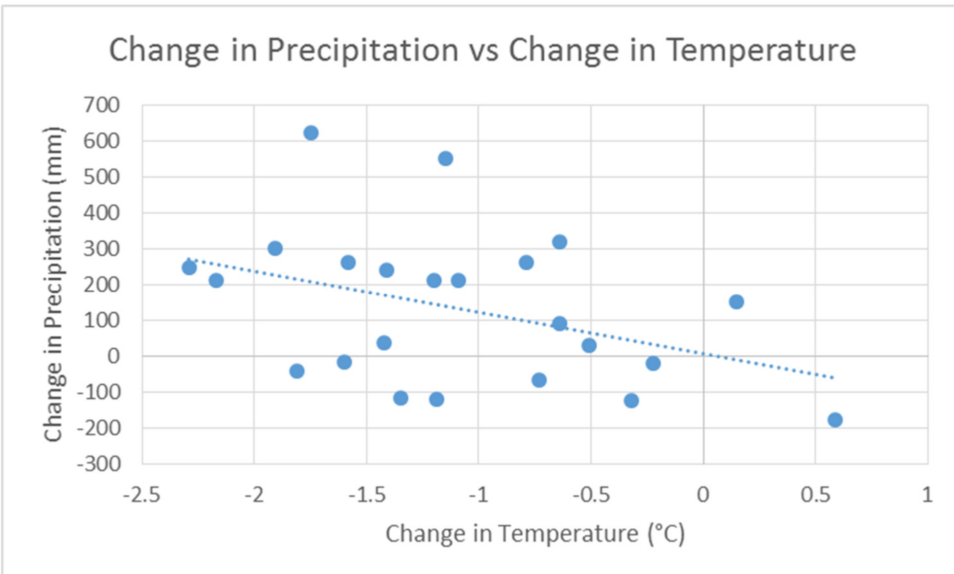


Figure 4: Change in precipitation vs change in average temperature from the 1900 average to 2009 average(r = -.399). Each point represents a weather station in Kansas. Illustrates that as temperature increases precipitation will decrease.

Results

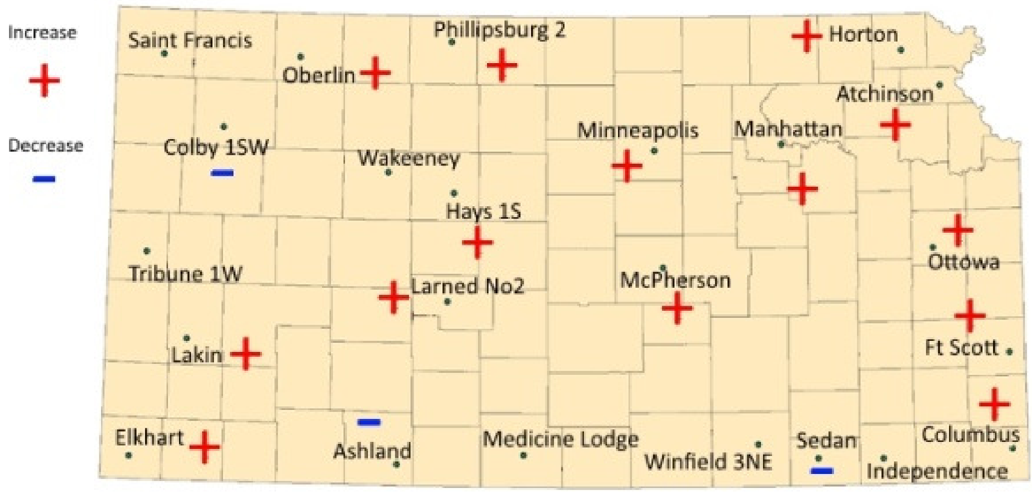
Mann-Kendall Test

	Hightemp		Lowtemp		Precip	
City	**Tau**	**pvalue**	**Tau**	**pvalue**	**Tau**	**pvalue**
Ashland	-0.0099	0.0034	-0.0277	0	-0.0115	0.0035
Atchison	-0.002	0.557	0.0237	0	0.0083	0.0315
Colby	-0.0198	0	-0.0094	0.0051	0.0032	0.4077
Colombus	0	0.9821	0.0156	0	0.0198	0
Elkhart	-0.0012	0.718	0.0341	0	0.0134	0.0007
FortScott	-0.0026	0.4365	0.0224	0	0.0072	0.0619
Hays	-0.0126	0.0001	0.0159	0	0.0358	0
Horton	0.0282	0	0.0076	0.0236	0.0259	0
Independence	-0.0105	0.0018	0.0009	0.7786	-0.0033	0.932
Lakin	-0.0157	0	0.023	0	0.0364	0
Larned	0.0008	0.8154	0.0086	0.0103	-0.0017	0.6589
Manhattan	-0.0057	0.0901	0.0172	0	0.0396	0
Mcpherson	0.0074	0.0269	0.0146	0	0.0241	0
MedicineLodge	-0.0062	0.0668	0.004	0.2297	0.007	0.0607
Minneapolis	0.017	0	0.0242	0	0.0257	0
Oberlin	0	0.9771	0.0066	0.0491	0.0103	0.0082
Ottowa	0.0081	0.0158	0.03	0	0.0082	0.0333
Phillipsburg	-0.0017	0.6075	0.0118	0.0004	0.0176	0
SaintFrancis	-0.0047	0.1595	0.0053	0.1158	-0.0183	0
Sedan	0.0034	0.3162	-0.0135	0	0.0235	0
Tribune	0.0052	0.1245	-0.0027	0.4301	0.0194	0
Wakeeny	-0.0184	0	0.0029	0.3872	0.0399	0
Winfield	0.0018	0.5869	-0.0054	0.1065	0.0457	0

Figure 3: Data collected daily from 1909 to 2009. Kendall tau statistic is 0 if no correlation between the two variables exists. Any value listed at 0 means it was smaller than $1*10^{-4}$. Autocorrelation was not accounted for.

Six cities had a significant (pvalue < .05) negative trend for the maximum temperature and four had a significant positive trend. The negative trends are clustered in the west while positive trends are clustered in the east; Independence is the exception with a negative trend in the southeast. For minimum temperature, three cities had a significant negative trend and fourteen had a significant positive trend. The positive trends occur throughout the state with the majority of negative trends in the south central region of the state. For precipitation, two cities had a significant negative trend while sixteen cities had a significant positive trend. The two negative trends were seen in the northwest and southwest. Only significant trends were marked on the maps (Figure 5).

Change in Minimum Temperature



Change in Maximum Temperature

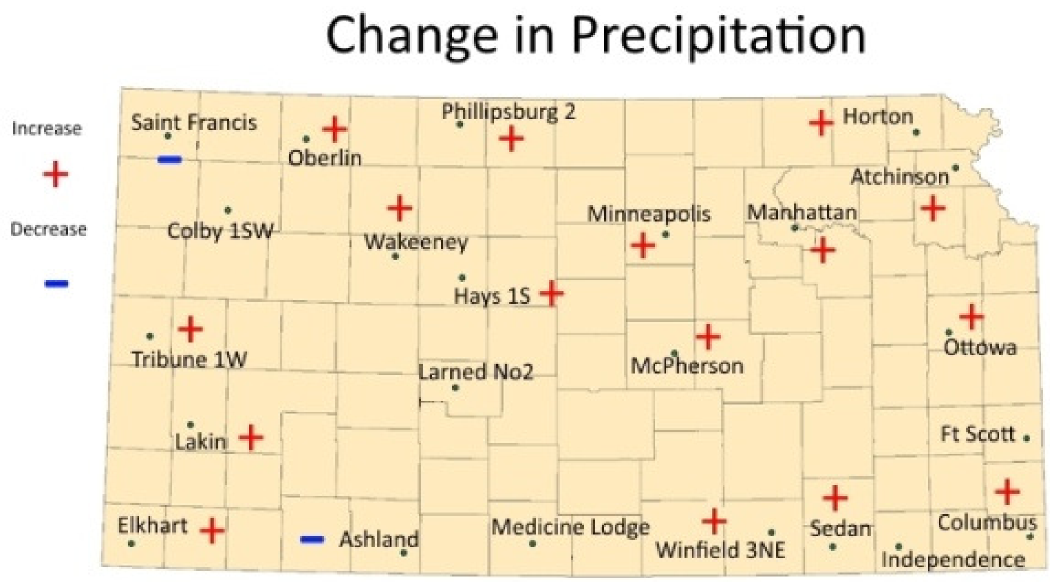


Figure 5: Significant positive and negative trends in minimum and maximum temperature, and precipitation for the 23 stations in Kansas. Only significant trends were marked on the map.

Adaptation measures

Adaptation measures	Climate	What is the climate change observed	Region of study	Advantages of the measure	Disadvantages of the measure	Applicability for SGP(High, Medium, or Low)	Reference
Agirculture							
Enhance soil nutrient	Arid, semiarid, temperate, and humid agroecological zones	Increase in temperature, change in precipitation, increase in occurance and of low/high extreme precipitation and temperature events	Kenya	Increases soil conservation, boost crop production and increases revenue, and provides a buffer against negative impacts of climate change	Cost of manure, mulching, inorganic ferterlizer etc.	High	Bryan et al. (2012)
Improved feeding practices	Arid, semiarid, temperate, and humid agroecological zones	Increase in temperature, change in precipitation, increase in occurance and of low/high extreme precipitation and temperature events	Kenya	Increases productivity of dairy cattle, reduce methane emissions	Potential to reduce productivity during destocking	Low	Bryan et al. (2012)
Hardier cultivars	Boreal, Alpine, Atlantic, Continental, Mediterranean	Warmer temperatures, longer growing seasons, reduced water availability, frequent low/high extreme precipitaiton and temperature	Europe	More resistant to drought and pests, improves productivity and increases profit	Cost of developing cultivars and cost of purchase to the stakeholder	High	Iglesias et al. (2011)
Change crop rotation timing and diversity	Boreal, Alpine, Atlantic, Continental, Mediterranean	Warmer temperatures, longer growing seasons, reduced water availability, increase in occurance and of low/high extreme precipitation and temperature events	Europe	Improve crop productivity, mitigate high temperatures, increase diversity of crop sales	Cost of crops and any additional equipment	High	Iglesias et al. (2011)
Water erosion buffers	Boreal, Alpine, Atlantic, Continental, Mediterranean	Warmer temperatures, longer growing seasons, reduced water availability, increase in occurance and of low/high extreme precipitation and temperature events	Europe	Mitigate flood damage, increased water availability, reduces loss of topsoil, reduces runoff	Cost of cover crops and construction of terraces or other physical buffers	Med	Iglesias et al. (2011)
Improved irrigation efficiency	Boreal, Alpine, Atlantic, Continental, Mediterranean	Warmer temperatures, longer growing seasons, reduced water availability, increase in occurance and of low/high extreme precipitation and temperature events	Europe	Reduces water usage and cost of water	Cost of irrigation equipment	High	Iglesias et al. (2011)
Improved water management	Temperate	Increase in temperature and increase in precipitation	Netherlands	Increased water storage capacity, mitigation of floods, barriers to rise in sea levels, higher water availability	Cost of infrastructure	Medium	Bruin et al. (2009)

GHG mitigation	Semiarid steppe, humid subtropical, marine westcoast, mediterranean, humid continental, alpine, tropical wet/dry, desert	Increase in CO_2, rise in temperature, change in precipitation, increased frequency of extreme events	United States	Improve soil quality and crop production, increase soil carbon sink, reduce climate effects on crop productivity	Associated financial costs	High	Walthall et al. (2012)
Avoid high risk areas	Semiarid steppe, humid subtropical, marine westcoast, mediterranean, humid continental, alpine, tropical wet/dry, desert	Increase in CO_2, rise in temperature, decrease in precipitation, increased frequency of extreme low/high precipitation and temperature	United States	Reduce financial losses	Loss of farmable land over extended periods of time	Med	Walthall et al. (2012)
Forest							
Afforestation and Reforestation Clean Development Mechanism	Tropical	Increase in temperature increases carbon availability	Sri Lanka	Coconut trees and home gardens to do carbon sequestration for the local forests.	It is hard to acquire funds to subsidize home gardens and coconut trees.	Med	Mattsson, E. (2012).
Responding to Climate Change in National Forests: A Guidebook for Developing Adaptation Options	North American climate	Increase in temperature	North American Forest	Creates a step-by-step plan to conserve forests	This measurement is for established forests, but could be used to create forests in needed areas	High	Peterson et al., (2011)
Rangeland							
Increased burning frequency	Arid, semiarid, temperate, and humid	Increased woody plant competition due to increasing CO_2	North America	Easy to implement, cost effective	Negative effects on some range species, more CO_2 released.	High	Joyce et al., (2013)
Changing livestock production areas	Arid, semiarid, temperate, and humid	Shifting ecotones in response to increase in temperature and decrease in precipitation	North America	Continue to use grazing for animal product production	Damage to local economies as livestock markets move	High	Ash et al., (2012)
Changing livestock breed/specie	Arid, semiarid, temperate, and humid	Declining forage quality due to increased temperature	North America	Could quickly adapt	Could change seasonal markets	High	Joyce et al., (2013)
Altering grazing periods and claving season	Arid, semiarid, temperate, and humid	Increase in temp and increase/decrease precip plant physiological cycles	North America	Continue to use forage most effectively	Changes time of animal product availability	High	Joyce et al., (2013)
Water							
Create a canal connecting water bodies	Dry and hot	High temperatures low precip	Jordan River Basin	Create more regulated system of flowing water	Economically risky; area of sediment runoff	Low	Comair et al., (2013)
Decrease water supply	Temperate	High precipitation; moderate temperatures	Czech Republic	More consumption for people; less human interaction	More policies placed; more laws	High	Dvorak et al., (1997)
Building Dams and Reservoirs	Humid and warm	High Precipitation	Brazil	Create more bodies of water	Economically risky; strain on the areas in question	Med	Krol et al., (2015)

Figure 6: Table of adaptations to climate change for water, forests, rangeland, and agriculture from regions other than the Southern Great Plains.

Further results on forests

While the most information for adaption measures is geared towards the other three ecoregions, there are a couple adaption measures that have been shown to help forests. For example, Eastern Red cedar is one of the most well-known invasive species of the prairie. It has been found that while red cedar is invasive, it is also a benefit for the prairie. Red cedar has been found to increase the carbon of the soil around it. Pines, while they have more carbon in the biomass around the stand, actually leaches the soil of the carbon. However, because of the resilience and high reproductive rate of the red cedar, without management techniques, it would eventually take over the prairie. Increased temperature of the prairie can encourage red cedar to grow faster (Mellor et al, 2012).

In tropical rainforests, carbon was a main limiting factor in how rainforests could be healthy. Temperate forest are found to be more resilient to temperature increases and thus carbon availability fluctuations. As the carbon cycle is varied by an increase in temperature, rainforests are starting to dye off (Reed et al, 2011).

In a place that implemented an adaptation program, there were consequences seen in the economy. Sri Lanka wanted to find above ground biomass carbon stocks to estimate a reference level to calculate the cost of reducing emissions from deforestation and degradation. Sri Lanka's coastal areas could be restored through some programs such as Afforestation and Reforestation Clean Development Mechanism. Coconut trees and home gardens are used to aid these programs because they are multipurpose and have a good carbon sequestration potential. The deforestation was a cause of agriculture (Mattsson 2012).

In India, there was an interesting correlation with market fluctuations and deforestation. They found that in the four research zones where biomass increased, then two effects will happen to the market. The greater availability of biomass encourages a larger harvest. This harvest will lower the market price. This lower market price will lower rent rates of the land, but also discourages the high harvest rates. If policies were put into place, then maybe this roller coaster effect could be stemmed (Aaheim et al 2010).

Policy

From the information found in the literature review, we can see that there are many policies in progress, but not many are enforced in the United States. For example, the Durban Climate Summit concluded with a collective agreement to increase the laws concerning climate change while decreasing emissions by 2020 (Carlarne 2010). Kansas will be one of the states most affected by climate change due to being in an area of a climate gradient (Johannes J. Feddema, 2007). This means that while one area is drier, but another area has increased precipitation, the projections for the future suggest that Kansas will become drier. Since there is already a shortage of water in the state, it can only get worse. Since precipitation events will become less frequent and more severe, agriculture practices will have to adapt, as well as our technology that uses water as an energy source. Feddema (2013) points out that fossil fuel costs are going to increase if climate change policies are implemented. This can affect which energy production technology we use. Policies concerning emissions can harm Kansas if we do not come up with policies to start gradually reduce emissions today (Feddema 2013).

During the 9th Session of Working Group III of the IPCC in Bangkok, Thailand, the authors summarized four main points that can be used to evaluate climate change policies. These include: environmental effectiveness, cost effectiveness, distributional effects, including equity, and institutional feasibility. There was high evidence and much agreement for policies that provide an incentive for low-GHG products and technologies. Such policies could include economic instruments, government funding and regulation. If the government were to give support through subsidies and tax credits, then efficient technology can be produced for helping with climate change policies. These technologies can be transferred to other developing countries to help them with financing and policies (Barker et al, 2007).

The key to making laws dealing with climate change is to create incentives for mitigation and regulate adaptation measures. Climate change should be used as a matter of justice. The countries with the less contribution to climate change are the ones who will be most affected. The poorest places will have to pay for the consumption that the larger, more developed countries consumed, but the poorer countries could not consume at that time because of lack of technology. Laws and policies should be made to consider social justice along with striving for a more sustainable world (Gloppen 2012).

Overall, climate change policies are still a work in progress. Many laws have been proposed, to only be pushed back by agriculture practices, especially in Kansas. However, there are few programs that have been implemented to help with getting the public involved in adapting to the climate change. "The Clean Water Neighbor program provides funding opportunities for nonpoint source pollution prevention planning and implementation projects. Potential projects can include source water protection, nonpoint source pollution management, green-infrastructure, local environmental protection and other projects to achieve a reduction in nonpoint source pollution. The program promotes partnerships in urban and rural communities to achieve water quality improvements." – Kansas Department of Health and Environment. The program is intended to promote a state and local partnership, encouraging citizens to take steps to plan management practices and protect important water resources. While this program can reduce the issue of non-point source pollution, there are currently no funding for projects that implement this program.

Discussion

Other studies have shown a wide variety of changes to precipitation and temperature. Anandhi et. al (2013) show a significant increase in minimum temperature for 12 stations of .1° C/decade. We found more cities with a significant increase in minimum temperature, however the tau statistic was not adjusted for serial correlation which would change significance values. Rahmani(2014) found an increase in extreme rainfall events of 90mm or more from northwest to southeast and a gradual positive trend in total rainfall from west to east in 21 of the 23 stations analyzed. The results from his Mann-Kendall test show 8 stations with a significant increase in precipitation(Rahmani 2014). Comparatively our results show 16 stations with a significant positive trend in precipitation. This is most likely due to his study accounting for serial correlation. Again this difference may be due to serial correlation. The results also show an overall positive trend in precipitation and a positive trend in maximum temperature from west to east.

The few stations which do not follow the overall trend in temperature and precipitation indicate the ability for climate to be spatially variable on a local scale. This necessitates that adaptation measures be applied locally as opposed to regionally.

Application to the Southern Great Plains

Agriculture

A decrease in maximum temperatures in the west may provide farmers with opportunities to produce a wider variety of plants due to the lessened heat stress. They also see a decrease in precipitation which will make water management an important measure for adapting to the changing climate. The positive trend in minimum temperature and precipitation from west to east suggests different climate adaptations. Higher temperatures will ultimately decrease crop production unless the prop water supply is maintained. The increase in precipitation will help but as Rahmani states in his dissertation, there is an increase in rainfall events of 90mm or more (Rahmani 2014). Flooding and erosion may be an increasing concern due to the high precipitation. Water erosion buffers, hardier cultivars, enhanced soil nutrients, greenhouse gas mitigation, and improved water management are important adaptations to consider for the Southern Great Plains; for the reasons above these adaptation measures are listed as having high to medium applicability to this region.

Rangeland

The mitigation of climate change refers to trying to stop or slow the rate at which it is changing. There are two main ways to go about this. Either through the reduction of greenhouse gases or by increasing carbon sinks. Although rangeland management has to potential to influence of greenhouse gas emissions, these emissions account for only a small amount of global emissions. While there is some potential of managing rangelands for the use of carbon sinks by increasing carbon storage in the vegetation and soil, this potential is also minor. Some rangeland management options aimed at climate change mitigation include: grazing at moderate or low stocking rates, increasing legumes in rangeland vegetation and the conversion of agricultural land back to rangeland (Joyce et al. 2013). For rangelands to have the greatest impact, future mitigation policies should be aimed at keeping the carbon already stored in the soil from being released through the conversion to cropland.

The best way for rangeland adaptation to climate change is through how it is managed. As climate change continues to impact rangelands, management practices will also need to continue to change. However, due to the complexity with which the climate and rangeland ecosystem interact, it is not precisely known what to expect or when. This makes adapting management practices to climate change more reactive than proactive, though some things may still be expected.

With the expected changes in rangeland vegetation, more than likely grazing practices will need to change. Although increased productivity means more forage available, quality is expected to decrease. With lower forage quality, rangelands may not support the number of animals they do now. If herd sizes are not reduced, changes such as animal breed or species grazed may need to be made (Joyce et al. 2013). As composition changes and ecotones shift, it may become necessary to change geographic locations of livestock production. As temperature and precipitation increases increase biomass productivity to the west and woody invasion begins to occur to the east, we could see a shift in livestock production (Ash et al. 2012).

Changes in the growing season will also affect how the rangeland is used. To optimize range use efficiency, it is recommended that livestock producers match forage production with animal needs. This means synchronizing calving cycles to forage availability so that forage quality is at its peak the same time that animal nutrition requirements are at their highest also. If climate change impacts rangeland vegetation in such a way, as has been suggested, that physiological processes are altered and growing seasons shift, then animal production cycles will also need to shift. This could have a large impact on livestock and livestock product markets.

With increasing pressure from woody species comes the added difficulty in controlling their invasion. Rangeland ecosystems developed under conditions where fire was common. The need for controlled burning is still there to maintain the health and productivity of these ecosystems. As woody species invasion increases, so too will the frequency with which fire is needed for suppression. It is unclear now if a threshold will be reached where woody specie invasion will outcompete rangeland grasses and forbs (Joyce et al. 2013).

Water

Water is a provider of many things including nourishment and our sustainability for life, hydroelectric energy and its ability to power businesses and households, and it is even used as a means for recreational activities such as fishing and boating. Water is an essential part of life for everyone that inhabits Earth, but none more so than Kansas. Kansas has been known as the "Breadbasket of America," and there is a good reason for it too. Agrarian ideals have shaped our very way of life, and if the source of agriculture's growth were to fail, then our way of life would be altered in a fairly dramatic way. However, what once was a bountiful resource in some parts of the world, is now but an exotic commodity. Some of these events are natural in which humans have no control, although, many events happening today have been anthropogenic. Reservoirs are depleting due to the ever changing climate that we live in. The Aral Sea has seen a drastic decrease in size due to human activity over the past fifty years. Damming the Colorado River is another issue in regards to human activity between international borders of Mexico and the United States which has caused decreased water flow into Mexico. An aquifer in which the Southern Great Plains depend on, the Ogallala aquifer, is depleting as well. As shown, evidence is here for further discussion in the Southern Great Plains Region. The end goal seems simple, but just like the research studies, there is a lot of information that needs to be considered before assuming. As stated before, water is very important, and if we are to continue to use it, it's about time to start thinking of our anthropogenic impact on this precious resource and what we can do to decrease our footprint.

Forest

As earlier discussed, Eastern Red Cedar is an invasive species in the prairie and across North America. To see how these trees could be managed for the benefit of the prairie instead of cutting the red cedars all down, we will take the steps presented in the Responding to Climate Change in National Forests: Guidebook for Developing Adaptation Options. Our first group of steps is to figure out what stakeholders there are that can be involved in the adaptation measures. For the Southern Great Plains, we can say government organizations, the public, and education facilities are the main stakeholders in the prairie. After this, scientists provide information on climate change and climate change effects, including vulnerability assessments, while resource managers provide strategic and tactical adaptation options and guidance on how they can be implemented. To identify adaptation options, there are steps that can reveal new options that have not been seen previously. These steps can be seen below:

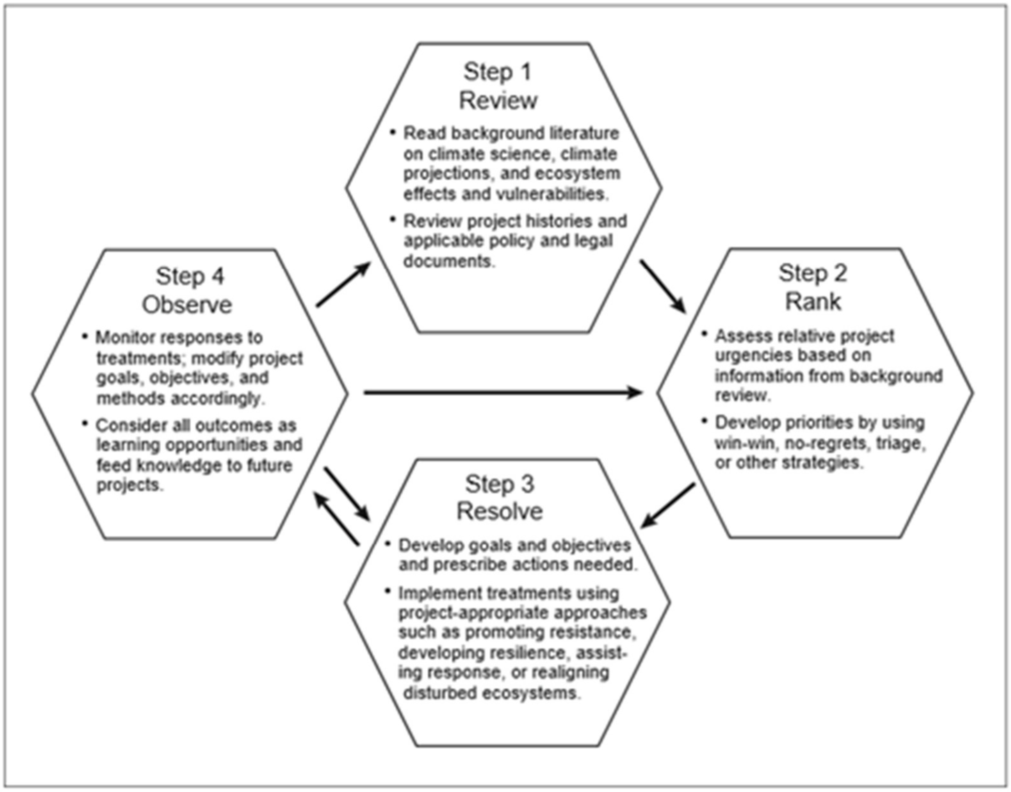


Figure 7—Steps for developing and implementing adaptation options.

Figure 6: Steps for implementing adaptation strategies for forests (Peterson et al 2011).

The first step is to review. This is where being informed and educated on current climate change data and policies is very important. The cedar forests in Kansas are increasing with the higher temperature (Polley 2013). In Kansas, we can see that the severity of storms is increasing while the frequency of precipitation events is decreasing (Feddema 2013). As Kansas gets drier, there in an increase in susceptibility to climate change caused by less available water during drought. Right now, there are no climate change policies in effect in Kansas. The second step is to figure out which project has first priority. For example, the declining prairie-chicken is not going to be as important as figuring out a way to stop cedars from fragmenting the prairie that they live in. Step three is to resolve. This includes developing goals and objectives for the project. After finding a solution that could work, implementation happens. For our example of red cedars taking over a non-fragmented piece of prairie, then our goal would be to stop the invasion of red cedars onto that piece of prairie. To do this, our objective would be to 1) reduce the amount of red cedars, 2) create ideal conditions for the promotion of prairie grass, and 3) decrease red cedar reproduction potential. For a treatment, we could implement burning. Step four is to observe how the prairie responds to these treatments. If this does not work, then we must go back a step to figure out what another treatment option might be.

Policy

According to our results, there are not a lot of policies, or even programs, that enforce the reduction of actions that increase climate change. From the summary of the IPCC report, the main findings are that the more the government is involved in the implementation of climate change policies, then the more effective the laws will become. These actions the government should consider are subsidies and tax credits to a community for deciding to participate in state-hosted climate change programs. While this is not a particular policy, this can help the community get involved with changing their unsustainable actions.

Another way that the state government could get involved is to enforce climate change policies concerning the worst pollutants. California has implemented laws that prohibit cars that expel too much pollutants. This policy should apply to all states at different levels. This could also lead the way to creating laws and policies that reduce pollution from all transportation devices, including agriculture machines and airplanes. As we reach closer to a society free from fossil fuels, the options for non-fossil fueled transportation is increasing. If states were to implement policies that required more dependence on renewable resources and was backed by the federal government, then dependence on fossil fuels would decrease. Pollution would decrease, and climate change would slow.

Overall, there have not been many policies that are implemented in the United States concerning climate change. Once the United States realizes that we only have about 60 years of fossil fuels left, then maybe it will start to implement climate change policies. Right now, there are a few state run programs that encourage the community to participate in helping with climate change. Without the federal government backing these programs, then there will not be progress towards new laws and policies on climate change.

Conclusion

There is an increasing trend in precipitation and minimum temperature since the past 100 years in Kansas. We found climate change adaptation measures that are suitable for the Southern Great Plains, but no policies were identified. We saw variation between weather stations across Kansas which implies that climate is variable spatially on a local scale, and temporally. Identifying adaptation measures for the wide array of climates is essential to prepare for the future. Policy needs to start being developed for climate variability. When developing policy it is important to think about the wide range of implications for adaptation within each ecoregion.

Future Research

Quantifying the vulnerability and risk factors for the Southern Great Plains via modeling and public surveys would allow for efficient application of adaptation strategies. Identifying local regions with the highest potential for adaptation would increase the cost effectiveness. Furthermore, developing effective policy plans to aid in implementing adaptation strategies would improve the process of applying them. Below, future research options are outline for each ecoregion specifically.

Agriculture

Selecting adaptation strategies is overwhelming with the many different associated variables. It is important to look at what the regional risks are, regional risk severity, and costs and benefits of the mitigation strategy for each risk. Those three areas require more research. Agroecological zonation is an important research area as well because it may provide an accurate method in assigning risks and adaptations. Many adaptation strategies themselves are constantly being improved through research and should be continued. A few examples are water and cropland management, irrigation technology, and pest and drought resistant cultivars.

Rangeland

Future research should continue to develop models, such as DGVMs, to be used at regional scales. DGVM's provide researchers the ability to match climate changes to ecological processes within rangeland ecosystems (Neilson et al. 2005). Instead of focusing on how just one factor of climate change, such as temperature or precipitation, affects the ecosystem, more research aimed at climate ecosystem interactions needs to be conducted. Climate thresholds for rangeland have also not yet been identified. Research needs to be done to try to find these thresholds before they are reached and mitigation and adaption are no longer options.

Water

A big tool that will help our group in the Southern Great Plains is gathering the climate data in order to perform statistical analysis and derive ideas from that in order to achieve success in the assumption of either passing or failing. Another thing regarding future research is to understand how water management works. Water management is the idea of incorporating adaptation strategies to help consolidate water. Many areas are performing this action including Europe and South America. If we were to delve into this idea more, then efforts towards the conservation of water would improve. Another idea is to look at models and see how the future outlook is. Many studies performed these models and tried to delve deep into the subject. If the Southern Great Plains region takes this idea and figures out how much time is left before a critical level is reached within the Ogallala aquifer, then these scenarios may play out in a more positive manner.

Forest

Since there is not a lot of research geared toward the interaction of forested areas and the Southern Great Plains, we propose potential future research to be done. The simplest of these would be try to manipulate the system so that both the surrounding area (whether that be prairie, water, or urban) and the forests can benefit. To best figure this out is to have research plots with different forested areas and surrounding land. Over the years, different adaptation measures (specifically in response to climate change) should be implemented over a set period of time. After this time lapse, then the plot with the greatest forest-land relationship should be the adaptation measure that is recommended throughout the Southern Great Plains.

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References

Aaheim, A., Gopalakrishnan, R., Chaturvedi, R., Ravindranath, N., Sagadevan, A., Sharma, N., & Wei, T. (2010). A macroeconomic analysis of adaptation to climate change impacts on forests in India. Mitigation and Adaptation Strategies for Global Change, 229-245. Retrieved February 26, 2015.

Anandhi, Aavudai, et al. "Long-Term Spatial and Temporal Trends in Frost Indices in Kansas, USA." Climatic Change 120.1-2 (2013): 169-81. ProQuest. Web. 24 Apr. 2015.

Ash, Andrew et al., "Is Proactive Adaptation to Climate Change Necessary in Grazed Rangelands?" Rangeland Ecology & Management 65.6 (2012): 563-68. BioOne. Web. 3 Feb. 2015.

Agriculture. (n.d.). Retrieved April 13, 2015, from http://www.merriam-webster.com/dictionary/agriculture

Bekele, E., & Knapp, H. (n.d.). Watershed Modeling to Assessing Impacts of Potential Climate Change on Water Supply Availability. Water Resources Management, 3299-3320.

Bele, M., Somorin, O., Sonwa, D., Nkem, J., & Locatelli, B. (2010). Forests and climate change adaptation policies in Cameroon. Mitigation and Adaptation Strategies for Global Change, 369-385. Retrieved February 26, 2015.

Brown, R. A., Rosenberg, N. J. (1999). Climate change impacts on the potential productivity of corn and winter wheat in their primary united states growing regions. *Climatic Change, 41*(1), 73-107. doi:http://dx.doi.org/10.1023/A:1005449132633

Bryan, E., Ringler, C., Okoba, B., Koo, J., Herrero, M., Silvestri, S. (May 2013). Can agriculture support climate change adaptation, greenhouse gas mitigation and rural livelihoods? insights from Kenya. *Climatic Change, 118,* 151-165. doi: 10.1007/s10584-012-0640-0

Carlarne, C. P. 2010. Climate Change Law and Policy: EU and US Approaches. New York, NY: Oxford University Press.

Comair, G., Gupta, P., Ingenloff, C., Shin, G., & Mckinney, D. (n.d.). Water resources management in the Jordan River Basin. Water and Environment Journal, 495-504.

Cozzetto, K., Chief, K., Dittmer, K., Brubaker, M., Gough, R., Souza, K., . . . Chavan, P. (n.d.). Climate change impacts on the water resources of American Indians and Alaska Natives in the U.S. Climatic Change, 569-584.

Daniels, Brigham; 2011; 2011, 6; Addressing Global Climate Change in an Age of Political Climate Change. Brigham Young University Law Review, ProQuest Research Library pg. 1899 Gloppen, S., A. L. St. Clair. 2012. Climate Change Lawfare. Social Research 79:4: 899- 930.

Dvorak, Vaclav, Josef Hladny, and Ladislav Kasparek. (1997). Climate Change Hydrology and Water Resources Impact and Adaptation for Selected River Basins in the Czech Republic. Kluwer Academic Publishers.

Engle, Nathan L. (2013). The Role of Drought Preparedness in Building and Mobilizing Adaptive Capacity in States and Their Community Water Systems. Climatic Change 118.2: 291-306.

Feddema, Johannes J. (2007). Testimony to the Joint House and Senate Committee on Energy and Environment. Department of Geography, University of Kansas, Lawrence, KS.

Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.). 2014. *Summary for policymakers. In: Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

Hamed, K. H. (2008). Trend detection in hydrologic data: The mann-kendall trend test under the scaling hypothesis. *Journal of Hydrology (Amsterdam), 349*(3-4), 350-363. doi:http://dx.doi.org/10.1016/j.jhydrol.2007.11.009

He, Chansheng. (2003). Integration of Geographic Information Systems and Simulation Model for Watershed Management. Environmental Modelling & Software 18.8-9: 809-13.

Hennemuth, B., Bender, S., Bülow, K., Dreier, N., Keup-Thiel, E., Krüger, O., Mudersbach, C., Radermacher, C., Schoetter, R. (2013). Statistical methods for the analysis of simulated and observed climate data, applied in projects and institutions dealing with climate change impact and adaptation. *CSC Report 13*, Climate Service Center, Germany

IPCC, 2007: Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Izaurralde, R. C., et al. "Climate Impacts on Agriculture: Implications for Forage and Rangeland Production." Agronomy Journal 103.2 (2011): 371-81. ProQuest. Web. 11 Feb. 2015.

Hirsch, R.M., Slack, J.R. and Smith, R.A. (1982). Techniques for trend assessment for monthly water quality data, *Water Resources Research, 18,* 107–121.

Iglesias, A., Quiroga, S., Moneo, M., & Garrote, L. (2012). From climate change impacts to the development of adaptation strategies: Challenges for agriculture in europe. *Climatic Change, 112*(1), 143-168. doi:http://dx.doi.org/10.1007/s10584-011-0344-x

Morgan J. A. et al., "Management Implications of Global Change for Great Plain Rangelands." Rangelands 30(3)(2008):18–22. BioOne. Web. 9 Mar. 2015

Steiguer J. E., Brown, Joel R., Thorpe, Jim "Contributing to the Mitigation of Climate Change Using Rangeland Management." Rangelands 30.3 (2008): 7-11. BioOne. Web. 11 Feb. 2015.

Kendall, M. G. 1975. Rank Correlation Methods. *4th edn.* Charles Griffin, London.

Klein, Tank AMG, Zwiers FW, Zhang X (2009) Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. Climate data and monitoring WCDMP-No 72, WMO-TD No 1500, 56 pp

Kothyari, U. C., Singh, V. P. (1996). Rainfall and temperature trends in India. *Hydrological Processes*, *10(3)*, 357-372. doi:10.1002/(SICI)1099-1085(199603)10:3<357::AID-HYP305>3.0.CO;2-Y

Krol, Maarten S., Marjella J. Vries, Pieter R. Oel, and José Carlos Araújo. "Sustainability of Small Reservoirs and Large Scale Water Availability Under Current Conditions and

Climate Change." *Water Resources Management* 25.12 (2011): 3017-026. Web. 2 Feb. 2015.

Joyce, Linda A., et al., "Climate Change and North American Rangelands: Assessment of Mitigation and Adaptation Strategies." Rangeland Ecology & Management 66.6 (2013): 512-28. BioOne. Web. 3 Feb. 2015.

Lopez, Ana, Fai Fung, Mark New, Glenn Watts, Alan Weston, and Robert L. Wilby. (2009). From Climate Model Ensembles to Climate Change Impacts and Adaptation: A Case Study of Water Resource Management in the Southwest of England. Water Resources Research 45.8.

Mann, H.B. (1945). Nonparametric tests against trend, *Econometrica*, 13, 245–259.

Mattsson, E. (2012). Forest and land use mitigation and adaptation in Sri Lanka, Aspects in the light of international climate change policies (Doctoral these). University of Gothenburg, Sweden.

McLeod, A.I., Hipel, K.W. & Bodo, B.A. (1990). Trend analysis methodology for water quality time series*, Environmetrics, 2,* 169–200.

Mellor, N. J., J. Hellerich, R. Drijber, S. J. Morris, M. E. Stromberger, E. A. Paul. Sept. 2012. Changes in Ecosystem Carbon Following Afforestation of Native Sand Prairie. Soil Sci. Soc. Am. J. 77:1613–1624

Nemec, Kristine T., and Ciara Raudsepp-Hearne (2013). The Use of Geographic Information Systems to Map and Assess Ecosystem Services. Biodiversity and Conservation 22.1: 1-15.

Hobbs, N. T., et al., "Fragmentation of Rangelands: Implications for Humans, Animals, and Landscapes." Global Environmental Change 18 (2008):776–785. ScienceDirect. Web. 10 Mar. 2015.

Peterson, David L.; Millar, Connie I.; Joyce, Linda A.; Furniss, Michael J.; Halofsky, Jessica E.; Neilson, Ronald P.; Morelli, Toni Lyn. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 109 p.

Peterson, D.L., J.L. Whistler, J.M. Lomas, K.E. Dobbs, M.E. Jakubauskas, S.E. Egbert, and E. A. Martinko. 2005. *2005 Kansas Land Cover Patterns Phase I: Final Report. KBS Report 150. Kansas Biological Survey*, University of Kansas, 29pp.

Polley, H. Wayne, David D. Briske, Jack A. Morgan, Klaus Wolter, Derek W. Bailey, and Joel R. Brown. Sept. 2013. Rangeland Ecol Manage 66:493–511.

P. SMITH and J. E. OLESEN (2010). Synergies between the mitigation of, and adaptation to, climate change in agriculture. The Journal of Agricultural Science, 148, pp 543-552. doi:10.1017/S0021859610000341.

Ramirez-Villegas, J., Salazar, M., Jarvis, A.,, Navarro-Racines, C. E. (2012). A way forward on adaptation to climate change in Colombian agriculture: perspectives towards 2050. *Climatic Change, 115*, 611-628. doi:10.1007/s10584-012-0500-y

Moss, Richard H., et al., "The next Generation of Scenarios for Climate Change Research and Assessment." Nature 463.7282 (2010): 747-56. ProQuest. Web. 9 Mar. 2015.

Neilson, Ronald P., et al., "Forecasting Regional to Global Plant Migration in Response to Climate Change." BioScience 55.9 (2005): 749-759. JSTOR. Web. 3 Mar. 2015.

Reed, S., Wood, T., & Cavaleri, M. (2011). Tropical forests in a warming world. New Phytologist, 27-29. Retrieved February 26, 2015.

Rosenberg, Norman J., Daniel J. Epstein, David Wang, Lance Vail, Raghavan Srinivasan, and Jeffrey G. Arnold. (1999). Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region. *Climate Change* 42: 677-92.

Sieve, Travis. Clean Water Neighbor Program. Retrieved from http://www.kdheks.gov/nps/cwn.htm

Thomson, A. M., Rosenberg, N. J., Izaurralde, R. C., & al, e. (2005). Climate change impacts for the conterminous USA: An integrated assessment: Part 5. irrigated agriculture and national grain crop production. *Climatic Change, 69*(1), 89-105. doi:http://dx.doi.org/10.1007/s10584-005-3611-x

Walthall, C.L., J. Hatfield, P. Backlund, L. Lengnick, E. Marshall, M. Walsh, S. Adkins, M. Aillery, E.A. Ainsworth, C. Ammann, C.J. Anderson, I. Bartomeus, L.H. Baumgard, F. Booker, B. Bradley, D.M. Blumenthal, J. Bunce, K. Burkey, S.M. Dabney, J.A. Delgado, J. Dukes, A. Funk, K. Garrett, M. Glenn, D.A. Grantz, D. Goodrich, S. Hu, R.C. Izaurralde, R.A.C. Jones, S-H. Kim, A.D.B. Leaky, K. Lewers, T.L. Mader, A. McClung, J. Morgan, D.J. Muth, M. Nearing, D.M. Oosterhuis, D. Ort, C. Parmesan, W.T. Pettigrew, W. Polley, R. Rader, C. Rice, M. Rivington, E. Rosskopf, W.A. Salas, L.E. Sollenberger, R. Srygley, C. Stöckle, E.S. Takle, D. Timlin, J.W. White, R. Winfree, L. Wright-Morton, L.H. Ziska. (February 2013). *Climate Change and Agriculture in the United States: Effects and Adaptation*. http://www.usda.gov/oce/climate_change/effects.htm

Rahmani, Vahid. (2014). Assessing Impacts of Climate Change on Kansas Water Resources: Rainfall Trends and Risk Analysis of Water Control Structures (Doctoral dissertation). Retrieved from K-state Research Exchange. http://krex.k-state.edu/dspace/handle/2097/18342

Allard, Vincent, et al., "Elevated CO2 Effects on Decomposition Processes in a Grazed Grassland." Global Change Biology 10.9 (2004): 1553-564. Wiley Online Library. Web. 3 Feb. 2015.

Yue, S., & Wang, C. (2004). The mann-kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resources Management, 18*(3), 201-218. doi:http://dx.doi.org/10.1023/B:WARM.0000043140.61082.60