Problem Statement

My PhD research focuses on the vulnerability of groundwater resources in Indian cities in the context of climate variability. I am particularly interested in exploring the relevance of conjunctive ground and surface water management in measures for adaptation to climate variability.

This class project for LA 221 explores the possibility of creating a GIS model which will help me identify spatial correlation between rainfall trends and groundwater recharge trends. In this class project I shall focus on data from US counties since it is well organized and readily available.

Literature Review

Cities across the world depend on groundwater to varying extents to meet their requirements. In some parts of the US like the arid West, urban areas have increasingly depended on groundwater since surface water has already been over-allocated (Collins and Bolin, 2007). Over the past decade researchers have increasingly examined vulnerability of urban areas to climate variability (Romero Lankao and Qin, 2011) and in particular the vulnerability of urban areas dependent on groundwater (Green et.al., 2011, Collins and Bolin, 2007).

In India, much of the newer urban development is dependent on groundwater to meet domestic needs since public infrastructure planning lags behind the initiative of private capital and housing demands. Using the survey of water utilities completed by the National Institute of Urban Affairs in 2002, Patel and Krishnan (2009) demonstrate that smaller cities are more dependent on groundwater sources for their water supply. In this context it is significant to evaluate the vulnerability of these cities to climate change related variability in precipitation and identify possible adaptation measures.

Aquifers provide an opportunity for large scale water storage which may help buffer fluctuation in water availability and conjunctive management of ground and surface water management could be a significant part of climate adaptation strategies. While some urban areas already rely on conjunctive water management for their water supply (Alameda County Water District, 2011) cities like San Francisco are
also exploring the possibility of using groundwater to supplement surface water supply in case of climate variability related fluctuations or emergency (SFPUC, 2011).

Identification of sources of recharge would be a critical first step towards the formulation of conjunctive water management proposals. In this class project I propose to address this question using GIS to identify correlation between historic trends of rainfall and groundwater levels.

**Solution**

A conceptual model of the proposed solution is provided below:
Explanation of Conceptual Model and Results

1. **Input U.S. groundwater consumption data at the county level (2005):**

   This data was obtained from the USGS website (http://water.usgs.gov/watuse/data/2005/index.html). The dataset provides county level water consumption data under many heads. The quantity of interest to this GIS project comes under the head of ‘total public groundwater supply’.

2. **Classify counties based on dependence of public water supply on groundwater:**

   This was done by creating a new column in the dataset and computing the percentage of groundwater in relation to total public supply. The resulting map is given below:

   ![Map of groundwater dependence](image1)

3. **Input rain gauge locations and historic rainfall data:**

   This data was obtained from (http://www.ncdc.noaa.gov/oa/climate/research/ushcn/). These rain gauges have continuous data from the late nineteenth century till the present day. The map below shows the rain gauge locations superimposed on the map showing county level groundwater dependence of public water supply.

   ![Map of rain gauge locations](image2)
4. **Select a state with high groundwater dependence and sufficient number of rain gauges:**

I selected Kansas since it satisfies both the conditions mentioned above, and is also known to lie predominantly on the Ogallala aquifer, while also being at the geographic center of the U.S. Besides, it is also relatively flat, hence limiting influence of topography in groundwater recharge.

5. **Input locations and historic data from groundwater monitoring wells:**

This data was obtained from the USGS website (http://nwis.waterdata.usgs.gov/ca/nwis/gwlevels?search_criteria=county_cd&submitted_form=introduction).

Since there was a very large amount of data and since the more recent years have relatively better record, I decided to download data for the forty year period from 1970-2009. This data had to be reformatted in order to make it usable and this was done using a python script. Using the script I also selected all the wells which have less than 5 years of missing data. This selection was used for all subsequent operations.

6. **Perform spatial join of rain gauges with nearest monitoring well and export data to excel:**

In order to check for correlation between rainfall trends and groundwater level trends, I first performed a spatial join of the rain gauges with the nearest monitoring well and exported the data to excel. The map below shows selected rain gauges and surrounding wells with upto 5 years of data gaps.

![Map of rain gauges and monitoring wells](image)

After exporting it to excel I used a linear regression model to check for correlation between each of the rain gauges and their nearest groundwater monitoring well. In order to do this, the rain gauge measurement data was first converted to a ‘cumulative deviation from mean’ format. The resulting graphs of rain fall trends and groundwater level trends are shown in the following pages.
7. **Identify well and rain gauge pair with strongest correlation:**

Based on the regression analysis, it is clear that two of the rain gauges and their nearest monitoring wells have relatively high correlation. Rain gauge no.5 which had the highest correlation with its nearest well (Rsquare: 0.8) was selected for more detailed subsequent analysis.

8. **Identify other wells near this rain gauge and check for correlation:**

For this, I visually selected three more wells in the vicinity of the selected rain gauge. The intention was to check whether the groundwater levels in the vicinity of this particular rain gauge is somehow very closely related to the rainfall trend. The results of the correlation analysis is shown below.

9. **Input NED data and satellite imagery for the area in which the selected rain gauge and surrounding wells are located:**

NED data was obtained from the seamless server, while satellite imagery was obtained from Google Earth. I used both of these to further understand local conditions which may be contributing to variation in correlation between the selected rain gauge data and its four surrounding wells. NED imagery and satellite image from Google Earth for the selected area is shown below.
10. Check for physiographic factors which may explain variation in correlation:

Examination of the NED data and satellite imagery shows that the selected rain gauge lies along a stream channel. The selected monitoring wells north and south of the rain gauge are also relatively close to the stream channel and I expected them also to show a high correlation with the rainfall trend, since it is quite possible that rain water conveyed through the stream channel is contributing substantially to groundwater recharge. But there seems to be very little correlation between these wells and the selected rain gauge. The well which is further to the east seems to have even lesser correlation and this could be because, based on the NED dataset and satellite imagery it seems to be within another watershed altogether.

Discussion

The results show that there can be strong correlation between historic rainfall trends and groundwater levels and this can be identified using GIS. But correlation clearly does not imply causation and to understand the causes one needs to be able to understand other local factors like topography, geology and soil and aquifer conditions. Of these, I was only able to take into account topography using the NED dataset. Besides these local factors, rate of extraction of groundwater and location of these extraction wells are other critical factors which will contribute to trends in groundwater levels. Since the county level water consumption data was available only at 5 year intervals, it was very difficult to understand rate of extraction of groundwater in these areas, while the location of the extraction wells were unavailable due to security considerations.

Conclusions

The attempt to build a GIS model to evaluate the spatial distribution of correlation between historic rainfall and groundwater level trends was only partly successful. I had to use a combination of excel and GIS to do even the most basic of correlation studies. Besides, much effort went into sorting and reformatting the groundwater level data. Both of these convince me that I need to learn Python well in order to automate the correlation analysis and also to efficiently and quickly reformat and subset the datasets. The study also helped me identify other factors which I need to take into consideration while doing future analysis of such correlation.
It should be possible to construct a GIS model in which I automate the process of checking correlation between each rain gauge and the wells around it, probably moving from the closest wells to the farthest. Such a model may help me identify which rain gauges are correlated to which wells and the model might provide many new insights since rainfall in surprisingly distant areas may contribute to groundwater level fluctuations due to the geologic conditions. A model of this nature could be very useful to identify areas which have higher potential for conjunctive water management.

References


