1.0 Introduction

Arizona deserts are regions of minimal precipitation typically receiving less than 12 inches of rain annually. Arizona Department of Water Resources (ADWR) monitors groundwater, surface water and is generally responsible for the water resources of the state. ADWR proclaims that the state is in the midst of a drought which began roughly a decade ago. The severity of this drought of course would vary both spatially and temporally. A preliminary study conducted using Fortran based statistical tools and GIS- analysis on water resources data and meteorological data indicates good correlation between water resources variability and climate variability. The study attempts better understand the spatial patterns and trends pertaining to rainfall, groundwater fluctuations and their relationship to metrological parameters such as drought index in selected areas.

2.0 Methodology

The study includes development of arc-hydro including arc hydro ground water data model) for Phoenix Area and compilation of water resources database. The initial phases of analyses and database development are currently ongoing and will be reported at a later stage. This preliminary report includes only some basic geospatial analysis of rainfall and groundwater in Arizona and Phoenix Metro Area. Surface water analysis and more conclusive findings will be presented at the upcoming ESRI conferences/reports.

3.0 Rainfall

The paper presents several statistical models developed which describe rainfall patterns in the state. In particular, we have examined the following: changes in precipitation of each station compared to the overall state wide change in precipitation, total yearly precipitation compared to the elevations of the stations, spatial variation in rainfall trends (holistic statewide all seasons approach), Ground Water Variability in Arizona, differences in rainfall trends for summer and winter seasons, and an analysis of the total available precipitation over the Gila River watershed.

Spatial analysis for precipitation monthly totals was performed for 496 stations across the state of Arizona, using National Climatic Data Center (www.ncdc.noaa.com) . The completeness of the data records for these stations varied widely and hence some adjustments and data manipulation was carried out. Pre-analysis data manipulation included discarding some data which reduced. Further processing included the calculation of the mean and trends (linear regression) for each station and for each season.

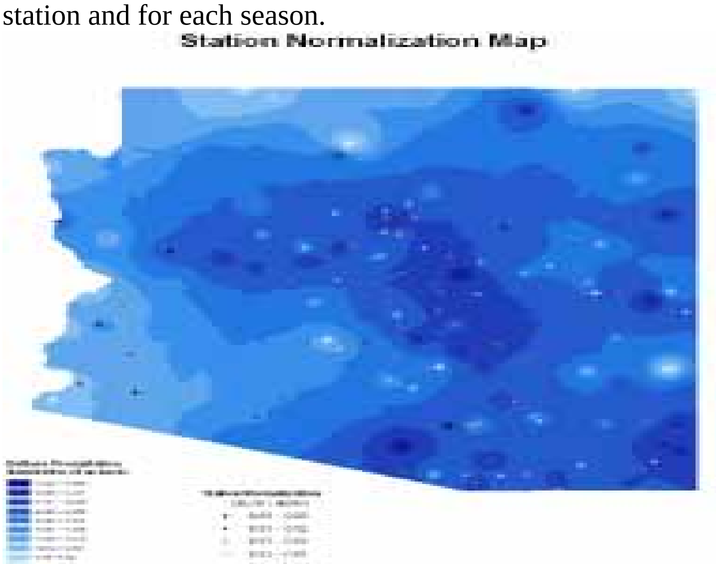


Figure 1. Normalization of precipitation stations; statewide change in precipitation from 1980-2003.

This analysis was derived from using a combination of the interpolation method of Inverse Distance Weighting (IDW) and normalization. The goal from these two methods was to identify two different types of correlations. The first correlation was between the changes (delta) in precipitation of each station compared to the overall state wide change in precipitation in Arizona. The second correlation focused on the total yearly precipitation compared to the elevations of the stations.

Station Normalization Map (Figure R-1) represents the percentage change of each of the stations compared to the overall state wide change in precipitation. A smaller normalization value, in terms of its negativity, indicates a greater impact of decline in precipitation per station. This is based on the overall negative values of the simple linear regression. These stations were plotted within the Inverse Distance Weighting interpolation of the deltas of the stations total precipitations. The analysis is based on the normalization of the stations yearly precipitation means with regard to the delta value (simple linear regression) of each of those stations total yearly precipitation. A graduated colors filled contours display was mapped from this data. The station normalization was coupled with the IDW of the delta in precipitation for each of the stations yearly totals.

This revealed a trend and a conclusion to this analysis. The stations that have been affected the most by declining precipitation are located in areas of largest precipitation decrease. This is a trend that one would most likely predict. These changes are occurring primarily through the central portion of Arizona and continuing through the southeastern corner of the state.

The Station Delta (change in ppt) with Station Elevation Map depicts the stations annual precipitation deltas mapped within an IDW of the stations elevations. IDW of the stations elevations were interpolated and mapped by a graduated colors filled contour map. This was coupled with the stations yearly rainfall total delta. Each of the stations was symbolized by a graduated quantities symbols map with the delta of each for the precipitations stations as the value. The data reflects that stations with the smallest (negative) deltas, representing the greatest precipitation decrease, tend to be located in the areas of the highest elevation. Areas within or around the Colorado Plateau and the southeastern part of Arizona with higher elevations, have a high correlation between the greatest delta values and the increase in elevations. Locations along the western and central part of the state, which are at lower elevations, contain the stations with the smallest change in precipitation. Thus, the analysis represents that areas of higher elevation in Arizona may be experiencing the greatest drought during the past 23 years. It may however be noted that the span of 23-years analyzed herein may not be enough to make solid conclusions. This study will continue and collect more data for further analyses. The final findings of current and future analyses this study will be presented at the conference and updated on the ESRI professional publications online.

In conclusion the analysis provided us a clear window into the precipitation trends through out Arizona. We observed the areas that are experiencing the greatest decline in precipitation also contain the stations that are experiencing the greatest percentage decreases in precipitation. This was to be expected. Also, the correlation of the stations experiencing the greatest totals in precipitation loss was identified to be in locations of higher elevation. This was an unpredicted analysis. The choice of data sampling stations their location and judgment made about the data and purpose of analysis are of prime importance in spatial statistics and therefore the findings of this study are preliminary and shall be refined even further at a later stage of this study.

4.0 Groundwater

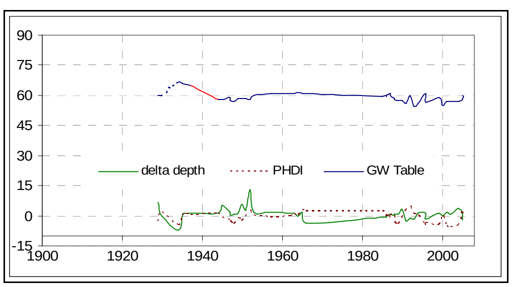
The groundwater analysis section of this study deals with the phoenix area rather than the state of Arizona. Because there are no consistent and continuous records only 26-stations containing some 6000 records were analyzed. The following paragraphs present description of groundwater resources in the phoenix area and results of analysis for these.

There are seven groundwater sub basins in the phoenix area namely: East Salt River Basin, West Salt River Basin, Hassayampa Basin, Rainbow valley Basin, Lake Pleasant Basin, Carefree Basin and the Fountain Hill Basin. For decades, more groundwater has been pumped from Arizona's aquifers for agricultural, municipal, and industrial uses than has naturally recharged back into the aquifers. This imbalance has changed and continues to change due to land development activities in Arizona and particularly in the phoenix valley as well as stringent groundwater management programs imposed by the state in late 1940s. Significant depletion of groundwater resources was occurring due heavy irrigation and other agricultural use in 1920s to 1940s. Using renewable supplies and recharging water underground reduced and continues to reduce this imbalance. However available data of water resources did not allow conclusive analysis of water balance in the phoenix area.

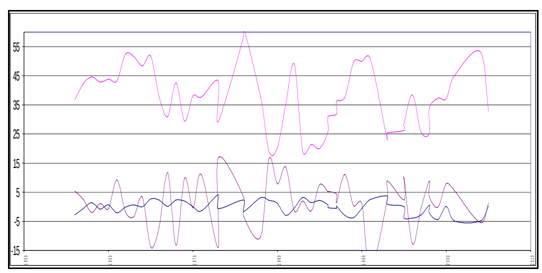
Two types of analysis of ground water data are also presented herein.

4.1 Spatial and Temporal Variability of Groundwater

Using statistical methods the variation of groundwater for selected stations/wells are shown below:



Station # 11 GW Fluctuation



Station # 5 GW Fluctuation

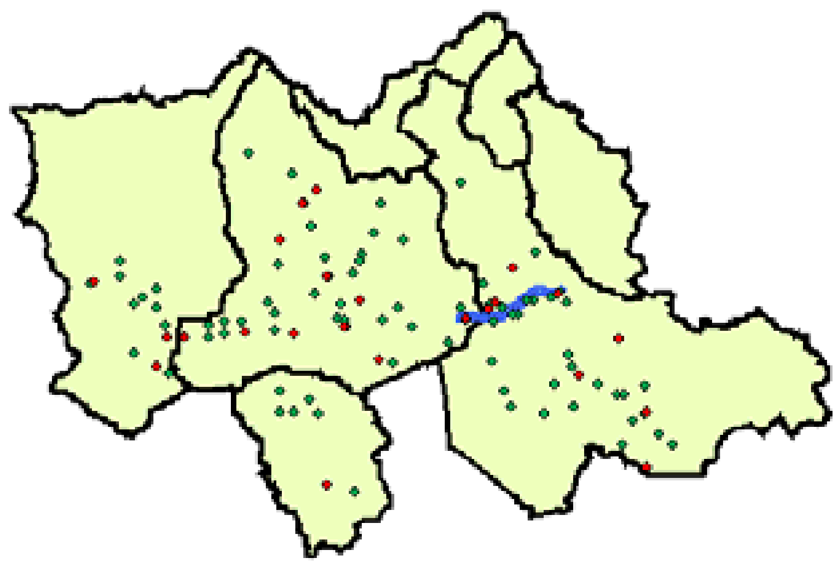
Spatial analyses for some 26 selected stations were carried. The statistical prediction of groundwater levels across given aquifer is mathematically very similar to temporal analysis and hence defines variation of groundwater level in space. However this mathematical similarity can not be used if reasonable results are to be expected. Water level variation at given time in space are influenced a host of factors amongst which are land use and aquifer types. Incorporating these factors in the analysis has merits and demerits; the geospatial analysis are generally non parametric yet if a parameter such as aquifer characteristics etc is used it will be first difficult to describe and second the dependence on that parameter would render the analysis not any more "non-parametric'

Per Toblers' first law proximity is used as criteria to incorporate spatial aspects of groundwater level variability in the prediction of groundwater change across given space. Initial analysis is based on groundwater level variations per sub-basin.

4.2 Impact Climate/ Metrological factors on groundwater

The Palmer Drought Index (PHDI) to represent drought conditions in our study area. The PHDI accounts not only for precipitation totals, but also for temperature, evapotranspiration, soil runoff, and soil recharge. It was developed in Midwest and may not be the best method to use for Arid Southwest; however the method is best used in for diagnostic, or historical, analyses. There are certainly limitations when using the PHDI incl (or any other index), and these are described in detail by Alley (1984), Karl and Knight (1985), and Guttmann (1991).

Our analyses produced strong correlation between groundwater fluctuation and Palmers Drought Index. The Pearson product-moment correlation coefficient of the range 0.85 to 0.07 and the significance of the coefficient. The combined the standardized regression coefficient is –0.11 and the significance level is 0.0034. All significant coefficients show that in times of drought (when PHDI is negative), the depth increases and in times of moisture (PHDI positive), unlike rainfall. We therefore conclude that rainfall depths are not good indicators of groundwater recovery in Phoenix valley nor do they seem to be a factor of importance in natural groundwater replenishment. The reason may be the fact that upper layers of phoenix area aquifers do not permit good infiltration to the deeper layers of those with exception of some areas in west valley.



Phoenix Area Groundwater Monitoring Wells

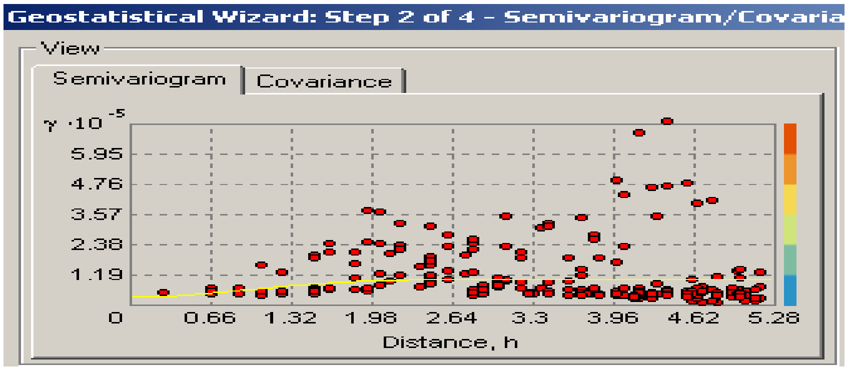


Fig 2.2a Semi-Variogram and Distribution of data

Exploratory Data Analysis was made for the ground water data, Fig G-2.a Semi-Variogram and Fig G-2.b shows histogram distribution of Ground water data. These show a good correlation of spatial data and near normal distribution respectively.

References

Alley, W. M., 1984: The Palmer Drought Severity Index - Limitations and assumptions. *J. Clim. Appl. Meteorol.*, **23,** 1100-1109.

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