Understanding the Complexity of Nebraska's Nitrate Groundwater Occurrence

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Background

Elevated nitrate concentrations in drinking water can cause "methemoglobinemia" or "blue baby syndrome" in infants and stomach cancer in adults. Thus, the US Environmental Protection Agency (US EPA) has established a maximum contaminant level (MCL) of 10 mg/l NO_3-N (US EPA, 1995). Nebraska has a large number of wells showing nitrate above the drinking water standard. High nitrate concentration in groundwater prompted the Natural Resource Districts (NRDs) in the 1988 crop season to institute a groundwater quality management program using a phased approach. Areas with nitrate concentrations ≤7.5, 7.6-15, and ≥15 mg N/l are classified for Phase I, II, and III, respectively.

Nebraska state agencies and NRDs have collected a large amount of nitrate data since 1974. However, accurately characterizing the groundwater quality in a complex aquifer system has always been difficult in the state. Naturally, Nebraska has obvious differences of hydrogeology and areal characterizations between the west and east (e.g. rainfall intensity, soil texture, the number of population and agriculture, etc.). Thus, groundwater nitrate contamination should comparatively be considered on both region of western and eastern Nebraska.

Objectives

- To utilize the large dataset of groundwater nitrate concentration that have been recorded until present (1974-2013), in order to determine the nitrate-contaminated areas in Nebraska.
- To analyze a long-term trend of groundwater nitrate concentration on contaminated areas.
- To investigate the areal characterization of contaminated area (e.g. irrigation systems, soil drainage capacities, crop production) in order to find the probability of causes of nitrate contamination in groundwater.

Methods

- The nitrate concentrations in groundwater that NRDs have sampled since 1974 (107,716 analyses with ~200 times a year in every months), were collected from the data website of NRDs (http://dnrdata.dnr.ne.gov/Clearinghouse/Clearinghouse.aspx).
- The nitrate concentration in each well during each decade (1974-1983; 1984-1993; 1994-2003; 2004-2013) was computed across 2 km by 2 km grid cells using the conversion tool (point-to-raster) by ArcGIS 10.3.1.
- The spatial analyst and analysis tools (interpolation by Inverse Distance Weighting (IDW), reclassify and contour) were used on grid cells with maximum concentration level (MCL) of ≥ 10 mg N/L in order to be able to determine nitrate-contaminated area.
- Nitrate trend was analyzed in wells located in contaminated areas. If more than one concentration was reported in a well in a year, the concentrations were averaged.
- Statistical significance was described by the p value for a 2-tailed test. p values < 0.05 were considered statistically significant.

Results

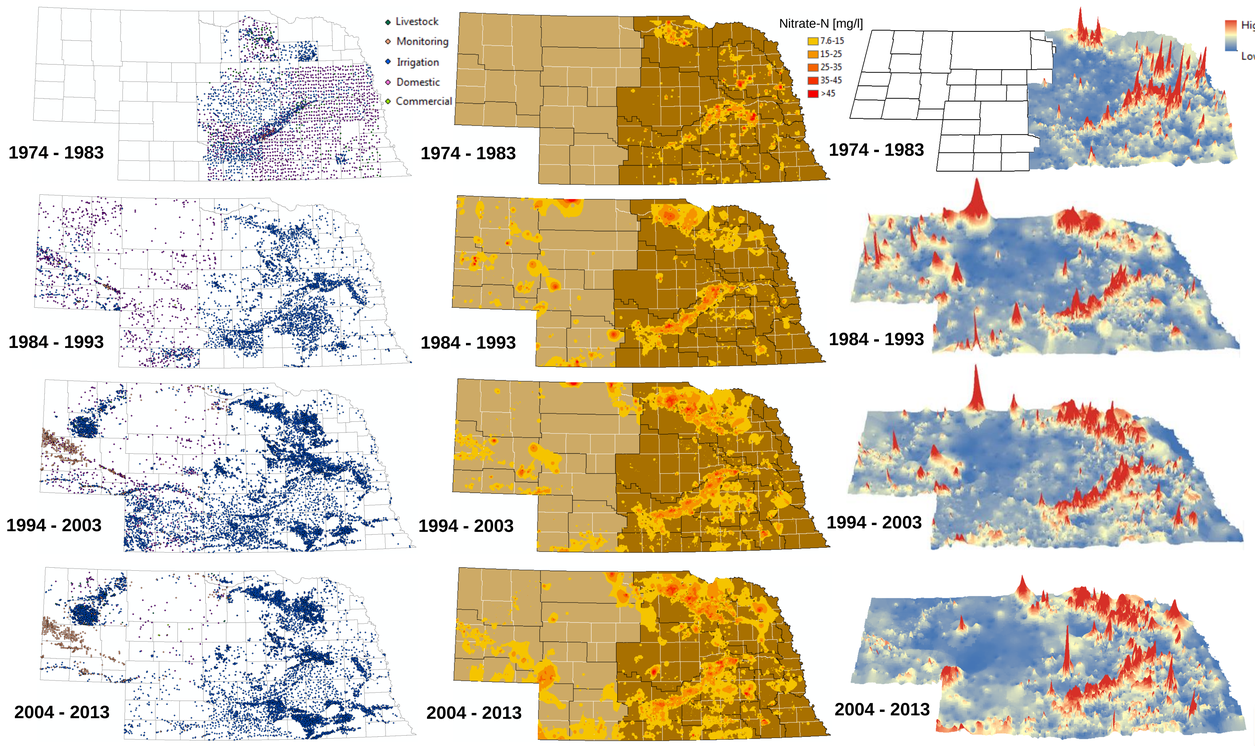


Fig. 1: Well locations (26,604 wells and 79,152 analyses) and interpolations by IDW technique in ArcGIS 10.3.1

Results

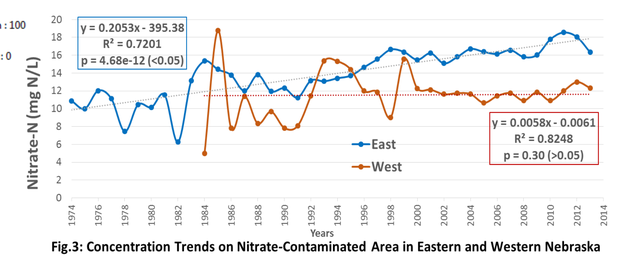


Fig.3: Concentration Trends on Nitrate-Contaminated Area in Eastern and Western Nebraska

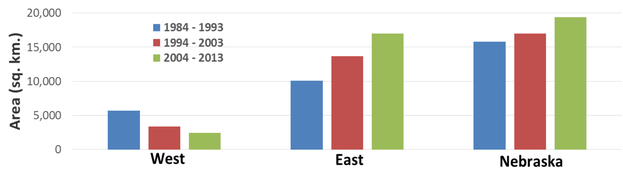


Fig.4: Estimated area that has nitrate concentrations in GW more than 10 mg/L

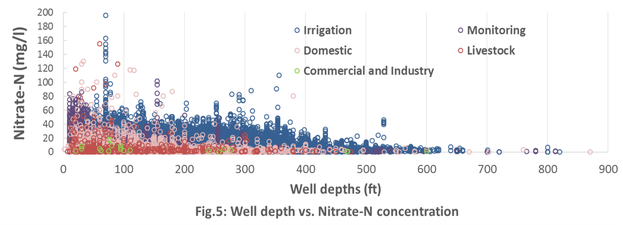


Fig.5: Well depth vs. Nitrate-N concentration

Summary

- The study shows a correlation between the expansion in nitrate-contaminated areas with the intensity of corn production and expansion in irrigation. This was only shown for Eastern Nebraska (Fig.1 and 2).
- The trend of nitrate concentration in groundwater in Western Nebraska is not obvious. In fact, the total area having nitrate above 10 mg/L decreased over time (Fig.3 and 4).
- The areas with nitrate above MCL are interpolated by IDW technique. It is possible that some wells within these areas are still below MCL as all wells were not tested.
- In the future works, vadose zone and groundwater flow modeling will be applied to analyze and forecast nitrate-contaminated areas in Nebraska.

Interpolation Technique

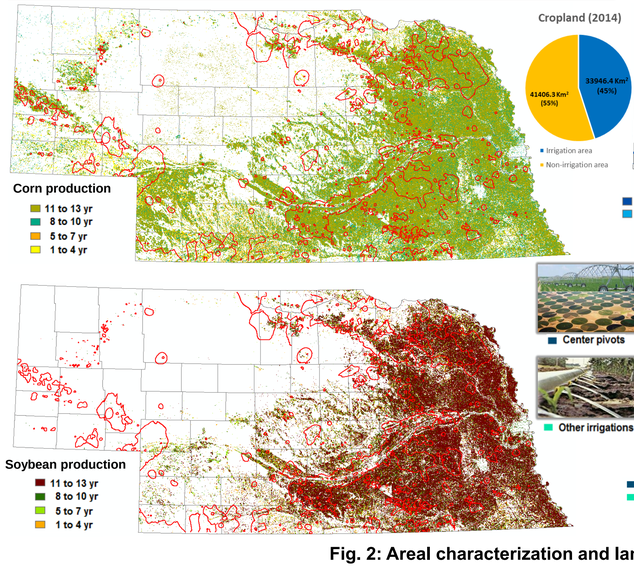
Inverse Distance Weighting (IDW) is a nonlinear interpolation technique that uses a weighted average of the attribute values from nearby sample points to estimate the magnitude of that attribute at non-sampled locations.

The weight of a particular point is assigned in the averaging calculation depends upon the sampled point's distance to the non-sampled location. The general IDW formula used in this study is:

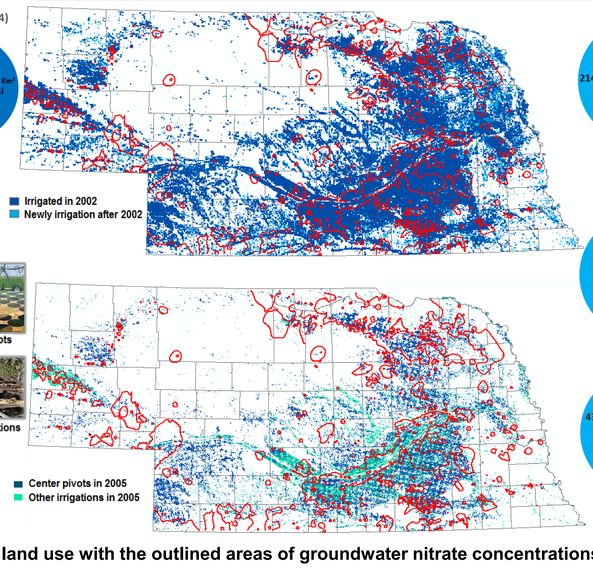
$$Z(x) = \frac{\sum w_i z_i}{\sum w_i}$$

where, Z(x) is the predicted value at x-unknown location, z_i is the measured value at i^{th} location and w_i is the weight of a point differs with the inverse square of distance (i.e., 1/distance^2).

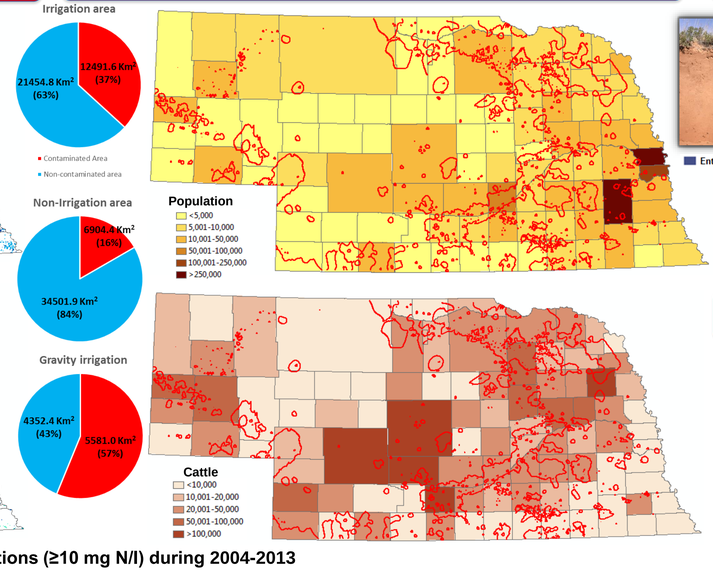
Crop Productions



Irrigation Systems



Population and Livestock



Soil Drainage Capacity

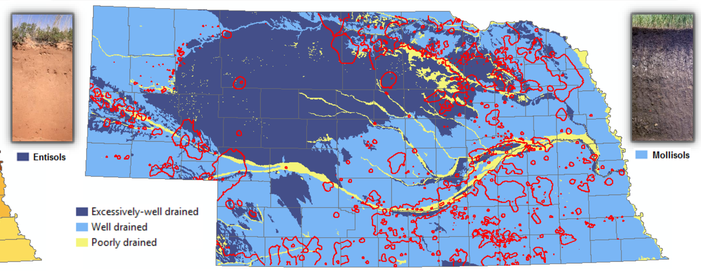


Fig. 2: Areal characterization and land use with the outlined areas of groundwater nitrate concentrations (≥10 mg N/l) during 2004-2013

Source of Data

- Crop production: The National Agricultural Statistics Service (NASS) Cropland Data Layer; http://nassgeodata.gmu.edu/CropScape/
- Irrigated area: the MIrAD-US project under the USGS Early Warning and Environmental Monitoring Program; http://earlywarning.usgs.gov/USirrigation/ and the 2005 Nebraska Land Use Map; http://www.calmit.unl.edu/2005landuse/statewide.shtml
- Irrigation methods: The University of Nebraska-Lincoln Conservation and Survey Division 1988 Center Pivot Inventory; http://snr.unl.edu/data/geographygis/NebrGISwater.asp#pivot and the Center for Advanced Land Management Information Technologies 2005 Nebraska Land Use map; http://www.calmit.unl.edu/2005landuse/statewide.php)
- Soil drainage capacities: The Soil Survey Geographic Database; http://www.dnr.state.ne.us/databank/ssurgo2.html