Using GIS For Water Resources Management in Nebraska: A Case Study

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Abstract

Groundwater nitrate contamination and water level decline are common concern in Nebraska. Intensive use of agrochemicals is the major source of nitrate and atrazine in Nebraska groundwater. This study was conducted to determine the increase of groundwater wells in some areas and the effect of land use "agriculture practices" on nitrate and atrazine concentrations in Nebraska using GIS tools and applications. Dams and lakes location in Lancaster County in southeast Nebraska were mapped along with nitrate and atrazine concentration in each location. GIS maps of land use, groundwater layer thicknesses, water table contours, rivers, and railroads were prepared. For nitrate and atrazine concentrations, the study showed that the high concentrations were associated with areas of intense irrigated crops (mostly corn and soybean) production. These high concentrations are attributed to high application of fertilizers and pesticides. The study also indicated an increased number of wells especially in the eastern part of the state. The study result however indicated that the groundwater layer thicknesses were associated with spatial well distribution. Areas near the rivers and railroads also had high numbers of irrigated wells due to accessible maintenance operations and lower cost of transportation.

Keywords: *Contamination, Groundwater, GIS.*

1. Introduction

Groundwater nitrate contamination and water level decline are common concern in Nebraska. Nearly 85% of the state's residents use groundwater as their source of drinking water [2]**.** The safety of drinking water is dependent on which impurities are present and in what concentration that amounts. Many of the contamination problems in agricultural areas are the result of too much nitrogen application thus facilitating the movement of excess nitrogen fertilizer into groundwater.

Nebraska is one of the most groundwater-rich areas in the US, and probably the entire world. The Ogallala aquifer, which is the world's largest aquifer system, represents the largest groundwater storage reservoir in the area known as the US Great Plains (Figure 1). In the eastern parts of the state, groundwater may be encountered often a few feet below the surface, while in western areas; it may be a few hundred feet underground. The Great Plains area in Nebraska, known as the Sand Hills area, represents the major recharge zone of the Ogallala aquifer system.

As of October 2006, the Nebraska Department of Natural Resources (NDNR) listed over 90,000 active irrigation wells and nearly 20,000 domestic wells registered in the state [8]. Groundwater pollution is caused by human activities whether as point-source pollution (contaminants originating from a single tank, disposal site, or facility, industrial waste disposal sites, accidental spills, leaking gasoline storage tanks, and dumps or landfills) or non-point-source pollution that caused by chemicals used in agriculture, such as fertilizers, pesticides, and herbicides; similarly runoff from urban areas. Naturally, the sources of water minerals and microorganisms are from the rocks, soil and air. However, human activities can add many more of these substances to water. Surface water is readily accessible to use, measure, and analyze compared to the groundwater. However, surface water and groundwater are often intimately connected therefore; contaminated surface water can eventually enter groundwater and contaminate it depending on the type of soil or rock formations separating surface and ground water systems.

Groundwater scientists have determined that groundwater in Nebraska can flow as fast as one to two feet per day in areas like the Platte River valley and as slow as one to two inches per year in areas like the Pine Ridge area in northwest Nebraska or the glacially deposited sediments in the southeast part of the state.

Although natural groundwater quality in Nebraska is good, many cases of groundwater contamination have been reported. The most common water quality problems identified in lakes are nutrient enrichment and sedimentation that followed by salt accumulation in the water, suspended solids, and nutrients. Major sources of groundwater contamination include agricultural activities, industrial facilities, leaking underground storage tanks, oil or hazardous substance spills, solid waste landfills, wastewater lagoons, brine disposal pits, and septic systems.

It has been indicated that tile drainage and surface runoff from farm land accounted for most of the nitrogen detected in monitoring efforts, with urban runoff contributing about 2.4 percent of the nitrogen detected [3]. While atrazine movement is primarily a function of surface runoff, the results indicated that subsurface movement also can occur. The impact of agrichemical contamination of groundwater in the eastern region was documented by a series of "Special Protection Area" studies by the Nebraska Department of Environmental Quality [4, 5, 6]. The researchers concluded that nonpoint-source agricultural contamination was responsible for groundwater degradation. Discovery of atrazine in groundwater overlain by irrigated row crops in central Nebraska was reported since the late 1970s ([8]). Triazine and acetamide herbicides are the most frequently reported pesticides in groundwater in corn and soybean growing areas [9]; [10]; [7]; [2]

Atrazine, the most widespread pesticide in the nation's groundwater, and its transformation products together with cyanazine, simazine, and alachlor and metolachlor and their degradation byproducts are the most commonly detected herbicides in row-cropped regions [2]. According to the NDNR regulations, all water wells must be registered except: test holes used ten days or less, dewatering wells with intended use of 90 days or less, vapor extraction wells, and domestic wells constructed prior to September, 1993. Well registration entails completing a water well registration form, and aerial photograph, and proper fees to the NDNR. The well registration program stipulates separation criteria between agricultural irrigation wells and other water wells, including industrial and public water supply wells. Based on the NDNR data, the extent of nitrate contamination is illustrated by the data in Table 1 which shows the percentage of analyses that are greater than 10 mg-NO_3-N/L, which is the US federal drinking water standard for nitrate-nitrogen. The principal objectives of this paper were: 1) assess changes in ground water wells distribution in Nebraska from 1970 through 2005; and 2) correlate the extent of spatial agricultural contamination by nitrate and atrazine in the state. Geographic Information System (GIS) can be a valuable tool to assess the groundwater quality by integrating biophysical parameters such as land use, elevation, aquifers, water table and chemical parameters [1].

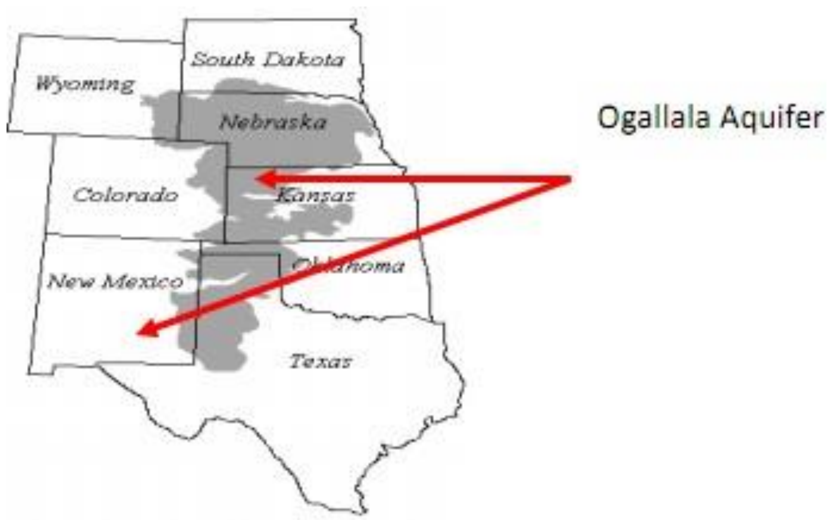

Figure 1. The Ogallala Aquifer system in the US Great Plains region

Table 1. Nitrate – nitrogen concentrations sorted by concentration categories. (Source: Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater, 2006)

Years	Total # Analyses	# > Lab Reporting Limit	< 7.5 mg/l	7.5 – 10 mg/l	10 – 20 mg/l	> 20 mg/l	% > 10 mg/l
1974 – 2001 (2002 Report)	33,075	30,961	21,504	2,707	5,554	3,310	26.8%
1974 – 2002 (2003 Report)	44,721	42,009	28,394	3,931	8,128	4,268	27.7%
1974 – 2003 (2004 Report)	52,798	49,265	33,100	4,606	9,857	5,027	28.2%
1974 – 2004 (2005 Report)	66,822	63,009	37,346	5,603	12,244	11,629	35.7%
1974 – 2005 (2006 Report)	74,522	70,022	42,916	6,573	13,161	11,872	34.2%

2. Materials and Methods

Several agencies perform monitoring of groundwater in Nebraska for a variety of purposes: the Natural Resources Districts (23 districts in Nebraska), the Nebraska Department of Agriculture, The Nebraska Department of Environmental Quality, the Nebraska Department of Health and Human Services, the University of Nebraska-Lincoln, and the United States Geological Survey.

Water quality contaminants (nitrate and atrazine) and well distribution in Lancaster County (S.E. Nebraska) are presented in this paper. In addition to, general map of Nebraska representing well distribution and contaminated area is discussed as well. Water quality data were collected by the US Geological Survey (USGE) using automated sensing devices. The USGS measures a wide variety of water quality indicators – much of these data are available online. Water sample analyses and measurement provide the results of groundwater monitoring for agricultural compounds in Nebraska. Also the database provides an indicator of the methodologies that were used in sampling and analysis for each of the results. Recently, agricultural contaminants such as nitrate and pesticides are the focus of the water database because of their widespread use, and also because historical data suggest that these compounds pose the greatest threat to the quality of groundwater across the state.

The US Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) Census of Agriculture was used to track trends in the extent of "crop and pasture" land and "farm rangeland." The NASS data indicate that corn and soybean were the dominant crops in Nebraska in 2005. Digital Elevation Map (DEM), water quality data, and ground water wells locations were obtained from Nebraska Department of Natural Resources database.

3. Results and Discussion

Under the Nebraska Department of Health and Human Service (NHHS) rules, when a contaminant in the drinking water is over the federal Safe Drinking Water Act limit (also known as the maximum contaminant level [MCL]), the water system receives an Administrative Order for compliance which requires that the contamination issue be remedied. The MCL for nitrate nitrogen is 10 mg-NO_3-N/L, but public water supply systems with wells or intakes testing over 5 mg-NO3-N/L may be required to perform quarterly monitoring. There are several methods to solve a nitrate related Administrative Orders include the drilling of new or deeper wells, hooking on to a neighboring complaint water system, or building a treatment plant. In this paper, it was noted that occurrence of elevated levels of nitrate (more than 10mg-NO3-N/L) and atrazine (more than 3 µg/L) in groundwater were associated with the intense practice of irrigated agriculture, especially corn and soybean agriculture land.

Nitrate is a form of nitrogen common in human and animal waste, plant residue, and commercial fertilizers. The locations of wells sampled for nitrate, as well as their measured hazard classes in Lancaster County are presented in figure 2 (a and b). Nitrate concentration, DEM and slope values are presented in figure 3. Groundwater wells distribution and flow aspects are shown in Figure 3 (a and b respectfully). The following terms are noted:

- Low hazard potential means hazard potential classification such as the failure or miss-operation of a dam would result in no probable loss of human life and in low economic loss.
- High hazard potential means a hazard potential classification such that failure or miss-operation of a dam result in the loss of human life is probable.
- Minimum hazard potential means a hazard potential classification such that failure or miss-operation of the dam would likely result in no economic loss beyond the cost of structure itself and losses principally limited to the owner’s property.
- Hazard potential classification means classification of dams according to the degree of incremental adverse consequence of failure or mis-operation of dams but does not reflect on the current condition of a dam, including safety, structural integer routing capacity.

Atrazine is an herbicide used for weed control in a variety of crops such as corn and beans. In addition, atrazine is identified as one of the herbicides as priority compounds by the

Nebraska Department of Agriculture for development of pesticide State Management Plans. The locations of wells sampled for atrazine and the concentrations of that herbicide are presented in figure 5. Typically, concentrations are between 0 and 2 µg/L (compared to the U.S. Environmental Protection Agency's Maximum Contaminant Level of 3.0 µg/L for atrazine) (Source: Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater, 2006).

Atrazine was observed to be in high concentration in the irrigated crop with corn and soybean figure 6. High hazard dam's constructions are with red dots in Figure (4-1). Figure (4-12) provides an illustration of groundwater layer thickness which was observed in the central part of Nebraska, therefore groundwater should be low number due to the depth of water table in that layer. The number of wells increased in the south eastern part of Nebraska (Figure (4-5)) notably due to high population, low water table depth, and the availability of suitable soils for crop production.

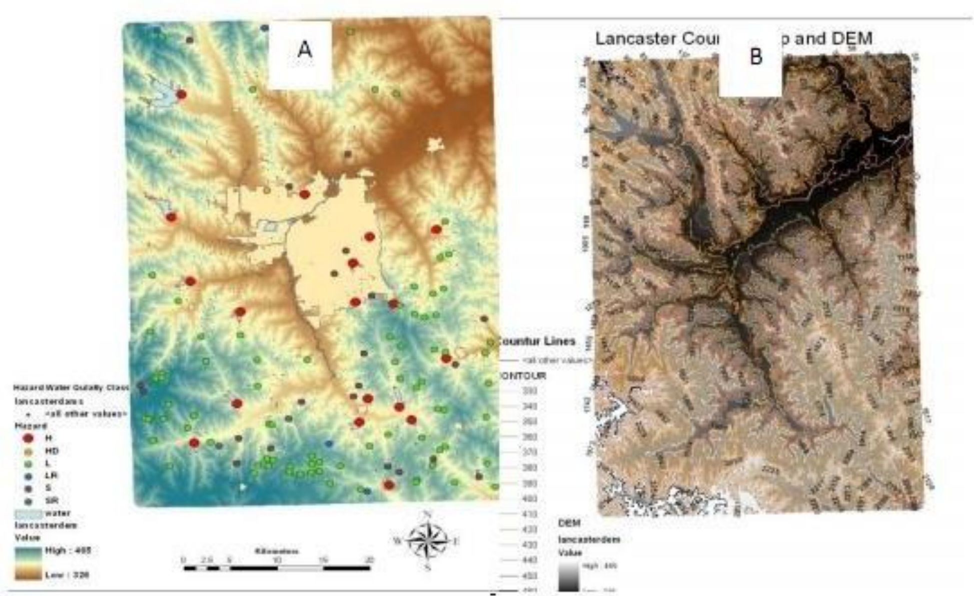

Figure 2 Lancaster County maps (dam's location and contour map)

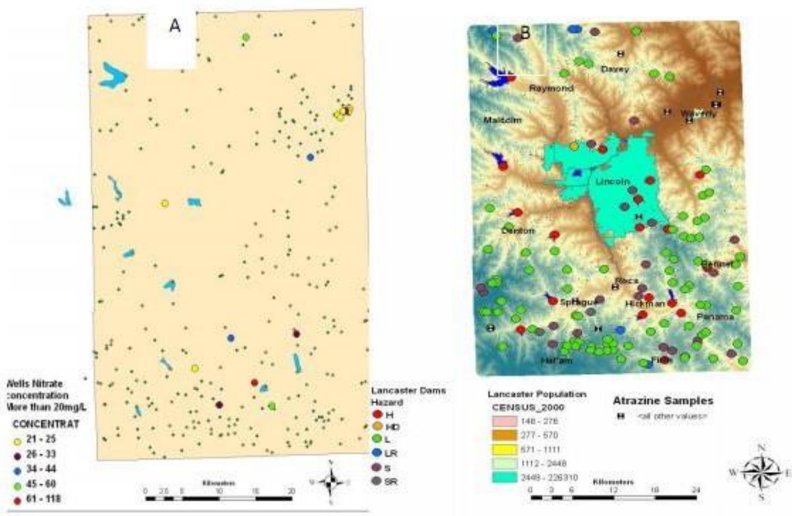

Figure 3 Lancaster County map dams location and population)

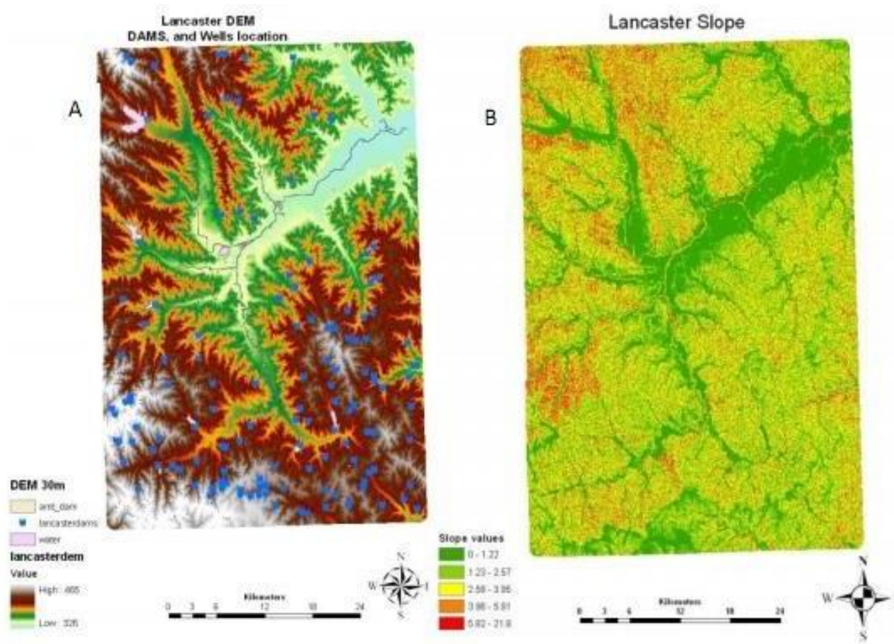

Figure 4 Lancaster maps (a)DEM, (b) nitrate concentration, and (c) slope values respectfully)

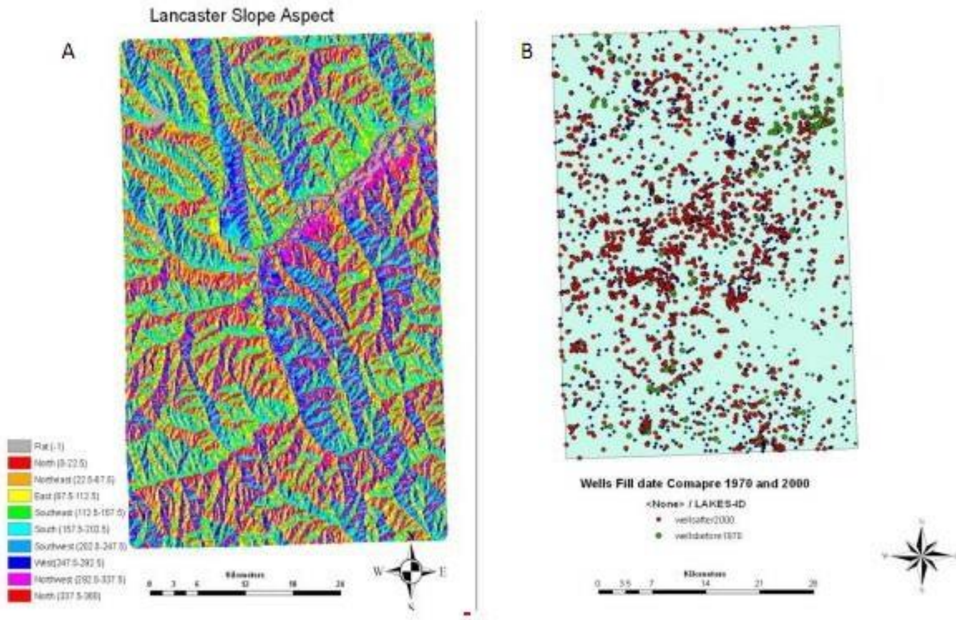

Figure 5 (a) Slope aspect and (b) Wells distribution (1970-2000)

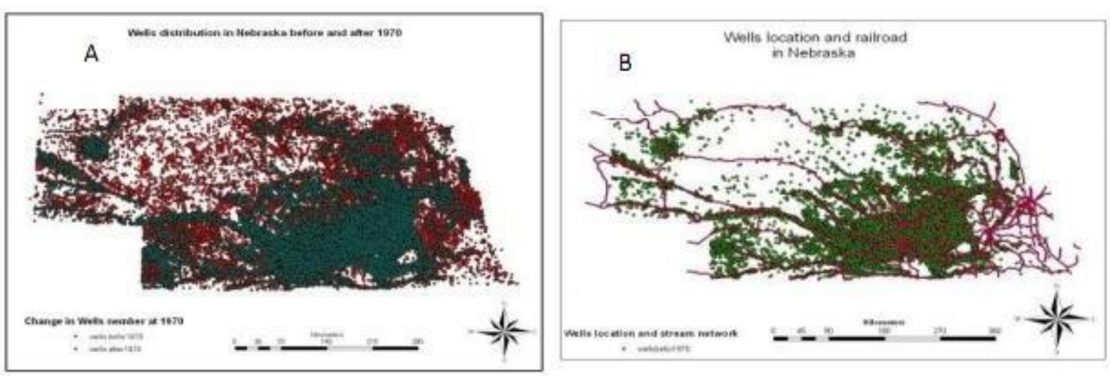

Figure 6 Wells in 1970-2000, and wells location and railroads.

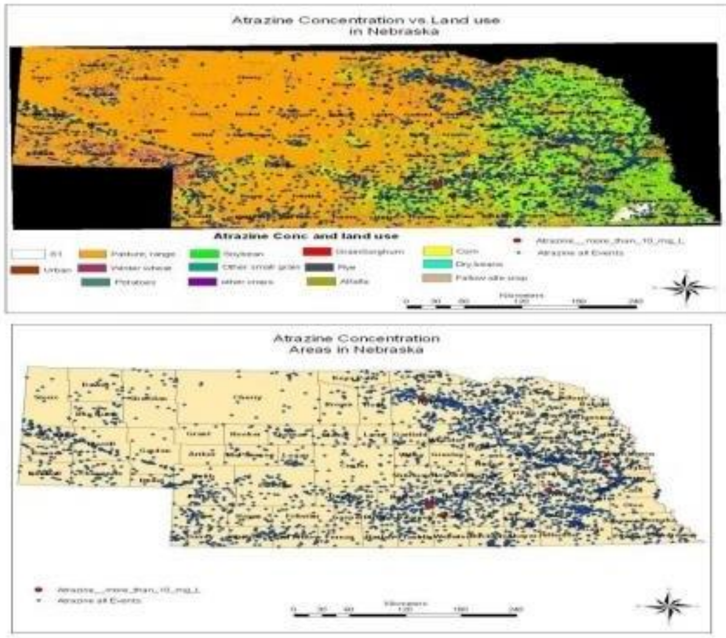

Figure 7 (a) Atrazine concentration and land use in Nebraska (b) Locations of high atrazine concentrations in Nebraska.

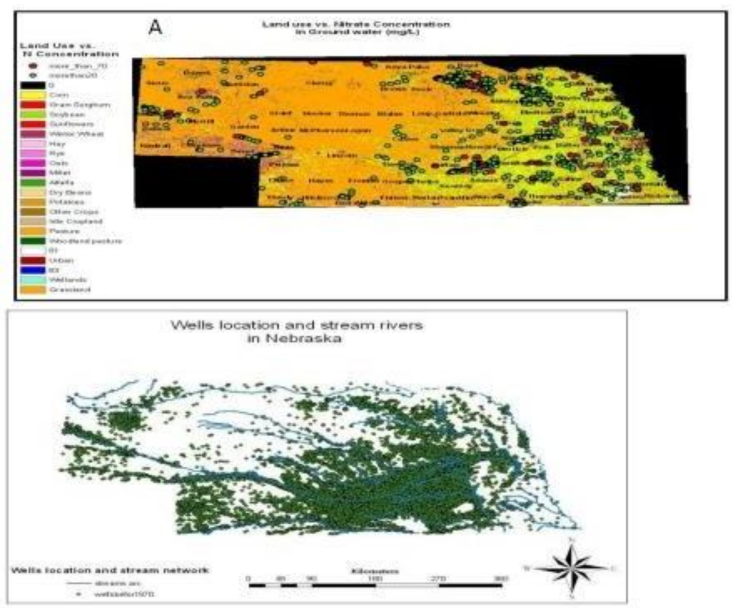

Figure 8 (a) Nitrate concentration and land use in Nebraska (b) Wells location and streams in Nebraska.

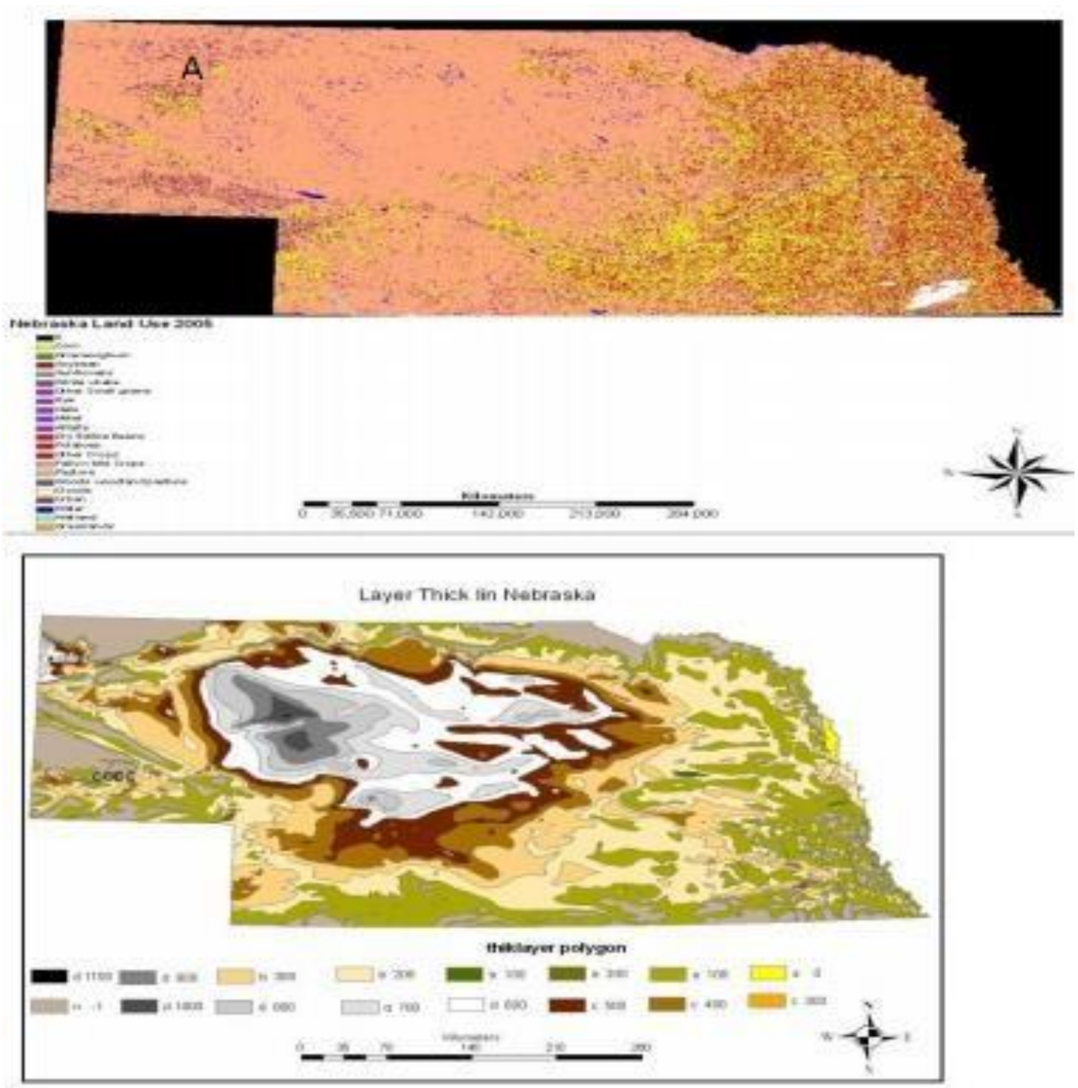

Figure 9 (a) Nebraska land use 2005 (NASS 2005) (b)Nebraska water table contour map

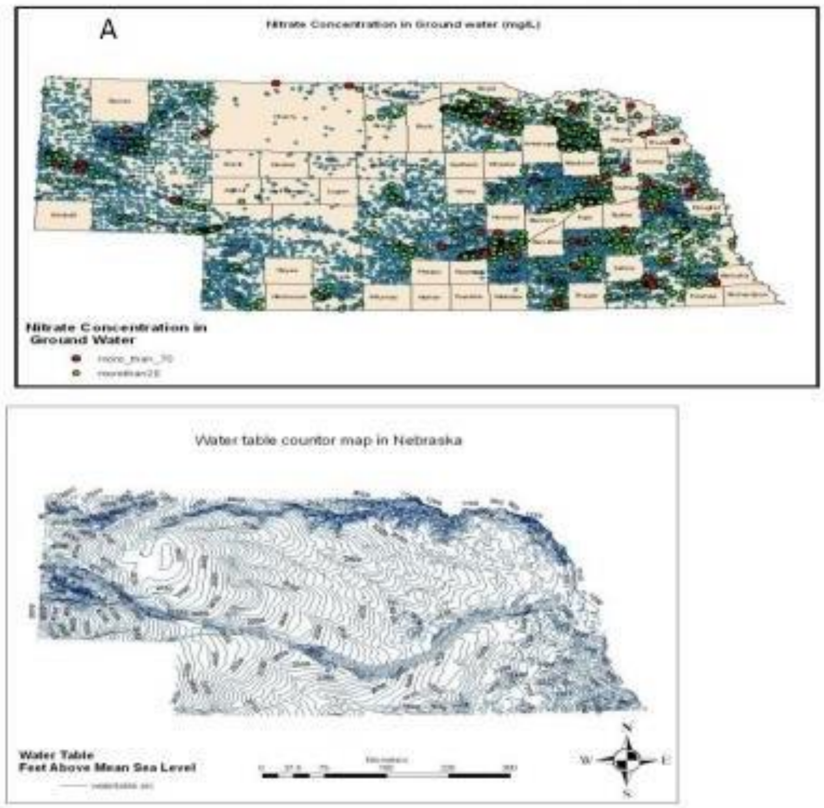

Figure 10 (a) Layer thick "ft" in Nebraska (b)Nitrate concentration and counties names in Nebraska.

Cleanup of Contaminated Groundwater

To clean up a contaminated site, the nature and extent of the contamination must be determined along with an assessment of remedial actions. If the risks of contamination are high, which is determined using appropriate risk analysis, then all cleanup remedial actions must be considered through a feasibility study of all sustainable alternatives. These alternatives include:

1. **Removal:** All actions that can be done by physically removing a full range of contaminants (including metals, volatile organic chemicals, and pesticides) from an aquifer by capturing the pollution with groundwater extraction wells.

2. **Bioremediation:** Generally considered to include all treatment processes that use naturally occurring microorganisms to break down some forms of contamination into

less toxic or non-toxic substances. By adding nutrients or oxygen, this process can be enhanced and used to effectively clean up a contaminated aquifer.

3. **Treatment:** The selection of treatment methods depends on the complexity of the aquifer and the types of contamination. Under these conditions, the only way to regain use of the aquifer is to treat the water at its point of use. For example, domestic well owners may need to install whole-house carbon filters or reverse osmosis systems depending on the type of contaminants present. For large water providers, this may mean installing costly treatment units consisting of special filters or evaporative towers called air strippers, and so on.

4. Conclusion

Agriculture practices and land-use patterns can affect the environment and the sustainability of production. Significant relations exist between high groundwater contamination and various practices including: 1) corn and soybean production areas; 2) silty-level soils compared to silty-sloping soils; and 3) the use of chemical pesticides in high concentrations. Many studies have concluded that nitrate and atrazine are the two most widespread contaminants detected in groundwater in Nebraska. Concentrations of contaminants such as nitrate and atrazine can be elevated above natural levels with many intense agricultural practices. Although nitrate is a naturally occurring compound, levels of that constituent in groundwater suggest that many areas of the state are experiencing levels above what would occur naturally. Any detections of atrazine, a man-made compound, indicate that human activity has impacted groundwater. Other factors that probably influence the nitrate and atrazine concentrations in groundwater, as suggested by some agencies, include:

- well-construction factors: casing type (for example, steel or PVC); installation date (age); diameter; well completion (in or out of a pit); sanitary seal; and well type (drilled or not);

- distance factors: distance to cesspool/septic systems, waste lagoons, barnyards, pasture, and cropland; and
- Site hydrogeology factors including soil types, aquifer well depth, depth to water, landscape and soil characteristics and agricultural chemical use.

5. References

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