The impact of Land Use Land Cover Change on Water Quality in the Big Sioux River: 2010-2015

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Abstract

The conversion of grassland into cropland in the Western Corn Belt Plains Ecoregion during the early twenty-first century has led to an increased amount of nitrate runoff from agricultural land (particularly from the corn cropland) to river. The river transports the nitrates downstream leading to an increased nitrogen proportion from the headwaters to the lower basin. Nitrate increases in the Big Sioux River (BSR) may be associated with increased areas and intensities of agriculture in the watershed. High concentrations (10ppm) are associated with human health issues and regulated by EPA. My research used NASS Cropland Data Layer to characterize and determine the rates of LULC change, and ArcSWAT model in ArcGIS to calibrate and validate the nitrate data from 2010 to 2015. The SWAT model calibrated the water flow and water quality parameters from the years 2010 to 2015. My research illustrates that there was an increase of 65,000 acres of corn cropland and 46,000 acres of soybean cropland, while a decrease of 119,000 acres of grassland and 42,000 acres of other crops from 2010 to 2015. Additionally, it shows the increasing trend of nitrogen leaching from cropland to river; the year of 2012 and 2015 having high amount of nitrogen leaching of 210,000 kg and 370,000 kg, respectively. This concludes that there is a direct correlation with an increase in converted croplands and increased nitrogen levels in the Big Sioux River.

Keywords: Big Sioux River basin, water quality, Soil and Water Assessment Tool (SWAT), land use/land cover

Introduction

Land use land cover changed significantly in Westen Corn Belt Plains Ecoreigion during last 30 years (Waisanen 2003). Wright and Wimberly, 2013 stated that the annual rate of grassland to cropland in this ecoregion was 1.0-5.4%. Intensive cropping dominated all other uses of land cover in the region. Reitsma et.al 2015 stated that there was a conversion of 1.8 million acres of grassland to cropland, from 2006 to 2012 in South Dakota (SD). Most of the conversion took place in eastern SD. With the increase in cropland, the use of industrial fertilizers also increased to support production and yield increases, but resulted in the nutrient rich soils which when leached to river enrich water with nutrients. Nutrient leaching, particularly nitrates, potentially degrades water quality and endangers human health. Conversion of lands to cropland and use of fertilizer for increasing the productivity have led to an increased quantity of nitrates in the soil which dissolve and infiltrate through the soil to river system; which is tranported to thousands of kilometers to the ocean and lead to ocean eutrophication. The Big Sioux River transports nitrates to the Missouri River which then enters the Mississippi River and flows to the Gulf of Mexico.

Generally, the sources of nitrates pollutant in the Big Sioux River is point source such as municipal waste treatment units. According to East Dakota Water Development District (EDWDD), the gauge stations WQM67 near Alcestor, R16 near 20th Avenue, and LBSRM on Military Road at North Sioux City showed

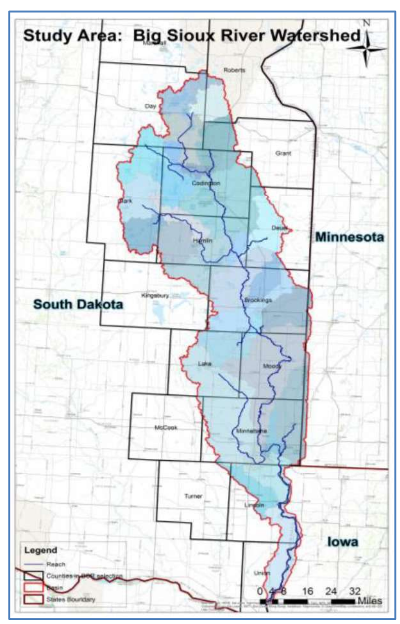


Figure 1: Study area, the Big Sioux River Basin that covers 5799 sq. Miles of eastern South Dakota

the highest nitrate concentrations of 9.1, 8.9, and 8.4 ppm respectively. The bump in nitrogen level was because of the municipal waste treatment plant. Guage station—WQM32 near Richland had 9 ppm, where the nitrate pollutant come from non-points source—cropland.

High concentrations (>10 ppm) are associated with human health and regulated by EPA. High concentration of nitrates in drinking water causes methemoglobinemia to infants and carries a potential cancer risk to adults. The nitrogen problem can be limited by good farmland management, therefore, farmers should pay special attention when choosing the proper N-fertilizer to avoid acidification and degradation of soils and, at the same time, to limit the nitrate pollution of the ground waters (Assimakopoulos, 2003, 19).

Objectives

The objectives of my research were to determine (1) LULC in the CBSR, (2) spatial and temporal trends of nitrogen concentration in the CBSR, and (3) determine whether there is a correlation between LULC and trend of nitrogen levels in the basin. I used the NASS Cropland Data Layer from year 2010 to 2015 to determine the rates of land use land cover change. I used the Soil and Water Assessment Tool (SWAT) model in Geographic Information System (GIS) to delineate the watershed and to calibrate simulations from 2010 to 2015.

Material and methods

Study Area

My study area covers approximately 15 billion acres (5799 sq. miles) of Big Sioux River basin that lie in east South Dakota (figure 1). The Big Sioux River is 420 miles long river that begins in Robert County, SD and flows south until it meets up with the Missouri River in Sioux City, Iowa (eastdakota.org 2016).

Table 1: Reclassification table

Classes	Categories
Corn	Corn, Sweet Corn
Soybean	Soybeans
Other Crops	Wheat, Alfalfa, Cotton, Rice, Potato, and other crops.
Water	Water, Perennial Ice/Snow, and Wetlands
Developed	Open/low/mid/high density developed
Grassland and Forest	Forest, Fruit Trees, Shrub land, Barren, and others

Eastern South Dakota is largely drained by the Big Sioux River, a tributary of the Missouri. Farmers rely upon Big Sioux River for irrigation. Agriculture has historically been a key component of the South Dakota economy (Reitsma et al. 2015, 2364). The five most valuable agricultural products in South Dakota are cattle, corn, soybeans, wheat, and hogs (Reitsma et al. 2015, 2363). There is an evidence of high conversion rate of grassland to cropland i.e. 1.8 million acres in South Dakota, from 2006 to 2012 (Reitsma et.al 2014, 1). The region has been encountering the water pollution problem for more than two decades. It is the most populated and most polluted river basin in the state (Press 2012).

Data Collection

Land Use Land Cover Change

For the purpose of LULC, National Agricultural Statistics Service's (NASS) CropScape-Cropland Data Layer from 2010-2015 were used. The data were available online (https://nassgeodata.gmu.edu/CropScape/). The CDL is a raster, geo-referenced, crop-specific land cover data layer created annually for the continental United States using moderate resolution satellite imagery and extensive agricultural ground truth. CDL Data Layer

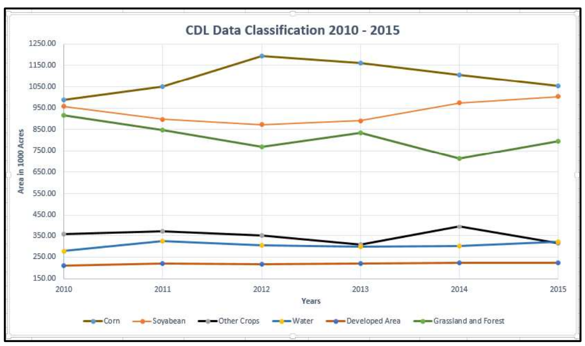
Table 2: CDL Data Reclassification into 6 major class types, area in 1000 of acres, from 2010 to 2015.

Value	Class Type/Year	2010	2011	2012	2013	2014	2015	Difference	% Change
1	Corn	989.17	1050.30	1192.44	1159.67	1106.49	1054.32	65.15	6.18
2	Soyabean	957.09	897.84	872.49	891.18	974.63	1002.96	45.88	4.57
3	Other Crops	356.94	369.64	352.41	308.53	392.12	314.73	-42.21	-13.41
4	Water	278.63	324.62	306.04	298.45	300.95	320.46	41.83	13.05
5	Developed Area	209.22	219.88	218.45	219.51	222.57	222.01	12.79	5.76
6	Grassland and Forest	915.43	848.68	769.18	833.53	714.01	796.29	-119.14	-14.96

has 225 different classes. These classes were reclassified into six broad groups: (1) Corn, (2) Soybean, (3) Other Crops, (4) Water/Wetland, (5) Developed, and (6) Grassland and others (table1).

There was an increase in corn cropland that increased from 989,000 acres to 1054,000 acres from 2010 to 2015. There was a gain of 65,000 acres of corn cropland which sums up to a change of 6.18%. Soybean cropland increased too. It had a gain of 45,800 acres which is 4.57% increase. The developed land remained constant while water/wetland had a gain of 41,000 acres of land. Grassland and others, and other crops significantly loss their acre area, 119,000 and 42,000 respectively.

Corn cropland has an increasing trend from early 2010 to 2012 when it reached to a peak, 1192,000 acres. The corn cropland gradually began to decrease from 2012 until 2015 (graph 1). Conversely, soybean cropland decreased has a decreasing trend from 2010 until 2012 and an increasing trend from 2012 to 2015. Grassland and forests and other crops seem to increasing and decreasing trend.



Graph 1: Land cover land use change in the Big Sioux River from 2010-15.

SWAT Analysis:

Soil and Water Assessment Tool (SWAT) model in Geographic Information System (GIS) was used to delineate the watershed and to calibrate and validate the nitrate data from 2000 to 2015. The datasets required were: Arc Grid representing a DEM for the Big Sioux River Valley (Quad 1:24,000), topographic map sheet from USGS (30m x 30m cell size; heights in meters). Also, the land use/land cover dataset was obtained from National Land Cover Department, Soil Data from Geospatial Data Gateway.

The SWAT model involved basically three steps: Watershed Delineation, HRU Definition and Weather Data input. After all these steps are completed, some parameters are input from the SWAT database and finally SWAT Model is run. There were 29 sub-basins created for my watershed. The total area of the basin is 5977 sq. miles. The model was set to run from 01/01/2010 to 12/31/2015, in daily basis.

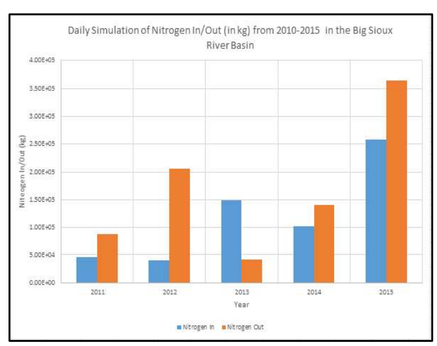
Results and discussion

Land use land cover change

From the total area acres of land (3710000 acres), 27% and 26% of corn and soybean increased to 28% and 27% from 2010 to 2015, squeezing other crops and grassland and forest from 10% and 25% to 8% and 21%, respectively (Figure 1a and 1b). Change in corn cropland and soybean cropland made a mirror image, meaning that when corn cropland increased soybean cropland decreased and vice versa. From 2010 to 2015, 15.62% of corn cropland is converted to soybean while 16.11% of soybean cropland is converted to corn cropland. However, there were increased acres of land for both the corn and soybean cropland. Where did the land come from? Yes, they came from the other crops and grassland and forests. 2.17% and 2.32% of other crops (= 80,000 acres, and 86,000 acres) were converted to corn and soybean, respectively (table 3). Similarly, 1.94% and 2.13% of grassland and forest (= 69151 acres and 72142 acres) were converted to corn and soybean cropland. But there fewer acres of corn and soybean cropland converted to other crops and grassland and forest.

SWAT analysis

The Watershed delineation categorized the basin into 29 sub-basins. I was able to simulate the nitrogen flow from 2010-2015 with the help of SWAT model. The graph below gives us the idea of the amount of nitrogen flowing in the soil and flowing out from the soil. There was high amount of nitrogen leached from soil in 2012 and 2015 (graph 2).



Graph 2: Daily simulation of nitrogen in and out (in kg) from 2010-2015 in the Big Sioux River Basin.

Table 3: A contingency table for land change is a FROM-TO table. In this example it shows land covers in 2010 and what they changed to in 2015.

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		2015						
		Corn	Soybean	Other Crops	Water/ Wetlands	Developed	Grassland and Forest	Total
2010	Corn	8.10	15.62	2.15	0.22	0.05	0.54	26.69
	Soybean	16.11	7.03	2.17	0.08	0.06	0.37	25.82
	Other Crops	2.17	2.32	2.57	0.56	0.05	1.96	9.63
	Water/ Wetlands	0.15	0.11	0.23	6.59	0.01	0.42	7.52
	Developed	0.03	0.02	0.01	0.01	5.56	0.02	5.65
	Grassland and Forest	1.87	1.95	1.35	1.17	0.26	18.10	24.70
	Total	28.44	27.05	8.49	8.62	5.99	21.42	100.00

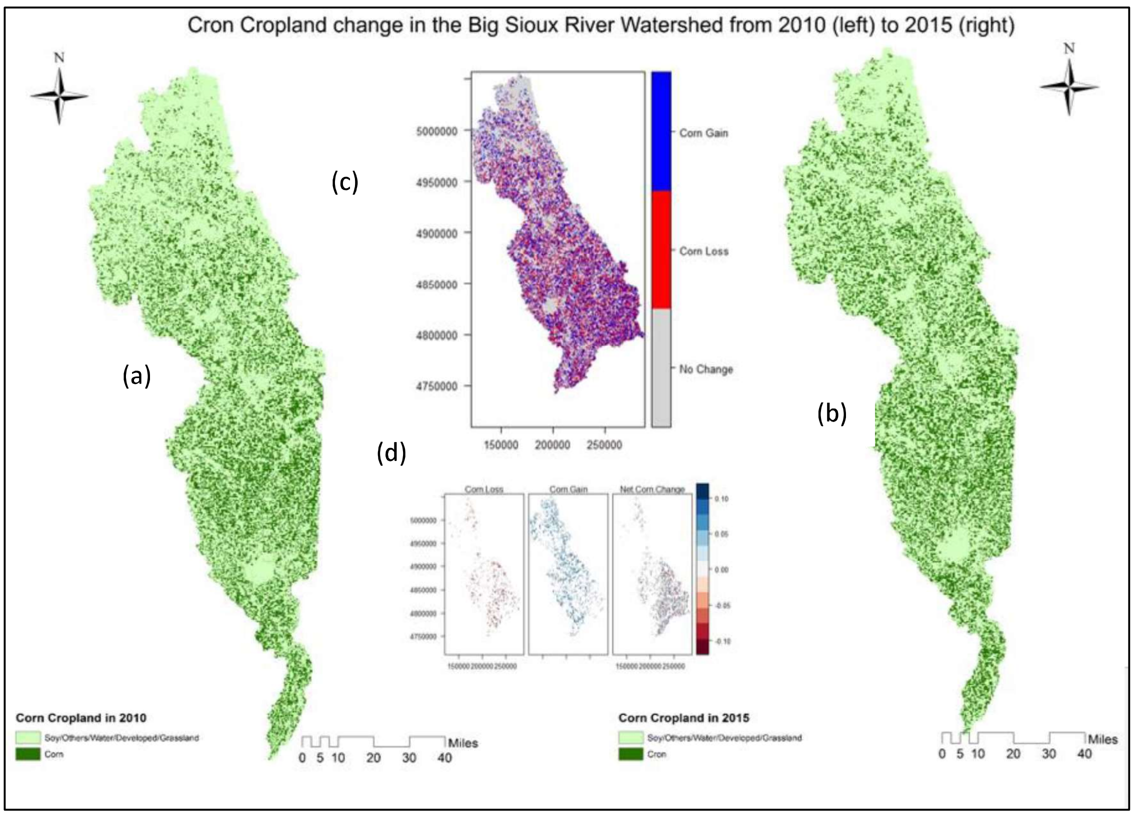

Figure 2: Net change in Corn Cropland in the Big Sioux River Watershed from 2010 to 2015: (a) Map showing the corn cropland vs other class in 2010, (b) Map showing the corn cropland vs other class in 2015, (c) Map showing the corn gain and corn loss from 2010 to 2015, and (d) Graph showing the corn gain and loss, and net change from 2010 to 2015.

Conclusion

High nitrates concentration in the river waters has always been a major problem in the rivers of the USA. Eutrophication in Gulf of Mexico and Chesapeake Lake are the examples. This issue has become one of the major concerns of public and federal water authorities (Kreiling 2016). Nitrate increase in the river water are associated with increased cropland and intensities of fertilizer use because with an increase in cropland, the use of industrial fertilizers increases; which bolsters the production yield, but also results in nutrients rich soil which when washed away to river enriches water with nutrients. Nutrients leaching, particularly nitrates have potential threats to degrade the water quality, and lead to diseases such as methemoglobinemia. The lawsuit in Iowa about this issue has elicited attention of water authorities in South Dakota. A good farmland management can limit the intensity of nitrates leaching to the rivers. Removing nitrates from water is expensive, therefore, it could be a wise choice if farmers pay special attention when choosing the proper N-fertilizer to avoid acidification and degradation of soils and, at the same time, to limit the nitrate pollution of the ground waters (Assimakopoulos, 2003, 19).

This research used NASS-Cropscape CDL data layer to look at temporal and spatial change in LULC in the Big Sioux River form 2010-2015. Use of Landsat images to look at the changes for longer period of time may give a better trend and conclusions regarding the LULC. Similarly, the SWAT analysis for longer period of time may give a better picture of nitrate trends in the river.

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