Irrigation dynamics in the Ogallala aquifer between 2000 - 2017

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Background

In the United States, irrigation for agriculture utilizes 42% of freshwater withdrawals but approximately 80 to 90% of total consumptive water (Dieter et al. 2018). Expansion of groundwater-fed irrigation has resulted in substantial declines in groundwater levels (Scanlon et al. 2012). Given that the Ogallala Aquifer accounts for most net irrigation expansion in the nation (e.g., over 97% for the period of 2002 – 2007) (Brown and Pervez 2014), it is necessary to know detailed and timely information about irrigated agriculture in the region. This information is also critical to meet increasing demands for food and fuel, especially if we are to fully understand the impact of agriculture on water resources and formulate effective policies for management (Lark et al. 2015; McDonald et al. 2011; Rosegrant et al. 2009; Seager et al. 2012; Seto et al. 2012). Therefore, we developed a method to map annual irrigation distribution across the region from 2000 to 2017 at the 30m resolution.

Methods

We extended our methodology used to extract irrigation across the entire US for 2012 to map yearly irrigation distribution in the Ogallala Aquifer for the period of 2000 – 2017. First, county-level USDA-NASS Irrigation Census Data for the years 2002, 2007, and 2012 were used to extract potential training samples by using the approach described in Xie et al. (Under review). These training samples were then used to train the random forest classifier, which was utilized to annually classify irrigation vs non-irrigation for the whole period. Finally, the resulting annual irrigation maps were spatially filtered and assessed.

A frequency map was generated to show irrigation intensity for the Ogallala Aquifer during the period (Figure 1), which was calculated as:

$$irrFreq = \sum_{yr=2000}^{2017} irr_{yr} \tag{1}$$

where irr_{yr} is a binary map for the year *yr*, showing irrigation (value 1) *versus* non-irrigation (value 0). A higher value of *irrFreq* indicates that a field is more frequently irrigated (on a yearly basis) than those with low values. In addition, we mapped the change of irrigation occurrence intensity (irrCh) between two sub-periods (i.e., 2000 – 2008 and 2009 – 2017) to study irrigation trends over time (Figure 2).

$$irrCh = \sum_{yr=2000}^{2008} irr_{yr} - \sum_{yr=2009}^{2017} irr_{yr} \tag{2}$$

To evaluate irrigation dynamics at the state scale, irrigation area for the states overlaid with the Ogallala Aquifer was calculated from the annual maps (Table 1). We further analyzed irrigation trends by using linear regressions. Increasing/deceasing rate (slope of linear fitting) was calculated if statistically significant trends were derived. The trend of “stable” was assigned to the states that did not show significant linear fittings.

Further, to study crop-specific irrigation changes, we mapped crops for which irrigation was intensified or reduced for the two periods: 2000 – 2008 and 2009 – 2017 (Figure 3). For areas detected as irrigation intensification or reduction, the most frequently planted crops during 2009 – 2017 were identified.

Summary Findings

We mapped annual irrigation distribution in the Ogallala Aquifer for the period of 2000 – 2017 and assessed its trends:

- Croplands with intensive irrigation is mainly distributed in Nebraska, southern Kansas and northern Texas. Nebraska, Kansas, Oklahoma, Texas, and Wyoming show stronger irrigation variation compared to New Mexico and Colorado (Figure 1 and Table 1).
- Irrigated croplands in the Ogallala Aquifer increased from ~55,000 km^2 in 2000 to ~66,000 km^2 in 2017 for an annual averate rate of expansion of 751 km^2/yr (Table 1).
- Nebraska contained the most irrigation expansion in the Ogallala Aquifer, expanding from ~25,000 km^2 in 2000 to ~38,000 km^2 in 2017 with yearly increases of 687 km^2/yr (Table 1).
- Irrigation intensification from 2000 – 2008 to 2009 – 2017 in the region was mainly located in Nebraska (Figure 2a), while irrigaiton reductions were distributed across the southern Ogallala Aquifer, especially Texas (Figure 2b).
- Corn and soybeans were the most common crops grown using new irrigation (Figure 3a). Cotton in Texas tended to be the most common crop grown on lands with reduced irrigation (Figure 3b).

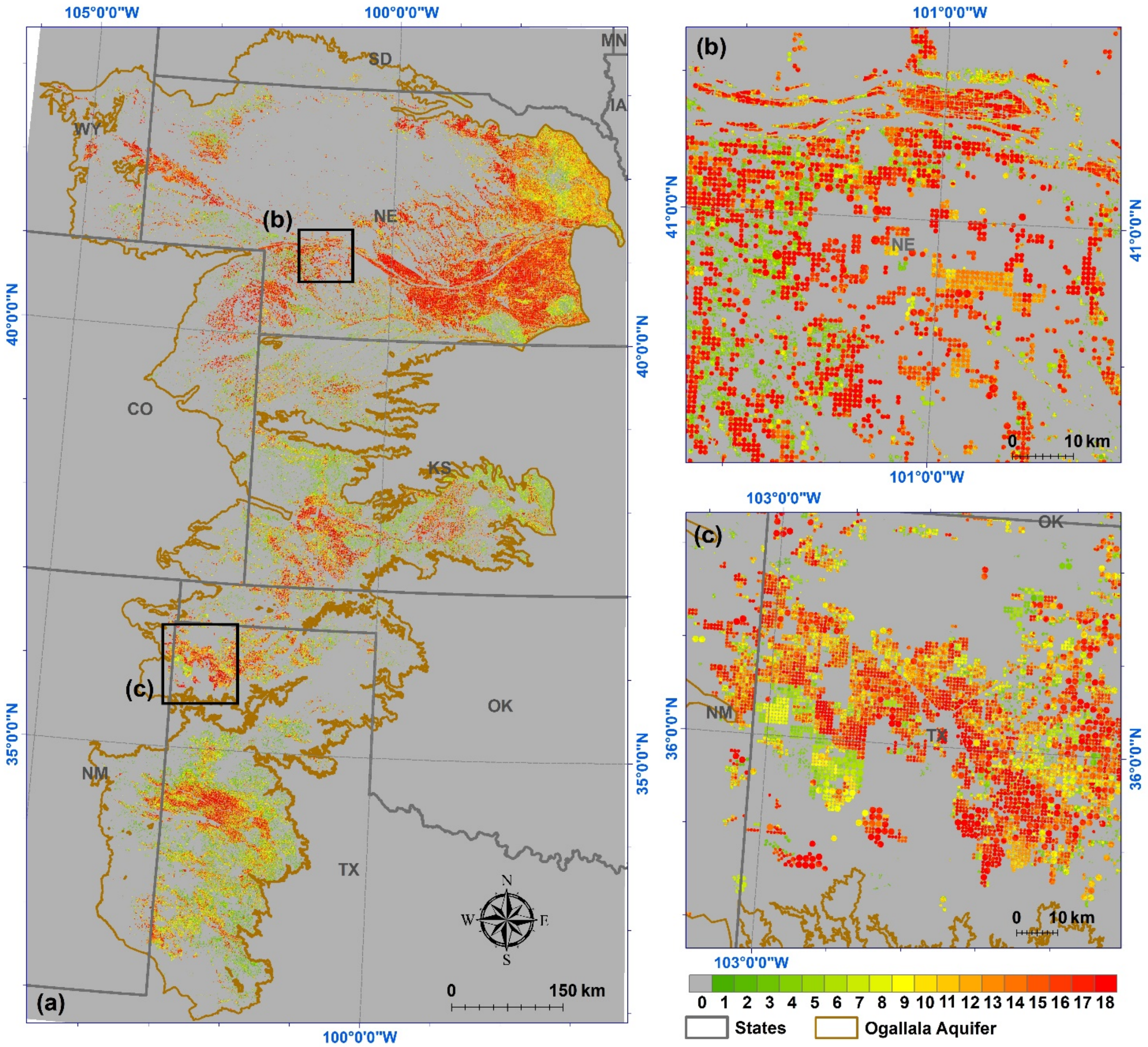

Figure 1. Irrigation frequency for the Ogallala Aquifer during the period of 2000 – 2017. (a): overview of the entire Ogallala Aquifer. (b) and (c): two regional views in the southern Nebraska and northern Texas. Irrigation outside the Ogallala Aquifer is shown as background.

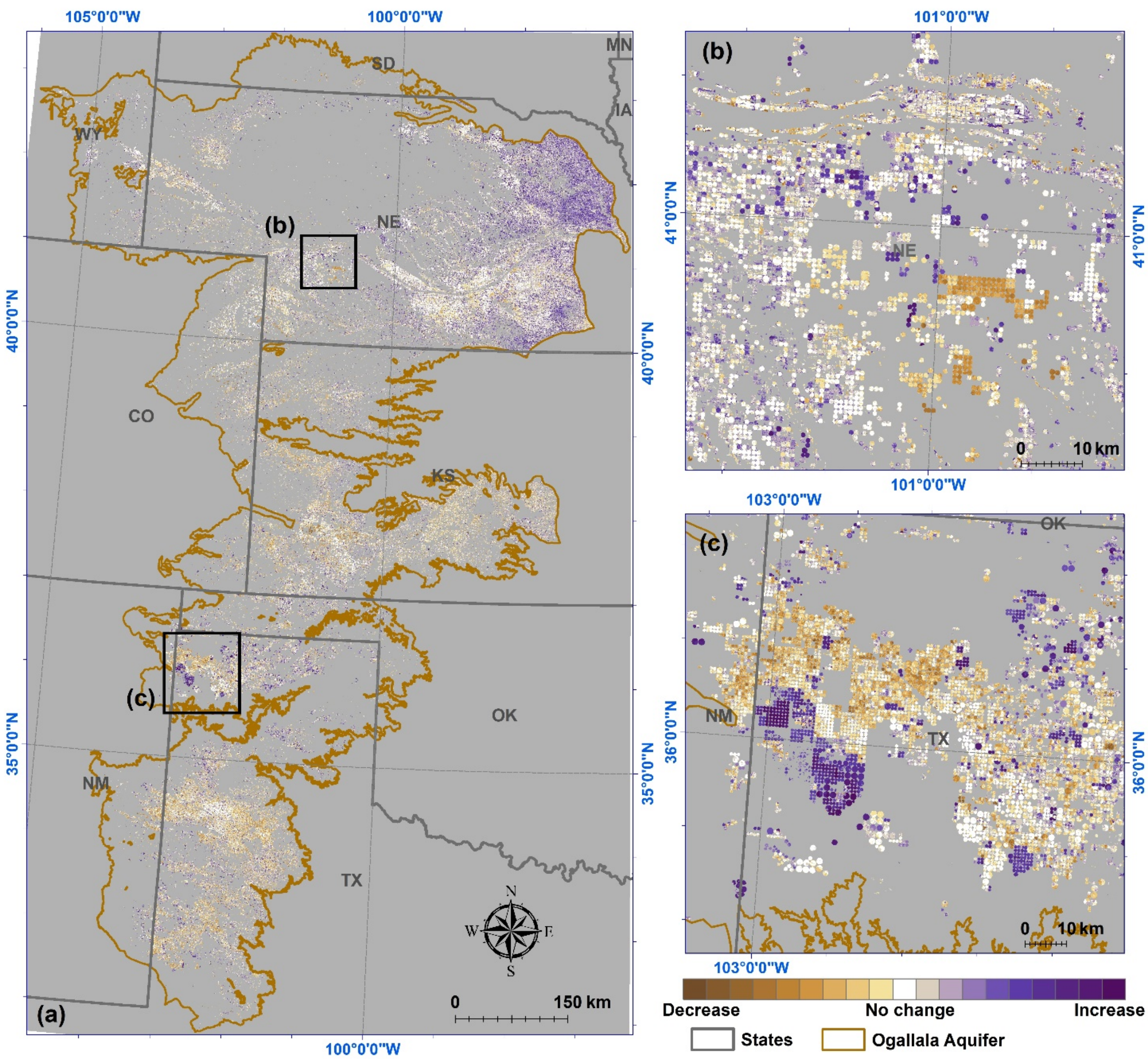

Figure 2. Change of irrigation occurrence intensity from 2000 – 2007 to 2008 – 2017. (a): overview of the entire Ogallala Aquifer. (b) and (c): two regional views in the southern Nebraska and northern Texas. Irrigation outside the Ogallala Aquifer is shown as background.

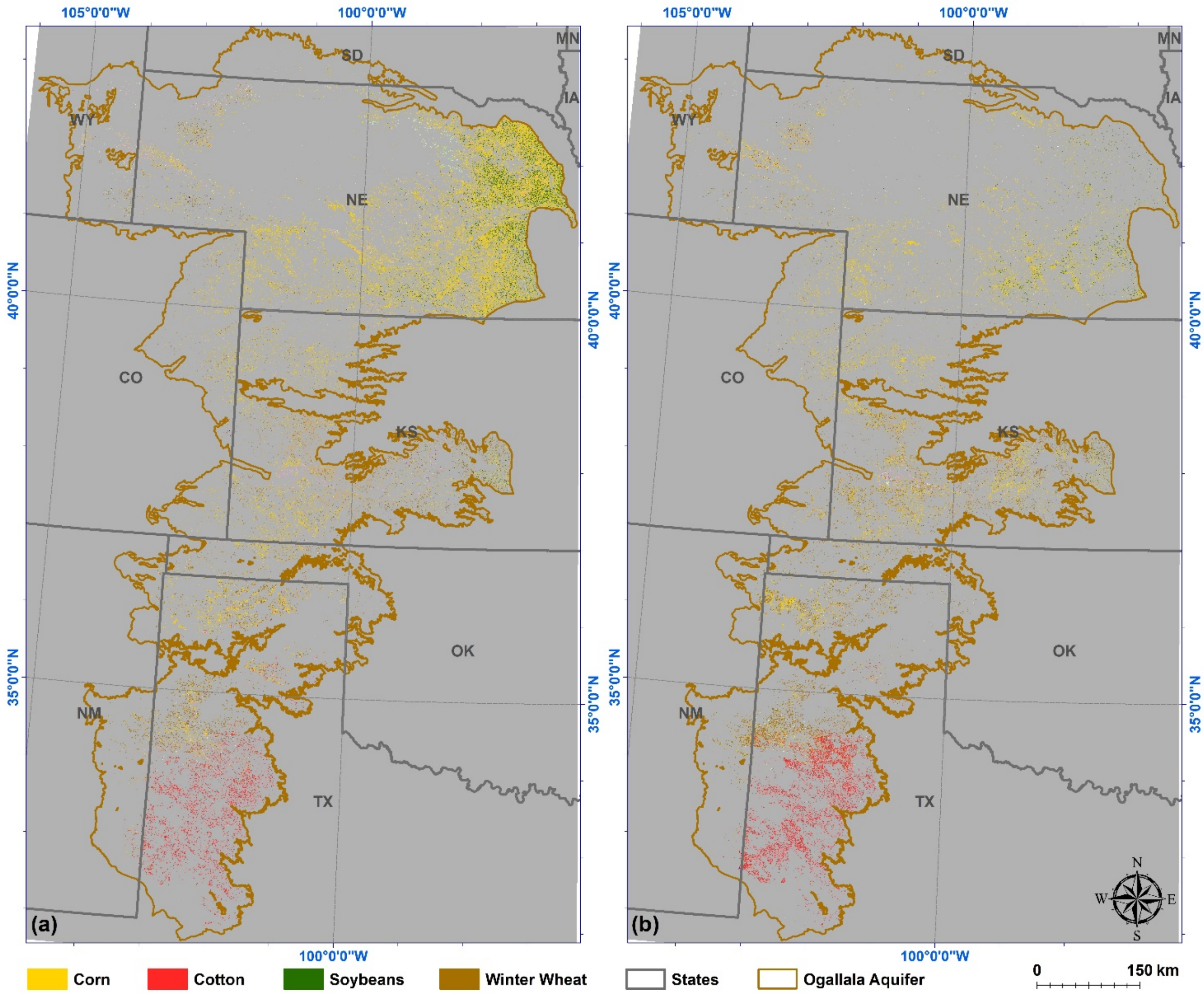

Figure 3. Crops impacted by irrigation intensification (a) and reduction (b) from the period 2000 – 2008 to 2009 – 2017. The legend only shows four major crops.

Table 1. Irrigation area (km^2) per year for the states overlaid with the Ogallala Aquifer. South Dakota is not presented because of its relatively small irrigation area.

Year	Nebraska	Wyoming	Colorado	Kansas	Oklahoma	Texas	New Mexico	Ogallala Aquifer
2000	24,815	1,134	2,837	12,138	1,022	12,751	914	55,611
2001	32,217	1,185	2,410	9,075	998	10,960	925	57,769
2002	27,888	9,57	2,493	9,136	961	13,257	1,052	55,745
2003	29,907	1,163	2,274	10,153	1115	11,173	1,046	56,831
2004	35,342	1,045	2,184	9,867	1133	14,272	968	64,810
2005	34,772	1,270	2,247	10,726	1056	14,661	1,005	65,736
2006	31,639	9,99	2,480	8,584	915	12,217	1,007	57,843
2007	30,859	1,003	2,414	9,299	904	13,411	949	58,838
2008	35,574	1,200	2,351	10,132	899	12,401	816	63,374
2009	40,676	1,298	2,423	10,348	978	13,695	988	70,406
2010	39,138	1,305	2,655	10,573	1072	14,154	1,085	69,982
2011	42,684	1,287	2,378	9,544	827	9,044	835	66,599
2012	30,349	9,48	2,202	9,190	892	11,507	799	55,887
2013	39,047	1,220	2,450	10,034	1102	14,860	981	69,693
2014	34,990	1,584	2,246	9,054	1076	12,343	834	62,127
2015	39,851	1,450	2,048	9,265	1265	12,230	951	67,060
2016	41,887	1,388	2,672	13,290	1510	15,311	1,049	77,107
2017	37,890	1,328	2,393	8,377	1101	13,713	989	65,792
Max Extent	49,797	1,791	4,006	19,683	2,014	22,862	1,614	101,768
Mean	34,974	1,209	2,398	9,933	1,046	12,887	955	63,401
Std	5,103	176	192	1,222	159	1,589	86	6,234
$\frac{std}{mean}$	0.15	0.15	0.08	0.12	0.15	0.12	0.09	0.1
Trend	Increasing $p < 0.01$ rate = 687 km^2/yr	Increasing $p < 0.01$ rate = 20 km^2/yr	Stable $p = 0.4$	Stable $p = 0.8$	Stable $p = 0.1$	Stable $p = 0.5$	Stable $p = 0.6$	Increasing p < 0.01 rate = 751 km^2/yr

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