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Has the Initial Development of Haynesville Gas Play Impacted the Overlying Carrizo-Wilcox Aquifer Water Quality?*

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Abstract

There has been a great deal of concern within area communities due to possible impacts on water quality due to drilling and hydraulic fracturing associated with the development of unconventional hydrocarbon deposits (Carlson et al., 2014). One of the unconventional shale gas plays developed is the Haynesville Formation in northwest Louisiana and northeast Texas. There are approximately 2640 Haynesville wells drilled in northwest Louisiana with approximately 300 drilled in Caddo Parish (Figure 1).

Two studies of the Carrizo-Wilcox (Wilcox) Aquifer have been completed by Louisiana Geological Survey (LGS) staff (Figure 1). The first survey involved collection and analysis by LGS staff of samples from 130 domestic wells in southern Caddo Parish. These samples were collected in 2007 and 2008 prior to almost all drilling and hydraulic fracturing associated with the Haynesville. The second study involved collection and analysis by LGS staff of samples from 1100 domestic wells in southern Bossier, southern Caddo and northern De Soto parishes. These samples were collected during the peak of drilling and hydraulic fracturing activity in the Haynesville during 2010 and 2011 (Figure 2). Within these two sets of wells are approximately 80 wells which were sampled during both studies. This set of 80 wells allows for analysis to determine if there have been significant changes in water quality over the approximately three-year interval between studies for approximately 20 different analytes during the period of initial increasing drilling activity associated with the development of the Haynesville gas play (Figure 2). However, for trace elements such as arsenic, or lead in most cases at least one observation was a non-detection. As a result, for the 2007-2008 study or for the 2010-2011 study or both studies, concentrations were below the detection limit for many of the samples analyzed and hence there was less than 80 observation pairs.

Results

For some of the ions (arsenic, cadmium, lead, and nitrate) there 0 to 10 pairs of observed samples. For other ions (chromium, nickel, nitrate, rubidium, and sulfate) there were between 11 and 30 observation pairs. However, most of the analytes have at least 40 pairs of concentrations and for many analytes there were over 70 pairs, which includes aluminum, boron, bromide, calcium, chloride, copper, fluoride, iron, magnesium, manganese, phosphate, phosphorous, silicon, sodium, strontium, total dissolved solids (TDS), and zinc

These two sets of data allowed for the comparison of water quality prior to Haynesville development and during the peak of drilling and hydraulic fracturing activity (Figure 2). Comparison of these two sets of data was completed using two non-parameter statistical tests: Mann-Whitney ranks-test and Wilcoxon rank sum (Conover, 1999; and Ai-therapy.com, 2017). Both of the data sets are normalized to values in the 2007-2008 data set. Then a percentage change between the two temporal data sets was determined. As result the first data has all values of 100 while second was the percentage change added to the value of 100. Prior to comparison extreme outliers within the change data set were removed, which were any values more than 4 standard deviations from the mean within the second data set. This standard is more conservative standard than the typical 3 or 3.5 standard deviations noted by others (Docs.oracle.com, no date; Itl.nist.gov, no date; Trevorwhitney.com, no date) and removed, which typically involved removing approximately 0 to 10% of the initial set of observation pairs.

After statistically analyzing the changes it is apparent that some of the differences, changes in concentration, are significant for some of the analytes: aluminum, boron, bromide, calcium, chloride, iron, magnesium, nickel, rubidium, sodium, strontium, and TDS. For this study any difference with confidence of difference determined by both of the tests greater than 95% or a p value under 0.05 are considered a significant difference, which is often considered a significant difference by others (Kirk, 1990; and Neter et al., 1990). Some of these significant differences are significant increases of concentrations for aluminum, bromide, calcium, chloride, iron, magnesium, nickel, rubidium, and strontium (Figure 3 and Figure 4) and others are significant decreases of concentrations for boron sodium, and TDS (Figure 5). It appears that concentrations of many of the analytes have been impacted, but not in the way one may expect from leakage of produced waters in northern Louisiana which have very elevated concentrations of 1000s to 10,000s of mg/L for chloride, sodium and TDS (Collins, 1970; and Blondes et al., 2016). There is an increase of bromide, chloride, and sodium but no increase in TDS.

Discussion

However, these changes are reasonable considering that the Wilcox is composed in most areas of three fine sands which have low permeability; and the water quality of the top sand and second sand downwards are significantly different. The Wilcox is being stressed by individual hydraulic fracturing jobs consuming typically 3 to 8 million gallons of water (Figure 6), and other stresses from commercial, industrial and domestic use of water which use on average 3.90 to 6.78 millions of gallons of water daily in Caddo Parish (Sargent, 2002, 2007, and 2011). These other sources have caused a cone of depression to develop in southeastern Caddo Parish (Rapp, 1996) which is where dozens of this study's wells are located.

Although it is noted many hydraulic fracturing jobs are supplied by a surface water body, these are usually small local ponds that in a humid setting such as Louisiana act as indirect sources of groundwater because lakes/ponds in humid setting are just outcrops of groundwater (Winter et al., 1998; and Fetter, 2001). So, if a lake/pond is a water source it just indirectly draws on groundwater which in this case is usually the Carrizo-Wilcox Aquifer. These large stresses can cause significant vertical movement of water from the top sand towards the next sand downwards through leaky silts between sands and in turn cause the water quality in the second sand to change significantly. Movement of water downwards would explain the increases in calcium, iron, and magnesium, because it has been observed that concentrations of calcium, iron (Figure 7), and magnesium are significantly higher in the top sand than in the second sand downwards where most domestic wells are screened across within both the 2007-2008 (Carlson and Van Biersel, 2010) and 2010-2011 study (Carlson and Horn, 2014, and 2016). The concentrations of both sodium and TDS are generally decreasing between 2007-2008 and 2010-2011. This would be as expected due to water moving downwards from the top sand which has lower concentrations of sodium (Figure 8) and TDS (Carlson and Van Biersel, 2010; and Carlson and Horn, 2016). In summary, concentrations of the five analytes calcium, iron, magnesium, sodium, and TDS are changing in a manner that would be expected from downward movement of water from the top sand into the next sand downwards where most of the domestic wells sampled in these studies are screen in.

There are two analytes, bromide and chloride, that do not neatly fit into this model of water moving downwards from the top sand into the next sand downwards. The observed change for bromide and chloride is typically an increase (Figure 3). It would be expected that the change should be a decrease because the concentrations of both these ions are lower in the top sand than in the next sand downwards (Carlson and Van Biersel, 2010; and Carlson and Horn, 2016).

So, what could be causing this difference from the other five analytes that seem to behave in manner expected by a downward movement of water from the top sand into next sand downwards? There are possibly three sources of water richer in chloride: local surface water bodies (Van Biersel, and Carlson, 2009; and Carlson and Horn, 2016), produced waters leaked due to accidents or poorly constructed oil or gas wells in the area (Blondes, et al., 2016; and Collins, 1970), and lastly septic systems (Minnesota Pollution Control Agency, 1999; and Putnam and Anderson, 2009). In addition to the increased chloride there is an increase in average nitrate concentration between 2007-2008 and 2010-2011 of approximately 60%, which is, although not statistically significant, reasonable because both Carlson and Van Biersel (2010) and Carlson and Horn (2016) studies observed higher concentrations of nitrate in the top sand than the next sand downwards (Figure 9). So, once again this change makes sense.

In addition, the values for nitrate values are more reasonable for a source of surface water or near surface groundwater rather than deep produced waters which do not include nitrate measurements. For example, in Blondes et al. (2016) set of 5700 produced waters samples analyzed from Louisiana there is not one which includes results for nitrate. So, maybe chloride/bromide are sourced from a combination of leaking septic systems, and/or interaction with surface water bodies such as Cross Lake or Red River which tend to have higher chloride concentrations (Van Biersel and Carlson, 2009; and Carlson and Horn, 2016).

Conclusions

In summary, hydraulic stresses are causing top sand groundwater to move downwards into the next lower sand, which is the source of most domestic water sampled in the studies. This movement has caused increasing iron concentration that in turn causes poorer water quality due the increased iron concentration plus sulfate. Sulfate that is more abundant than iron has allowed bacteria within the aquifer to generate more hydrosulfide which in turn yields the rotten egg odor noted by many well owners (Carlson et al., 2014). Although some of the well owners noted changes of water quality, increased odor, when increase use of water due to drilling and hydraulic fracturing, there was a major drought (Carlson, et al., 2012; and Hanson et al., 2012) in the study during 2010 and 2011 plus other uses of water which also caused a major decrease of water level. The average of daily water use for hydraulic fracturing, approximately 3 million gallons, is clearly less than other uses within Caddo Parish. The water use associated with hydraulic fracturing probably contributed to changes in water quality, but the impact of other users and the drought are as important if not more so.

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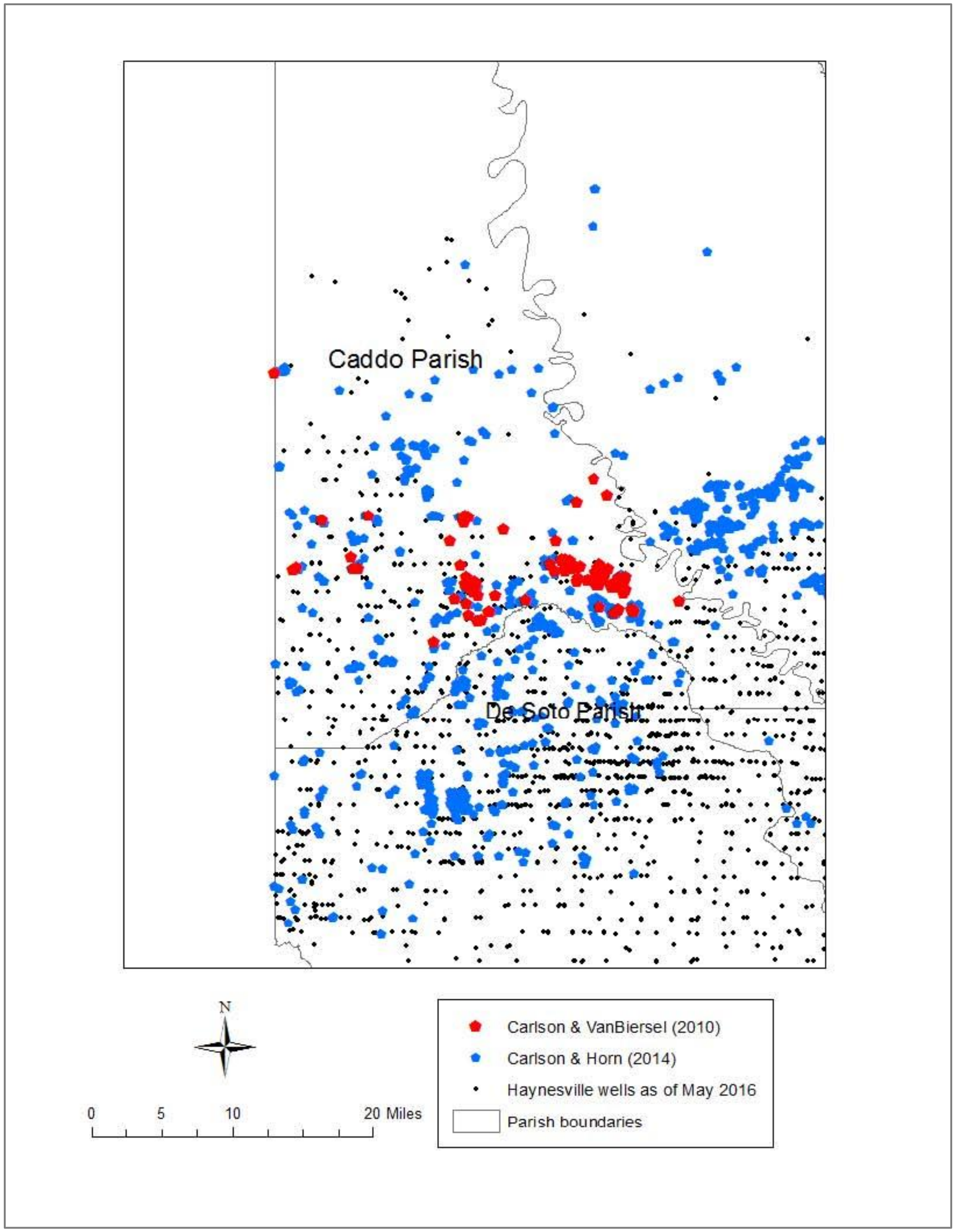

Figure 1. Location of wells sampled for two water quality studies completed by Louisiana Geological Survey staff in 2007-2008 (Carlson, and Van Biersel, 2010), and 2010-2011 (Carlson, and Horn, 2014, and 2016).

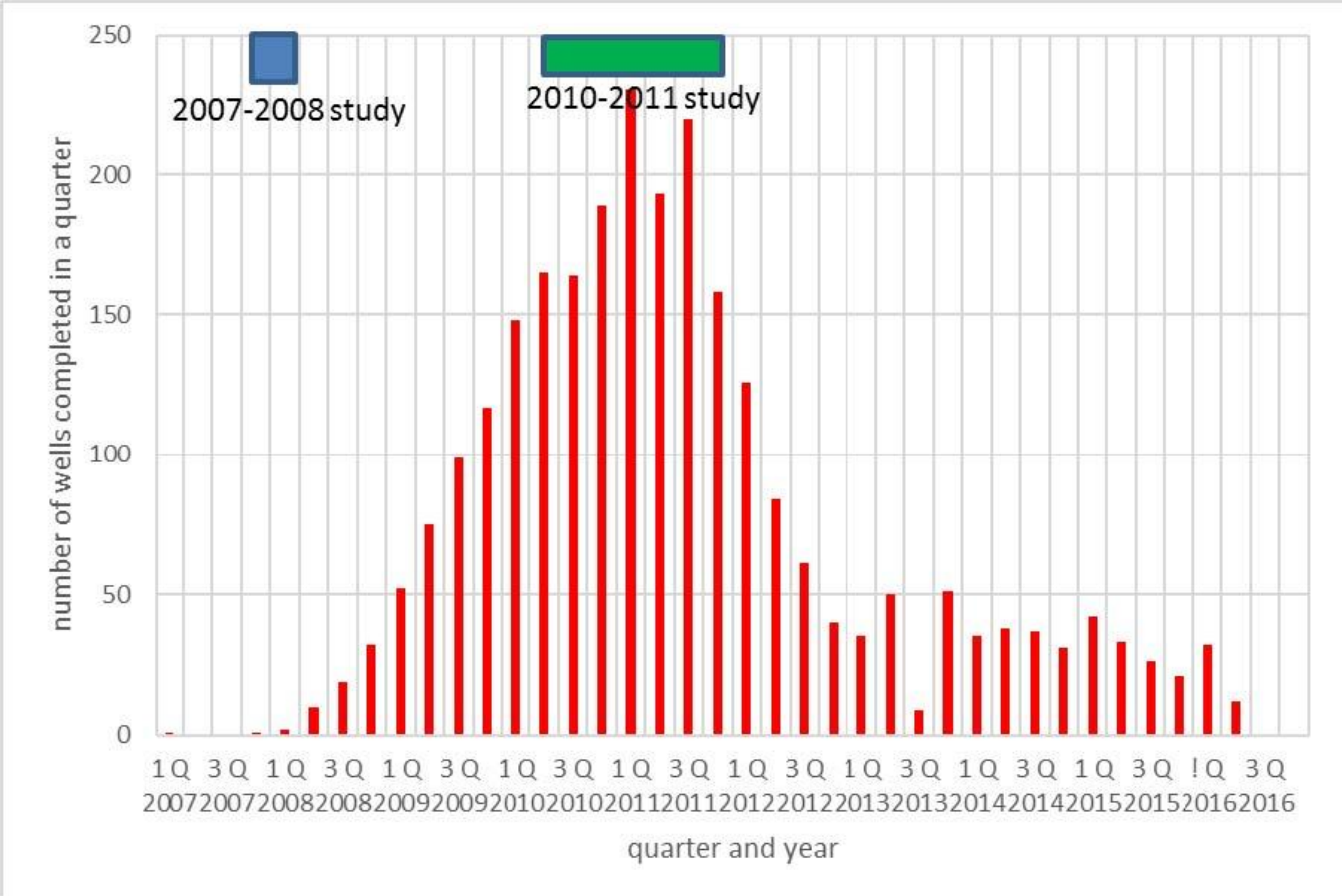

Figure 2. Number of Haynesville wells completed by quarter prior, during and after LGS groundwater studies of the Carrizo-Wilcox Aquifer. Source of drilling data is Louisiana Department of Natural Resources (2017).

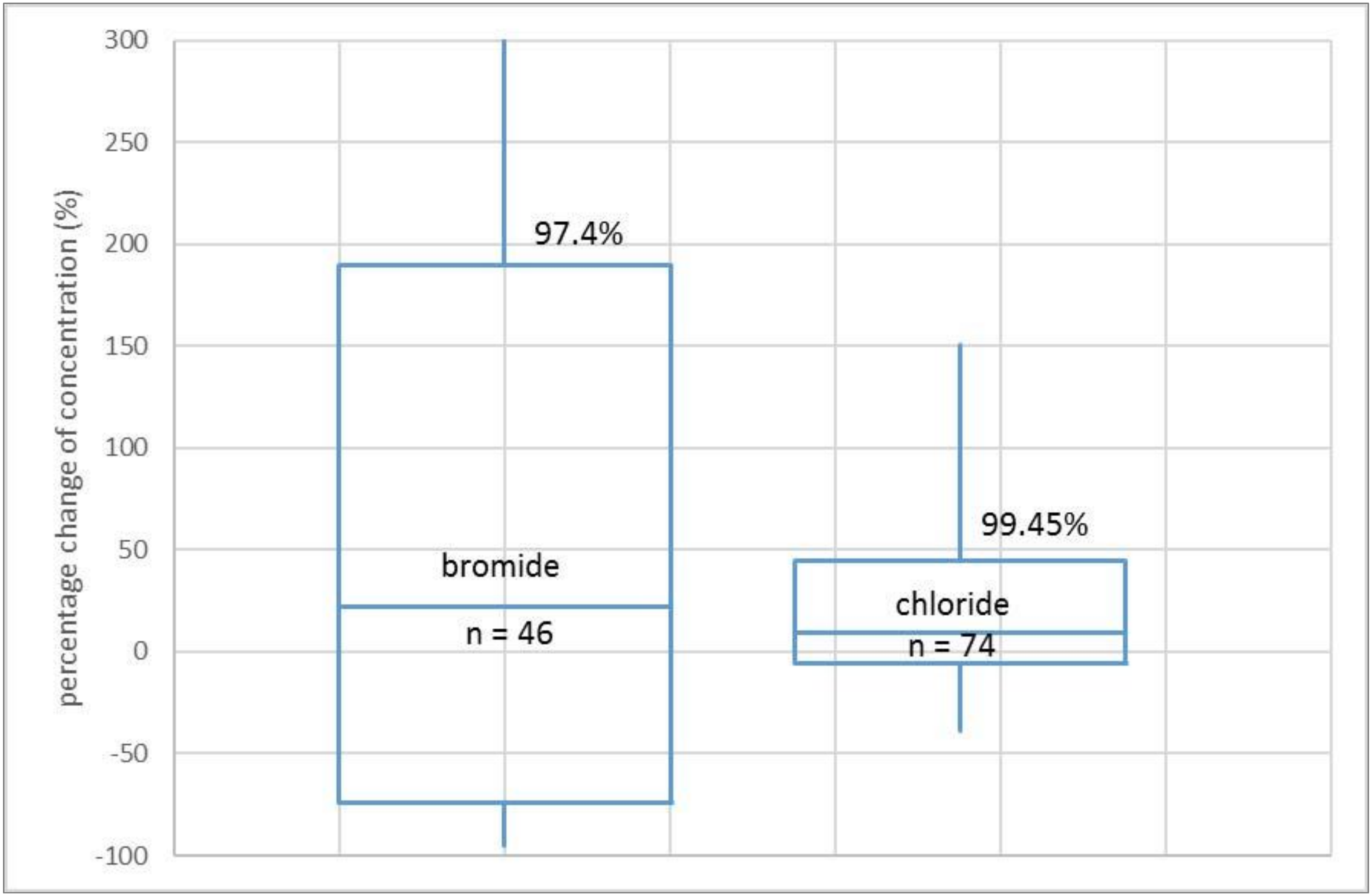

Figure 3. Distribution of the percentage change of concentrations for anions which usually increase between 2007-2008 and 2010-2011. N is the number of observation pairs for an anion. Confidence of increase is noted above right side of the box.

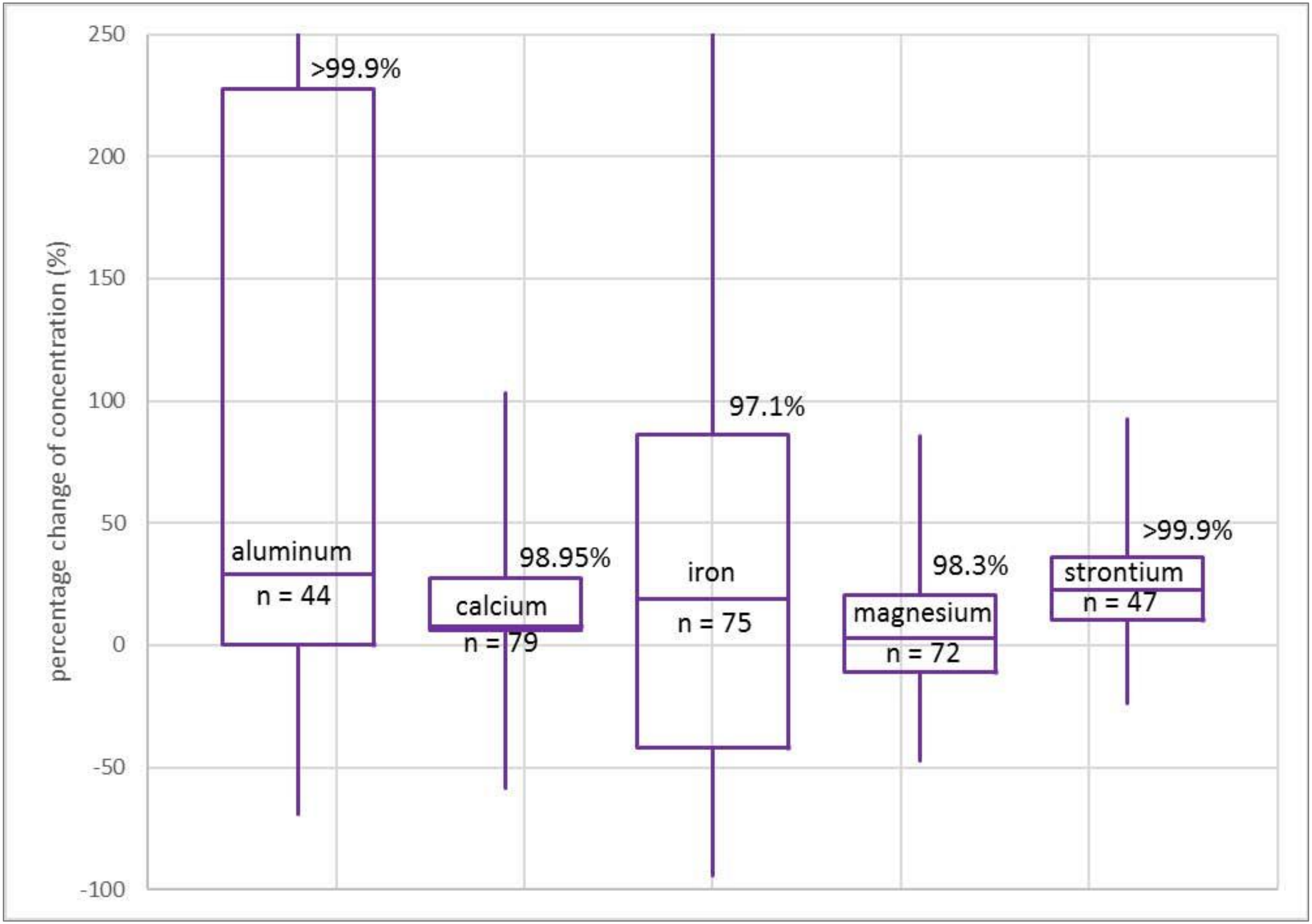

Figure 4. Distribution of the percentage change of concentrations for cations which usually increase between 2007-2008 and 2010-2011. N is the number of observation pairs for an anion. Confidence of increase is noted above right side of the box.

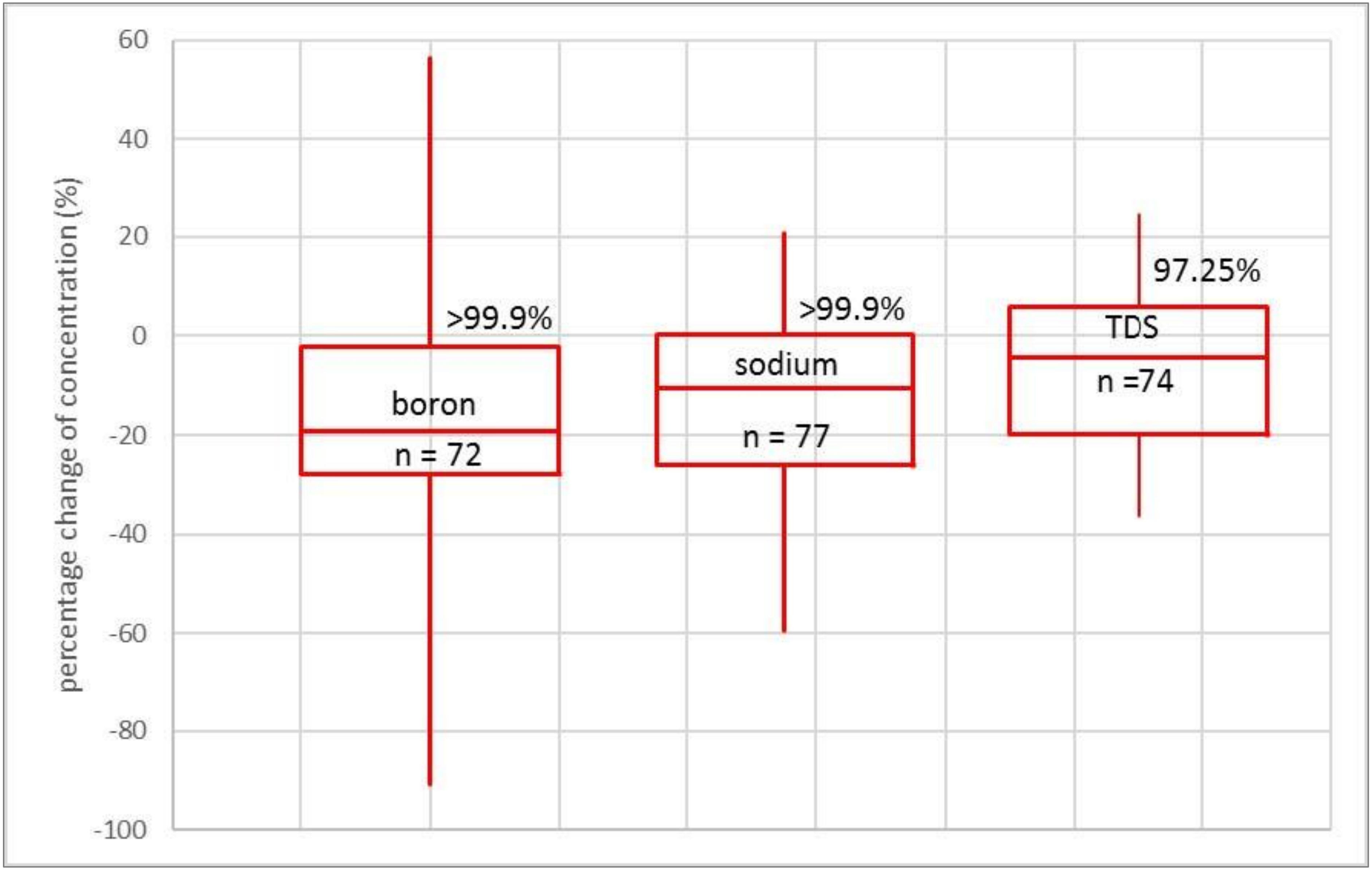

Figure 5. Distribution of the percentage of change of concentrations for analytes which usually decrease between 2007-2008 and 2010-2011. N is the number of observation pairs for an anion. Confidence of increase is noted above right side of the box.

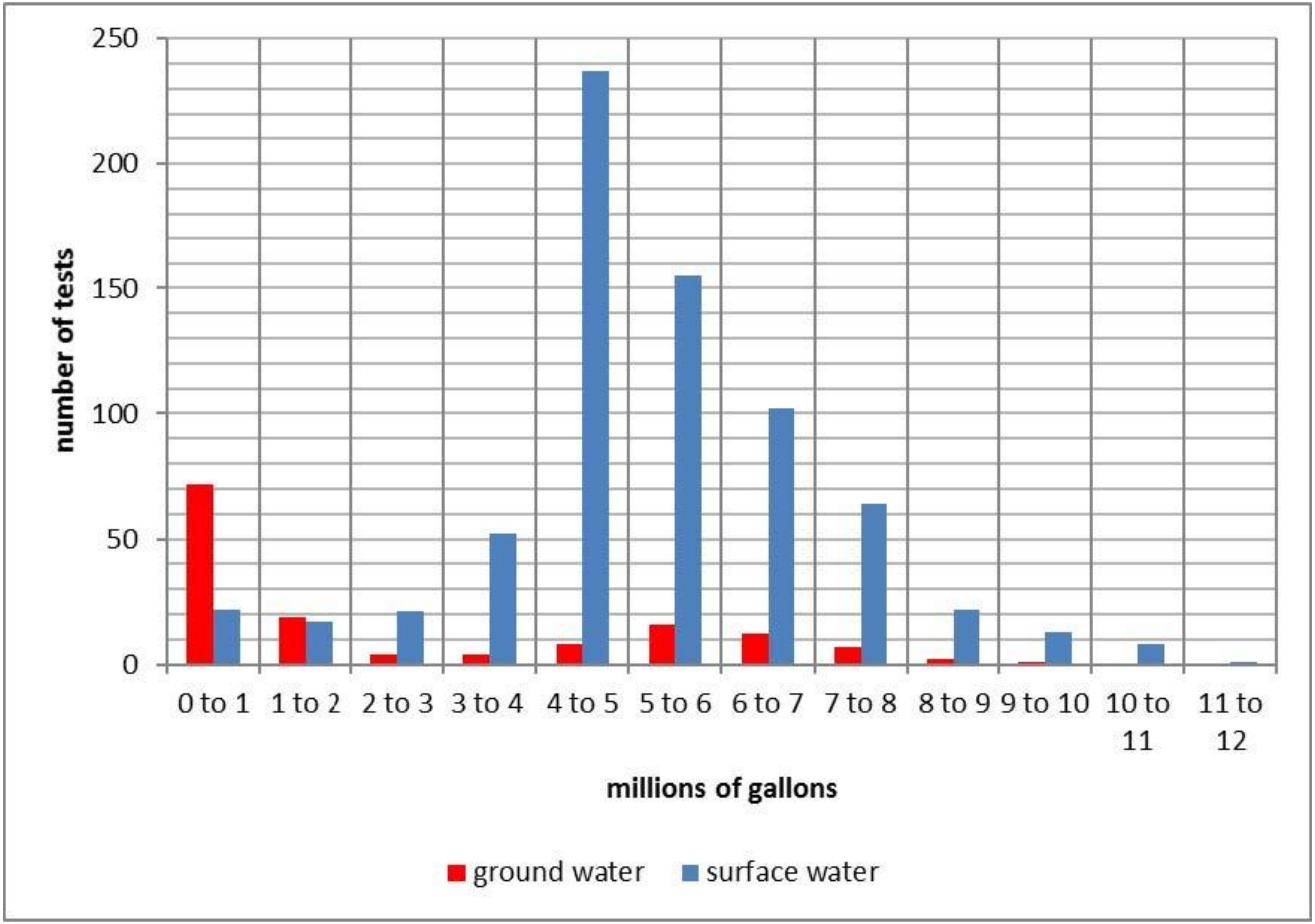

Figure 6. Volumes of water used for hydraulic fracturing of the Haynesville Shale, results include145 ground water tests and 714 surface water tests (Louisiana Department of Natural Resource, 2011).

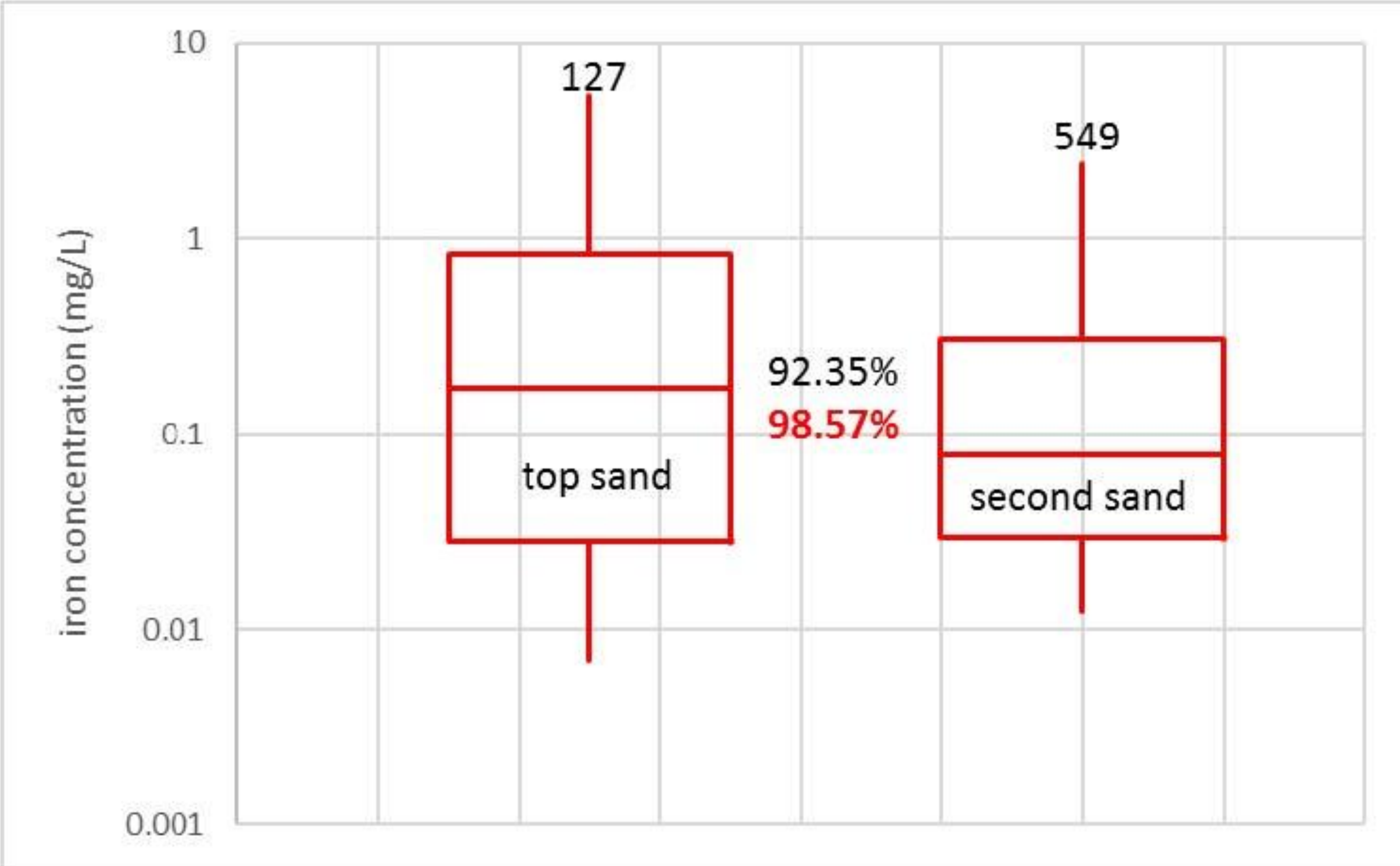

Figure 7. Iron concentration within a well as dependent which sand water is drawn from (source is Figure 5 of Carlson and Horn, 2016).

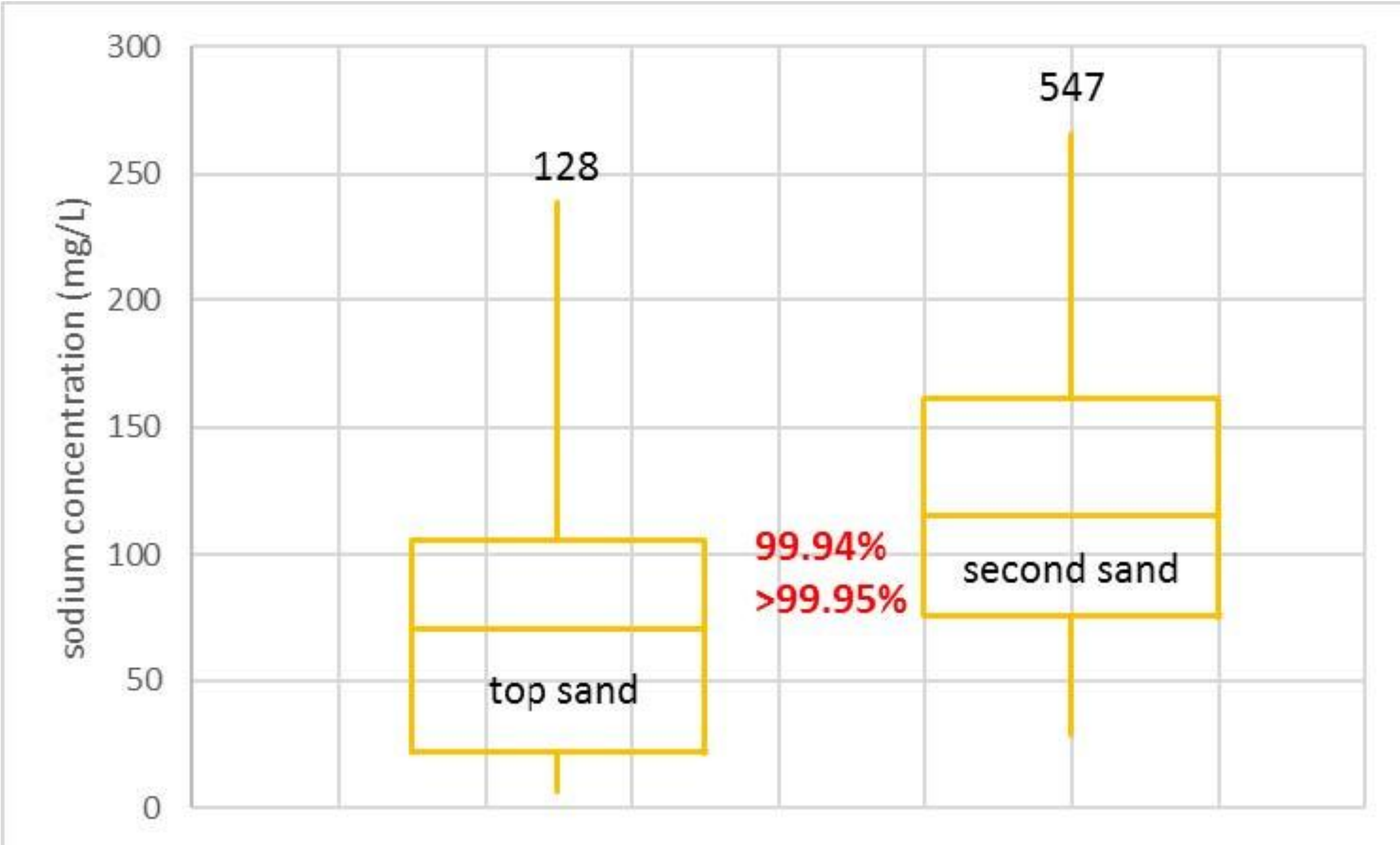

Figure 8. Sodium concentration within a well as dependent which sand water is drawn from (source is Figure 9 of Carlson and Horn, 2016).

Figure 9. Nitrate concentration within a well as dependent which sand water is drawn from (source is Figure 6 of Carlson and Horn, 2016).