Poll Res. 41 (2) : 467-473 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i02.012

A SUGGESTION FOR SUSTAINABLE GROUNDWATER USE ON INTENSIVE ARABLE AREA IN SEMIARID REGION

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(Received 10 April, 2021; Accepted 26 October, 2021)

ABSTRACT

Topsoil and groundwater qualities were investigated by obtaining onsite measurements in the Alxa semiarid region in Inner Mongolia, north western China. The groundwater quality was found to be unacceptable for drinking as the concentration of groundwater nitrate (NO_3^-) was 66–250 mg l^{-1}, with an average value of 130 mg l^{-1}; this value is 1.3–5.6 times higher than that specified by the regulatory drinking water standards recommended by the World Health Organization (50 mg NO_3^- l^{-1}) or U.S. Environmental Protection Agency (44.26 mg NO_3^- l^{-1}). The mean values of the groundwater electrical conductivity (EC) and nitrate NO_3^- in intensive agricultural areas were, respectively, 2.9 and 3.2 times higher than those in non-intensive agricultural areas. In addition, the groundwater EC and NO_3^- of the intensive and non-intensive agricultural areas exhibited considerable differences (EC: p<0.001, NO_3^-: p<0.05, Student t-test). This study suggests a sustainable groundwater use (as irrigation water use) without nitrogen fertilization on intensive arable area in semiarid region. The recommended amount of irrigation water use can help improve the degradation of the topsoil and enhance the groundwater qualities while decreasing the surplus N content.

KEY WORDS : Groundwater quality, Intensive agricultural area, Land uses, Nitrate pollution, Onsite measurement, Semiarid area

INTRODUCTION

Groundwater is vulnerable to nitrate (NO_3^-) pollution, which is a critical environmental problem in agricultural areas worldwide (Strebel *et al*., 1989; Zhang *et al*., 1996; Agrawal *et al*., 1999; Kumazawa, 2002; Thorburn *et al*., 2003; Mohammad *et al*., 2004; Ju *et al*., 2006; Dochartaigh *et al*., 2010). It has been reported that the nitrate level in groundwater in agricultural areas in northern China, Japan, Europe, southern Africa and western United States is 22–55% higher than the value specified in the regulatory drinking water standards recommended by the World Health Organization (50 mg NO_3^- L^{-1}) or U.S. Environmental Protection Agency (44.26 mg NO_3^- L^{-1}) (Zhang *et al*., 1996; Fujii *et al*., 1997; Laegreid *et al*., 1999; Tredoux *et al*., 2000; Paul *et al*., 2007). Furthermore, several researchers have reported that the nitrate surplus in groundwater is a result of agricultural activities such as nitrogen (N) fertilizer use (Burden, 1982; Strebel *et al*., 1989; Faillat, 1990; Keeney and Follett, 1991; Bernhard *et al*., 1992; Spalding and Exner, 1993; Zhang *et al*., 1996; Rivers *et al*., 1996; Nolan *et al*., 1997; Oenema *et al*., 1998; Rass *et al*., 1999). The high nitrate levels in drinking water are well known to cause severe health problems such as methemoglobinemia in infants and non-Hodgkin's lymphoma and stomach cancer in adults (Johnson *et al*., 1987; Lee *et al*., 1992; Ward *et al*., 1994; Knobeloch *et al*., 2000; Wolfe and Patz, 2002).

Although Zhang *et al*. (1996), Chen (2005), Ju *et al*. (2006) and Brighid *et al*. (2010) have reported upon the degradation of groundwater quality in cultivated areas in northern China, the onsite data pertaining to semiarid areas, which are subjected to extreme environmental conditions such as drought, depletion, and water stress of plants are extremely limited. To this end, the objectives of this study are to 1) assess the groundwater quality in a semiarid area, 2) compare the nitrate concentrations corresponding to different land uses (non-intensive and intensive arable areas), and 3) suggest a sustainable groundwater use (as irrigation water use) in intensive arable areas in the Alxa semiarid region in Inner Mongolia, north western China.

MATERIALS AND METHODS

Study area

Figure 1 shows the study area located in Left Banner in Alxa League in Inner Mongolia, north western China (38°43′–38°27′N, 105°34′–105°39′E); this region is approximately 900 km west of Beijing. The Left Banner has two main deserts (Tengeer and Wulanbuhe) with a total area of 34,000 km^2 (Hu *et al*., 2008; Wei *et al*., 2009). The study areas were divided into two different land use areas as follows: 1) non-intensive agricultural area, which is a typical semiarid area with limited agricultural activities (*e.g.*, semiarid pastures and greening activities) and 2) intensive agricultural area, which is subject to single crop cultivation involving maize and sunflower in April–October. The depth of the groundwater in the non-intensive agricultural area was 115–165 m, and the water was primarily used for the domestic water supply and irrigation activities. In general, in the intensive agricultural areas, 800–1,700 mm of water was used annually for irrigation purposes, with the typical N fertilizer application rates being 280–350 kg N ha^{-1} (Wei *et al.*, 2009). Topologically, the study areas include slopes from the north to the south with the elevation ranging from 1,403–1,307 m. The geographical data and Figure 1 were determined and created using Google Earth 6.1.

The annual average air temperature was 7.8 °C with a maximum value of 41 °C (in July) and minimum value of -33.1 °C (in January). The sunshine duration for a year was 3360 h. The annual mean precipitation was 110–180 mm, and 70–80% of the precipitation occurred during June–September. The annual potential evaporation reached up to 3,400 mm, which is approximately 20 times higher than the annual precipitation value.

Analyses of pH, EC and NO_3^- in groundwater samples

After sampling in August 2011, the pH, electrical conductivity (EC) and NO_3^- content in each groundwater sample were measured by using a portable pH meter (Horiba, Twin pH B-212), an EC meter (Horiba, Twin Cond B-173), and a NO_3^- meter (Horiba, Twin NO_3^- B-342), which employ a glass electrode method, an AC bipolar method, and an ion electrode method (Peng *et al.*, 2012; Tully and Weil, 2014; Russo *et al.*, 2017), respectively. The detection ranges for the pH, EC and NO_3^- were 2–12 (repeatability: ±0.1), 0–19.9 mS/cm (repeatability: ±1%), and 30–600 (reproducibility: ±10%), respectively.

Several topsoil samples were collected from a depth of 0–10 cm in the non-intensive and intensive arable areas in August 2012. The pH, EC, and NO_3^- of the topsoil were measured considering samples having a weight-by-volume ratio of the field-moist soil to commercial mineral water of 1:5. The mineral water had a pH of 7, EC of 22 μS cm^{-1} and NO_3^- content of 10 mg L^{-1}, as determined using the same analytical methods. The supernatant liquid was

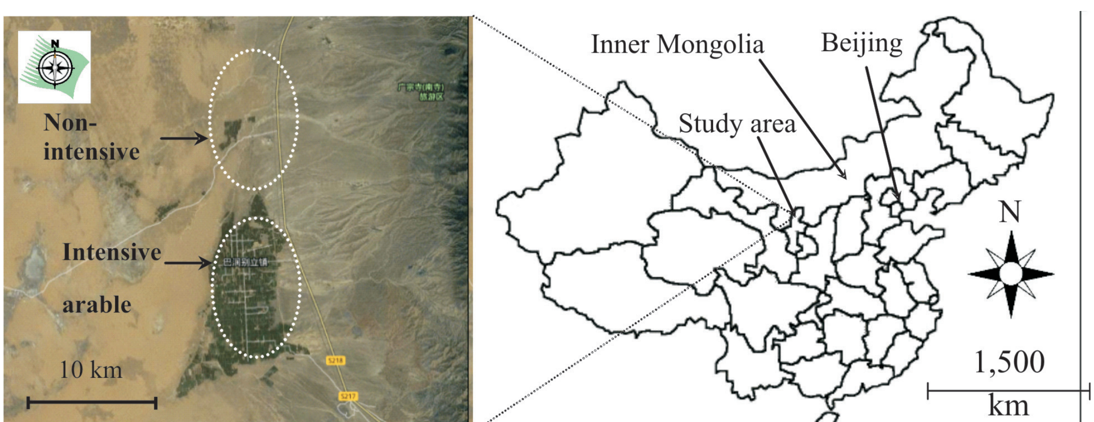

Fig. 1. The description of study areas (Background data source of satellite image map downloaded from Google Earth 6.1).

shaken for 1 min and used to perform the measurements. For the measurement of the NO_3^- concentration, all the samples were filtered through a membrane filter having a pore size of 10 μm.

Statistical analyses

The differences in the groundwater pH, EC, and NO_3^- between two independent sample groups (non-intensive and intensive agricultural areas) were tested using the Student *t*-test. All the differences with $p<0.05$ were considered significant. The normality was tested using the Kolmogorov–Smirnov test. The equality of the variances was tested using Levene's test. The outlier data, having extremely high or low values, were excluded from the entire dataset. All the statistical analyses were performed using a statistical program (IBM SPSS Statistics 19.0, IBM Corporation) for Windows.

RESULTS AND DISCUSSION

pH, EC, and NO_3^- content of the topsoil

Figure 2 shows that the topsoil pH of the non-intensive and intensive arable areas ($t(28)=4.362$, $p<0.001$) exhibit considerably different values. The pH of the topsoil in the non-intensive arable area ranged from 9.2–10.0 (average of 9.6), demonstrating that the topsoil had a very strongly alkaline nature, as classified by the United States Department of Agriculture terminology (Singer and Munns, 2002). In the intensive arable area, the pH of the topsoil ranged from 8.5–9.7 (average of 9.1), also demonstrating that the topsoil had a highly strong alkaline nature. An extremely high pH (above 9) can directly injure some plants; however, a more severe problem of high pH corresponds to the introduction of nutrient deficiencies or toxicities (Singer and Munns, 2002).

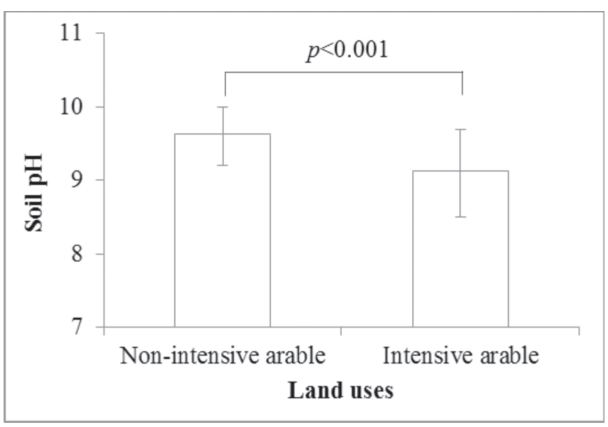

Fig. 2. The mean, maximum and minimum values in the pH of topsoil samples. The soil pH value in intensive agricultural area is significantly lower than that in non-intensive agricultural area ($p<0.001$, Student *t*-test).

Figure 3 shows that several intensive arable sites were likely affected by the high content of salt owing to the high electrical conductivities. The soil EC values in the intensive arable area varied between 133–620μS cm^{-1} with an average value of 344μS cm^{-1}; these values are all lower than the critical level (approximately 1,500μS cm^{-1}) that can damage the crops in alluvial soil (Kamewada, 2000; Singer and Munns, 2002). However, three outlier data points (3,200, 10,700, and 10,800μS cm^{-1}) were present, which accounted for 20% of the total data (15 data points); the EC level in these cases exceeded the damage level for the crops. In contrast, the topsoil EC values in the non-intensive arable area ranged from 74–103μS cm^{-1} with an average value of 87μS cm^{-1}. The topsoil EC values in different land uses were significantly different ($t(11)=6.118$, $p<0.001$), with the mean EC value of the topsoil in the intensive arable area being six times higher than that in the non-intensive arable area. It was thus concluded that the topsoil with a high pH and EC could adversely affect the yield and other plant species endemic to the intensive arable area.

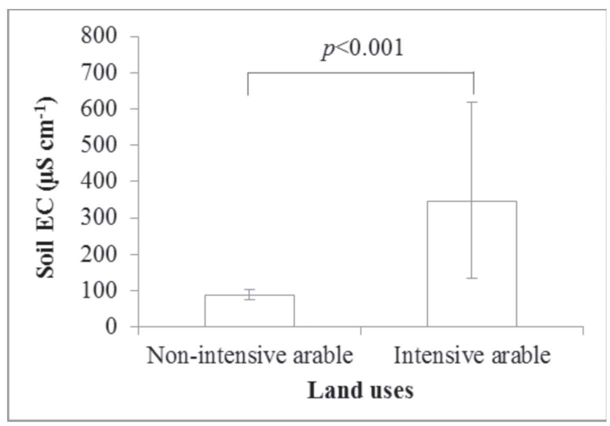

Fig. 3. The mean, maximum and minimum values in the electrical conductivity (EC) of topsoil samples. The soil EC value in intensive agricultural area is significantly higher than that in non-intensive agricultural area ($p<0.001$, Student *t*-test).

Figure 4 shows that the topsoil water nitrate (NO_3^-) concentrations in the non-intensive and intensive arable areas were respectively 11–31 mg L^{-1} and 18–96 mg L^{-1} with average values of 22 mg L^{-1} and 42 mg L^{-1}. Four intensive arable topsoil samples corresponding to approximately 31% of all the samples (13 samples) exceeded the regulatory drinking water standards recommended by the World Health Organization (50 mg NO_3^- L^{-1} = 11.3 mg N L^{-1}) or U.S. Environmental Protection Agency (44.26 mg NO_3^- L^{-1} = 10 mg N L^{-1}), but not the regulatory groundwater water standard (133 mg NO_3^- L^{-1} = 30 mg N L^{-1}) specified by the Ministry of Environmental Protection of the People's Republic of China (1994). Furthermore, two outlier data points were present (140 and 480 mg NO_3^- L^{-1}), which accounted for 13% of the complete data (15 data); the value for these samples exceeded those specified by all the regulatory drinking water standards. The topsoil water NO_3^- concentration in the intensive arable area was 3.1 times higher than that in the non-intensive arable area, and the values under the different land uses also exhibited a significant difference ($t(13)=2.873$, $p<0.05$).

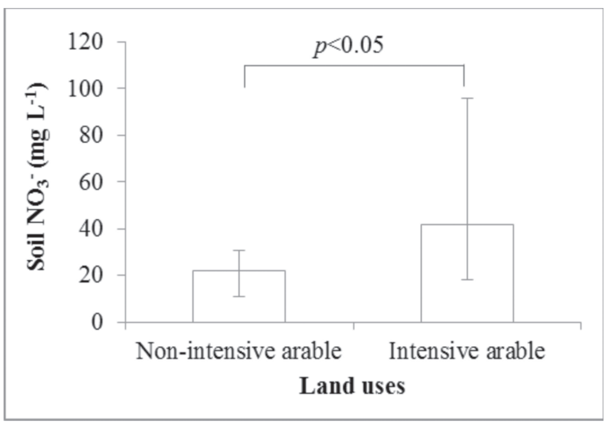

Fig. 4. The mean, maximum and minimum values in the NO_3^- concentration of topsoil samples. The soil NO_3^- value in intensive agricultural area is significantly higher than that in non-intensive agricultural area ($p<0.05$, Student t-test).

pH, EC and NO_3^- in groundwater

Figure 5 shows that the groundwater pH in the non-intensive arable area ranged from 7.9 to 8.2 (average value of 8.0), indicating the alkaline nature of the groundwater. In the intensive arable areas, the groundwater pH varied from 7.7–8.0 with the average value of 7.8. Both the areas exhibited an acceptable pH range according to the regulatory groundwater water standard (Ministry of Environmental Protection of the People's Republic of China, 1994). Although the groundwater pH values in the non-intensive arable area were slightly higher than those in the intensive arable area, a significant difference between the groundwater pH

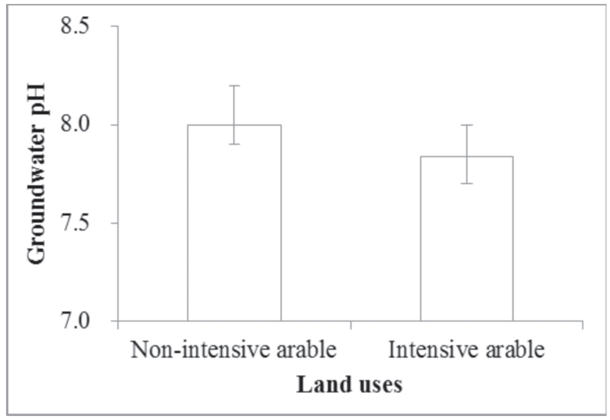

Fig. 5. The mean, maximum and minimum values in the pH of groundwater samples.

values under the different land uses was not observed ($t(8)=1.969$, $p=0.084$).

Figure 6 shows that the groundwater EC in the intensive arable area was 1,640–2,300μS cm^{-1} with an average value of 1,914μS cm^{-1}; these values are all higher than the value that could damage crops in alluvial soil (approximately 1,500μS cm^{-1}) (Kamewada, 2000; Singer and Munns, 2002). In contrast, the groundwater EC in the non-intensive arable area was 166–1,020μS cm^{-1} with an average value of 653μS cm^{-1}. The groundwater EC values under the different land uses were noted to be significantly different ($t(8)=6.737$, $p<0.001$), with the mean EC value in the intensive arable area being approximately three times higher than that in the non-intensive arable area.

Figure 7 shows that the groundwater NO_3^-

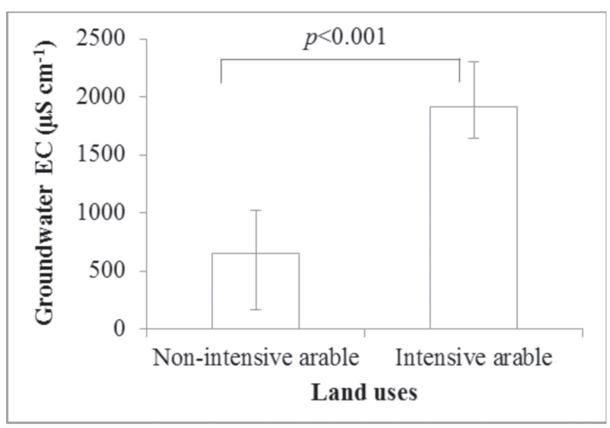

Fig. 6. The mean, maximum and minimum values in the electrical conductivity (EC) of groundwater samples. The groundwater EC value in intensive agricultural area is significantly higher than that in non-intensive agricultural area ($p<0.001$, Student t-test).

concentration in the intensive arable area ranged from 66–250 mg L^{-1} with an average value of 130 mg L^{-1}, which 1.3–5.6 times higher than that specified by the regulatory drinking water standards recommended by the World Health Organization (50 mg $NO_3^-L^{-1}$ = 11.3 mg N L^{-1}) or U.S. Environmental Protection Agency (44.26 mg $NO_3^-L^{-1}$ = 10 mg N L^{-1}), but not the regulatory groundwater water standard (133 mg $NO_3^-L^{-1}$ = 30 mg N L^{-1}) provided by the Ministry of Environmental Protection of the People's Republic of China (1994). In contrast, the groundwater NO_3^- concentration (36–49 mg L^{-1}, average value of 41 mg L^{-1}) in the non-intensive arable area was acceptable in the context of drinking water. The mean groundwater NO_3^- concentration in the intensive arable area was 3.2 times that in the non-intensive arable area with a significant difference ($t(8)=2.814$, $p<0.05$).

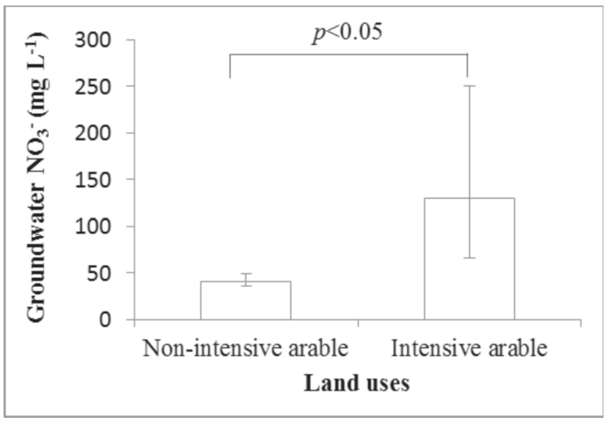

Fig. 7. The mean, maximum and minimum values in the NO_3^- concentration of groundwater samples. The groundwater NO_3^- value in intensive agricultural area is significantly higher than that in non-intensive agricultural area ($p<0.05$, Student t-test).

Table 1 presents the suitable amount of irrigation water use corresponding to the 1994–2003 annual mean amount of N fertilizer use (150 kg N ha^{-1}) for a corn field per hectare in the USA (USDA, 2015). The annual recommended irrigation water use range from approximately 3,000–10,000 ton per hectare in the intensive arable area. In addition, the daily recommended amount of irrigation water use was calculated as 30–112 ton per hectare in the intensive arable area under a 90-day cultivation period. This result shows that, theoretically, the N fertilizer use is no longer required if conventional irrigation water use is realized in the intensive arable area.

CONCLUSION

A highly deteriorated alkaline topsoil can adversely affect the plantation to combat desertification, the yield and other plant species endemic to the intensive arable area in the considered semiarid area. The highly deteriorated alkaline topsoil can be restored by performing coffee grounds and tea grounds as organic amendments, which are excellent soil amendments (in preparation).

Intensive irrigation and fertilizer use can result in substantial NO_3^- leaching down to the groundwater because soils are usually light-textured and originate from alluvium contained in the gray desert soils in the Left Banner, Alxa League in Inner Mongolia, north western China. Topsoil and groundwater qualities are subject to land use (intensive arable area) in this region. Frequent consumption of groundwater with a high NO_3^- concentration can be detrimental to human health under the condition of chronic nitrogen loading from arable areas, which is only the drinking water resource in this semiarid region. This study suggests that a recommended amount of irrigation water use (groundwater use) in Table 1 can help improve the degradation of the topsoil and enhance the groundwater qualities while decreasing the surplus N content. In addition, the NO_3^- concentration is sufficient to cultivate a corn

Table 1. Annual recommended amount of irrigation water use corresponding to the 1994-2003 annual mean amount of N fertilizer use (150 kg N ha^{-1}) per hectare in USA (USDA, 2015). Daily recommended amount of irrigation was calculated under a 90-day cultivation period.

	Non-intensive arable area					Intensive arable area				
No. of Well	1	2	3	4	5	6	7	8	9	10
NO_3^--N (mg N L^{-1})	8.1	9.5	11.1	8.6	8.8	56.5	14.9	21.2	27.1	27.1
Annual recommended irrigation water (ton ha^{-1} y^{-1})	18,452	15,816	13,557	17,481	17,033	2,657	10,065	7,067	5,536	5,536
Daily recommended irrigation water(ton ha^{-1} y^{-1})	205	176	151	194	189	30	112	79	62	62

field when performing only the irrigation of groundwater without nitrogen fertilization. Consequently, it is concluded that nitrogen fertilization should be controlled for the sustainable groundwater use.

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