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Yearly fluctuations in gas saturation in a karst spring at a fish hatchery

Abstract

Natural springs are common characteristics of karstic landscapes, such as those found in the Black Hills of South Dakota, USA. Water from these springs is supersaturated with nitrogen gas, which can be problematic if the spring water is used for fish rearing. This study recorded gas levels over 15 months from a spring at McNenny State Fish Hatchery, South Dakota USA. Mean (SE) percent nitrogen saturation was 114.0 (0.4) and ranged from 108.9 to 119.1%. Total gas pressure was never below 100%, and mean oxygen saturation was 79.2%. Both percent nitrogen saturation and total gas pressure significantly decreased over the course of the study. Conversely, oxygen saturation significantly increased during the study period. Rapid aquifer recharge is likely responsible for the fluctuations in nitrogen gas saturation in the spring water. This study highlights that nitrogen saturation and total gas pressure are not static and underscores the significance of nitrogen gas supersaturation monitoring in spring water used in aquaculture.

Keywords: karst formation, spring, fish hatchery, gas saturation, nitrogen supersaturation

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Introduction

Karst landscapes are formed by the dissolution of water-soluble bedrock.[1] Springs, sinkholes, underground caves, and disappearing streams are characteristic karst features.[1,2] Formation of karst features occurs in carbonate and evaporite sedimentary layers such as limestone ($CaCO_3$), gypsum ($CaSO_4 \cdot H_2O$), dolomite ($MgCO_3 \cdot CaCO_3$), and anhydrite ($CaSO_4$).[1,2]

The Black Hills of South Dakota, USA, contain rock formations that commonly display karst features.[3] The Minnelusa and Madison formations composed of mainly dissolvable limestone are largely responsible for the numerous occurrences of sinkholes throughout the area.[1,3] They act as major aquifers in the Black Hills and are recharged by streams and precipitation through outcrops in higher elevations.[3] Other sedimentary confining layers found in the Minnelusa and Madison formations are fine-grained varieties that impede water penetration. Because of these nearly impermeable layers, the aquifers are constantly under pressure. The active dissolution of the carbonate layers creates karst springs, such as those located at McNenny State Fish Hatchery at the northern edge of the Black Hills.[3] These springs are likely supplied by the Minnelusa and Madison aquifers.[3–5] The spring water is supersaturated with nitrogen gas, presumably due to the high-pressure buildup in its originating aquifer(s).[6,7]

Nitrogen supersaturation is of particular concern because of the negative effects of excess nitrogen on fish health.[8–12] In aquaculture facilities using spring water, gas saturation monitoring and remediation efforts routinely occur.[13,14] While karst spring gas saturation levels are known to vary throughout the day,[15] it is not known how much, if any, they fluctuate over longer time periods. Thus, the objective of this study was to document nitrogen gas levels in a karst spring for over a year.

Methods

Study area

The study site was located at McNenny State Fish Hatchery, Lawrence County, South Dakota, USA (Figure 1 and 2). The hatchery is built on top of the Spearfish Formation overlying the Madison and Minnelusa Formations. The top layer of soil is composed of fine-grained sandstone, siltstone, red shales, and soluble gypsum lenses.[1,2,16] Deeper layers mainly consist of dissolvable limestone and confining layers.[1,2,16] Karstic collapse beneath the hatchery in the Spearfish Formation is responsible for the numerous springs that supply the hatchery with water.[1,2,15]

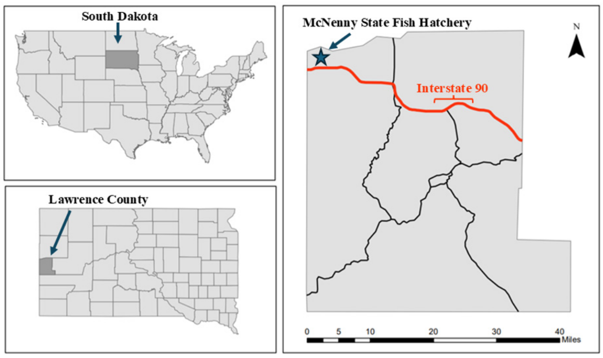

Figure 1 Location of McNenny State Fish Hatchery outside of Spearfish, South Dakota, USA.

https://www.google.com/maps/place/McNenny+Fish+Hatchery/@44.5586124,-104.0108369,387m/data=!3m1!1e3!4m6!3m5!1s0x5332918fc07c5a19:0x7729ef32173d93bc!8m2!3d44.5588518!4d-104.0111728!16s%2Fg%2F1w15z2ql?entry=ttu&g_ep=EgoyMDI1MDkxNy4wIKXMDSoASAFQAw%3D%3D

Figure 2 Aerial photo from Google Earth showing the location of the spring tested at McNenny State Fish Hatchery.

Data collection

Data was collected in a spring located at McNenny State Fish Hatchery (approximate latitude 44°33'32" N, longitude 104°00'40" W). Water flow from the spring is approximately 0.02 m^3/sec. The spring water has an approximate total hardness as $CaCO_3$ of 360 mg/L, alkalinity as $CaCO_3$ at 210 mg/L, pH of 7.6, and total dissolved solids of 390 mg/L. The water in the spring was sampled about once a week starting January 24, 2023, and ending May 8, 2024, excluding the month of May 2023. Samples were taken at sunrise using a total gas pressure meter (Handy Polaris, OxyGuard, Farum, Denmark) with barometric pressure obtained from wunderground.com[17] for a nearest location from the hatchery (approximately 8 km). The gas pressure meter was calibrated prior to daily use.

Total gas pressure was calculated by taking total gas pressure at saturation divided by 100 and multiplied by the overall barometric pressure.

Where:

$$P_{TOTAL} = \frac{P_{SAT}}{100} \times P_{BAR}$$

Delta *P* was determined by subtracting barometric pressure from total gas pressure.

Where:

$$\Delta P = P_{TOTAL} - P_{BAR}$$

Nitrogen saturation was calculated using the following formula:

$$N_2(\%) = \left[BP + \Delta P - \frac{\left(\frac{O_2}{b_{O2}}\right) \times 0.5318 - P_{H_2O}}{\left(BP - P_{H_2O}\right) \times 0.7902} \right] \times 100$$

Where:

N_2 = partial pressure of nitrogen gas in the water (percent nitrogen saturation);

BP = local barometric pressure (mmHg);

O_2 = oxygen concentration (mg/L);

B_{O2} = Bunsen's coefficient for oxygen;

P_{H2O} = partial pressure of the water vapor (mmHg).

Data analysis

Data were analyzed using the SPSS (24.0) statistical program (IBM, Armonk, New York, USA). Significance was predetermined at $p < 0.05$. A two-way analysis of variance was performed. If there was an interaction, then a one-way analysis of variance was performed with a post hoc means separation test using Tukey HSD.

Results

Mean (SE) percent nitrogen saturation was 114.0 (0.4) and ranged from 108.9 to 119.1% (Table 1). The highest level of nitrogen gas super-saturation was 119.1%. Total gas pressure was never below 100%, and mean oxygen saturation was only 79.2%. Both percent nitrogen saturation and total gas pressure significantly decreased over the course of the study (Figure 3 and 4). Conversely, oxygen saturation significantly increased during the study period (Figure 5).

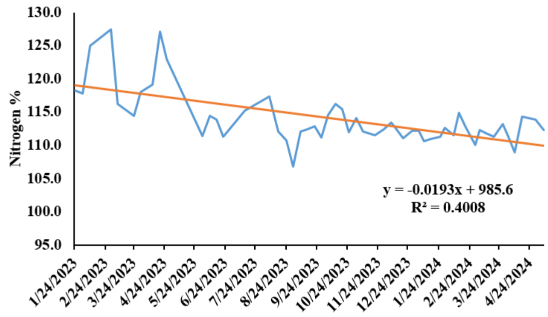

Figure 3 Change in percent nitrogen in the spring at McNenny State fish Hatchery over 15 months.

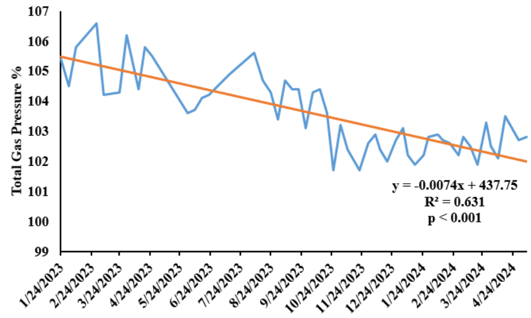

Figure 4 Change in percent total gas pressure in the spring at McNenny State fish Hatchery over 15 months.

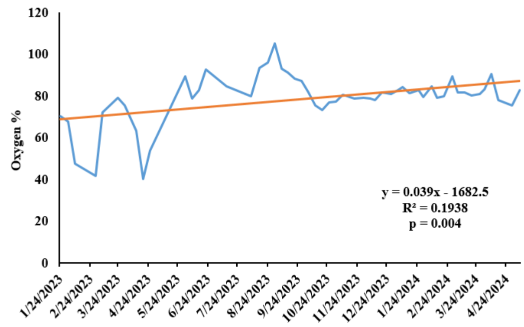

Figure 5 Change in percent oxygen saturation in the spring at McNenny State fish Hatchery over 15 months.

Table 1 Mean (SE), minimum, and maximum values of nitrogen gas (N2), total gas pressure (TGP), and oxygen (O_2) percent saturation in a karst spring at McNenny State Fish Hatchery over 15 months

Variable	Mean (%)	Minimum (%)	Maximum (%)
N_2 %	114 (0.4)	108.9	119.1
TGP %	103.6 (0.2)	101.7	106.2
O_2 %	79.2 (0.9)	63.4	91.3

Discussion

While nitrogen gas saturation levels declined over the course of the year, they still remained problematic regarding the use of the spring water for fish rearing. Nearly all of the recorded values were above the US Environmental Protection Agency's maximum criteria is 110% which marks the threshold for when potential disease can occur.[7,18] Nitrogen gas fluctuations in karst springs are common resulting from a variety of influences.[19] Ground water nitrogen saturation can occur through the process of surface water or precipitation being drawn into aquifers, where atmospheric air is supersaturated

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into the water because of high pressure.[7,18,20,21] The dissolution and weathering of carbonaceous other bedrock can also entrain nitrogen gas in groundwaters.[22,23] Furthermore, local rapid recharge caused by influxes of precipitation, vegetation inputs, organic matter, and human activity can increase nitrogen gas percent in spring waters.[24–27] However, samples were taken near the spring vent, and it is unlikely that these factors contributed to recorded nitrogen percent in this study.

Oxygen saturation had a negative correlation with nitrogen saturation and a positive linear relationship with time. Oxygen levels in the spring never fell below 63.4% saturation, which is lower than recorded by Gross et al.[15] in the same location but much higher than reported in other sampling locations of springs and ground water.[19,21] Oxygen gas saturation fluctuates through the seasons given that temperature and hours of daylight all affect oxygen levels in water, however this is unlikely due to the location of sampling.[28,29] The mixing of atmospheric air or precipitation with ground water can also influence oxygen saturation.[7,18,20,21,30] Oxygen gas typically inversely correlates with nitrogen gas, thus its general behavior in this study was expected.[18,30]

The total gas pressure had a significantly negative linear relationship with time over the course of this study. Total gas pressure is determined by a variety of factors such as the surrounding geology and rate of recharge leading to a higher water table.[31,32] The total gas pressure in karst springs is subject to change when there is an abundance of precipitation and runoff and accelerated recharge.[31,33,34] However, the negative linear relationship displayed by total gas pressure with time is unusual given that the precipitation varied throughout the year.

The time of day that the data was collected was significant for the focus of this study. Gross et al.[15] reported significantly higher supersaturation of nitrogen in the morning, and lower levels later in the day. Because the focus of this study was to monitor nitrogen supersaturation in the water that would ultimately be used for fish rearing, it was important that the readings were taken when the nitrogen levels were highest. Monitoring nitrogen levels in the water used for raising fish is crucial because nitrogen gas supersaturation can lead to gas bubble disease.[7,19,21,35,36]

This study was conducted for 15 months, but fluctuations in aquifer recharge and precipitation will influence percent nitrogen in spring waters.[7,18,20,21] To properly monitor and access all factors of gas supersaturation, a longer-term study is required.

Conclusion

The results of this study indicates that total gas supersaturation is not static in natural karstic springs. The changes in nitrogen supersaturation, total gas pressure, and oxygen saturation are likely because of the rapid recharge of the springs originating aquifers. Because elevated nitrogen gas levels can create fish health issues during hatchery rearing, the results from this study underscore the significance of nitrogen gas supersaturation monitoring.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

References

1. Williamson JE, Carter JM. *Water-quality characteristics in the Black Hills area, South Dakota*. U.S. Geological Survey, Water-Resources Investigations Report. 01–4194. 2021. p. 1–202.
2. Stetler LD, Davis AD. Gypsum and carbonate karst along the I-90 development corridor, Black Hills, South Dakota. U.S. Geological Survey Karst Interest Group Proceedings, Rapid City, 12-15 September 2005, U.S. Geological Survey, Scientific Investigations Report 2005-5160, 134. 2005.
3. Epstein JB. *Hydrology, hazards, and geomorphic development of gypsum karst in the Northern Black Hills, South Dakota and Wyoming*. U.S. Geological Survey Karst Interest Group Proceedings, Water-Resources Investigations Report 01-4011. 2001:30–37.
4. Naus CA, Driscoll DG, Carter JM. *Geochemistry of the Madison and Minnelusa Aquifers in the Black Hills Area, South Dakota*. U.S Geological Survey, Water- Resources Investigation Report 01-4129. 2001. p. 1–123.
5. Putnam LD, Long AJ. *Characterization of ground-water flow and water quality for the Madison and Minnelusa Aquifers in Northern Lawrence County, South Dakota*. U.S. Geological Survey, Scientific Investigations Report 2007-5001. 2007.
6. Marsh MC. Notes on the dissolved content of water and its effect upon fishes. *Bull Bur Fish*. 1910;28(2):891–906.
7. Marking LL. *Gas supersaturation in fisheries: causes, concerns, and cures*. U.S. Fish and Wildlife Leaflet 9, Washington DC. 1987. p. 1–15.
8. Nebecker AV, Andros JD, McCrady JK, et al. Survival of steelhead trout (*Salmo gairdneri*) eggs, embryos, and fry in air-supersaturated water. *J Fish Board Can*. 1987;35:261–264.
9. Bouck GR. Etiology of gas bubble disease. *Trans Am Fish Soc*. 1980;109:703–707.
10. Gunnarsli KS, Toften H, Mortensen A. Effects of nitrogen gas supersaturation on growth and survival in larval cod (*Gadus morhua L.*). *Aquaculture*. 2009;288:344–348.
11. Liu X, Li K, Du J, et al. Growth rate, catalase and superoxide dismutase activities in rock carp (*Procypris rabaudi Tchang*) exposed to supersaturated dissolved gas. *J Zhejiang Univ-Sci B*. 2011;12:909–914.
12. Wang Y, Li Y, An R, et al. Effects of total dissolved gas supersaturation on the swimming performance of two endemic fish species in the Upper Yangtze River. *Scientific Reports, 8, Article No. 10063*. 2018.
13. Krebs E, Muggli AM, Barnes JM, et al. A novel trout pond inlet structure. *J Aquac Eng Fish Res*. 2018;4:120–126.
14. Caasi JMA, Krebs E, Huysman N, et al. A degassing inlet structure for aquatic ponds. *World J Eng Technol*. 2020;8:159–167.
15. Gross MA, Voorhees JM, Domagall AS, et al. Nitrogen gas saturation in karst springs varies throughout the day. *J Water Resour Prot.* 2023;15: 23–32.
16. Epstein JB. National evaporite karst-some western examples. U.S. Geological Survey Karst Interest Group Proceedings, Rapid City, 12-15 September 2005, U.S. Geological Survey, Scientific Investigations Report 2005-5160. 2005:122–133.
17. Local weather forecast, news and conditions. Weather Underground. n.d.
18. Weitkamp DE, Katz M. A review of dissolved gas supersaturation literature. *Transactions of the American Fisheries Society.* 1980;109(6):659–702.
19. Dawson VK, Marking LL. An integrated system for treating nitrogen supersaturated water. *Prog Fish-Cult*. 1986;48:281–284.

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20. Rucker RR, Kangas PM. Effect of nitrogen supersaturated water on Coho and Chinook salmon. *Prog Fish-Cult*. 1974;36:152–156.

21. Ott BD, Torrans EL, Allen PJ. Design of a vacuum degassing apparatus to reduce nitrogen supersaturation and maintain hypoxia in well water. *N Am J Aquac*. 2022;84:480–485.

22. Densmore JN, Böhlke JK. Use of nitrogen isotopes to determine sources of nitrate contamination in two desert basins in California. *USGS Publications Warehouse*. 1999;260:63–73.

23. Wan J, Tokunaga TK, Brown W, et al. Bedrock weathering contribute to subsurface reactive nitrogen and nitrous oxide emissions. *Nat Geosci*. 2021;14:217–224.

24. Bateman AS, Kelly SD. Fertilizer nitrogen isotope signatures. *Isot Environ Health Stud*. 2007;43:237–247.

25. Heffernan JB, Albertinm AR, Fork ML, et al. Denitrification and interference of nitrogen sources in the karstic Floridan aquifer. *Biogeosciences*. 2012;9:1671–1690.

26. Albertin AR, Sickman JO, Pinowska A, et al. Identification of nitrogen sources and transformations withing karst springs using isotope trackers of nitrogen. *Biochemistry*. 2012;108:219–232.

27. Eller KT, Katz BG. Nitrogen source inventory and loading tool: an integrated approach toward restoration of water-quality impaired karst springs. *J Environ Manage*. 2017;196:702–709.

28. Vassilis AZ, Gianniou SK. Simulation of water temperature and dissolved oxygen distribution in Lake Vegoritis, Greece. *Ecol Model.* 2003;160:39–53.

29. Marcy SM, Suter G II, Cormier S. Dissolved oxygen. Environmental Protection Agency. 2024.

30. Pitkänen P, Partamies S. Origin and implications of dissolved gases in groundwater at Olkiluoto. Posiva Oy. 2007.

31. Mahler BJ, Bourgeais R. Dissolved oxygen fluctuations in karst spring flow and implications for endemic species: Barton Springs, Edwards Aquifer, Texas, USA. *J Hydrol*. 2013;505:291–298.

32. Koit O, Retike I, Bikse J, et al. Hydrochemical signatures of springs for conceptual model development to support monitoring of transboundary aquifers. *Groundwater Sust Dev*. 2023;21.

33. Mahler BJ, Lynch FL. Muddy waters: temporal variation in sediment discharging from a karst spring. *J Hydrol*. 1999;214:165–178.

34. Bakalowicz M. Karst groundwater: a challenge for new resources. *Hydrol J*. 2005:13:148–160.

35. Wold E. Surface agitators as a means to reduce nitrogen gas in hatchery water supply. *Prog Fish-Cult*. 1973;35:143–146.

36. Surbeck H. Dissolved gas as natural tracers in karst hydrology; radon and beyond. Center of Hydrology (CHYN), University of Neuchâtel, Neuchâtel. 2007.

Citation: Wagner A, Roduner K, Tuttle M, et al. Yearly fluctuations in gas saturation in a karst spring at a fish hatchery. *Int J Hydro.* 2025;9(3):112–115.
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