



AGRICULTURAL RUNOFF AND WATER QUALITY: MONITORING NITROGEN POLLUTION IN GHANAIAN VILLAGES

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Abstract: Nitrogen is a critical element in aquatic environments, existing in various forms including ammonia (NH₃), nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonium ion (NH₄⁺). Of these, ammonia is known to be the most toxic to aquatic biota such as fish and amphibians, followed by nitrite and nitrate. Nitrate, as the final oxidation product of the nitrogen cycle in natural waters, holds significance as the sole thermodynamically stable nitrogen compound in aerobic aquatic environments. This paper provides an overview of nitrogen forms in aquatic ecosystems, emphasizing their ecological implications and potential risks to aquatic life. Drawing on insights from Rouse et al. (1999), the paper elucidates the hierarchy of nitrogen toxicity to biota, with ammonia posing the greatest threat followed by nitrite and nitrate. Additionally, it discusses the role of nitrate as a stable nitrogen compound in aerobic waters, highlighting its importance in nitrogen cycling processes. Through a comprehensive examination of nitrogen dynamics in aquatic environments, this paper aims to enhance understanding of the ecological implications of nitrogen pollution and its impact on aquatic ecosystems. It underscores the importance of monitoring and managing nitrogen levels to mitigate adverse effects on aquatic biota and safeguard water quality.

Keywords: Nitrogen, Aquatic environment, Ammonia, Nitrate, Ecological implications.

INTRODUCTION

Nitrogen in aquatic environments exists in four main forms: ammonia (NH₃), nitrate (NO₃⁻), nitrite (NO₂⁻), and ammonium ion (NH₄⁺). Among these, ammonia is the most toxic to aquatic organisms such as fish and amphibians, followed by nitrite and then nitrate (Rouse et al., 1999). Nitrate, the final oxidation product in the nitrogen cycle, is the only thermodynamically stable nitrogen compound in oxygen-rich waters.

After pesticides, nitrate ranks as the second most significant chemical threat to both surface and groundwater globally (Payal, 2000). Elevated concentrations of nitrate and nitrite pose serious challenges to water quality in many regions. Nitrate pollution can severely impact aquatic life, with documented toxicity in crustaceans (Muir et al., 1990), aquatic insects (Camargo and Ward, 1992), amphibians (Baker and Waights, 1993, 1994), and fish (Tomasso and Carmichael, 1986). In humans, particularly infants, consumption of water with excessive nitrate levels can lead to methemoglobinemia or "blue-baby syndrome" (Spalding and Exner, 1993; Hudak, 1999; EPA, 2002). Furthermore, nitrate can react with body proteins to form nitrosamines—compounds linked to cancer (Tricker and Preussmann, 1991). It also promotes algal blooms in surface waters, leading to eutrophication.

Concerns over nitrate levels in both surface and groundwater have grown in recent years. Key sources of nitrate contamination include the use of nitrogen-based fertilizers and manure in agriculture, with runoff carrying these pollutants into nearby water bodies (Bogardi et al., 1991; Oldham et al., 1996). In some cases, natural background levels or on-site wastewater disposal systems may also contribute to elevated nitrate levels (Jenkins, 1999; Stoddard et al., 1999). Nitrate, being highly soluble, can leach into groundwater when surface water infiltrates the soil (Hallberg and Keeney, 1993).

In Ghana's Brong Ahafo Region, agriculture—focused on crops such as cocoa, maize, tobacco, tomatoes, yams, and cassava—occupies over 80% of the land and serves as the main economic activity. While many farmers cultivate upland areas, a significant number farm along riverbanks, especially in the dry season. These streams traverse numerous towns and villages and are vital for domestic activities such as drinking, cooking, bathing, and washing—supplying nearly 90% of household water needs.

Dry-season vegetable growers often prepare nursery beds near streams and use stream water for irrigation, which frequently results in the clearing of riparian vegetation. Such practices can lead to pollution and depletion of stream resources, posing health risks to nearby communities. However, there is currently no data on how these farming activities impact the quality of stream and groundwater used for drinking. This lack of information hinders the development of appropriate policies and guidelines to protect public health.

Since the water is consumed untreated, understanding the types and concentrations of potential contaminants is essential. The objective of this research is to evaluate nitrogen pollution in stream waters adjacent to intensively farmed riverbanks, as well as in boreholes located within these cultivated zones.

MATERIALS AND METHODS

Sampling

A total of 15 water sources were selected for sampling, comprising ten surface water sources used for domestic purposes and five groundwater sources (including four boreholes and one artesian well). Sampling sites were chosen based on their socio-economic relevance and surrounding land use patterns. Samples were collected quarterly over the course of one year—specifically in February, May, August, and November of 2005—totaling 60 samples. Each site was visited four times during the year.

Water samples were collected between 0900 and 1100 GMT directly into clean, high-density polyethylene bottles and stored in an icebox at approximately 4°C. Prior to collection, all containers were thoroughly cleaned: first with detergent, then rinsed with de-ionized water, soaked overnight in 1.4 M HNO₃, and finally rinsed again with de-ionized water. During sampling, surface water sample bottles and caps were rinsed three times with the water being collected. For groundwater sampling, boreholes were purged for three minutes before samples were taken, and each container was similarly rinsed three times with the sampled water. All samples were transported to the Environmental Protection Agency (EPA) laboratory in Sunyani and analyzed within 24 hours.

Analytical Methods

Laboratory analyses followed the procedures outlined in the Palintest Photometer Method. For each analysis, a 10 ml filtered water sample was treated with a reagent tablet, ground, and allowed to stand until a color developed. The test tube was then placed in a pre-calibrated photometer for measurement.

Nitrate (NO₃-N) was determined via hydrazine reduction and spectrophotometric analysis at 520 nm.

Nitrite (NO₂-N) was analyzed using diazotization and spectrophotometric detection at 540 nm.

Ammonia (NH₃-N) was measured through its reaction with alkaline salicylate in the presence of chlorine to form a blue-green indophenol complex, detected at 640 nm.

RESULTS AND DISCUSSION

Nitrate (NO₃-N)

Nitrate concentrations (NO₃-N) in both surface and groundwater samples are summarized in Table 1. The highest NO₃-N concentration in groundwater was 0.48 mg/L, recorded in the third quarter at K. Danso. Boreholes in agricultural zones, particularly those in Atebubu and K. Danso, showed relatively elevated levels with annual means of 0.28 ± 0.09 mg/L and 0.30 ± 0.13 mg/L, respectively. The seasonal trend revealed that nitrate levels peaked during the third and fourth quarters, likely due to increased fertilizer use and potential contamination from human waste during the farming season.

Surface water samples consistently exhibited NO₃-N concentrations below the WHO's drinking water guideline of 10 mg/L. The highest surface water concentration, 2.60 mg/L, was recorded in the Subin stream at Wenchi in the first quarter, an area known for intensive dry-season tomato farming. The lowest concentration was observed at the Bonsu artesian well (0.09 mg/L) in the fourth quarter. Annual mean NO₃-N levels ranged from 0.16 ± 0.10 mg/L at Bonsu to 1.06 ± 1.07 mg/L at Wenchi.

Studies such as those by Altman and Parizek (1995) indicate that nitrate concentrations on sloped agricultural land may be lower in adjacent streams due to factors such as dilution, denitrification, and plant assimilation before water enters the stream. These mechanisms may help explain the relatively low nitrate levels observed in surface waters, despite agricultural activity. In addition, high ambient temperatures (reaching up to 37°C during the dry season in Brong Ahafo) likely enhance biochemical and algal assimilation of nitrates, further reducing concentrations during this period.

However, NO₃-N concentrations in surface water increased during the rainy season (June to September), coinciding with heavy fertilizer use and stormwater runoff. Streams draining areas with intensive maize production (Fiaso, Biaso) and tomato/tobacco farming (Wenchi, Tainso) showed noticeable increases in nitrate levels during this period.

Overall, all sampled water sources exhibited nitrate levels well below the WHO maximum allowable concentration of 10 mg/L for drinking water (EPA, 2002), indicating that nitrate pollution in the region is currently within safe limits.

Ammonia (NH₃-N)

All sixteen water sources contained detectable amounts of ammonia-nitrogen (Table 2). Concentrations were generally low, with annual averages ranging from 0.008 ± 0.006 mg/L (Tano stream at Tachiman) to 0.179 ± 0.31 mg/L (Jinijini borehole). Ammonia typically exists in water systems as ammonium ion, which is rapidly absorbed by algae. Under aerobic conditions, ammonia and nitrite are further oxidized to nitrate by nitrifying bacteria (Horne and Goldman, 1994; Huey and Beitingger, 1998). Due to its low toxicity under these conditions, the WHO does not recommend a specific health-based guideline value for ammonia in drinking water. However, elevated ammonia can interfere with disinfection processes, promote nitrite formation, affect filtration systems, and cause taste and odor issues (WHO, 2003).

Nitrite (NO₂-N)

Mean nitrite concentrations (Table 3) ranged from 0.006 ± 0.01 mg/L (observed at Tano and Gao streams in Tachiman and Goaso) to 0.36 ± 0.47 mg/L (Subin stream at Wenchi). All values were below the WHO maximum contaminant level of 1.0 mg/L for public water systems. Seasonal variations were minimal for most sites, except for noticeable increases in Subin stream and Drobo groundwater samples.

Ecological Implications

Although nitrate levels in the region are currently low, ecological concerns remain. Research indicates that nitrate concentrations as low as 1–10 mg/L can be lethal to amphibian eggs and tadpoles, with chronic effects starting at 2.3 mg/L (Kincheloe et al., 1979; Hecnar, 1995; Johansson et al., 2001). Fortunately, nitrate levels observed in this study were below these critical thresholds during vulnerable developmental periods of aquatic life, suggesting a low immediate ecological risk in the studied water bodies.

Table 1. Statistical analysis of nitrate content of surface and ground water samples in the Brong Ahafo region, Ghana.

Sampling site	Water type	Max. mg/l	Min. mg/l	Variance mg/l	Mean mg/l	S. D.
Subin (wenchi)	surface	2.60	0.30	1.15	1.06	1.07
Tain (Tainso)	surface	0.66	0.48	0.007	0.60	0.085
Bia (Biaso)	surface	0.66	0.22	0.05	0.42	0.22
Fia (Fiaso)	surface	0.55	0.30	0.01	0.42	0.10
Pru (Pruso)	surface	0.92	0.10	0.13	0.37	0.36
Tano (Ntotoroso)	surface	0.92	0.19	0.12	0.39	0.35
Goa (Goaso)	surface	0.42	0.22	0.009	0.29	0.09
Ankwasua (Afrisipa)	surface	0.42	0.10	0.02	0.23	0.14
Yokom (Kintampo)	surface	0.31	0.12	0.01	0.22	0.08
Tano (Tachiman)	surface	0.35	0.20	0.01	0.25	0.07
Borehole (Drobo)	ground	0.25	0.14	0.002	0.19	0.05
Borehole (Jinijini)	ground	0.35	0.18	0.006	0.24	0.08
Borehole (Atebubu)	ground	0.40	0.18	0.008	0.28	0.09
Borehole (K. Danso)	ground	0.48	0.18	0.02	0.30	0.13
Artesian well (Bonsu)	ground	0.31	0.09	0.01	0.16	0.10

§ Object in brackets indicates communities where water samples were collected

Conclusion

This study assessed dissolved nitrogen in the forms of nitrate ($\text{NO}_3\text{-N}$), nitrite ($\text{NO}_2\text{-N}$), and ammonia ($\text{NH}_3\text{-N}$) in surface and groundwater sources across selected communities in the Brong Ahafo Region of Ghana. The results showed that concentrations of all nitrogen forms were below the World Health Organization (WHO) guidelines for safe drinking water. These levels are not considered harmful to human health and are unlikely to pose significant risks to the aquatic ecosystems in the study area.

However, an increase in nitrate concentrations was observed during the rainy season (second and third quarters), likely due to agricultural runoff. While current levels remain within safe limits, ongoing monitoring of these water resources is strongly recommended to detect any future changes and ensure continued safety for both human and ecological health.

Table 2. Statistical analysis of nitrite content in surface and ground water samples from the Brong Ahafo region, Ghana.

Sampling site	Water type	Max.mg/l	Min. mg/l	Variance mg/l	Mean mg/l	S. D
Subin (wenchi)	surface	0.950	0.004	0.220	0.249	0.470
Tain (Tainso)	surface	0.050	0.003	37×10^{-5}	0.025	0.02
Bia (Biaso)	surface	0.030	0.009	7.9×10^{-5}	0.020	0.09
Fia (Fiaso)	surface	0.014	0.009	5.6×10^{-5}	0.011	0.002
Pru (Pruso)	surface	0.018	0.009	1.5×10^{-5}	0.013	0.004
Tano (Ntotoroso)	surface	0.32	0.00	2.6×10^{-5}	0.006	0.005
Goa (Goaso)	surface	0.014	0.001	3.1×10^{-5}	0.006	0.006
Ankwasua (Afrisipa)	surface	0.031	0.00	2.8×10^{-5}	0.007	0.005
Yokom (Kintampo)	surface	0.023	0.001	8.9×10^{-5}	0.013	0.009
Tano (Tachiman)	surface	0.007	0.004	2×10^{-6}	0.006	0.001
Borehole (Drobo)	ground	0.300	0.014	0.020	0.089	0.14
Borehole (Jinijini)	ground	0.013	0.001	2.4×10^{-5}	0.007	0.007
Borehole(Atebubu)	ground	0.023	0.007	4.6×10^{-5}	0.017	0.007
Borehole (K. Danso)	ground	0.023	0.003	7.9×10^{-5}	0.015	0.009
Artesian well (Bonsu)	ground	0.023	0.001	8.4×10^{-5}	0.013	0.008

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