

Health concerns associated with nitrates in drinking water

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1. Introduction

Nitrate (NO_3^-) is a naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in the environment. Nitrate is formed from fertilizers, decaying plants, manure and other organic residues. It is found in the air, soil, water and food (particularly in vegetables) and is produced naturally within the human body. Due to the increased use of synthetic nitrogen fertilizers and livestock manure in intensive agriculture, nitrate contamination in vegetables and drinking water is now widespread.

The contamination of water with nitrates associated with fertilizer use has human health risks related mainly to three processes (for a more detailed review, see (Townsend et al. 2003):

1. Drinking water or eating food contaminated with nitrates.
2. Changes in the dynamics of some human diseases (like malaria).
3. Harmful algal blooms in rivers, lakes or coastal areas, which can produce poisonous toxins and affect humans.

People ingest nitrate (NO_3^-) via drinking water and from various dietary sources including many vegetables (spinach is one of the largest accumulators of nitrate) and processed meats. It is not nitrate per se that is a health concern, but rather nitrite and N-nitroso compounds; these compounds appear after a metabolic reaction of nitrate in the human body.

The three main sources of nitrate intakes are vegetables, water and cured meat. Vegetables constitute the major dietary source of nitrate; lettuce, spinach and rocket are among the vegetables with highest concentration of nitrates.

The World Health Organization (WHO) and the European Commission have set an Acceptable Daily Intake (ADI) for nitrate (NO_3^-) of 0–3.7mg per kg of bodyweight. Compared with the current ADI, the ingestion of only 100 g of raw vegetables with a nitrate concentration of 2500 mg kg^{-1} will already lead to an intake of 250 mg NO_3^- . Consuming this item alone, for a person of 60 kg, would exceed the ADI for nitrate by 13%. The EU limits for NO_3^- in spinach and lettuce range between 3000 and 2000 mg kg^{-1} . In China, a maximum level of nitrate in leafy vegetables of 3000 mg kg^{-1} has been established. The European Commission established in 2004 the maximum permitted level for nitrate in baby foods and processed cereal-based foods for infants and young children of 200 mg kg^{-1} on an 'as sold' basis. (Santamaria 2006)

In order to gain as much as possible from the indisputable benefits of vegetables, a reduction in nitrate levels is highly desirable for consumers and probably profitable for farmers (Santamaria 2006).

Nitrates in drinking water in agriculture areas and vegetables come mainly from nitrogen fertilizers applied to farm soils (Galloway et al. 2003). Plants need nitrogen to grow. Farmers apply nitrogen fertilizers (like urea) to increase plant yield, but too often fertilizers are applied in excess quantities and in inefficient ways. As a result of this inefficiency, a large part of the nitrogen applied to soils is not taken up by the plant and end up in the soil, from where it moves to the atmosphere and to water bodies (groundwater, lakes, river, and coastal areas) where it contaminates drinking water and the environment (Galloway et al. 2003).

Nitrogen is the most abundant chemical element of the Earth's atmosphere (almost 80%), and it is also an essential component of the biological structures (proteins, enzymes, etc). The bulk of the atmosphere is nitrogen gas (N_2), but this form of nitrogen cannot be used directly by most living organisms. However, humans have found ways to "fix" this nitrogen into forms that living organisms can use. Humans are now dramatically increasing nitrogen fixation, mainly by fertilizer production, fossil fuel combustion, and the widespread cultivation of N_2 -fixing crop species (like legumes).

Nitrogen fixation induced by humans has lead to a global increase in nitrogen forms that are used by living organisms and readily move among land, oceans and atmosphere. This is changing the chemical and physical composition of the Earth, and it will have unpredictable and dramatic consequences for climate, biodiversity and human health (Townsend et al. 2003).

2. Human health risks associated with nitrate pollution

2.1 Drinking water or eating food contaminated with nitrates

Groundwater nitrate contamination is common in areas where farmers use large quantities of nitrogen fertilizers (Townsend et al. 2003, Shindo et al. 2006, Wang et al. 2006).

Leafy green vegetables and some root crops assimilate nitrate naturally. Fertilizer applied in excess may result in the accumulation of large amount of nitrate in some vegetables. Eating these vegetables contribute to the daily ingest of nitrate as well as drinking water contaminated with nitrates.

The World Health Organization (WHO) has established a nitrate maximum standard for safe drinking water of 50 mg/l NO_3^- (equals to 10 mg/l NO_3^- as N, or 10 ppm NO_3^- as N), but worldwide this standard is often exceeded. Groundwater nitrate contamination associated with fertilizer use is common in both developed and developing regions (Townsend et al. 2003).

The potential health effects of drinking water or eating food contaminated with nitrate are diverse, the most significant are blue-baby syndrome (methemoglobinemia) and cancer. Babies and infants living around agricultural areas and who are fed water from wells are the most vulnerable to health risks from nitrates. Additionally, anyone drinking from a contaminated well

or eating vegetables with high levels of nitrate could be vulnerable to the long term effects of nitrates, like various types cancer (Ward et al. 2005).

2.1.1 Blue-baby syndrome

The greatest risk of nitrate poisoning (methemoglobinemia) occurs in infants fed well water contaminated with nitrates, and affects particularly babies under 4 months of age (Greer et al. 2005).

Blue-baby syndrome (or methemoglobinemia) occurs when the hemoglobin in the blood loses its capacity to carry oxygen, and this can ultimately cause asphyxia and death. This occurs because nitrites (resulting from the reduction of the nitrate in the anaerobic conditions of the digestive tract) blocks hemoglobin in the blood (Greer et al. 2005). Blue-baby syndrome can, in turn, provoke cyanosis, headache, stupor, fatigue, tachycardia, coma, convulsions, asphyxia and ultimately death. (Greer et al. 2005, Camargo and Alonso 2006).

Since 1945 more than 3000 cases of blue-baby syndrome have been reported worldwide, most of which were associated with private wells in farming areas with high nitrate concentrations (concentrations > 50 mg/l NO₃⁻). Some health professionals believe that the blue-baby syndrome is often under- or misdiagnosed (Townsend et al. 2003).

2.1.2 Cancer

Drinking water or eating food contaminated with nitrates has a potential role in developing cancers of the digestive tract, and has also been associated with other types of cancer (non-Hodgkin's lymphoma and bladder and ovarian cancers) (Townsend et al. 2003, Ward et al. 2005).

The link between nitrates and cancer comes from the contribution of nitrates to the bacterial formation of N-nitroso compounds (like nitrosamines) in the digestive tract, particularly in the stomach. These nitrosamines are among the most potent of the known carcinogens in mammals. (Ward et al. 2005, Camargo and Alonso 2006)

Some studies have shown that long-term consumption of drinking water with nitrate concentrations even below the maximum safety level of 50 mg/l NO₃⁻ may stimulate the formation of these nitrate-related carcinogens (nitrosamines) in the digestive system (Ward et al. 2005).

Other types of cancer have been also linked with cases of long-term consumption of drinking water with nitrate concentrations even below the maximum contaminant level, like non-Hodgkin's lymphoma and bladder and ovarian cancers (Ward et al. 2005). For example, in Iowa (USA) levels of nitrate in drinking water below the recommended WHO concentration standard have been linked with an increased risk of bladder and ovarian cancers in women drinking water from municipal and private farm wells (Weyer et al. 2001).

A recent study in Taiwan showed that drinking water with high levels of nitrates was associated with increase risk of bladder cancer (Chiu and Tsai 2007).

2.2. Changes in the dynamics of some human diseases

Indirect ecological feedbacks caused by fertilizer use can affect health in numerous ways. Feedbacks include changes in the dynamics of some human diseases. Some evidence suggests, for example, that increases in abundance of malarial *Anopheles* mosquitoes are related to increased concentration of inorganic nitrogen in surface water (Teng et al. 1998). The same trend has been shown for other important vectors, like those of the West Nile virus or Japanese encephalitis, which increase in abundance with increasing fertilizer use in rice fields (Sunish and Reuben 2001).

2.3. Harmful algal blooms

One common and well-documented effect of intensive fertilizer use is the eutrophication of coastal and marine ecosystems (Beman et al. 2005). This can lead to ecological changes with impacts on human health. One of the consequences of eutrophication is the worldwide increase in harmful algal blooms (Townsend et al. 2003).

Algal blooms can lead to the proliferation of algal species that produce toxins. When the algae are ingested by shellfish this can result in neurological, amnesic, paralytic, and/or diarrhetic shellfish poisoning in human consumers.

Blooms of toxic dinoflagellates in estuaries and coastal waters, leading to several poisoning syndromes following consumption of contaminated seafood or after water or aerosol exposure, have been reported from Australia, Europe, Japan, North America, Southeast Asia and other parts of the world. The paralytic shellfish poisoning (PSP) and the neurotoxic shellfish poisoning (NSP) are syndromes often associated with red tides: PSP is caused by the consumption of molluscan shellfish contaminated with saxitoxins. On a global basis, more than 2000 cases of human intoxications by PSP and NSP are reported per year, for PSP some intoxications have been fatal. (Camargo and Alonso 2006)

In general, it is thought that increasing nutrient availability as a result of intense fertilizer use may favour opportunistic, disease-causing organisms (Townsend et al. 2003). Evidence suggests that increasing N availability often causes overall declines in species diversity (Tilman 1987; Aerts and Berendse 1988). In turn, reductions in diversity can increase the transmission of vector-borne diseases (Ostfeld and Keesing 2000).

Human sickness and death, resulting directly (e.g., ingested nitrates and nitrites from polluted drinking water) or indirectly (e.g., aerosol exposure to algal toxins, consumption of contaminated seafood causing poisoning syndromes) from inorganic nitrogen pollution, can have elevated economic costs because of lost wages and work days, and because of medical treatment and investigation. For example, the annual average estimate of the public health costs of illnesses due to shellfish poisoning in USA could range from \$400 thousand to \$2 million. (Camargo and Alonso 2006)

3. References

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