Nitrates in drinking water in the Philippines and Thailand

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Executive Summary

Today, over 1.1 billion people worldwide lack access to safe drinking water. In Asia alone, inadequate water supply and poor sanitation cause more than 500,000 infant deaths a year. Intensive agricultural practices present a direct threat to the world's clean water supply.

Excess application of nitrogen fertilizers in intensive crop production is leading to nitrate pollution of the artesian wells that people use for drinking water. Away from agricultural areas, nitrogen loading also leads to toxic algal blooms and loss of coral and fish species in aquatic ecosystems. Drinking water with high levels of nitrate can cause serious health problems, especially for children.

Nitrogen fertilizer consumption in Asia has grown dramatically, increasing approximately 17-fold in the last 40 years. Fertilizer application rates are increasing rapidly in some developing countries, reaching excess amounts that the crops cannot use but cause problems for human health and the environment. In Thailand, for example, in asparagus fields in Nakhon Pathom province the application rates of nitrogen fertilizers reach 1000 kg N ha^{-1} $year^{-1}$. Shockingly, the crop recovers only 5% of this nitrogen and the rest is lost to the soil, water or air.

We investigated the nitrate levels in drinking water and their relation with nitrogen fertilizer use in several farming areas in the Philippines and Thailand. We surveyed some examples of crops and farming practices in different regions and tested nitrate levels in water from wells and streams around farms.

Drinking water from artesian wells in agricultural areas in the Philippines and Thailand shows evidence of pollution with nitrates, and this pollution correlates with intensive farming practices where nitrogen fertilisers are applied in excess.

Drinking water from 30% of all groundwater wells sampled in both countries showed nitrates levels above the World Heath Organization safety limit of 50 mg l^{-1} of nitrate (NO_3^-). This nitrate pollution was highest in the most intensive crops, with nitrate levels 3 times the WHO safety limit (>150 mg l^{-1}) in asparagus farms in Kanchanaburi, Thailand. Groundwater wells in vegetable farming areas in Benguet, the 'salad bowl' of the Philippines, were also polluted with nitrates levels above WHO limits.

As confirmed by our results, groundwater nitrate contamination is common in areas where farmers use large quantities of nitrogen fertilizers. Babies and infants living around agricultural areas and who drink water from wells are the most vulnerable to health risks from nitrates. Additionally, anyone drinking from a contaminated well could be vulnerable to the long-term effects of nitrates, such as various types of cancer.

Some of the excess nitrogen applied to soils is transformed to the gas nitrous oxide. Nitrous oxide is an important greenhouse gas with 296 times the global warming potential of CO_2. Besides the effect of fertilizers applied to soils in nitrous oxide emissions, synthetic fertilizers are also an important source of CO_2 emissions. Fertilizer production is a very energy intensive process and emits up to 1.2% of all global greenhouse emissions.

Greenpeace believes it is possible to produce food and at the same time keep both a healthy livelihood and environment. There are many examples, especially in developing countries, where farmers maintain high yields from their land in biologically and biodiversity-based systems that ensure both a healthy livelihood and environment.

Greenpeace demands clean and safe drinking water for all. The dangerous practice of over-using fertilizers in intensive agriculture is a serious threat to human health and the environment and must be stopped. Governments should phase out subsidies for fertilizers and implement fertilizer reduction policies to reduce nitrogen losses. Experiences in other countries show that fertilizer reduction policies significantly contribute to a cleaner and safer drinking water supply.

Introduction

Today, over 1.1 billion people worldwide lack access to safe drinking water (Prasad 2006). In Asia alone, inadequate water supply and poor sanitation cause more than 500,000 infant deaths a year (UNEP 2002). Intensive agricultural practices present a direct threat to the world's clean water supply. Water quality around agricultural areas is decreasing, primarily due the leaching of fertilizers and pesticides (Scanlon et al. 2007). Nitrogen loading from intensive crop production is leading to toxic algal blooms and loss of coral and fish species in aquatic ecosystems. Nitrogen lost from farm soils also accumulates in groundwater and pollutes the artesian wells that people use for drinking water. Drinking water with high levels of nitrate can cause serious health problems, especially for children (Camargo and Alonso 2006). In the past 40 years, there has been a 700% increase in global fertilizer use, and this is one of the main drivers of water degradation (Foley et al. 2005).

As nitrogen application rates increase, so do nitrogen losses to the environment. In intensive agriculture, half (or more) of the fertilizer applied to the soil generally does not stay on the soil to help crops grow, but rather is lost via water and air to adjacent ecosystems where it can fundamentally change the way those ecosystems function. Worldwide it is estimated that cereal production only uses 33% of the nitrogen applied as fertilizer. The remaining 67% represents a $15.9 billion annual loss of nitrogen fertilizer that escapes into the environment through surface runoff, volatilization, leaching, plant emissions and soil denitrification (Raun and Johnson 1999).

Nitrogen fertilizer consumption in Asia has grown dramatically, increasing approximately 17-fold in the last 40 years (Dobermann and Cassman 2004). Average fertilizer application rates in the Philippines and Thailand are relatively low compared to more industrialized countries (in 2005: the Philippines 70 kg ha^{-1}, Thailand 101 kg ha^{-1}, USA 113 kg ha^{-1}, China 321 kg ha^{-1}, the Netherlands 382 kg ha^{-1} -source FAO STAT). However, averages can be misleading since application rates vary very much among regions, crops, and farming practices, and rates are increasing rapidly in some developing countries. In China for example, in some intensive vegetable growing areas fertilizer application rates exceed 1000 kg of N ha^{-1}; rates reach 2000 kg ha^{-1} for flowers (Zhang et al 2004). It is usually believed that fertiliser use is low in the Philippines and Thailand, as represented by average estimates, but there is some evidence of increased consumption of fertilizers in highly intensified farming systems. In asparagus fields in Nakhon Pathom province, Thailand, farmers apply nitrogen fertilizers in rates close to 1000 kg N ha^{-1} $year^{-1}$. Shockingly, only 5% of this nitrogen is recovered by the plant, the rest being lost to the soil, water or air (Phupaibul et al. 2004).

As an initial study on the current status of the effect of agricultural practices in water quality in the Philippines and Thailand, we investigated the nitrate levels in drinking water in several farming areas in these countries. We surveyed some examples of crops and farming practices in different regions in the Philippines and Thailand, and tested nitrate levels in water from wells and streams around farms.

Sampling design and methods

A total of 49 groundwater samples and 14 surface water samples from different agricultural regions in the Philippines (Northern and Central Luzon) and Thailand (Northwest and Central Plain) were tested.

Sampling locations in the Philippines

We selected two agricultural regions in the island of Luzón in the Philippines, Benguet and Bulacán provinces, to use as case studies of the effect of agricultural practices on water pollution with nitrates.

We selected one sampling area in the Benguet province (Northern Luzon), where vegetables for the Metro Manila markets are produced. The Benguet province is in the Cordillera Administrative Region, and it includes an extensive area of upland mountain terraces dedicated to commercial vegetable farming. Much of Benguet, which has come to be known as the "salad bowl" of the Philippines, is now given over to intensive cultivation of vegetables (Peterson 1994).

In Benguet province we selected two municipalities, Atok and Buguias, where the main land use is vegetable farming, and a third municipality, La Trinidad, which is mostly urban residential and densely populated (Table 1). In the municipalities of Atok and Buguias vegetable farming is the main land use and also the main economic activity of the local population. Vegetable production is used both for self-subsistence and income generation. The main crops grown in these two municipalities are cabbage, carrot, potatoes, and celery.

Table 1. Sampling locations for water sources in agricultural areas in North and Central Luzon, the Philippines.

				Groundwater				Surface water		
Region	**District town**	**Land use[1]**	**Coordinates**	**Well depth[2] (m)**	**n[3]**	**pH[4]**	**EC (mS)[4]**	**n[3]**	**pH[4]**	**EC (mS)[4]**
Benguet	Atok	Farming (vegetables)	N16°37' E120°46'	24	3	6.15 ± 0.26	0.08 ± 0.03	3	6.44 ± 0.21	0.10 ± 0.02
Benguet	Buguias	Farming (vegetables)	N16°47' E120°49'	6	7	6.23 ± 0.05	0.24 ± 0.03	5	7.72 ± 0.18	0.11 ± 0.02
Benguet	La Trinidad	Urban	N16°27' E120°35'	5	4	7.20 ± 0.12	0.48 ± 0.07	1	7.02	0.45
Bulacan	Angat	Farming (rice and mixed)	N14°59' E120°55'	10	4	6.75 ± 0.02	0.93 ± 0.18	-	-	-

[1] The main land use around sampled water sources.
[2] Average depth of the wells sampled in the area.
[3] Number of samples (water sources: artesian wells for groundwater and creeks/rivers for surface water, see more details in Table 3, appended to this paper). Each water source was sampled and tested on the same day, from 26th to 29th of September 2007.
[4] pH and electric conductivity (EC) values are given in mean ± standard errors.

We selected another sampling area in the Bulacan province (Central Luzon). Paddy rice farms dominated this area until recently and now rice fields are intermingled with residential areas and other crop farms. Due to limited time, we only sampled one farming municipality, Angat, in Bulacan province (Table 1).

Sampling locations in Thailand

In Thailand we selected three agricultural provinces to survey the effect of agricultural practices on water pollution with nitrates. The selected provinces were Chiang Mai in the North, and Kanchanaburi and Suphanburi in the Central Plains (

Table 2). Chiang Mai is a mountainous region with important forested areas. Within Chiang Mai we located most of our study sites in the Mae Ai district, where farmers grow highland staple food crops like rice and also cash fruit crops like oranges. The rainfall in the mountains feed important rivers and irrigation canals which provide the water necessary for Chiang Mai's agriculture.

Table 2. Sampling locations for water sources in agricultural areas in the North and Central Plains of Thailand.

			Groundwater				Surface water		
Region	Land use[1]	Coordi-nates	Well depth2 (m)	n[3]	pH[4]	EC (mS)[4]	n[3]	pH[4]	EC (mS)[4]
Chiang Mai	Farming (oranges, rice and vegetables)		4 - 70	10	6.62 ± 0.13	0.32 ± 0.06	5	6.26 ± 0.21	0.10 ± 0.03
Kanchanaburi	Farming (rice, sugarcane and asparagus)		6 - 12	16	7.06 ± 0.07	1.16 ± 0.09	-		
Suphanburi	Farming (rice, sugarcane and maize)		6 - 80	5	6.76 ± 0.06	1.06 ± 0.03	-		

[1] The main land use around sampled water sources.
[2] Range of depths on the wells sampled in the area.
[3] Number of samples (one sample per water sources: artesian wells for groundwater and creeks/rivers for surface water, see more details in Table 3, appended to this paper). Each water source was sampled and tested on the same day, from 1st to 5th of October 2007.
[4] pH and electric conductivity (EC) values are given in mean ± standard errors.

We selected two other provinces in the Central Plain: Kanchanaburi and Suphanburi. The Central Plain is known as the Green Revolution area of Thailand; lowlands are mostly farmed with paddy rice and upper land with maize, sorghum, soybean, cotton, cassava, sugar cane and other vegetable cash crops. In the 1960s the Green Revolution brought to the Central Plains the intensification of farming with high yielding varieties, irrigation, and the heavy use of synthetic fertilizers and pesticides. In the late 1970s a structural shift took place from farm intensification to the industrialization of the agriculture sector. Farm production began to be vertically integrated with factory processing and agribusiness management. Farmers were contracted to produce a specified quality and quantity of output for agro-processing businesses. Farmers were provided with credit, necessary farm inputs, technical advice and even consumption loans for in-between harvest periods. When the produce was harvested, the farmers were obliged to sell at a price earlier agreed, only to the agribusiness company (UNESCAP 2002). This system is sometime referred to as “contract farming”, and it is widespread in areas of the Central Plains. One of our study areas in Kanchanaburi corresponds to this pattern of contract farming were asparagus is grown intensively under contract farming to be exported to Japan.

Sampling and testing methods

In each study area we sampled water from a number of groundwater and surface water sources (Table 3, see appendix); in each study area we selected a number of sampling sites (i.e. farms) and in each of them we collected one water sample (i.e., from wells in farms or households, details in Table 3). Groundwater sources were mostly artesian wells from farms or farmer houses, all had concrete casing for protection from contamination by surface water and were fitted with manually or power operated pumps. We took surface water samples mostly from irrigation tanks or mountain creeks diverted for the town domestic use (see details for each sample in Table 3). Both water sources were usually used for irrigation and in households for domestic uses and drinking. When sampling groundwater we let the water outlet (i.e. hand or electric pump) run for approximately 3 minutes before collecting the sample in a sterile plastic bottle. Measurements of pH and electric conductivity (EC) were taken on site at the time of sampling (Hanna Instruments, UK). Water samples were kept in a cool box until later in the day when chemical testing was carried out. All nitrate testing was done on the same day of sampling, within 6-10 hours of collection. All sampling and testing was carried out between the 26th of September and 5th of October 2007.

Nitrate (NO_3^-) concentration in water samples was tested colorimetrically with the chromotropic acid method (Method 10020, Test ‘N Tube™ Vials, Hach Lange, UK) using a portable spectrophotometer (DR2400, Hach Lange, UK). The value given for each sample is the average of testing 2 or 3 sub-samples.

When possible, we also recorded information about the characteristics of the water sources we sampled (i.e., depth of the artesian well) and about the specific farming practices at each sampling site by interviewing the farmers on site.

Results and Discussion

Drinking water extracted from artesian wells in agricultural areas in the Philippines and Thailand shows evidence of pollution with nitrates, and this pollution correlates with intensive farming practices where nitrogen fertilisers are applied in excess (Table 3, Figures 1, 2 and 3).

Water pollution with nitrates in the Philippines

In the Philippines, the results show examples of groundwater pollution with nitrates in the two provinces we sampled, Benguet and Bulacan, and this pollution seems related to intensive farming areas where nitrogen fertilisers (and other agrochemicals) are applied in excess (Reyes and Laurean 2006, 2007). In 5 out of the 18 artesian wells tested, nitrates levels were above the World Health Organisation (WHO) drinking water safety limit of 50 mg/l NO_3^- (Figure 1); this water pollution could have serious health implications for the local population, especially for children (see below). Surface waters generally showed lower nitrate levels than groundwater sources (Table 3), pointing to the rapid cycling of nitrate in surface waters in tropical climates. For both surface and ground waters, the high input of nitrogen into the aquatic ecosystem could have negative environmental effects on the local and regional level, from eutrophication in lakes to harmful algal blooms in coastal waters (Beman et al. 2005).

In Benguet province we found nitrates levels above the safety limit established by the WHO of 50 mg/l NO_3^- in the farming municipality of Buguias (in 2 out of the 7 groundwater wells we tested, Table 3, Figure 1). In the municipality of Atok, also in Benguet province, we found nitrates levels in groundwater higher than in unpolluted areas (~20.0 vs. 2.3 mg/l NO_3^-, (Bouman et al. 2002)) which suggests pollution from fertilisers, but in concentrations lower than the WHO limits (Table 3, Figure 1). This lower nitrate concentration in artesian wells in Atok could be explained by the deeper wells in this municipality: pollution from the application of nitrogen fertilisers in the soil reach the deeper groundwater at a lower extent than in the shallower groundwater in Buguias. Both the municipalities of Atok and Buguias are clearly centres of intensive vegetable farming, where application of nitrogen fertilizer is very high, and thus this could explain the high nitrate levels in the wells, especially in the shallower ones.

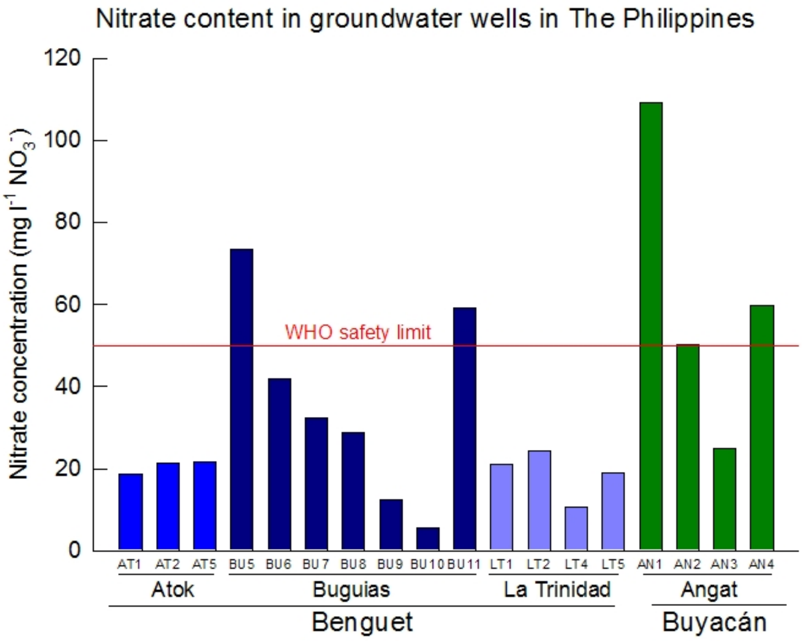

Figure 1. Nitrate concentration in groundwater wells in agricultural areas in the Philippines.

The population density in the mountain areas of Atok and Buguias (the Philippines) is much lower than the population in the other municipality we studied in Benguet province, La Trinidad (where there is not intensive farming). Where population density is high, human sewage is a source of nitrate pollution in the groundwater in places with controlled disposal and where treatment is limited. By comparing Buguias and La Trinidad (where groundwater depth is similar, but land use is different), we can explain the importance of the different factors affecting nitrate pollution. If population density (through human sewage) were the main source of nitrate pollution in the groundwater, we would have found higher pollution with nitrates in the artesian wells in La Trinidad (given other factors as disposal and treatment, aquifer depth, geology, etc., are similar). The lower nitrate levels found in groundwater in La Trinidad (where population density is very high), compared to the high nitrate levels found in Buguias (where highly-fertilised crops are extensively grown but population is low), points to the role of intensive use of nitrogen fertilisers in nitrate pollution. Groundwater wells in Atok are deeper than in Buguias or La Trinidad (24 m vs. 5 m, Table 1), and this may confound their comparison. However, the fact that nitrate values in Atok and La Trinidad are similar also points to the importance of intensive use of nitrogen fertilizers in nitrogen pollution, even in remote sites with low population density.

Water pollution with nitrates in Thailand

In Thailand we found examples of water pollution with nitrates in intensive farming areas in the Central Plain (Kanchanaburi and Suphanburi). In Kanchanaburi, we found a clear example of heavy fertilizer use related to water pollution with nitrates in asparagus farms (Table 3, Figure 2). In 6 out of 11 asparagus farms, nitrates levels in groundwater wells were above the WHO drinking water safety limit of 50 mg/l NO_3^-, and even in the other five wells nitrate levels showed evidence of pollution (Table 3, Figure 2). In Suphanburi, two of the five wells in farms we sampled had nitrates levels higher than the WHO safety limit (Table 3, Figure 2). These high levels of nitrates in drinking water could have serious health effects for the local population, especially for children.

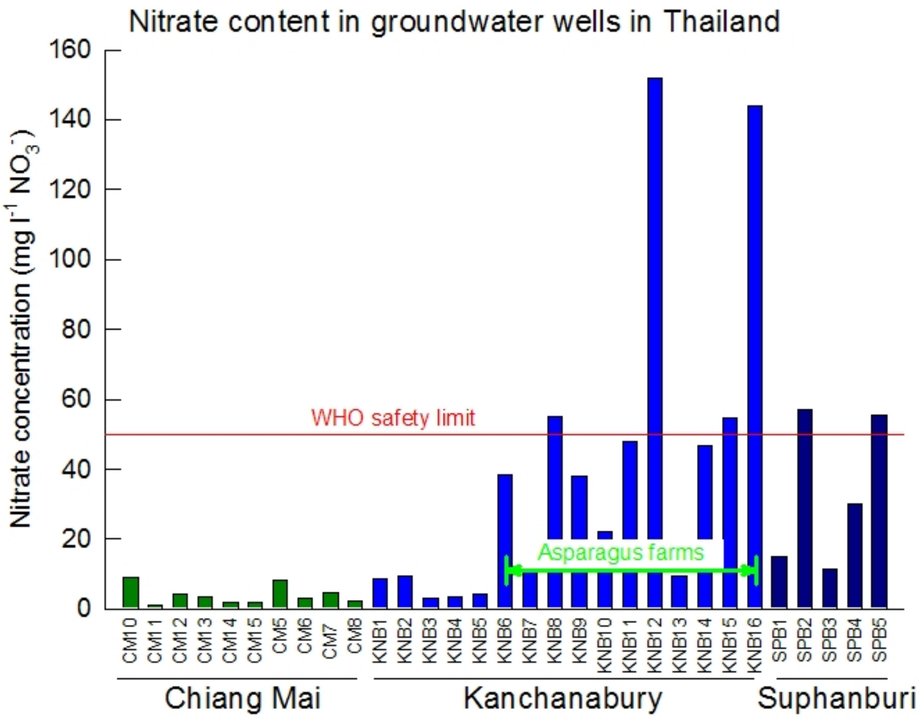

Figure 2. Nitrate concentration in groundwater wells in Thailand.

Asparagus are grown in Kanchanaburi mostly under ‘contract farming’; farmers grow and harvest asparagus spears year-round and they sell the fresh green spears directly to a Japanese agro-business company for export. According to local farmers, asparagus farming is very intensive in the amount of labour, irrigation and agrochemicals it requires. One of the farmers we interviewed said that he needed to irrigate and harvest everyday and apply fertilizers, hormones and pesticides every week.

Groundwater wells in two of these asparagus farms were heavily polluted, with nitrates levels 3 times the safety limit (>150 mg l^{-1}, Figure 2, Table 3). These two farms belong to two brothers who proudly told us they apply the highest rates of fertilizers in the area (around 200 kg urea per rai per month = 7000 kg N ha^{-1} yr^{-1}), about 70 times the recommended application rate of 100 kg N ha^{-1} yr^{-1}. These farmers believe that this ‘excess’ fertilization secures the highest asparagus yield, but many studies worldwide have shown that plants cannot use all that ‘excess’ fertilizer, and often a much smaller fertilization secures a good harvest and at the same time avoids water pollution. For example, researchers in Chile found that a fertilization of 50 kg N ha^{-1} was enough to secure the highest asparagus growth (Krarup et al. 2001).

Although limited in number of samples, our data on the relationship between fertilizer application rate and nitrate pollution in the groundwater show a close correlation pointing to the direct effect of heavy fertilizer use and nitrate pollution (Figure 3).

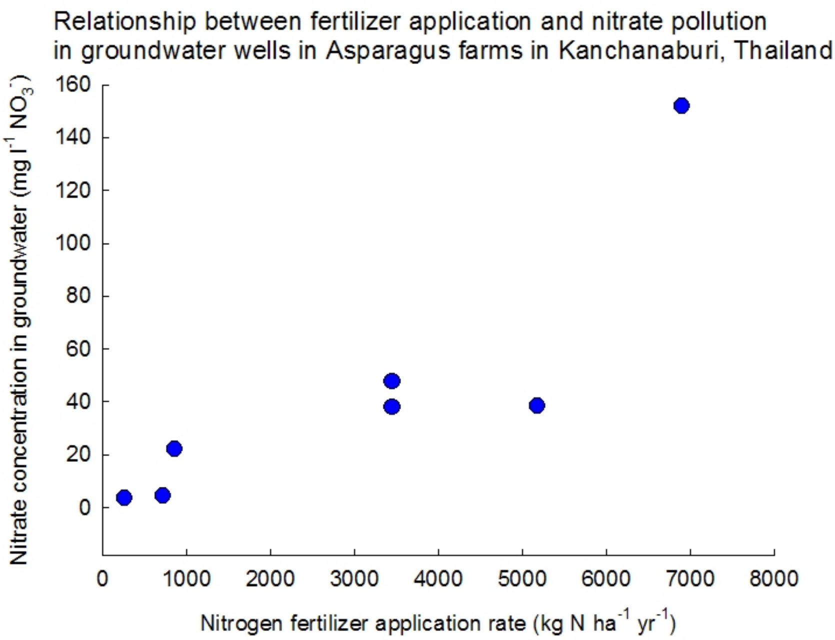

Figure 3. Relationship between fertilizer application rate and nitrate concentration in the groundwater in asparagus farms in Kanchanaburi, Thailand.

Heavy fertilizer use and water pollution with nitrates

It is well known that the excess application of fertiliser on agricultural soils is one of the main sources of nitrogen pollution of water bodies, mostly in the form of nitrate. When farmers apply fertilizer to farms, half (or more) of that fertilizer generally does not stay on the soil to help crops grow, but rather is carried away in water and air. The run-off of fertilizers in water first reaches local wells and creeks, from where it travels to rivers and lakes and ultimately the coast. Nitrogen pollution in water bodies causes eutrophication when too much nitrogen disrupts the aquatic ecosystem and oxygen levels are reduced. This eutrophication leads to the suffocation of fish and invertebrates, the loss of biodiversity, the creation of toxic and overabundant algae blooms.

Farmers apply fertilizers in excess for a number of reasons, such as the perception that it is always better to apply in excess to secure a good harvest, or a lack of expertise about specific crop requirements and efficiency in the timing of application. But in many cases, farmers are not directly responsible for this excess in fertiliser application. Agriculture extension officers from the government institutions, who are responsible for providing technical recommendations to farmers in terms of agrochemicals application rates, etc., are often limited in capacity and do not reach farmers effectively. Throughout developing countries it is common to find that agrochemical dealers (for example in local shops) are in reality acting as agricultural extension officers providing the technical expertise to farmers and recommending the optimal application rates, etc. It has been suggested that the conflict of interest in agro-dealers (in terms of how much to sell and how much to apply) is one of the reason for this massive over-application of fertilizers that it is starting to appear in some developing countries, like China (Zhang et al. 2004), or like the example in Thai asparagus farms.

Human health risks associated with nitrate pollution

As confirmed by our results, groundwater nitrate contamination is common in areas where farmers use large quantities of nitrogen fertilizers (Ward et al. 2005). Babies and infants living around agricultural areas and who are given water from wells are the most vulnerable to health risks from nitrates. Additionally, anyone drinking from a contaminated well could be vulnerable to the long term effects of nitrates, such as various types of cancer (Greer et al. 2005).

The greatest risk of nitrate poisoning is considered to be the *blue baby syndrome* or *methemoglobinemia*, which occurs in infants given nitrate-laden water, and affects particularly babies under 4 months of age (Greer et al. 2005). Blue-baby syndrome occurs when the hemoglobin in the blood losses 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) block hemoglobin in the blood (Townsend et al. 2003). Blue-baby syndrome can provoke cyanosis, headache, stupor, fatigue, tachycardia, coma, convulsions, asphyxia and ultimately death. (Townsend et al. 2003, Ward et al. 2005). 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 NO_3^-). Some health professionals believe that the blue-baby syndrome is often under- or misdiagnosed (Ward et al. 2005, Camargo and Alonso 2006).

Drinking water contaminated with nitrates has a potential role in developing cancers of the digestive tract, and has also been associated with other types of cancer such as non-Hodgkin's lymphoma, bladder and ovarian cancers (Ward et al. 2005). The link between nitrates and cancer is based on 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 (Weyer et al. 2001). Some studies have shown that long-term consumption of drinking water with nitrate concentrations even below the WHO maximum safety level of 50 mg/l NO_3^- may stimulate the formation of these nitrate-related carcinogens (nitrosamines) in the digestive system (Chiu and Tsai 2007). For example, in Iowa (USA) levels of nitrate in drinking water below the recommended WHO levels have been linked with an increased risk of bladder and ovarian cancers in women drinking water from municipal and private farm wells (Beman et al. 2005). A recent study in Taiwan showed that drinking water with high levels of nitrates was associated with increased risk of bladder cancer (Townsend et al. 2003).

One common and well-documented effect of intensive fertilizer use is the eutrophication of coastal and marine ecosystems (Robertson and Swinton 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 (Pretty et al. 2003, Badgley et al. 2007). 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.

Excess nitrogen fertilizer also contributes to climate change

Some of the excess nitrogen applied to soils is transformed to the gas nitrous oxide. Nitrous oxide, also known as laughing gas, is an important greenhouse gas with 296 times the global warming potential of CO_2. Scientists believe that agricultural runoff is a major source of nitrous oxide, and this runoff is related, at least in part, to the amount of nitrogen fertilizer applied to agricultural fields (IPCC 2007).

Besides the effect of fertilizers applied to soils in nitrous oxide emissions, synthetic fertilizers are also an important source of CO_2 emissions. Fertilizer production is a very energy-intensive process and through fossil fuel burning emits up to 1.2% of all global greenhouse emissions.

It is possible to produce food and keep both a healthy livelihood and environment

Farming requires new approaches that integrate people, biodiversity, and environment and are based on agro-ecological principles . There are many examples, especially in developing countries, where farmers maintain high yields from their land in biologically and biodiversity-based systems that ensure both a healthy livelihood and environment .

Greenpeace demands

1. Clean and safe drinking water for all. The dangerous practice of over-using fertilizers in intensive agriculture is a serious threat to human health and the environment and must be stopped.

2. All subsidies on fertilizers – on a national and local level – should be phased out. Public subsidies must not award environmentally and socially destructive practices. Subsidies should be re-oriented towards sustainable farming systems by subsidizing practices that increase soil fertility, water retention, and biodiversity, or that reduce greenhouse gas emissions. Rather than subsidized, fertilizers and pesticides should be taxed to internalize the real costs of chemical-intensive farming.

3. National fertilizer reduction policies that define maximum nitrogen applications per area should be implemented and enforced. Experiences in other countries and regions show

that fertilizer reduction policies significantly contribute to a cleaner and safer drinking water supply.

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APPENDIX: TABLE 3.

Description of groundwater and surface water samples taken in the Philippines and Thailand

a) Groundwater samples in the Philippines

Province	Sample	Land use	Water source	Description of sample	Nitrate mg/l NO_3^-
Benguet	AT1	Vegetables	Open well	Well in a tree patch among vegetable farms	18.6
Benguet	AT2	Vegetables	Artesian Well	Hand-pump well in Englandad, uphill from Atok	21.4
Benguet	AT5	Vegetables	Artesian Well	Well that supplies water to Atok Hospital, School, and Town hall	21.5
Benguet	BU5	Vegetables	Artesian Well	Hand-pump well in farmer house near nursery school in Lower Loo	**73.6**
Benguet	BU6	Vegetables	Artesian Well	Hand-pump well in farmer house in Lower Loo	**42.0**
Benguet	BU7	Vegetables	Artesian Well	Hand-pump well in farmer house	32.4
Benguet	BU8	Vegetables	Artesian Well	Hand-pump well old Municipal Hall in Lower Loo	28.8
Benguet	BU9	Vegetables	Artesian Well	Hand-pump well in farmer house	12.5
Benguet	BU10	Vegetables	Artesian Well	Hand-pump well in farmer house	5.7
Benguet	BU11	Vegetables	Artesian Well	Hand-pump well in the Elementary School in Lower Loo	**59.2**
Benguet	LT1	Residential	Artesian Well	Hand-pump well in residential area	21.0
Benguet	LT2	Residential	Artesian Well	Hand-pump well in residential area	24.2
Benguet	LT4	Residential	Artesian Well	Hand-pump well in residential area	10.5
Benguet	LT5	Residential	Artesian Well	Hand-pump well in residential area	19.1
Bulacan	AN1	Paddy rice, mixed farms	Artesian Well	Hand-pump well in house surrounded by paddy and mixed farms	**109.2**
Bulacan	AN2	Paddy rice, mixed farms	Artesian Well	Hand-pump well in house surrounded by paddy and mixed farms	**50.2**
Bulacan	AN3	Paddy rice, mixed farms	Artesian Well	Hand-pump well in house surrounded by paddy and mixed farms	24.8
Bulacan	AN4	Paddy rice, mixed farms	Artesian Well	Hand-pump well in house surrounded by paddy and mixed farms	**59.7**

b) Groundwater samples in Thailand

Province	Sample	Land use	Water source	Description of sample	Well depth (m)	Nitrate mg/l NO_3^-
Chiang Mai	CM5	Paddy rice	Artesian Well	Open well in farmer house surrounded by paddy rice	5	9.0
Chiang Mai	CM6	Paddy rice	Artesian Well	Open well in farmer house surrounded by paddy rice		1.0
Chiang Mai	CM7	Paddy rice	Artesian Well	Open well in farmer house surrounded by paddy rice	5	4.3
Chiang Mai	CM8	Paddy rice	Artesian Well	Well in school among rice fields		3.5
Chiang Mai	CM10	Paddy rice	Artesian Well	Open well in house/restaurant surrounded by paddy rice	58	1.7
Chiang Mai	CM11	Vegetables, fruit trees	Artesian Well	Tap water pumped from deep well in local hospital surrounded by rice fields	70	1.9
Chiang Mai	CM12	Vegetables, fruit trees	Artesian Well	Tap water pumped from deep well in farmer house among vegetable farms	7	8.1
Chiang Mai	CM13	Vegetables, fruit trees	Artesian Well	Hand-pump well in Temple surrounded by vegetable and fruit tree farms.	4	2.9
Chiang Mai	CM14	Paddy rice, maize	Artesian Well	Electric pump in local government office in Chiang Dao among farms	4	4.5
Chiang Mai	CM15	Paddy rice, maize	Artesian Well	Tap water pumped from deep well in bottled water factory among farms	50	2.4
Kanchanaburi	KNB1	Paddy rice, sugarcane	Artesian Well	Hand-pump well in farmer house among fields	6	8.7
Kanchanaburi	KNB2	Paddy rice, sugarcane	Artesian Well	Hand-pump well in farmer house among fields	6	9.4
Kanchanaburi	KNB3	Paddy rice, sugarcane	Artesian Well	Hand-pump well in farmer house among fields	6	3.0
Kanchanaburi	KNB4	Sugarcane	Artesian Well	Hand-pump well in sugarcane field	12	3.6
Kanchanaburi	KNB5	Maize, sugarcane	Artesian Well	Hand-pump well in Asparagus farm	9	4.4
Kanchanaburi	KNB6	Asparagus, maize, sugarcane	Artesian Well	Electric-pump well in Asparagus farm	10	**38.3**
Kanchanaburi	KNB7	Asparagus	Artesian Well	Electric-pump well in Asparagus farm	10	10.7
Kanchanaburi	KNB8	Asparagus	Artesian Well	Electric-pump well in Asparagus farm		**55.1**
Kanchanaburi	KNB9	Asparagus	Artesian Well	Hand-pump well in Asparagus farm	12	**38.0**
Kanchanaburi	KNB10	Asparagus	Artesian Well	Electric-pump well in Asparagus farm	10	22.2
Kanchanaburi	KNB11	Asparagus, peppermint, sugarcane	Artesian Well	Electric-pump well in Asparagus farm	10	**47.8**
Kanchanaburi	KNB12	Asparagus	Artesian Well	Electric-pump well in Asparagus farm, well is in the middle of the Asparagus plants	8	**152.0**
Kanchanaburi	KNB13	Asparagus, sugarcane, cassava	Artesian Well	Electric-pump well in mixed farm with Asparagus, sugarcane, cassava, rice. In an area with less extension of Asparagus crops		9.4
Kanchanaburi	KNB14	Asparagus	Artesian Well	Electric-pump well in Asparagus farm		**46.7**
Kanchanaburi	KNB15	Asparagus	Artesian Well	Electric-pump well in Asparagus farm		**54.6**
Kanchanaburi	KNB16	Asparagus	Artesian Well	Electric-pump well in Asparagus farm	8	**143.8**
Suphanburi	SPB1	Paddy rice	Artesian Well	Tap water in rice farmer house, pumped from deep well	80	15.0
Suphanburi	SPB2	Maize	Artesian Well	Electric-pump well in maize farm	6	**56.9**
Suphanburi	SPB3	Sugarcane	Artesian Well	Electric-pump well in the middle of a sugarcane farm	20	11.6
Suphanburi	SPB4	Maize	Artesian Well	Tap water in maize farmer house, pumped from deep well		30.1
Suphanburi	SPB5	Sugarcane	Artesian Well	Tap water in sugarcane farmer house, pumped from deep well	40	**55.6**

c) Surface water samples in the Philippines and Thailand

Country	Area	Sample code	Land use	Water source	Description	Nitrate mg/l NO_3^-
The Philippines	Benguet	AT3	Vegetables	Creek	Creek water piped into town for domestic use	9.8
The Philippines	Benguet	AT4	Vegetables	Creek	Creek water piped into town for domestic use	32.2
The Philippines	Benguet	AT6	Vegetables	Creek	Creek water piped into Municipal Hall for domestic use	19.9
The Philippines	Benguet	BU1	Vegetables	Creek	Creek used for farm irrigation uphill from Buguias town, among vegetable farms	4.3
The Philippines	Benguet	BU2	Vegetables	Creek	Creek used for farm irrigation uphill from Buguias town, among vegetable farms	2.8
The Philippines	Benguet	BU3	Vegetables	Creek	Creek used for farm irrigation uphill from Buguias town, among vegetable farms	2.9
The Philippines	Benguet	BU4	Vegetables	Creek	Creek water piped into farmer house for domestic use. House is uphill from town, among vegetable farms	2.2
The Philippines	Benguet	BU12	Vegetables	River	River passing through the municipality	13.2
The Philippines	Benguet	LT3	Residential	River	Small river passing through the municipality	11.2
Thailand	Chiang Mai	CM1	Oranges	Irrigation tank	Irrigation tank in orange farm	21.6
Thailand	Chiang Mai	CM2	Oranges	Irrigation tank	Irrigation tank in orange farm	6.6
Thailand	Chiang Mai	CM3	Oranges	Irrigation tank	Irrigation tank in orange farm	9.3
Thailand	Chiang Mai	CM4	Oranges	Irrigation tank	Irrigation tank in orange farm	6.2
Thailand	Chiang Mai	CM9	Paddy rice	Rainwater reservoir	Tap water from a rainwater reservoir	1.0