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# Nitrate Ion Contaminated Groundwater: Its Health Hazards, Preventive & Denitrification Measures

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**ABSTRACT**

*The occurrence of high nitrate levels in groundwater has to be recognized as a threat to human and animals. Infant methaemoglobinaemia and nitrate poisoning in livestock occur at unexpected times and places. An important reason is that nitrate concentrations are variable, particularly under extreme climatic conditions. All instances of nitrate pollution related to anthropogenic sources can be managed to reduce or eliminate nitrogen inputs and for protecting groundwater resources. Hence the purpose of this manuscript is to present the facts related to the health hazards, describe processes leading to nitrate pollution of groundwater, and to present strategies to eliminate nitrate pollution.*

***Keywords:*** *Nitrogen cycle; Anthropogenic sources; Health hazards; Action plan; groundwater protection; Public awareness; Denitification; $LD_{50}$*

## INTRODUCTION

Elevated nitrate concentrations occurring in groundwater present a serious threat to infants and livestock. The presence of nitrates in groundwater is mainly perceived as a pollution problem, and in general this has been shown to be valid. However, nitrate deposits as well as high nitrate concentrations in groundwater are found in many arid and semi arid zones around the world[1]. In most of these areas recent anthropogenic impacts can be ruled out. Whereas nitrate pollution, which by definition is derived from anthropogenic sources, can be managed and be reduced, natural nitrate sources generally cannot be controlled and other means will have to be adopted for managing the nitrate content of the groundwater in such areas. This manuscript describes the sources of nitrate in groundwater, lists the associated hazards, and provides guidance on the management of anthropogenic activities that cause nitrate pollution[2].

In view of the complexity of the nitrogen cycle and the myriad of sources an understanding of the natural nitrate accumulation factors and pathways is essential. Such knowledge contributes to the successful management of nitrate concentrations in groundwater as the factors favouring natural accumulation are also expected to intensify the problems related to pollution-derived groundwater nitrate. Nitrate in groundwater is a feature found in many regions and a significant part of the world population uses water with nitrate levels in excess of the WHO maximum drinking water standard. The WHO stated that evidence is accumulating that nitrate levels in many aquifers are increasing and that the problem of exposure of the world population to high nitrate inputs will become more pressing particularly in the developing nations. The full extent of the occurrence of methaemoglobinaemia amongst infants is unknown. Also, not all instances where livestock are lost due to nitrate poisoning are recorded either because the cause death may not be recognized or due to the sensitive nature of livestock losses. It is the purpose of this manuscript to bring the problem to the attention of the public at large in order to improve environmental management, to reduce groundwater pollution, and to prevent methaemoglobinaemia and stock losses[3].

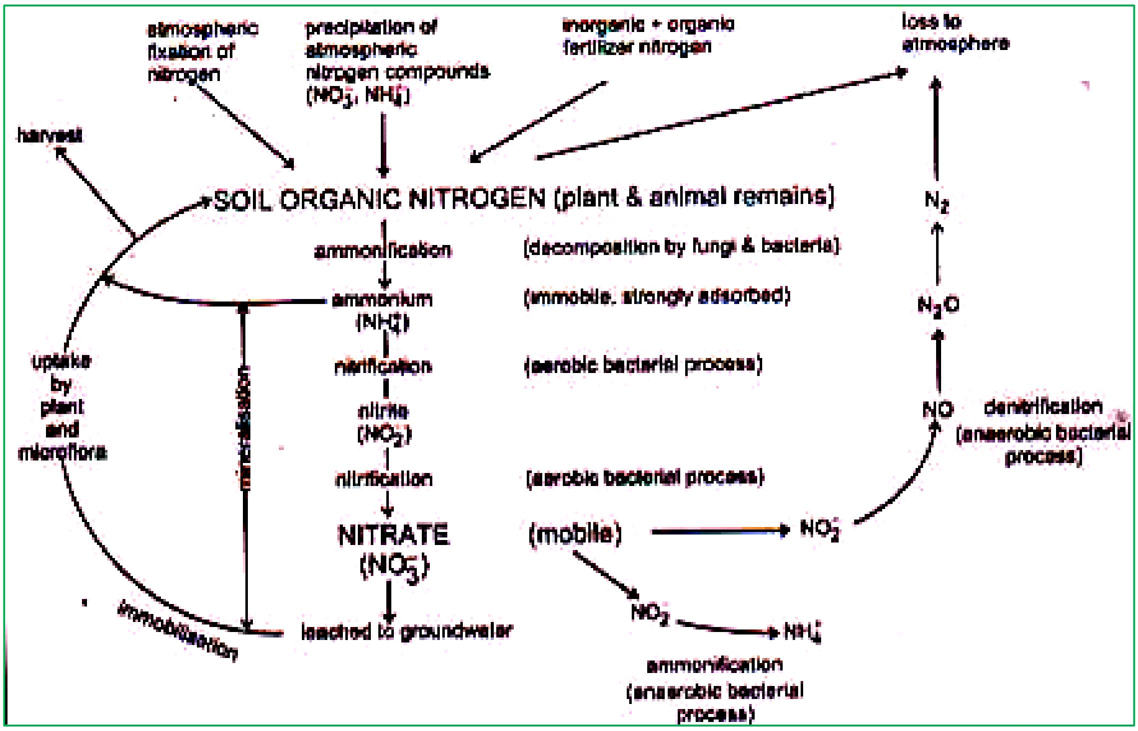
## SOURCES AND DISTRIBUTION OF NITRATE IN GROUND WATER

### Nitrogen cycle

Nitrogen ($N_2$) is one of the main biogeochemical elements and along with carbon (C), Oxygen ($O_2$), sulphur (S) and phosphorus (P) these elements in their biogeochemical cycles constitute the main life-supporting system for our planet. The most important reactions involving nitrogen are of a biochemical nature and are either driven by microorganisms or enzymes. For this reason the impact of nitrates on groundwater needs to be viewed in terms of the nitrogen biogeochemical cycle (Diagram 1). Whereas nitrogen compounds in most environments play a beneficial role. The presence of such compounds in water is generally detrimental. Nitrogen inputs, whether due to natural fixation of nitrogen, fertilizer application, or pollution, all contribute to the pool of soil organic nitrogen. A series of (bacterially mediated) transformations are needed to convert the organic nitrogen to nitrate which could potentially be leached to the groundwater. Anthropogenic inputs increase the soil nitrogen pool to such an extent that leaching of nitrate is enhanced. This is also true for fertilizer application to land as well as the tilling of the soil which enhances the nitrification of soil organic nitrogen. Depending on the conditions in the unsaturated zone and in the aquifer, denitrification, i.e. reduction of the nitrate is also possible. This is an important natural process which assists in maintaining the balance with respect to the nitrate in the groundwater.

## NATURAL OCCURRENCE OF NITRATE IN GROUND WATER

In nitrate contamination, various factors are involved, which may include the nature and thickness




of surface deposits, rainfall quantity, and distribution, depth to the ground level, distribution of vegetation types and presence of nitrogen-fixing vegetation. High levels of "natural" nitrate only occur in groundwater, when most or all of the above factors are acting in unison. Natural **Diagram**

**Fig 1: The Biogeochemical Nitrogen Cycle[5]**

disturbances of the plant cover, for example droughts (and possibly also bush fires) affect nitrogen cycle, leading to nitrate leaching beyond the root zone, particularly during subsequent heavy rainfall events[4].

## ANTHROPOGENIC SOURCES OF NITRATE IN GROUNDWATER

Apart from the natural sources of nitrate discussed above, most groundwater nitrates are derived from a wide range of anthropogenic sources. Anthropogenic generation of nitrate is well known and includes on-site sanitation, application of nitrogenous materials to land, tilling of the soil, irrigation and other activities. Whereas agriculture is main source of nitrate in the highly-developed countries such as Europe and USA. In contrast, most other rural incidences are related to pollution point sources such as on-site sanitation, kraals, and other places where livestock congregate, especially at stock watering points, and feedlots. Non-point sources include manure and fertilizer application to land, and tilling of the soil, while deforestation and land clearing also provide significant nitrate addition to groundwater. In the urban and peri-urban context sewage sludge drying beds at sewage farms and sludge "application" to land pose the greatest threat to groundwater, in addition to areas with inappropriate on-site sanitation.

## EXTREME VARIABILITY OF NITRATE CONCENTRATION IN GROUNDWATER

The nitrate concentration in groundwater can vary over a wide range depending on the aquifer and its recharge characteristics. Pollution derived from livestock congregation at feed troughs and watering points, as well as from on-site sanitation, generally enters into the unsaturated zone and collects above the water table. Only at the next rainfall event of sufficient magnitude the pollution is transported to the groundwater body and at the stage the groundwater quality may become degraded. In the semiarid to arid zones every one to two decades the seasonal rainfall has exceeds the mean annual precipitation. During such extreme events, large areas are flooded and the groundwater recharge processes are modified causing leaching of salts, including nitrates, which collected in the unsaturated zone over many years. This may affect the groundwater quality to such an extent that it becomes toxic to infants and livestock [6].

## HEALTH HAZARDS

### Specifications for potable water and stock watering

The table below shows the specifications for nitrate in potable water

| Nitrate-N Specifications (mg/L) | | |
|---|---|---|
| Potability Class | Ideal | < 6 |
| | Acceptable | 6-10 |
| | Marginal | 10-20 |
| | Poor | 20-40 |
| | Unacceptable | >40 |
| Livestock | Acceptable | <110 |

The "ideal" and "acceptable" levels agree with the WHO guidelines which are applied in most countries, and at these levels the health risk is negligible.

### Nitrate Toxicity

Nitrate as such is only not toxic to adults when ingested. The oral $LD_{50}$ for sodium nitrate ($NaNO_3$) is 4300mg/kg, which is equivalent to an intake of 300g for 70kg person. On the contrary, nitrite, which is formed by reduction of nitrate, is highly toxic. The oral $LD_{50}$ for $NaNO_3$ is 120mg/kg, which is equivalent to an intake of only 8.4g for a 70kg person. $NaNO_3$, a salt used in meat processing, can, therefore, be fatal to *all*, i.e. also adults at intakes above the threshold.

### Methaemoglobinaemia

Nitrate reduction happens in the digestive tract of infants and livestock and hence they are at risk at high nitrate levels. The nitrite binds strongly to the haemoglobin in the blood causing the infant to suffer methaemoglobinaemia which can be fatal. Should the water also be bacterially polluted, as is generally the case with pollution from on-site sanitation, e/g. septic tank overflow, the illness is often fatal. The condition can be recognized by the colouration of the lips and other parts and hence the term "blue baby syndrome" is widely used. In the case of sun-lethal levels (nitrate-N < 20parts per million, i/e. ppm or mg/L), children may show symptoms of "failure to thrive", headache, fatigue, shortness of breath, and lack of energy. For mothers ingesting higher nitrate water there is an abortion risk or the chance of still birth.

Methaemoglobinaemia caused by the decreased ability of blood to carry vital oxygen around the body. One of the most common causes is nitrate in drinking water. It is most important in bottle fed infants and water from wells in rural areas is of special concern. Controlling nitrate levels in drinking water sources to below around 50ppm is an effective preventive measure.

Methaemoglobinaemia is characterized by reduced ability of blood to carry oxygen because of reduced levels of normal haemoglobin. It is uncommon. Infants are most often affected, and may seem healthy, but show signs of blueness around the mouth, hands, and feet, hence the common name "blue baby syndrome". These children may also have trouble breathing as well as vomiting and diarrhoea. In extreme cases, there is marked lethargy, an increase in the production of saliva, loss of consciousness and seizures. Some cases may be fatal. In the body nitrates are converted to nitrites. The nitrites react to haemoglobin in the red blood corpuscles (RBCs) to form methaemoglobin, affecting the body's ability to carry enough oxygen to the cells of the body. Bottle-fed infants less than three months of age ate particularly at risk. The haemoglobin of infants is more susceptible and the condition is made worse by gastrointestinal infection. Older people may also be at risk because of decreased gastric acid secretion [7].

Malnutrition and infection seem to increase the risk of methaemoglobinaemia [8]. The general health of the infant as well as Vitamin C intake may determine whether or not the condition develops [9]. Others at risk for developing methaemoglobinaemia include: adults with a hereditary predisposition, people with peptic ulcers or chronic gastritis, as well as dialysis patients. The most common cause of methaemoglobinaemia is high levels of nitrates in drinking-water. High nitrate levels may be present in drinking-water due to the use of manure and fertilizers on agriculture land. The natural levels of nitrates and nitrites from the environment are normally a few milligrams per litre, although high levels may occur naturally in some areas. Intense farming practice may increase this to more increase this to more than 50mg/litre (WHO). Levels greater than 50 mg/litre, are known to have been associated with methaemoglobinaemia in bottle fed infants. Nitrate is also found in vegetables. Methaemoglobinaemia can also be a side effect of some drugs (phenacetin and sulphonamides), although this very rare with modern drugs.

Methaemoglobinaemia is now rare in most of the industrialized countries due to control of nitrate contamination in water supplies, although occasional cases continue to be reported from rural areas. It is a risk in developing countries, for example where the drinking water is from shallow wells in farming areas. There is no reliable estimate of the extent of the problem worldwide. WHO is presently collecting information in order to make such an estimate? Control of nitrate in drinking water is an effective preventive measure [9]. WHO's Guideline Value for nitrate in drinking water is 50mg.litre and for nitrite is 3mg/litre. This is relatively readily achieved in centralized piped, supplies, but is difficult in rural and small supplies. The group at greatest risk is bottle fed infants. Breastfeeding protects babies from methaemoglobinaemia. Boiling water doesn't remove nitrate. For severely affected individuals medical treatment is possible. The "blue baby syndrome" is often not recognized as such, however in mild cases if it is correctly identified the infant cab be treated with methylene blue intravenously, or with ascorbic acid, and can make a full recovery. Alternative treatments include hyperbaric oxygen therapy, while in severe cases exchange blood transfusions are indicated [10].

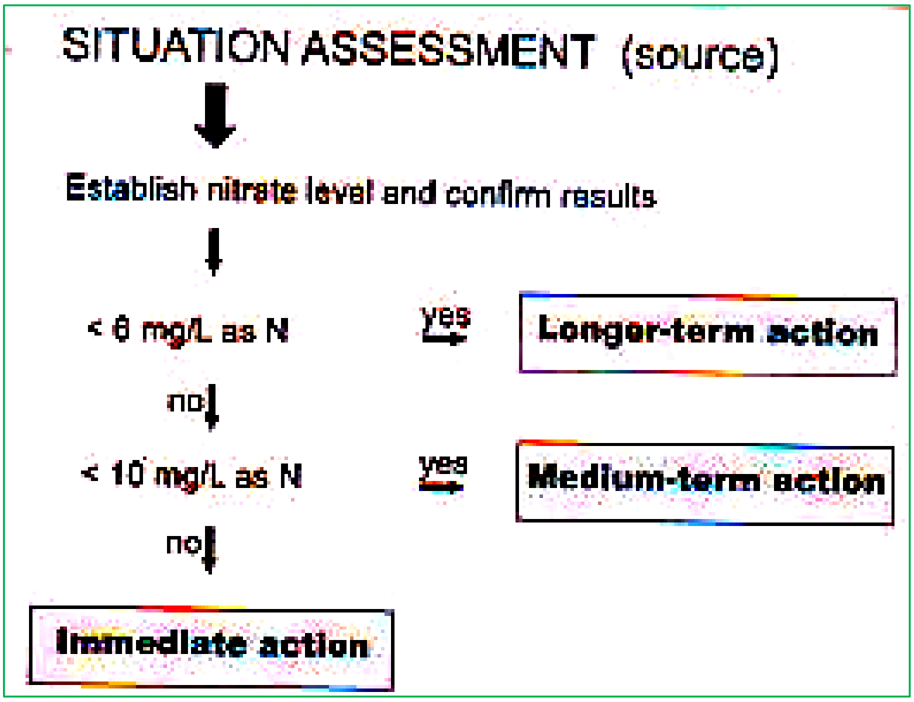
## NITRATE POISONING: LIVESTOCK LOSSES

In several instances poisoning has been identified as the cause of stock losses. This generally happened after periods of very heavy rainfall when some months after the event groundwater that was perfectly suitable for potable use becomes laden with nitrate and other salts, and often also harmful bacteria. It is therefore important for the public at large to be aware of the problem in order to improve environmental management, particularly to reduce groundwater pollution, and to prevent methaemoglobinaemia and stock losses. Nitrate poisoning is characterized by a brown colouration of the blood of the affected animal and the colour change can also seen on mucous membranes and other body parts. At sun-lethal levels of nitrate (but often above 100ppm as N) abortion and poor milk production have been recorded for lactating cows [11].

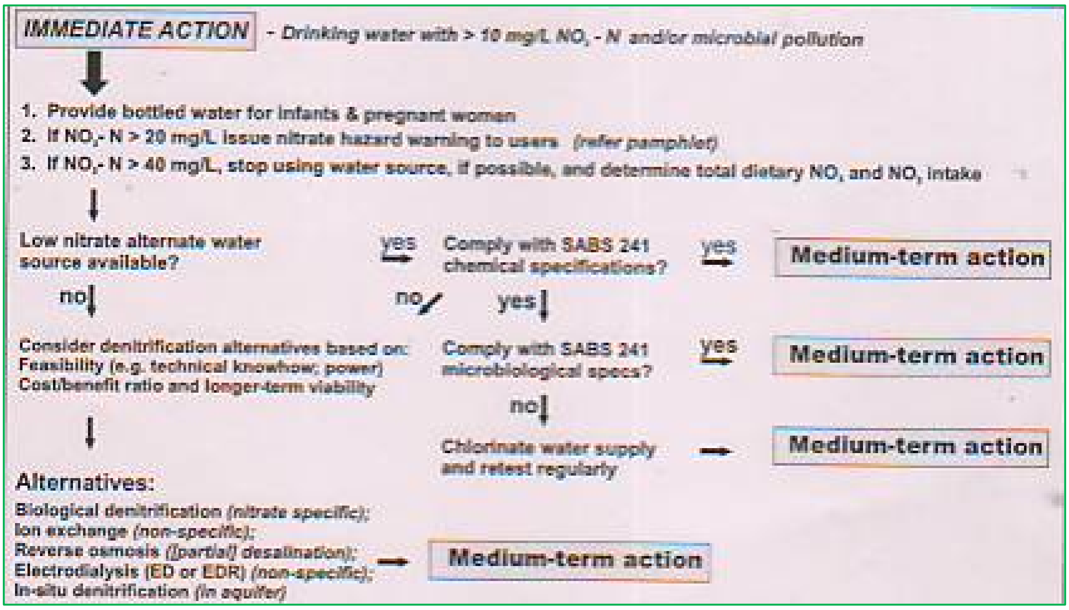
## ACTION PLAN

An action plan was devised for guiding the response to nitrate occurrences and for managing the nitrate concentration in groundwater.

**Measuring Nitrate:**




The action plan is based on the groundwater nitrate concentration. This is best determined by



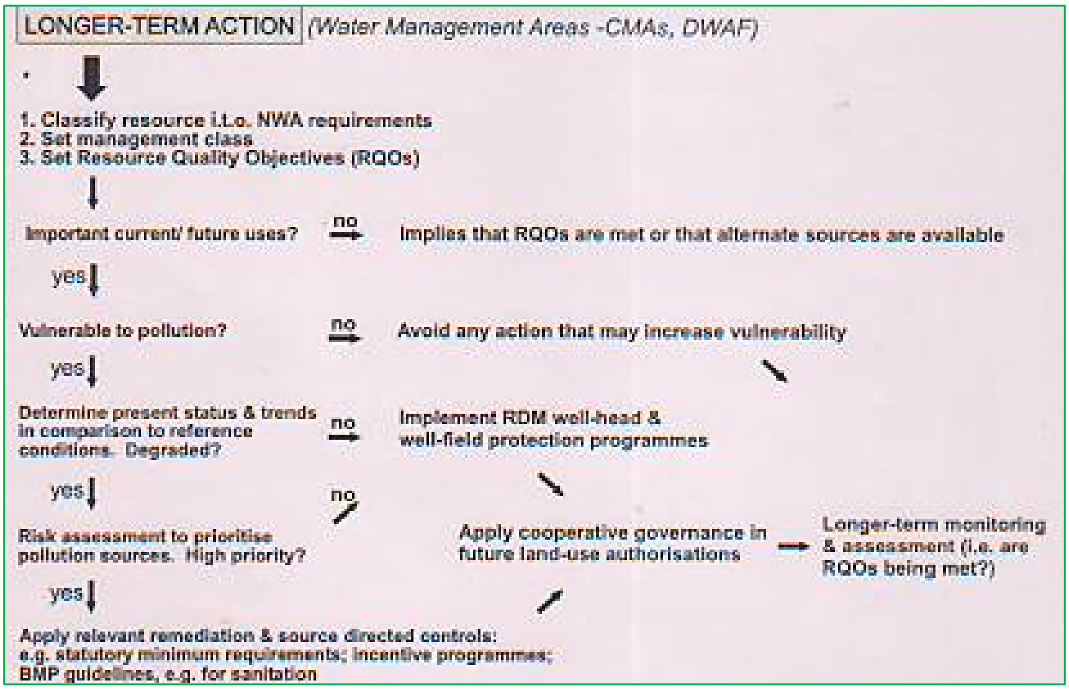

laboratory analysis. However, sample preservation between sampling and analysis is essential while consulting the laboratory. For a rough, on-site indication of the nitrate level, nitrate test strips (obtainable from chemical companies) may be used but caution is needed as it is essential a quantitative measurement while the value is indicated as ppm of nitrate (i.e. not as N).

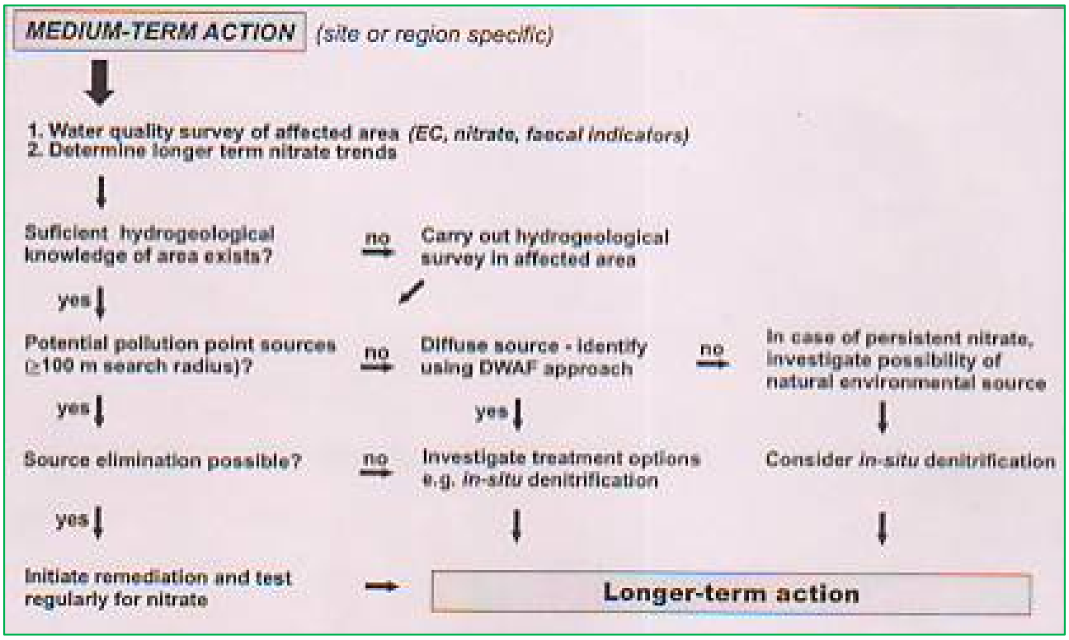
**Immediate Action**

As set out the specifications, however, if the nitrate concentration exceeds 20mg/Litre, or the water is bacterially polluted, immediate action is needed. All users should be altered to the risk and nitrate-free and bacterially safe bottled water provided for infants and pregnant women. If the nitrate exceeds 40ppm, use of the source should be terminated and an alternative nitrate-free supply found or dentrification measures implemented. Bacterially polluted water should be disinfected, e. g. ozonization and UV treatment.

## Medium Term Action

When nitrate exceeds 10mg/L but is less than 20mg/L, it can still pose a threat to certain users, e/ g. immune compromised individuals, particularly infants. In such cases all potential nitrate sources, e.g. septic tank soakways, stock watering points, etc., need to be identified. Should such pollution point sources exist then relocation of the borehole or well will be necessary.




## Longer Term Action

Should the nitrate concentration exceed the recommended potability level of 6mg/L, and pollution sources can be identified. Further action may be needed, e. g. relocation of the well or borehole, longer term, monitoring of the nitrate levels, etc. in the case of regionally elevated nitrate in groundwater. Other measures may be needed for which expert advice should new sought.

## NITRATE REMOVAL

Removing nitrate from water is generally not easy task. For potable purposes nitrate may be removed non-selectively by ion-exchange or desalination, i. e. removing all salts from the water, e. g. reverse osmosis. Biological dentrification, a nitrate-specific method, is used widely in treatment plants abroad but all these processes require considerable technical know-how. Therefore, for potable purposes in the rural situation it may be preferable to find an alternate supply as explained above. For town supply, dentrification, also by *in situ* treatment methods, i.e. in aquifer, may be considered [12].

## GROUNDWATER PROTECTION

The management and reduction of groundwater nitrate levels depends on an understanding of the nitrogen sources and the pollution and nitrification mechanisms. A successful groundwater strategy has to consist of a dual approach, i.e. legislation, as well as education and public awareness programmes for resource protection in rural areas. In rural areas the communities and farmers have to take their own resource directed protection measures as these are for their own benefit. That is also the purpose of this little flyer namely to distribute knowledge and to generate an interest in resource protection at all level. Communities and farmers are encouraged voluntarily to take all necessary steps that will ensure a reduction in environmental nitrogen inputs, particularly avoiding nitrate leaching in groundwater.

## PUBLIC AWARENESS

A public awareness and education programme forms an essential part of the groundwater protection strategy. This is key component that will ensure the success of the legislative and pollution control approach for reducing nitrogenous inputs to the environment. The fact is that not all polluting activities in remote areas can be controlled by authorities. For this reason, the public, including the farming community and other rural communities have to be convinced to own groundwater resources.

## CONCLUSION

The occurrence of nitrate in groundwater is a serious calamity. Nitrate in groundwater can be derived from various sources which can be grouped into two main categories"

- Anthropogenic nitrogenous pollution, and
- Natural nitrate accumulation, primarily present in arid and semi arid regions.

  In the highly developed countries the main anthropogenic source is agricultural nitrate, largely derived from excessive fertilizer and manure applications. Such sources are controllable and in Europe strict measures are in place for limiting the nitrogen fertilizer and manure application rates. Pollution point sources are generally associated with specific activities, e/ g. sewage sludge beds, land application of sludge, and irrigation of (partly) treated wastewater. At the large cities, high levels of sewage sludge application to land have caused serious groundwater pollution. The above confirms that main source of nitrate in ground water is anthropogenic pollution but such nitrate inputs are manageable. In the rural setting voluntary action regarding nitrate management us essential, but overall legislation and control are also needed. Nitrate removal may be feasible in certain instances but generally expert advice and technological input will be required.

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