SCIENCE AND ENVIRONMENT FORTNIGHTLY

Down To Earth

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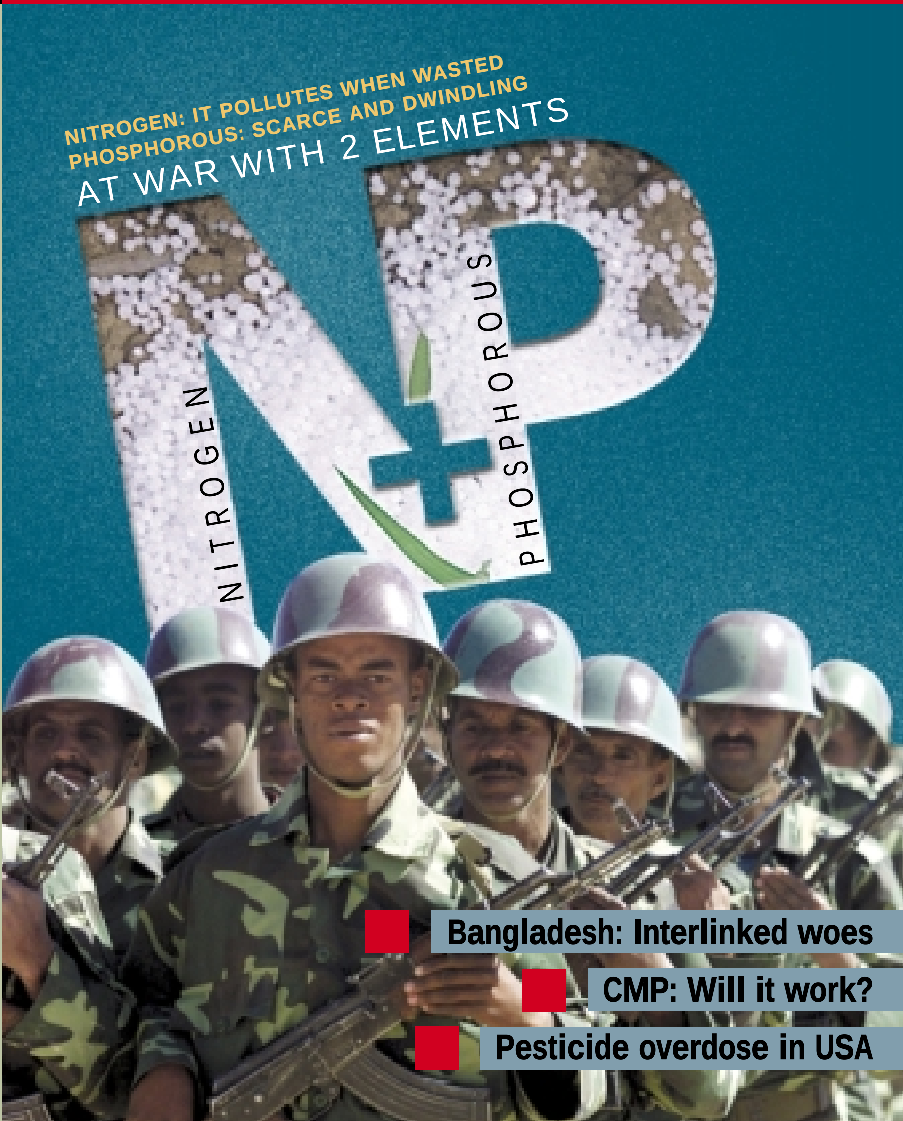
NITROGEN: IT POLLUTES WHEN WASTED
PHOSPHOROUS: SCARCE AND DWINDLING

AT WAR WITH 2 ELEMENTS



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IN A FIX

Both nitrogen and phosphorous are essential to life. Lynchpins both to global food production, circulating through synthesis or export and then through croplands and food into — and out of — our bodies, both elements today inhabit cycles that, in their own ways, function more in the breach.

Phosphorous is a scarce resource. As ARNO ROSEMARIN tells us, it is the focus of intense geopolitical interest. At the centre of this interest: internecine conflict in Africa, and a global rush for Western Sahara's reserves.

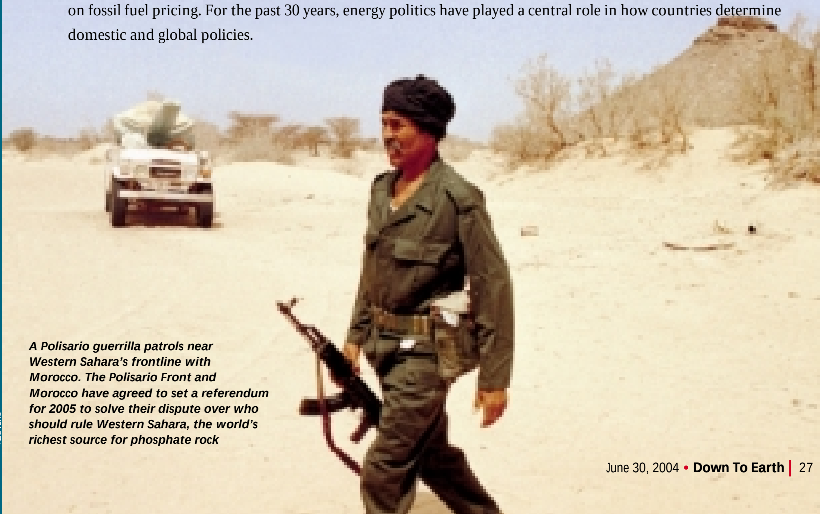
Nitrogen is a resource in plenty. But, as T V JAYAN shows, that isn't helping. Indeed, the world today faces a nitrogen deluge. That's because a lot of it exists in the form of waste. And that's because the cycle has been broken. Now, nitrogen-bearing waste goes not back to the land but into water.

Is it possible not to be at war with these two elements?

The precarious geopolitics of PHOSPHOROUS

Over the ages, human civilisations have excelled and fallen depending on the availability and use of limited resources. Fossil fuels, minerals, land, freshwater and food are often the measuring sticks of relative wealth. These limited resources determine just how long exploitation can continue before we have to adapt more sustainable practices.

Geopolitics and limited natural resources can create major problems and challenges, causing enormous inequities within countries and between various regions of the world. The so-called "oil crisis" of the early 1970s, which was caused by a geopolitical shift in control of the Middle East oil reserves, created a global dependency on fossil fuel pricing. For the past 30 years, energy politics have played a central role in how countries determine domestic and global policies.



REUTERS

A Polisario guerrilla patrols near Western Sahara's frontline with Morocco. The Polisario Front and Morocco have agreed to set a referendum for 2005 to solve their dispute over who should rule Western Sahara, the world's richest source for phosphate rock

No substitute

It is therefore of interest to take a more in-depth look at other natural resources, which are limited in supply and which have a highly skewed geographical distribution. The case in point is the global supply of phosphorous, a non-renewable but essential nutrient for all forms of life. Phosphorous is about 10 times more abundant in living organisms than what is found in the earth's crust, thus demanding a "luxury" consumption mechanism. Phosphate rock is mined to produce phosphoric acid and elemental phosphorous. Sulphuric acid is reacted with phosphate rock to produce the fertiliser triple superphosphate, or with anhydrous ammonia to produce ammonium phosphate fertilisers. Elemental phosphorous is the base for furnace-grade phosphoric acid, phosphorous pentasulfide, phosphorous pentoxide, and phosphorous trichloride. Approximately 90 per cent of phosphate rock is used for fertilisers and animal feed supplements and the rest for industrial chemicals. Urbanisation and intensive agricultural practices have brought about the application of chemical fertilisers in order to produce adequate amounts of food. But we have neglected to close the nutrient cycle, and have instead chosen to exploit phosphorous and other important minerals without ecological controls (see flow chart: *Tracking phosphorous*). This has left us in a situation where little phosphorous is recycled either within populated areas or from agricultural land. Excess runoff and discharge of phosphorous in surface waters have resulted in eutrophication and algal overgrowth, which creates oxygen-poor conditions, reduces water quality and damages ecosystems. This approach to resource use has also made us highly dependent on expansive extraction of limited supplies.

About one billion metric tonnes of phosphorous were mined between 1950 and 2000. During this period, about 800 million metric tonnes (one megatonne=one million metric tonnes) of phosphorous-containing fertilisers were applied to the Earth's croplands. This has increased the standing stock of phosphorous in the upper 10 centimetres of soil in the world's croplands to roughly 1,300 million metric tonnes, an increase of 30 per cent. Close to a quarter of the mined phosphorous (250 million tonnes) since 1950 has found its way to the aquatic environment (oceans and fresh water lakes) or buried in sanitary landfills or 'sinks'. Of the next billion tonnes of phosphorous we mine between 2000 and 2050, a significant percentage can be recovered by using sustainable agriculture and sanitation. This should be a priority for the global policy agenda.

A phosphorous-dependent world

Little has been published on the risks and limitations of global supply and demand of phosphorous, but after reviewing the available data there is cause for considerable concern. The US will deplete its commercially viable reserves within 30 years. Most of the commercially viable reserves (those that can be extracted profitably under present economic, infrastructure and technical conditions) are found only in Morocco/Western Sahara and China. India is the largest country in the world that is most dependent on foreign sources of phosphate.

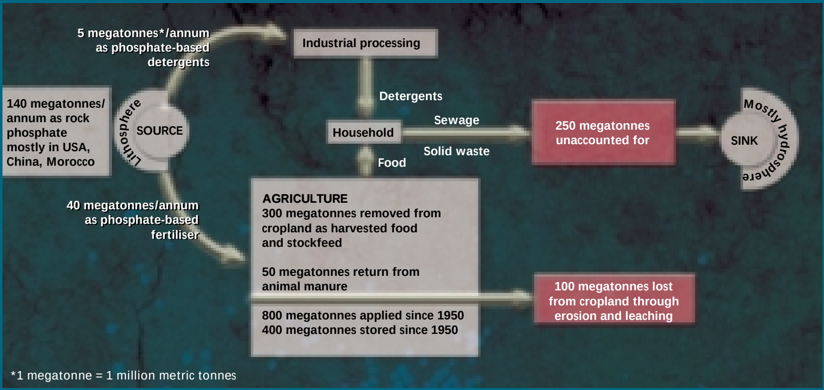
The business of phosphate

The phosphate business can be analysed in terms of the estimates of economically viable reserves, the production of phosphate rock (mainly from marine sedimentary deposits called phosphorite) and production of phosphoric acid. Economic extraction of phosphate from rock depends on large quantities of sulphur, also a limited natural resource.

COMMERCIALLY VIABLE RESERVES: There are about 18, 000 megatonnes of phosphate rock. China has 37 per cent of the reserves, Morocco/Western Sahara 32 per cent and USA 5 to 6 per cent. But Morocco/Western Sahara's potential reserves and geological *in situ* resources are approximately 60 per cent

Tracking phosphorous

Where it comes from, where it goes: a lot is certainly wasted



is more vulnerable than one focussed on fossil fuel availability

of the total world resources, estimates the US Geological Survey (USGS)

EXTRACTION: About 138 megatonnes of phosphate rock is extracted each year in the world. Extraction is dominated by USA (24 per cent), China (17 per cent) and Morocco/Western Sahara (17 per cent)

ORE EXPORT: As much as 30 megatonnes of phosphate rock is exported in the world each year. Morocco dominates 40 per cent of the exports, followed by Jordan (13 per cent), China (13 per cent) and Russia (10 per cent)

PRODUCTION: Annual phosphoric acid production is about 21 megatonnes. Sector dominated by USA (50 per cent), Morocco (15 per cent), Russia (10 per cent) and Tunisia (5 per cent)

PRODUCT IMPORTS: About 3.7 megatonnes of phosphoric acid is imported each year. India's share, the largest, is 60 per cent; it is followed by Europe at 18 per cent

It's clear from these figures that the distribution of commercially viable phosphate reserves is heavily skewed and in the control of Morocco and China. Export is dominated by Morocco alone as China is not a major exporter.

The situation thus is a familiar one: countries will become more and more dependent on phosphate rock imports while reserves dwindle. That phosphorous is limited and non-renewable has similarities to the oil crisis of the 1970s, but one major difference should be kept in mind: phosphorous cannot be substituted using alternative resources. Thus, a world dependent on phosphorous is much more vulnerable than the one focussed on fossil fuel availability.

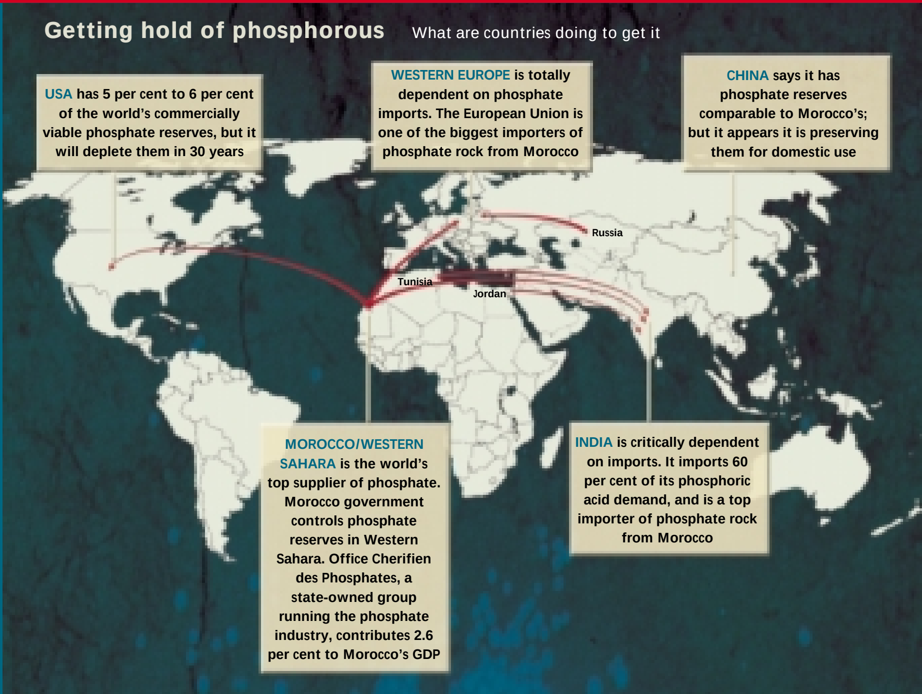
The fight for Western Sahara

In Western Sahara, "paradise" to millions of tourists from all over the world, continues one of the least publicised geo-political conflicts. Western Sahara, so named in 1975 by the UN, is the last African colony still to get its independence. The region was a Spanish colony till 1975, and after that was invaded and occupied by Morocco. In 1988 Morocco and the Polisario Front, which is fighting for the independence of the region's Sahrawi people, agreed to solve the conflict peacefully. The United Nations Mission for the Referendum in Western Sahara (MINURSO) was set up in 1991, but the referendum to determine whether the region will be independent or integrated with Morocco has never been held. The UN Security Council in January 2004 decided to extend the mandate of MINURSO until April 30, 2004; the date has now been extended again to October 31, 2004.

The geopolitical importance of Western Sahara's independence or integration with Morocco continues to be minimal because of two reasons: the world is unaware of this conflict and phosphorous limitation has not yet become a global concern. But this conflict could have major impacts on the world economy through Western Sahara/Morocco's monopoly of over one-third of the global supply of rich phosphate rock. Presently, the Moroccan government controls all trade and other economic activities in Western Sahara.

Many countries have trade pacts and joint ventures with Morocco for mining, extracting and shipping phosphorous. Morocco earned US $1.5 billion from phosphate exports in 2001. The Office Cherifien des Phosphates (OCP), a state-owned group which controls the phosphate industry in Morocco, contributes 2.6 per cent to the country's gross domestic product and 18.5 per cent to its exports. The Moroccan monarchy is the major shareholder in Omnium Nord Africain (OND), the country's largest private company, which controls the resources, including phosphorous.

AMIT SHANKER / CSE



Phosphorous politics became even more complex in 2003 when China revealed to the world that it, too, had large phosphate reserves, about the same size as Morocco's. This news has gone almost completely ignored, but may be one of the most important developments that will determine phosphorous geopolitics. China and Morocco together hold about 70 per of the world's economic reserves for phosphate rock, estimates the USGS. But China appears to be holding on to its phosphate reserves for domestic consumption: according to the USGS its export share is less than 15 per cent of the reported production. China in 2002 imported 30 per cent of its phosphate requirements. The European Union, followed by the US, India, Australia, New Zealand and Brazil are the top importers of phosphate rock from Morocco, says USGS.

Morocco in March 2, 2004 signed a free-trade agreement with the US. Issues that were hindering this agreement up to now within Morocco were related to food import controls (imports of subsidised wheat from the US will overtake domestic growers) and lack of free enterprise surrounding the phosphorous industry. Increased military aid from the US, an attempt to split Arab country alliances, is also part of this development. USA's phosphate imports come from Morocco/Western Sahara, and this dependency will increase over the next few decades.

What does this all say then? It doesn't require very much analysis to realise that the geopolitical agenda for control of phosphorous is well advanced. But what is alarming is the little concern being shown by the world at large. How can leaders of the world dwell in this state of ignorance?

India's position: Tied to the world

In this great game for getting phosphorous, India is desperate. After France and Spain, it is the biggest importer of phosphate and phosphoric acid. It is one of Morocco's most important trading partners and has signed several joint ventures with it. An Indian company invested about US $230 million in 1998 for a phosphoric acid plant in Morocco. India has 260 megatonnes of low-grade phosphate rock deposits, but they are unsuitable for fertiliser production. Its position is similar to many other countries.

Global population increase and the striving to increase the standard of living in many developing parts of the world will

The real concern is highly skewed distribution of phosphate reser

Global reserves in million metric tonnes

Countries	Mine production 2002	Mine production 2003*	Reserves	Reserve base
United States	36.1	33.3	1,000	4,000
Australia	2.025	2.2	77	1,200
Brazil	4.85	4.96	260	370
Canada	1	1.2	25	200
China	23	24	6,600	13,000
Egypt	1.5	1.5	100	760
India	1.25	1.25	90	160
Israel	3.5	4	180	800
Jordan	7.18	7.2	900	1,700
Morocco & Western Sahara	23	24	5,700	21,000
Russia	10.7	11	200	1,000
Senegal	1.5	1.5	50	160
South Africa	2.91	2.5	1,500	2,500
Syria	2.4	2.4	100	800
Togo	1.28	2.1	30	60
Tunisia	7.75	7.7	100	600
Other countries	4.83	7	800	2,000
World total (rounded)	135	138	18,000	50,000

*Estimated
Source: United States Geological Survey, 2004

further aggravate the task of managing this limited resource. At the current extraction rate of 138 megatonnes per year, commercially viable phosphorous reserves will last 130 years. If one includes commercially unviable reserves, we can go on for another 130 years but at much higher prices. The demand for phosphate rock as a nutrient for food production will vary throughout the world. The overall demand is forecasted to increase by 1 to 2 per cent. In agriculturally mature countries, the increase in demand will be closer to 1 per cent per year. At an increased rate of 3 per cent, the world's commercially viable reserves would be depleted by 2060.

But presently, the real concern should be the highly skewed distribution of phosphate reserves compared to where the needs are in the world. India, Western Europe and many other countries depend entirely on foreign sources. USA's commercially viable reserves are running out. Canada's wheat belt is totally dependent on phosphate from Togo at present.

As reserves dwindle, food security will become the central issue in all countries. Daily protein intake in Asia in 1996, when the population was 3.3 billion, was about 15 gm per individual. Estimates for 2030 are a population of about 4.5 billion and a four-fold increase in protein intake, mainly as meat. This amounts to over a five-fold increase in meat consumption over 35 years. The ensuing increase in fertiliser to support this massive population growth will surely bring the question of limited phosphorous into focus. That USA's commercially viable reserves will be depleted by then, and that the geopolitical volatility around the world will only increase, make further the case for phosphorous limitations. By 2020, rock phosphorite may become the keystone resource of the world economy.

ves compared to where needs are

Recycling phosphorous

As the world becomes more aware of the need to save and recycle phosphorous, certain characteristics of this mineral will unfortunately aggravate this response. Phosphate once applied to soil is not easily recycled. When applied as chemical fertiliser, phosphate transforms to less available forms (for example, from highly available dicalcium-P to less available octo-calcium-P). These forms then remain bound to the upper soil layer and can't be used by plants.

Australia's Commonwealth Scientific and Industrial Research Organisation is trying to extract phosphorous using white lupine (*Lupinus albus*), a grain legume used for nitrogen fixation but which also excretes small amounts of organic acid from its rootlets. There will be attempts to gene-modify soil bacteria and plants in order to achieve higher phosphorous recovery. But even if biotechnology helps, it cannot give us abundant phosphate.

Slash-and-burn methods won't help either — they will affect crop cycles and could start millions of small fires around the world resulting in release of carbon dioxide and particulate matter. Recycling from sanitation and solid waste systems can be a partial remedy. The phosphorous we consume in foodstuffs or add to our laundry in the form of water softeners can be recycled, but our mixed and diluted solid waste and sewage systems make this very costly. Radical changes to these systems in terms of source-separation and containment (ecological sanitation) will be needed in order to make recycling economically viable.

Risks

The present attitudes around fertiliser use within the agricultural sector were formed during the "Green Revolution" whereby nutrients were given the status of being limitless. As the population of the world has increased, energy resource questions have kept the fertiliser debate from developing. And more recently the recognition that water resources and soil are the largest present-day limiting factors in agriculture have further delayed any attention paid toward limiting nutrients and the need for their more frugal management.

Whether the world reserves of cheap phosphorous become depleted in 100 years or even 200 years is a minor question when compared to the present situation regarding the heavily skewed global distribution. The geopolitics of phosphorous makes this one of the most precarious global resource questions requiring immediate attention.

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Visit www.downtoearth.org.in for more coverage on phosphorous

SURYA SEN / CSE

FATALLY fixated

In nature, nitrogen remains constant. The Earth's atmosphere has 78 per cent nitrogen, but very little of this vital nutrient can be absorbed by plants. A chain of chemical reactions deposits atmospheric nitrogen in rain and then takes it to the soil. Nitrogen-fixing bacteria and lightning help plants to absorb this nitrogen, which is then consumed by humans and animals through food. The nitrogen returns to the soil through excrement, and then again goes to the atmosphere through bacterial decomposition of organic matter. For millions of years, this cycle kept nitrogen in closed loops (see box: *Nature's check and balance*). No longer. Nitrogen is entering water in millions of tonnes instead of going to the soil.

Changing the cycle

Human activities in the last 100 years have terribly damaged the nitrogen cycle (see graphic: *Breaking the loop*). Fossil fuel combustion has increased the amount of nitrogen oxides, which are blamed for the greenhouse effect. Large-scale cultivation of legumes, which support nitrogen-fixing bacteria, have also increased nitrogen in the soil. Fertilisers improved global food production in the last century by increasing the amount of nitrogen available to plants. But now agricultural fields in some countries have nitrogen in such massive quantities that plants can't absorb them. The nitrogen in fertilisers, present in a form called nitrate, is extremely soluble and so easily goes from soil to groundwater reservoirs feeding lakes and streams.

Flush-and-forget sewage disposal systems improved sanitation, but have aggravated the damage to the nitrogen cycle. Instead of returning plant nutrients in human waste to the soil, sewage systems take them to treatment plants. Thus, the nitrogen in human waste too is reaching surface water bodies and oceans.

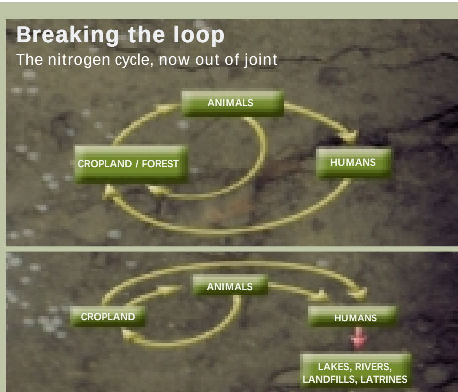
Humans each year ingest nearly 20 million tonnes of nitrogen through food, all of which enters the environment. What's terrible is that while we consume 20 million tonnes of chemical nitrogen, 100 million tonnes of it is produced and supplied in the form of chemical fertilisers.

About 32 per cent of the nitrogen fertilisers applied in USA each year (about 3.6 million tonnes) reaches surface water and groundwater, say Robert Howarth, David R Atkinson professor of ecology and environmental biology, Cornell University, USA, and other researchers.

Their study shows that the excess nitrogen in USA's rivers had increased from 3 million tonnes in 1961 to 5 million tonnes in 1997, which is 45 per cent of the total 11.2 million inorganic nitrogen fertiliser consumed in the US in 1997. The Mississippi river in 1996 alone carried 1.5 million tonnes of nitrogen, says a paper by W R Raun and G V Johnson of the department of plant and soil sciences at Oklahoma State University, USA.

And paying for it

Scientists say the global rate of increase in nitrogen was slow from 1860 to 1960 but the amount has now increased. The amount of nitrogen added to the environment between 1860 and 2000 has increased from 15 TG (One terragramme is equal



Instead of returning nitrogen in human waste to the soil, sewage systems pass it into rivers and so to oceans

to one million tonnes) of nitrogen per year to over 165 TG of nitrogen per year, write James Galloway, professor of environmental sciences, University of Virginia, USA, and others in a paper published in the April 2003 issue of *BioScience*.

Half of all the nitrogen ever applied for agriculture was done in the last 15 years, says Howarth in a paper published in *Ambio* in 2002.

Changing the natural nitrogen cycle has given us benefits: Almost 40 per cent of humans are alive today thanks to the substantial increase in nitrogen through fertilisers and cultivation-induced biological nitrogen fixation. The flip side: the runaway increase in nitrogen in the ecosystem has several serious environmental consequences, many of which are being noticed first in advanced countries.

Deluge

Scientists predict the global production of nitrogen will reach between 250 million tonnes to 900 million tonnes per year by 2100. What are the exact effects of this nitrogen deluge?

High nitrate levels in drinking water can cause 'blue baby' syndrome or methaemoglobinaemia. In this rare but sometimes fatal condition red blood cells can't carry oxygen, which subsequently turns an infant's lips blue. Cases, particularly among infants, of stomach cancer and of non-Hodgkin's lymphoma due to nitrate-contaminated water have been reported. Nitrosamines, which are produced from a nitrogen form called nitrite, are reported to be carcinogenic.

HARMING GREEN, CHOKING LIFE: Excess nitrogen chokes plants. A team of researchers led by John Aber, a professor of natural resources at the US-based University of New Hampshire's Institute for the Study of Earth, Oceans, and Space, has since 1988 found through experiments that adding nitrogen to the soil around trees slows their growth. The excess nitrogen interferes with the trees' ability to produce chlorophyll, has also lowered their resistance to frost and caused conifers to lose needles.

Excess nitrogen can wreak havoc on the structure of ecosystems, affecting the number and diversity of species. Researchers in the UK and the US have found that applying nitrogen fertilisers to grasslands lets a few grass species dominate, while others disappear. In one experiment in Britain, grass species decreased five-fold in plots with excess fertilisers. In The Netherlands, which has one of the highest nitrogen deposition rates in the world, entire ecosystems have been altered. Species-rich heath lands in this country are turning into species-poor forests and grasslands that better accommodate to excess nitrogen.

Excess nitrogen is now considered the biggest pollution problem in the world's coastal ecosystems, where it can cause eutrophication, hypoxia, anoxia, harm aquatic life and destroy their habitat.

Eutrophication, a process in which the dissolved oxygen in water bodies decreases because of excessive plant growth or 'algal bloom' caused by excess nutrients, is one of the most serious threats to aquatic environments today. The Baltic Sea, Black Sea and Mediterranean Sea — partially enclosed seas rich in commercial fish and shellfish species — have been hard hit by eutrophication.

Research has shown that approximately two-thirds of USA's coastal rivers and bays have been moderately to severely affected by eutrophication caused by excess nitrogen. The Mississippi River's mouth in the Gulf of Mexico and the

Nature's check and balance

How we have too much nitrogen in the works

Nitrogen is the most abundant element on Earth: the total amount present in the earth's atmosphere, hydrosphere and biosphere is estimated to be 4×10^{21} gm. It forms just 1.5 per cent of a living being's constitution, but is a fundamental component of the nucleic acids which determine the genetic character of all beings and the enzymes which drive the tiny metabolic machinery of cells. However, more than 99 per cent of this nitrogen is not available to living organisms. The reason? The form in which nitrogen usually exists on Earth.

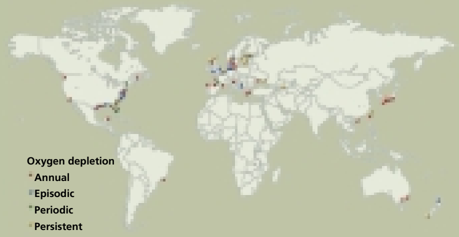
Usually, a nitrogen molecule consists of two atoms very strongly bonded together and therefore non-reactive. It is, literally, useless. The kind that plants can absorb, the chemically active kind, is called reactive nitrogen. Some of the major reactive nitrogen compounds are ammonia, ammonium, nitric acid and various oxides of nitrogen such as nitrous oxide, nitrogen dioxide and nitrate.

The reactive nitrogen form is also present several organic compounds such as urea, amines, proteins and amino acids. There was a time reactive nitrogen got to be produced only through lightning and biological nitrogen fixation. So produced naturally, it did not accumulate in environmental reservoirs. This was due to a process called dinitrification, where certain other set of microbes convert reactive nitrogen back into non-reactive form. However, human activities in the last century have considerably upset this equilibrium. Scientists say the global rate of increase in reactive nitrogen was slow from 1860 to 1960 but since then:

- **Cultivation-induced reactive nitrogen production increased from approximately 15 teragrammes (Tg) per year to nearly 33 Tg per year in 2000 (One terragramme is equal to one million tonnes)**
- **Reactive nitrogen production because of fossil fuel combustion increased from less than 1 Tg per year in 1860 to approximately 25 Tg in 2000**
- **Reactive nitrogen creation through the Haber-Bosch process to manufacture fertilisers increased from 0 in 1910 to more than 100 Tg per year in 2000.**

The nitrogen deluge

Dead zones that cannot support any lifeform litter the industrialised world. Developing countries seem poised to follow the way of excess nitrogen use



	Nitrogen consumption (million metric tonnes)			
	1970-71	1980-81	1990-91	2000-01
Western Europe	7.08	10.2	10.38	9.29
North America	7.69	11.77	11.4	11.93
South Asia	1.91	4.93	10.26	14.2
China, Vietnam	3.36	12.47	20.32	23.42
Developed	23.13	35.79	35.39	28.19
Developing	8.61	24.9	42.16	52.61

Source for map: Geo Year Book 2003, *United Nations Environment Programme; Source for Table: International Fertilizer Industry Association*

Chesapeake Bay have been declared 'dead zones' (water bodies which have very low amounts of dissolved oxygen).

Hypoxia (low dissolved oxygen levels in water) can impair the growth and reproduction of aquatic life, while anoxia (water without oxygen) can kill most of them. The United Nations Environment Program (UNEP), in its *Geo Year 2003* publication, has identified 146 oxygen-starved coastal areas in the world. These areas were created due to increased flow of nitrogen since the 1960s.

Worldwide alert

Nitrogen is seeping into the waters and lands of industrialised nations, but it doesn't mean that the developing world is safe. In the next decade, Asia is expected to use more nitrogen fertilisers than any other place in the world (see box: *The nitrogen deluge*). Out of the 87.5 million tonnes of fertilisers used for global agriculture in 2000, Western Europe, USA and India consumed 11 million tonnes to 12 million tonnes each while China consumed over twice that amount. India in 1959 used 23,470 tonnes of nitrogenous urea, but by 2000-2001 it had consumed over 11 million tonnes of nitrogenous fertilisers.

World fertiliser consumption has increased from 14 million tonnes in 1950 to 143 million tonnes today. The share of nitrogen fertiliser in overall consumption was 36 per cent in 1960-1961, and it grew to 56 per cent by 1990-1991.

But while millions of tonnes of fertilisers are being used, only a tiny bit of plant nutrients are found in the food we eat. Wheat crop absorbs 32 per cent to 52 per cent nitrogen under optimal conditions and paddy 21 per cent to 31 per cent, says a research paper prepared by Bijay Singh and Yadvinder Singh of Department of Soils, Punjab Agricultural University, Ludhiana. A study done by New Delhi-based Indian Agriculture Research Institute in 1992 found that for one tonne of wheat grain produced, only 28 kg of nitrogen was used from the soil. The soil uses some nitrogen to engage organic carbon, but even then about 50 per cent of nitrogen in fertilisers isn't used.


SURYA SEN / CSE

Waste wasted

Fertilisers pollute, but food security can't be compromised upon. So where else can the world get nitrogen from? One possible source: human excreta. Treated human and animal waste can partially correct the disruption in the nitrogen cycle. It is estimated that a human being consuming 300 gm of carbohydrates, 100 gm of fat and 100 gm of protein everyday, excretes about 16.5 gm of nitrogen, mostly as urea, each day.

About 550 litres of human urine and 50 kg of faeces contain 5.6 kg of nitrogen, 0.4 kg phosphorous and 1 kg of potassium. These amounts are estimated to be enough to produce 200-250 kg of food grain annually.

Eighty per cent of the nitrogen unused by a human is found in urine, which also contains two-thirds of phosphorous and up to 80 per cent of potassium. These are the three major nutrients used to make fertilisers.

The disruption of the geochemical nitrogen cycle — from land to water and not from land to land — is as serious as the disruption of the global carbon cycle, the cause of global warming. But little is understood of this critical cycle, which we have tampered with. It is very clear that for sustainability we will have to subject technology to environmental security. That has to be the way ahead. ■