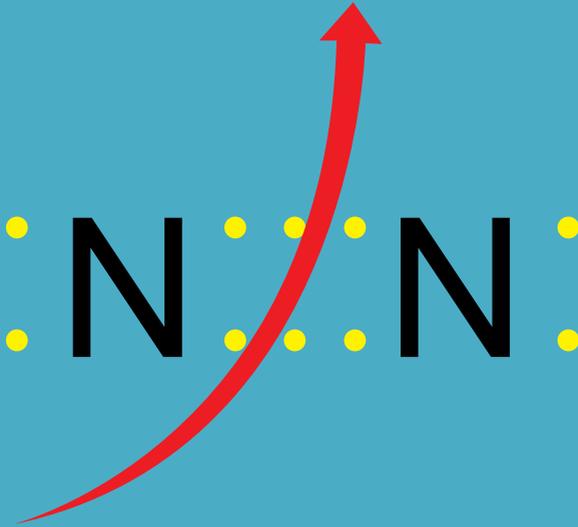




*There is an invisible Nirav
Modi in every heavily-fertilised
farm in India.*



Death by nitrogen

We are all familiar with the perils of a runaway carbon emissions cycle but there is a lesser known one that may be worse, the rise of reactive nitrogen to dangerous levels.

BY GBSNP VARMA

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f your hippocampus has of late been focused on carbon emissions, warming, heat, floods and fires and species loss, it is probably oblivious to a far more elemental broth that is brewing. Nitrogen compounds are present in the air we breathe, the water we drink, the land we live on. Excessive concentrations of these compounds in soil, water, and air are wrecking the environment at local, regional, and global levels. We're affected on multiple fronts by them. Indeed man-made forms of reactive nitrogen are accumulating far beyond nature's capacity to neutralise them, making the nitrogen cycle the most anthropogenically disturbed elemental cycle on earth.

Carbon (C), oxygen (O), nitrogen (N), phosphorus (P), and sulphur (S)—are essential for life. Except for nitrogen, all are available in forms usable by living organisms. Although nitrogen comprises 78 per cent of the atmosphere as a gas, plants cannot use it directly. They get it as usable nutrients like ammonium and nitrate ions. Plants, however, can directly absorb oxygen and carbon dioxide.

According to a 2003 review, published by James Galway and others in *BioScience*, more than 99 per cent of atmospheric nitrogen is unavailable to more than 99 per cent of living organisms. Nitrogen atoms are held

together by a triple bond so strong that it is practically impossible to break, except in high-temperature, high-pressure processes. But life as we know it is not possible without nitrogen.

So it needs to be converted into usable forms. Nature transforms nitrogen in two ways: with the help of enzymes, soil bacteria alter chemically inactive nitrogen gas into usable forms—called biological nitrogen fixation (BNF)—or through lightning. It breaks the nitrogen molecules, helping them combine with oxygen and forming nitrogen oxides, which then mix with rain, producing nitrates and fertilising the soil.

Some nitrogen oxides and ammonia emitted by human activities from the earth also dissolve in rain water to return to earth. This is called wet deposition. There is also dry deposition as reactive N compounds in particulate matter, especially PM2.5.

In nature, therefore, two groups of nitrogen are available: chemically inactive (N) and reactive (Nr) compounds such as ammonia (NH_3) and ammonium [NH_4^+], nitrogen oxide [NO_x], nitric acid [HNO_3], nitrous oxide [N_2O], and nitrate [NO_3^-], and urea, amines, proteins, and nucleic acids.

Before human civilisation became a factor, the natural process of N to Nr and back was both efficient and sufficient. Plants took Nr compounds, used them, grew, died, decomposed, and Nr went back to N in a process called denitrification. What humans could not absorb they excreted and it too was recycled. The cycle left no excess Nr in the environment.

In the last few decades, however, according to the review, the Nr load is increasing exponentially in the environment, at every level. There are three main causes: “Widespread cultivation of legumes, rice, and other crops that promote conversion of N_2 to organic N through BNF; combustion of fossil fuels, which converts both atmospheric N_2 and fossil N to reactive NO_x ; and the Haber-Bosch process, which converts nonreactive N_2 to reactive NH_3 to sustain food production and industrial activities.”



The amount of human-created reactive N is staggering, especially the rate of increase. From 1860 to 1960, anthropogenic Nr was relatively slow to rise; but modern agriculture was responsible for an increase from approximately 15 teragrams (Tg) N per year in 1860 to approximately 33 Tg per year in 1960 to a whopping 165 Tg per year in 2000. (One teragram is equal to one million tonnes.) We have used fossil fuels like coal for millennia but the Industrial Revolution and the massive rise in hydrocarbons use led to an increase from less than 1 Tg per year in 1860 to approximately 25 Tg in 2000. Nr from the Haber-Bosch process was zero before 1910; it was more than 100 Tg per year in 2000, with about 85 per cent used in the production of fertiliser.

Nitrous oxide as a greenhouse gas is 300 times more powerful than carbon dioxide, yet governments and the public only think of carbon when they talk of climate change. The planetary overloading of nitrogen has happened right under our nose, but beyond our vision.

According to an estimate from Peter Vitousek of Stanford University, half the fertiliser produced industrially in human history has been used since 1984.

“Between 1860 and 2000, the anthropogenic Nr creation rate increased from approximately 15 Tg N per year to approximately 165 Tg N per year, with about five times more Nr coming from food production than from energy,” the article states. The increase in the rate of creation is no match for the rate of denitrification.

Nitrogen is an inert gas, and is not toxic, nor is it a pollutant. Reactive nitrogen compounds are nutrients that flow through soil, air, water, into the food chain, into humans, and back into the environment through excreta and urine. All of this is broken down by natural processes and nitrogen returned to the environment as N. But the excess piles up and this is the problem. Reactive nitrogen is being produced at a rate that the biosphere cannot handle.

Galloway explains what a single atom of Nr can do in Scott Field’s article—“Global Nitrogen: Cycling out of Control” (*Environmental Health Perspectives*, 2004) in this way:

“If you put a molecule of NO_x in the atmosphere from fossil fuel combustion or a molecule of ammonium on an agricultural field as fertilizer, you have a cascade of effects that goes from acid rain to particle formation in the atmosphere, decreasing visibility and causing impacts on human health, acid rain, soil and stream acidification, coastal eutrophication (nutrient enrichment), decreasing biodiversity, human health issues in groundwater, and nitrous oxide [N_2O] emissions to the atmosphere, which impact the greenhouse effect and stratospheric ozone.”

Nitrous oxide as a greenhouse gas is 300 times more powerful than carbon dioxide, yet governments and the public only think of carbon when they talk of climate change.

The planetary overloading of nitrogen has happened right under our nose, but beyond our vision. According to Rockstrom and colleagues (*Nature*, 2009) Nr pollution crossed the planetary boundaries long ago, making it impossible to repair and recover much of the damage, which includes loss of some biodiversity. For the last 20 years, the nitrogen community has been sounding the alarm.

The Indian nitrogen community is at the front line of efforts to address the crisis, at par with developed countries, as India, too, is a contributor to and is affected by nitrogen pollution. The government even hosted a special session

on reactive nitrogen as a part of the World Environment Day in New Delhi on June 1-5, 2018.



We are all in it unknowingly, but Prof Nandula Raghuram, Prof Yash Pal Abrol and their colleagues are aware of the nitrogen issue. They have quietly prepared the country for over 15 years, organising interdisciplinary team of scientists to gather all available scientific information for informed decisions and action. Unasked and unsupported by the government, their efforts culminated in the publication of *The Indian Nitrogen Assessment* by Elsevier in late 2017. It is the most comprehensive document detailing the sources of reactive nitrogen, environmental and climate effects, trends from the past to present and future outlook, management options and policies.

The biggest beneficiary of this assessment is the government, giving it the know-how to deal with Nr pollution in a timely manner. It could also help India to change from a reactive, defensive, at times stonewalling player in international environmental diplomacy to a potential leader in efforts to repair the environment.

What Raghuram was not aware of or, perhaps, did not foresee, is how nitrogen would shape his thinking on India's environment, economy and politics, apart from his own research plans. "It's the dilemma between primary research that generates more and more data about less and less (aspects of a larger problem) and secondary research that aggregates primary research into more usable scientific decision support systems for policies and action for national development. While primary research is most incentivised by the government and brings all the personal glory, awards and rewards, I realised that spending a part of my time on secondary research brings a lot more personal fulfilment and satisfaction of contributing to the country," he says.

When Raghuram started his career as a biologist in Mumbai 20 years ago, he began to see references to reactive nitrogen as an environmental issue. Till then, he had only thought of it as an economic issue and wanted to study how to improve the efficiency of nitrogenous fertilisers in rice to save input costs. Between 1997 and 2002, when he was in the city, he wanted to check his own assumptions with those of soil scientists, agronomists and others on how to improve N use efficiency.

Whenever he visited Delhi, he would meet Yash Pal Abrol, professor in plant physiology at the Indian Agricultural Research Institute (IARI). When he moved to Delhi in 2002, they held wider consultations with scientists from IARI, National Physical Laboratory and elsewhere, before forming the Indian Nitrogen Group in 2004. They got small grants to hold meetings and national consultations from relevant ministries that eventually flagged reactive nitro-



Professor Nandula Raghuram (left), presented the 'India Nitrogen Assessment' at the UN earlier this year. Photo: Special arrangement

gen in their thrust areas, but projects for a comprehensive Indian nitrogen assessment were never funded.

Raghuram's interest in nitrogen use efficiency in rice emerged as a spin off from his own doctoral research. He worked under Prof. Sudhir Sopory (Bhatnagar awardee and later Padma Shri) at New Delhi's Jawaharlal Nehru University. His thesis was on the light regulation of nitrate reductase in maize, the first enzyme of nitrate metabolism. His research showed that nitrate is the primary trigger for nitrate reductase gene expression, while light only adds to it, reversing the two-decade logic of his lab.

By the time he got his first faculty position in Bombay University, his interest crystallised around how plants respond to nitrate (rather than how light regulates plant genes). He hypothesised that given the uncertainties in nitrate availability in the soil, plants with a better ability to sense and use available nitrate and other forms of Nr in the soil would use nitrogenous fertiliser more efficiently than others.

But this is a problem that remains unsolved till date and so he consulted Abrol, a veteran in the field of nitrogen response in wheat and rice. He also happened to be Raghuram's Ph.D. examiner. The discussions not only encouraged him to stick to his research plan, but broadened into the environmental aspects of Nr, from the economic or cost-saving aspects. His journalistic ex-

perience at the Centre for Science and Environment helped him connect the dots and read between the lines in the early literature and imagine what would eventually become the writing on the wall.

Abrol who did his Ph.D from the University of Chicago, and post doctoral work at the University of California, was a scientist at IARI until retirement in 1995. As a member of the interdisciplinary nuclear research group during his initial years at IARI, he had a broad idea of things happening with nitrogen. Later, he worked on the physiological and biochemical aspects of N-response and NUE in wheat and rice crops under field conditions for many years.



Nature fixes nitrogen in the soil through leguminous plants like beans which have microorganisms in their root nodules that convert nitrogen gas into ammonium ions. It can also be done by some free-living microbes. Other microbes then convert those ions into nitrites, which in turn get converted into nitrates, a process called nitrification. Such compounds are also generated by microbial decomposition of dead plant and animal organic matter in the soil. This allows even non-legumes and other plants that do not have symbiotic microbes, like cereals, vegetables, fruits, flowers, grasses and forest plants to obtain ready-made reactive nitrogen compounds from the soil.

These are the reactive nitrogen compounds. Plants use only a fraction of what is available; a lot is lost in the soil. These compounds undergo a lot of conversions under different atmospheric conditions. Humans and animals get their share in the form of plant and animal products. Reactive N enters the food chain from plants into herbivores, then into carnivores that eat the herbivores, to eventually reach the human diet as vegetarian or non-vegetarian food. Their digestion generates organic N (amino acids, nucleotides, etc.) that are recycled in the body and excess N is excreted.

So far so good, but the first major wrinkle was the Industrial Revolution, which brought in more forms of nitrogen fixation than pulse production. The Haber-Bosch process was first used to make bombs in the First World War. Later, it was used to produce industrial fertiliser. The Industrial Revolution was premised on steam power which required an unprecedented

amount of coal burning (and later petroleum). That produced Nr compounds as by-products, further loading the nitrogen cycle.

Industrial production of reactive nitrogen compounds, whether ammonia, nitrites or nitrates, dominates the nitrogen cycle today. “The biogeochemi-

The first major wrinkle was the Industrial Revolution, which brought in more forms of nitrogen fixation than pulse production. It was premised on steam power which required an unprecedented amount of coal burning (and later petroleum). That produced Nr as by-products, further loading the nitrogen cycle.

Fertiliser is the main source of agrarian nitrous oxide emissions. But agriculture is not just crops. It includes poultry, animal husbandry, fisheries and aquaculture. Globally half of all Nr emissions are from animal farming and food processing wastes.

cal cycle of reactive nitrogen is the most anthropogenically altered elemental cycle,” Raghuram says. Globally, 70 per cent of Nr goes waste, into the soil, water or atmosphere.

(‘Biogeochemical’ means all the elements present in nature—oxygen, calcium, phosphorus, and so on—in inorganic matter and organic matter, are constantly cycling between these two. Some go into water, some into ground water, some into the food chain, from where they go out as excreta and urine. N species are the most anthropogenically altered species.)

Galloway and his colleagues in America estimated in 2011 that of all the synthetic N fertiliser used for crop production, only 14 per cent eventually reaches the dinner table if you are a vegetarian, and 4 per cent if you are a non-vegetarian, due to N-losses along the food chain.

Raghuram realised that sources of nitrogen pollution differ from country to country. Agriculture, sewage, domestic and municipal, fossil fuels, industry—anything can be a source. Unabsorbed fertiliser in farms, however, is the biggest human-driven source of nitrogen pollution.

“Fertiliser is the main source of agrarian nitrous oxide emissions,” he says. But agriculture is not just crops. It includes poultry, animal husbandry, fisheries and aquaculture. “Globally half of all Nr emissions are from animal farming and food processing wastes,” he adds.

“This meant that my research idea of fertiliser N use efficiency covers only half the story. There is the other half of ‘full chain nitrogen use efficiency’, which may vary for each country as per its own production systems and consumption habits. This makes it all the more necessary for each country to assess its own main sources of reactive N leakages for informed decisions.”

Indian farmers, unable to afford labour costs, dump fertiliser in one or two huge doses, which plants cannot use properly. “It’s like one or two meals for a whole lifetime. How much can you eat? You starve the rest of the time,” Raghuram says.

The unused fertiliser, mostly for cereal cultivation, contaminates soil, water, and air. Government policies such as support price, and guaranteed uptake for rice, wheat and sugarcane has shifted cultivation towards these crops and away from pulses and cereal-pulse rotation, which traditionally kept soils fertile by fixing nitrogen.

Chemical fertiliser is not required in massive doses. The excessive focus on cereal yields for food security means that cereal production has increased, but pulses have lagged for the last 15 years. But cereals, often grown in unsuitable agro-climatic zones, require fertiliser and have depleted water tables. So what we also lost in the process is nitrogen-use efficiency in crop production.



In 2016, India used 30 million tonnes of urea (₹5,400 per tonne), which comes to ₹16,200 crore. More than 70 per cent of this is wasted money. Since urea has a 75 per cent subsidy, it means that while the farmer harvests nearly what he pays for (25-30%), the government subsidy of about ₹12,000 crore only pollutes the environment.

“There is an invisible Nirav Modi in every heavily-fertilised farm in India,” he says.

In China, nitrogen pollution is mainly from cash crops or horticulture, whereas livestock farming is the culprit in Europe and both crops and livestock in North America. Africa, on the other hand, has the reverse problem of too little nitrogen in the soil, similar to the rainfed areas of Indian agriculture.

With such abysmal levels of nitrogen use efficiency and costs to human life, they started to think about an assessment of how reactive nitrogen is moved.

Although reactive nitrogen has more extensive consequences for humans, public discussions centre on carbon: emissions, trading, emission cuts and so

on. Intergovernmental discussions too have been carbon-centric. There were no discussions on or solutions for nitrogen.

After struggling with the early reports of IPCC in the early 1990s, Indian scientists were able to prove that methane emissions from livestock in developing countries did not match carbon emissions from developed countries. The average diet of Indian cattle and therefore their body weight and emissions were far lower than those of the developed countries. Moreover, the industrial and vehicular emissions of developed countries were far higher. So they concluded that the West could not impose on developing countries for filling up the hole they had punched in the atmospheric equilibrium. They could not apportion blame equally on other countries.

The challenge for developing countries to bring together scientific talent and adopt an interdisciplinary approach to find answers is immense, especially as Indian scientists often work in isolation from each other, even in the same field. Here was a case where the carbon cycle—from photosynthesis

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in plants to hydrocarbon emissions, household dung-cake burning—needed quantitative assessment. The cycle encompasses a huge range of activity, encompassing many sectors and industries, some organised and some unorganised. The emissions from diverse sectors needed to be expressed in precise quantities.

Taking the cue from some NGOs that bridged the institutional rigidities and collected government data more efficiently than government institutions, the Indian Nitrogen Group worked under the “Society for Conservation of Nature” a registered NGO founded by Abrol. In the era of climate change where data is necessary, governments need to reorient their scientific communities to come together, as Raghuram says, “like a rapid action force”, should some urgent international challenge come up.

Abrol, now 83, learnt about the International Nitrogen Initiative well after retirement, in 2004-5. James Galloway, who spearheads it, was in town. Abrol met him, and requested him to hold the next international conference in Delhi. Since the triennial had just been held in China, Galloway said the 2007 conference was in Brazil, but promised to hold it in India in 2010

He says there were innumerable hurdles to organising it. First, he requested ICAR’s director-general Dr Ayyappan to give them some space as they were operating out of his house. Ayyappan got space in the national agricultural science complex for the Society for Conservation of Nature (SCON).

For the conference, they pooled the money saved from their previous workshops. Galloway also helped get some funding from UNEP and the fertiliser industry.

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It is acknowledged that nitrous oxide is 300 times more powerful as a greenhouse gas than carbon dioxide. It is also known that small increases in it cause far more lasting damage than large increases in carbon dioxide. The nitrogen group felt the country should not be caught flat-footed if and when the nitrogen crisis began to register on the international radar. So they applied for a government grant to do a comprehensive study, but they did not get even working support.



Tapan Adhya, honorary director, South Asian N Centre of the International Nitrogen Initiative.
Photo: Special arrangement.

Undaunted, they revived SCON, which was in suspended animation for some years. They started talking among themselves without the government asking them to do so. They knew what was happening in the fields and saw the nitrogen crisis before any politician or bureaucrat could.

So they created an Indian Nitrogen Group (ING) under SCON. They pooled time and resources, chatted in Abrol's home for long hours. The nitrogen issue only got bigger after every meeting, and the challenge more daunting. Scrounging from many sources, they held dozens of workshops and meetings, mainly in Delhi. They spent weekends and holidays chasing reactive nitrogen, worked from their homes, reading and aggregating, compiling, and collating scattershot data, despite official indifference. With government support and funding they could have done it two, three years. Without that, it took 10 and happened in phases.

In 2004, they began identifying who was well-informed about reactive nitrogen in their respective fields—in crop-based, fertiliser based agriculture, in livestock, poultry, fisheries, automobile and energy—through national academies, industry associations and other contacts, and asked them for status reports.

By 2007, they had put out the first-ever book on reactive nitrogen in India, a 500-page tome on industry, environment and agriculture. The book was released at the 4th International Nitrogen Conference in Brazil. Leveraging the book, Raghuram successfully bid for the next triennial conference in Delhi (2010) and also to establish the South Asian Nitrogen Centre for the International Nitrogen Initiative, founded a few years earlier by Jim Galloway.

In 2008, when *Current Science*, considered the mouthpiece of Indian science, was celebrating C.V. Raman's centenary, Raghuram persuaded then editor, Prof. Balaram, to devote a special issue to reactive nitrogen. The peer-reviewed special issue, containing a dozen articles covering the major aspects of reactive nitrogen in

India, had a great impact and obtained many more citations than the average impact factor of the journal.

In 2009, when the UN Environment Programme (UNEP) established the first Global Partnership on Nutrient Management (GPNM) under its Global Programme of Action (GPA) for Prevention of Marine Pollution from Land-based Sources, Indian Nitrogen Group became a founding member and Ra-



Yash Pal Abrol, a founder-member of the Indian Nitrogen Group.

Photo: Yash Pal Abrol

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ghuram continues to be on its steering committee. Its initial emphasis was on nitrogen and gradually expanded to phosphorus and beyond. He emphasised national and regional nitrogen/nutrient assessment as the pillar of any international nitrogen management system (INMS), which has since been accepted by UNEP and is now under implementation.

Between 2009 and 2010, they published 19 bulletins, each devoted to a sector, of 50-100 pages, a detailed state-of-the-art reports of the nitrogen cycle in particular areas like rice and wheat, livestock, aquaculture, automobiles, biofertiliser, health, and so on. They were refining their work. These bulletins were released at the 5th International Nitrogen Conference in Delhi in 2010. Raghuram and Mark Sutton drafted the Delhi declaration, an important step forward on reactive nitrogen. Some of the negotiation principles of the carbon era—polluter pays, historic emissions, common but differentiated responsibility, etc., were included and other areas of concern for developing countries were strengthened and adopted.

When Raghuram went to the UN headquarters in Geneva earlier this year to present the *India Nitrogen Assessment*, he learnt about India being the host of World Environment Day. He also learnt that the UN environment programme opened a permanent office in Delhi last year and was likely to be involved in the World Environment Day in a big way. This provided an opportunity to bring nitrogen to the high table of government and intergovernmental bodies.

The first ever nitrogen session was hosted by the government at Vigyan Bhavan, New Delhi, on June 4, with the theme “Nitrogen: Joining up for a Cleaner Environment.” Raghuram presented the highlights of the Indian Nitrogen Assessment, with 31 chapters by over 60 authors, covering every sector that produces or is affected by reactive nitrogen. Every aspect of reactive nitrogen is covered.

Abrol recalls that they had no funding for the *Assessment* and little encouragement. He was turned down everywhere he went. When he met people beyond his discipline, some were enthusiastic, while others rejected the idea. One oceanographer told him to mind his own business.

“You’re in agriculture, you mind your own business, why do you come into oceans,” Abrol remembers him saying.

“In India,” says Abrol, “we write review articles, that somebody said this and that, quote mostly American and European literature.” Assessment, he contin-

ues, is finding out where we stand; so far as nitrogen is concerned, where it's put, where it's going, what are the leakages, and so on, collected from Indian literature and field studies.

American and European governments spent millions on their assessments but, "We documented everything without taking any money. We didn't get money from any source."

Tapan Adhya who succeeded Raghuram as honorary director of the South Asian N Centre of INI, knows how the bureaucrat's mind works. When he was trying to explain the nitrogen crisis to a secretary in the ministry of environment, he said it was not their problem, but the agriculture department's, "as if agriculture is something that happens outside of and is unrelated to the environment. They don't look for interconnections."



The assessment is a significant achievement. With this report India will have the tools to provide answers if IPCC-like negotiations take place on reactive nitrogen.

"In fact, India could even lead it on the world stage if the government decides. We are ready with the science support system in place if and when needed," says Raghuram.

The ING became the regional hub for International Nitrogen Initiative and now leads the South Asian Nitrogen Assessment as part of the GEF-funded UNEP project on "International Nitrogen Management System". In fact, Raghuram championed the importance of a regional N assessment for the accuracy and credibility of any international management system.

India's traditional posture in the international environmental diplomacy has so far been the reactive, stonewalling and delaying kind. The invariable stand is, "We have to alleviate poverty, we cannot slow down development and care for environment because of our poverty". The fact, though, is we have neither removed poverty nor addressed the environment.

It suited India to strategically mix self-pity and a "when-we-look-in-a-mirror-God-looks-back-at-us" kind of grandiosity.

At present the world seems to be in a state of "environment fatigue". US President Donald Trump more often walks out of than into anything. Europe, which did far more legislating than other countries on climate change, is grappling with a migrant crisis.

There is a vacuum in environmental leadership. Although China is pushing hard to fill it, the world prefers India, because of its democracy and diplo-

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THE INDIAN NITROGEN ASSESSMENT

- Agriculture is not only adversely affected by climate change, but also contributes to climate change. Agricultural soils contributed to well over 70% of N₂O emissions from India in 2010, followed by wastewater (12%), residential and commercial activities (6%).
 - Chemical fertiliser (over 82% of it is urea) accounts for over 77% of agricultural N₂O emissions in India, while manures, compost etc. make up the rest. Most of the fertilizers consumed (over 70%) go into cereals, especially rice and wheat, which accounts for most of the N₂O emissions from India. This makes them the focus of NUE.
 - Nutrient recovery/recycling from wastewater for agriculture could cut down N₂O emissions from sewage and wastewater by up to 40%.
 - Non-agricultural emissions of N₂O and NO_x are growing many fold faster, with sewage and fossil fuel burning leading the trend, indicating that arresting the growth of emissions from these sectors may be as important as reducing urea consumption. Indian NO_x emissions grew at 52% between 1991-2001, but 69% between 2001-2011 and probably higher thereafter. Annual NO_x emissions from coal, diesel and other fuel combustion sources are growing at 6.5% per year currently, at par with GDP growth. The introduction of Euro-6 diesel and electric vehicles in India could reduce them.
 - Crop residue burning contributes over 240 Gg (1 Gg = 100 tonnes) of NO_x and about 7 Gg of N₂O per year, while only particulate matter makes media headlines. There are many more harmful emissions and loss of most crop nutrients and health impacts due to air pollution.
 - Water pollution (ground/surface water) with reactive N such as nitrate, nitrite, ammonium, urea etc., emerging from unused fertilizers, sewage etc., not only makes such water unfit for drinking, but also promotes algal growth and eventual eutrophication, death of fish and other ecosystem services and livelihoods. The ground water nitrate levels in many parts of India have exceeded the WHO safety limit for potable water. Surface water is not far.
 - India currently loses Nr worth billions of dollars every year as fertiliser value, but adding its costs to health, ecosystems, and climate could push the cost up to US\$75 billion per year in 2015. Avoiding such costs need appropriate policies/technologies.
 - Since the neem-coated urea policy and 10% reduced bag size of urea has been introduced by the Indian government, there has been a deceleration in urea consumption and even slight decline from peak levels. Therefore, India may arrest the growth of nitrous oxide from agriculture, will need major focus on NO_x and NH₃ emissions in future.
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macy. Moreover, because of continual economic growth, contributions from China and India to the UN have grown, and the gap between them and the West is decreasing. India now knows doing nothing is not an option. It is committing to more ambitious goals for sustainable development although implementation is lacking on many fronts.

But with studies such as the Indian Nitrogen Assessment available for ready reference, its scientists are better prepared to play a substantive role than in the past. It has an opportunity to project itself a leader, moving to a proactive leadership role.

“The Indian Nitrogen Assessment is the first such integrated nitrogen perspective for anywhere in Asia. It clearly highlights the critical role India has to play in the global nitrogen cycle,” says Mark Sutton, a professor at NERC Centre for Ecology & Hydrology, Edinburgh Research Station, U.K., and Chair, International Nitrogen Initiative (INI).

As Sutton details, India has some of the worst air pollution, much of it linked to nitrogen compounds as ammonia from agriculture and nitrogen oxide from combustion sources react to form fine particulate matter. At the same time, water pollution by nitrate and other nitrogen compounds worsens the problem, affecting drinking water quality, freshwater ecosystems and creating coastal dead zones. There is a major case for India to champion better management of nitrogen especially as it spend billions of dollars annually on fertiliser subsidies. Better nitrogen management would simultaneously offer cost savings for the government and a cleaner environment.

According to the report, nitrogen oxide emissions show a 6 per cent annual increase, which is bad news. “The scale of the nitrogen crisis, with extremely low nitrogen use efficiency, highlights the potential of Indian leadership as a global nitrogen champion,” says Sutton.

Sutton’s research centre is working with Raghuram and is leading the NEWS India-UK virtual joint centre on agricultural nitrogen, providing primary research on how to improve nitrogen use efficiency and reduce pollution.

“Following on from India’s success in hosting World Environment Day 2018, there is now a perfect opportunity for India to alert the UN to the global nitrogen challenge,” Sutton says.

The 53-old Raghuram has not given up his primary research all along. His work on “identifying the phenotype and genotype for nitrogen efficiency in rice” goes on in his lab at the School of Biotechnology, Guru Gobind Singh Indraprastha University. His primary research is well funded and his lab has grown over the years with projects worth a few crores

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from DST, DBT, IACR, UGC and CSIR.

He is also leading an Indo-UK “Virtual Nitrogen Centre” with Mark Sutton, involving partners from IARI, Aligarh Muslim University, Indian Institute of Rice Research, Hyderabad and National Rice Research Institute, Cuttack on the Indian side and the Centre for Ecology and Hydrology, University of Edinburgh and University of Aberdeen on the UK side.

“We have identified thousands of nitrate-responsive and urea-responsive genes in rice and are comparing them between more N-efficient and less N-efficient cultivars of rice and have shortlisted less than a hundred genes for further testing before publishing our results”, he says.

“We also identified a few simple plant phenotypic characters associated with nitrogen use efficiency and have submitted them for publication. But primary research of this kind is a painfully slow process and it is too early to say how soon and how much improvement in N use efficiency we can achieve from the rice plant. What is certain is that improvements are also required in fertiliser formulation, dosage, frequency and method of application, apart from manure and crop residue management and soil health to achieve drastic enhancement in N use efficiency”.

With reactive nitrogen, the past is never dead, nor the present ever finished.

