

Reflection

From South Asia to the world: embracing the challenge of global sustainable nitrogen management

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South Asian regional cooperation with the International Nitrogen Initiative and the India-led UN Resolution on Sustainable Nitrogen Management (UNEP/EA.4/L.16) brought South Asia into global focus. Here, we reflect upon its proactive scientific community, growing scientific capacity, and international collaborations, which have enabled the emergence of the UKRI-GCRF South Asian Nitrogen Hub, which has great potential both regionally and globally.

Introduction

Reactive nitrogen (N_r) can be a boon in the right place and a bane in the wrong place. Elemental nitrogen (N₂) is predominant in the air we breathe (78%) and is relatively unreactive and harmless. However, N_r compounds containing oxygen, hydrogen, or carbon—although essential for the very existence of life on this planet—threaten its sustainability when they accumulate in the environment. The voluntary efforts of scientists globally to bring international and intergovernmental attention to N_r over the last two decades culminated in the India-led Resolution on Sustainable Nitrogen Management (UNEP/EA.4/L.16)¹ adopted at the 4th UN Environment Assembly (UNEA4) in March 2019. This article reflects on the emergence of South Asia as a major hub of these efforts and its future potential.

The biogeochemical cycle of N_r depends on the abiotic and biotic worlds for interconverting its inorganic and organic forms to sustain the planet. This involves “fixation” of some atmospheric N₂ into N_r and “denitrification” of excess N_r back to N₂. Since the invention of agriculture in Asia over 11,000 years ago, exploiting natural biological nitrogen fixation in symbiotic legumes has supported human population growth and civilization sustainably for millennia.² The industrial

era brought in N_r emissions as by-products of the combustion of fossil fuels for energy and transport, and the advent of the Haber-Bosch process after 1908 enabled industrial nitrogen fixation, initially for fertilizers and later for war munitions. The resulting anthropogenic conversion of atmospheric nitrogen into reactive forms exceeded all of Earth's terrestrial processes combined by well over 2-fold.² This nitrogen pollution continues unabated today with the accumulation of oxides of nitrogen (NO_x), ammonia (NH₃), or nitrous oxide (N₂O) in air and nitrates (NO₃⁻) in water, among others. They have been affecting our health, causing eutrophication of water bodies, altering biodiversity, and worsening climate change. N₂O is a greenhouse gas with 298 times more global warming potential than CO₂, whereas NO_x has ten times more potential. In addition, NO_x pollution has serious implications for human health, including respiratory disorders due to NO₂³ (Figure 1). Nitrates and NH₃ can contribute to fine particulate matter (PM) in air, constituting up to half of the constituents of PM 2.5 and PM 5, causing serious respiratory, cardiovascular, and other diseases over prolonged exposure. The World Health Organization (WHO) estimates that globally, over 7 million people die each year as a result

of PM pollution (<https://www.who.int/airpollution/en/>). The UN Environment Programme (UNEP) recognized N_r as one of the emerging threats to the planet in its Frontiers 2018/19 report.⁴ This report provided timely impetus to the UNEA4 Resolution on Sustainable Nitrogen Management,¹ which itself emerged in South Asia and was led by India.

Why South Asia?

South Asia is one of the most populous and fastest growing regions in the world. With less than 5% of the world's land mass, 14% of global arable land, 2.73% of the world's forest area, and 4% of the world's coastline, it supports over 25% of the world's population or over 45% of Asia's population. The region's ecosystem services are under pressure, and its countries are already parties to all three Rio Conventions (UN Framework Convention on Climate Change [UNFCCC], Convention on Biological Diversity [CBD], and UN Convention to Combat Desertification), the Manila Declaration (2012) on nutrient pollution, and the Global Partnership on Nutrient Management. There are several South Asian regional intergovernmental mechanisms, such as the South Asia Co-operative Environment Programme (SACEP), the South Asian Seas Programme, the South

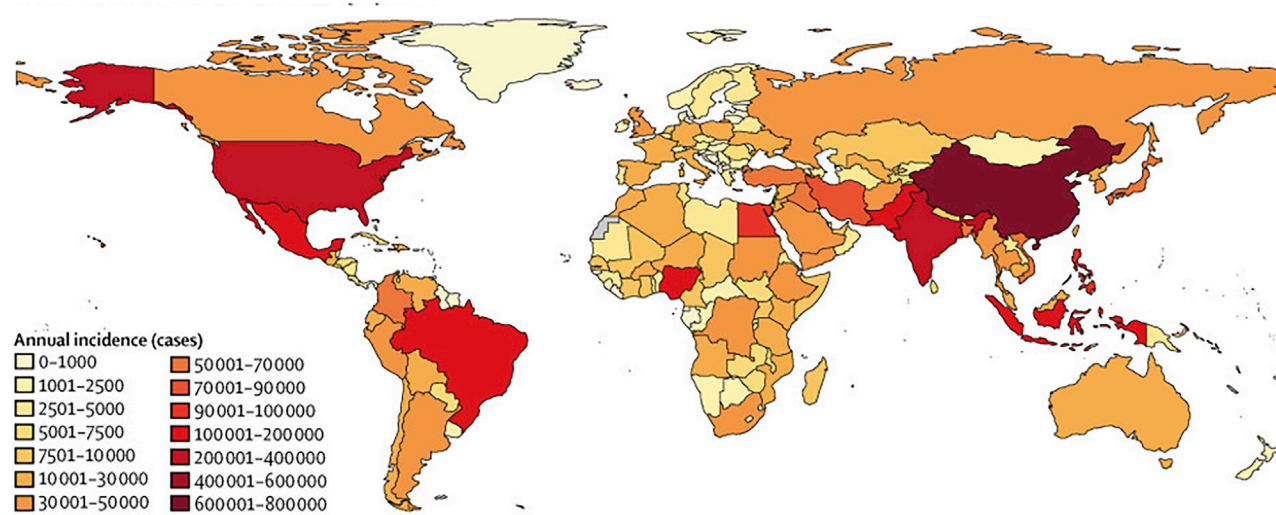


Figure 1. National annual estimates of the number of new asthma cases attributable to ambient NO_2 exposure for children aged 1–18 years
Data are from Achakulwisut et al.,³ who derived the values shown by using the central mean relative risk estimate and assuming a counterfactual NO_2 concentration of 2 parts per billion.

Asia Environment and Natural Resources Information center, the South Asia Coral Reef Task Force, the Malé Declaration on Control and Prevention of Air Pollution and its likely transboundary effects, and the South Asia Biodiversity Clearing House Mechanism.

Although the South Asian Nitrogen Assessment is still underway, it is becoming increasingly clear that South Asia is one of the global hotspots for N_r pollution in that NO_x , N_2O , and NH_3 are causing air pollution^{5,6} and nitrates are causing water pollution.⁷ In relative quantitative terms, water pollution seems to be the highest in the region, and this is followed by air pollution due to ammonia, NO_x , and N_2O in that order.⁸ Agriculture and livestock are the major contributors to ammonia and N_2O pollution of air, and sewage is fast emerging as a major contributor to nitrogenous air and water pollution in the region. Indeed, N_2O replaced methane as the second most important greenhouse gas from Indian agriculture over 15 years ago, and this could be true for other major agrarian countries in the region. Recent global estimates of the incidence of childhood asthma attributable to NO_2 air pollution (a major constituent of NO_x) indicate its importance in South Asia as well (Figure 1). The contribution of NH_3 , nitric acid (HNO_3), and other N compounds to PM is a serious issue in South Asia. According to the WHO, most of the

world's worst cities in terms of PM 2.5 pollution are in South Asia, which also accounts for the largest number of deaths due to air pollution globally (<https://www.who.int/airpollution/en/>). Building on the global awareness of nitrogen pollution developed by the International Nitrogen Initiative (INI), the Indian Nitrogen Assessment included a review on the health impacts of N_r .⁹

The INI and the Indian Nitrogen Group

The need for an international organization to highlight the scientific and policy aspects of N_r was first felt in 1998 during the First International Nitrogen Conference held in the Netherlands and crystallized in 2001 during the Second International Nitrogen Conference held in the US. The INI's eventual formation in 2003 was co-sponsored by the Scientific Committee on Problems of the Environment and the International Geosphere-Biosphere Program, both originally established by the International Science Council (then the ICSU). The INI's main goal has been to optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects on human health and the environment from food and energy production. It grew rapidly with regional representatives in North America, Latin America, Europe, Africa, Asia, and now Australia (<https://initrogen.org/>).

Around the same time, the Indian Nitrogen Group (ING) was independently taking shape as a voluntary network of Indian scientists under the Society for Conservation of Nature (SCON), a registered non-governmental organization (NGO) based in New Delhi (<https://www.scon-india.org/>). Soon, the ING and INI came into contact with each other and set up a South Asian Nitrogen Centre for the INI (Figure 2), and China continued to represent the countries of East Asia. Over the years, the INI has become a major international voice on scientific and policy aspects of N_r . It has been consistently highlighting the growing importance of N_r through scientific collaborations, science dissemination, policy messages, and stakeholder engagement with governments, the UN, civil society, and the fertilizer industry. The INI's policy briefs and conference declarations have been as important as research articles in mobilizing wider awareness. The INI's Third International Nitrogen Conference (2004) brought out the Nanjing Declaration on Nitrogen Management. This was followed by the Delhi Declaration on Reactive Nitrogen Management for Sustainable Development (2010), the Kampala Statement-for-Action on Reactive Nitrogen in Africa and Globally (2013), and the Melbourne Declaration on Responsible Nitrogen Management for a Sustainable Future (2016) during the fifth, sixth, and seventh INI

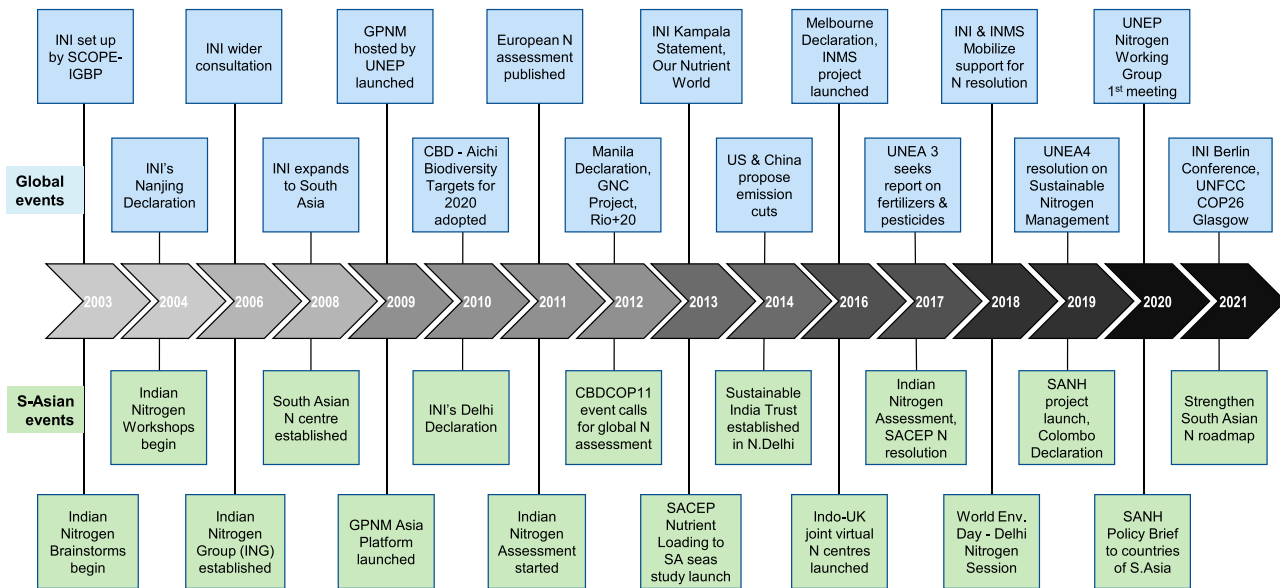


Figure 2. Timeline of global and South Asian developments toward global cooperation on sustainable nitrogen management
The events above the timeline depict international developments, and the events below the timeline depict South Asian developments.

conferences, respectively (Figure 2). They were all submitted to UN agencies and disseminated widely among all stakeholders. The forthcoming eighth INI conference in Berlin (2021), sponsored and hosted by a national government (Germany) for the first time, amply indicates the INI's impact on the global nitrogen landscape.

Synergy with the UN

The INI and its South Asian representatives had important roles in ensuring that nitrogen became an important focus in the Global Partnership on Nutrient Management (GPNM), currently chaired by India, under the UNEP Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities. Nutrient pollution due to nitrogen and phosphorus compounds that cause eutrophication of marine ecosystems mostly emerged from terrestrial activities such as agriculture and industry and needed to be addressed at the source. The representation of the INI chair and the ING on the GPNM steering committee, as well as the establishment of its nitrogen-use efficiency (NUE) task force, provided a strong impetus for the UNEP to engage with nitrogen. Its Asia focus was obvious in the GPNM's Global Nutrient Cycling project, funded by the Global Environment Facility (GEF) and im-

plemented by UNEP (2012–2016). It mainly focused on two highly populous but contrasting developing-country sites, the urban Manila Bay in the Philippines and the rural Chilika Lagoon on the east coast of India. An interesting insight that emerged during this project was that the nutrient pollution of Manila Bay was not entirely urban and was also affected by agricultural runoffs into the adjacent lake, Laguna de Bay (<https://www.unenvironment.org/news-and-stories/story/paralysed-growth-lake-under-siege>). Similarly, the nutrient loading of Chilika Lagoon was not entirely from rural or agricultural runoffs and included urban effluents from the nearby urban areas (http://www.nutrientchallenge.org/sites/default/files/documents/files/Chilika%20Rpt%20Card_A4%20web.pdf). These findings highlighted the importance of understanding local and regional linkages to global assessments, especially when they are intended for intergovernmental cooperation.

The success of this project and that of the first global overview on nutrient management¹⁰ prepared by the GPNM and INI led to a dedicated major project on nitrogen. This ongoing \$6 million GEF project is titled "Targeted research for improving understanding of the global nitrogen cycle toward the establishment of an international nitrogen management

system (INMS)." It is being implemented by the UNEP, executed by the INI, and hosted at the UK Centre for Ecology & Hydrology (<https://www.thegef.org/project/targeted-research-improving-understanding-global-nitrogen-cycle-towards-establishment>). It includes tools for understanding and managing the global nitrogen cycle; quantifying N flows, threats, and benefits; and regionally demonstrating the full nitrogen approach, among others (<https://inms.international/>). Learning from the previous global carbon assessments, this project combines seven regional nitrogen studies in all the INI regions, including the first ever South Asian Nitrogen Assessment, due to be published in 2022.

The emergence of South Asian champions

The establishment of the ING in 2006 and the INI South Asian Nitrogen Centre in New Delhi in 2008, which co-hosted the INI's Fifth International Nitrogen Conference in 2010, galvanized interdisciplinary expertise on nitrogen at the national and regional levels in South Asia. This was initially spearheaded by a civil society organization (the SCON) and later by the Sustainable India Trust (SIT), both voluntary NGOs free from institutional rigidities of universities and national laboratories. These organizations also built the agenda

for the International Nitrogen Assessment at a side event during the 11th session of the Conference of the Parties (COP11) to the CBD in Hyderabad, India, in 2012. Event no. 2776, titled “The challenge to produce more food & energy with less pollution: toward a global nitrogen assessment,” was organized in association with the INI and UNEP-GPNM to highlight the linkages between nitrogen, nutrients, and the 20 CBD-Aichi Targets set in 2010 to be met by 2020. However, they remain unmet by most countries to date, although India has exceeded most of its targets (<https://www.cbd.int/aichi-targets/>).

Even as the ING was championing the cause of N_r through brainstorming meetings with various Indian ministries and other stakeholders, the first opportunity for regional intergovernmental engagement in South Asia came in 2013. The SACEP commissioned a study entitled “Nutrient loading and eutrophication of coastal waters of the South Asian seas” under a UNEP-funded project. This scoping study outlined the nitrogen losses to freshwater and marine environments and consequent threats to critical marine habitats and suggested coordinated interventions through intergovernmental cooperation (http://www.sacep.org/pdf/Scoping_study_on_Nutrient_loading_in_SAS_Region.pdf). The acceptance of this study report by South Asian member governments was an important milestone in the regional recognition of N_r as an important issue and laid the foundation for the ongoing South Asian nitrogen assessment. The Global Overview on Nutrient Management¹⁰ mentioned earlier also offered regional insights on nitrogen pollution in South Asia. These efforts demonstrated the scientific capacity and boosted the appetite for national and regional nitrogen assessment as the best way to join global efforts through intergovernmental cooperation.¹¹

After global interest in nitrogen was triggered by the European Nitrogen Assessment,¹² a major impetus for South Asian leadership came from the comprehensive Indian Nitrogen Assessment.¹³ Indian scientists carried it out in citizen-science mode without waiting for the Indian government’s commissioning or funding. They compiled published data on the Indian sources and sinks of anthropogenic N_r in all sectors of human activity and on

the potential to reduce nitrogen pollution and included an assessment of the nitrogen policies and scenarios.¹⁴ Such a national-scale assessment was to provide scientific support to the Indian government for informed domestic actions, as well as for international negotiations on nitrogen. This led to envisaging “India as an emerging nitrogen champion.”⁸ The civil-society umbrella provided by the SCOP and SIT also proved instrumental in formulating the proposal for a preliminary South Asian Nitrogen Assessment under the INMS project. These bodies established a partnership with regional governments through the SACEP, which hosted the first meeting of South Asian partners in Malé, Maldives, in September 2017. Based on the previous INI conference declarations and the Indian Nitrogen Assessment, a draft resolution on “sustainable nitrogen management” was adopted for submission to the UN Environment Assembly. The SACEP mobilized support for its member countries for this resolution, which was submitted to the UNEP by the governments of India, Sri Lanka, and Bangladesh in 2018. The Indian government also highlighted N_r and the Indian Nitrogen Assessment during the World Environment Day celebrations hosted in New Delhi in 2018. Eventually, the nitrogen resolution was piloted and successfully negotiated by Indian diplomats in the fourth UN Environment Assembly (March 2019) with the scientific support of the INI and INMS. The passage of the UN resolution was a historic moment for Indian and South Asian leadership on the global issue of N_r.

Indo-UK virtual nitrogen centers and the South Asian Nitrogen Hub

The above successes were primarily led by scientists and were partly aided by international projects. But they cannot be sustained without liberal investments from the member countries of South Asia and the rest of the world. The Indian government utilized one such opportunity to support research by, jointly with the UK, investing in four virtual centers focusing on rice (Newton-Bhabha Virtual Centre on Nitrogen Efficiency of Whole Cropping Systems [NEWS India-UK]), wheat (Indo-UK Centre for the Improvement of Nitrogen Use Efficiency in Wheat), millets and others (Cambridge-India Network in Translational Nitrogen),

and legumes (India-UK Nitrogen Fixation Centre) during the period of 2016–2019. NEWS India-UK combined plant science, agronomic, and environmental aspects to provide insights on agricultural nitrogen management from the laboratory to the national scale. Its highlights include the phenotype for NUE in rice;^{15,16} emission reduction with neem-coated urea; the potential to replace 50% urea with manure and biofertilizer; whole farm system models for rice, wheat, and sorghum; ammonia inventories; and national budgets for agricultural nitrogen. Another highlight was the development of the first ever massive open online course on N_r, launched in several languages by the University of Edinburgh on the Edex platform (<https://www.edx.org/course/nitrogen-a-global-challenge>).

The success of NEWS India-UK’s bilateral project involving past and current INI chairs, along with their involvement in the GEF-UNEP project on the INMS, paved the way for a more extensive South Asian partnership on N_r research and policy (Figure 2). This ongoing £20 million project (2019–2023) funded through the Global Challenge Research Fund (GCRF) of UK Research and Innovation (UKRI), entitled “GCRF South Asian Nitrogen Hub (SANH),” involves 40 institutions all over South Asia and the UK and is led by the UK Centre for Ecology & Hydrology. Through the INMS and SANH projects, several consultations and workshops were held throughout 2019 in Kathmandu, Nairobi, Dhaka, Malé, New Delhi, and Chennai. These contributed to the launch of the UN Global Campaign on Sustainable Nitrogen Management at a high-level summit hosted by the Sri Lankan government in Colombo in October 2019. This campaign is now promoting the goal to “halve nitrogen waste” by 2030, highlighting the multiple benefits across all the UN Sustainable Development Goals.¹⁷ The Colombo declaration built on the UNEA4 Resolution on Sustainable Nitrogen Management. This was followed by the establishment of the UNEP Nitrogen Working Group in 2020, which included a national representative from each member country and whose goal was to work toward the establishment of an inter-convention nitrogen coordination mechanism involving the UNFCCC, CBD, and UN Economic Commission for Europe, among others. These

developments further strengthened the UNEP-INITI-SACEP-SANH partnership and enabled South Asian leadership on nitrogen while building wider international support.

Policy implications for South Asian nitrogen management

It is becoming increasingly clear in South Asia that reducing nitrogen pollution is possible and a necessary policy goal for every country in the region. The current policies for monitoring and controlling N_r are neither uniform nor adequate in any of the region's countries. As nitrogen pollution emerges from different sectors (e.g., agriculture, energy, transport, and industry) governed by different ministries and departments in South Asian countries, assigning nodal ministries for each nitrogen pollutant could help avoid the complications of inter-ministerial coordination. Policy interventions for sustainable nitrogen management can include technology choices, emission and effluent standards, taxes, subsidies, and public procurement pricing. Because pollution sensitivity can be different for human consumption (air, water, or food), forests, rivers, marine produce, or coral systems, it is highly desirable to have ecosystem-specific standards for best results to protect ecosystem services and livelihoods. The solutions to reduce nitrogen pollution require increasing the fertilizer nitrogen equivalence value of animal manure and recycling wastewater nutrients; reducing fossil fuel dependence in power, transport, and industry; promoting energy-efficient gadgets and systems; reducing food waste and meat consumption, etc. The available global best practices need to be adapted to local situations, apart from developing and adopting new technologies to recapture and reuse N_r.

Regional intergovernmental coordination is also important because of the emerging evidence that nitrogen pollution spills across borders through air and water, affecting neighboring countries in the region. It is not only possible but also highly desirable to develop a common policy framework for South Asian cooperation for national and regional nitrogen assessment and management. It also helps to coordinate a regional approach for global implementation of the UN Resolution on Sustainable Nitrogen

Management. There is adequate scientific capacity in the region to support evidence-based policy interventions. If necessary, the INI and others can supplement it with their international scientific expertise to realize the full potential for South Asian leadership toward sustainable nitrogen management both regionally and globally.

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