PAKISTAN NITROGEN POLICY REPORT

SCIENTIFIC EVIDENCE, CURRENT INITIATIVES AND POLICY LANDSCAPE

UKRI GCRF South Asian Nitrogen Hub

University of Agriculture, Faisalabad-Pakistan
South Asian Nitrogen Hub (SANH)

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Message from the Vice Chancellor, University of Agriculture, Faisalabad

PROF. DR. IQRAR AHMAD KHAN
(S.I., H.I.)
Vice Chancellor, University of Agriculture Faisalabad, Pakistan

In collaboration with south Asia nitrogen (SANH), the University of Agriculture, Faisalabad is to present this comprehensive document, analysing over 170 policies linked with nitrogen management and the mitigation of climate change effects. These policies signify our unwavering commitment to addressing the critical challenges of food security, rising nitrogen pollution and climate change. This document not only showcases our current efforts but also serves as a foundation for the development of future national strategies. Our aim is to align Pakistan's policies with global standards and commitments, ensuring a sustainable and healthy environment for future generations.

The report outlined herein represents a collaborative effort among policymakers, scientists, and stakeholders from various sectors. This holistic approach has enabled us to address the multifaceted nature of nitrogen management and climate change mitigation effectively. By reducing nitrogen pollution through sustainable management, we can achieve cleaner air, water, and soil, which are essential for the well-being of our citizens and the health of our ecosystems in addition to achieving food security. Moreover, this document will support Pakistan's compliance with international agreements and resolutions, such as the Sustainable Nitrogen Management Resolutions adopted at UNEA-4 & 5 and the commitments of the Colombo Declaration to halve nitrogen waste. Though the goal to halve nitrogen waste by 2030 is ambitious, yet attainable, with the right strategies and collective effort.

As nitrogen is linked with many of the sectors including agriculture, industry, energy, transport, waste, the policies available are fragmented and are not yet doing enough to tackle excessive GHGs emissions and nitrogen pollution, thus putting an enormous pressure on the environment. The available policies from 1947 were analysed to guide the development of future policies, ensuring that Pakistan remains at the forefront of global efforts to combat nitrogen pollution and climate change. We believe that by working together, we can create a sustainable and prosperous future for all. We invite all stakeholders, including government agencies, the private sector, academia, and civil society, to join us in this endeavour. Together, we can turn these policies into tangible actions that will lead to significant environmental, health, and economic benefits.

Message from the Director of South Asian Nitrogen Hub

PROF. DR MARK SUTTON

Director UKRI GCRF South Asian Nitrogen Hub Edinburgh, UK, 2024

The work in this report represents one fruit of this cooperation between policy makers, and of social and natural science researchers into current nitrogen policies in South Asia providing a foundation to inform future policy development. Apart from its immediate contribution to the SACEP Roadmap for Nitrogen Policies in South Asia, and the GCRF Nitrogen Hub, this document is also an important regional contribution to following up the Resolution on Sustainable Nitrogen Management at UNEA-4.

Actions in this wider policy context have since been accelerated by the Colombo Declaration in October 2019, which highlighted the need for National Roadmaps on Sustainable Nitrogen Management alongside a new ambition to 'halve nitrogen waste' from all sources by 2030. The policies presented in this report provide building blocks for the necessary change, and at the same time the opportunity for cleaner air, water, soil, less climate and biodiversity impacts, healthier lives and stronger economy. Globally, halving nitrogen waste could offer a resource saving worth 100 billion USD per year, which is a strong motivation for action.

The present report will be especially useful as we move forward. In addition to input to SANH, INMS and SACEP, other UN member countries can see comparative data and share lessons. We are celebrating the adoption in February of a new Resolution on Sustainable Nitrogen Management at UNEA-5. This encourages countries 'to accelerate action to substantially reduce nitrogen waste by 2030 and beyond'. This is the first time that such a reduction intent for nitrogen waste has been agreed universally by the UN, and it is therefore a major step forward to the UN Sustainable Development Goals (SDGs). The information and the lessons from the present report are therefore very timely in providing support to turn this ambition into reality.

Executive Summary

This report, being first of its kind, describes essential measures and steps to effectively understand the nitrogen policy arena for Pakistan in the broader context of South Asia. It also provides a comprehensive account of issues and challenges linked with nitrogen application, its management and externalities in the form of pollution along with potential remedial measures.

Nitrogen Challenge Overview

- Nitrogen remains an essential element to support life on earth. However, an excessive amount in its reactive form (N_r) can lead to severe threats both for the environment and people and poses a major issue globally and regionally for South Asia.
- An excess amount of N_r threatens five areas – quality of soil, air and water, disturbing greenhouse-gas balance and biodiversity. The range of impacts depends on the extent of N use along with vulnerability and exposure to people and the environment.
- South Asia is a global hotspot for N_r emissions for three main nitrogen compounds: nitrogen oxide, nitrous oxide and ammonia, with emission levels above global averages.
- Multiple sectors like agriculture, industry, transportation, buildings and energy are sources of nitrogen pollution.
- Because of agricultural activity and the excess application of synthetic fertilizers and manures, nitrogen pollution can pollute both surface and ground water.
- Managing nitrogen is essential for international climate change mitigation: nitrous oxide (N_2O) has 267 times more warming potential, in a one-year period than CO2.
- Government and non-government measures can support and encourage efficient nitrogen management, and hence, can effectively minimize the negative impacts.
- Managing nitrogen is a major issue both for national and international policy, however, the body of information about nitrogen policies that exists at national levels is scarce.
- Improving our understanding of the existing policies, the issues they address, the types of instruments used, and how existing policies might impact nitrogen pollution can further support the drive to curb excessive N emission.

Nitrogen-Related Policy Analysis for Pakistan

- As of 2019, 175 active policies related to nitrogen directly or indirectly were identified for Pakistan. These policies were formulated between 1873 and 2019. They contribute 18% of the total number of nitrogen-related policies in the SANH South Asian policy database. The policies directly targeting N_r emissions have a direct relevance to N-management whereas those policies which can indirectly influence the entry of N_r into the environment have an indirect relevance to N_r management.

- The focus of these policies varies widely therefore, policies were classified – according to various characteristics – into environmental sink; sector; sub-sector; policy type; pollution-source type; impact direction; relevance; and impact scope.

- Many policies were sub-national (57%), set at the provincial level, in contrast to other South Asia countries where national policies pre-dominate.

- Regarding relevance and scope of the studied policies, 41% of policies demonstrate a high (direct) relevance and large impact scope to N_r management.

- Multiple sector-based policies were more commonly established (16%) during the years 2011-2020. Likewise, 17% of all policies addressing multiple sinks were established during 2011-2020 which implies an increased level of responsibility and focus on the environment during this period.

- About 58% of policies included reference to one or more environmental sinks such as Air, Water, Climate, Soil, and/or Ecosystems whereas around 42% policies do not focus any sink.

- For sector-focused policies, about 31% of policies (55 in total) covered multiple sectors. Such features provide examples of how integrated policies and thinking across sectors could potentially support a more coordinated and coherent response across sectors to manage N_r sustainably.

- A quarter of the policies were agriculture-specific (25%) such as the National Food Security Policy 2018 whereas 14% were land use change-specific such as Punjab Forest Act 1999.

- About 10% of the policies (17 policies) did not cover a specific sector. Such policies are generally broad in nature and might include a few sinks but not specific enough to deliver targeted action.
- The policy type classification considers the type of instrument – single or multiple ones – employed to realize policy objectives. For Pakistan, there are 322 policy types (one policy can have multiple policy types) viz. Framework (39%), Regulatory (18%), Economic (12%), Data & Method (12%), Research and development (R&D) (11%), Pro-Nitrogen (4%), and Commerce (4%)

- For expected impact on N_r, 59% policies could potentially lead to mixed or neutral impact direction whereas, 38% had potentially positive impact on N-management. Only 5 policies were identified as having a potentially negative impact on N-management.

- There are 117 (about 67%) policies that have a direct relevance (high to medium) to nitrogen but only 33 (19%) policies have a high impact scope in terms of nitrogen management.

- Out of the total 98 N_r-relevant policies, 26 policies do not involve any environmental sink whereas 68 (39% of 175 of all policies or 69% of 98 directly nitrogen relevant) policies either do not specify or are non-applicable to any pollution-source type such as point source or non-point source pollution.

- Nearly 11% of policies focused on multiple sinks and multiple sectors and with multiple policy instruments (hence having integrated policy objectives and approaches). Such policies offer a great potential to confront the multidimensional challenge of nitrogen management in the country. Some examples of policies that meet these criteria are the 'National Sustainable Development Strategy 2012' and the 'Punjab Water Policy 2018'.

- The existing policies require further scrutiny to determine their effectiveness for improved N_r management by recognizing if a specific policy could effectively contribute to curbing the point source or non-point source (NPS) or both pollution sources. Such attributes in a policy are favourable for dealing with N_r management. Further research by multidisciplinary teams on these N_r relevant policies is needed inter alia, to assess their policy impact.

- There is a dire need to adapt the existing policies to directly affect nitrogen management in an effective manner. For instance, policies such as 'The On-Farm Water Management and Water Users' Associations Ordinance 1981', or the 'National Quality Policy and Plan 2004', may be indirectly relevant to nitrogen management, but can still have implications in how it is managed. Hence, amendments in existing policies to address N_r management more directly considering the sources and impacts would be a crucial step in moving towards sustainable N_r management in Pakistan.

Reactive Nitrogen Emission and its Drivers

- Emissions from all three nitrogenous compounds considered in the report, viz. ammonia, (NH_3), nitrogen oxides (NO_x), and nitrous oxide (N_2O), have been increasing over time in South Asia as well as in Pakistan based on EU-Emissions Database for Global Atmospheric Research (EDGAR)[1]. These emission trends highlight that current policy efforts have so far not been able to stabilize or reduce nitrogen emissions.

- Ammonia is the most abundant compound in 2015, followed closely by nitrogen oxides. The emissions for NH_3, NO_x and N_2o were, respectively, 1231, 1166 and 199 Gigatons (GG)/year in 2015/2018.

- Nitrous oxide (N_2O), a major contributor in Greenhouse Gas (GHG) emission, has risen the most out of three N_r compounds, by +63% between 2000 and 2018.

- Nitrogen oxides (NO_x), have increased in Pakistan, posing greater threats for, air pollution. A rise of around +58% in NO_x emission was recorded between 2000 and 2015.

- Ammonia (NH_3) emissions, also an air pollutant, have been increasing since the 1970's. Nevertheless, there has been around +42% increase in NH_3 emissions from 2000 to 2015. NH_3 is the most abundant in terms of overall amounts.

- Agriculture contributes to all three N_r compounds. It is the major emission source for ammonia (NH_3) and nitrous oxide (N_2O) emissions by 84-85%. Agriculture contributed to 10% of overall nitrogen oxides (NO_x) emissions.

- At farm level, the increased level of N_r pollution is mainly the consequence of excessive use of synthetic fertilizers by farmers who generally prefer to sow crop varieties that are fertilizer responsive. The excessive and injudicious use of fertilizers in the country is complemented by the easy access to irrigation water and policies promoting excessive use of inputs through subsidies on fertilizers, tubewell water and crop seeds.

- On the supply side (industry level), the sales of fertilizers in Pakistan are at US$3.74 billion per year due to incentives in the form of gas subsidies and tax rebates along with attractive investment options thus spearheading the expansion of the fertilizer industry. This, in turn, prompts fertilizer manufactures to promote fertilizer use among farmers with no heed to environmental consequences. This necessitates additional measures to combat N_r pollution.

- Transport sector's contribution to overall nitrogen oxide (NO_x) emissions has grown by +62% from 2000 to 2015, contributing 41% to overall NO_x emission in 2015, mostly from road transportation.

[1] *Available at https://edgar.jrc.ec.europa.eu/country_profile/PAK*

- The building sector has shown consistent growth in its nitrogen-based emissions. For instance, NO_x emissions from this sector grew by around +42% from 2000 to 2015. Contributions to overall NO_x emission, were 7% in 2015. The emissions from this sector may further be expected to grow due to the rapid conversion of agricultural land into build-up areas.
- Nitrogen oxide (NO_x) emissions by industry (power and industrial combustion - combined) grew by around +30-49% between 2000 and 2015. The industry sector contributed to overall NO_x emission by 42% in 2015.

Way Forward/Recommendations

- Current policy is not yet doing enough to tackle excessive GHGs emissions and nitrogen pollution from the agriculture sector, and other sectors, thus putting an enormous pressure on the environment.
- Despite 41% of policies being highly related to nitrogen, only a few of these specifically focused or referenced measures to control nitrogen waste. For an effective nitrogen management system, such policies should also be accompanied by direct actions, such as 'core' policies, that entail regulatory and economic policy instruments. For this, setting up of quantifiable and enforceable limits/ constraints in relation to the production and consumption of nitrogen in policy is recommended.
- There is a dire need to adapt/amend existing policies to effectively and directly address the challenges of nitrogen pollution by explicitly specifying the relevant N compounds and the permitted level of pollution. For addressing nitrogen pollution issues, amendments in the existing policies – ranging from minor to major – can be an efficient approach.
- As 42% of the existing policies do not consider any environmental sink, the need arises to consider adapting those sector-based policies to consider the environmental implications, directly or indirectly, and ensure policy cohesion. This can be achieved through comprehensive coverage of potential risks, or options to mitigate negative N impacts by referring to one or more environmental sinks.
- For effective management of N_r pollution, nitrogen-relevant policies will perform better if they cater to multiple sectors, sinks, and policy instruments, increasing their implementation potential and reduce the chances of lapse/oversight. Currently, 11 policies meet this criterion among a total of 175 policies linked with N_r management. Thus,

many other N_r-relevant policies only cover some aspects with limited scope.

- The historical development of N_r-relevant policy formulation also follows a random pattern where 50% policies had been formulated prior to 1990. Eighteen (18) out of 30 policies having focused water as sink came into operation before 1990 whereas many multiple sink policies (17% of all policies) were established between the years 2011 and 2020. This fact necessitates revisiting majority of policies given enormous changes that have occurred post-1990 with significant evolution of environmental, socioeconomic and political challenges.
- For policies with high nitrogen management-relevance, amendments to specify pollution source type and the risk of nitrogen waste would be beneficial. In the case of Pakistan, it is encouraging that 31 policies meet such a benchmark to directly link with nitrogen vis-à-vis pollution source (point source, non-point source or both). However, those ignoring this aspect, especially those policies with direct relevance to N management, indicate a potential policy gap.
- From amongst the sectors, agriculture is a key contributor to the national income (GDP) yet also a major contributor to national nitrogen emissions. Improving nitrogen use efficiency (NUE) via the sustainable use of fertilizer inputs viz. application method, its timing and amount etc. has the potential to save considerable costs and help to maintain soil, plant, and human health.
- Action is needed in emerging sectors in relation to their contribution to N_r emissions such as transport, energy and field crops. As different sectors contribute to the emission of N_r compounds in various ways and are growing at different paces, an integrated effort is needed to specify targets and measures to contain N-pollution. The overlap in contributing sectors to different compounds indicates areas where integrated policies are needed to avoid pollution swapping and promote coordinated actions.
- In-depth research on the N-relevant policies is necessary for assessing, inter alia, their impacts and impediments/constraints in the proper implementation of such policies. This can strengthen decision making around nitrogen management.
- Stakeholders'[2] involvement from policy formulation to implementation is the key to success of any policy instrument. There is a great need for a range of stakeholder perspectives, expertise, and experiences in policy development inducing a sense of ownership among the ultimate actors and beneficiaries.
- A thorough understanding of policy requirements can be achieved through raising public awareness and involvement in decision processes leading to better prospects of adoption and implementation.
- Science-based decision-making is crucial to move towards N_r sustainability and SANH is supporting efforts to create the scientific evidence to help strengthen Pakistan's contributions to address N both nationally, regionally and beyond.

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[2] *Stakeholders' identification and involvement is a necessary and key step while designing any intervention aimed at influencing people/stakeholders' attitude, actions, and practices. It is the systematic identification, planning and implementation of actions directed engage with stakeholders. Robust evidence supports the effectiveness of stakeholder engagement for transparent, democratic and participatory decision-making which can then legitimize final decisions and more effective solutions (Van de Kerkhof 2006)*

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1. Introduction

1.1 Lead Institutions and SANH

The South Asian Nitrogen Hub (SANH) is a UKRI GCRF funded research partnership that brings together 32 leading research organisations and project engagement partners from South Asia and the United Kingdom. SANH is working towards enabling South Asia to 'adopt and champion a strategic approach to nitrogen management, as a key step towards the Sustainable Development Goals'. SANH aims to provide relevant scientific insights, identify barriers to change, and demonstrate the economic benefits of tackling nitrogen pollution.

SANH includes eight south Asian countries: Afghanistan, Pakistan, India, Nepal, Bhutan, Bangladesh, Maldives and Sri Lanka. These eight countries are also partners in the South Asia Co-operative Environment Programme (SACEP), which outlines a shared vision for a 'healthy environment, resilient society and regional prosperity for the present and future generations' for the 2020 - 2030 decade. Within this network of institutions, University of Agriculture, Faisalabad (UAF) is a leading partner from within the South Asian region. The University takes pride in imparting quality education and research in agriculture and allied disciplines. It has remained among the top-most university in the field of agriculture as per Higher Education Commission (HEC) of Pakistan and THE rankings for many years. The University has contributed effectively in the promotion of sustainable agriculture and rural development within the country where majority of population's living is sourced from agriculture. Within the SANH, UAF has remained an active partner in conducting policy analysis related to Nitrogen management.

Sanh Research Programmes Focus on the Following Four Key Areas:

Building the nitrogen policy arena for South Asia.

Testing options for improving N management, from agricultural practices to technological recapturing.

Studying the impact of nitrogen pollution on the key ecosystems, corals and lichens.

Building an integrated framework to look at nitrogen flows between land, water and atmosphere across the region.

1.2 What is the Purpose of this Report?

This report provides a snapshot of Nitrogen-related policies that were formulated since the country's independence and are in action since their inception/promulgation. It is one of the necessary steps to create awareness and build understanding on the current nitrogen policy arena for Pakistan within South Asia. This report follows on from a regional report (SANH-SACEP, 2021) and several other national N policy reports for Nepal, Bangladesh, India, Sri Lanka, and Maldives[3].

This SANH report has been developed by the University of Agriculture Faisalabad (UAF) as part of a collaborative research effort. UAF and SANH, via this report, have made a concerted effort towards building a nitrogen policy arena for South Asia including Pakistan. It is specifically focused on the evaluation of current N-related policies, progress and barriers across different scales for Pakistan. Further highlighting the nitrogen use and emission trends and legislative opportunities and barriers to move towards sustainable N_r management.

This report features the following content:

- An overview of Nitrogen issues at the global and local level
- Nitrogen pollution and management – issues and challenges
- SANH Nitrogen policy database, methodology and key findings
- Nitrogen emission drivers, intensity and trends at the country level
- Policy insights into Nitrogen management
- Recommendations for effective management of nitrogen pollution

1.3 Nitrogen and the SDGs

The core agenda of the SANH and UAF, is to pioneer UK - South Asia research partnership which may catalyse a transformational path where South Asia becomes a world leader in championing a strategic approach to nitrogen management. There are multitude of challenges at the global as well as local level confronting sustainable development. The United Nations (UN) has identified 17 areas where key interventions are needed to ensure a sustainable pat to prosperity and development. As a key step towards the UN Sustainable Development Goals (SDGs) 2030 on a global as well as national level, this comprehensive report can inform multiple SDGs in particular: SDGs 1 & 2 (poverty & hunger), by finding and promoting ways and means to increase Nitrogen Use Efficiency (NUE); SDGs 3 & 11 (health, cities & communities), by fostering synergies between N management for air pollution, waste management and optimum fertilizer use especially through political and social interventions; SDG 13 (climate action), by reducing NO_x and other greenhouse gas (GHG) emissions per unit of food produced, while fostering development of climate-resilient practices; SDGs 6 & 14 (water), helping prioritize actions to reduce water pollution in the context of climate threats (e.g. coral bleaching); and SDG15 (life on land) by improving knowledge of the impact of nitrogen pollution on ecosystem services (especially Himalayan forests). With this backdrop, an in-depth evaluation of existing policies in terms of their focus, mean of impact and coverage would be instrumental in effectuating selected SDGs both locally and regionally.

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[3] *Note: As this report is part of a collection of SANH N policy reports, some of the generic background content within this chapter has been drawn from the other reports.https://sanh.inms.international/sites/default/files/2022-12/sacep_sanh_south_asia_regional_nitrogen_pollution_and_policy_report_2022.pdf*

1.4 Why Focus on Nitrogen Pollution?

Nitrogen occurs naturally in the atmosphere in its reactive form (N_r) and is essential for human and plant growth. Overtime, Nitrogen balance has been altered due to industrial, human and agricultural interventions (Fowler et al., 2013). The growing demands of sectors such as agriculture, transport, industry and energy have given rise to sharp increases in the levels of nitrogen pollution and related greenhouse gas (GHG) emission (UN, 2019). Five principal threats of nitrogen pollution are to water quality, air quality, greenhouse-gas balance, ecosystems and biodiversity (Figure 1).

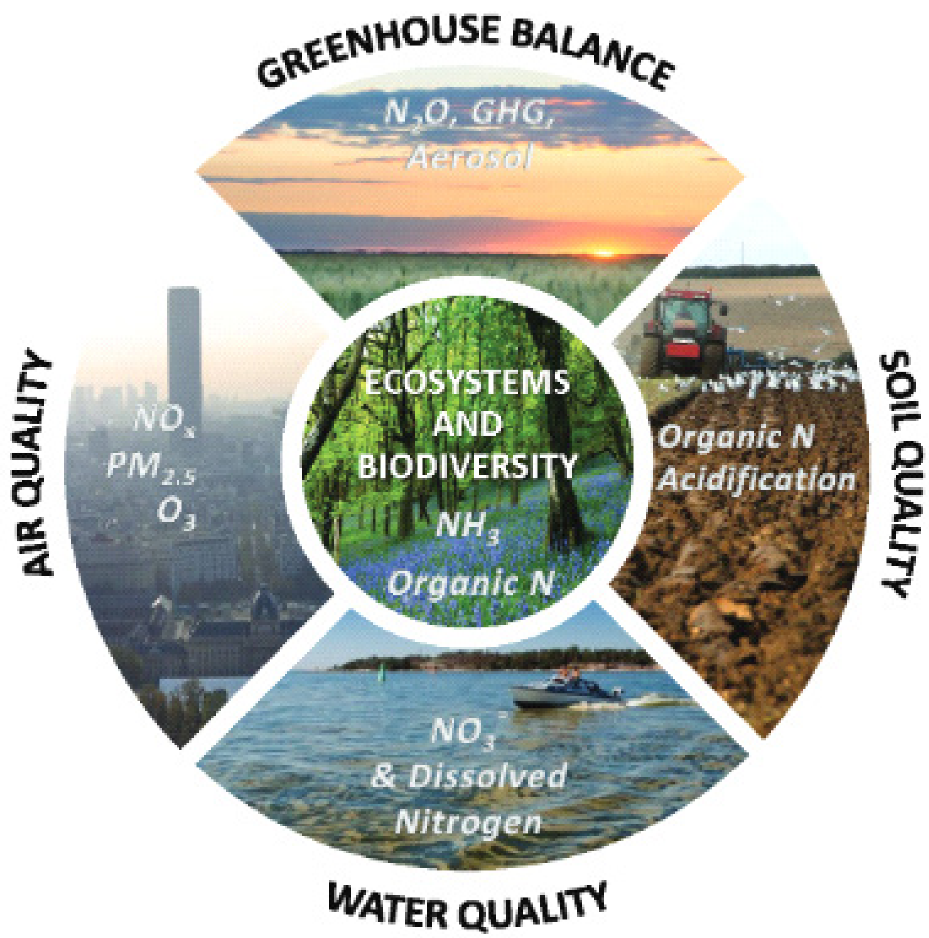


Figure 1: Threats from nitrogen pollution
Source: Sutton and Billen, 2010

Agriculture heavily depends on nitrogenous fertilizers – the use of which has increased manifolds – ultimately leading to nitrogen pollution. In the early 1900s, producing enough food was constrained by depleting soil nitrogen (N) stocks. This N constraint was unlocked by Fritz Haber and Carl Bosch by converting the inert di-nitrogen gas into reactive N (N_r). The significance of nitrogen can be gauged from a recent estimate that global food production could be reduced to one-half of the current level if it weren't for N fertilizer applications (Erisman et al., 2008). The need for N_r use is both a boon and bane in the process of agricultural production (Anjana and Umar, 2018). On the one hand, its use is crucial in reducing poverty and hunger and boosting economic development through its augmenting role in the production of grains, fodders and fibres, but on the other hand, it can pose risks to health, environment, and economy on through varying degree and nature. It has been estimated that "global N_r production has more than doubled during the last century as a result of human activity" (Sutton et al., 2012).

Human interventions, and increasing use of N_r, have led to nitrogen pollution. Nitrogen pollution can be defined as nitrogen containing compounds which contribute to the disruption of the nitrogen cycle, causing environmental damage. N_r compounds occur as gaseous air pollutants and include ammonia (NH_3), nitrogen oxides (NO_x), and nitrous oxide (N_2O). N_r further occurs as water pollution in the form of nitrites (NO_2^-); nitrates (NO_3^-); and ammonium (NH_4^+) (Sutton et al., 2012).

With the advent of the Haber-Bosch process, it seemed that the nitrogen problem had been solved. The net result was a massive increase in chemical nitrogen fertilizers, especially from the 1950s, providing the fuel for the Green Revolution, where new high-demand, high-yield crop varieties were the driving force.

It is almost very clear now that nitrogen use is rather inefficient, meaning that a large amount of Haber-Bosch nitrogen compounds is lost to the environment. At the same time, it was realized that nitrogen is not just an agricultural challenge but rather has many implications for human and animal life and the environment (Lin et al., 2014; Parker and Schimel 2011; Sutton et al., 2012). Apart from agriculture, industry, energy, and transport, the whole food system is implicated, such as wastewater systems release nitrogen to groundwater, water courses, and the coastal zone, threatening drinking water, ecosystems, and fisheries. The aquatic ecosystems are no exception to the vagaries inflicted by excessive nitrogenous compounds especially in the reactive forms. When polluted air by nitrogen lands on forest, mountains, and other natural habitats, the ecology is changed, affecting ecosystem resilience and compromising ecosystem services.

High synthetic N_r inputs when applied in excessive amounts to crops beyond their demand can lead to excessive N_r losses. This causes a lower N utilization efficiency with a negative impact on production as well as soil and plant ecosystem. This is compounded by a poor management and utilization of livestock manure, leading to further losses of N_r in the system. The amount of N_r released into the biosphere through anthropogenic means is prodigious and is estimated at 120 Tg yr^{-1} which is twice that of the N_r fixed by all natural terrestrial processes, i.e., 63 Tg yr^{-1} (Fowler et al., 2013). In the early 21st century, anthropogenic perturbation of the global N_r cycle has contributed about two-thirds of the annual flux of N_r into the atmosphere and with a growing population, South Asia has become a hotspot for N_r emissions (SANH & SACEP, 2021).

N_r can enter surface water and groundwater because of agricultural activity and due to the excess application of synthetic fertilizers and manures (WHO, 2011). Nitrogen pollution, in its reduced form, can occur in the air as ammonia (NH_3) and in the water as ammonium (NH_4^+). Ammonia (NH_3) is increasingly seen as problematic. The deposition of ammonia, both wet and dry, can lead to soil acidification, nutrient leaching, eutrophication, and ground water pollution (European Commission, 2013). Agricultural activities reportedly account for approximately 80% – 90% of the overall anthropogenic ammonia emissions (Bouwman et al., 1997; Zhang et al., 2010).

The past century has also witnessed rising demand of livestock products, which has accelerated the demand for fodder crops, hence fertilizer use resulted in the production of more animal waste globally (Dangal et al., 2017). As per an FAO estimate, the livestock manure production is estimated at about 6,252 million tons per year which is equivalent to 113 million tons of N_r per year (FAO, 2018). Generally, the livestock manure is beneficial for soil health and can improve crop yields, but it can potentially contain pathogens, antibiotics and heavy metals, which can, if directly applied to land, cause environmental risks, spreading of diseases, groundwater contamination and soil pollution (Zubair et al. 2020). N_r losses in the system result in costly impacts on the environment and human health (Raza et al., 2018; Shahzad et al., 2019; Sutton et al., 2021; Aziz et al., 2022). Sutton et al. (2013) estimated an annual social cost of all forms of N pollution in the range of 200 to 2000 billion US dollars globally.

Reductions in greenhouse gas (GHG) emissions are key to combating climate change, and a key area in international politics. The Paris agreement, in 2015, is a legally binding international commitment to limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels (UNFCC, 2021). Nitrogen management is essential for international climate change mitigation actions.

1.5 How does Reactive Nitrogen (N_r) Impact the Environment and Human Health?

Nitrogen's global emission maps reveal south Asia as a hotspot (see Figures 2 and 3). Figure 2 illustrates the hotspots for nitrogen dioxide (NO_2) atmospheric pollution. Figure 3 illustrates the extent of nitrogen oxide (NO_x) emissions across South Asia in 2015. The darker colours in the map represent those locations with higher emissions. Direct and indirect exposure to NO_x, can lead to respiratory issues including lung damage. These emissions are often correlated with toxic pollutants from industry and transport. Transport is also a significant source for nitrogen oxides (NO_x) and particulate matter (PM) emissions (Kegl, 2007).

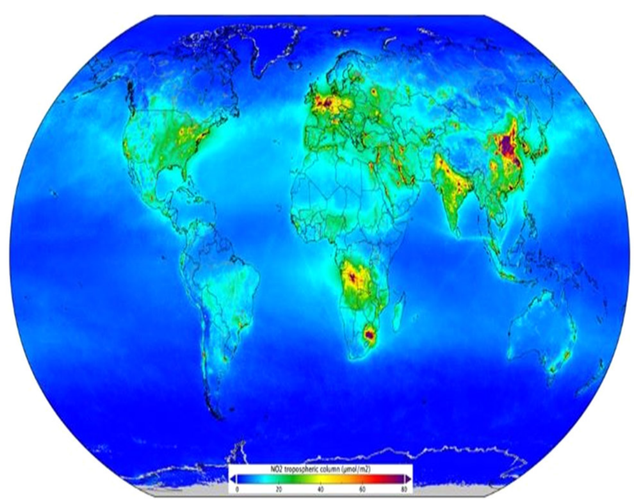


Figure 2: Global map of NO_2 (nitrogen dioxide) atmospheric pollution
Source: European Space Agency (2019) Note: Low levels of pollution are dark blue running to dark red for highest levels.

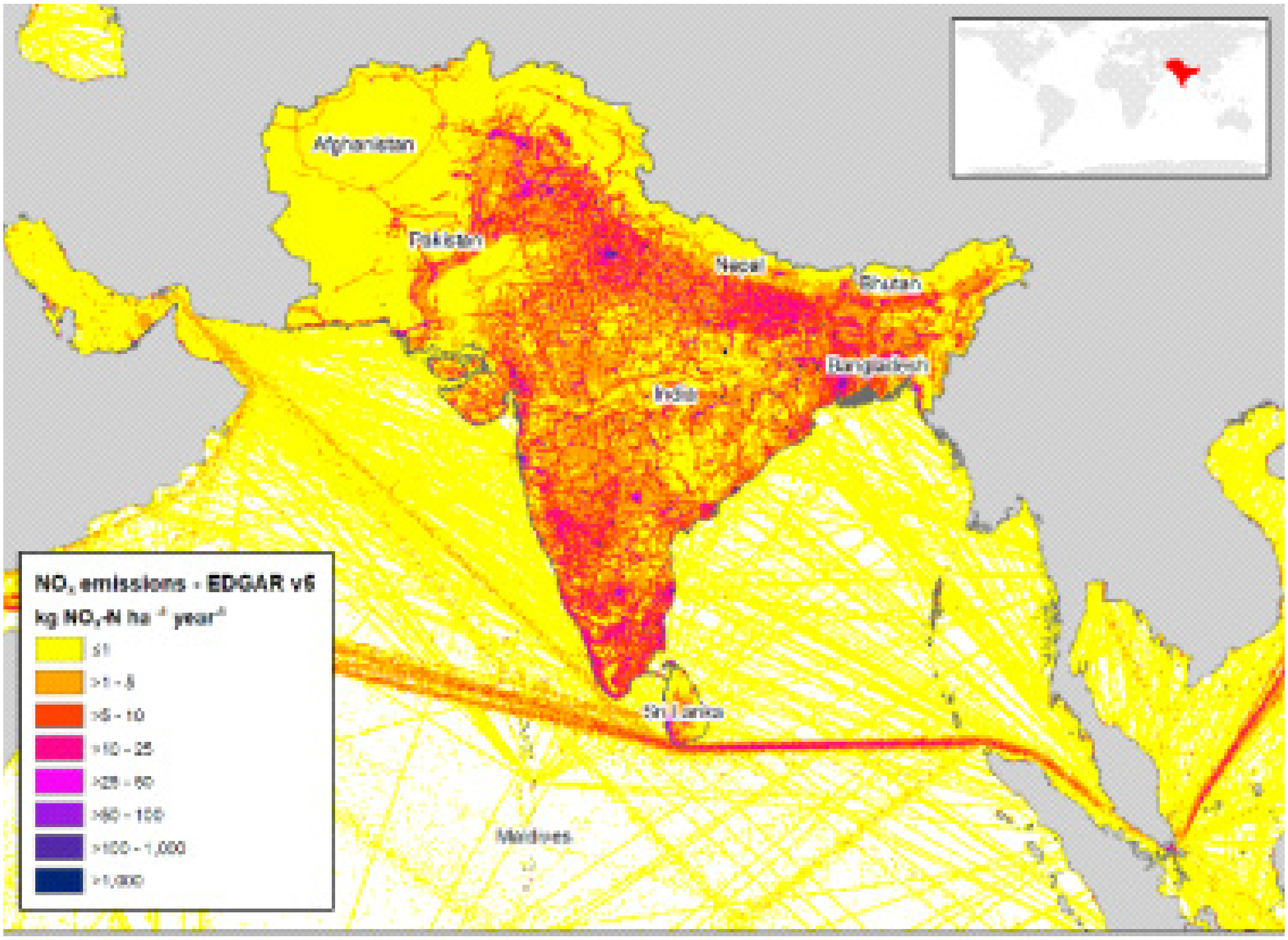


Figure 3: NO_x (Nitrogen Oxide) emissions across South Asia, 2015
Source: SACEP-SANH (2021) EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa et al (2019). The darker purple to blue colours indicate high concentrations of NO_x per hectare per year

According to the World Health Organisation (WHO), many of the world's most severely-affected cities in terms of $PM_{2.5}$ pollution are in South Asia, accounting for the largest number of deaths and disabilities due to air pollution. Particle size is directly related to their potential for causing health problems. Fine particles ($PM_{2.5}$) can cause the greatest health risk (United States Environmental Protection Agency, 2019). PM concentrations are argued to be higher in areas of populations undergoing fast urbanization and industrialization (Ji et al., 2018).

NH_3 is more harmful to ecosystems than nitrogen oxides (NO_x) especially when deposited in its dry form (Hicks et al., 2011). South Asia is a global hotspot for Ammonia emissions as indicated in Figure 4. The extent of ammonia emissions in South Asia are illustrated in further detail in Figure 4.

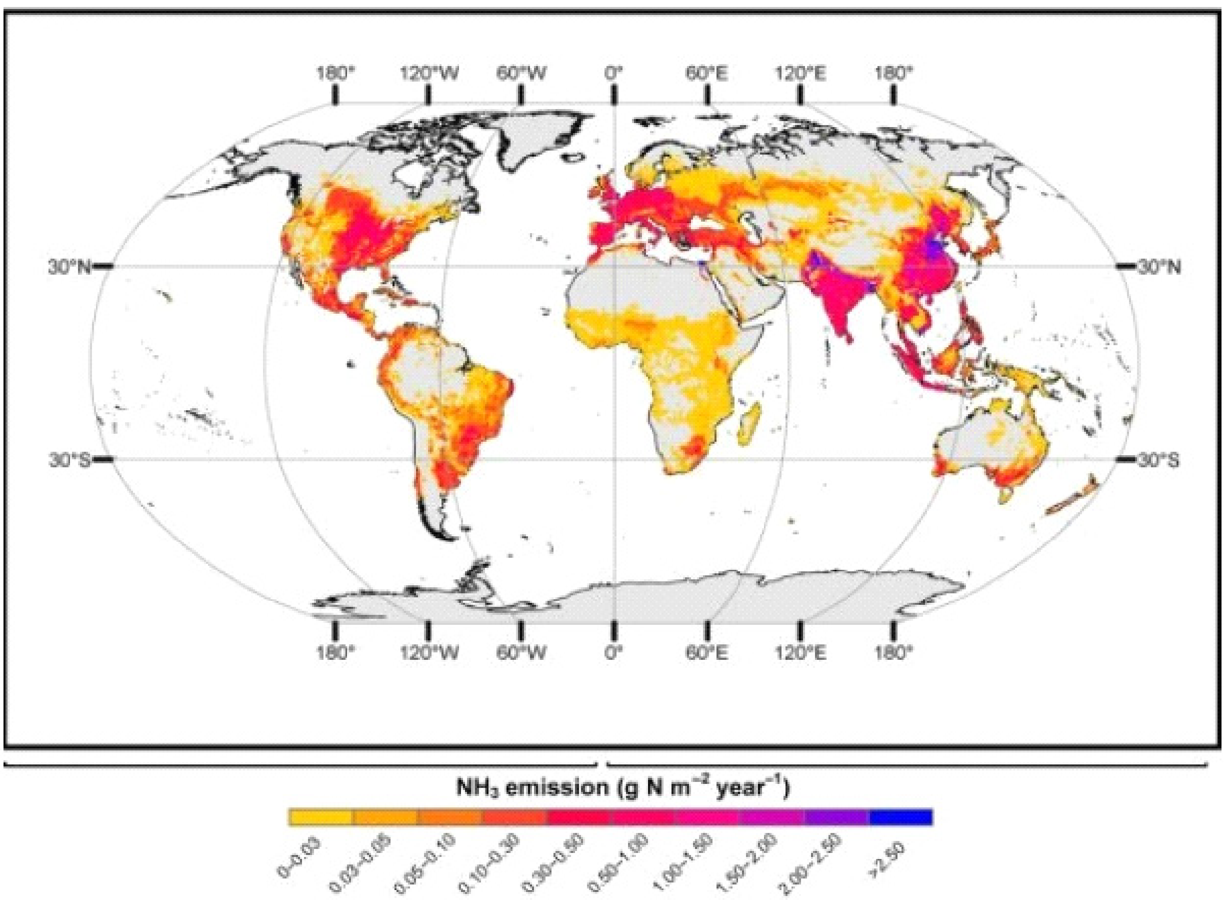


Figure 4. Global map of NH_3-emissions.
Source: Xu et al. (2019) Note: this map is based off simulated ammonia emissions in response to application of synthetic nitrogen (N_r) fertilizer in the 2000s. Spatial resolution of 0.5 by 0.5 degree.

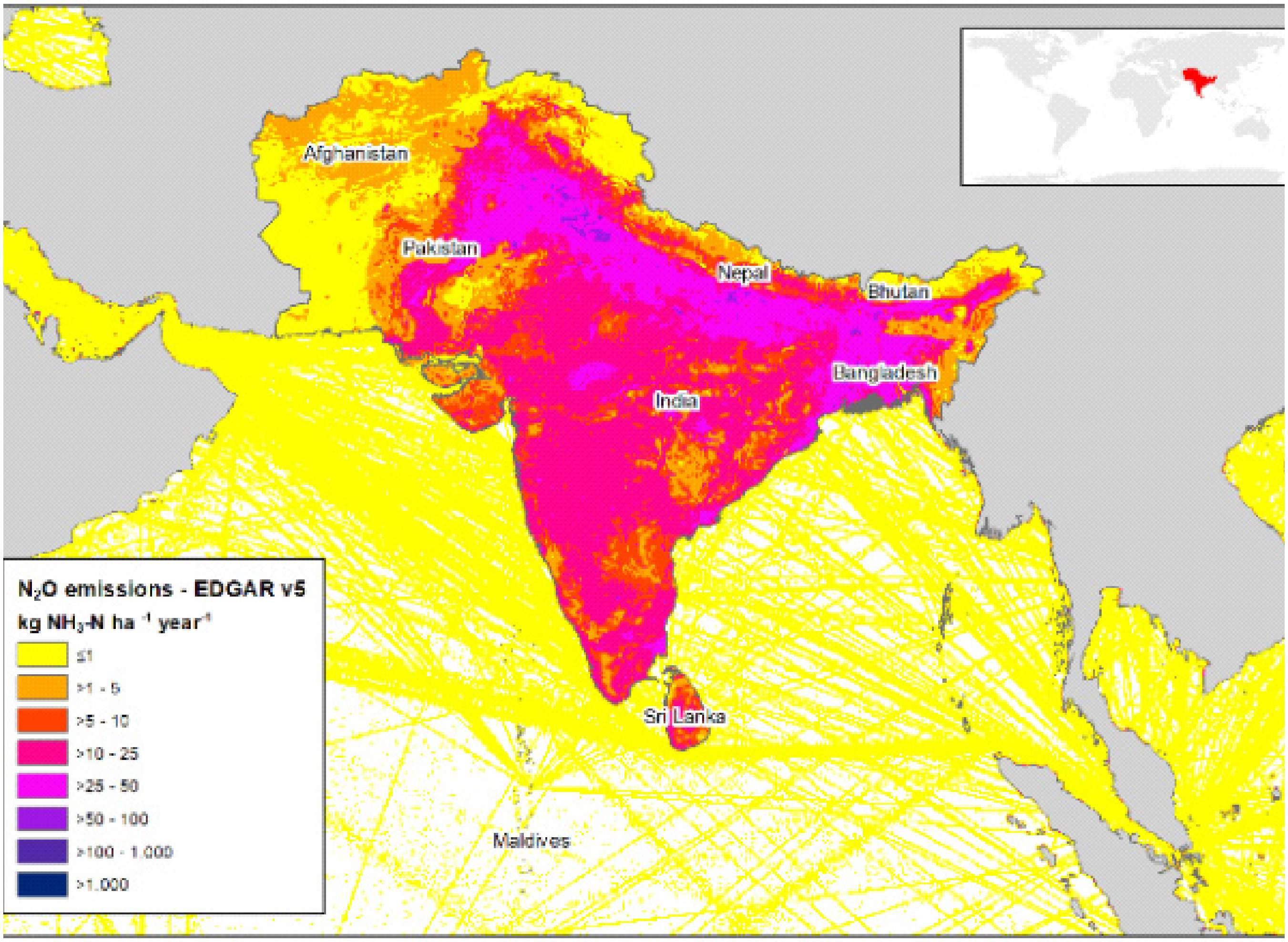
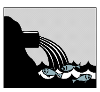
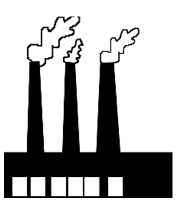


Figure 5. Nitrous Oxide (N_2O) across South Asia, 2015
Source: SACEP-SANH (2021) EDGAR v5.0 Global Air Pollutant Emissions data sourced from Crippa, et al. (2019)

The direct and indirect environmental and health impacts of different nitrogen molecules are illustrated in Table 1. The table also points some overlaps between N_r emission sources and impacts, along with unique differences.

Table 1. Overview of reactive nitrogen emissions and related environmental and health impacts.

Emission	Source	Benefit	Environmental and Health impacts
Nitrate (NO_3) 	Wastewater, agriculture and oxidation of NO_x.	Widely used in fertilizer and explosives.	NO_3 forms particulate matter (PM) in air and affects health. In water it causes eutrophication.
Nitric oxide (NO) and nitrogen dioxide (NO_2) – collectively known as NO_x (nitrogen oxides) 	Combustion from transport, industry, and energy sector.	NO is essential for human physiology but NO_2 has no known benefit.	NO and NO_2 (or NO_x) are major air pollutants, causing heart disease and respiratory issues, e.g., asthma, respiratory disorder, inflammation of airways, reduced lung functions, bronchitis, and cancers.
Ammonia (NH_3) 	Manure, urine, fertilizers, and biomass burning.	NH_3 is the foundation for amino acids, protein and enzymes. Ammonia is commonly used in fertiliser.	NH_3 causes eutrophication and affects biodiversity. It forms particulate matter (PM) in air affecting health (See NO and NO_2 above). - modest odour contribution
Nitrous oxide (N_2O) 	Agriculture, industry, and combustion.	Used in rocket propellants and in medical procedures as laughing gas.	Health impact due to global warming, often enhanced by eutrophication health impact due to loss of stratospheric ozone depletion. In addition, the enhancement of vectors for infectious diseases (e.g. malaria) and frequency of infestations (e.g. algae blooms, insects etc).

Source: adapted from Erisman et al., (2008) Provisioning, regulating, supporting and cultural ecosystem services[4] can be directly and indirectly affected by N_r. Impacts are further intensified via interactions with other human-caused environmental change, such as land use and climate change, along with other pollutants. For example, fertilizer runoff can cause freshwater eutrophication, leading to harmful algal blooms and dead zones, killing fish stocks, as visible in Figure 6.

Figure 6. A fish farm in Birgal village, where waste from about 30 fish farms flows into the Ghizer River.

Yet understanding nitrogen and its interactions with the environment is complex due to the large spatial and temporal variability; this is made even more complicated '*through the cascade of nitrogen through the environment and related linked effects*' (Erisman et al., 2013).

Whilst local sources of nitrogen pollution, such as air emissions and run off, contribute to local effects, they also can contribute to accumulations at subnational to global scales (Erisman et al. 2013). Nitrogen pollution does not respect country boundaries. Therefore, tackling nitrogen pollution requires trans-national cooperation.

SANH works across the eight south Asian counties to reinforce and support effective nitrogen management through a coordinated and integrated approach in the region. Collaborative efforts to tackle nitrogen are already underway. In 2019, spearheaded by Sri Lanka with the support of the UNEP, the "Colombo Declaration on Sustainable Nitrogen Management'" was adopted and outlines an ambition to 'halve nitrogen waste by 2030'. United Nation member states have endorsed a proposed roadmap for action addressing nitrogen challenges.

1.6 How can Policy Support Sustainable Nitrogen Management?

Governments may take several legislative, financial or regulatory measures in order to manage nitrogen pollution directly and indirectly. Additionally, measures both through government and outside of government can support and incentivise the management of nitrogen more effectively, minimising negative impacts. Multiple scales and actors also need to be considered in how to target actions.

Traditional policy interventions that deal with nitrogen management can include (Dalgaard et al. 2014):

- *Command and control (C&C)* i.e. the classic regulation type, where an action or pollution practice is forbidden by law, controlled by the authorities, and fined if in violation.

- *Market-based regulation and governmental expenditure (MBR)*, for example, when the management of pollution behaviour is regulated via market incentives, typically via a green tax (e.g. N-taxation) under the

[4] *Ecosystem services are defined as the ecological and socio-economic value of goods and services provided by natural and semi-natural ecosystems (Erisman et al. 2014)*

'polluter pays' principle (Carter 2007) or when funds are provided to promote environmentally friendly behaviour.

- *Information and voluntary action (IVA);* the promotion of sustainable N-management practices via knowledge production, communication, technologies as well as research and extension services. These actions may also be subsidised or funded by government(s).

An additional measure for reducing nitrogen pollution requires the efficient use of nitrogen particularly in agriculture (see box 1). This can be effectively achieved by improving nitrogen use efficiency (NUE). This requires establishing, introducing and promoting various techniques and measures where less amount of nitrogen can produce same level of output or same amount of N_r can fetch better yields per unit of area. Improving NUE in agriculture is becoming increasingly vital; as global food demands are set to grow by 50% – 100% by 2050 (Connor et al. 2011; FAO 2017).

Focusing measures at one scale can also be limited. A study identified that most policies aiming to reduce N_r pollution in agriculture targeted one scale, i.e., farm level (Kanter et al 2020b). However, such policies on their own are argued to be inadequate as N_r loss also happens beyond the farm. There are opportunities for intervention along the value chain; from fertilizer manufacturers, transportation, retailers, consumption and wastewater treatment (Kanter et al. 2020b). One approach that takes this into account is 'the nitrogen circular economy'. This was adopted by the EU in 2015, aiming to maximise resource efficiency at all steps along the value chain (UNEP, 2019).

Nitrogen pollution is not just an issue for agriculture. Addressing other sectors such as energy, waste, industry, transport, urbanisation, tourism, and more, are also vital for addressing the global N challenge. For example, tackling emissions of air pollutants from transport, national measures can include setting of limits or target values for ambient concentrations of pollutants, limits on total emissions (e.g., national totals) and regulating emissions from the traffic sector by setting emissions standards or by setting requirements for fuel quality (EEA, 2021). Localised measures may include low-emission zones in cities and congestion charges.

Figure 7 provides some examples of other measures that can promote clean air practices to reduce PM pollution. These are the 25 'most effective' measures listed by the Climate and Clean Air Coalition (CCA). Figure 7 indicates some existing measures, those with recent legislation, and those with further potential for being implemented in Asia and the Pacific. Post-combustion controls, clean cooking, industrial process emissions, along with emission standards for road vehicles are indicated to have the most impact in reducing $PM_{2.5}$.

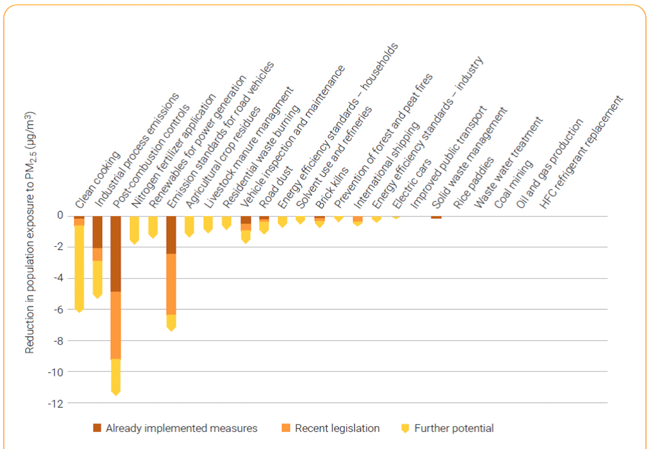
Box 1. Nitrogen Use Efficiency (NUE) in Agriculture

Agriculture is the economic sector with the highest nitrogen use; and the main source of Nr pollution (European Commission, 2013). Nitrogen use in agriculture is often extremely inefficient; the global NUE of cereals decreased from ~80% in 1960 to ~30% in 2000' (Erisman et al., 2007). These figures highlight that the majority of fertiliser applied globally is wasted, with NUE decreasing over time. NUE is further reduced when widened out to the entire food system. Sutton et al., (2009 p.18) stated that:

"The global food chain has a mean nitrogen use efficiency of 14% for plant products and 4% for animal products (meat, dairy, egg). The remainder is dissipated into the environment ... to air, and ... to groundwater and surface waters."

Addressing NUE could provide a 'win-win scenario' argues Sutton et al. (2009). Studies have shown it could be both environmentally and financially beneficial. Improving NUE is focused on minimising damaging emissions of nitrogen whilst maximising the benefits gained (European Commission, 2013). Wang et al (2018) also suggested that integrated management practices have indicated that NUE could increase with increases in planting densities and tillage depths, reductions in N rates, improved water management, and the application of organic fertilizer

Improvements to NUE require changes to agricultural practices. Scientists argue that sustainable agriculture practices, especially those closer to the natural systems as a way forward. Such practices can include "minimal tillage, intercropping, cover crops, catch crops, green manures (including legumes), animal manures, broad crop rotation, effective use of crop residues, and landscape planning" to reduce Nr waste and increase NUE (Jarvis et al., 2011; Sutton and Billen, 2010; European Commission, 2013). Yet any intervention can have drawbacks and the suitability will be site specific. Policy itself plays a crucial role in guiding actions towards more efficient and effective nitrogen management.



IMPACTS ON POPULATION-WEIGHTED EXPOSURE TO $PM_{2.5}$ IN 2030 FROM IMPLEMENTATION OF 25 CLEAN AIR MEASURES, RANKED BY FURTHER POTENTIAL

Figure 7. Impacts on population-weighted exposure to PM2.5 in 2030 from implementation of 25 clean air measures, ranked by further potential
Source: Climate and Clean Air Coalition (2019); UNEP (2019.)

Interactions between sectors need to be considered alongside potential impacts to environmental sinks. Likewise sink focused policies, such as those focused on air quality, soil, climate, ecosystems, and water, are best placed when they identify the risks from sector-based activities with options to mitigate adverse impacts. The UNEP (2019) advises, in science and policy, a multi-source, multi sector perspective will allow synergies and trade-offs to be better understood. In addition, a holistic and integrated and coherent approach is required to address the global challenge of managing nitrogen effectively and efficiently. Moreover 'smart regulation', the use of multiple rather than single policy instruments, and a broader range of regulatory actors, will also produce better regulation outcomes (Gunningham and Sinclair 1998).

1.7 Global and South Asia Policy Events

The UNEP report (2019) on 'emerging issues of environmental concern' states that nitrogen policies are fragmented, which is apparent, for example, in the Sustainable Development Goals (SDGs). The SDG indicators reveal that nitrogen is "relevant almost everywhere but barely visible anywhere". The exception is for the nitrogen related indicators associated with the SDG 14.1 on life below water.

Several international policy events in relation to nitrogen can be linked to activities in South Asia (Figure 8). The International Nitrogen Institute (INI), established in 2003, is a key initiative that helped catalyse following events globally and in South Asia. INI has a core goal to optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects (Raghuram et al. 2021). In 2012, the South Asian Nitrogen Centre (SANC) was established as one of the six INI centres in the world.

SANC also is part of the Global Partnership on Nutrient Management (GPNM) which forms a partnership of governments, scientists, policy makers, private sector, NGOs and international organisations to respond to the 'nutrient challenge'. The GPNM is under the UNEP Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (UNEP/GPA). This partnership has facilitated further research on N_r and led to further initiatives, including the formation of SANH.

The UN Resolution on Sustainable Nitrogen Management (UNEP/EA.4/L.16) has further brought South Asia into global focus, leading to the Colombo declaration, on October 2019. With the declaration comes the ambition to 'halve nitrogen waste by 2030' whilst highlighting the multiple benefits across all the UN SDGs. Furthermore, a roadmap for policy change was proposed, including in its activities to establish an Inter-convention Nitrogen Coordination Mechanism (INCOM). INCOM would establish coordination mechanisms across related international conventions to promote action on Sustainable Nitrogen Management 2022-2024 to address nitrogen pollution and report to the sixth session of United Nations Environment Assembly (UNEA). In March 2022, at UNEA-5.2 a new resolution on nitrogen management was adopted to build the pathway for the second phase of action in UNEA-6. UNEA-5 encourages member states to nominate the focal points and to develop nitrogen National Action Plans. Prior to these events in 1982, SACEP was established with the mission to promote regional co-operation in South Asia in the context of sustainable development. SACEP, amongst other actions, commissioned UNEP funded research on; "Nutrient loading and eutrophication of coastal waters of the South Asian seas". SACEP serves as another key mechanism for regional intergovernmental collaborations to tackle nitrogen waste.

The policy agenda to implement the UN resolution, calling for a roadmap for action, is still under development. An important step is 'to establish a baseline understanding of the national and regional N_r policies currently in force around the world' (Kanter et al 2020a). Policies to improve N_r balance include but are not restricted to legislation, regulations, standards, taxes and subsidies. Such policies cover a range of sectors and environmental areas that are under threat from N_r. The accumulation of N_r compounds adversely affects the environment by contributing to poor quality of air, soil, freshwater and marine environments, climate change, eutrophication and biodiversity loss (Galloway et al 2003, 2008, Sutton et al 2011a, Erisman et al 2013, Abrol et al 2017). A global study by Kanter et al (2020a) noted that global N_r policies lacked coherence and integration regarding environmental sinks and warned of negative consequences for N_r pollution due to the risk of pollution swapping. Policy integration is desirable because nitrogen is part of complex systems, where anthropogenic alteration of the nitrogen cycle results in diverse impacts.

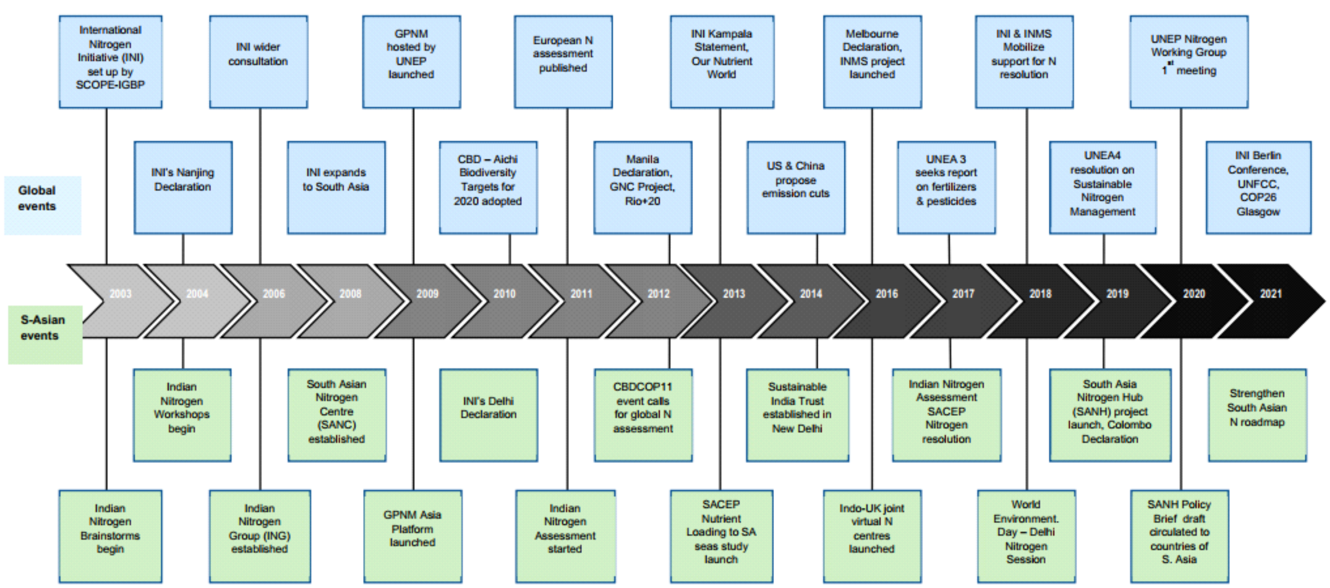


Figure 8. Timeline of global and South Asian developments toward global cooperation on sustainable nitrogen management.
Source: Raghuram et al. (2021)

However, separate government ministries typically oversee separate sectors, leading to uncoordinated or fragmented policy responses. In environmental policy analysis, measuring policy integration is important to assess to what extent policies have considered the dynamics and interactions within a system to avoid exacerbating environmental problems. Effective control of N_r needs policy integration and inter-ministerial co-ordination. A multilevel approach, striking a balance between different contexts can help to avoid policy gaps and enhance policy coverage and efficacy. Here we present the results of a rigorous process of assembling and analysing policies related to N_r across Pakistan.

1.8 What do we Know about Nitrogen Policies?

Nitrogen management is a major international policy issue and international policy actions are easier to track. Less is known about the nitrogen policy landscape at national levels (Kanter et al. 2020). A limited understanding remains of how many nitrogen-related policies there are, what issues they address, and what types of instruments are used. In addition, how existing policies may inadvertently lead to increases in nitrogen pollution is also poorly understood. An initial international assessment attempted to address this knowledge gap by creating the world's first nitrogen pollution policy database by Kanter et al. (2020a) identified 2,726 policies across 186 countries derived from the ECOLEX database. This database was developed with the basic aim of identifying the gaps and opportunities in N policy, around the world. Overall, their analysis revealed that policy integration was limited and ill-equipped to deal with the cross-cutting nature of the global N_r challenges. Policy fragmentation, and the lack of understanding on nitrogen-related policies and their trade-offs, are barriers against an effective tackling of the nitrogen challenge. This is one of the challenges that SANH aims to examine. Investigating the regional and country level implications of the N policy database has yet to be examined for South Asia. Making this step from global to regional analysis is a core aim of the SANH project. An initial regional assessment of nitrogen emissions and policy was undertaken by SACEP and SANH (2021) for South Asia, and results are summarized in a joint report. These regional results also featured in a scientific article by Yang et al. (2022). This SANH report outlines the country level implications of these earlier findings.

This report is the first of its kind to provide a national overview for Pakistan on the extent of nitrogen-related policies. This analytical report also considers the indirect policies that may not consider nitrogen in their formulation but potentially have implications for nitrogen management. By building a better understanding of the current nitrogen policy landscape, both at the national and region level, this report will support efforts to develop effective nitrogen management policies for the future.

2.
Country Level Profile and Priorities

2.1 Biophysical and Geographical Characteristics

Pakistan is in South Asia adjacent to Arabian Sea in Indian Ocean. It is situated between 23° and 37° north latitude and 61° and 75° east longitude. There are ten major agro-ecological zones of the country. The country possesses a diverse climate as well as hosts a variety of land use types – from irrigated agricultural land mainly in the east and south to arid areas in north (Figure 9). The climate generally ranges from subtropical to semi-arid. This, however, drastically changes with altitude. Annual rainfall ranges from 125 mm in the extreme southern plains to 500-875 mm in the northern plains and mountainous regions. About 70% of the total rainfall occurs in monsoon season (July-September) as heavy storms. The Indus plains and the Thar Desert are extremely hot in summers with mean monthly maximum temperatures going beyond 40ºC, sometimes reaching up to 53ºC on individual days. Contrastingly, the mean monthly temperature of plains in winters can drop to 2ºC-5ºC, however, it can drop below zero in mountainous areas.

Pakistan is an ethnically and linguistically diverse country, with a similar variation in its geography and wildlife. The national language is Urdu. This is also the official language, along with English. The country has several regional languages, inter alia, Punjabi, Saraiki, Pashto, Sindhi, Balochi, Brahvi, Hindko, Kashmiri, Shina, and Balti amongst other local languages.

The country has a population of 240 million with a geographical area of 796096 Km2. The total value of GDP of the country is US $375 billion (World Bank, 2022) with per capita income of US $1588. Agriculture has been a vibrant sector of the country's economy having around 23% contribution in the GDP as per Economic Survey 2023. This sector employs around 40% labour force. A population growth rate of around 2.5% can have implications for natural resources, food security, livelihoods and environmental sustainability.

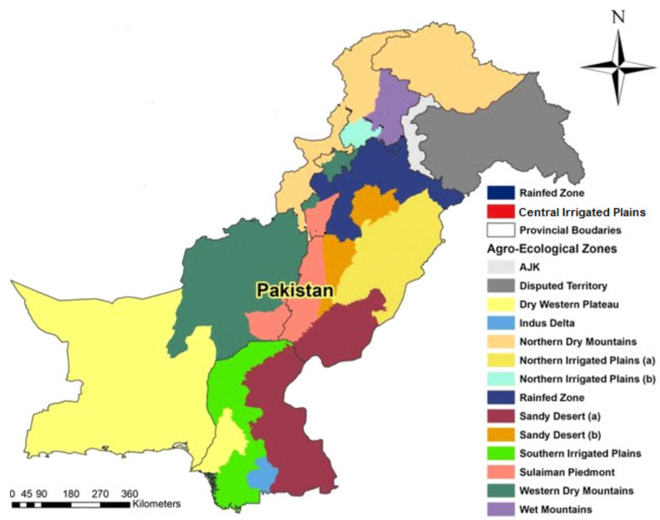


Figure 9. Land cover map of Pakistan
Source: Mahmood et al. 2020

Pakistan has a semi-industrialised economy with a major share of agro-based industries as the agriculture sector has strong backward-forward linkages with them – from provision of raw material in the form of primary farm products to purchase of fertilizers, machinery, equipment, chemicals, seeds, services and so on. In terms of land use, out of the total area of 79.6 million hectares, nearly 24 million hectares are cultivated/cropped including the fallow land, while forests cover 4.6 million hectares of the total land. The country has the world's largest contiguous irrigation system covering almost 80% of arable land producing nearly 90% of the total food for humans and livestock consumption (Table 2).

Table 2: Land use/Land cover of Pakistan.

Sr. No	Land use/Land cover	Area (ha)	Percent share
1	Forest	4523.4	5.4
2	Rangeland	22451.3	26.9
3	Agriculture	16604.7	19.9
4	Fallow land	8315.5	10
5	Exposed rock	20396.0	24.5
6	Desert	8127.1	9.7
7	Build-up area	319.9	0.4
8	Waterlogged-saline area	440.1	0.5
9	Water bodies	417.6	0.5
10	Snow glaciers	1829.6	2.2
	Total	**83425.2**	**100**

Source: Ministry of Climate Change (2016)

Five major rivers flow within the country, mainly constituting Indus Basin. These rivers include Jhelum, Chenab, Ravi, Sutlej and Indus. A major part of the country's agricultural production is dependent on the waters from these rivers reaching farms via integrated canals and watercourse networks. Major investment has taken place in recent decades on the improvement and lining of canals and watercourse in a bid to conserve the maximum amount of water from leaching and seepage losses.

2.2. Socio-Economic Background

2.2.1 Administration

Pakistan is a democratically governed nation with a parliamentary system where elected representatives have the power to legislate and administer through ministries and departments. Like many democracies in the world, the Pakistani government comprises of three branches: Executive, Legislative and Judiciary. The president, who is the head of the state, is elected by the parliament and provincial assemblies through the vote of elected representatives. Likewise, the Prime Minister is the head of government who is chosen by the national assembly members. Both Prime Minister and president hold their offices for a term of five years. The country is administratively divided into 4 provinces namely Punjab, Sindh, Khyber Pakhtunkhwa (KPK) and Balochistan. Gilgit Baltistan (GB) – famous for its touristic beauty and temperate climate, in the northern highlands – is another province administered by Pakistan, however, constitutionally independent. Likewise, Azad Jammu and Kashmir is a relatively autonomous state, compared with the provinces, however, the country is responsible for budgetary support as well as administrative oversight. The provinces are run by a Chief Minister who is elected by provincial assembly members of the respective province. The Governor in the provinces serves as a representative of federation within the province. The Chief Ministers, too, are elected for a term of five years. At the national level, parliament is comprising of National Assembly and Senate. National Assembly members are elected representative from their respective constituencies. However, members to the Senate of Pakistan are chosen by the elected members of both national and provincial assemblies. Elected representatives are entrusted to run ministries with administrative support from secretaries.

The Supreme Court, a Court of Appeal, High Courts and a number of subordinate courts together form the judicial system of the country. The federal capital has its own high court having similar powers as those of provincial high courts. There are multiple other specialized courts pertaining to services matters, accountability, banking, anti-corruption etc. The legal system of the country, particularly pertaining to criminal and civil laws, is mainly based on British law. There are multiple lower courts at district/ provincial level including Session courts, many specialized courts such as Family courts, Banking courts, Service tribunals and so on.

The 18th Amendment in the Constitution passed in April 2010 devolved multiple federal powers to the provinces leading to significant provincial autonomy – both administratively and financially. This amendment exclusively delineated control of various ministries that were handed over to the provinces such as agriculture, food, livestock, health, education, land management, irrigation, local government, transport etc. The provinces are governed democratically under the lead of Chief Ministers supported by provincial cabinet.

2.2.2 Economy

Three main sectors constitute the economy of Pakistan: Agriculture, Industry and Services. Agriculture and industry are collectively known as commodity producing sectors. The contributions of these sectors to the national output are 23% (agriculture), 18.5% (industry) and 58.5% (services). Agriculture is the mainstay of many rural households who heavily depend on it for their livelihood and food security. Pakistan is amongst the world's top ten producers of wheat, cotton, rice, sugarcane, mango, dates and Kinnow oranges. Major crops (wheat, rice, cotton, maize and sugarcane) contributed around 4.2 percent, while minor crops contributed around 3.3 percent to the country's total GDP in the fiscal year 2023 (GOP, 2023). In addition, the livestock sector contributed more than half to the agricultural GDP (around 63%) with around 14 percent share in the national GDP. This sub-sector employs approximately 35 million people. Fisheries and forestry sectors each contribute a minimal share in the GDP (less than 1 percent cumulatively).

The industrial sector comprises on manufacturing and mining with the former having large scale manufacturing (LSM), small scale manufacturing (SSM) and slaughtering. LSM include, inter alia, Textile, Food & Beverages, Coke & Petroleum Products, Pharmaceuticals, Chemicals, Automobiles Iron and Steel Products, Fertilizers etc. likewise, services sector has various subsectors such as Whole sale and retail trade (share GDP of 18% and 31% in Services), Transport, storage and communication (share in GDP of 11% & 18% in Services), Finance and insurance (share in GDP of 1.8% & 3.1% in Services), Housing, construction and dwellings (share in GDP of 7% & 12% in Services), General Government services (share in GDP of 12% & 21% in Services), Other private services (Share in GDP of 8.8% & 15% in Services).

Despite the tremendous and ongoing growth of agricultural production, the nation continues to face issues related to food and nutritional security, rural unemployment and income inequality. As noted by World Food Programme, the country has become a food surplus producer especially in case of wheat which is distributed to needy people through various mechanisms. Nevertheless, a significant proportion of population still strives to ensure easy access to healthy and nutritious food particularly children under the age of 5 years and the lactating women. As per the National Nutritional Survey of 2018 (UNICEF, 2018), around 37% of the total population was reported to be under-nourished with 40 percent of children under 5 suffering from stunting. The survey further reports that an average household spends nearly half of its income on food making them highly vulnerable to food inflation. The Government under BISP (Benazir Income Support Programme) has, however, devised a strategy to build resilience against multiple shocks including food insecurity through direct cash transfers and in-kind provision of food items at subsidized rates. Nearly, 60 percent of the total population is aged 24 or under showing a majority of youth (around one-third population in the age bracket of 10-24 years), which can be transformed into an asset with proper education and skill development. However, according to World Bank (2019), 27 percent of primary school-aged children were not enrolled in schools. A quarter (24%) of the population resides below the official poverty level. Similarly, 39% of people live in poverty, according to the Multidimensional Poverty Index (MPI) (FAO 2018).

A World Bank (2023) study states that although Pakistan has significantly reduced poverty over the past 20 years, results in terms of human development have lagged and the country's economy is still fragile and growing slowly. Almost 47 million Pakistanis were lifted out of poverty between 2001 and 2018 because of the growth in non-agricultural economic opportunities, immigration, and related remittances. Although poverty is being reduced quickly, human capital results are still subpar and stagnant, as evident from a very high level of learning poverty (75% children at late primary age) meaning low level of proficiency in reading (Khan, 2023).

The people and the economy of Pakistan had been greatly impacted by the floods in 2022 casting severe implications for development drive in the post-flooding times both at national level and household level. Strong seasonal winds and heavy rainfall since June 2022 until the mid-September 2022 caused unparalleled catastrophic flooding. More than 33 million people were impacted (World Bank, 2022)[5].

[5] *https://www.worldbank.org/en/news/press-release/2022/10/28/pakistan-flood-damages-and-economic-losses-over-usd-30-billion-and-reconstruction-needs-over-usd-16-billion-new-assessme*

Almost 2 million homes were either completely damaged or demolished. According to reports, 1,700 people lost their lives (BRC, 2023)[6]. Nearly 1.1 million animals perished and more than 25,000 suffered severe injuries. The flood losses to agriculture included the destruction of more than 9.4 million hectares (ha) of farmland, with overarching economic impact on the agricultural industry (GOP, 2023b). Given the reliance on cotton by the textile industry (textiles making up 25% of industrial production), the reduction in agricultural production could have a detrimental effect on business operations in the industrial and service sectors. The destruction of infrastructure had potentially led to the disturbance of crop cycle, the distortions in financial sector (with most of small lending institutions acting as the first line of solution), and the devastation to the human capital, all leading to declining food production and compromised access to food.

2.3 Environmental and Health Impacts of Nitrogen Pollution in Pakistan

There are a variety of views on society-environment linkages suggesting the drivers and dynamics that lead to the sustainability of natural resources and environment. Environmental degradation, on one hand is attributed to population pressure, and the public or society's wellbeing is highly influenced by the quality of the environment wherein societies thrive, on the other hand. The relationship between society and environment is mediated by several socioeconomic, cultural, political, and developmental variables whose relative significance varies considerably from one context to another. Over the past three to four decades, economists, biologists, and environmentalists have been debating the role of society in environmental degradation. Nevertheless, as the members of a particular society ensure their survival within a geographical bound, they tend to manipulate natural resources owned by and present within that country, there are untoward consequences of such manipulation leading to negative consequences to be borne by that society.

Other than macroeconomic data on fertilizer/manure use trends in Pakistan, there is limited context-specific data available on N_r usage, or the environmental and health impacts of excessive N_r in the environment. Reasons for this are the lack of understanding among policy makers, practitioners, and researchers of why excess N_r in the environment is a problem: how transformations of excess N_r takes place in the environment or in the soil. This section discusses various question such as:

- Why N_r in the environment is a global and regional concern including Pakistan?
- What is the fate of N_r through the transformations that take place in soil-plant system and the processes that can lead to losses from the system?
- What is the impact of this N_r on air quality, ecosystems, biodiversity, food production capacity, and human health at a global level?
- What have been the historical changes in N_r use and emission trends from agriculture in Pakistan?
- What are the gaps in our knowledge on N_r usage, its impact within our food production and consumption systems?
- What are the key areas where strategies need to be developed to improve our understanding of the agricultural systems in Pakistan, the N_r pathways, the field level practices, the extent of the N_r problem, and the identification of good practices which can inform future strategies?

Due to limited data availability for Pakistan, global and regional datasets have been used to demonstrate the enormity of anthropogenic perturbation on the N_r cycle and resulting implications for the environment and public health. These issues are likely to exist in Pakistan, however, there is still little attention being paid to them. Strategies need to be developed and implemented that reduce demand for N_r or

[6] *British Red Cross, 2023. Available at: https://www.redcross.org.uk/stories/disasters-and-emergencies/world/climate-change-and-pakistan-flooding-affecting-millions*

those that limit the emissions from entering into the bio-geochemical system.

About a 10-fold increase in total N_r input (including synthetic fertilizers, manure, biological N_r fixation, and atmospheric deposition) has been recorded in Pakistan between 1961 and 2018 (FAOSTAT, 2021). Raza et al. (2018) estimated a rapidly increasing surplus N_r ranging from 171 to 3,581 Gg N yr-1 during the period 1961 to 2013. This has led to an increase in N_r emissions.

2.3.1 Air Quality

Air pollution has emerged as a significant threat to the environment, quality of life, and health of the population in Asia, especially in South Asia where emission control technologies and strategies are either not in place or not adopted fully. Considerable evidence is available that poor air quality is playing havoc with the health of the population in the region (WHO 2002a). Urban air pollution is estimated to be responsible for 865,000 premature deaths every year and about 60% of these deaths occur in Asia (World Health 2007). Elevated concentrations of pollutants have been found in various countries throughout Asia: India (Jain and Khare 2008; Oanh et al. 2006), Bangladesh (Begum et al. 2006), Philippines (Cassidy et al. 2007; Oanh et al. 2006), Malaysia (Omar et al. 2007), Vietnam (Oanh et al. 2006), Indonesia (Oanh et al. 2006), and China (Chan and Yao 2008).

Pakistan is ranked third-most polluted country globally in terms of air quality with a very high health and economic toll both for humans and the economy. The exposure to air pollution was reported to cause 235,000 premature deaths only in 2019 in the county Pakistan, whereas its prevalence has reduced average life expectancy by almost 2.7 years (MoCC, 2023).

It is further noted that the most harmful air pollutants are particulate matter PM2.5 and NO_x. The concentration of just PM2.5 is estimated to be 63 micrograms per cubic meter (µg/m3) in the country for the year 2019. This concentration is 12.6 times higher than the recommended limit of 5µg/m3 by WHO (WHO, 2022; UNEP, 2024). Likewise, the data reported by UNEP (2024) show that the deaths caused by fine particle pollution in the year 2019 were 114,008 (51 deaths per 100,000 people). Of these deaths, 25 %were attributed to chronic obstructive pulmonary disease, followed by strokes (20%), lower respiratory infections (19%), ischemic heart disease (18%), tracheal, bronchus, and lung cancer (18%) and others such as type-2 diabetes and neonatal disorders (22%). With such an intense disease and death burdens, only one out of nine targets for cleaner air had been met till 2019 under the UNEP's Actions on Air Quality (UNEP, 2024). Similarly, a World Bank report of 2016 has observed that the economic loss from air pollution in Pakistan was US$47.8 billion in 2013 equivalent to 5.8 percent of GDP (World Bank, 2016). The main sources for this high level of air pollution are the domestic use of fossil fuels in the absence of or inadequate access to clean modern energy for domestic purposes), industrial and transport emissions, and agricultural emissions from fertilizers, livestock, and the burning of crop residues.

Almost whole populations in countries like Pakistan, Bangladesh and India lives in areas with pollutant concentrations beyond the World Health Organization's guidelines. This is manifested by the WHO's interim targets which remained higher than 35 µg/m3 since 1990 (Anjum et al. 2021). Due to poor monitoring facilities as well as lack of public awareness, severe health risks have erupted and reported frequently particularly the frequent and intensive onslaught of smog in the country leading to respiratory and vision complications. However, after 2015 smog incidences, there was a boost in public awareness about air quality while various steps were introduced by the Government particularly after 2020 whereby prohibiting the burning of crop residues such as those of rice and wheat remained on top. The Air Quality Index has remained quite poor in last few years with selected cities (such as Lahore, Karachi, Faisalabad), among the top cities of the world with poorest air quality for an extended period. This reflects the severity of air pollution in Pakistan with a great potential of intervention by the Government. This severity can further intensify in the case of urbanized settlements. These urban areas are highly vulnerable to deteriorating quality of air where congestion, less availability of open space and poor environmental conservation potential can further aggravate the situation.

2.3.2 Water Quality

Pakistan is extremely vulnerable to water scarcity both in the wake of climate change and exponential population growth. The per capita availability of water has significantly declined from independence of the country to date. The aquatic environment of the country can be divided into three components: (i) inland waters, (ii) estuarine waters and (iii) marine water. The rivers, streams of the Indus System, lakes and other wetlands and groundwater form the inland waters. In case of estuarine water, the lower delta of the river Indus mainly splitting into numerous distributaries constitute this component. This delta is often inundated by tidal floods generally during monsoon. The marine water generally forms the Exclusive Economic Zone (EEZ) of the country extending to 240,000 km^2 with an additional continental shelf area of 50,000 km^2 (UNEP, 2013). The total maritime area of the country is around 30 percent of the total land area (NIO, 2024). Both renewable and non-renewable forms of water are available in the country. The former includes freshwater resources, fisheries (inland and marine), mangroves and related vegetation, and other aquatic fauna and flora.

An FAO working paper by Habib and Wahaj (2021) portrays the country as one of 36 most water stressed countries globally. The country withdraws more than 70 percent of total renewable water with 228 billion cubic meters (BCM[7]) and 62 BCM of surface water and groundwater, respectively. The per capita water availability is currently around 1150 m3 per year compared with 5237 m3 per year in 1962 (Habib and Wahaj, 2021). Nearly 170 BCM of water enters the Indus Basin annually, out of which 128 BCM is used for irrigation of crops through interlinked canals while the remaining 42 BCM flows to the sea (UNEP, 2013). As this flow is helpful in maintaining a viable river ecosystem particularly the Indus estuary, yet there is a great potential of storing enough of this water for irrigation purposes especially usable during droughts. However, there are weaknesses in currently available storage capacity due mainly to heavy silting of reservoirs.

The surface water in the country is mainly sourced from the Indus River[8] and its major tributaries viz. the Kabul, Swat, Chitral, and Panjkora Rivers on the right bank, and on the left bank from the Jhelum, Chenab, Ravi, Beas and Sutlej Rivers. With the introduction and implementation of World Bank sponsored Indus Water Treaty in 1960 (World Bank, 1960) between India and Pakistan, only Jhelum and Chenab on the left bank have fallen to the share of Pakistan, while Sutlej and Beas are affiliated with India. The tributaries on the left bank of Indus and Indus itself flow in shallow channels meandering across the vast alluvial plain, gently sloping towards south to south-west along the river having extremely flat gradients from 2 meter per 10 km (about 0.02 percent) in the Punjab

[7] 1 BCM = 0.81 Million Acre Feet (MAF)

[8] The length of Indus River is about 2800 km with 2682 km falling in Pakistan. The alluvial plain area of this river is about 207,200 km2, and the deltaic area is about 20,000 km2. The annual water runoff is about 200 km3 with a yearly sediment discharge of around 200 billion Kgs. Originating from the Tibetan tableland at Singi Kahad spring, on Kailas Parbat (mountain) near Mansarwar Lake, it passes through the Himalayan range, and, collects runoff from the Hindu Kush and Sulaiman ranges (Habib and Wahaj, 2021).

to as low as 1 meter per 10 km (0.01 percent) in Sindh. The flow of these rivers exhibits unique characteristics but there are few similarities as all of them rise in the spring and early summer due to glacial/snow melt and monsoon rainfall with a combined peak discharge in July/ August. In contrast, the winter flows (during the November to February) are much lower and fluctuate around less than one-tenth of those of the summer monsoon (UNEP, 2013).

Sources Of Water Pollution

There are ample challenges linked with the quality of surface and ground water although with sufficient options for sustainable development and use of available water resources. Water quality degradation or water pollution around the globe, primarily adheres towards human activities. The significant ones are unmanaged disposal of mechanical, civil and household wastes in water bodies (Azizullah et al. 2011). The main sources of water pollution can be viewed as point and non-point sources, where point sources incorporate release from metropolitan sewage, treatment plant etc. and are relatively easy to measure and control. On the contrary non-point sources are hard to trace and control. Agricultural movement can be considered as a major non-point source incorporating the utilization of nitrogen compost, mineralization of soil nitrogen etc. (Arefin and Mallik 2018). Common point and non-point sources of water pollution are given in Table 3.

Table 3: Common point and non-point sources of water pollution

Pollution Source	Factors
Point Source	• Wastewater effluent (Municipal and industrial) • Runoff and leachate from waste disposal site • Runoff and inflation from animal feedlots • Runoff from mines, oil fields, unsewered industrial sites • Storm sewer outfall from cities of population <100000 • Overflow of combined storms and sanitary sewers • Runoff of construction sites > 2ha
Non-point Source	• Runoff from agriculture (including return flow from irrigated agriculture) • Runoff from pasture and range • Urban runoff of un-drained and drained areas of population <100000 • Septic tank leachate and runoff from septic system • Runoff from construction sites <2ha • Runoff from abandoned mines • Atmospheric deposition over a water surface • Activities of land that generate contaminates such as logging • Wetland conversion, construction and development of inland • Waterways

Source: Arefin and Mallik (2018).

The abstraction rate of the aquifer has been far more than the recharge leading to the fusion of the fresh and saline zone and secondary salinization. Excessive abstraction is deemed to happen in the wake of subsidized electric supply for tube-wells leading to the over-abstraction as well as poor irrigation practices. The Pakistan Council for Research in Water Resources (PCRWR) conducted a comprehensive study in Pakistan and revealed the substantial contamination owing to NO_3 (23 %) which was found in water samples collected from both the Balochistan and Punjab provinces from irrigated and non-irrigated districts like Lahore, Kasur, Faisalabad, Khushab, Chakwal, Mianwali, Jhelum, Bahawalpur, Karachi, Mirpur Khas, Peshawar, Risalpur, Quetta, Ziarat, Loralai and Mastung (Alamgir et al. 2016).

Out of the total groundwater abstraction, the highest being 81 percent, takes place in the Punjab province having majority share in agricultural production. In the Punjab province, 80 percent of the abstracted water is fresh and clean while remaining 20 is saline. On the other hand, abstraction share of Sindh province is 12% in which the freshwater is 23%, and the rest saline (Ahmad et al. 2021). Additionally, the deteriorating quality of ground and freshwater by the contamination of chemical residues emanating from pesticides and fertilizers application in agriculture along with industrial and municipal wastes is yet another challenge that needs to be challenged before acute water scarcity becomes imminent. The water quality levels are way below the recommended guidelines of WHO (Shahid et al. 2014). As a result, around 80 percent of the total population is devoid of safe drinking water (Daud et al. 2017). Moreover, the pollutants' load due to urban waste and sewerage has severely affected surface water quality. Most of the industrial cities except Karachi are located along the rivers. The pollution by municipal and industrial sources has affected the rivers of the country to different degrees. The degree of pollution to Indus and Jhelum is slightly less compared with Ravi and Sutlej. It is because the former two have a relatively high flows and fewer discharge sources. On the other hand, various reaches of Ravi and Sutlej rivers intercept heavy effluents as large urban settlements and industrial areas are present along these rivers accompanied by a significant low river flow. Similarly, few sections of the Kabul and Chenab rivers are also significantly impacted by the inflow of urban and industrial effluents.

Significant microbial contamination of both surface and groundwater in the adjoining areas of Ravi and Sutlej rivers has been reported by Imran et al. (2018). A high microbial contamination at various sites of both the rivers, for coliforms as well as fecal coliforms was found in majority of the samples drawn from river, drains and groundwater (Table 4).

Table 4: Fecal load in surface and groundwater sources of Pakistan

Water Source	No. of Samples tested	Fecal Contamination	
		+ve	-ve
River	72	72	0
Drains	54	54	0
Groundwater	108	58	42

Source: Imran et al. (2018).

2.3.3 Climate

Aridity remains the most common feature of Pakistan's climate, and its continental nature can be seen in the extremes of temperature. Situated on the edge of a monsoonal (i.e., wet-dry) system, the country experiences an erratic rainfall pattern at all places with a highly variable volume and frequency. The rainy monsoonal storms, the exact margins of which vary from year to year, blow in intermittent bursts, and most moisture comes in the summer. Tropical storms from the Arabian Sea provide precipitation to the coastal areas but are also variable in character (Burki and Ziring, 2024). Gaseous emissions have significantly risen in the last few decades and are a major source of changes in the rainfall pattern as well as temperature.

Due to the depletion of hydrological resources, Pakistan is already under severe threat by fast changing climate and its effects in the recent past (Chaudhry et al. 2009) as well as the recent catastrophic floods in 2010, 2013, 2016 and 2022. The temperature in Pakistan is projected to rise from 0.9 °C in 2020 to 1.5 °C in 2050. During 1998–2004, Pakistan faced the worst drought in its history (Hussain and Mumtaz 2014). Likewise, around 84% population was affected and 76% deaths in Baluchistan province occurred due to heatwaves (Ullah et al. 2018). Furthermore, it is predicted that high temperatures, frequent and persistent droughts, heavy pests' infestation, diseases severity and health problems, and the lifestyles impacts will persist for many years to come (Hussain et al. 2018).

Climate change has transboundary causes as well as effects. It can cause severe implications for the countries that have little contribution in the actions that lead to climate change. The classical example is the 2022 flooding event in Pakistan which was attributed by UN as an externality from global climate crisis fuelled by the industrialized countries with a very modest contribution of Pakistan (UN, 2022), noting that "compared to many industrialised countries, Pakistan and its people had only modestly contributed to global warming that was resulting in extreme weather events and climate change".

Pakistan is highly vulnerable to the worldwide Climatic changes' harmful effects such as frequent famines, rising temperature, changed precipitation patterns, and agricultural destruction. Risks are exacerbated by its low per capita income and, constrained coping capacity also brought about by poor institutional and infrastructural support. Pakistan's economy is agriculture-based but has insufficient infrastructure to adapt and mitigate the effects of climate change. It is among the top vulnerable countries facing severe impacts of climate change due to its heavy dependence on water resources for agriculture. Regions are not equally affected by climate change. Climate change will have more severe effects for the poorer segments of the society such as marginalized farmers, women, children and rural labour mainly due to their high vulnerability and low coping capacity (Qamer et al. 2022; CDP, 2022; ReliefWeb, 2022; Al-Jazeera, 2023; Puskur and Mishra, 2022).

The 2010 and 2022 floods showed that farmers in rural areas are more vulnerable to climate-driven natural disasters. Pakistan is among the countries facing its adverse impacts (Danish et al., 2018). However, at regional level, the country stands second, after India, in terms of GHGs contributions, hence necessitating a coordinated and multiscale approach to the mitigation of climate change at local as well as regional level.

The country's climate indicators are expected to deviate significantly from the historic averages. Already, the annual mean temperature has increased by roughly 0.5°C in the last 50 years (ADB, 2017). Similarly, the number of heatwave-days per year has increased nearly fivefold in the last 30 years. In addition, annual precipitation has been highly variable historically but has slightly increased in the last 50 years. Sea level along the Karachi coast has risen approximately 10 cm in the last century (ADB, 2017). The rapidly increasing population is one of the major driving forces putting pressure on the environment. Since 1947, country's population has grown nearly at 2.5 percent per annum, increasing from 32.5 million to 241.5 million in 2023 (UNEP, 2013; PBS, 2023). Population increases have heightened pressure on natural resources for the need, to provide living and livelihood to more people thus leading to their degradation and depletion. For instance, the rate of deforestation has remained greater than other countries in the same income group during the last decade of previous century. This implies that with economic growth alone, the country cannot simply "grow-out" of environmental or social problems (UNEP, 2013). The growth of population, on the other hand, also means increased human power, which can be used for sustainable production and for reaping the benefit from demographic dividend. However, needing an integrated strategy clearly taking stock of socioeconomic, cultural, political, institutional and regional dimensions.

2.3.4 Soil Quality

Pakistani soil is generally dry in nature with a high concentration of calcium carbonate and a low level of organic matter, defining features of an arid and unstable terrain. Soil diversity results from the unique patterns of soil formation, even in a small area. These soils differ from location to location in terms of their texture, chemical composition, colour, and organic content (Samie et al. 2017). Although most of the country's soil is developed on alluvial deposits, there are hilly formations and evergreen and/or deciduous forest vegetation.

Land in Pakistan is used for various purposes with around 22.54 million hectares being used for agricultural purposes. Although land degradation and desertification is a global issue it is acute in Pakistan, where three-fourths of the land is either already affected or likely to be affected in near future (UNEP, 2013). Desertification is a process or a set of processes, which cause a diminution of the biological potential of land, ultimately leading to desert-like conditions and a complete loss of production.

Salinity, waterlogging and siltation t have led to further serious implications for the sustainability of land for production as well as other purposes including residential development. Around 25 percent of the irrigated land is exposed to various levels of salinity. Although the soil in Pakistan is fertile and favours agricultural production gradual changes in soil quality because of land use and management practices has meant soils are often deficient in organic matter and nitrogen. As a response to this problem, the increased use of chemical fertilizers to incorporate nitrogen into the soil is further causing soil and water pollution and resulting in lower soil fertility (Syed et al. 2021).

Pakistan is one of the countries with the highest quantity of excess N_r on agricultural land (West et al. 2014). Agricultural N_r use increased to 3,838,000 tonnes in 2021-22 from 2,265,000 tonnes in 2000-01 in Pakistan (NFDC, 2024). The agricultural use of all chemical fertilizers has been witnessing an increasing trend mainly fuelled by increased cropped area, population growth and subsidies by the government. The use of urea fertilizer in agriculture has more than doubled between the period 1993-94 and 2020-21 (from 3,152,000 tonnes to 6,691,000 tonnes). An average annual growth rate of around 2.85 percent is observed since 2000-01 till 2020-21 in the use of urea fertilizer (Table 5).

Table 5: Amount of N nutrient and different chemical fertilizers used in Pakistan agriculture, 2000-01 to 2020-21 ('000 tonnes).

Year	N_r offtake	Fertilizer offtake (product-wise)					Total Fertilizer Nutrients' offtake
		Urea	DAP	NP	CAN	SSP	
2000-01	2265	4185	1103	310	308	166	6179
2001-02	2285	4262	1098	374	359	211	6422
2002-03	2349	4637	1068	392	356	197	6850
2003-04	2527	5120	1374	354	330	161	7688
2004-05	2796	5405	1385	368	314	120	7893
2005-06	2927	4678	1612	421	338	179	7553
2006-07	2649	5579	1088	274	245	156	7641
2007-08	2925	5757	1090	399	343	141	7865
2008-09	3034	6555	1536	334	366	158	9112
2009-10	3476	5765	1325	335	595	224	8407
2010-11	3134	5992	1076	403	602	145	8317
2011-12	3207	5197	1345	446	432	87	7585
2012-13	2854	5747	1623	478	508	82	8523
2013-14	3185	5937	1801	516	487	100	8954
2014-15	3309	4558	1823	605	382	112	7575
2015-16	2672	6372	2329	759	750	84	10435
2016-17	3730	5825	2440	572	670	96	9753
2017-18	3435	5971	2200	450	541	102	9484
2018-19	3408	6015	1984	578	502	70	9389
2019-20	3415	6267	2170	786	852	89	10487
2020-21	3711	6691	1863	838	820	107	10561
2021-22	3838						

Source: NFDC (2023). (Note: DAP: Di-Ammonium Phosphate; NP: Nitro-Phos; CAN: Calcium Ammonium Nitrate; SSP: Single Super Phosphate)

Soil is undoubtedly a dynamic resource for humans and is also a key recipient of multiple pollutants like hazardous elements (Luo et al. 2007). Currently, contamination of hazardous elements into soil (particularly of urban soil, sourced from industrial emissions, coal and fuel combustion, vehicle emissions etc.) has become a major environmental issue all over the world (Karim et al. 2014). Pakistan too is faced with such challenges where excessive intrusion of contaminants has been happening for decades leading to the deterioration of soil health particularly in the urban areas. Whereas lands in rural areas of the country are being harmed mostly through fertilizer overdose.

3.
Nitrogen-related Policies Analysis

3.1 Brief Methodological Overview

As part of the actions towards building 'the nitrogen policy arena for South Asia', nitrogen-related polices from South Asia were collected and analysed by SANH. Assessing nitrogen-related policies can potentially help in identifying the gaps in and opportunities for managing nitrogen in the region including Pakistan. An analysis of this kind provides a starting point to understanding what policies are in place to help determine what is needed for the future to effectively and efficiently manage N_r. This policy assessment identifies the sectors and environmental sinks and the policy instruments that are suggested and/or are in place amongst other indicators for effective performance.

This work builds on from an initial global nitrogen policy assessment conducted by Kanter et al. (2020). Their global database had a collection of 2,726 policies from across 186 countries derived from the ECOLEX database. We have adjusted the data collection approach and used multiple online data sources. We added to the 61 policies from South Asia, identified by Kanter et al. (2020) and created a new SANH policy database (Yang et al. 2021)[9] with a total of 966 policies for South Asia. The policies were collected during 2020-2021. Table 6 provides an overview of the nitrogen-relevant policies collected per country in South Asia. Pakistan has cumulatively 175 policies which account for 18% of the total number of the SANH policies presented so far. Overall, 136 out of 175 policies are sourced from the FAOLEX database whereas 39 (4% of the total regional policies and 22% of the country-specific ones) are sourced through local/national sources (online). An overview on the advantages/disadvantages of these 2 databases is presented in the Appendix.

[9] *SANH Database https://catalogue.ceh.ac.uk/documents/e2f248d5-79a1-4af9-bdd4-f739fb12ce9a*

Table 6: Total Number of policies and percentage per country in the SANH database, breakdown by policy data source, and relevance and impact scope

Countries	SANH database 2019 total No. of policies	% of total SANH database	SANH database 2019 Sources		SANH subset policies high-medium relevance & large-medium scope
			Policies sourced from FAOLEX	Policies sourced from national websites	
Afghanistan	89	9	79 (8%)	10 (1%)	58 (6%)
Bangladesh	187	19	67 (7%)	120 (12%)	119 (12%)
Bhutan	60	6	31 (3%)	29 (3%)	38 (4%)
India	192	20	69 (7%)	123 (13%)	136 (14%)
Maldives	40	4	20 (2%)	20 (2%)	29 (3%)
Nepal	108	11	63 (7%)	45 (5%)	65 (7%)
Pakistan	*175*	*18*	*136 (14%)*	*39 (4%)*	*98 (10%)*
Sri Lanka	115	12	61 (6%)	54 (6%)	106 (11%)
South Asia Total	966	100	526	440	649
Percentages			**55 %**	**46%**	**67%**

Source: SANH Database formulated by FAOLEX listings (http://www.fao.org/faolex/en/) corroborated and updated by SANH partners.

The policy documents collected include Legislation, Acts, Laws, Ordinances, Plans, Strategies, Regulations, Statute, Standards, Rules, Orders, Codes, Frameworks, and Guidelines. To ensure coverage of all nitrogen-related policy documents, relevant sectors and sub-sectors were identified: agriculture, land use, environment, human health, marine, urban development, water and waste management, transport, energy, and industry. Within each country, the responsible ministries and commissions for these sectors were also identified to assist in the policy searches. For instance, not only the core ministries such as Ministry of Industries and Production, but also the less obvious ministries such as Ministry of National Health Services were also searched for the existence of N-related policies. The policies were then filtered, classified, and analysed. Figure 10 provides an overview of the data collection, search and filtration methods.

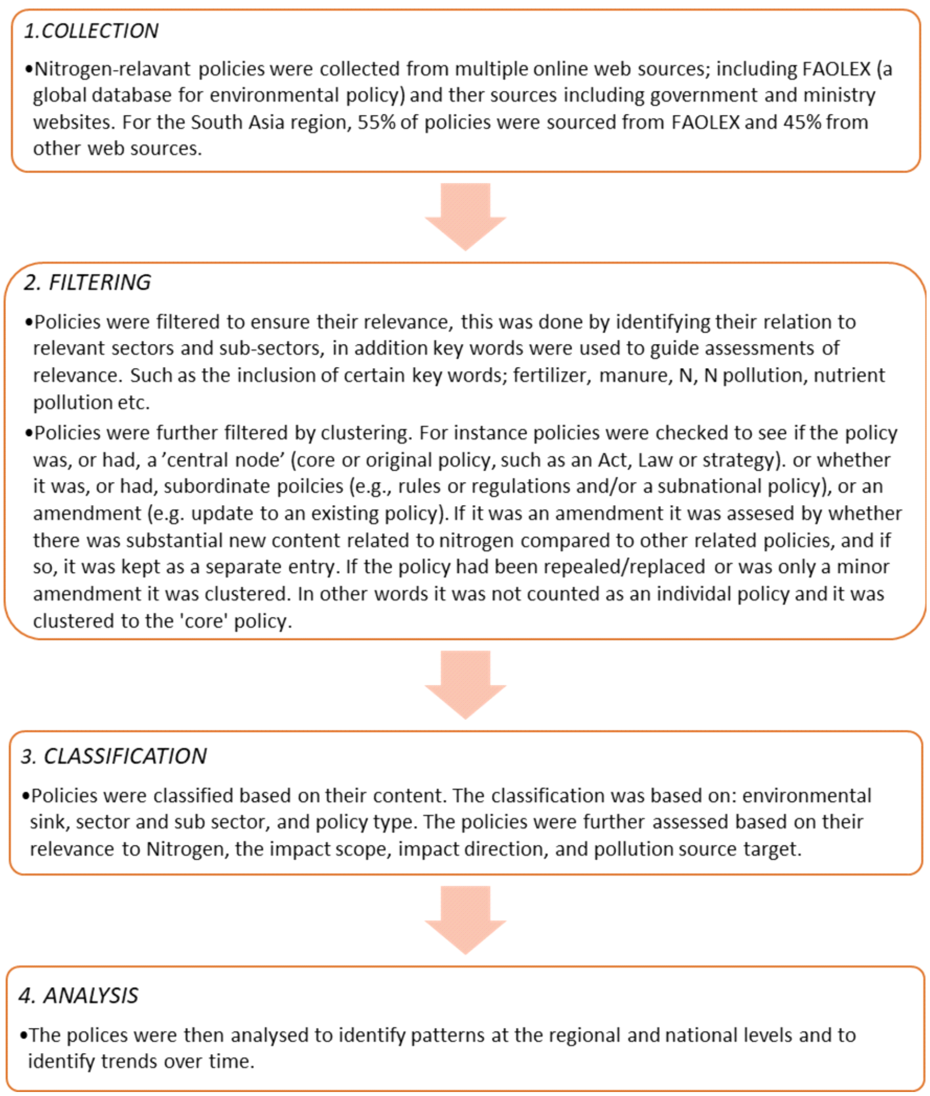


Figure 10. An overview of the nitrogen policy assessment methods adopted by SANH

3.2 Policy Classification

The nitrogen-related policies collected were classified based on certain characteristics to identify patterns in the types of polices in place for Pakistan. Policies were classified by: environmental sink; sector; sub-sector; policy type; pollution source type; impact direction; impact scope; relevance; and impact scope. The classifications list is provided in Table 7. The classification approach followed closely to the global study approach used by Kanter et al. (2020), with additional classifications. For classification definitions see Appendix 1.

Table 7: SANH nitrogen–relevant policy classification lists

Sink	Sector	Sub-sector	Policy Type	Pollution type	Impact Direction	Impact scope	Relevance
Air	Agriculture	Synthetic fertilizer	Regulatory	Point source	Positive	Large	High
Water		Manure management	Economic	Non-point source	Negative	Medium	Medium
Soil		Crop residues	Framework	Both	Mixed / neutral	Small	Low
Climate		Organic farming	Data & methods	Non-applicable Unspecified			
Ecosystem		Livestock	Research & Development (R&D)				
Multiple		Aquaculture	Commerce				
No sink included		Agriculture other	Pro-nitrogen				
	Waste	Municipal waste					
		Industrial/ commercial waste					
		Flood water					
		Medical waste					
		Organic waste					

Sink	Sector	Sub-sector	Policy Type	Pollution type	Impact Direction	Impact scope	Relevance
	Industry	Non-applicable					
	Food	Food safety					
		Food security					
		Food waste					
	Energy	Low carbon and renewable					
		Non-renewable energy					
		Biofuel and bioenergy					
	Transport	Road transport					
		Aviation					
		Rail					
		Maritime & inland water transport					
		Transport other					
		Biomass burning					
	Land use change	Forestry					
		Other land use and land use change					
	Urban dev. & tourism	Non-applicable					
	Other	Non-applicable					
	Multiple	Non-applicable					
	No sector included	Non-applicable					

4. SANH Nitrogen-Related Policy Dataset: Results for Pakistan

4.1 Policies' Relevance and Scope

The nitrogen-related policies were classified according to their relevance and impact scope. These classifications are helpful for filtering policies with direct and indirect relevance to N_r management. Table 8 portrays the number and percentage of policies classified as having high, medium, and low relevance for N_r management. A policy was classified as directly relevant with N_r management if they featured one or more of the 29 key words in the policy text[10].

Table 8. Number and percentage of nitrogen-related policies in Pakistan for policy relevance and impact scope

Relevance			Impact scope		
Relevance	**Total No. of policies**	**% of policies**	**Impact scope**	**Total No. of policies**	**% of policies**
High (direct)	71	41	Large	36	20
Medium (indirect)	46	26	Medium	66	38
Low (indirect)	58	33	Small	73	42
Grand Total	**175**	**100**	**Total**	**175**	**100**

Specifically, 71 policies (41%) out of 175 were classified with direct and 'high' relevance for Pakistan in terms of relevance to Nitrogen. Such policies included, for example, the 'Hazardous Substances Rules, 2003.' which has references to ammonia (NH_3), Ammonium Chloride, Ammonium Sulphate among other nitrogenous compounds. Indirectly relevant policies with 'medium' relevance do not contain one of the 29 key words but may feature synonyms of those words. We also expanded the list of relevant words to help identify policies. Pakistan policies classified with medium relevance include, for example, 'Auto Industry Development Policy 2016-21 (previous version AIDP 2008-2012), Khyber Pakhtunkhwa Livestock Policy 2018, Strategic Trade Policy Framework 2015, National Disaster Risk Reduction Policy 2013, Azad Jammu and Kashmir Land Preservation Act, 1954

[10] *The 29 key words were: fertilizer, manure, Nitrogen (N), Nitrogen pollution, nutrient pollution, nitrate, nitrates, ammonia, N oxides, nitrous oxide, , NH_3, NO_3, NO_x, eutrophication, hypoxia, air quality, air pollution, emissions, groundwater quality, groundwater pollution, freshwater quality, freshwater pollution, water quality, ozone depletion, climate change, greenhouse gas, agrochemical and effluent.*

(Council Order No. 319/54) and Cutting of Trees (Prohibition) Act 1992. A total of 46 policies (26%) were classified as having medium relevance.

Those classified as having 'low' relevance were identified as having presumed indirect links with N_r due to their association with a certain sector(s) and/or sink(s). In total, 58 policies (33%) were classified as having low relevance, including, the 'Land Reforms Act 1977', 'Baitulmal Trees Protection Act of 1949' and 'Punjab Animals Feed Stuff and Compound Feed Rules, 2017'. Such policies remain in the database although they have no direct reference to nitrogen, they could still have implications for N_r management. For example, seed policies are relevant due to impacts on yield which may influence agro-management decisions including fertiliser use. Likewise, animal husbandry policies may affect N_r pollution via the management of livestock waste decisions.

Table 9 also presents the percentage of policies, classified as having large, medium, and small impact in terms of their scope. Impact scope gives an indication of a policy's spatial coverage and its pertinence for N_r management. For example, there were 36 (20%), policies with a 'large' scope, including national level policies which have the potential to influence many people and are more directly relevant to N_r management. Policy examples include the 'Pakistan Climate Change Act, 2017', 'National Food Security Policy 2018', 'National Sanitation Policy 2006' and 'National Forest Policy 2015' among others.

In the case of medium scope, 66 policies (38%) are categorized under this group including those policies which may be sub-national, or less directly relevant to Nitrogen, for example, the 'Khyber Pakhtunkhwa Livestock Policy 2018' and 'Punjab Agriculture Policy 2018'. These include policies with either a very specific location or zone focus, or if nationwide, they are considered to have distant consequences for N_r management. Selected policies include within this category are the 'Pakistan Antimicrobial Resistance National Action Plan 2017', 'Khyber Pakhtunkhwa Agricultural and Livestock Produce Markets Act 2007' and 'National Disaster Risk Reduction Policy 2013'.

A majority of the collected policies exhibit a low-impact scope. In all, 73 policies (42%) had a low impact scope in terms of nitrogen management. Policy examples include, inter alia, the 'Fertilizer Policy, 2001 (*previous version 1989', 'National Sustainable Development Strategy: Pakistan's pathway to a sustainable & resilient future 2012', 'Hazardous Substances Rules, 2003', 'Khyber Pakhtunkhwa Environmental Protection Act, 2014' and 'National Food Security Policy 2018'.

4.2 Policy Types

Policy type, as a classification category, indicates what type of policy instrument(s) or parameter(s) are being suggested or applied within that particular policy. A single policy may have multiple policy type characteristics e.g. framework, data and methods, research and development (R&D) and some other categories. In the case of Pakistan, there were 322 classifications for the 175 policies (multiple types are possible as one policy can have more than one type of policy instrument or a combination of multiple policy options/tools). Policies with multiple instruments can be more effective and favoured over the other single-instrument policies as they have a more comprehensive approach to achieving their objectives (Table 9).

Table 9: Number and percentage of nitrogen-related policies in Pakistan for policy type.

Policy Type	Total No. of policies	% of classifications
Regulatory	58	18
Economic	39	12
Framework	124	39
Data & methods	39	12
R&D	36	11
Commerce	14	4
Pro-N	12	4
Total	**322**	**100**

Table 9 shows the number and percentage of nitrogen-related policies in Pakistan by policy type. Out of the total 175 policies, 78 policies (44.5%) had more than one policy type based on the type of policy instrument used to achieve policy goals. The most common type of policies is mainly the framework policies, i.e. 124 policies (39% of the total 322 policy types). Such policies often include those with broader objectives and/or designate governing bodies for achieving one or more types of objectives. Selected examples of Framework policy include 'Pakistan Environmental Protection Act, 1997 (Act No. XXXIV of 1997)', 'Pakistan Climate Change Act, 2017' and 'Pakistan Water Charter 2018'.

The second most common classification is the regulatory type of policies making 18% followed equally by data and methods (12%) and economic (12%) policies. Regulatory and economic policies are considered 'core nitrogen policies' as outlined by Kanter et al. (2020) in that 'they directly address nitrogen production, consumption or loss in a measurable way'. Selected example of regulatory policy is the 'NWFP River Protection Ordinance 2002' and that of economic policy is 'Land Reforms Regulation, 1972'. Data and Methods type of policies include 'Punjab Agricultural Marketing Regulatory Authority Act 2018' and the 'Indus River System Authority Act, 1992 (Act No. XXII of 1992)'. The least common policy types featuring in the dataset were research and development (R&D) constituting 11% of the total policies, commerce (4%) and pro-N (4%). An example of R&D type of policy includes 'Pakistan Agricultural Research Council Ordinance, 1981 (No. XXXVIII of 1981)' while the examples for commerce and pro-N policies respectively are 'Export policy order 2016 (2015-18)' and 'Hydrocarbon Development Institute Of Pakistan Act, 2006'.

4.3 Economic Sectors and Sub-Sectors

An overview of the total number of Pakistan's nitrogen-relevant policies and their percentages broken down by sector and sub-sector types are presented in Table 10. The most common type of policies were related with multiple sectors, i.e. 31%. This is an advantageous policy characteristic because a policy with a multisector purview could better facilitate N_r management in an integrated manner. Some examples of such policies include the 'National Water Policy 2018', 'National Sanitation Policy 2006', 'NWFP River Protection Ordinance 2002', 'Pakistan Vision 2025 One Nation One Vision (replaced 2009 version)' and 'National Energy Efficiency and Conservation Act 2016'.

The second most common classification (25%) consisted of single sector-oriented policies, such as agriculture. The other main sectors feature only a small percentage of the overall policy collection (ranging from 1% to 14%). Lastly, only a small percentage (3%) of policies had no reference to any sector, implying that these policies generally focused only on one or more environmental sinks rather than a particular economic sector. While such policies should ideally be linked to sector actions, sink-oriented policies are still considered to be effective because they focus on environmental protection and sustainability actions more specifically.

Selected examples of this category are the 'National Environmental Quality Standards (Certification of Environmental Laboratories) Regulations 2000' and 'National Drinking Water Policy 2009'.

The category for sub-sectors identifies policies with a more specific sub-sectoral focus. The majority of the collected policies (59%) did not have a specific sub-sector and hence classified as 'Non-applicable'. It is a default for policies that specify only a main sector, with no sub-sectors listed, or for policies that are generalised and do not refer to any specific area. The next most common sub-sector classification was 'livestock' (13%) within the agriculture sector such as the 'Pakistan Halal Authority Act, 2016 (No. VIII)'. The next most common category, with a lower percentage overall, was for forestry at 7%, for example, the 'Cutting of Trees (Prohibition) Act, 1992'. The rest of the sub-sectors were small with ≤3% policies.

Table 10: Number and percentage of nitrogen-related policies in Pakistan for sectors and sub-sectors

Main Sector	No. of policies	% of policies	Sub-sector	No. of policies	% of policies
Agriculture	43	25	Agriculture Other	4	2
			Livestock	22	13
			Synthetic Fertilizer	1	1
			Aquaculture	4	2
			Biomass Burning	2	1
Energy	9	5	Low Carbon and Renewables	4	2
			Non-Renewable Energy	1	1
			Food Safety	3	2
Food	8	5	Food Security	1	1
Land Use Change	24	14	Forestry	12	7
			Other Land Use and Land Use Change	3	2
Other	12	7			
			Road Transport	1	1
Transport	3	2	Maritime & Inland Water Transport	2	1
Urban Development & Tourism	0	0	-		0
Waste	4	2	Medical Waste	1	1
			Industrial/Commercial Waste	1	1
			Non-Applicable*		0
Multiple	55	31		9	5
No Sector Included	17	10	Non-applicable*	104	59
Grand Total	**175**	**100**	**-**	**175**	**100**

Note: For Other, urban development and tourism, no sub-sectors were identified. For any main sector policy classified as 'Multiple' for sub-sectors they were by default classified as non-applicable.

* Non-applicable represents general sectoral policies that do not specify a sub-sector

4.4 Environmental Sinks

The policy classification for environmental sinks indicates if a policy is oriented in its objectives/ intent towards either climate, water, air, soil, and/ or ecosystems. As a category, sinks can also reflect the environmental aspect at risk (under threat) from N_r. A policy may refer to more than one sink, and if so, would be classified as having covered multiple sinks.

For Pakistan, the most dominant classification of policies had not explicitly focused a particular sink and hence were categorised as 'no sink' with 42% of the total as shown in Figure 11, representing a potential gap in focusing on a particular environmental sink. On the other hand, more than half of the policies collected were purely sink-oriented. This could be regarded as a plus point in terms of major focus by the policies on particular sink(s) that could have potentially benefitted the sinks under their coverage through targeting risks to those sinks in the country or putting in place options to mitigate negative N_r impacts to the environment. Alternatively, these policies have been partially formulated keeping in view potential risks to air, water, climate, ecosystem and/or soil, whether collectively or individually.

For Pakistan, 27% policies focused on multiple sinks. This is considered a highly favourable characteristic as these policies address two or more sinks. This included policies such as the 'Pakistan's Intended Nationally Determined Contribution (The Pak-INDC) 2016'. It is part of the country's vision 2025 and encompasses a mirage of related plans, policies and growth targets in all sectors of the economy set by various ministries and departments. The Pak-INDC is a complete package focusing on the conservation of most of the sinks. This package provides an estimation of the overall mitigation measure potential with respect to various sectors. In particular, it provides an overview of mitigation options and mitigation potential in the two major emission-generating sectors, i.e. agriculture and energy. Other examples of multiple sink-oriented policies include the 'National Climate Change Policy – 2012', 'National Disaster Risk Reduction Policy - 2013', 'Pakistan Environmental Protection Agency (Review of IEE and EIA) Regulations, 2000' and 'Pakistan Climate Change Act, 2017'. These are policies that address climate, water, and ecosystems, and the 'National Environmental Policy 2004' which deals with all five sinks.

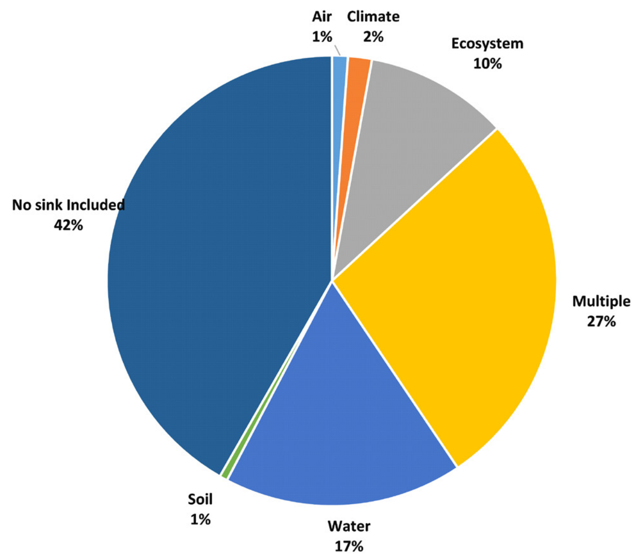


Figure 11: Percentage of nitrogen-related policies in Pakistan for environmental sinks.

The most common single sink focus was on water (17% policies), including for example the 'National Water Policy 2018' and 'Punjab Water Policy 2018'. The other single sink focused policies (either air, climate, or ecosystems) had a low percentage of nitrogen-related policies associated with them (<10%).

4.5 Pollution Source Type

Policies that are directly relevant to N_r and are concerned with environmental protection should aim to target and mitigate N_r pollution effectively by recognising the difference between pollution type sources. Point source and non-point source (NPS) pollution involve different challenges and different mitigation measures are needed to address them.

Nitrogen pollution released as a 'point source' refers to whether it is discharged directly into water or into the atmosphere at a 'discrete point', making it easier to control and monitor. Only three policies (2%) in our collection were identified as referring to 'point source' pollution, namely the 'National Environmental Quality Standards (Self-Monitoring and Reporting by Industry) Rules 2001 (amended in 2005)', 'National Environmental Quality Standards for Municipal 1995' and 'Hydrocarbon Development Institute of Pakistan Act, 2006.'

Non-point source (NPS) covers N_r pollution that comes from various sources such as land, air and/or water and can be carried overland, underground, and/or in the atmosphere, making it difficult to measure and control (Islam et al. 2018; Liu et al 2020). Only four policies were identified as having targeted and noted NPS (Table 11). These include Sindh Agriculture Policy 2018-2030, Punjab Agriculture Policy 2018, Agriculture Policy - Khyber Pakhtunkhwa - A Ten Year Perspective 2015 – 2025 and 'Punjab Disaster Response Plan 2014'.

Table 11: Number and percentage of nitrogen-related policies in Pakistan for pollution type source.

Pollution type source	No. of policies	Percentage of policies (%)
Point source	3	2
Non-point source (NPS)	4	2
Both pollution type sources	25	14
Unspecified	45	26
Non-applicable	98	56
Total	**175**	**100**

Although an environmental policy should recognise either point source or NPS, it is even more advantageous to consider both. This indicates a more comprehensive understanding of how N_r pollution can enter systems, thus enabling one to recognise how different approaches can be put in place to tackle them. For Pakistan, 14% of the policies achieved this milestone as given in Table 11 including the 'Pakistan Climate Change Act 2017', 'National Biodiversity Strategy and Action Plan (NBSAP) for achieving Aichi Biodiversity Targets and Sustainable Development Goals (previous versions; 1999 and 2015)', 'National Water Policy 2018' and 'National Food Security Policy 2018.'.

However, 26% of policies specified neither point source nor NPS. This could be a disadvantage for a policy's ability to support sustainable N_r management. For example, the Pakistan Water

Charter 2018, Pakistan Multi-sectoral Nutrition Strategy 2018-2025, National Forest Policy 2015, Pakistan Vision 2025 One Nation One Vision (replaced 2009 version), National Sustainable Development Strategy 2012' etc. were classified as unspecified. However, such policies could be amended to consider types of pollution sources, as appropriate.

Out of the total 175 policies, there were 56% policies that were grouped as 'non-applicable' as they do not explicitly relate to a pollutions source type or NPS. This was the default classification for policies classified with a negative impact direction, and/or as having an indirect relevance to nitrogen. Selected examples are 'Pakistan Antimicrobial Resistance National Action Plan 2017', 'The Forest Act, 1927 (amended 2001, 2002, 1972) (implemented 1975, NWFP forests rules 1975) and 'The On-Farm Water Management and Water Users' Associations Ordinance 1981'.

4.6 Impact Direction

Impact direction was introduced by the SANH study as a new classification to indicate whether a policy was presumed to have a positive, negative or mixed/neutral impact on N_r pollution. It is worth highlighting that this is based on the assessment of the policy text. Evidence of actual policy impacts on N_r, is outside the scope of this study, as it would be necessary to determine how those policies work in practice. All the policies require further scrutiny to determine effectiveness linking proposed objectives to actual impacts.

For Pakistan, it is encouraging that 38% of policies had a presumed positive impact (Figure 12), i.e., it promoted a reduction in N_r pollution and/or improved nitrogen management whether directly or indirectly. This included environmentally oriented policies such as the 'Pakistan Environmental Protection Agency (Review of IEE and EIA) Regulations 2000', 'Pakistan Water Charter 2018', and the 'National Water Policy 2018.'
Only a small number (3%) of policies were indicated has having a potentially negative impact, i.e., where environmental considerations were absent from the policy text. This is an unfavourable policy indicator as such policies may have the potential to increase nitrogen waste, by causing excess N_r. Polices classified as having negative impact include the 'Khyber Pakhtunkhwa Agricultural and Livestock Produce Markets Act 2007', 'National Policy for Power Co-Generation by Sugar Industry 2008', 'Fertilizer Policy, 2001 (previous version 1989)', 'Pakistan Halal Authority Act, 2016 (No. VIII)', and 'Pakistan Water and Power Development Authority Act, 1958 (No. XXXI of 1958) (amended 1998)'.

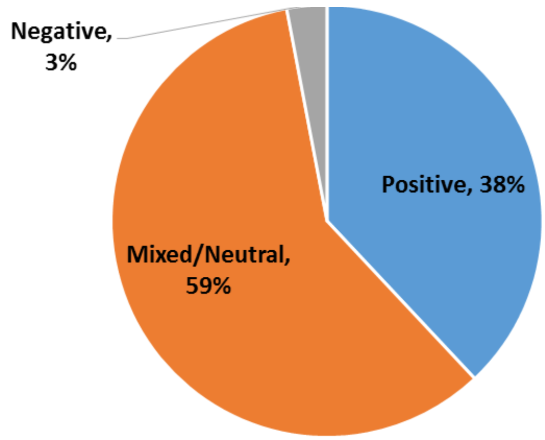


Figure 12: Percentage of Pakistan's nitrogen-relevant policies for impact direction.

As shown in Figure 12, there were 59% policies that have 'mixed/neutral' impact including those policies that can have both positive and negative impacts, for example, a policy that aims to enhance food production and increase access to fertilizer but also considers the environmental impacts, or a policy that is potentially neutral in its impacts (i.e., neither positive nor negative). Such policies may, or may not, lead to sustainable N_r management. Further assessments of the policies with mixed/neutral policy impacts would be needed to identify how far these policies could achieve or affect sustainable outcomes related to N_r use and management. Few selected examples of policies having mixed or neutral impacts are 'Pakistan Antimicrobial Resistance National Action Plan 2017', 'National Food Security Policy 2018' and 'Pakistan Multi-sectoral Nutrition Strategy 2018-2025, 2018'.

5. Cross Comparison of Policies

In this section, the policies are cross compared by the classifications for sink and sector, sink and policy type, sector and policy type. These cross comparisons enable patterns to be further assessed to identify strengths and weaknesses for promoting sustainable N_r management in policy.

5.1 Policies by Sink and Sector

Table 12 presents the cross comparison of N_r related policies with respect to sector vis-à-vis sink. Most combinations had a low number of policies, i.e., <5% policies in respect of various sectors linked with various sinks. The most common combination was for sector-specific agricultural policies that do not refer to any sinks (17% policies). Any single-sector focused policies that overlook sinks would benefit from further review and possible adjustments to mitigate negative environmental impacts. The single sector, no sink-focused policy category is followed by multiple sector policies focused on multiple sinks (16% policies). These policies point towards an integrated objective framework for N_r management within sectors and sinks. Such policies are favourable as they indicate 'integrated objectives' that consider both the multiple environmental aspects as well as multiple sectors. Examples of such policies include, but are not limited to, 'Framework for Implementation of Climate Change Policy 2014', 'National Climate Change Policy 2012', 'National Environmental Policy 2005' and 'National Technology Policy and Development Plan 2010'. Any single sector-focused policies that overlook sinks would benefit from further review and possible adjustments to mitigate negative environmental impacts. Similarly, the third most common combination (8% policies) was the policies that refer to land use but have not considered any sink. These policies would also benefit from considering potential impacts on sinks to avoid negative externalities. Examples of such policies include 'National Resettlement Policy Punjab 2005', 'Development of Damaged Areas Act, 1952 (Punjab Act XV of 1952)' and 'Cutting of Trees (Prohibition) Act, 1992'.

The fourth most common combination is multiple sectors policies having considered water as a major focus area, with 7% policies in this category. Within this category, the selected examples are 'Pakistan Water Charter 2018', 'National Water Policy 2018' and

'The Canal and Drainage Act 1873 (Khyber Pakhtunkhwa Canal and Drainage (Amendment) Act 2015'. Similarly, there are 7% policies related to ecosystem as sink, but they do not consider any sector. An example of no-sector, one sink-focused policies is 'Northern Areas Wildlife Protection Act, 1975'.

Table 12: Percentage of nitrogen-related policies by sink and sector, from Pakistan

Sink	Agriculture	Energy	Food	Land Use Change	Multiple	Other	Urban Development & Tourism	Waste	No Sector Included	Grand Total
Air	0	0	0	0	1	0	0	0	0	1
Climate	1	0	0	0	1	0	0	0	0	2
Ecosystem	1	1	0	1	0	0	0	1	7	11
Multiple	3	0	1	4	16	2	0	0	1	27
Water	2	0	1	0	7	3	1	1	2	17
No Sink Included	17	4	3	8	6	1	1	1	0	41
Soil	1	0	0	0	0	0	0	0	0	1
Total	**25**	**5**	**5**	**13**	**31**	**6**	**2**	**3**	**10**	**100**

5.2 Policies by Sink and Policy Type

Table 13 presents the distribution of nitrogen-related policies in terms of their focus on specific environmental sink, and the type of such policy (instrument). From the results, most of the combinations of policy type and sink range from 0 to 4%of total policies. The most common combination was for framework policies, i.e. 39% policies with this policy instrument, but many of them (16%) had not specifically focussed any sink, including for example 'Pakistan Environmental Protection Agency Ban on (Manufacturing, Import, Sale, Purchase, Storage and Usage) Polythene Bags Regulations, 2019.' This category of policies was followed by regulatory policy types with a greater focus on multiple sinks (6% policies). Data and method type of polices focusing multiple sinks also had a higher number (relative to other combinations), i.e., 7%. The percentage of framework policies focusing water sector is 8% followed by R&D policies focusing multiple sectors (7% policies), and economic policies (4%) considering multiple sinks. The overall results illustrate that for any single sink-oriented policies there were no predominant policy types associated with it. Policies that refer to multiple sinks are most likely to be policies that include framework, data and methods, and regulatory aspects. Those policies with multiple sinks and having multiple policy types would be considered better suited for N_r management as they are considered to have more integrated objectives and approaches.

Table 13: Percentage of classifications by policy type and sink for Pakistan's nitrogen-related policies.

Sink	Regulatory	Data & methods	Framework	Economic	R&D	Commerce	Pro-N	Grand Total
Air	1	1	1	0	0	0	0	3
Climate	0	0	1	0	0	0	0	1
Ecosystem	3	0	2	3	1	0	1	10
Multiple	6	7	11	4	7	2	2	39
No sink included	5	2	16	3	1	2	1	30
Water	3	2	8	2	2	0	0	17
Soil	0	0	0	0	0	0	0	0
Grand Total	**18**	**12**	**39**	**12**	**11**	**4**	**4**	**100**

Note: The percentage is calculated from the total number of classifications (i.e., 322) and not the total number of policies. This is because one policy could have multiple policy types.

5.3 Policies by Sector and Policy Type

In Table 13, the classification for policy type and sectors are compared. As with sinks, most combinations indicate a low percentage ≤4%. The exception for single sectors includes 'agriculture' in relation to 'framework' type policy features as the second most frequent pair (11%). Some examples of this combination are the 'Punjab Poultry Production Rules, 2017', 'Sind Shrimps (Control) Order, 1976' and 'West Pakistan Goats Restrictions Rules 1961'. Like sinks, the category for 'multiple' sectors was also more commonly linked to certain policy types including, in descending order: framework, as the most common combination (13%), data and methods (8%), regulatory (8%) and R&D (6%). Again, if those policies are associated with multiple sectors and multiple policy types these would be considered better suited for N_r management.

Table 14: Percentage of classifications by policy type and sector for Pakistan nitrogen-related policies.policies.

	Policy Type							
Sectors	**Regulatory**	**Data & methods**	**Framework**	**Economic**	**R&D**	**Commerce**	**Pro-N**	**Grand Total**
Agriculture	1	2	11	1	2	1	2	20
Energy	1	0	2	0	1	0	1	5
Food	0	0	3	0	0	0	0	3
Land use change	4	0	4	2	0	0	0	10
No sink included	5	2	16	3	1	2	1	30
Multiple	8	8	13	5	7	2	1	44
Other	1	1	3	0	0	0	0	5
Urban dev. & tourism	0	0	0	0	0	0	0	0
Waste	1	1	0	0	0	0	0	2
No sector included	3	1	2	2	1	0	0	9
Transport	1	0	1	0	0	0	0	2
Grand total	**20**	**13**	**39**	**10**	**11**	**3**	**4**	**100**

5.4 Policies by Sector, Sink and Policy Type

In all of the above cross comparisons, policies that have included references to multiple sinks and/or sectors and/or include multiple policy instruments, stand out as being those best able to support N_r management. The policies that are considered the best placed to deal with N_r issues are those that meet 'all' those conditions and have multiple policy instruments, and multiple sinks, and multiple sectors. From Pakistan, 19 (11%) policies have multiple sectors, sinks and policy instruments (see Table 15) Out of these 19 policies, 12 policies sand out as having a positive impact direction towards N_r management, for example the 'Punjab Water Policy 2018', 'Khyber Pakhtunkhwa Environmental Protection Act, 2014', 'Balochistan Environment Protection Act, 2012', 'National Climate Change Policy 2012' and 'National Biodiversity Strategy and Action Plan (NBSAP) for achieving Aichi Biodiversity Targets and Sustainable Development Goals (previous versions; 1999 and 2015). In addition, all of these policies have high relevance and large impact scope. However, if policies with low relevance or/ and low impact scope (See Appendix).

Table 15: Pakistan nitrogen-related policies that refer to multiple sectors, sinks and mixed policy types and classification for impact direction and pollution source type

Policy name	Year	Impact direction	Pollution Source Type
Pakistan Environmental Protection Agency (Review of IEE and EIA) Regulations	2000	Positive	Both
National Biodiversity Strategy and Action Plan (NBSAP) for achieving Aichi Biodiversity Targets and Sustainable Development Goals (previous versions; 1999 and 2015)	2017	Positive	Both
National Sustainable Development Strategy	2012	Mixed /neutral	Unspecified
Federally Administered Tribal Areas (FATA) Agriculture Action Plan	2015	Mixed /neutral	Unspecified
Pakistan's Intended Nationally Determined Contribution Pak-INDC	2016	Positive	Both
The Balochistan Government Rules of Business	2012	Mixed /neutral	Unspecified
Sustainable Development Goals (SDGS) National Framework	2018	Mixed /neutral	Unspecified
Framework for Implementation of Climate Change Policy	2014	Positive	Both
National Climate Change Policy	2012	Positive	Unspecified
National Environmental Policy	2005	Positive	Both
National Technology Policy and Development Plan	2010	Mixed /neutral	Unspecified
National Science, Technology and Innovation Policy	2012	Mixed /neutral	Unspecified
Punjab Water Policy	2018	Positive	Both
Khyber Pakhtunkhwa Multi-sectoral Integrated Nutrition Strategy	2014	Mixed /neutral	Unspecified
Khyber Pakhtunkhwa Environmental Protection Act	2014	Positive	Both
Balochistan Environment Protection Act	2012	Positive	Both
Punjab Environmental Protection Act (No. XXXIV of 1997).	1997	Positive	Both
Sindh Environmental Protection Act (No. VIII of 2014).	2014	Positive	Both
Statutory Notification S.R.O. 549 (I)/2000 amending Statutory Notification S.R.O. 742 (I)/93 on National Environmental Quality Standards (replaced 1993)	2000	Positive	Both

It is, however, further noted that as the effectiveness of a policy is predicted by a variety of internal and external factors, the actual impact of any policy in practice is beyond the scope of this analysis and would require further investigation. However, having these policy characteristics would be encouraged in policy interventions to address the N_r challenge via amendments to existing policies, especially those with higher N_r relevance.

Further to this analysis, a brief schematic overview of the selected policies in terms of policy instruments, sectoral and sink coverage, relevance, impact direction and pollution source targeting, is presented in the Figure 13. It is clear from this figure, that there are 48 policies that individually consider multiple sinks, 55 policies that cater for multiple sectors and 78 policies have employed multiple policy instruments (policy types). Out of the above-mentioned policies, there are 19 policies that consider all three aspects, i.e., sinks, sectors and policy types within their ambit, implying that each of these policies focus at least more than one sink, more than one sector and employ more than one policy instrument. In the next refinement, out of these 19 policies, 8 policies are shown to have positive impact direction for N_r management, i.e., high in both relevance and impact scope. From these 8 policies, 7 policies consider both pollution source types (point source and non-point source). In the next level, there are 3 policies that, along with having the above features, exhibit a positive impact direction for N_r management.

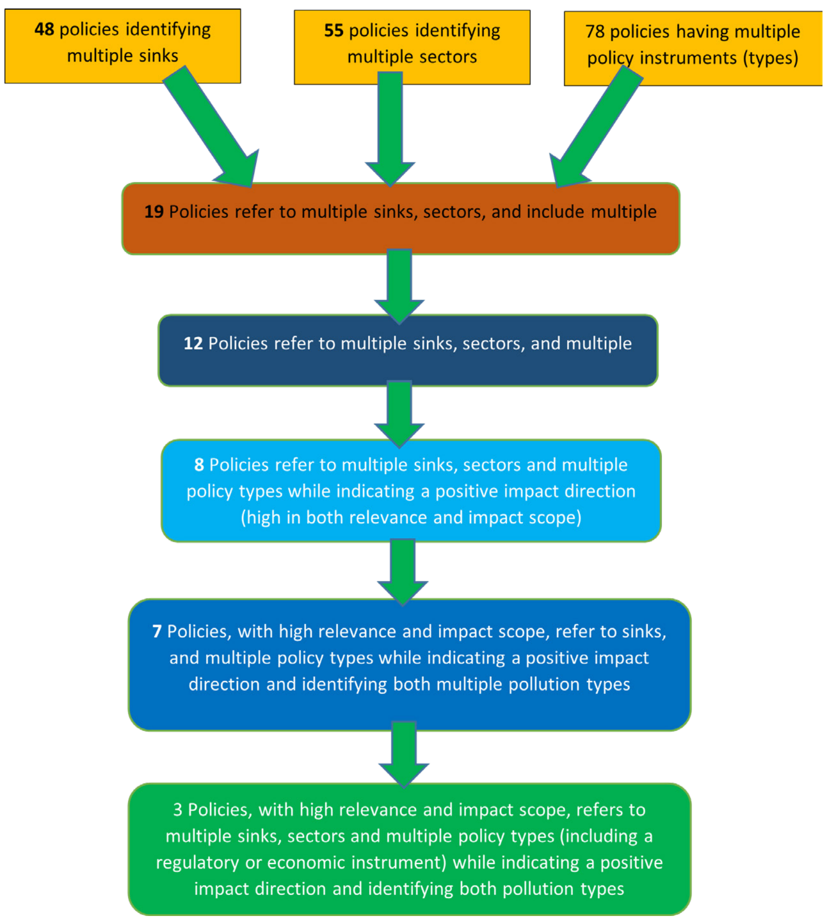


Figure 13. Overview of Pakistan's stand out nitrogen related policies based on multiple characteristics from a total of 175 policies.

5.5 Temporal Distribution of N-Related Policies

Looking at the development of nitrogen-related policies, it is clear that a large portion of policies were created prior to 1990 and between 2011 and 2020[11]. A similar pattern was evident for agriculture sector-based policies. Multiple sector-based policies became more numerous (16%) in the latest period 2011-2020.

However, there were 67 policies from the independence in 1947 till the year 1990 making 38% of all the policies instituted till 2020. However, the scope of such polices was general and not specifically focused N_r pollution and related issues. Similarly, 38% policies out of 175 policies were introduced between the years 2011 – 2020 (Table 16). It is pertinent to note that majority of multiple sector policies were introduced during this time, 2011-2020. Such policies address multiple issues facing different sectors of the economy like water through 'Punjab Water Policy 2018 and Pakistan Water Policy 2018', or the UN SDGs National Framework 2018', and climate action and pollution control with the 'National Climate Change Policy 2012'. However, agriculture sector-related policies were introduced before 1990, followed by policies linked with land use change. Policies instituted between 1991-2000 constitute only 9% of total policies whereas 14% policies were introduced during the period 2001-2010.

Table 16: Number and percentage of Pakistan nitrogen-relevant policies at different time periods.

Sector	Total No. of policies				% of policies			
	<1990	1991-2000	2001-2010	2011-2020	<1990	1991-2000	2001-2010	2011-2020
Agriculture	20	2	3	18	11	1	2	10
Energy	0	1	6	2	0	1	3	1
Food	3	0	0	5	2	0	0	3
Land use change	18	2	2	2	10	1	1	1
Multiple	9	8	10	28	5	5	6	16
No sector included	9	1	2	5	5	1	1	3
Other	5	1	1	5	3	1	1	3
Transport	2	0	0	1	1	0	0	1
Waste	1	1	1	1	1	1	1	1
Grand Total	**67**	**16**	**25**	**67**	**38**	**9**	**14**	**38**

[11] *This includes only policies that were active as of 2019. Therefore, policies that were replaced or inactive were not included in this assessment.*

In Table 17, distribution of policies with respect to their time of inception/promulgation with respect to their focus on various sinks. Most policies (19%) established prior to 1990 had no sink focus. Water related policies dominated sink-specific policies during this period (10% policies). However, between 2011–2020, multiple sink policies dominated.

Table 17: Number and percentage of Pakistan's nitrogen-relevant policies before 1990 to 2019 (broken down by sink)

Sink	Total No. of policies				% of policies			
	<1990	1991-2000	2001-2010	2011-2020	<1990	1991-2000	2001-2010	2011-2020
Air	0	0	0	2	0	0	0	1
Climate	0	0	2	1	0	0	1	1
Ecosystem	9	1	3	5	5	1	2	3
Multiple	5	6	8	29	3	3	5	17
No sink included	34	4	9	26	19	2	5	15
Soil	1	0	0	0	1	0	0	0
Water	18	5	3	4	10	3	2	2
Grand Total	**67**	**16**	**25**	**67**	**38**	**9**	**14**	**38**

6. Overview of Pakistan's Reactive Nitrogen (N_r) Emission Trends and Sector Sources

This section provides an overview of the N_r trends for Pakistan for the three major N_r emissions; nitrogen oxides (NO_x), ammonia (NH_3), and nitrogen oxide (NO_x), according to sector sources.

6.1 Regional Reactive Nitrogen (N_r) Emission Trends of Key Compounds

The major three reactive nitrogen (N_r) compounds of global concern include the greenhouse gas (GHG) nitrous oxide (N_2O) and the two ambient air pollutants nitrogen oxides (NO_x) and ammonia (NH_3). South Asia is a global hotspot for all three nitrogen compounds, with emissions above that of global levels (SACEP & SANH, 2021).

Nitrogen oxide (NO_x) emissions have been increasing rapidly across South Asia and doubled since 2000. Electricity and heat generation is the main nitrogen oxide (NO_x) emission source, with 'road transport' and 'manufacturing and construction' also major regional contributors. Ammonia (NH_3) and nitrous oxides (N_2O) have also been increasing steadily with agricultural as a major source through managed soil and fertilizer use (SACEP & SANH, 2021).

The data presented in this section is sourced from the 'Emission Database for Global Atmospheric Research (EDGAR)' developed by the Joint Resource Centre (JRC). EDGAR provides independent estimates of emissions compared to those reported by European Member States or by Parties under the United Nations Framework Convention on Climate Change (UNFCCC), using international statistics and a consistent IPCC methodology. SANH selected EDGAR as the common data source for N_r emissions to enable comparability and consistency across its analyses of the eight South Asian countries.

The EDGAR datasets provide an overview of N_r emissions only. 'Emissions' refer to the production and discharge of substances into the air, especially pollutants as gas. Nonetheless, N_r enters the environment from a variety of sources and states, not only as atmospheric emissions but also through soils and water. For this report, we assess emissions that impact the air and climate, but also indirectly, due to nitrogen cascades, impact other sinks (Galloway et al., 2003). The definition of sectors under EDGAR methodology is given in the appendix.

6.2 Pakistan's National Nitrous Oxide (N_2O) Emission Trends

Nitrous oxide has a 267[12] times more Global Warming Potential (GWP) than that of carbon dioxide (CO2) for a 100-year timescale. On average, N_2O emitted today remains in the atmosphere for more than 100 years (US-EPA, 2024).

Nitrous oxide (N_2O) emissions have been increasing steadily since the 1970's, as seen

[12] https://unfccc.int/process/transparency-and-reporting/greenhouse-gas-data/greenhouse-gas-data-unfccc/global-warming-potentials

in Figure 14. Agriculture has been the major contributing source of emissions accounting for 82% of emissions in 2022. The second biggest contributing sources are Industrial processes (7%), followed by waste (4%) in 2022. Overall, a total of 241 Gg of emissions were produced in 2022.

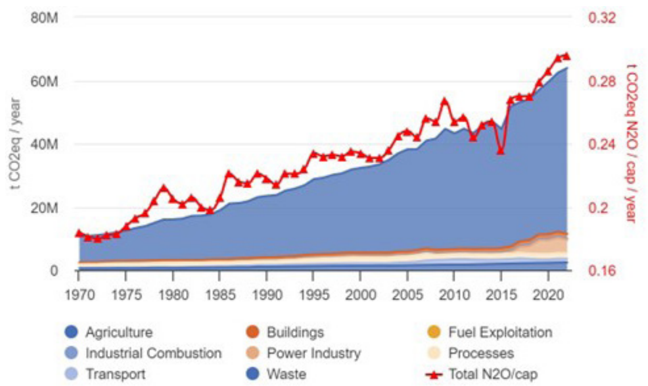


Figure 14: Pakistan's nitrous oxide (N_2O) emission trends by sector (1970-2022) NB: The total emissions have been converted to carbon dioxide (CO_2) equivalents. The right vertical axis indicates the total emissions per capita, expressed as CO_2 equivalents. Source: EDGAR v8.0 Greenhouse Gas Emissions; Crippa et al (2023a)

6.3 Pakistan's National Nitrogen Oxides (NO_x) Emission Trends

Nitrogen oxides (NO_x), including nitric oxide (NO) and nitrogen dioxide (NO_2), are significant air pollutants primarily generated through the combustion of fossil fuels. Since the 1970s, NO_x emissions have been steadily increasing, as shown in Figure 15. According to EDGAR data, various sectors in Pakistan contribute to NO_x emissions. In 2022, the largest contributor was the industrial combustion sector (26%), followed closely by the transportation sector (25%), agriculture (21%), and the power sector (5%). In total, Pakistan produced 1007 Gg[13] of NO_x emissions in 2022.

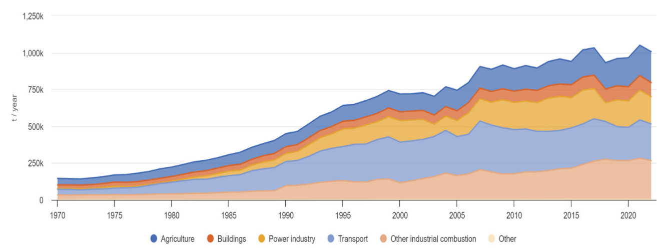


Figure 15: Pakistan's nitrogen oxides (NO_x), emissions by sector (1970-2022) Source: EDGAR v8.1 air pollutants; Crippa et al (2023b)

6.4 Pakistan's National Ammonia (NH_3) Emission Trends

In Pakistan, in line with the regional results, agriculture is by far the largest contributor to ammonia (NH_3) emissions, as depicted by Figure 16. In 2022, the agriculture sector contributed to 90% of the overall NH_3 emissions. The second largest contribution is from buildings which includes small scale non-industrial stationary combustion. Whereas for the category 'other' emission and 'other industrial combustion' contributions were relatively small. An abrupt decline in NH_3 emissions in 2015, however, by 2016 the increasing emissions trend resumed. In 2022, Pakistan produced 2136 Gg of NH_3.

[13] *Gigagram (Gg) (1 tonne = 0.001 Gg)*

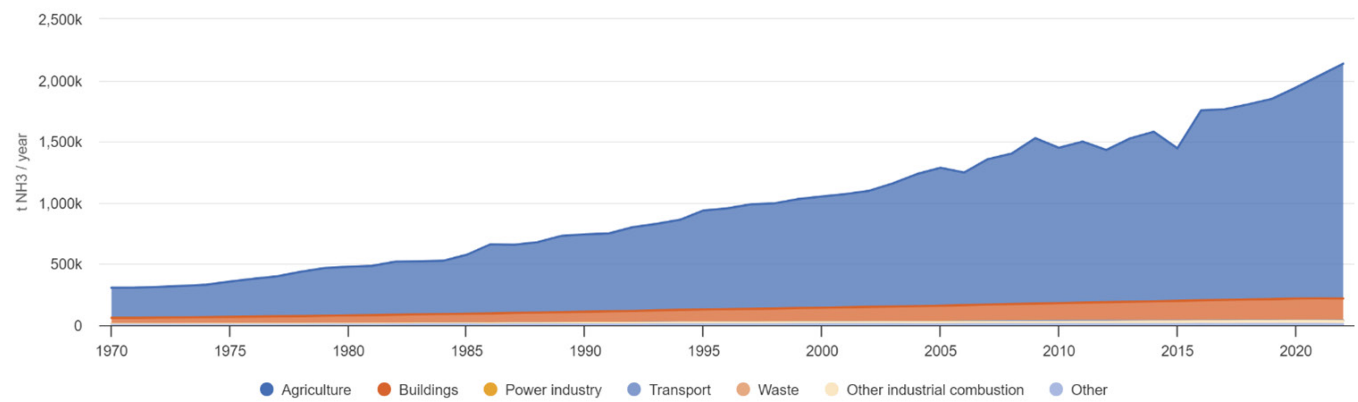


Figure 16: Pakistan's ammonia (NH_3) emissions by sector (1970-2022) Source: EDGAR v8.1 air pollutants; Crippa et al (2023b)

Overall, NH_3 had the steepest rise in the last two decades compared to NO_x and in Pakistan, as seen in Table 18. NH_3 emissions more or less than doubled from 2000 to 2022. On the other hand, emission also witnessed a 97% increase (from 122 Gg in 2000 to 241 Gg in 2022. There was a 40% increase in the emission of Nitrogen oxide during this period (Crippa et al. 2023a).

Table 18: Changes in major reactive nitrogen compound emissions in Pakistan (2000-2022) Data source: EDGARv8.1; Crippa et al. (2023b)

N_r emissions	**2000**	**2022**	**% Change**
Ammonia - NH_3 emission (Gg/year)	1052	2136	103
Nitrogen oxides - NO_x emission (Gg/year)	719	1006	40
Nitrous oxide - emission (Gg/year)	122	241	97

7. Fertilizer Policy Development and Future Perspectives on N_r Management

In Pakistan, N_r fertilizers were introduced in 1952 primarily through imports. Later, the government of Pakistan realized that its reserves of natural gas could confer a comparative advantage for substituting the imported N_r fertilizers with the locally manufactured N_r fertilizers. Starting from the late 1950s and the early 1960s, the government started pursuing an "import-substituting" domestic fertilizer industrial development policy program. As a result, about 92% of N_r fertilizer consumed in Pakistan was being produced locally during 2019-20 (NFDC 2021). In the coming years, the growing production and use of fertilizers in Pakistan led to the development of various regulations, policies, and institutions. The Provincial Essential Commodity Act (PECA), which was promulgated in 1971, made fertilizer production and marketing a federal subject.

Just 2 years later, the 'Punjab Fertilizer (Control) Order of 1973' rendered the provincial management of fertilizers subservient to PECA which helped further strengthen the federal regulators. Besides these initiatives, various key organizations were also established in order to promote fertilizer use such as Fertilizer Research and Development (R&D) under the Directorate of Soil Fertility in the research wing of the Agriculture Department of the government of Pakistan.

In 1977, the National Fertilizer Development Centre (NFDC) was established to address various issues related to production, imports, pricing, subsidies, and regulations. After 12 years of the establishment of the NFDC, the first fertilizer policy was announced in 1989 which was updated in 2001. The 'Fertilizer Policy of 1989' was primarily about ensuring regular gas supply to the domestic fertilizer industry and permitting duty-free import of machinery to attract the local producers of fertilizer in the country. Few amendments were made in the 2001 version of the 'Fertilizer Policy' except for revising the existing fuel and gas prices and import duties on machinery for fertilizer industry. The Fertilizer Policy of 2001 mainly stipulated the provision gas to fertilizer manufacturers enabling them to compete with imported fertilizers from the Middle East. Moreover, its main focus was on production rather than consumption of fertilizers or to improve the efficiency of fertilizer use (Ali, 2015).

Pakistan approved its first National Climate Change Policy (NCCP) in 2012 which recognized N emissions sources from the agriculture and the livestock sector and intends to exploring ways and methods to reduce N_r (particularly) emissions from the agricultural soils. Such as by changing the traditionally used fertilizer mix and increasing fertilizer use efficiency. However, this policy requires updates to address newly emerging issues related to the imbalance and excessive use of nitrogen across various sectors, including energy and transport. Additionally, the fertilizer policies should be aligned with the climate change policy and other related agricultural policies. Strengthening the connections between policies and ministries is crucial. As currently, for example, the Ministry of Climate Change, responsible for the development and implementation of the National Climate Change Policy (NCCP), and the Ministry of National Food Security and Research (MoNFSR), responsible for agricultural and fertilizer policies, operate under distinct mandates that are yet to be integrated. The proposed draft of the National Agriculture and Food Security Policy by the MoNFSR lacks measures for institutional, interdepartmental, or inter-ministry collaboration for sustainable nitrogen management. The 'National Food Security Policy 2018' only emphasizes the need to make fertilizers available on time and at affordable prices yet overlooks issues around sustainable use and the impacts of waste. Pakistan, a country highly vulnerable to the impacts of climate change, must rethink its future interventions to ensure sustainable nitrogen management. This is especially important as Pakistan is part of the Colombo Declaration, a global campaign to halve nitrogen waste by 2030. Implementing such actions is crucial for meeting international commitments and mitigating climate change impacts.

There is an immediate need to improve fertilizer productivity, crop yields, and reduce N_r losses to the environment from agriculture sector along with other actions to mitigate N_r emissions and waste from industry, transport, and domestic combustions. This requires the development of a policy framework to encourage sustainable N_r fertilizer use through better management practices as well as revamping industrial production technology, greening transport and consumption.

Currently, there is no direct N_r management policy available in Pakistan. However, several indirect N-related policies exist, and some indirect measures are being undertaken specifically in agriculture sector of the country in relation to fertilizer management such as:

- Balanced use of fertilizers is being encouraged by promoting the use of potassium (K) and phosphorous (P) fertilizers through subsidies on the use of balanced fertilizers in the Punjab under its Agriculture Policy 2018.
- Attempts are being made to develop and introduce efficient N_r fertilizers in collaboration with private sector and few efficient N fertilizers have been introduced at a limited scale.
- Split application of N_r fertilizers is widely adopted by the farmers for its better NUE.
- Burning of crop residues has been strictly banned especially the burning of rice and wheat stubbles, and sugarcane trash. In this regard, the 'Punjab Policy on Controlling Smog 2017' is a notable step forward in the Punjab province.
- Large-scale upscaling of high efficiency irrigation systems, especially drip irrigation, is in progress which have indirect effects to reduce the leaching losses of NO_3^-.
- Large-scale upscaling of high efficiency irrigation systems especially drip irrigation is being promoted through subsidies and technical guidance that can possibly indirectly reduce leaching losses of NO_3^-.

7.1 Emerging Issues and Options

It is becoming increasingly clear in South Asia that reducing N_r pollution is possible and a necessary policy goal for every country in the region must be envisioned. The current policies for monitoring and controlling of N_r are neither uniform nor adequate in any of the region's countries including Pakistan. 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 N_r 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.

Pakistan needs to have a toolbox based on the framework proposed by Oenema (2019) for developing an integrated sustainable N_r use and management approach for developing efficient and effective N_r pollution mitigation.

1. Awareness among the general population, policy advisors, and legislators for explaining the meaning, purpose, targets, and actions for dealing with N_r pollution and allied issues through integrated approaches.

2. Environmental footprints analysis and cost-benefit analysis of N_r use.

3. Information on all available N_r sources.

4. Coordination (knowledge sharing/best practices) between research scientists, farmers, NGOs and community leaders, policy makers, and private sector within the country and outside the country.

5. Identification and application of best N_r use and management practices.

The following specific recommendations within the context of Pakistan are developed based on discussions with experts, stakeholders and literature review.

7.2 Recommendations

Recommendations for the Agricultural Sector:

- Research and development are urgently needed to assess the amount of N_r accumulation and movement within the environment such as soil profile, rivers, and water resources in areas where N_r application rates are excessive. Zones with shallow the groundwater table and high precipitation need to be identified where N_r applications are high (including organic inputs) by farmers so that advice can be rendered accordingly to farmers in high-risk zones.

- The existing fertilizer use recommendations throughout the country are too general and outdated; hence, site-specific and crop-specific N_r fertilizer use recommendations need to be developed and disseminated widely.

- The development and use of efficient N_r fertilizers should be encouraged.

- Customized crop specific agricultural and fertilizer use machinery should be engineered and promoted.

- Research on local development of machinery for crop residue management is also needed that can potentially be carried through reverse engineering of imported implements and as well as development of new implements as per local demands.

- Nutrient stewardship is required for practical implantation by adopting 4Rs principle through the 'right source' of fertilizer, applied at the 'right rate' and at the 'right time', and in the 'right place'. These actions and interventions can effectively promote conservation practices and lead to saving of considerable amounts of N_r fertilizers, and hence application would be cost-effective.

- A system of developing and disseminating site-specific fertilizer recommendations.

- Besides local testing of N-efficient fertilizer products (including that of green/blue ammonia from renewable, carbon-neutral energy sources) developed globally, new low cost N_r inhibitor compounds (urease and nitrification inhibitors) should be identified through exploration of the local flora which might perform better under high temperature and calcareous soils.

Multi-Sector Recommendations:

- There is a general call for research and actions across all sector sources including agriculture, as well as livestock, and other sectors such as industry, transport, energy, waste management, to effectively reduce N_r related pollution.

- Regular monitoring of air and water quality can potentially alleviate public health concerns, and this too requires a mass awareness as well as large scale interventions involving multiple sectors to curb such pollution.

- Increased nutrients' (N_r as well as others) recovery and recycling from waste and other underutilized resources need to be on prioritized both for research and policy.
- Impact of N_r pollution on lichen's growth in the northern areas and coral reefs in coastal area should be studied.
- For estimation of NO_3 leaching, samples from the high-risk areas should be taken for in-depth analysis and mapping purpose.

Policy Recommendations:

- There are 26% policies that do not focus any pollution source type, for which, a concerted effort is needed to formulate/amend policies to consider multiple sinks as well as multiple sectors. In this regard, policy planning needs to align priorities focusing on the development of policies involving multiple instruments (viz. regulatory, R&D, framework, Research, etc.) that can potentially cater multiple sectors, multiple sinks with multiple pollution sources.

- Similarly, an immediate new national agricultural policy and a new national fertilizer policy are needed that fully appreciate the negative impacts of N_r losses suggesting actionable measures both for short-term and long-term to reduce N_r wastage and improve NUE.

- In industrial policy, transport policy and other allied sectoral policies need to envision the harmful effects of N_r emissions by articulating measures that are easily taken up and popularized.
- Sink-specific policy goals need to be streamlined either in the existing policies or need to be thoroughly embedded in upcoming policies/guidelines/rules etc.

Overall, N plays a critical role in the global economy, food security, and environmental sustainability. However, in recent years, experts have raised serious concerns about the negative impacts of the excessive use of N_r on human health, ecosystem, and environmental sustainability. Given the recently realized N_r challenges, it becomes imperative to include N_r in the mainstream policy agenda for sustainable development. This need further intensified due to currently increasing trends in N_r emissions from different sectors such as energy, agriculture, industry and transport. As the challenge is multipronged laden with multiple implications, the measures would also need to be overarching and integrated.

Different policies in different countries have started recognizing the nitrogen challenge and suggesting measures for sustainable N_r use across different sectors. Recently, the United Nations Environment Programme (UNEP) has launched a global campaign on sustainable nitrogen use and to halve N_r use by 2030. Pakistan would hence need concerted efforts to this end as being signatory of the Colombo.

Currently, Pakistan lacks a direct policy for managing reactive nitrogen (N_r), and existing indirect policies do not sufficiently address the impacts of nitrogen losses. To effectively manage N_r across various sectors, Pakistan needs to develop a comprehensive and integrated approach. This approach should be based on nitrogen system analysis, communication strategies, nitrogen balance assessments, integrated modelling of nitrogen footprints, and cost-benefit analysis. It should also include comprehensive N_r information dissemination, relevant stakeholder engagement, and the implementation of best nitrogen management practices.

Furthermore, coordinated measures at the policy, institutional, research and development, and outreach levels are essential to reduce N_r losses and improve nitrogen use efficiency (NUE). These measures should encompass all sectors, including agriculture, energy, transport, and waste management, to ensure a holistic approach to sustainable nitrogen management.

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Appendix

Appendix Table 1: Classifications used in the SANH policy analysis approach

Classification	Codes	Description
Sink:	Water; Air; Climate; Soil; Ecosystem; Multiple (if more than one sink was referred to); & Not Applicable (NA) (if no sink was referred to).	If the policy objective or content mentioned one or more sinks. Classifications were not based on assumed links or impacts. A sink refers to a reservoir that takes up a nitrogen or, where nitrogen loads can accumulate and can have an 'impact'.
Sector:	Main sectors: Agriculture; Energy; Food; Industry; Land Use Change; Transport; Urban Development & Tourism; Waste; Other; Multiple. Not Applicable (NA).	Policies were coded to a main sector, where possible, they were also coded to a sub-sector, indicating the specificity of a policy. If the policy covered multiple sub-sectors, categorising as a main sector was sufficient.

Policy type. (Policies could include multiple policy instruments, therefore policies could be coded under one or more of these codes as appropriate.)	Regulatory	Policies that set quantifiable limits or restrictions on N production, consumption and loss. This could also include broader strategies if they include quantifiable targets that could have impacts on N management.
	Economic	Policies that use financial incentives and signals to spur quantifiable improvements in N management and N mitigation'. Following Kanter et al. (2020) regulatory and economic policies were classified as 'core' policies, i.e. those most likely to have an impact on N production, consumption of management.
	Framework	Broad objectives relevant to N pollution with no quantifiable constraints and/or delegation of authority for N policymaking to another governing body'. A number of indirectly relevant policies fell under this definition. For example, it could be a regulatory policy, but in the absence of direct quantifiable constraints on nitrogen it would be classified as a 'framework' as in the case of the Regulations on Safe Food (Healthy Environment Protection), from Pakistan.
	Data and methods	Those that 'establish data collection and reporting protocols for various aspects of N pollution but do not set environmental standards or enforce them'. This would also include standards (which could in addition be classified as regulatory). Policies that refer to an objective and/or actions for Monitoring and evaluation (M&E) were also classified under this
	Research & Development (R&D)	Policies that allocate funding for R&D both into the effects of N pollution on the environment and human health and into new technologies that could improve N management'. A policy could be classified under this code if it referred to promoting research in the text and that research relates to N related practices
	Commerce	Policies that regulate an aspect of the business environment surrounding N production and consumption'.
	Pro-N	Policies that lower the price of N production and consumption via government aid or other means, usually incentivizing higher farmer-level N use'

Pollution type	Point source	Point source pollution is where nitrogen pollution is discharged directly into water or into the atmosphere at a 'discrete point', making it easier to control and monitor. A policy would be classified as this if it states actions to target/control/measure point source pollution.
	Non-point source	Non-point sources covers pollution that comes from many land, air or water sources and can be carried overland, underground, or in the atmosphere, making them difficult to measure and control (Islam et al. 2018; Liu et al 2020).
	A policy would be classified as this if it states actions to target/ control/measure non-point source pollution.	
	Both	Policies refer targeting both point and non- point source pollution
	Unspecified	For policies that do not reference or recognise the different types of N pollution sources, and do not specify any intention/ measure/control pollution from either of those source types.
	NA	The default classification for Policies classified with a negative impact direction, and/or as having an indirect relevance received.
Impact direction	Positive	A policy was coded with 'positive' impact if it promoted a reduction in N pollution and/or improved nitrogen management whether directly or indirectly. This would likely include policies that were environmentally oriented such as environmental standards, and water quality control policies.
	Mixed/ neutral	Policies coded 'mixed neutral' if it could do both, e.g., aiming to enhance food production but also considering environmental impacts, or if the policy is potentially neutral in its impacts
	Negative	A policy that could potentially cause excess nitrogen, such as those that promote synthetic fertiliser use or fossil fuels, would be coded as 'negative' e.g. promotion of fossil fuels
Impact scope:	Large	This classification was for distinguishing the scale of 'possible' impact a policy could have on N use.
	A 'large' scope would include nation-wide policies such as an agricultural policy with wide implications for N management.	
	Medium	Medium scope would include those that may encompass a large area (national) but have fewer implications for N management, or sub-national level but large implications for N management. For example, national food and security policies, or a provincial Forest Act
	Small	Policies with a small scope include smaller spatial areas than provincial, and may be area/zone specific, and/or with minor implications for N management, e.g., plant quarantine rules

Relevance	High (direct)	For high and direct relevance to N, 29 key words were used to identify policies, i.e., if the policy contained one or more of these listed key words[14].
	Medium (indirect)	Those classified with 'medium' relevance included 'indirect policies' that still had clear relevance to nitrogen but did not contain the key words.
	Low (indirect)	Policies classified with 'low' relevance include those policies more distantly related to N management such as 'seed' policies or road expansion policies. These policies did not contain any key words or related synonyms but could have indirect knock-on implications for N pollution. For example, road expansion policies that encourage more cars, thus leading to increases in NOx emissions, unless mitigated by other policy initiatives and measures.

Appendix Table 2 gives a brief overview of nitrogen policy databases with their advantages and drawbacks. These databases have been used to draw N_r policies for Pakistan along with other local resources.

[14] *Key words: fertilizer, manure, N, N pollution, nutrient pollution, nitrate, nitrates, ammonia, N oxides, nitrous oxide, , NH_3, NO_3, NOx, eutrophication, hypoxia, air quality, air pollution, emissions, groundwater quality, groundwater pollution, freshwater quality, freshwater pollution, water quality, ozone depletion, climate change, greenhouse gas, agrochemical and effluent.*

Table 2: Advantages/Disadvantages of various policy databases used in this analysis.

Policy sources	Advantages	Disadvantages
Shared characteristics of the FAOLEX and ECOLEX databases	• Provision of an open access database. • Policy details are provided on country, year, subject, key words, policy abstract, web links to the original policy text and linkages with other related policies e.g. amendments or repeals. • Policy abstracts are useful for initial checks and where the original policies are unavailable in English. • Inbuilt search tool enables the filtering of policies.	• Uneven representation of nitrogen relevant sectors e.g. lacking policies on transport and energy • Not all original policy texts were available in English (* such policies were interpreted and coded by our research team).
ECOLEX www.ecolex.org/	• The global nitrogen policy database (Kanter et al 2020a) was established using ECOLEX policies. • Joint initiative of United Nations Environment Programme (UNEP) and International Union for Conservation of Nature (IUCN) and Food and Agriculture Organisation of the United Nations (FAO).	• Fewer policies are available for certain sectors. For example, agriculture and rural development policies for SA totalled 224 in ECOLEX and 489 in FAOLEX. • ECOLEX is not regularly updated (policies available between 2017 and 2020 totalled 28 in ECOLEX and 234 in FAOLEX).
FAOLEX www.fao.org/ faolex/ en/	• For SA FAOLEX had more policies (2,699 as at Feb 2021) than ECOLEX (1918 policies). • All policies identified as nitrogen relevant in SA from the ECOLEX database were originally sourced from FAOLEX. • FAOLEX has been collecting policies systematically since 2014 and collects information directly and proactively. The database is regularly updated (FAO, 2021).	• Although FAOLEX is more extensive than ECOLEX, it does not contain all nitrogen related policies therefore it was necessary to search for alternative sources.
Additional policy sources (e.g. government/ ministry websites, other web sources)	• Enabled a more comprehensive collection of policies from a wider range of N_r relevant sectors. • Availability of policies varied according to the country. • Where policies identified by local experts were unavailable from government websites we searched for other online sources.	• Relevant policies are more challenging to locate and identify as websites ranged in quality, and due to the absence of inbuilt website search tools. • Websites are occasionally unstable with broken web links, and/or have an unsafe web location. • Often policy abstracts are not provided. – Some policies are only available as hardcopies which were difficult, or not possible to access. • Not all policies, or policy descriptions are available i

Appendix Section 5

Cross Comparatives Policies

Policy Distribution with Reference to Relevance and Impact Scope

Appendix Table 3 shows the classification of policies with respect to their relevance and impact scope. There are 54 policies (33%) that have low relevance and low impact scope while the rest of them have medium to high relevance and medium to large impact scope. In other words, 67% of the total policies collected for Pakistan can be considered of medium to high relevance and scope. These 'selected' policies are assumed to have a greater impact on how N_r enters the environment. Those policies identified to have lower relevance and/or impact scope should, however, not be considered as irrelevant, as such policies still hold potential to have an impact via amendments to consider and mitigate N_r waste.

Appendix Table 3: Number of nitrogen-related policies in Pakistan for relevance and impact scope

	Impact scope			
Relevance	**Large**	**Medium**	**Small**	**Total**
High	33	28	10	71
Medium	3	34	9	46
Low	0	4	54	58
Total	36	66	73	175

As with the previous section, the results below illustrate a cross comparison of two classification types i.e., pollution source and impact direction, sink and sector, and sector and sub-sectors with policy type.

Selected Policies for Pollution Source and Impact Direction

Appendix Table 4 illustrates the pollution source type with the impact direction for the selected policies. Policies classified as positive have the largest percentage at 59%. Positive impact direction policies were commonly associated with both point source and NPS (24%) i.e., representing favourable policy characteristics. However, the same percentage (24%) of all positive policies have unspecified pollution sources, including, e.g., the 'Regulation of water and water resources and facilities 2015'. Such environmentally centred policies could be enhanced by amending them to consider the implications of pollution type, where suitable. No policies classified as positive addressed NPS, and 2% addressed point source pollution.

For mixed/neutral impact direction policies (31%) the majority were classified as unspecified (17%), such policies may require attention to see how pollution sources could be more carefully considered. Overall, the percentage of 'unspecified' pollution sources policies was higher for the selected policies (41%) compared to the percentage for all the whole dataset (30%). 10% of mixed/neutral policies were classified as non-applicable as a default for policies with 'indirect' relevance. All policies classified as negative (another 10%) were also by default classified as non-applicable. The percentage of non-applicable was reduced by 20% in the selected policy analysis, as expected since less relevant policies were filtered out.

Appendix Table 4: Percentage of selected Pakistan nitrogen-relevant policies for pollution source and impact direction*

Impact direction	Both	Non-Point Source (NPS)	Point Source	Unspecified	Non-applicable	Total
Mixed /Neutral	4	3	1	21	15	45
Negative	0	0	0	0	3	3
Positive	20	0	2	13	16	52
Total	24	3	3	35	35	100
*Selected policies are based on high–medium relevance and impact scope, a total of 98 policies						

Appendix section 6

The EDGAR sector definitions include:

- Power Industry - Power and heat generation plants (public & auto-producers)
- Industrial combustion - Combustion for industrial manufacturing
- Buildings - Small scale non-industrial stationary combustion
- Transport - Mobile combustion (road & rail & ship & aviation)
- Agriculture - Agricultural soils, crop residues burning, enteric fermentation, manure management, indirect emissions from agriculture
- Fuel exploitation - Production, transformation and refining of fuels
- Processes - Industrial processes (e.g. emissions from the production of cement, iron and steel, aluminum, chemicals, solvents, etc.)
- Waste - Solid waste disposal and wastewater treatment