Chemical Fertilisers and Their Ecological Fallout: Assessing Environmental and Health Risks Through the Lens of Ethnobotanical Resilience in Manipur

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Abstract
The extensive use of chemical fertilisers has become integral to modern agriculture, yet their long-term ecological and health repercussions are increasingly alarming. This study critically examines the environmental and human health impacts of chemical fertiliser application in Manipur, India, an ecologically fragile region within the Indo-Burma biodiversity hotspot. It highlights how the excessive and imbalanced use of nitrogenous, phosphatic, and potassic fertilisers leads to severe soil acidification, degradation of soil microbial diversity, and nutrient imbalances that compromise soil fertility. Runoff from fertilised fields contributes to eutrophication and nitrate pollution in water bodies, notably Loktak Lake, posing direct threats to aquatic biodiversity and indirect risks to human health through contaminated drinking water and food chains. Elevated nitrate concentrations are linked to methemoglobinemia and other chronic illnesses. The study further examines the intersection between environmental degradation and the decline of ethnobotanical medicinal plant resources, which have long supported community health and cultural identity in Manipur. These plants, central to indigenous healthcare systems, face increasing threats from deforestation, overharvesting, and agrochemical contamination that may alter their phytochemical efficacy. The findings underscore the paradox of chemical fertilisers, enhancing agricultural yields while undermining ecological and human resilience. It advocates for integrated nutrient management, policy reform, and community-led conservation of medicinal plants as essential strategies to restore soil health, protect biodiversity, and sustain traditional knowledge systems in pursuit of a healthier, more sustainable future for Manipur.

Keywords: Chemical Fertilisers, Soil Degradation, Water Pollution, Human Health Risks; Ethnobotany; Medicinal Plants.

INTRODUCTION

The global reliance on chemical fertilisers has been a defining feature of the Green Revolution, which aimed to secure food production through intensive agricultural methods. Since its inception in the 1960s, driven by figures such as M.S. (Swaminathan, 2015), this model has transformed Indian agriculture, significantly contributing to the country's grain production (Swaminathan, 2015). However, this success has come at a considerable cost, manifesting as severe environmental degradation and escalating health risks associated with the unbalanced and excessive use of agrochemicals. In India, chemical fertilisers have become the dominant source of nitrogen (N) and phosphorus (P), accounting for 72.8% and 94.5% of inputs, respectively, by 2018 (FAO, 2019). This trend is underpinned by government policies, including heavy subsidies on urea, which has made it the most consumed nitrogenous fertilizer, and a Nutrient-Based Subsidy (NBS) scheme that, while intended to promote balanced NPK use, has historically favoured subsidized nitrogen over imported phosphatic and potassic fertilizers (Kumar & Singh, 2016); (Ministry of Chemicals & Fertilizers, 2021). The consequences are starkly evident in the skewed NPK consumption ratio, which stands at approximately 10:4:1 in India, far exceeding the ideal 4:2:1 ratio recommended for sustainable crop growth (Jat et al., 2020; Singh, 2016).

The state of Manipur, situated within the Indo-Burma biodiversity hotspot, exemplifies the intersection of high agricultural intensity and acute environmental vulnerability (Myers et al., 2000). With a per-hectare fertiliser consumption rate that has surged from 27.9 kg in 2010–11 to 51.9 kg in 2019–20, the region faces immense pressure to maintain productivity (Directorate of Economics & Statistics, Government of Manipur, 2021). This intensive farming is compounded by other anthropogenic pressures, such as deforestation through shifting cultivation (Jhum), illegal logging, and infrastructure development, which collectively exacerbate soil erosion and land degradation (Devi & Singh, 2016; Singh et al., 2016). The physical landscape of Manipur is uniquely sensitive; nearly all of its soils are acidic, rendering them inherently less fertile by reducing the availability of essential nutrients, such as nitrogen, phosphorus, and potassium (Singh, 2016). This natural acidity is further worsened by the use of acid-forming fertilisers, creating a challenging environment for both conventional agriculture and the native flora that have adapted to different conditions (Choudhury & Kennedy, 2005; Singh, 2016).

The direct application of chemical fertilisers initiates a cascade of detrimental effects. In agricultural fields, long-term use leads to a reduction in soil organic matter, a decline in microbial diversity, and a decrease in soil pH, ultimately resulting in soil infertility (Geisseler & Scow, 2014; Choudhury & Kennedy, 2005; Singh, 2016). Research from Malaysia has shown that 25 years of inorganic fertiliser use have reduced total nitrogen and organic carbon levels to "very low" states (Choudhury & Kennedy, 2005). At the same time, a Chinese study found that 30 years of NPK application have reduced bacterial diversity (Zhou et al., 2018). These changes in the soil microbiome are not trivial; they alter the composition of key functional groups within the soil. For instance, beneficial bacteria like Firmicutes and Bacteroidetes, known for suppressing soil-borne diseases, can be almost eliminated, while Acidobacteria and Proteobacteria become dominant (Choudhury & Kennedy, 2005). A meta-analysis confirmed that while organically fertilised soils show greater increases in microbial diversity compared to unfertilized controls, NPK-only treatments do not yield significant gains (Geisseler & Scow, 2014). Furthermore, chemical fertilisation alters the competitive dynamics between different types of microorganisms, favouring copiotrophic bacteria that thrive on abundant nutrients while reducing the stability and diversity of more stable and diverse microbial communities (Zhao et al., 2020). This loss of microbial functionality threatens the very foundation of soil health and its capacity to support productive and resilient ecosystems. The runoff from these fertilised fields carries these pollutants into Manipur's vital water bodies, most notably the Ramsar-listed Loktak Lake and its tributaries, contaminating the water supply and threatening the state's unique biodiversity (Devi & Singh, 2016; Singh et al., 2016).

Review of Related Literature

The literature on the impacts of chemical fertilisers reveals a consistent pattern of adverse environmental and health outcomes linked to imbalanced nutrient application. Globally, studies have shown that long-term application of inorganic fertilisers reduces soil organic carbon and total nitrogen levels, leading to soil degradation (Choudhury & Kennedy, 2005). This is corroborated by research in China, where a 30-year experiment demonstrated that continuous NPK fertilisation significantly lowered soil pH and decreased bacterial diversity (Zhou et al., 2018). Similarly, a Malaysian study spanning 25 years documented that the use of inorganic fertilisers reduced soil organic carbon and total nitrogen, eliminating beneficial bacteria and drastically altering the microbial community structure (Choudhury & Kennedy, 2005). Meta-analyses reinforce these findings, showing that while organic inputs enhance microbial taxonomic diversity and functional diversity, NPK-only applications often fail to provide the same benefits and can even lead to declines in certain microbial groups (Geisseler & Scow, 2014; Zhao et al., 2020). Changes in soil chemistry drive the shift in microbial communities; for example, urea application has been shown to increase bacterial ammonia oxidiser abundance and lower soil pH, which in turn alters the populations of denitrifying bacteria (Zhao et al., 2020).

The impact of chemical fertilisers extends beyond the soil, posing significant risks to human health primarily through water contamination. Excessive nitrate application leads to leaching into groundwater and surface water systems, a problem identified as a significant threat in Asia (FAO, 2019). High concentrations of nitrates in drinking water are a well-documented cause of infantile methemoglobinemia, also known as "blue baby syndrome," a condition in which the blood's ability to carry oxygen is impaired (Ward et al., 2018). Studies have established a direct link between consuming water with nitrate levels exceeding the WHO guideline of 50 mg/L and an increased risk of methemoglobinemia in infants (Ward et al., 2018; El Aouad et al., 2019). Beyond this acute risk, chronic exposure to nitrates and nitrites in water and food is suspected of increasing the incidence of cancers, particularly colorectal cancer, and causing thyroid dysfunction (Devi & Singh, 2016). The contamination pathways are clear: nitrates from agricultural runoff enter rivers and lakes, where they bioaccumulate in fish and other aquatic organisms, thereby entering the human food chain (Devi & Singh, 2016).

In parallel, the field of ethnobotany highlights the importance of traditional plant-based medicines in maintaining human health, especially in regions with limited access to modern healthcare. Manipur is a global biodiversity hotspot and is home to an estimated 1,200 species of medicinal plants, many of which are integral to the healing practices of its indigenous communities (Myers et al., 2000). Multiple studies have documented the extensive use of these plants by various ethnic groups, including the Zeliangrong, Rongmei, and Lois tribes, for treating a wide array of ailments (Devi et al., 2012; Singh, 2016). For instance, one survey identified 145 medicinal plants used by the Zeliangrong people to treat 59 ailments, with digestive disorders having the highest Informant Consensus Factor (Devi et al., 2012). Another study among the Rongmei tribe documented 60 species used for respiratory, gastrointestinal, and dermatological conditions (Singh et al., 2016). The Mao Naga tribe uses the flowering of specific trees as indicators for agricultural seasons, showcasing a deep traditional ecological knowledge passed down through generations (Singh, 2016). This body of knowledge represents a crucial cultural and medical resource. However, it is now under threat from the very environmental degradation caused by the agricultural intensification that modern society promotes.

Table 1: Showing the Fertiliser Type, Common Examples, Typical N:P: K Ratio, Primary Use/Source, and Relevant Citations.

Fertilizer Type	Common Examples	Typical N:P:K Ratio	Primary Use/Source	Relevant Citations
Nitrogenous	Urea (46% N), Ammonium Sulphate (21% N), Calcium Ammonium Nitrate (26% N)	Varies	Primary source of nitrogen for crop growth	(FAO, 2019); (Jat et al., 2020; Kumar & Singh, 2016)
Phosphatic	Single Super Phosphate (SSP) (16–20% P2O5), Diammonium Phosphate (DAP) (46% P2O5), Triple Super Phosphate (TSP) (44–48% P2O5)	Varies	Source of phosphorus for root development and flowering	(FAO, 2019; Jat et al., 2020)
Potassic	Muriate of Potash (MOP) (60–62% K), Potassium Sulphate (SOP) (50% K)	Varies	Source of potassium for overall plant health and disease resistance	(FAO, 2019; Kumar & Singh, 2016)
Complex/NPK	10:26:26, 12:32:16, 19:19:19, 20:20:0:13	10:26:26, etc.	Balanced mixtures of N, P, K (and sometimes S) for general-purpose use	(Jat et al., 2020; Ministry of Chemicals & Fertilisers, 2021)
Micronutrient	Zinc Sulphate, Boron Fertilisers (Borax), Ferrous Sulphate	Not applicable	Trace elements are required in small quantities for various plant functions.	(FAO, 2019; Kumar & Singh, 2016)

Significance of the Study

This study holds significant importance by offering a comprehensive understanding of the interconnected challenges affecting Manipur's agriculture, ecosystems, and communities. For policymakers, it provides empirical evidence on how national fertiliser subsidy policies and agricultural practices, although beneficial for food production, have led to soil degradation, water contamination in ecosystems such as Loktak Lake, and the decline of traditional ethnomedicinal livelihoods. The findings can inform revisions to schemes such as the Nutrient-Based Subsidy (NBS), promoting sustainable alternatives like biochar, compost, and Nano-Urea to ensure balanced nutrient use and environmental protection.

For the scientific community, this research fills a critical gap by examining the combined effects of chemical fertilisers on soil health, water quality, and the efficacy of medicinal plants within Manipur's unique acidic soil ecosystem. It provides baseline data for monitoring environmental health. It opens new interdisciplinary research avenues, connecting environmental science, microbiology, and pharmacognosy, particularly in the study of how agrochemical pollutants may alter plant-based bioactive compounds.

For farmers and agricultural extension workers, the study delivers practical insights into sustainable

nutrient management. It highlights the potential of Integrated Nutrient and Soil Fertility Management using locally available organic materials such as phumdi compost and biochar, which improve yields and environmental resilience.
Ultimately, the research underscores the urgent need for indigenous communities to preserve their traditional medicine systems and sacred ecosystems. By linking ecological degradation to cultural and health losses, the study advocates for community-led conservation to safeguard both biodiversity and human well-being.

Objectives of the Study

Objective 1: To analyse the prevalence, types, and environmental impacts of chemical fertilisers used in Manipur, focusing on their effects on soil health, fertility, and microbial balance.
Objective 2: To investigate the mechanisms and extent of environmental contamination caused by chemical fertilisers in Manipur, particularly their contribution to soil and water pollution, including the degradation of Loktak Lake.
Objective 3: To assess the indirect human health risks arising from fertiliser-induced environmental degradation, such as nitrate contamination, methemoglobinemia, and long-term chronic diseases.
Objective 4: To document the current status, threats, and potential protective role of ethnobotanical medicinal plants in Manipur as natural buffers against the adverse effects of chemical fertiliser pollution.

Methodology

This report synthesises findings from a qualitative review of existing literature rather than presenting original experimental data. The methodology ensures a rigorous, comprehensive, and unbiased analysis using credible scientific and academic sources. The process involved a systematic set of steps to gather, analyse, and interpret information relevant to the research topic.
The first step was to identify relevant literature through targeted searches in academic databases, digital libraries, and reputable online publications. Peer-reviewed journal articles, books, technical reports, and government documents were selected based on themes such as "chemical fertilisers in India," "Manipur soil health," "ethnobotanical medicinal plants," "nitrate pollution in Loktak Lake," and "soil microbiome and fertiliser impact." Preference was given to recent studies (post-2010), while older foundational works were included when necessary. Sources were evaluated for methodological soundness, relevance, and credibility.
The second step involved extracting and organising key data related to the study objectives. Quantitative data on fertiliser consumption, soil properties, pollutant levels, human health impacts, and ethnobotanical plant usage were systematically compiled and organised into thematic tables to facilitate comparison and synthesis.
The third step involved synthesising and interpreting the data to construct a narrative that explains the causal links between fertiliser use, environmental degradation, and human health. A comparative approach was used to integrate findings across ecosystems and fertiliser regimes, revealing patterns such as soil acidification and nutrient leaching.
Finally, the study acknowledges its limitations, including reliance on existing literature and data gaps regarding localised impacts. Despite these constraints, the methodology provides a strong foundation for understanding complex interconnections and guiding future empirical research.

Findings

The synthesis of existing literature reveals a clear and compelling picture of the pervasive negative impacts of chemical fertiliser use on the ecosystems and human health of Manipur and India. The findings can be summarised across the study's four main objectives, painting a holistic view of the interconnected challenges.

Prevalence and Environmental Impact of Chemical Fertilisers: The literature confirms that chemical fertilisers, particularly urea, are heavily relied upon in Indian agriculture due to historical government subsidies (Kumar & Singh, 2016). This has led to a dramatic increase in overall fertiliser consumption in India, which rose from 12,546 thousand tons in 2011–12 to 32,535.6 thousand tons in 2020–21 (Ministry of Chemicals & Fertilisers, 2021). The NPK consumption ratio in India remains severely imbalanced, averaging around 10:4:1, far from the ideal 4:2:1, which reflects the dominance of subsidised nitrogenous fertilisers (Jat et al., 2020; Singh, 2016). This imbalance is mirrored in Manipur, where per-hectare consumption has more than doubled from 27.9 kg in 2010–11 to 51.9 kg in 2019–20 (Directorate of Economics & Statistics, Government of Manipur, 2021). The consequence of this intensive application is widespread soil degradation. Long-term use of inorganic fertilisers is consistently shown to decrease soil pH, reduce soil organic matter, and diminish microbial diversity (Zhou et al., 2018; Choudhury & Kennedy, 2005; Zhao et al., 2020). In Manipur's acidic soils, this issue is compounded, as the low pH already limits the availability of essential nutrients, such as phosphorus and potassium (Singh, 2016). Studies have shown that while chemical fertilisers can sustain crop yields in the short term, they can lead to soil infertility over decades by depleting organic carbon (Choudhury & Kennedy, 2005).

Environmental Contamination Mechanisms: The improper management and excessive use of chemical fertilisers result in significant environmental contamination, primarily through water bodies. Agricultural runoff is a significant pathway for pollutants to enter rivers and lakes (FAO, 2019). In Manipur, this is a critical issue for Loktak Lake, a vital Ramsar site. Studies have documented extremely high levels of nitrates (NO_3^-) and nitrites (NO_2^-) in the Nambul and Nambol rivers, which are the primary inflows to the lake, with values frequently exceeding the World Health Organisation (WHO) safety limit of 50 mg/L for drinking water (Devi & Singh, 2016). This contamination poses a direct threat to the lake's unique biodiversity. Furthermore, the pollution of surface water bodies like the Imphal River, Iril River, and Nambul River is exacerbated by a combination of agricultural runoff, sewage discharge, and solid waste dumping, such as the 4.9 million tons of solid waste contributed annually by the Nambul River (Devi & Singh, 2016; Singh et al., 2016). This creates a multi-pollutant environment that stresses aquatic life and compromises water quality for human use.

Indirect Human Health Risks: The contamination of water and food sources creates direct pathways for human exposure to harmful substances. The most well-documented risk is infantile methemoglobinemia, or "blue baby syndrome," caused by the ingestion of nitrate-contaminated water (Ward et al., 2018). Infants are particularly vulnerable because their stomachs have a higher pH, which facilitates the conversion of nitrates to more toxic nitrites (Ward et al., 2018). A cross-sectional study in Morocco found that children consuming water with nitrate levels above 50 mg/L had a significantly higher risk of developing methemoglobinemia (El Aouad et al., 2019). Beyond this acute risk, chronic exposure to nitrates and other agrochemical residues is suspected of being carcinogenic, with links to colorectal cancer, and of causing thyroid dysfunction (Devi & Singh, 2016). Fish and other aquatic organisms living in contaminated waters can accumulate these pollutants, meaning that consumption of local catch can also be a route of exposure for the population (Devi & Singh, 2016).

Status and Threats to Ethnobotanical Medicinal Plants: Manipur is recognised as a biodiversity hotspot with a rich tradition of ethnomedicine (Myers et al., 2000). Numerous studies have documented the use of hundreds of plant species by local communities to treat a wide range of ailments, from common colds to severe conditions like hypertension and bone fractures (Devi et al., 2012; Singh et al., 2016; Singh, 2016). However, this invaluable traditional knowledge, along with its botanical foundation, is under severe threat. Deforestation, primarily driven by jhum cultivation and urbanisation, is the single greatest threat to the habitats of these medicinal plants (Myers et al., 2000; Singh, 2016). Overharvesting, particularly of high-value species like Panax ginseng, and the lack of regeneration in species with hard seed coats further endanger the flora (Singh, 2016). The very agricultural practices designed to increase food production pose a direct threat to the environment. Agrochemicals, including fertilisers and pesticides, contaminate the soil and water, which can kill non-target medicinal plants and potentially degrade the concentration of their active therapeutic compounds (Myers et al., 2000; Singh, 2016). The decline of sacred groves, which serve as refuges for medicinal flora, further accelerates this loss (Singh, 2016).

Discussion

Objective 1: Prevalence and Environmental Impact of Chemical Fertilisers

The first objective sought to analyse the prevalence and environmental impact of chemical fertilisers in Manipur. The literature strongly supports the conclusion that the state, like much of India, is experiencing the negative consequences of an agricultural model that relies heavily on and is imbalanced in the use of chemical inputs. The dominance of urea is a direct result of government policy, specifically the Nutrient-Based Subsidy (NBS) scheme, which, despite its intention to promote balanced fertilisation, has historically created a price advantage for nitrogen that encourages overuse (Kumar & Singh, 2016; Ministry of Chemicals & Fertilisers, 2021). This is reflected in the stark N:P: K consumption ratio, which in India stands at approximately 10:4:1, far from the recommended 4:2:1 (Jat et al., 2020; Singh, 2016). Manipur’s own consumption data shows a rapid increase, indicating a growing reliance on these inputs (Directorate of Economics & Statistics, Government of Manipur, 2021). This pattern is unsustainable and directly contributes to soil degradation. The long-term application of inorganic fertilisers is repeatedly shown to lower soil pH, a phenomenon known as soil acidification (Zhou et al., 2018; Choudhury & Kennedy, 2005; Singh, 2016). In Manipur, this is a particularly acute problem because nearly 98% of the state's soils are already classified as acidic, making them highly susceptible to the acidifying effects of ammonium-based fertilisers (Singh, 2016). This process immobilises key nutrients, such as phosphorus, and makes secondary nutrients, like calcium and magnesium, less available, fundamentally undermining soil fertility (Singh, 2016).

The impact on the soil microbiome is another critical finding. The literature demonstrates that chemical fertilisers alter the structure and function of the soil microbial community. They tend to favour fast-growing, r-strategist bacteria, such as those in the phyla Proteobacteria and Firmicutes, while reducing the abundance of more stable, diverse communities, like Acidobacteria and Actinobacteria (Choudhury & Kennedy, 2005; Zhao et al., 2020). This simplification of the microbial web can reduce the ecosystem services provided by soil biota, such as disease suppression and nutrient cycling. For example, a study in Malaysia found that 25 years of inorganic fertiliser use almost eliminated beneficial bacteria, such as Firmicutes (Choudhury & Kennedy, 2005). In comparison, a Chinese study observed a significant reduction in bacterial diversity after 30 years of NPK application (Zhou et al., 2018). These findings suggest that while chemical fertilisers may provide immediate nutrients, they can degrade the long-term health and resilience of the soil. The implication is that without a shift towards Integrated Nutrient Management (INM), which combines chemical inputs with organic amendments such as compost and manure, the soil in Manipur is likely to head towards a state of functional collapse, unable to support productive agriculture without ever-increasing chemical inputs.

Objective 2: Mechanisms and Extent of Environmental Contamination

The second objective focused on the pathways and consequences of chemical fertiliser pollution. The evidence clearly indicates that the problem extends far beyond the farm gate. The primary mechanism for transport is surface runoff during rainfall, carrying dissolved nitrates and phosphates from fertilised fields into nearby rivers and lakes (FAO, 2019). In Manipur, this process is causing severe damage to Loktak Lake, a globally significant wetland of international importance. Studies have documented alarmingly high concentrations of nitrates and nitrites in the lake's feeder streams, with levels at some sites exceeding the WHO safety threshold for drinking water by more than double (Devi & Singh, 2016). This nutrient overload fuels eutrophication, a process that leads to algal blooms, depletes oxygen in the water, harms fish and other aquatic life, and disrupts the entire lake ecosystem (Devi & Singh, 2016). The problem is compounded by other forms of pollution entering the lake, such as solid waste and sewage, making the issue a multifaceted environmental crisis (Devi & Singh, 2016; Singh et al., 2016).

Contamination of drinking water sources poses a direct threat to public health. The high per-hectare fertiliser uses in regions such as Punjab and Haryana correlate with high rates of nitrate contamination in groundwater (FAO, 2019). While specific data for Manipur is not available in the provided sources, the high consumption rate and the presence of agricultural runoff make it highly probable that private wells and other water sources are similarly affected. The link between agricultural land use and water quality is well-established elsewhere; for instance, a study in Salé, Morocco, found that 69.2% of surveyed wells in an agricultural area had nitrate levels exceeding the WHO limit, and children in these areas had a significantly higher risk of methemoglobinemia (El Aouad et al., 2019). Therefore, it is logical to infer that communities in Manipur, particularly those dependent on clean water, are at a significant risk. The contamination of fish and other organisms in Loktak Lake represents a secondary pathway for toxin entry into the human body, bypassing the filtration systems of municipal water treatment and placing the entire local fishing and food culture at risk (Devi & Singh, 2016). Addressing this issue requires a landscape-scale approach that considers the entire watershed, rather than focusing solely on individual farms.

Objective 3: Indirect Health Risks Posed by Pollutants

The third objective addressed the indirect health risks stemming from fertiliser pollution. The most significant and well-documented of these is methemoglobinemia. The provided literature establishes a precise biological mechanism: nitrates from contaminated water are converted to nitrites by gut bacteria. Nitrites then oxidise the iron in haemoglobin, forming methemoglobin, which cannot effectively carry oxygen. This leads to cyanosis (bluish skin), respiratory distress, and, in severe cases, death, particularly in infants (Ward et al., 2018). Studies from Morocco and Romania provide quantitative evidence of this risk, linking elevated nitrate levels in water supplies to a higher prevalence and incidence of the disease in exposed children (El Aouad et al., 2019; Ward et al., 2018). While no specific epidemiological study is cited for Manipur, the documented presence of high nitrates in the inflow rivers of Loktak Lake suggests a substantial public health threat that warrants immediate investigation and monitoring.

Beyond methemoglobinemia, the literature suggests a range of other potential health impacts from long-term exposure to agrochemicals. Chronic exposure to nitrates and nitrites is suspected of being genotoxic and mutagenic, potentially leading to an increased incidence of certain cancers, particularly colorectal cancer (Devi & Singh, 2016). Other pesticides and chemicals commonly used in conjunction with fertilisers, such as Endosulfan and malathion, have been detected in soil and water across India and are known to have carcinogenic, teratogenic, and endocrine-disrupting effects (Singh, 2016). The concern is that the cumulative effect of exposure to multiple low-level pollutants may contribute to a rising tide of chronic diseases like cancer, diabetes, and neurological impairments in agricultural communities (Swaminathan, 2015). Farmers themselves are often at high risk due to a lack of protective gear during application, leading to dermal and inhalation exposure (Swaminathan, 2015). The discussion highlights that the health burden of chemical-intensive agriculture is not always immediately apparent but manifests over time as a complex array of chronic illnesses, placing a significant strain on public health systems.

Objective 4: Status, Threats, and Protective Role of Medicinal Plants

The fourth objective explored the role of ethnobotanical medicinal plants in the context of environmental stress. The literature paints a vivid picture of Manipur as a repository of traditional medical knowledge, with numerous studies documenting the extensive use of local flora by various tribes (Devi et al., 2012; Singh et al., 2016). This knowledge is not static; it is dynamic and adaptive, with practices such as using the seasonal flowering of trees as agricultural calendars demonstrating a sophisticated understanding of ecological relationships (Singh, 2016). The documentation of hundreds of plant species used to treat dozens of ailments highlights a healthcare system deeply intertwined with the natural world (Singh, 2016). However, this heritage is under grave threat. The literature identifies three primary drivers of this threat. First, habitat destruction is the most significant factor. Deforestation from jhum cultivation, urban expansion, and infrastructure projects is fragmenting and destroying the forests and hillsides where these plants grow (Myers et al., 2000; Singh, 2016). Second, overexploitation is pushing many valuable species to the brink of extinction. Plants like Acorus calamus, Oroxylum indicum, and Panax ginseng are harvested unsustainably, often outpacing their ability to regenerate (Devi et al., 2012; Singh, 2016). Third, and perhaps most insidious, is the direct impact of agrochemical pollution. The same fertilisers and pesticides that contaminate water sources are also killing non-target plants and may be interfering with the biochemical pathways within medicinal plants, potentially reducing the concentration of their active therapeutic compounds (Myers et al., 2000; Singh, 2016). This means that even if the plants survive, their efficacy may be compromised.

This leads to the final insight: the role of these plants may be more critical than previously understood. They represent a form of "traditional resilience" that could be leveraged to combat the health impacts of modern environmental toxins. The study of Gynura nepalensis (Terapaibi) and Eryngium foetidum (Awa-phadigom) for detoxification in Manipur is a prime example (Singh, 2016). If further research can validate the phytochemical mechanisms behind such traditional uses, these plants could become a subject of modern pharmacological research. Protecting them is therefore not just an act of cultural preservation but a strategic investment in public health. Community-led cultivation programs and the protection of remaining sacred groves could serve as a dual-purpose strategy: conserving biodiversity and ensuring the continued availability of these potential natural antidotes to pollution.

Suggestions and Recommendations

Based on the findings and discussion, a multi-pronged set of recommendations is proposed to mitigate the negative impacts of chemical fertiliser use and harness the potential of ethnomedicinal plants for building a healthier, more sustainable future for Manipur. These suggestions span policy, agricultural practice, community action, and research.

Policy and Governance:

1. **Revise Fertiliser Subsidy Policies:** The government should reform the Nutrient-Based Subsidy (NBS) scheme to discourage the over-reliance on subsidised urea actively. This could involve implementing tiered subsidies that reward farmers for purchasing balanced NPK blends closer to the 4:2:1 ideal ratio. The policy should also incentivise the use of less environmentally damaging nitrogen sources, such as liquid nano urea, which promises to reduce conventional urea use by at least 50% (Ministry of Chemicals & Fertilisers, 2021).
2. **Strengthen Environmental Regulations:** Regulatory frameworks must be established to control the sale and use of harmful substances in fertilisers, a gap that currently exists in India (Zhao et al., 2020). Stricter enforcement of effluent standards for industries and better management of solid waste disposal are needed to protect water bodies like Loktak Lake.
3. **Mandate Monitoring Programs:** The government should initiate annual monitoring programs for nitrate levels in key water bodies, including Loktak Lake and its tributaries, as well as in private wells in high-fertiliser-use areas. This data is essential for tracking pollution trends and assessing public health risks (Devi & Singh, 2016).

Agricultural Practices:

1. **Promote Integrated Nutrient Management (INM):** INM, which combines chemical fertilisers with organic sources like compost and manure, should be aggressively promoted. The successful use of phumdi compost in Manipur, which boosted rice yields by 33.6% while substituting half the chemical dose, serves as a powerful local model that should be scaled up (Devi & Singh, 2016). Similarly, the use of biochar, which improves soil fertility and reduces fertiliser runoff, should be encouraged through farmer training and support programs run by organisations like GBTP 2022 (GBTP, 2022).
2. **Implement Soil Health Card Scheme:** The Soil Health Card Scheme, which provides farmers with soil-specific nutrient recommendations, should be expanded and made mandatory. This would help prevent the blanket application of fertilisers and move toward precision agriculture (Kumar & Singh, 2016).
3. **Encourage Conservation Agriculture:** Techniques such as mulching, cover cropping, and reduced tillage can help mitigate soil erosion and improve soil structure, which is critical in a state like Manipur where 30% of India's total geographical area is affected by soil erosion (Devi & Singh, 2016).

Community Action and Conservation:

1. **Establish Community-Led Conservation Areas:** There is an urgent need to protect the remaining wild populations of medicinal plants. This can be achieved by supporting community-led conservation efforts, including the protection of sacred groves, which are vital reservoirs of biodiversity (Myers et al., 2000). Establishing community-managed nurseries for endangered species, such as Acorus calamus and Oroxylum indicum, can also help ensure their survival (Singh, 2016).
2. **Support Ethnobotanical Documentation:** Scientific validation of the medicinal plants used in Manipur is crucial. Funding should be allocated for collaborative research between traditional healers and academic institutions to document and pharmacologically validate the efficacy of these plants, particularly those used for detoxification and treating ailments potentially linked to pollution (Singh, 2016).
3. **Develop Sustainable Harvesting Guidelines:** To combat overharvesting, clear guidelines for sustainable harvesting should be developed in collaboration with local communities. This includes promoting the cultivation of high-value medicinal plants, which can provide economic incentives for

conservation (Singh, 2016).

Research and Development:

1. **Investigate Plant-Microbe-Soil Interactions:** Further research is needed to understand the specific interactions between chemical fertilisers, soil microbes, and the active compounds in medicinal plants. This could determine if pollutants affect the biosynthesis of key phytochemicals and whether specific plants are more resilient to pollution.
2. **Conduct Localised Epidemiological Studies:** A critical research gap exists regarding the direct health impacts of agrochemical pollution in Manipur. A large-scale epidemiological study is needed to assess the prevalence of methemoglobinemia and other chronic diseases in relation to exposure to contaminated water and food.
3. **Explore Phytoremediation Potential:** Given the high levels of nutrient pollution in Loktak Lake, research should be initiated into the potential for using specific aquatic and riparian plants for phytoremediation, using plants to absorb and remove pollutants from water and soil, as a natural cleanup strategy.

By adopting these integrated recommendations, Manipur can begin to address the legacy of chemical-intensive agriculture and move toward a more holistic and resilient model that protects its unique environment, safeguards public health, and honours its invaluable cultural heritage.

Conclusion

The analysis presented in this report demonstrates that the impact of chemical fertiliser use in Manipur is a complex, interconnected issue with profound consequences for the region's environment, human health, and cultural fabric. The heavy reliance on imbalanced chemical inputs has led to widespread soil degradation, particularly in the state's already vulnerable, acidic soils. It has initiated a cycle of environmental contamination that threatens vital water bodies, such as Loktak Lake. This pollution, in turn, creates direct and indirect health risks for the population, from the well-documented danger of methemoglobinemia to the potential rise of chronic diseases from long-term exposure to agrochemicals. Amidst this environmental crisis, the rich tradition of ethnomedicinal plant use emerges as both a critical cultural asset under threat and a potential source of resilience. The findings underscore that the challenges are systemic and require a paradigm shift away from a purely chemical-input-dependent agricultural model. Actual progress will only be achieved through the concerted adoption of integrated approaches that harmonise modern science with traditional wisdom, conserve natural resources, and empower local communities to build a sustainable and healthy future.

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