Nevee Mishra
North Oconee High School, Bogart, Georgia, USA
India, Fisheries and Aquaculture / Sustainable Agriculture
[08/26/2026]

Poisoned Ponds: Cyanotoxin Contamination in Indian Aquaculture and the Case for Democratized Monitoring

Introduction

India is one of the world's largest producers of farmed fish. The country's aquaculture sector feeds hundreds of millions at home and exports seafood to dozens of nations, from the United States to Japan. But beneath that productivity lies a growing crisis, contamination of aquaculture ponds by toxin-producing cyanobacteria, commonly known as blue-green algae. Cyanobacterial harmful algal blooms (CyanoHABs) are not new, but several pressures in India's aquaculture landscape are making them more frequent and dangerous. Warming water temperatures, nutrient-laden pond water from unregulated feed inputs, and an underfunded regulatory framework have combined to create conditions in which blooms can flourish unchecked (Maniyar et al., 2022). The cyanotoxins they release, particularly microcystins, cylindrospermopsins, and anatoxins, can accumulate in fish tissue and move up the food chain to consumers within India and beyond its borders (Ibelings & Chorus, 2007). This paper examines the problem, connects it to deeper cultural, political, and economic realities in India, and proposes one solution, a phased technology-guided system that puts bloom monitoring, safe response tools, and farmers' training directly in the hands of the people who manage these ponds every day.

Part I: The Problem - India's Aquaculture Boom and Its Hidden Contamination Crisis

A Country Profile

India is home to approximately 1.44 billion people, about 65% of whom live in rural areas (World Development Indicators, DataBank, n.d.). Agriculture, including fisheries and aquaculture, supports nearly half the population. The country's coastal and inland water systems are vast, with over 7,500 kilometers of coastline, an estimated 3.15 million hectares of reservoirs, and millions of small farm ponds across states like Andhra Pradesh, West Bengal, Odisha, and Bihar (FAO, 2022). Farmed fish is not merely a commodity; it is a cornerstone of nutrition, culture, and income for tens of millions of families.

India is now the second-largest aquaculture producer in the world, contributing roughly 8% of global fish production (FAO, 2022). The sector has expanded rapidly over the past two decades, driven by government incentives, growing domestic demand, and an export market worth over USD 7 billion annually (Suresh et al., 2023). In states like Andhra Pradesh, the typical farm family may manage one to three ponds and raise species such as rohu, catla, pangasius, and, most importantly for exports, shrimp. It accounts for about 70% of total production, contributing close to 1 million tons of aquaculture output.

The Cyanotoxin Problem

Cyanobacteria thrive under conditions of excess nutrients, warm and stagnant water, and high sunlight (Paerl et al., 2016). These conditions describe many intensively farmed Indian aquaculture ponds during spring and summer. As pond operators increase stocking densities and feed inputs to maximize yields, nutrient loads rise. As temperatures climb, shallow ponds exceed thresholds that suppress cyanobacterial growth (Paerl & Huisman, 2008). The result is dense mats of cyanobacteria that discolor water, deplete oxygen, and release toxic metabolites. Microcystins, the most widely studied cyanotoxins, target the liver in humans. Chronic dietary exposure through contaminated fish has been linked in epidemiological research to elevated rates of primary liver cancer in communities with high

consumption of pond-raised fish in bloom-prone regions (Ueno et al., 1996; Zhou et al., 2000). Cylindrospermopsin damages multiple organ systems and has been detected in Indian water bodies at concentrations exceeding WHO advisory thresholds (Falconer and Humpage, 2006). Anatoxins are fast-acting neurotoxins that can cause paralytic symptoms at low doses. Fish often accumulate these toxins at sublethal levels, allowing contaminated products to enter the food chain (Ibelings & Chorus, 2007).

Published research from India has confirmed microcystin contamination in fish from aquaculture ponds in West Bengal, Andhra Pradesh, and Karnataka (Mohan et al., 2023). Yet systematic national monitoring of cyanotoxins in aquaculture products is largely absent (Maniyar et al., 2022). India's Food Safety and Standards Authority (FSSAI) has not established enforceable maximum residue limits for cyanotoxins in fish, and fisheries inspection infrastructure, particularly at small- and medium-sized farms, lacks the capacity or mandate to test for them routinely.

Political, Cultural, and Economic Dimensions

Understanding why this problem persists requires looking beyond biology. India's aquaculture governance is fragmented, shared between central and state governments in ways that diffuse accountability. The Ministry of Fisheries, Aquaculture and Animal Husbandry released a comprehensive National Fisheries Policy in 2020, but implementation at the pond level remains uneven, especially in poorer states (Indian Fisheries in the Context of WTO Regulations, 2023). Small farmers who lack the resources or knowledge to test water quality are left largely on their own.

Culturally, fish farming in India is deeply embedded in caste and community identity in many regions. Farming communities often inherit practices across generations without formal training. At the same time, economic pressures push farmers toward intensification by stocking more fish, adding more feed, and maximizing short-term yields, even when this accelerates nutrient loading that feeds bloom.

From a global food security perspective, the stakes extend beyond India's borders. Shrimp and fish processed in coastal India reach supermarkets, wholesale markets, and restaurants worldwide (FAO, 2022). If cyanotoxin contamination is not detected at the source, it is rarely caught downstream. Most seafood safety testing in importing nations focuses on microbiological hazards, heavy metals, and veterinary drug residues, not cyanotoxins, for which standardized residue testing methods have only recently begun to be developed internationally (Testai et al., 2016). The problem is a global food security issue hiding in plain sight.

Implications at a Micro Level (The Peri Family)

This portrayal of cyanotoxin impacts on food and economic security at a micro level comes from a phone conversation with Raju Peri and his wife, Lakshmi Peri, an aquaculture family from Guntur, Andhra Pradesh. The Peris' have raised Rohu and Catla in their two half-acre ponds behind their home for three generations. In recent years, they have added shrimp culture as export demand has grown. Each morning before dawn, Lakshmi and her husband walk around the ponds for the telltale green sheen and foul smell that signals the formation of a CyanoHAB. They rely on the same instincts passed down rather than any formal water quality testing. When the visual signs become clear, their options are limited: reduce feeding, hope the wind disperses the scum, or apply copper sulfate purchased from the local agro-input shop. Peris are often unsure of the correct dose and application procedure of copper sulfate because of a lack of training or education. An uncontrolled bloom two years ago killed nearly two-thirds of their fish stock in under a week. That pushed the family to take an informal loan, which they still repay monthly. Like millions of families in India's aquaculture belt, the Peris' relationship with cyanotoxin risks is not shaped by laboratory data or satellite imagery, but by direct observation, inherited practice, and economic necessity. That's exactly the gap the proposed technology-guided

solution is designed to close for small family-owned pond-scale monitoring. For large pond-scale or landscape-scale monitoring, government intervention would be necessary.

Part II: Food Security Implications - Why This Cannot Wait

Food security, as defined by the United Nations, encompasses availability, access, utilization, and stability of nutritious food. Cyanotoxin contamination undermines all four pillars simultaneously.

On utilization, the presence of hepatotoxins and neurotoxins in fish consumed by Indian families, especially rural families who eat local pond fish several times a week, represents a genuine and underappreciated chronic health burden. Long-term low-dose microcystin exposure has been associated with liver fibrosis, non-alcoholic fatty liver disease, and tumor promotion in experimental and epidemiological studies (Carmichael et al., 2001; Gehringer, 2003). Where fish is often the primary or sole protein source, silent contamination translates directly into nutritional harm.

On availability, increasingly frequent blooms cause acute fish kills in affected ponds, destroying the livelihoods of farmers overnight. A family whose entire stock dies in a bloom loses both food and income, forcing it into debt and food insecurity. Such events are increasingly documented in India (Indian Fisheries in the Context of WTO Regulations, 2023).

More broadly, India's ability to remain a reliable, safe source of fish protein for the global south and its own rapidly urbanizing, nutritionally vulnerable population depends on the integrity of its aquaculture sector. A major food safety scandal involving cyanotoxin contamination would devastate exports, harm the incomes of hundreds of thousands of families, and erode consumer trust in fish as a food source.

Climate models project that South Asia will experience some of the largest temperature increases globally over the next 30 years (IPCC, 2022). Warming water, monsoon disruptions affecting pond drainage and flushing, and continued intensification of aquaculture will deepen the conditions promoting CyanoHABs. Today's problem may be only a preview of what India's aquaculture sector could look like in 2040 without deliberate, scalable intervention.

Part III: The Recommendation: A Phased, Farmer-Centered Monitoring and Response System

This paper recommends one solution: a farmer-centered, technology-guided system to detect and respond to CyanoHABs before they poison a pond. Because detection alone cannot protect a farmer's livelihood, and because tools often go unused without training, this recommendation is delivered through three interdependent components of a single system, not three separate solutions. Detection tools identify CyanoHAB risk in time to act using biological and mechanical control; and education and regulatory reform ensure both components are used correctly, adopted widely, and sustained over time. Removing any one component would undermine the solution's effectiveness and scalability.

Component 1: Democratized, Technology-Enabled Monitoring

Early detection of cyanobacterial blooms before they reach toxin-producing intensity is the most powerful intervention available. The challenge is scale: India has millions of aquaculture ponds across vast and often poorly connected rural landscapes. Traditional water quality sampling and laboratory testing are expensive, slow, and logistically unrealistic at that scale. This study proposes three monitoring approaches: pond-scale monitoring for small family-owned farms, network-scale monitoring for large pond systems, and landscape-scale monitoring for large aquaculture regions.

Small-family-owned pond-scale monitoring – (*Phase 1: low-cost, high-reach tool*) - Phone-based AI computer vision tools are now being developed that allow farmers to photograph pond water with a smartphone and receive a risk assessment within seconds. Self-monitoring apps for farmers in developing countries are already fairly common, such as *Farm Monitor for Africa* (Farm Monitor Ltd,

2026) and *Map My Crop* (Map My Crop, 2026). Apps using deep learning models trained on bloom imagery have shown promising accuracy in pilot studies in China and Southeast Asia (Kim et al., 2023). These low-cost approaches require minimal training and no laboratory equipment. Rather than waiting for a government officer or lab results, farmers can act on their own observations using devices they likely already own.

Large-ponds network-scale monitoring - (*Phase 2: network-scale tool for commercial operations*) - Recent advances in optical and biosensor-based technologies offer a scalable alternative for large aquaculture pond networks. Systems such as CyanoSense (Boddula et al., 2017) and CyanoSense 2.0 (Maniyar et al., 2025) use low-cost, solar-powered, wireless sensor networks to enable continuous detection of cyanotoxins across distributed water bodies. Compared with conventional analytical approaches, these devices support decentralized, continuous monitoring and early warning. While upfront costs may still limit adoption among small farmers, larger operations can achieve cost savings and risk reduction through improved monitoring efficiency, reduced sampling delays, and more proactive management of CyanoHABs.

Large-aquaculture landscape-scale monitoring - (*Phase 3: region-scale integration*) - Advances in remote sensing are changing what is feasible. Satellite platforms, particularly Sentinel-2 and Landsat, can detect chlorophyll-a and CyanoHAB pigment concentrations in water bodies at resolutions fine enough to flag individual ponds, at no cost to end users (Maniyar et al., 2022; Simis et al., 2005). Geospatial AI models are also becoming more powerful for cyanotoxin detection. Organizations like NASA and ESA provide this data freely, and cloud-based platforms, including tools developed by Indian research institutions like the National Remote Sensing Center (NRSC), can be configured to send automated alerts when spectral signatures of bloom formation are detected at registered farm locations.

Towards a Phased Rollout

The three monitoring approaches proposed above vary widely in cost, technical sophistication, and institutional readiness. A simultaneous, uniform national or state-level rollout would be unrealistic given India's governance and rural infrastructure. A phased approach would allow the most feasible interventions to build momentum and demonstrate value before scaling more resource-intensive tools.

The large-scale monitoring solutions proposed here would require a coordinated national effort led jointly by India's Ministry of Fisheries, the Indian Council of Agricultural Research (ICAR), and state fisheries departments. They could develop and distribute a standardized, free, multilingual smartphone application for cyanobacteria risk assessment in aquaculture ponds. The app would combine satellite-based early warning for enrolled ponds with local image capture and AI-based interpretation, giving farmers a simple, color-coded CyanoHAB risk level (low, moderate, high) and a recommended action. It should be designed for low-literacy users, available in regional languages including Telugu, Bengali, Odia, and Tamil, and functional on mid-range Android devices common in rural markets. The proposed phased design is aimed at ensuring that the intervention is feasible, culturally appropriate, and sustainable. In the short term, Phase 1 could reduce catastrophic fish kills like the one that struck Peris'. In the long term, data Phases 2 and 3 generate could support enforceable actions to protect India's export market.

Component 2: Post-monitoring Targeted Biological and Mechanical Control

Detection alone is insufficient if farmers have no safe, actionable response. This component focuses on a toolkit of targeted, low-harm interventions to be deployed at the pond level once a bloom is detected. The most common current response in India, as in many developing aquaculture regions, is indiscriminate application of copper sulfate or other algaecides. This approach has serious drawbacks: it is non-selective, can release intracellular toxins into the water in large pulses, and may introduce additional chemical hazards when farmers use products not approved for aquaculture use

(Christoffersen & Kaas, 2000). Safer alternatives exist. Barley straw has been shown to inhibit cyanobacterial growth as it decomposes (Everall & Lees, 1996). Mechanical aeration disrupts the stratification that allows cyanobacteria to form surface scums (Paerl et al., 2016). Biocontrol using specific bacteriophages and cyanophage preparations is an active area of research (Guo et al., 2024). For large pond networks, constructed wetlands can reduce nutrient loading before it enters pond systems.

Safer and more targeted alternatives exist. Barley straw application, placing dry bundles in ponds, has been shown to inhibit cyanobacterial growth by releasing hydrogen peroxide and phenolic compounds as the straw decomposes (Everall & Lees, 1996). Mechanical aeration using submersible aerators or paddlewheels disrupts surface stratification, which allows cyanobacteria to form surface scums, and reduces their competitive advantage (Paerl et al., 2016). Biocontrol using specific bacteriophages and cyanophage preparations targeting bloom-forming Microcystis and Anabaena species is an active area of research, with growing practical documentation (Guo et al., 2024). Finally, in large industrial pond networks, constructed wetlands can buffer inflows and reduce nutrient loading before they enter the pond system. This study recommends that India's fisheries extension services develop a regionally adapted response protocol, essentially a "bloom response menu" that farmers can access through the monitoring application described above, and that is supported by government subsidized provision.

Component 3: Education, Capacity Building, and Regulatory Reform

Technology and tools are only as effective as the people using them. The third component of this solution is an investment in the human infrastructure that sustains the first two components.

Farmer Field Schools, already used in India for pest management and crop practices, provide a practical framework for delivering cyanotoxin awareness training to aquaculture communities. These schools bring small groups of farmers together for hands-on learning sessions led by trained extension workers, covering conditions that promote blooms, how to use the monitoring app, what to do when a bloom is detected, and why overusing chemicals is counterproductive. The model is participatory, culturally adapted, and has documented effectiveness in changing farming practices in Southeast Asia (van den Berg & Jiggins, 2007).

This study also argues for regulatory reform to support sustainable aquaculture in the face of climate change. India should establish enforceable maximum residue limits for key cyanotoxins in fish and shrimp marketed domestically and for export. Inspection protocols at processing facilities and export checkpoints should be updated to include cyanotoxin screening using modern instruments. This step matters not only for domestic food safety but also for India's reputation in global fish markets. Importing nations that discover undisclosed cyanotoxin residues in Indian exports can impose import bans, damaging the entire sector. Proactive monitoring and transparent standards protect both public health and economic interests.

Conclusion

The challenge of cyanotoxin contamination in Indian aquaculture is, at its core, a story about growth without adequate stewardship. India has built a remarkable food production system from its inland waters, but the same intensification that made that growth possible has also made its ponds increasingly hospitable to toxin-producing organisms. The solution proposed here does not ask farmers to sacrifice productivity or income. Instead, it calls for a meaningful shift in how farms are monitored and how knowledge is shared. By putting accurate, real-time bloom detection in the hands of the people who stand at the water's edge every day and backing that monitoring with practical, ecologically responsible control options, it is possible to protect both the food and livelihoods Indian aquaculture provides. A phone, an app, and a trained eye can do what no distant laboratory has yet managed: catch the bloom before it poisons the pond, the fish, and the people who depend on them.

References

Boddula, V., Ramaswamy, L., & Mishra, D. (2017). CyanoSense: A Wireless Remote Sensor System Using Raspberry-Pi and Arduino with Application to Algal Bloom. In *2017 IEEE International Conference on AI & Mobile Services (AIMS)*. https://doi.org/10.1109/aims.2017.19

Carmichael, W. W., Azevedo, S. M., An, J. S., Molica, R. J., Jochimsen, E. M., Lau, S., Rinehart, K. L., Shaw, G. R., & Eaglesham, G. K. (2001). Human fatalities from cyanobacteria: chemical and biological evidence for cyanotoxins. *Environmental Health Perspectives*, *109*(7), 663–668. https://doi.org/10.1289/ehp.01109663

Christoffersen, K., & Kaas, H. (2000). Toxic cyanobacteria in water. A guide to their public health consequences, monitoring, and management. *Limnology and Oceanography*, *45*(5), 1212. https://doi.org/10.4319/lo.2000.45.5.1212

Cotruvo, J. A. (2017). 2017 WHO Guidelines for Drinking Water Quality: First addendum to the fourth Edition. *American Water Works Association*, *109*(7), 44–51. https://doi.org/10.5942/jawwa.2017.109.0087

Everall, N., & Lees. (1996). The use of barley-straw to control general and blue-green algal growth in a Derbyshire reservoir. *Water Research*, *30*(2), 269–276. https://doi.org/10.1016/0043-1354(95)00192-1

FAO, The State of World Fisheries and Aquaculture 2022. (2022). In *FAO eBooks*. https://doi.org/10.4060/cc0461en

Falconer, I. R., & Humpage, A. R. (2006). Cyanobacterial (blue-green algal) toxins in water supplies: Cylindrospermopsins. *Environmental Toxicology*, *21*(4), 299–304. https://doi.org/10.1002/tox.20194

Farm Monitor Ltd. (2026, March 2). *Track productivity and provide visibility across thousands of farms in real-time*. Track Productivity and Provide Visibility Across Thousands of Farms in Real-time. https://farmmonitor.africa/

Gehringer, M. M. (2003). Microcystin-LR and okadaic acid-induced cellular effects: a dualistic response. *FEBS Letters*, *557*(1–3), 1–8. https://doi.org/10.1016/s0014-5793(03)01447-9

Guo, Y., Dong, X., Li, H., Tong, Y., Liu, Z., & Jin, J. (2024). Cyanophage Engineering for algal blooms control. *Viruses*, *16*(11), 1745. https://doi.org/10.3390/v16111745

Ibelings, B. W., & Chorus, I. (2007). Accumulation of cyanobacterial toxins in freshwater "seafood" and its consequences for public health: A review. *Environmental Pollution*, *150*(1), 177–192. https://doi.org/10.1016/j.envpol.2007.04.012

Indian fisheries in the context of WTO regulations. (2023, December 11). Mercatus Center. https://www.mercatus.org/research/policy-briefs/indian-fisheries-context-wto-regulations

Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Kim, S., Sosnowski, K., Hwang, D. S., & Yoon, J. (2023). Smartphone-Based microalgae monitoring platform using machine learning. *ACS ES&T Engineering*, *4*(1), 186–195. https://doi.org/10.1021/acsestengg.3c00261

Maniyar, C., Kumar, A., & Mishra, D. (2021). Continuous and synoptic assessment of Indian inland waters for harmful algae blooms. *Harmful Algae*, *111*, 102160. https://doi.org/10.1016/j.hal.2021.102160

Maniyar, C., Raviprakash, K., Kumar, A., Seferian, M. A., Fiorentino, I. R., & Mishra, D. (2025). Low-Cost System to Support and Expand Cyanobacterial Harmful Algal Bloom Monitoring with New-Generation Ocean Color Satellites. *ACS ES&T Water*, *5*(11), 6246–6257. https://doi.org/10.1021/acsestwater.5c00301

Map My Crop. (2026). *Crop Monitoring & Farm Boundary Mapping | MapMyCrop*. https://mapmycrop.com/

Mohan, R., Anjaly, M. A., Thomas, L. C., & Padmakumar, K. B. (2023). Occurrence and toxicity of cyanobacterium Microcystis aeruginosa in freshwater ecosystems of the Indian subcontinent: a review. *Energy Ecology and Environment*, *8*(4), 332–343. https://doi.org/10.1007/s40974-023-00277-6

Paerl, H. W., & Huisman, J. (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. *Environmental Microbiology Reports*, *1*(1), 27–37. https://doi.org/10.1111/j.1758-2229.2008.00004.x

Paerl, H. W., Scott, J. T., McCarthy, M. J., Newell, S. E., Gardner, W. S., Havens, K. E., Hoffman, D. K., Wilhelm, S. W., & Wurtsbaugh, W. A. (2016). It Takes Two to Tango: When and Where Dual Nutrient (N & P) Reductions Are Needed to Protect Lakes and Downstream Ecosystems. *Environmental Science & Technology*, *50*(20), 10805–10813. https://doi.org/10.1021/acs.est.6b02575

Simis, S. G. H., Peters, S. W. M., & Gons, H. J. (2005). Remote sensing of the cyanobacterial pigment phycocyanin in turbid inland water. *Limnology and Oceanography*, *50*(1), 237–245. https://doi.org/10.4319/lo.2005.50.1.0237

Suresh, A., Panda, S. K., & Chandrasekar, V. (2023). Export of Fishery Products from India : Status, Challenges and the Way Forward. *Current Science*, *124*(6), 664. https://doi.org/10.18520/cs/v124/i6/664-670

Testai, E., Buratti, F. M., Funari, E., Manganelli, M., Vichi, S., Arnich, N., Biré, R., Fessard, V., & Sialehaamoa, A. (2016). Review and analysis of occurrence, exposure and toxicity of cyanobacteria toxins in food. *EFSA Supporting Publications*, *13*(2). https://doi.org/10.2903/sp.efsa.2016.en-998

Ueno, Y., Nagata, S., Tsutsumi, T., Hasegawa, A., Watanabe, M. F., Park, H., Chen, G., Chen, G., & Yu, S. (1996). Detection of microcystins, a blue-green algal hepatotoxin, in drinking water sampled in Haimen and Fusui, endemic areas of primary liver cancer in China, by highly sensitive immunoassay. *Carcinogenesis*, *17*(6), 1317–1321. https://doi.org/10.1093/carcin/17.6.1317

Van Den Berg, H., & Jiggins, J. (2007). Investing in Farmers—The impacts of farmer Field schools in relation to Integrated pest Management. *World Development*, *35*(4), 663–686. https://doi.org/10.1016/j.worlddev.2006.05.004

World Development Indicators | DataBank. (n.d.). https://databank.worldbank.org/country/IND/556d8fa6/Popular_countries

Zhou, L., Yu, D., Yu, H., Chen, K., Shen, G., Shen, Y., Ruan, Y., & Ding, X. (2000). Drinking water types, microcystins and colorectal cancer. *PubMed*, *34*(4), 224–226. https://pubmed.ncbi.nlm.nih.gov/11860936