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Agricultural Intensification and Groundwater Depletion in North India: A Geographical Assessment

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ABSTRACT

Agricultural intensification in North India — driven by the Green Revolution package of high-yielding variety seeds, assured minimum support prices, and subsidised electricity for tubewell irrigation — has produced a food-secure but hydrologically unsustainable agrarian regime. This paper undertakes a geographical and legal assessment of groundwater depletion across the Indo-Gangetic states of Punjab, Haryana, Rajasthan, Delhi and western Uttar Pradesh, situating the crisis at the intersection of physical geography, agricultural policy and environmental law. Drawing upon Central Ground Water Board (CGWB) datasets, satellite gravimetry (GRACE) studies, and doctrinal legal analysis, the paper demonstrates that the Stage of Groundwater Extraction (SoE) in Punjab and Haryana now exceeds 160% and 135% respectively, with over 87% of national groundwater draft attributable to irrigation.

The paper traces the legal architecture governing groundwater — from the colonial land-ownership doctrine embedded in the Indian Easements Act, 1882, through the judicially evolved public trust doctrine articulated in M.C. Mehta v. Kamal Nath and State of West Bengal v. Kesoram Industries, to state-specific legislative interventions such as the Punjab and Haryana Preservation of Subsoil Water Acts, 2009 — and argues that this framework remains fragmented, under-enforced and structurally incapable of delinking land ownership from groundwater extraction rights. The analysis further reveals an emerging co-occurrence of depletion and geogenic contamination, with over 60% of groundwater samples in Punjab exceeding safe uranium limits as per the CGWB Annual Ground Water Quality Report, 2025.

The paper concludes that resolving the crisis requires a tripartite reform combining geographical water-budgeting, rationalised power-agriculture subsidies, and a codified national groundwater statute grounded explicitly in the public trust doctrine and the right to water under Article 21 of the Constitution. Policy recommendations include crop diversification incentives, volumetric water pricing, strengthened Atal Bhujal Yojana implementation, and judicial recognition of groundwater as a res communis resource held in trust for present and future generations.

Keywords: Groundwater depletion; agricultural intensification; North India; public trust doctrine; Green Revolution; water law; Central Ground Water Board; Article 21; Punjab and Haryana Preservation of Subsoil Water Acts, 2009; sustainable irrigation.

INTRODUCTION

North India's Indo-Gangetic plain — comprising Punjab, Haryana, western Uttar Pradesh, Rajasthan and the National Capital Territory of Delhi — constitutes the physiographic and agronomic core of India's post-1960s food security architecture. The introduction of high-yielding variety (HYV) seeds, chemical fertilisers and assured procurement under the Green Revolution transformed this semi-arid alluvial tract into the nation's principal rice and wheat bowl. This transformation, however, was purchased at the cost of a hydrological resource whose renewal rate is fundamentally incommensurate with the pace of its extraction: groundwater. A National Geophysical Research Institute (NGRI) study estimates that approximately 450 cubic kilometres of groundwater was lost across northern India between 2002 and 2021, a rate of depletion that satellite gravimetric (GRACE) data situate among the most severe globally.

The geographical dimension of this crisis is critical: the depletion is not uniform but spatially concentrated in the rice-wheat cropping belt, where paddy cultivation — a water-intensive crop poorly suited to the region's natural aridity — has been incentivised by public procurement policy irrespective of agro-climatic rationality.[1]

This paper adopts a geo-legal methodology, combining spatial and statistical assessment of groundwater resource data with doctrinal analysis of the constitutional, statutory and judicial framework governing groundwater rights in India. Part II reviews the existing literature on groundwater depletion and law. Part III presents an analysis of the physical and policy drivers of depletion, supported by original data visualisations. Part IV sets out empirical and doctrinal findings. Part V offers recommendations, and Part VI concludes.

LITERATURE REVIEW

Existing scholarship on Indian groundwater law identifies the colonial-era linkage between land ownership and water rights, codified in Section 7, Illustration (g) of the Indian Easements Act, 1882, as the principal structural impediment to sustainable regulation.[2] This doctrine permits a landowner to extract groundwater beneath the land without meaningful reference to aquifer-level sustainability, a position scholars argue is incompatible with the physical reality that aquifers are shared, common-pool resources that do not respect cadastral boundaries.

Cullet situates India's water law reforms within a broader failure of the 1987 and 2002 National Water Policies to translate rhetorical commitments to conservation into enforceable entitlement structures, arguing that policy documents lacking statutory force cannot discipline politically entrenched free-power regimes.[3]

Naik advances the doctrinal argument that the public trust doctrine — applied by Indian courts to rivers, lakes and coastal zones since M.C. Mehta v. Kamal Nath — has not been consistently extended to groundwater, notwithstanding its logical applicability to a resource whose depletion imperils the Article 21 right to water for present and future generations.[4]

Geographically oriented studies, notably Sidhu, Sharda and Singh's spatio-temporal assessment of Punjab, quantify the depletion using district-level water-table data, finding an average decline of 8.91 metres between 2000 and 2019, with the proportion of the state's area exceeding a 10-metre depth-to-water-table rising from approximately 30% to over 75% during the same period.[5] Their study specifically evaluates the impact of the Punjab Preservation of Subsoil Water Act, 2009, concluding that while the statute has delayed the onset of the monsoon-season pumping period, it has not arrested the underlying volumetric decline because it addresses the timing rather than the quantum of extraction.

Recent policy literature from the South Asia Network on Dams, Rivers and People (SANDRP) documents the continuing underutilisation of Atal Bhujal Yojana funds and links subsidised electricity directly to unsustainable withdrawal patterns in Punjab and Haryana, while parallel CGWB water-quality reporting establishes a growing co-occurrence between depletion and geogenic contamination by uranium and fluoride.[6]

Taken together, the literature reveals three under-integrated strands: (a) hydrogeological and remote-sensing assessments quantifying depletion; (b) doctrinal legal scholarship on the public trust doctrine and land-water nexus; and (c) policy evaluation of subsidy-driven extraction incentives. This paper contributes to the literature by explicitly triangulating these three strands within a single geo-legal framework specific to North India.

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[1] V.M. Tiwari et al., "Groundwater Depletion in the Indo-Gangetic Plain," National Geophysical Research Institute Study, reported in The Deccan Herald (2024).

[2] The Indian Easements Act, 1882, s. 7, illustration (g), historically treating groundwater as an appurtenance of land ownership.

[3] Philippe Cullet, Water Law, Poverty and Development: Water Sector Reforms in India (Oxford University Press, 2009), Ch. 4.

[4] Gayathri D. Naik, "Groundwater Regulation in India: Applicability of Public Trust Doctrine and Right to Participation in Decision Making to Achieve Right to Water," SSRN Working Paper (2019).

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ANALYSIS AND DISCUSSION

A. The Physical and Agronomic Drivers of Depletion

The Central Ground Water Board's Dynamic Ground Water Resources of India, 2023 report records the Stage of Groundwater Extraction (SoE) — the ratio of annual extraction to annual extractable recharge — at 163.76% for Punjab and 135.74% for Haryana, against an all-India average of 59.26%.[7] In Haryana, annual extractable groundwater stood at 8.69 billion cubic metres (BCM) against actual extraction of 11.8 BCM in 2023; in Punjab, extractable recharge of 16.98 BCM was set against extraction of 27.8 BCM. Rajasthan's SoE of 148.77% reflects a comparable, if geographically distinct, over-exploitation pattern rooted in solar-subsidised pumping rather than paddy cultivation.

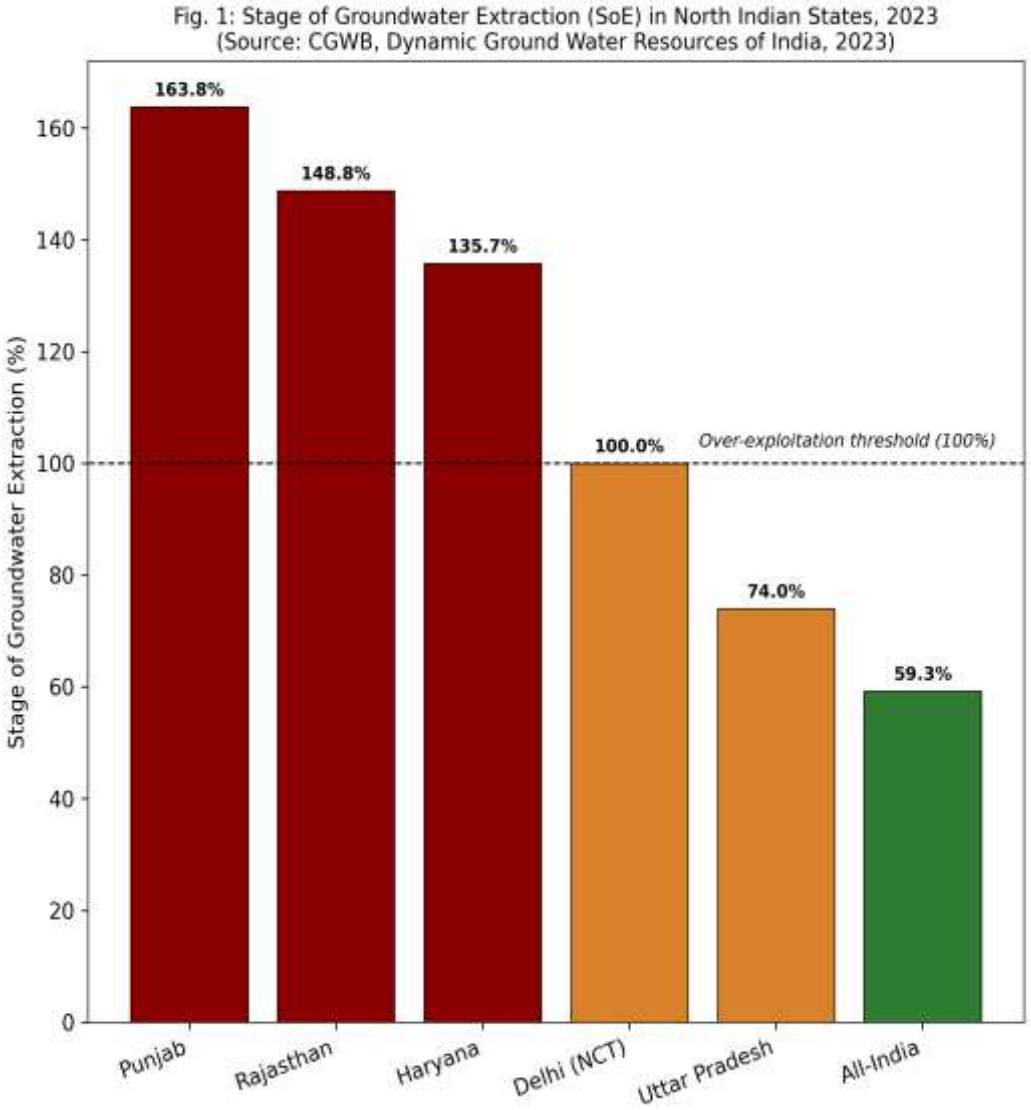


Fig. 1: Stage of Groundwater Extraction (SoE) in North Indian States, 2023 (Source: CGWB, Dynamic Ground Water Resources of India, 2023).

Approximately 87% of India's total groundwater extraction is deployed for irrigation, a proportion still higher in the paddy-wheat belt where the rice crop alone accounts for roughly 73% of irrigation water demand in Punjab.[8] This sectoral concentration is depicted in Figure 3 below and underscores that the crisis is fundamentally agronomic rather than domestic or industrial in origin — a conclusion with direct implications for the design of legal remedies, which must operate primarily through agricultural regulation rather than urban water-supply law.

[7] Central Ground Water Board, Dynamic Ground Water Resources of India, 2023 (Ministry of Jal Shakti, Government of India, 2024).

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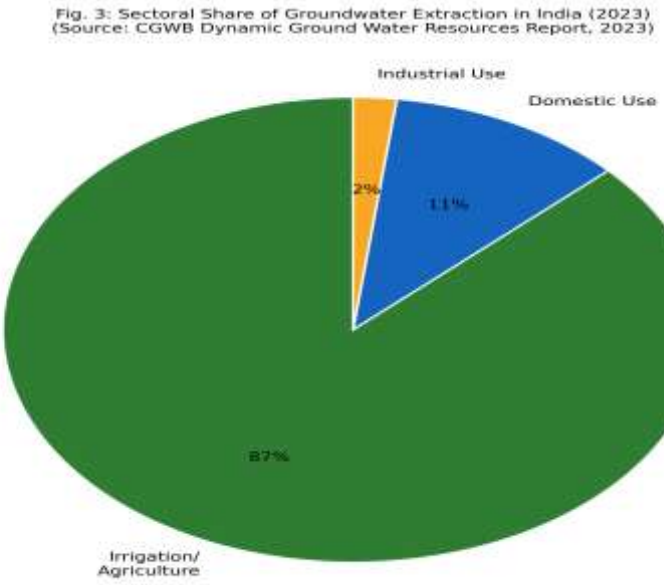


Fig. 2: Sectoral Share of Groundwater Extraction in India, 2023 (Source: CGWB Dynamic Ground Water Resources Report, 2023).

B. Spatio-Temporal Depletion Trends: The Punjab Case

The district-level assessment by Sidhu, Sharda and Singh offers the most granular geographical account of the depletion trajectory. Between 2000 and 2019, the average decline in Punjab's water table was 8.91 metres, with the worst-affected district, Barnala, recording a decline of 20.38 metres.[9] The proportion of the state's geographical area with a depth-to-water-table exceeding 10 metres rose from roughly 30% in 2000 to more than 75% by 2019 — evidence of the formation of regional cones of depression sufficiently severe to reverse the natural direction of groundwater flow in parts of the central and Malwa regions.

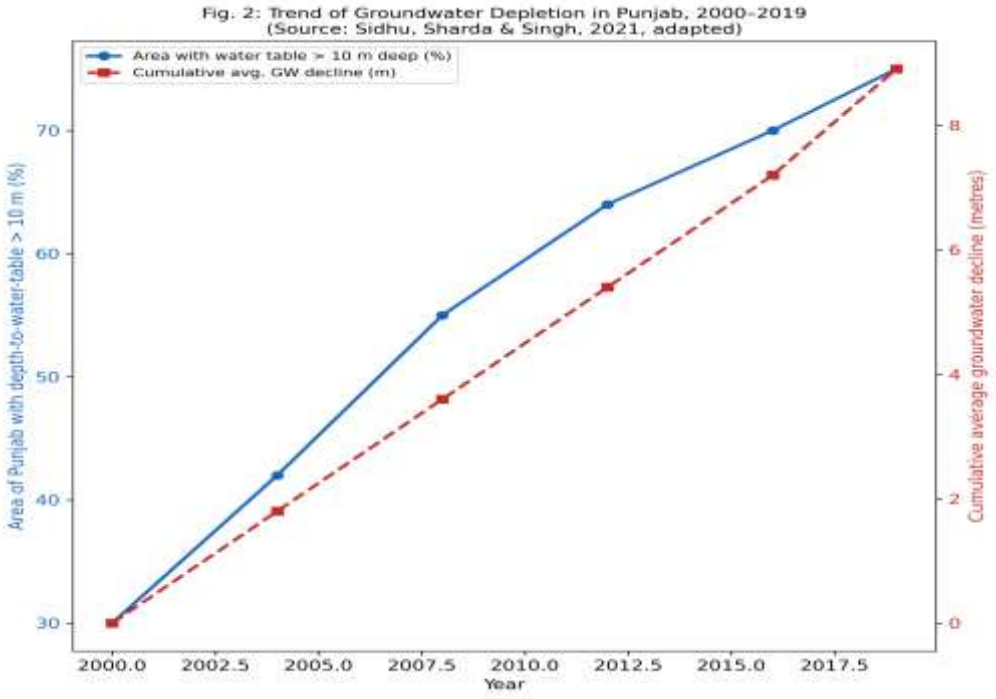


Fig. 3: Trend of Groundwater Depletion in Punjab, 2000–2019 (Source: Sidhu, Sharda & Singh, 2021, adapted by the author).

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C. Legal and Policy Architecture Governing Groundwater

Groundwater is not the subject of a dedicated central legislation. Constitutionally, "water" falls within Entry 17 of the State List, read with Entry 14 ("Agriculture"), placing primary regulatory competence with the States.[10] The consequence is a fragmented statutory landscape in which the Union has confined itself to advisory instruments — most notably the Model Bill for the Conservation, Protection, Regulation and Management of Groundwater, 2016 — that States remain free to adopt, modify or ignore.

The residual common-law position, inherited from Section 7, Illustration (g) of the Indian Easements Act, 1882, treats groundwater as an incident of land ownership, permitting a landowner unrestricted extraction beneath his own land.[11] This doctrine has been substantially — though not completely — displaced by judicial recognition of the public trust doctrine. In M.C. Mehta v. Kamal Nath, the Supreme Court held that certain natural resources are held by the State as trustee for public use, a principle subsequently extended to sub-soil water in State of West Bengal v. Kesoram Industries Ltd., where the Court held that "deep underground water belongs to the State in the sense that the doctrine of public trust extends thereto" and that a landholder possesses only a right of user, not ownership.

The most celebrated application of the doctrine to groundwater arose in Perumatty Grama Panchayat v. State of Kerala, where the Kerala High Court restrained Hindustan Coca-Cola Beverages Pvt. Ltd. from extracting groundwater in excess of sustainable limits at its Plachimada facility, holding that no one may claim ownership of groundwater merely by virtue of land ownership and that the State is duty-bound, as trustee, to protect groundwater on behalf of the general public.[12] The Court further held that State inaction against over-exploitation amounted to an infringement of the right to life under Article 21 of the Constitution.

On intra-court appeal, the Division Bench in Hindustan Coca-Cola Beverages (P) Ltd. v. Perumatty Grama Panchayat reversed the extraction ban and directed renewal of the company's licence, holding that the Panchayat lacked unilateral authority to revoke a validly granted licence absent a statutory framework prescribing extraction limits.[13] The matter reached the Supreme Court in subsequent civil appeals but was disposed of in 2017 without adjudication of the underlying public trust question, leaving the doctrinal status of groundwater ownership formally unresolved even as lower courts and the National Green Tribunal have continued to invoke the doctrine in analogous contexts, including in Susetha v. State of Tamil Nadu and Fomento Resorts and Hotels Ltd. v. Minguel Martins.

Against this doctrinally unsettled backdrop, Punjab and Haryana each enacted the Preservation of Subsoil Water Act, 2009, prohibiting the transplantation of paddy nurseries before a notified date (typically mid-June) so as to align the crop's peak water demand with the monsoon and thereby reduce pre-monsoon groundwater draft.[14] Empirical assessment, however, indicates that these statutes address only the temporal distribution of extraction and have not reduced its aggregate volume, since farmers compensate through deeper borewells and extended late-season pumping.

D. Contamination as a Compounding Consequence of Depletion

The CGWB's Annual Ground Water Quality Report, 2025, based on nearly 15,000 samples collected across pre- and post-monsoon seasons of 2024, finds that over 28% of samples nationally exceeded permissible limits for one or more parameters, with uranium contamination showing the sharpest geographical concentration in Punjab, Haryana, Delhi and Rajasthan.[15] In Punjab, 62.5% of post-monsoon samples exceeded the safe uranium limit of 30 parts per billion, up from 24.2% in 2019 — a near-threefold increase attributable in substantial part to declining water levels, which concentrate naturally occurring (geogenic) uranium salts within a shrinking aquifer volume, compounded by alkaline soil chemistry that promotes uranium dissolution.

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[10] Constitution of India, Seventh Schedule, List II (State List), Entry 17 (Water) read with Entry 14 (Agriculture); Article 246.

[11]

[12] Perumatty Grama Panchayat v. State of Kerala, (2003) SCC OnLine Ker 500; W.P. (C) No. 34292 of 2003 (Kerala High Court, 16 December 2003).

[13] Hindustan Coca-Cola Beverages (P) Ltd. v. Perumatty Grama Panchayat, (2005) 2 KLT 554 (Division Bench, Kerala High Court).

[14] The Punjab Preservation of Subsoil Water Act, 2009 (Punjab Act No. 3 of 2009).

[15] Central Ground Water Board, Annual Ground Water Quality Report, 2025 (Ministry of Jal Shakti, Government of India, 2025).

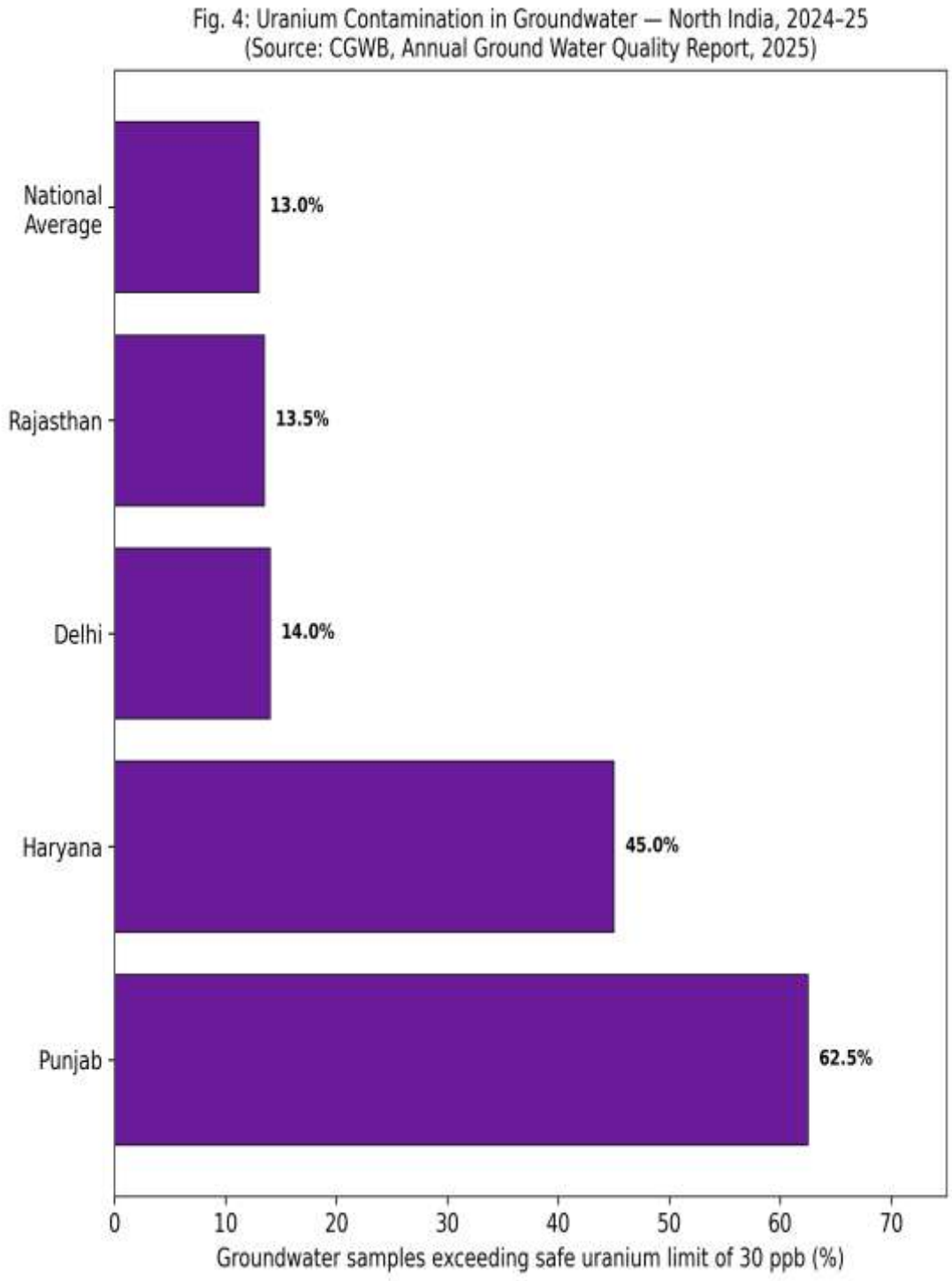


Fig. 4: Uranium Contamination in Groundwater — North India, 2024–25 (Source: CGWB, Annual Ground Water Quality Report, 2025).

This finding is of independent legal significance: geogenic contamination triggered or accelerated by anthropogenic over-extraction may constitute an actionable violation of the right to safe drinking water under Article 21, and arguably strengthens the case for treating groundwater quantity regulation and groundwater quality protection as a single, integrated regulatory object rather than the current bifurcated approach under separate pollution-control and water-resource statutes.

E. A Conceptual Framework

The causal chain linking agricultural policy to groundwater depletion and its contamination feedback loop may be represented schematically as follows:

Fig. 5: Conceptual Framework — Agricultural Intensification and Groundwater Depletion

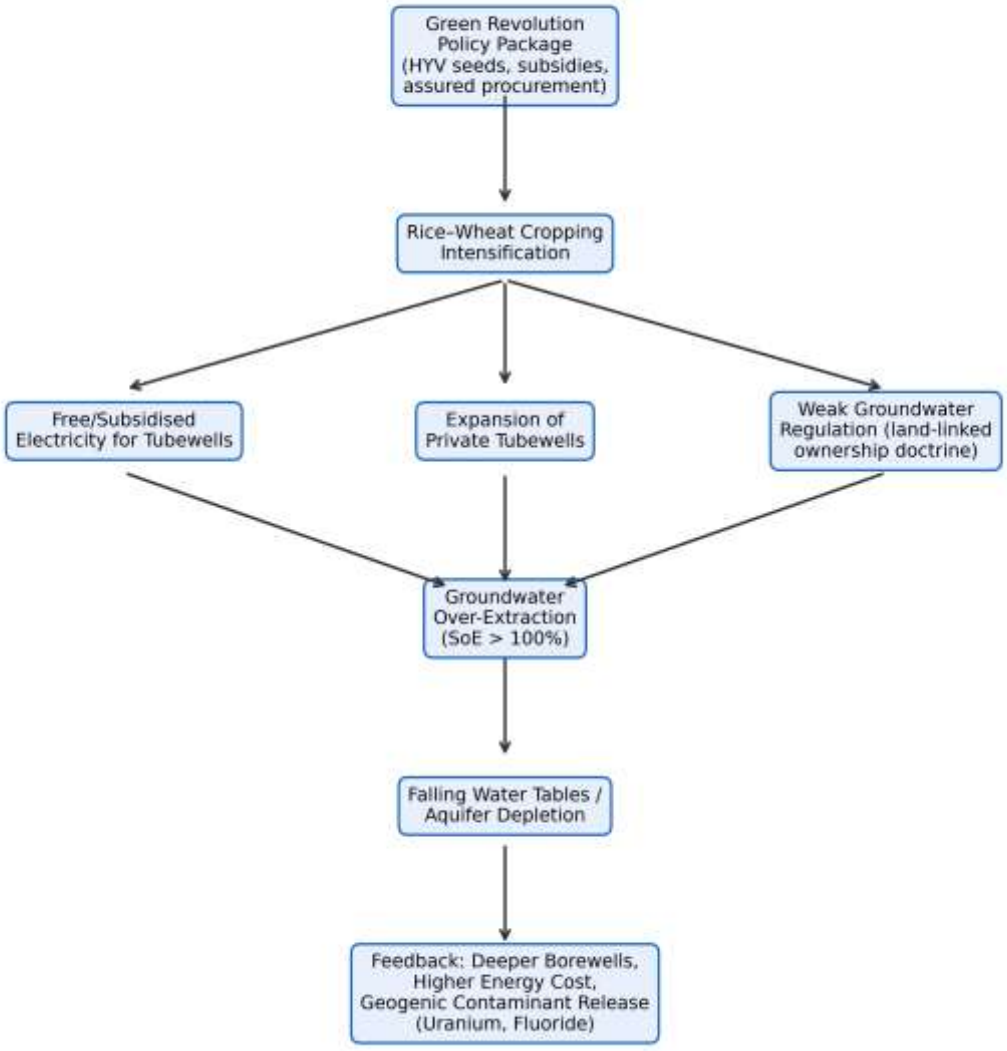


Fig. 5: Conceptual Framework — Agricultural Intensification and Groundwater Depletion (author's construction).

FINDINGS

1. The Stage of Groundwater Extraction in Punjab (163.76%) and Haryana (135.74%) places both States in the CGWB's "over-exploited" category, with extraction exceeding sustainable recharge by a margin that, on current trends, forecloses the possibility of tubewell-based irrigation within a projected horizon of one to two decades in the worst-affected districts.

2. Approximately 87% of national groundwater draft is attributable to irrigation, confirming that the crisis is agronomically, not domestically or industrially, driven, and that legal remedies confined to municipal water supply regulation will not address the core problem.

3. District-level data for Punjab show the area experiencing a water table depth exceeding 10 metres rising from 30% (2000) to over 75% (2019), evidencing the formation of regional depression cones and localised reversal of natural groundwater flow.

4. The prevailing legal architecture — rooted in the land-ownership doctrine under the Indian Easements Act, 1882 — has been judicially qualified but not displaced by the public trust doctrine, whose application to groundwater remains formally unresolved following the Supreme Court's non-adjudication of the Perumatty/Coca-Cola litigation in 2017.

5. State-level legislative interventions (the Punjab and Haryana Preservation of Subsoil Water Acts, 2009) regulateonly the timing of paddy transplantation and have not been shown to reduce the aggregate volume of extraction.

6. Depletion and groundwater contamination are empirically co-occurring phenomena: Punjab's uranium contamination rate rose from 24.2% (2019) to 62.5% (2024) of post-monsoon samples, indicating that over-extraction is compounding a public-health dimension of the crisis.

7. Subsidised electricity for agricultural tubewells operates as the principal proximate economic driver sustaining unsustainable extraction, and remains politically resistant to volumetric pricing reform in both Punjab and Haryana.

RECOMMENDATIONS

1. Enactment of a National Groundwater Regulation Statute: Parliament should, invoking Article 252 or through State adoption of a strengthened Model Groundwater Bill, enact a uniform statute explicitly codifying groundwater as a resource held by the State in public trust, thereby resolving the doctrinal uncertainty left open since Kesoram Industries and the Perumatty litigation.

2. Volumetric and Crop-Linked Power Pricing: Replace flat-rate free electricity for agricultural tubewells with a metered, slab-based tariff structure linked to crop-water budgets, insulated by targeted direct income transfers to protect smallholder farmers from adverse livelihood impacts.

3. CropDiversification Incentives: Redesign minimum support price and procurement policy to incentivise a shift from paddy to less water-intensive crops (maize, pulses, oilseeds) in the central Punjab and Haryana rice belt, building on but substantially expanding existing diversification schemes.

4. Strengthening Atal Bhujal Yojana: Address documented fund underutilisation and weak community mobilisation by decentralising implementation to Gram Panchayat-level water budgeting committees with statutory (not merely administrative) authority over local extraction limits.

5. Integrated Quantity-Quality Regulation: Amend groundwater and pollution-control statutes to require joint quantity-quality monitoring, given the demonstrated link between depletion and geogenic uranium/fluoride contamination.

6. Judicial Clarification: The Supreme Court should, in an appropriate future proceeding, conclusively resolve the applicability of the public trust doctrine to groundwater left open since 2017, providing binding precedent to guide State legislative and executive action.

7. Geographical Water-Budgeting: Mandate CGWB and State Ground Water Departments to publish sub-district (block-level) water budgets annually, with extraction permits calibrated to local, rather than state-average, recharge rates.

CONCLUSION

The groundwater crisis in North India is best understood not as an isolated hydrogeological phenomenon but as the cumulative legal and geographical consequence of a policy architecture that has, for over five decades, prioritised food-grain output over resource sustainability. The World Bank's projection that 60% of India's groundwater blocks would reach a critical condition by 2025 has, on the evidence reviewed in this paper, already materialised in Punjab, Haryana and Rajasthan.[16] Existing law — anchored in a colonial land-ownership doctrine only partially and inconsistently displaced by the judicially evolved public trust doctrine — has proved structurally inadequate to the task of aquifer-level regulation. A durable resolution demands the convergence of geographical water-budgeting, agricultural subsidy reform, and a codified, constitutionally grounded groundwater statute that treats the aquifer, rather than the individual landholding, as the fundamental unit of legal regulation. Absent such convergence, the food bowl of India risks becoming, within a generation, a cautionary geography of its own making.

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