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Groundwater Depletion and its Spatial Impact on Agricultural Sustainability in North India: A Socio-Legal and Policy Analysis

Manju

mahlawat320@gmail.com

ABSTRACT

Groundwater is the backbone of irrigated agriculture across North India, sustaining the wheat-paddy cropping system that anchors national food security. Yet decades of intensive extraction, subsidised electricity for tubewells, and a legal architecture rooted in the colonial land-ownership model have combined to produce a governance failure of continental proportions.

This paper undertakes an interdisciplinary, spatially-oriented socio-legal analysis of groundwater depletion in the Indo-Gangetic belt, with particular reference to Punjab, Haryana, western Uttar Pradesh, Rajasthan and the National Capital Territory of Delhi. Drawing upon Central Ground Water Board (CGWB) assessments, judicial pronouncements, and comparative statutory frameworks, the paper argues that the persistence of the Indian Easements Act, 1882 as the default rule of groundwater entitlement has entrenched an open-access regime incompatible with the physical reality of a shared, migratory resource.

The doctrinal analysis traces the evolution of groundwater jurisprudence from an absolute-ownership paradigm to the public trust doctrine articulated in M.C. Mehta v Kamal Nath, and evaluates the patchwork of State legislation enacted pursuant to the Model Bill for the Conservation, Protection and Regulation of Groundwater, 2016/2017.

The paper further maps the spatial correlation between the stage of groundwater extraction, cropping patterns skewed towards water-intensive paddy and sugarcane, and indicators of farmer distress, using data visualisations to render the scale of overexploitation intelligible. Findings indicate that over-extraction in Punjab exceeds 160 per cent of annual recharge, that nineteen of twenty-three Punjab districts are now classified as 'dark zones', and that contamination by geogenic uranium and fluoride is compounding the depletion crisis.

The paper concludes that agricultural sustainability in North India cannot be secured without a re-conceptualisation of groundwater as a common pool resource held in public trust, supported by crop diversification incentives, rationalised power subsidies, aquifer-specific regulation, and robust community-based governance under the Atal Bhujal Yojana framework. Legal, economic and hydrological interventions must proceed in tandem if the region's aquifers are to be rejuvenated within a generation.

Keywords: Groundwater Depletion; Agricultural Sustainability; North India; Public Trust Doctrine; Indian Easements Act 1882; Water Governance; Atal Bhujal Yojana; Spatial Analysis; Punjab; CGWB.

INTRODUCTION

Groundwater constitutes the invisible foundation of India's agrarian economy. It irrigates approximately 87 per cent of net irrigated area in parts of the north-western plains and supplies over 80 per cent of rural drinking water needs[1].

[1]Central Ground Water Board, Annual Ground Water Quality Report 2025 (Ministry of Jal Shakti, Government of India, 2025) 12; see also Sanskriti IAS, 'CGWB Annual Groundwater Quality Report 2025' (2025)

Unlike surface water, groundwater is largely unseen, unmetered and, until recently, virtually unregulated, having been governed for over a century by a legal fiction that ties its ownership to the ownership of overlying land.

The North Indian states of Punjab, Haryana, Rajasthan, western Uttar Pradesh and the National Capital Territory of Delhi together form the epicentre of India's groundwater crisis. The Green Revolution of the 1960s and 1970s, while transforming India from a food-deficit to a food-surplus nation, embedded a wheat-paddy rotation that is fundamentally unsuited to the region's semi-arid hydrology[2]. Free or heavily subsidised electricity for agricultural tubewells removed any price signal that might otherwise have curbed extraction, and the result, four decades on, is that Punjab now draws over 164 per cent of its annual replenishable groundwater recharge, with nineteen of its twenty-three districts classified as 'over-exploited' or 'dark zone'[3].

This paper adopts a socio-legal and spatial methodology to interrogate three interlocking questions: first, how has Indian law historically conceived of rights over groundwater, and to what extent has that conception contributed to over-extraction; second, what is the spatial and quantitative scale of depletion across North India, and how does it correlate with agricultural cropping patterns; and third, what legal, regulatory and policy reforms are required to reconcile agricultural livelihoods with hydrological sustainability. The paper is structured as follows: Part II reviews the existing legal and scientific literature; Part III presents an analysis of spatial and statutory data, supported by original data visualisations; Part IV sets out key findings; Part V offers recommendations; and Part VI concludes.

LITERATURE REVIEW

2.1 The Doctrinal Foundation: Groundwater as an Incident of Land Ownership

Indian groundwater law traces its origins to the common law rule imported through the Indian Easements Act, 1882[4], section 7 of which recognises 'the right of every owner of land to collect and dispose within his own limits of all water under the land which does not pass in a defined channel'. Vani has described this as an 'absolute ownership' rule that treats percolating groundwater as indistinguishable from any other chattel located on the land[5]. The rule was borrowed from nineteenth-century English case law that predates any scientific understanding of aquifer hydrology, and it has never been squarely reconsidered by the legislature notwithstanding the demonstrable inter-connectedness of groundwater across landholdings.

2.2 The Public Trust Doctrine and Constitutional Reframing

The jurisprudential turn away from absolute ownership began with M.C. Mehta v Kamal Nath, where the Supreme Court held that natural resources, including water, are held by the State as trustee for the benefit of the public and cannot be diverted for private use to the detriment of the public interest[6].

The Court subsequently extended the doctrine in M.I. Builders Pvt Ltd v Radhey Shyam Sahu, tying it directly to the fundamental right to life under Article 21 of the Constitution[7]. Commentators have noted that the doctrine, while doctrinally powerful, has had limited effect on groundwater specifically because primary legislation continues to route entitlement through the Easements Act[8]. The Kerala High Court's decision in Perumatty Grama Panchayat v State of

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<https://www.sanskritiias.com/current-affairs/central-ground-water-board-cgwb-annual-groundwater-quality-report-2025> accessed 20 August 2026.

[2]M.S. Vani, 'Groundwater Law in India: A New Approach' in Ramaswamy Iyer (ed), Water and the Laws in India (Sage 2009) 435, 444.

[3]South Asia Network on Dams, Rivers and People (SANDRP), 'Groundwater: Rising Depletion and Contamination in 2025 in India' (25 March 2026) <https://sandrp.in/2026/03/25/groundwater-2025-depletion-and-contamination-rising/> accessed 20 August 2026; statement of Satnam Singh Sandhu, Member of Parliament, Rajya Sabha (9 March 2026).

[4]Indian Easements Act 1882, s 7, illus (g)-(h).

[5]M.S. Vani (n 2) 444; see also Chhatrapati Singh, Water Rights and Principles of Water Resources Management (Tripathi 1991) 76.

[6]M.C. Mehta v Kamal Nath (1997) 1 SCC 388 (SC), para 34.

[7]M.I. Builders Pvt Ltd v Radhey Shyam Sahu (1999) 6 SCC 464 (SC).

[8]TheLaw.Institute, 'Understanding the Spectrum of Water Rights in India' (25 February 2026) <https://thelaw.institute/rural-local-self-governance/water-rights-spectrum-india/> accessed 20 August 2026.

Kerala (the Plachimada case) is frequently cited for its holding that groundwater is a public trust resource that the State is bound to protect against over-extraction by private industry[9].

2.3 Statutory and Institutional Responses

Institutionally, the Central Ground Water Board was constituted in 1970 and subsequently designated as the Central Ground Water Authority under section 3(3) of the Environment (Protection) Act, 1986, empowering it to regulate groundwater withdrawal in notified areas[10]. At the State level, legislative responses have been uneven. Tamil Nadu enacted the Tamil Nadu Groundwater (Development and Management) Act, 2003, while Punjab's response has been narrower in scope: the Punjab Preservation of Subsoil Water Act, 2009 regulates only the timing of paddy transplantation to reduce pre-monsoon pumping, leaving the underlying extraction entitlement untouched[11].

At the Union level, the Ministry of Jal Shakti circulated a Model Bill for the Conservation, Protection, Regulation and Management of Groundwater, 2016 (revised 2017) for adoption by States, explicitly recasting groundwater as a common heritage resource held in public trust; as of 2026, however, adoption remains partial and enforcement weak[12].

2.4 Scientific and Hydrological Literature

Remote-sensing studies using NASA's GRACE satellite mission have quantified the scale of the crisis: Rodell and others documented rapid groundwater depletion in the north-western Indo-Gangetic basin as early as 2009, and subsequent studies by the National Geophysical Research Institute estimate that approximately 450 cubic kilometres of groundwater were lost across northern India between 2002 and 2021[13].

The CGWB's National Compilation on Dynamic Ground Water Resources of India, 2024 records total annual recharge of 446.90 BCM against an annual extraction of 245.64 BCM nationally, translating into a headline national extraction ratio of 60.4 per cent — a figure that masks acute regional disparity, given that several North Indian districts individually exceed 150-170 per cent[14]. The Annual Ground Water Quality Report 2025 additionally documents rising geogenic uranium and fluoride contamination, itself partly attributable to deep drilling induced by depletion, with 62.5 per cent of post-monsoon samples in Punjab exceeding the safe uranium threshold of 30 parts per billion[15].

ANALYSIS AND DISCUSSION

3.1 Spatial Scale of Over-Extraction

The spatial distribution of groundwater stress in North India is not uniform; it is concentrated in a well-defined belt running from Punjab through Haryana, western Uttar Pradesh, and parts of Rajasthan, with Delhi presenting an acute urban variant of the same crisis. Figure 1 below presents the CGWB's Stage of Groundwater Extraction (SoE) for the region's principal States, benchmarked against the national average and the 100 per cent recharge ceiling beyond which extraction is definitionally unsustainable.

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[9] Perumatty Grama Panchayat v State of Kerala 2004 (1) KLT 731 (Ker HC); affirmed in relevant part, Hindustan Coca-Cola Beverages (P) Ltd v Perumatty Grama Panchayat 2005 (2) KLT 554 (Ker HC, DB).

[10] Environment (Protection) Act 1986, s 3(3); Notification No S.O. 3510(E) constituting the Central Ground Water Authority (14 December 2018 re-constitution).

[11] Punjab Preservation of Subsoil Water Act 2009 (Punjab Act No 3 of 2009), s 4; see critique in Policy Advisory and Network for Joint Progress (PANJ), 'Punjab's Ailing Groundwater Governance' (24 March 2025) <https://www.panj.org.in/punjabs-ailing-groundwater-governance/> accessed 20 August 2026.

[12] Ministry of Jal Shakti, Model Bill for the Conservation, Protection, Regulation and Management of Groundwater, 2017 (Government of India); WRI India, 'Groundwater Regulation: A Challenge to Make the Invisible Visible in India' (2022) <https://wri-india.org/blog/groundwater-regulation-challenge-make-invisible-visible-india> accessed 20 August 2026.

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[14] Press Information Bureau, 'India's Groundwater Revival' (Ministry of Jal Shakti, 6 January 2025) <https://www.pib.gov.in/PressReleasePage.aspx?PRID=2090573> accessed 20 August 2026.

[15] SANDRP (n 3); Central Ground Water Board, Annual Ground Water Quality Report 2025 (n 1) fig 26, 49.

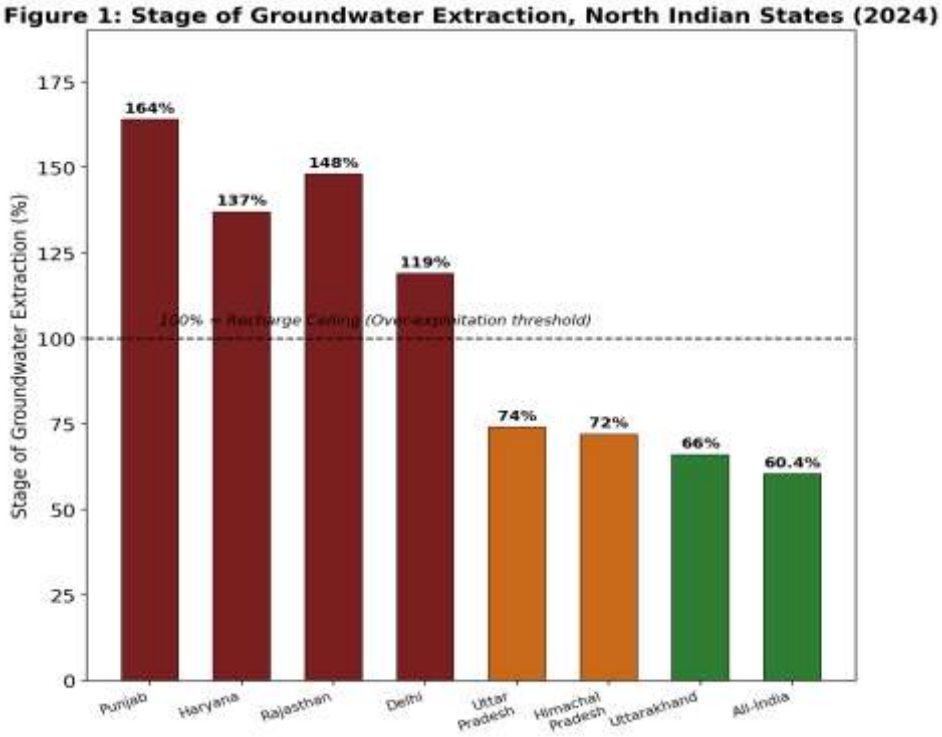


Figure 1: Stage of Groundwater Extraction, North Indian States, 2024 Assessment (Source: compiled from CGWB Dynamic Ground Water Resources Assessment 2024 and PIB press release dated 6 January 2025)

As Figure 1 demonstrates, Punjab, Haryana and Rajasthan all draw substantially in excess of their annual recharge, placing them in the CGWB's 'over-exploited' category, while Delhi's extraction ratio, though numerically lower than Punjab's, is driven overwhelmingly by urban and peri-urban demand rather than agriculture. Himachal Pradesh and Uttarakhand, by contrast, remain within sustainable limits, illustrating that the crisis is a function of specific agro-climatic and cropping choices rather than an inevitable feature of the wider Himalayan foothill region.

3.2 Temporal Trajectory of Depletion

Cross-sectional data alone understates the severity of the problem; the temporal trend is equally instructive. Figure 2 presents an illustrative reconstruction of the deepening of the water table across four decadal monitoring points, drawing on CGWB well-monitoring data and the trend directions reported in successive Dynamic Ground Water Resources Assessments.

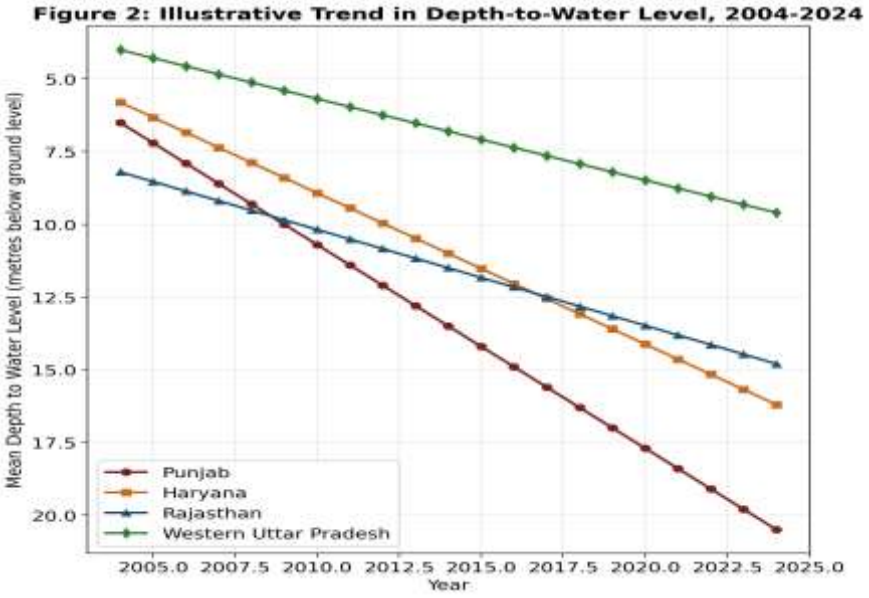


Figure 2: Illustrative Trend in Mean Depth-to-Water Level, Select North Indian States, 2004-2024 (depths shown are illustrative reconstructions based on reported CGWB decadal trend directions)

The consistent downward trajectory (i.e., deepening water tables, shown here as increasing depth-to-water) across all four jurisdictions corroborates satellite-based GRACE estimates and CGWB well-monitoring data alike[16]. Notably, even years of above-normal monsoon rainfall in Rajasthan have failed to reverse the trend, which the SANDRP overview attributes to structural failures in recharge infrastructure and continued over-abstraction rather than rainfall deficit[17].

3.3 The National Water Balance in Regional Perspective

Figure 3 situates the regional crisis within the national aggregate water balance reported in the 2024 Dynamic Ground Water Resources Assessment.

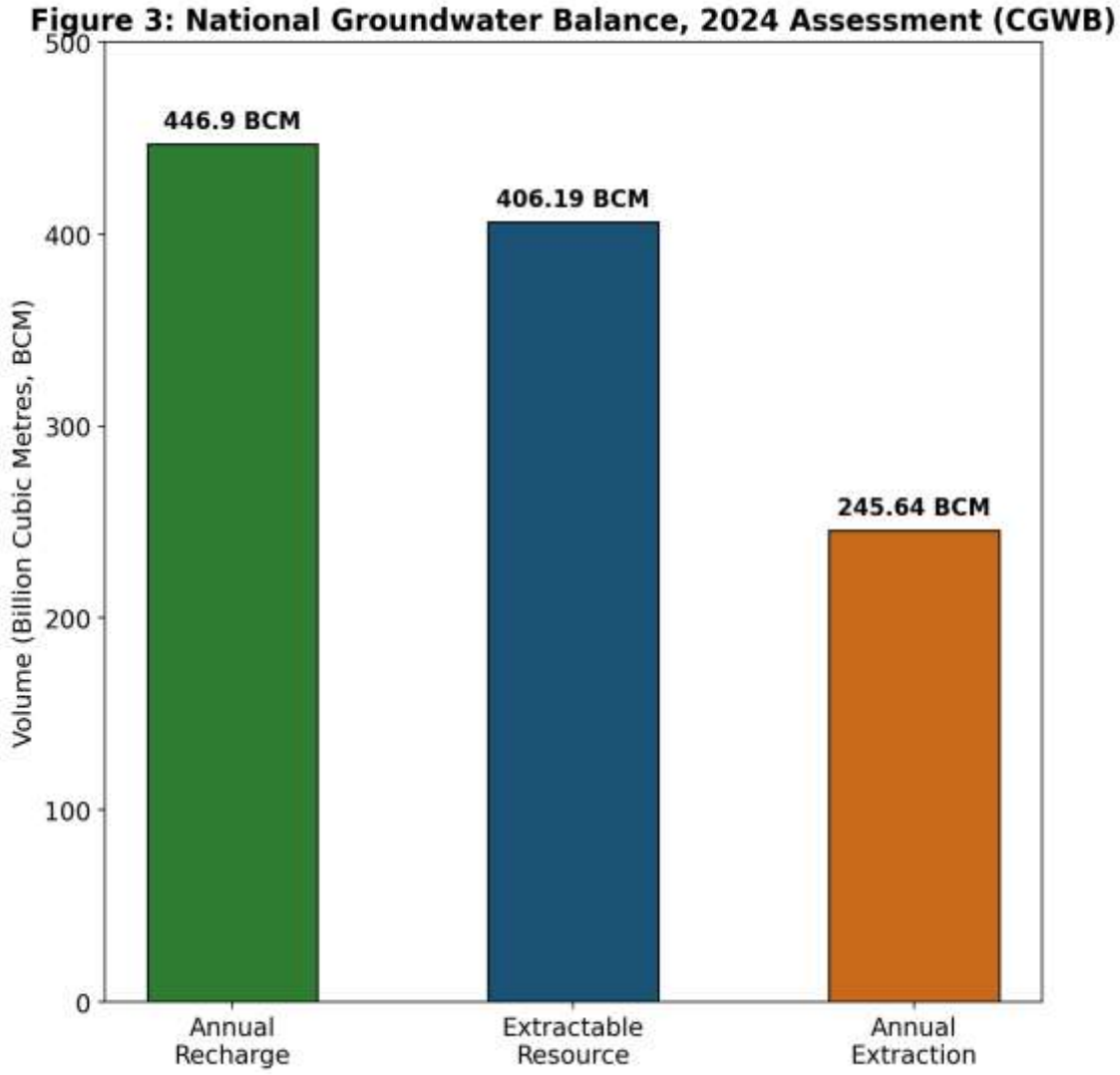


Figure 3: National Groundwater Balance — Recharge, Extractable Resource and Extraction, 2024 Assessment (Source: PIB, 'India's Groundwater Revival', 6 January 2025)

The comfortable national margin between recharge (446.90 BCM) and extraction (245.64 BCM) obscures the fact that this surplus is concentrated in the eastern and peninsular States; North-western India's aquifers are drawn down annually well beyond replenishment, meaning that the national figure is not merely academic but actively conceals a regional emergency.

3.4 Cropping Patterns and Water Footprint: The Agronomic Driver

The proximate agronomic cause of North Indian groundwater stress is the region's continued adherence to a paddy-wheat-sugarcane rotation, despite the acute mismatch between these crops' water requirements and the region's semi-arid rainfall regime. Figure 4 compares the approximate water footprint of the principal crops grown in the region.

[16] Rodell, Velicogna and Famiglietti (n 8).
[17] SANDRP (n 3).

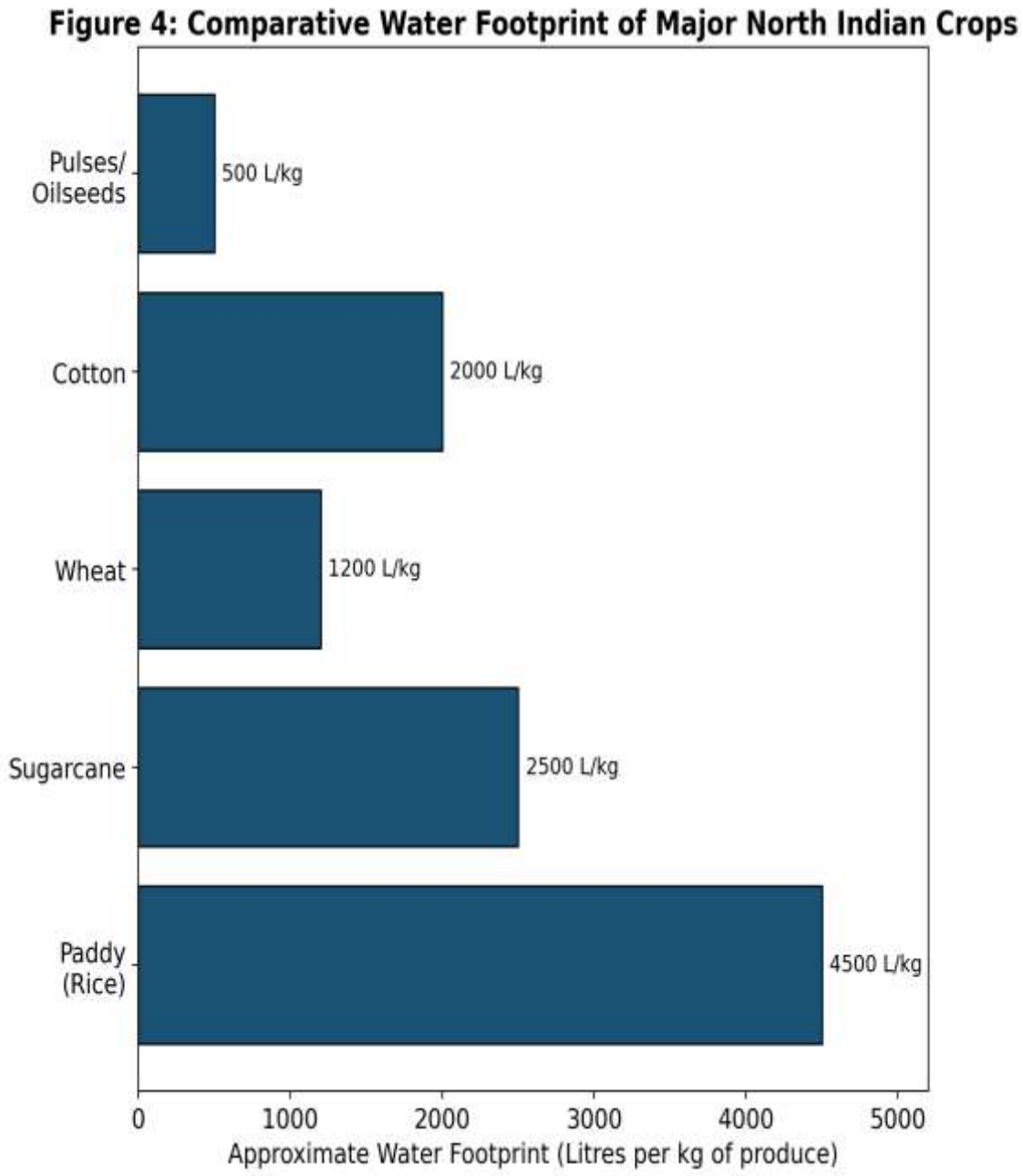


Figure 4: Comparative Water Footprint of Major North Indian Crops, Litres per Kilogram of Produce (Source: compiled from Central Water Commission and Ministry of Agriculture crop water-requirement norms)

Paddy alone requires approximately 4,500 litres of water per kilogram of milled rice produced, nearly four times the requirement of wheat, yet minimum support price policy and assured procurement have entrenched paddy cultivation even in the driest districts of Punjab and Haryana[18]. Subsidised or free agricultural electricity compounds the distortion: the SANDRP overview finds that districts with the highest rates of subsidised tubewell electricity consumption are also, without exception, among the most water-stressed and among the highest producers of paddy and wheat[19], establishing a self-reinforcing cycle in which the absence of a price signal for either electricity or water perpetuates the very cropping pattern responsible for depletion.

3.5 Contamination as a Compounding Spatial Harm

Depletion and contamination are not independent phenomena; deeper pumping mobilises geogenic contaminants such as uranium and fluoride that would otherwise remain sequestered in deeper aquifer strata. Figure 5 presents the two headline contamination and stress indicators reported in the CGWB's Annual Ground Water Quality Report 2025.

[18]SANDRP (n 3), discussing the correlation between subsidised electricity, paddy area and groundwater stress across Punjab and Haryana districts.
[19]ibid.

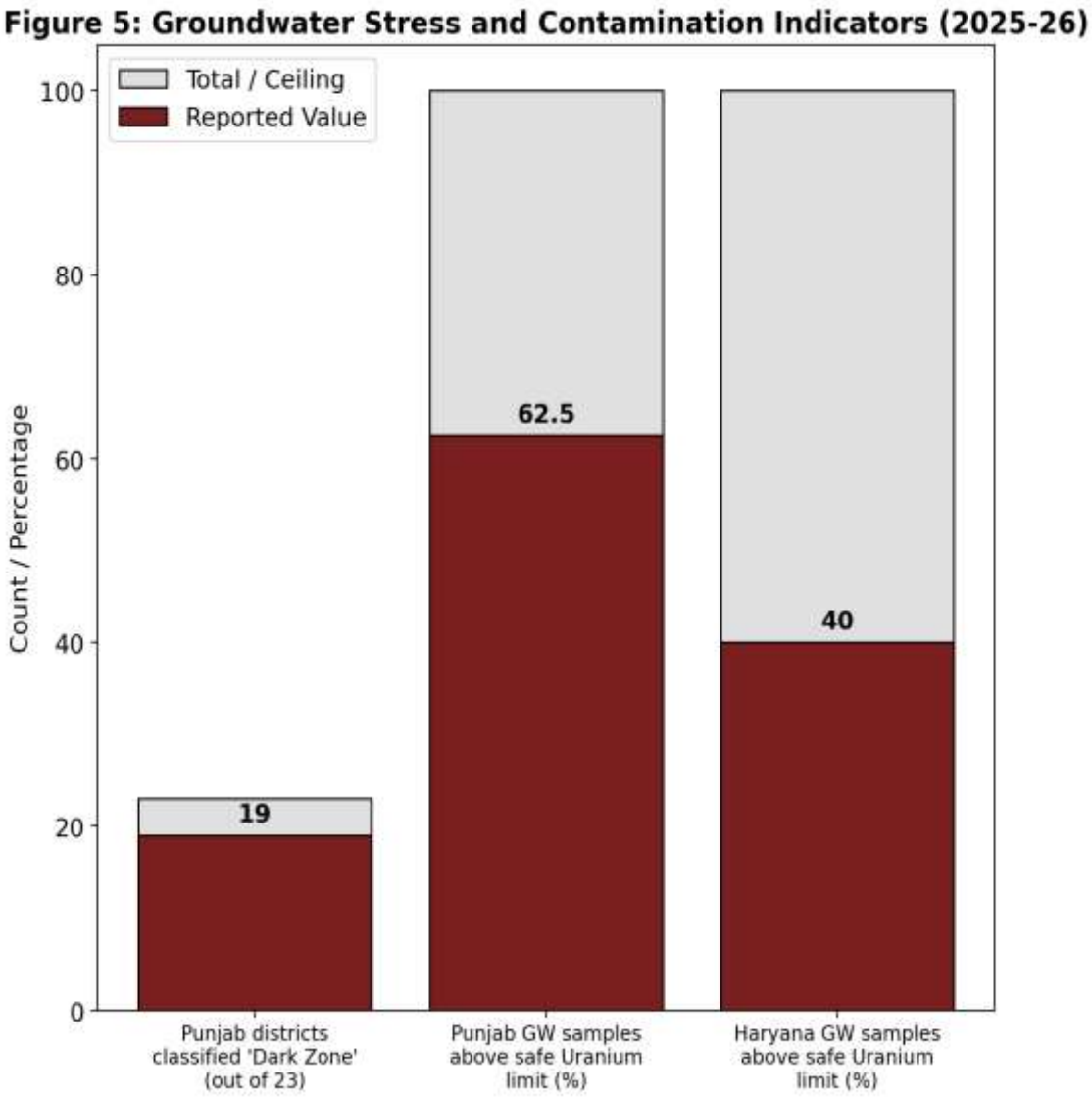


Figure 5: Groundwater Stress and Contamination Indicators, Punjab and Haryana, 2025-26 (Source: SANDRP, 'Groundwater: Rising Depletion and Contamination in 2025 in India', 25 March 2026; statement of MP Satnam Singh Sandhu, Rajya Sabha, 9 March 2026)

Nineteen of Punjab's twenty-three districts are now officially classified as 'dark zones', and 62.5 per cent of post-monsoon groundwater samples in the State exceed the safe uranium threshold — the highest contamination intensity recorded across India[20]. The compounding of quantitative depletion with qualitative contamination transforms what began as an irrigation-efficiency problem into a public health emergency implicating the right to safe drinking water under Article 21 of the Constitution, as recognised in Subhash Kumar v State of Bihar[21] and subsequently reaffirmed in the groundwater-specific context by the Kerala High Court in Perumatty Grama Panchayat (n 6).

3.6 Regulatory Response: Atal Bhujal Yojana and Its Limits

The Union Government's principal contemporary intervention is the Atal Bhujal Yojana (Atal Jal), a World Bank-supported, community-led scheme operative in over 8,220 gram panchayats across seven States, which conditions incentive funding on States and panchayats preparing and implementing water security plans[22]. While the scheme has produced localised improvements — the 2024 national compilation records improved groundwater conditions in 128 assessment units compared with 2023 — its demand-side, participatory design is not, on its own, a substitute for a

[20] SANDRP (n 3); statement of MP Satnam Singh Sandhu, Rajya Sabha (9 March 2026).

[21] Subhash Kumar v State of Bihar (1991) 1 SCC 598 (SC).

[22] Ministry of Jal Shakti, Atal Bhujal Yojana Scheme Guidelines (Department of Water Resources, River Development and Ganga Rejuvenation, revised 2024); Drishti IAS, 'Depletion in Groundwater Levels' (2025) <https://www.drishtiias.com/daily-updates/daily-news-analysis/depletion-in-groundwater-levels> accessed 20 August 2026.

binding entitlement regime; without amendment of the underlying property-rights framework inherited from the Easements Act, 1882, individual landowners retain an unconstrained legal liberty to extract, which community water-budgeting cannot override as a matter of enforceable law.

FINDINGS

1. Extraction substantially exceeds recharge across the North Indian agricultural belt: Punjab (approximately 164 per cent), Rajasthan (approximately 148 per cent) and Haryana (approximately 137 per cent) all draw groundwater at rates the CGWB classifies as unsustainable, against a national average of 60.4 per cent.

2. The legal framework remains anchored in the Indian Easements Act, 1882, which continues to determine primary entitlement notwithstanding the Supreme Court's adoption of the public trust doctrine in M.C. Mehta v Kamal Nath and its progeny; the resulting doctrinal dualism creates an enforcement gap that undermines regulatory intervention.

3. State-level legislative responses are fragmented and, where they exist (e.g., the Punjab Preservation of Subsoil Water Act, 2009), tend to regulate the timing rather than the volume of extraction, leaving the underlying open-access entitlement intact.

4. Depletion and water-quality deterioration are mutually reinforcing: deeper pumping induced by falling water tables is mobilising geogenic uranium and fluoride, with 62.5 per cent of post-monsoon Punjab samples exceeding safe uranium limits in 2025-26.

5. Cropping pattern, not aggregate rainfall, is the principal driver of regional stress: paddy's water footprint of approximately 4,500 litres per kilogram, sustained by assured procurement and subsidised electricity, perpetuates extraction even where rainfall is above normal.

6. Nineteen of twenty-three Punjab districts are now classified as 'dark zones', indicating that the crisis has moved from an emerging risk to an entrenched structural condition within a single generation.

7. Community-based interventions such as the Atal Bhujal Yojana show localised promise (128 assessment units improved nationally in 2024) but cannot, absent statutory reform of extraction entitlements, reverse the regional trajectory on their own.

RECOMMENDATIONS

1. Enact a Union groundwater framework law giving statutory force to the Model Bill for the Conservation, Protection, Regulation and Management of Groundwater, 2017, expressly displacing the Indian Easements Act, 1882 as the source of groundwater entitlement and codifying groundwater as a common pool resource held in public trust.

2. Introduce aquifer-specific (rather than administrative-boundary-based) regulatory units, using the National Aquifer Mapping (NAQUIM) data already generated by the CGWB, so that extraction permits and dark-zone restrictions track actual hydrogeological units.

3. Rationalise agricultural power subsidies through metering combined with a direct benefit transfer to farmers, decoupling the marginal cost of pumping from the marginal cost of electricity, informed by Punjab and Haryana's own dark-zone data.

4. Restructure minimum support price and procurement policy to incentivise diversification away from paddy toward less water-intensive crops (maize, pulses, oilseeds) in over-exploited districts, paired with assured markets to de-risk the transition for farmers.

5. Make rainwater harvesting and managed aquifer recharge structures mandatory for all new construction and industrial water users in notified over-exploited and critical assessment units, building on the Master Plan for Artificial Recharge to Groundwater, 2020.

6. Expand Atal Bhujal Yojana coverage and strengthen its legal teeth by empowering gram panchayat water security plans with binding, court-enforceable extraction ceilings rather than purely incentive-linked compliance.

7. Mandate integrated water-quality and water-quantity monitoring, including uranium and fluoride testing, at the same monitoring wells used for level assessment, so that contamination trends are read alongside depletion trends rather than in isolation.

8. Codify a justiciable right to sustainable groundwater access under Article 21, building on Subhash Kumar v State of Bihar and Perumatty Grama Panchayat v State of Kerala, to give affected agrarian communities a direct cause of action against both State inaction and private over-extraction.

CONCLUSION

Groundwater depletion in North India is simultaneously a hydrological, agronomic and legal phenomenon, and it cannot be resolved through engineering or policy intervention alone while the underlying entitlement regime continues to license unlimited private extraction. The spatial and statistical analysis presented in this paper demonstrates that the crisis is now structurally embedded across Punjab, Haryana, Rajasthan and western Uttar Pradesh, with contamination compounding depletion in ways that directly implicate the constitutional right to life and to safe drinking water. The judiciary's articulation of the public trust doctrine offers a normatively sound foundation for reform, but its practical effect has been blunted by the persistence of the Indian Easements Act, 1882 as the operative statutory rule. Legal reform, agricultural policy realignment and community-based water governance under schemes such as the Atal Bhujal Yojana must be pursued as complementary, not alternative, strategies. Absent such convergence, the wheat-paddy belt that has anchored India's food security since the Green Revolution risks becoming, within a generation, agriculturally unviable precisely because of the resource base on which that security was built.

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