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Review Article

One Health Approach to Rabies Elimination in India: Progress, Operational Bottlenecks, and Innovative Interventions

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Abstract:

Dog-mediated human rabies continues to be one of the most inequitably distributed vaccine-preventable zoonoses of our time, and India has historically carried a disproportionate share of this global burden. The launch of the National Action Plan for Rabies Elimination by 2030 (NAPRE 2030) marked a deliberate policy shift away from siloed, reactive, sector-specific responses toward an operationalised One Health framework that binds together human health authorities, veterinary and animal husbandry departments, urban local bodies, and forest and wildlife agencies under a common elimination target. This review synthesises the evolving epidemiological picture, the policy architecture of NAPRE 2030, the persistent ground-level operational bottlenecks that slow programme delivery, and the technological and biomedical innovations now reshaping the Indian rabies-control landscape. Importantly, this update incorporates the most recent nationally representative estimate of disease burden — a 2022–23 community-based decision-tree modelling survey that places annual human rabies mortality in India at approximately 5,726 deaths, a substantial downward revision from the long-cited figure of nearly 20,000 deaths, reflecting both genuine programmatic gains and improved epidemiological measurement. Ground-level constraints discussed include unmanaged free-roaming dog (FRD) demography sustained by open municipal solid waste, structural and financial limits on Animal Birth Control (ABC)/Catch-Neuter-Vaccinate-Release (CNVR) programmes, rural cold-chain fragility, chronic Rabies Immunoglobulin (RIG) supply deficits, and socio-culturally embedded delays in wound care. Against these constraints, the review evaluates a cluster of converging innovations — Oral Rabies Vaccination (ORV) sachets for catch-resistant dogs, recombinant human monoclonal antibodies (mAbs) progressively displacing serum-derived immunoglobulins, WHO-endorsed one-week intradermal (ID) dose-sparing post-exposure prophylaxis (PEP), digital and mobile spatial surveillance platforms, next-generation messenger RNA (mRNA) and self-amplifying RNA rabies vaccine candidates, and unmanned aerial vehicle (UAV)-assisted last-mile biologic delivery. Field-validated regional models from Goa and Sikkim are examined as proof of operational concept for the Indian socio-ecological setting. The review concludes with a set of strategic, resource-conscious recommendations — institutional, financial, and community-facing — necessary if India is to convert the stated ambition of NAPRE 2030 into a verified, internationally recognised elimination of dog-mediated human rabies.

Keywords: Rabies elimination; One Health; NAPRE 2030; Mass dog vaccination; Recombinant monoclonal antibodies; Oral rabies vaccination; Intradermal prophylaxis; mRNA vaccine; Digital surveillance; India

Introduction And The Changing Epidemiological Picture:

Rabies is an acute, invariably fatal encephalomyelitis caused by neurotropic, negative-sense single-stranded RNA viruses of the genus *Lyssavirus*, family *Rhabdoviridae* (Fooks et al., 2017). It remains almost entirely preventable through timely, correctly administered post-exposure prophylaxis (PEP) and through interruption of transmission at its animal source, yet it continues to exact a heavy toll on low- and middle-income countries (LMICs), where health-system access, veterinary infrastructure, and community awareness are frequently constrained. Globally, dog-mediated rabies is estimated to cause approximately 59,000–60,000 human deaths annually, with domestic and free-roaming dogs (*Canis lupus familiaris*) responsible for more than 99% of human exposures (Hampson et al., 2015; World Health Organization [WHO], 2018).

India has long been recognised as the single largest contributor to this global toll, and for over two decades the figure most frequently cited in the Indian and international literature was close to 20,000 human deaths annually, derived from a 2003 multicentre survey (Sudarshan et al., 2005) and corroborated by the nationally representative verbal-autopsy-based Million Death Study, which placed the estimate at 20,847 deaths per year, or roughly 2 deaths per 100,000 population (Suraweera et al., 2012). On the strength of these figures, India was long said to account for approximately 35–36% of the global rabies mortality burden (Chatterjee et al., 2016).

This picture has undergone a meaningful and encouraging revision. A large, nationally representative, community-based cross-sectional survey conducted across India in 2022–23, combined with probability decision-tree modelling, has produced a substantially lower estimate of 5,726 annual human rabies deaths, alongside detailed estimates of dog-bite incidence and PEP-seeking behaviour across states (Thangaraj et al., 2025). This is corroborated by an independent editorial synthesis placing the contemporary annual toll at “fewer than 6,000” deaths (Mani, 2025). Two points of scientific nuance deserve emphasis for the Indian reader. First, part of the apparent decline almost certainly reflects genuine programmatic gains — expanded PEP access, improved cell-culture vaccine (CCV) availability, and scaled mass dog vaccination (MDV) in several states — consistent with the trajectory documented in state-level elimination models (Gibson et al., 2022). Second, a meaningful part of the decline is attributable to methodological improvement: the 2022–23 survey used direct household-level case ascertainment and structured decision-tree modelling rather than the indirect verbal-autopsy extrapolations that underpinned earlier estimates, and is therefore not directly comparable in a naïve before–after sense (Thangaraj et al., 2025; Mani, 2025). Even with this substantial downward revision, India continues to account for approximately one-third of the world's dog-mediated rabies mortality, underscoring that the disease remains a public health priority of the first order even as absolute numbers fall (Figure 2).

The demographic distribution of risk has changed little even as absolute numbers have declined.

Rural populations, children under 15 years of age, and economically disadvantaged communities continue to bear a disproportionate share of animal-bite exposures and clinical rabies deaths, reflecting frequent unsupervised contact with free-roaming dogs, distance from tertiary referral care, and residual gaps in biologic availability at the primary-care level (Abbas et al., 2014; Gongal et al., 2022; Thangaraj et al., 2025). India's free-roaming and owned dog population remains very large by any estimate, with figures in the recent literature ranging from approximately 62 million to 90 million depending on survey methodology and the inclusion of owned versus unowned animals, implying an approximate dog-to-human ratio in the range of 1:15 to 1:23 in the most affected states (Mani, 2025; Mondal & Sudarshan, 2025).

Historically, India's rabies response suffered from acute inter-departmental fragmentation. Human health authorities concentrated almost exclusively on reactive case management — dispensing vaccines and immunoglobulins to bite victims — while municipal and veterinary bodies worked independently, and often with limited resources, on dog population management. This siloed model left the animal reservoir essentially unaddressed, permitting sustained viral circulation in both urban and rural canine populations (Menezes, 2010; Acharya et al., 2020). The recognition that clinical management of human cases, however excellent, cannot by itself interrupt a zoonotic transmission cycle has driven the shift toward an operationalised One Health paradigm, in which human, animal, and environmental health objectives are pursued jointly rather than sequentially.

Policy Framework and National Commitments: NAPRE 2030

In alignment with the global strategic plan “Zero by 30,” jointly formulated by the WHO, the World Organisation for Animal Health (WOAH), the Food and Agriculture Organization (FAO), and the Global Alliance for Rabies Control (GARC), the Government of India launched the National Action Plan for Rabies Elimination by 2030 (NAPRE 2030) in September 2021 under the joint stewardship of the Ministry of Health and Family Welfare (MoHFW) and the Department of Animal Husbandry and Dairying (DAHD) (MoHFW & DAHD, 2021). NAPRE 2030 was conceived explicitly to close the institutional gap that had historically separated human public health practice from veterinary and municipal dog-management functions (Figure 1).

The strategic architecture of NAPRE 2030 rests on three interlocking operational pillars:

- **Human Health Component:** universal availability of affordable, high-potency cell-culture vaccines (CCVs) and modern immunobiologicals (RIG or recombinant mAbs) at primary health centres (PHCs); complete national transition to the WHO-recommended intradermal (ID) route of vaccine administration; and mandatory notification of animal-bite and human rabies cases through the Integrated Health Information Platform (IHIP).
- **Animal Health Component:** achievement and maintenance of at least 70% anti-rabies vaccination coverage in free-roaming and owned dog populations through sustained mass dog vaccination (MDV)

campaigns; scale-up of humane population management through Catch-Neuter-Vaccinate-Release (CNVR)/Animal Birth Control (ABC) protocols; and strengthening of veterinary diagnostic laboratory capacity.

- **Joint Inter-Sectoral Coordination:** constitution of multi-tier One Health committees at national, state, and district levels to enable real-time epidemiological data exchange, joint outbreak investigation, coordinated community education, and synchronised budgetary and logistical planning.

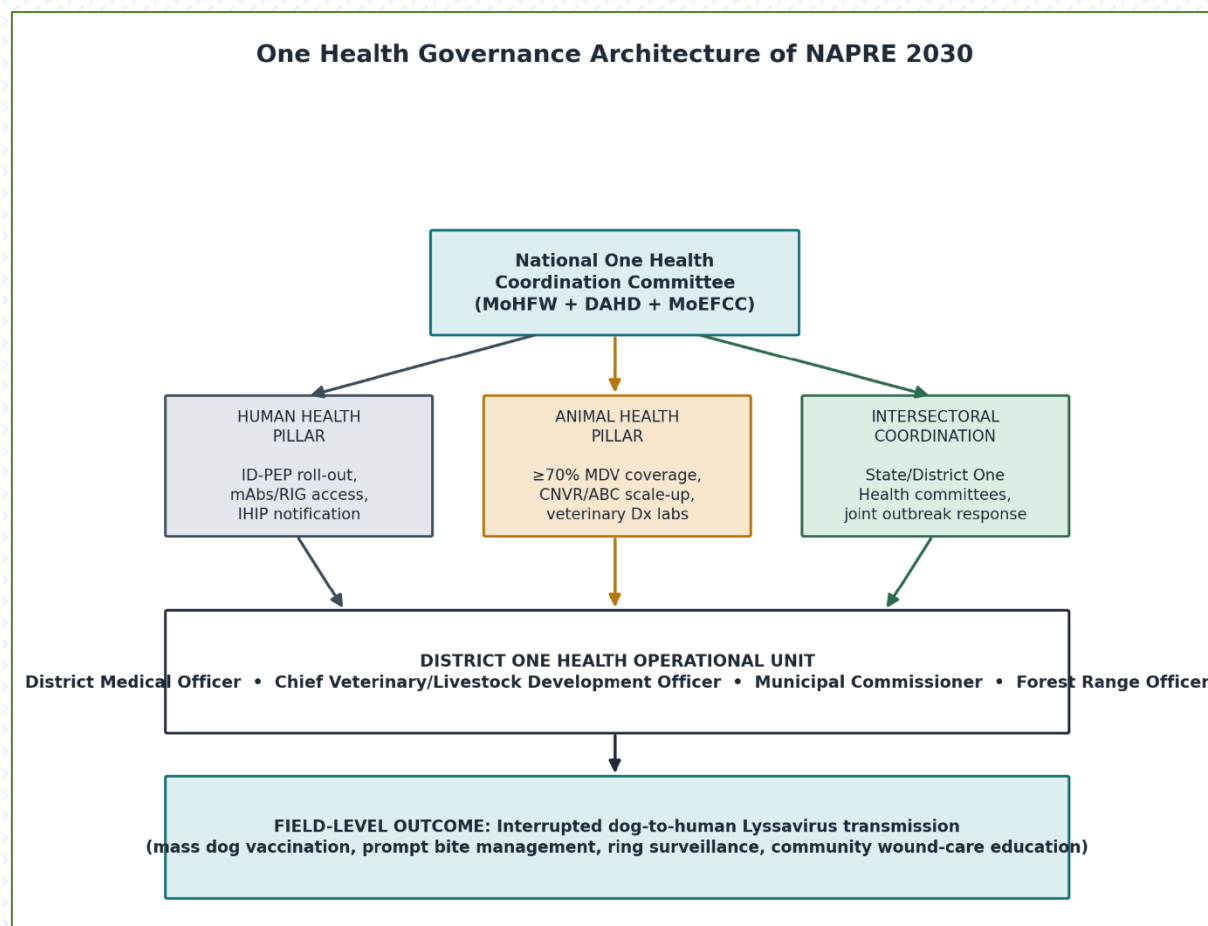


Figure 1. One Health governance architecture envisaged under NAPRE 2030, linking national policy pillars to district-level operational units and field outcomes.

Since 2021, implementation has progressed unevenly across states. The National Centre for Disease Control (NCDC) has piloted a “Rabies Free Cities” initiative that concentrates coordinated dog vaccination, rapid bite-management services, and digital case tracking in selected high-burden urban centres, intended as a scalable template for wider municipal adoption (Mani, 2025). Independent policy analyses published in 2025–2026, however, note that district-level One Health committees remain inconsistently constituted, that MDV coverage in most states still falls well short of the 70% herd-immunity threshold, and that cross-sectoral accountability — the central innovation NAPRE 2030 was designed to deliver — remains only partially realised on the ground (Phukan, 2026; Mani, 2025). Nationally, vaccine production capacity is not the binding constraint: India reportedly manufactures on the order of 8.17 crore (81.7 million) vials of anti-rabies vaccine and 1.77 crore (17.7 million) vials of RIG annually, yet access at the point of first care

— particularly RIG availability at primary health centres — remains severely inadequate, a distributional rather than a production problem (see Section 3.3).

Practical Operational Issues and Ground-Level Bottlenecks in India:

Despite the clarity of policy articulation under NAPRE 2030, translation into consistent district-level outcomes continues to face substantial operational friction across both the veterinary and human health arms of the programme.

3.1 Free-Roaming Dog (FRD) Population Dynamics and Urban Organic Waste:

India's free-roaming dog population is large, ecologically resilient, and characterised by high birth rates, rapid demographic turnover, and largely uninhibited movement across urban and peri-urban landscapes (Tenzin et al., 2015; Tiwari et al., 2018). A principal ecological driver of high canine carrying capacity is unregulated municipal solid waste management: open organic waste accumulations near abattoirs, wholesale markets, and residential dumping sites provide a continuous and abundant food resource, sustaining dog densities well above what a managed waste environment would support. Because population turnover is rapid, vaccinated cohorts are quickly diluted by unvaccinated recruitment (new litters and in-migration), causing herd immunity to fall below the critical ~70% threshold within a matter of months after a single vaccination round unless campaigns are sustained annually (Coleman & Dye, 1996; Gibson et al., 2022).

3.2 Operational Limitations of Animal Birth Control (ABC) and CNVR Programmes:

The Animal Birth Control (Dogs) Rules mandate sterilisation and vaccination prior to the release of dogs back into their original territory, but implementation is constrained by acute structural limitations. Establishing and maintaining sterile surgical facilities, post-operative holding kennels, and a cadre of trained veterinary surgeons requires capital and recurring expenditure that frequently exceeds the budgetary capacity of Tier-2 municipal bodies and rural gram panchayats (Reece & Chawla, 2006).

Conventional dog-catching methods (sack-and-loop or hand-net techniques) also show a strong selection bias, preferentially capturing docile, approachable animals while leaving aggressive, feral, or trap-shy dogs uncaught. Field evaluations suggest that 40–60% of a given street-dog population may remain effectively uncatchable through manual methods, creating a persistent unvaccinated reservoir sufficient to sustain viral circulation even where campaign coverage among catchable dogs is high (Taylor et al., 2017; Yale et al., 2022).

3.3 Cold-Chain Maintenance and Biologic Supply-Chain Disparities:

Maintaining an uninterrupted 2°C–8°C cold chain for rabies vaccines and biologicals across remote and rural primary health infrastructure remains an acute operational challenge. Power outages, inadequate refrigeration capacity, and irregular distribution logistics frequently produce localised stock-outs (Banyai et al., 2018). Passive immunisation for severe (Category III) exposures is particularly

constrained: recent national assessments reported in the lay scientific press indicate that Rabies Immunoglobulin — whether equine- or human-derived — is stocked in only about 5.9% of primary health centres nationally, and in as few as 1.8% of urban PHCs, despite overall national production being adequate (ThePrint, 2025; Bharti et al., 2017; Gogtay et al., 2018). Equine Rabies Immunoglobulin (ERIG) and Human Rabies Immunoglobulin (HRIG) also carry, respectively, a meaningful risk of serum sickness/anaphylaxis and a high unit cost driven by donor-plasma dependency, compounding the access problem for Category III bite victims in rural India.

3.4 Vaccine-Schedule Compliance and Socio-Cultural Wound-Care Practices:

Even where biologicals are available, schedule completion is imperfect: national data reported in 2025 indicate that while essentially all patients receive a first PEP dose, compliance falls to roughly 80% by the fifth scheduled dose under the older intramuscular regimen, with work commitments, missed follow-up dates, and travel inconvenience cited as the principal reasons for default (ThePrint, 2025). Health-seeking behaviour following animal exposure is further shaped by entrenched socio-cultural practice. In many rural communities, bite victims apply traditional remedies — red chilli powder, turmeric, lime, mustard oil, or herbal pastes — directly to open wounds, while foregoing immediate washing with soap and running water (Singh et al., 2019; Sambo et al., 2018). Immediate, thorough 15-minute wound washing is a simple but physically effective intervention, mechanically reducing viral inoculum by a substantial margin, and delay in favour of consulting traditional healers is directly implicated in preventable treatment failure.

3.5 Inter-Departmental Silos and Surveillance Fragmentation:

Prior to NAPRE 2030, human bite records maintained at government hospitals were rarely, if ever, transmitted to the veterinary officers responsible for tracking suspected rabid animals, and animal rabies cases confirmed in veterinary diagnostic laboratories were similarly disconnected from public health registries. This bidirectional reporting gap prevented timely ring vaccination around emerging hotspots (Abbas et al., 2014; Acharya et al., 2020). Even under NAPRE 2030, recent commentary notes that integration between the animal-side and human-side digital reporting systems remains incomplete in most states, and that laboratory-confirmed diagnosis of animal rabies is still heavily concentrated in a small number of reference centres, limiting the molecular and spatial resolution of surveillance data available to district One Health units (Phukan, 2026; Ashwini et al., 2026).

Cutting-Edge Innovations and Technological Breakthroughs in Rabies Control:

4.1 Oral Rabies Vaccination (ORV) for Catch-Resistant Street Dogs:

Because a meaningful fraction of the free-roaming dog population is effectively uncatchable by manual methods, non-invasive vaccine delivery is essential to closing the herd-immunity gap. Oral Rabies Vaccination (ORV) uses palatable bait sachets containing live-attenuated or recombinant vector vaccine

strains (for example, SPBN GASGAS, SAG2, or VR-G) that release vaccine onto the oral mucosa when a dog bites into the bait (Muller et al., 2015; Head et al., 2019). Field feasibility trials in Goa have demonstrated bait uptake exceeding 80% among street dogs previously uncatchable by manual netting, offering a practical route to bridging the residual coverage gap toward the 70% population-immunity target (Yale et al., 2022).

4.2 Recombinant Human Monoclonal Antibodies (mAbs): Transforming Passive Immunisation:

To reduce dependence on donor-plasma-derived immunoglobulin and address chronic RIG shortages, India has been an early and significant adopter of recombinant human monoclonal antibodies (mAbs) directed against the rabies virus glycoprotein. Rabishield (a single human mAb, clone 17C7) and Twinrab (a two-mAb cocktail, clones 62-71-3 and E588), both manufactured using recombinant Chinese hamster ovary (CHO) cell expression systems, provide standardised, high-purity viral neutralisation without the batch variability inherent to plasma-derived products (Kansagra et al., 2019; Sparrow et al., 2019). Rabishield has since been included in WHO guidance on rabies PEP, reflecting accumulating clinical evidence of safety and immunogenicity (Gogtay et al., 2018). The field continues to mature rapidly: a 2025 bibliometric analysis of the global anti-rabies mAb literature documents accelerating research output and an expanding pipeline of candidate antibodies, several with Indian institutional involvement, indicating that mAb-based passive immunisation is likely to become progressively more affordable and widely available over the coming years (Liu et al., 2025).

4.3 WHO-Recommended One-Week Intradermal (ID) Dose-Sparing PEP Protocols:

Adoption of the WHO-recommended one-week intradermal PEP regimen (2-site ID administration on Days 0, 3, and 7) represents a major advance in dose-sparing and cost efficiency (WHO, 2018; Warrell et al., 2019). Compared with the traditional 5-dose intramuscular (IM) schedule (1.0 mL per dose on Days 0, 3, 7, 14, and 28), the 2-site ID regimen uses only 0.1 mL per injection site, reducing total vaccine volume consumed by 60–80% and compressing the treatment timeline from 28 days to 7 days (Figure 4). This reduction in both direct biologic cost and the number of clinic visits required is expected to materially improve schedule completion, directly addressing the drop-out problem documented in Section 3.4.

4.4 Digital Surveillance, Spatial Mapping, and Mobile Field Platforms:

Digital tools have introduced real-time spatial intelligence into Indian rabies control. The Worldwide Veterinary Service (WVS) Mobile Data Collection application enables field vaccination teams to capture GPS coordinates, demographic data, and vaccination status for individual free-roaming dogs, generating coverage maps that can be used to direct repeat rounds to under-vaccinated zones (Gibson et al., 2018). At the national level, the Integrated Health Information Platform (IHIP) and the toll-free 15400 national rabies helpline support rapid bite recording, patient tracking, and dispatch of veterinary teams to suspected-rabid-animal locations, forming the digital backbone of an operationalised One Health

surveillance network, even though — as noted in Section 3.5 — full bidirectional integration with veterinary diagnostic data remains a work in progress.

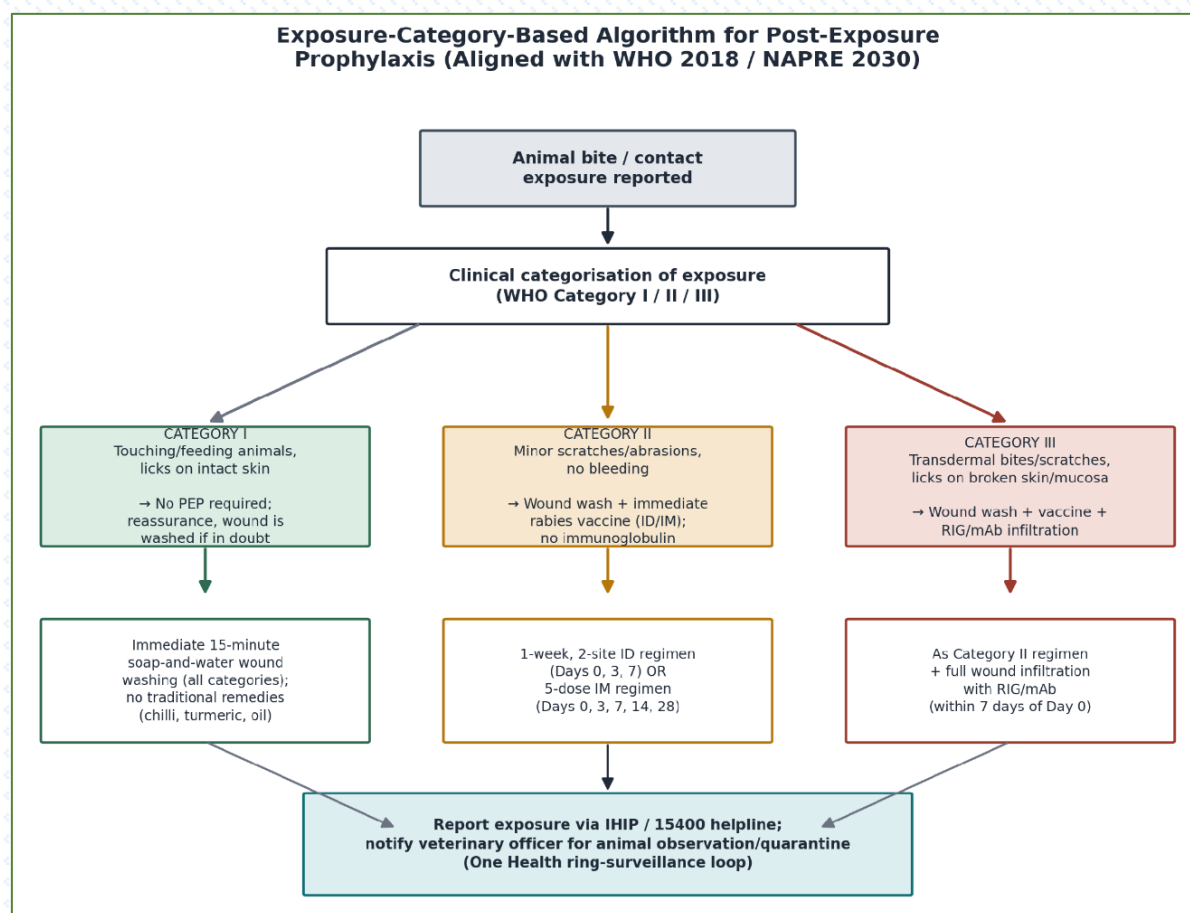


Figure 4. Exposure-category-based algorithm for post-exposure prophylaxis, integrating WHO 2018 categorisation with the dose-sparing intradermal regimen and the One Health ring-surveillance reporting loop.

4.5 Next-Generation Vaccine Platforms: mRNA and Self-Amplifying RNA Candidates

A distinct and rapidly advancing line of innovation, not yet reflected in most Indian policy documents but of direct future relevance to NAPRE 2030, is the development of nucleic-acid rabies vaccines. Conventional inactivated cell-culture vaccines are safe and effective but require cold-chain-dependent multi-dose series; messenger RNA (mRNA) and self-amplifying RNA platforms are being investigated as thermostable, rapidly manufacturable, potentially single-dose alternatives (Fang et al., 2024). Nucleoside-modified mRNA constructs encoding the rabies glycoprotein have shown durable and comprehensive immune responses in preclinical models (non-human primates and mice), and in 2025 the first head-to-head human Phase 1 trial of a self-amplifying RNA rabies vaccine candidate (RBI-4000) reported neutralising-antibody durability equal to or exceeding that of a licensed inactivated comparator vaccine over an 8-month follow-up period (Maine et al., 2025). Should these platforms progress through later-phase trials and achieve a favourable cost profile, they hold particular promise for India's cold-chain-constrained rural and hilly terrain, and merit close tracking by Indian public health and veterinary planners.

4.6 Drone-Assisted Vaccine Logistics and Last-Mile Cold-Chain Bridges:

In hard-to-reach terrain — hilly districts, forested tracts, and riverine islands — unmanned aerial vehicles (UAVs) are being trialled to transport temperature-sensitive vaccines, immunoglobulins, and diagnostic specimens. Documented drone-delivery trials in remote Indian districts report delivery-time reductions of approximately 70% relative to road transport, preserving cold-chain integrity and helping to ensure that time-critical PEP biologics reach patients within the clinically important post-exposure window (Chakraborty et al., 2023).

One Health Interventions Across Human, Animal, And Wildlife Interfaces:

While domestic and free-roaming dogs remain the overwhelmingly dominant vector for human rabies transmission in India, comprehensive elimination requires sustained vigilance across wildlife ecological interfaces. Wildlife species — including golden jackals (*Canis aureus*), Indian foxes (*Vulpes bengalensis*), Indian wolves (*Canis lupus pallipes*), jungle cats (*Felis chaus*), and non-human primates — can act as incidental hosts and, in some ecological settings, as sylvatic reservoirs (Rana et al., 2019; Banyard et al., 2021). Spillover events at the fringes of protected areas, where free-roaming dog territories overlap with wildlife habitat, present a bidirectional transmission risk, simultaneously threatening wildlife conservation objectives and creating spillback risk into adjacent human settlements. Recent field experience from Assam, generated through public-private One Health collaboration involving veterinary field workshops, illustrates both the feasibility and the persistent capacity gaps in extending structured animal rabies surveillance into such mixed-use, forest-fringe landscapes.

An operationalised One Health framework for the wildlife interface necessitates coordinated action across State Forest Departments, Wildlife Institutes, Veterinary Services, and Public Health Directorates. Key cross-interface interventions include:

- **Joint Wildlife Surveillance and Rapid Diagnostic Testing:** regional diagnostic laboratories equipped with the direct Fluorescent Antibody Test (dFAT), direct Rapid Immunohistochemistry Test (dRIT), and reverse-transcription polymerase chain reaction (RT-PCR) assays for rapid viral detection and molecular strain characterisation.
- **Immune Buffer Zones around Protected Areas:** targeted mass dog vaccination belts around wildlife reserves to reduce dog-to-wildlife viral spillover.
- **Integrated Zoonotic Outbreak Investigation Teams:** joint medical-veterinary-ecological response units, mobilised upon confirmation of an animal rabies cluster, to conduct contact tracing and ring vaccination.

Successful Regional Case Studies: Lessons from Goa and Sikkim:

The operational feasibility of rabies elimination within the Indian socio-cultural and administrative context is well illustrated by two state-level programmes.

- **The Goa Model: Sustained Mass Dog Vaccination and Spatial Efficiency**

Goa has become a widely cited benchmark, having recorded no indigenous human rabies deaths since 2017 and being formally recognised as free of dog-mediated human rabies in the years that followed. Implemented by Mission Rabies in partnership with the Government of Goa, the model rests on three operational pillars: (1) systematic annual mass dog vaccination using GPS-enabled mobile mapping to achieve and sustain greater than 70% coverage state-wide; (2) sustained public education reaching several hundred thousand schoolchildren and community members on bite prevention and correct wound washing; and (3) a 24/7 rabies hotline backed by rapid-response veterinary teams for suspect-animal quarantine and observation (Gibson et al., 2018; Gibson et al., 2022; Yale et al., 2022).

- **The Sikkim Model: Mandatory Registration and Integrated Governance**

Sikkim achieved comprehensive canine rabies control through the Sikkim Anti-Rabies and Animal Health (SARAH) programme — India's first government-sanctioned, state-wide One Health initiative of its kind. SARAH integrated mandatory pet-dog registration, state-wide free-roaming dog vaccination, humane ABC surgical drives, and stringent municipal waste control, embedding community veterinary nurses within rural panchayats to build a durable, locally owned surveillance network that has effectively eliminated dog-mediated rabies across the state's mountain communities (Loveridge et al., 2019).

Laboratory Diagnosis and Molecular Surveillance: Progress and Remaining Gaps

Accurate, timely laboratory confirmation of animal rabies is the diagnostic backbone on which ring vaccination, contact tracing, and outbreak-response decisions depend, yet it remains one of the least visible components of the Indian programme. A comprehensive 2025–2026 review of laboratory diagnostic capacity in India highlights continuing reliance on clinical suspicion in the field, with confirmatory testing — the direct Fluorescent Antibody Test (dFAT), the gold-standard assay, together with RT-PCR and next-generation sequencing for viral lineage characterisation — concentrated in a small number of apex referral laboratories, chiefly the National Institute of Mental Health and Neurosciences (NIMHANS), Bengaluru, and select National Institute of Virology and veterinary university nodes (Ashwini et al., 2026). Point-of-care and field-deployable assays, such as lateral-flow immunochromatographic tests and portable RT-PCR platforms, are being evaluated as a means of decentralising diagnosis to the district level, which would substantially shorten the interval between an animal-bite event and confirmatory classification of the biting animal — a critical determinant of whether Category III PEP, once started, can safely be curtailed if the animal tests negative and survives the observation period. Strengthening this diagnostic layer, and linking its output directly into IHIP and veterinary reporting systems, is identified consistently across recent Indian literature as one of the highest-yield, comparatively low-cost

investments remaining under NAPRE 2030 (Ashwini et al., 2026; Mani, 2025).

Comparative Analysis and Synthesis Tables:

Table 1 synthesises the principal practical bottlenecks facing rabies control in India alongside the corresponding One Health innovations now being deployed against them (see also Figure 3). Table 2 presents a comparative evaluation of passive immunisation modalities available for Category III exposures. Table 3 traces the successive revisions to India's national rabies mortality estimate, contextualising the burden figures discussed in Section 1.

Table 1. Operational Challenges in Rabies Control and Corresponding One Health Interventions in India

Operational Domain	Practical Ground-Level Bottleneck	Innovative One Health Intervention
Canine vector control	Catch-resistant street dogs (40–60%) unreached by manual net catching; rapid population turnover.	Oral Rabies Vaccination (ORV) sachet baits targeting aggressive/evasive street dogs.
Post-exposure prophylaxis	HRIG/ERIG shortages, high cost, and rural PHC availability deficits for Category III bites (as low as 5.9% PHC stocking).	Recombinant human monoclonal antibodies (Rabishield, Twinrab) offering standardised, lower-cost passive immunisation.
Vaccine schedule compliance	High drop-out (~20%) by the 5th dose of the intramuscular regimen; patient travel cost and time burden.	WHO 1-week, 2-site intradermal (ID) dose-sparing regimen (Days 0, 3, 7), reducing volume by 60–80%.
Disease surveillance	Fragmented reporting; incomplete real-time link between municipal bite logs and veterinary/laboratory data.	IHIP digital reporting, WVS mobile spatial tracking app, and the 15400 National Rabies Helpline.
Cold-chain logistics	Power disruptions and terrain barriers in rural/hilly districts causing biologic degradation and stock-outs.	Drone-assisted (UAV) cold-chain transport delivering vaccines and biologics to remote PHCs.
Laboratory diagnosis	Confirmatory testing concentrated in a handful of apex referral laboratories; slow turnaround for ring vaccination decisions.	Decentralised point-of-care assays (lateral-flow tests, portable RT-PCR) linked to digital reporting platforms.

Table 2. Comparative Evaluation of Passive Immunisation Modalities for Category III Rabies Exposures

Parameter	Human Rabies Immunoglobulin (HRIG)	Equine Rabies Immunoglobulin (ERIG)	Recombinant Monoclonal Antibodies (mAbs)
Source/origin	Human donor plasma pool	Hyperimmunised horse serum	Recombinant CHO cell culture
Global/local availability	Extremely limited; severe global shortages	Moderate; regional supply bottlenecks	High, scalable industrial production
Safety & anaphylaxis risk	Very high safety profile	Risk of serum sickness and severe allergic reaction	Highest safety; no animal-protein risk
Cost & affordability (approx.)	Exorbitantly high (~US\$100–200)	Moderate (~US\$15–30)	Increasingly affordable (~US\$10–20)
Regulatory/clinical status in India	Licensed; supply-constrained	Licensed; declining preferred use	Rabishield WHO-listed; Twinrab licensed; expanding pipeline (Liu et al, 2025)

Strategic Recommendations for NAPRE 2030 Realisation:

Translating the strategic commitments of NAPRE 2030 into sustained, nationwide disease elimination requires a set of targeted, resource-conscious policy actions, several of which are drawn together here from the operational analysis above and from recent expert synthesis (Mani, 2025; Phukan, 2026):

- 1. Institutionalise District-Level One Health Operational Units.** Formally empower joint task forces comprising District Medical Officers, Chief Veterinary/Livestock Development Officers, Municipal Commissioners, and Forest Range Officers, with dedicated budget lines and shared surveillance authority, rather than leaving coordination to informal or ad hoc arrangements.
- 2. Mandate Universal Intradermal PEP and Accelerate the mAb Transition.** Enforce 100% intradermal vaccination capability across public healthcare facilities down to the PHC level, and expand inclusion of recombinant monoclonal antibody cocktails on state essential-medicine lists, prioritising primary health centres where RIG availability is currently near zero.
- 3. Integrate Oral Rabies Vaccination with ABC/CNVR Campaigns.** Scale ORV bait-sachet distribution as a structured complement to parenteral mass dog vaccination, specifically targeting the 40–60% of street dogs that remain uncatchable by manual methods.
- 4. Enforce Municipal Solid Waste Governance.** Implement and audit strict waste-management protocols around abattoirs, markets, and residential areas to reduce the organic food subsidy that sustains high street-dog carrying capacity.
- 5. Expand and Decentralise Laboratory Diagnostic Capacity.** Invest in regional and, where feasible, district-level rabies diagnostic capability (dFAT, RT-PCR, point-of-care assays) to shorten confirmation turnaround and strengthen the evidentiary basis for ring vaccination.
- 6. Scale Grassroots Public Awareness and First-Aid Education.** Launch sustained, culturally tailored community campaigns dispelling harmful wound-care myths and normalising mandatory 15-minute soap-and-water washing immediately after any animal exposure.
- 7. Support Operational Research on Thermostable and Next-Generation Vaccines.** Track and, where appropriate, participate in trials of mRNA and self-amplifying RNA rabies vaccine candidates, given their potential relevance to India's cold-chain-constrained geography.
- 8. Institute Compassionate and Palliative Support for Confirmed Human Cases.** Recognising that clinical rabies remains uniformly fatal once symptomatic, formalise palliative-care protocols and family support at the district hospital level, an ethically necessary complement to preventive strategy.
- 9. Ring-Fence Sustainable, Dedicated Domestic Financing.** Secure multi-year, protected budget allocations — insulated from annual re-negotiation — for MDV, ABC/CNVR, and PEP biologic procurement, following the financing discipline that characterised India's polio eradication

programme.

Knowledge Gaps and Future Research Priorities:

Several evidentiary gaps merit dedicated research attention as India advances toward 2030. First, state- and district-level dog population estimates remain methodologically heterogeneous, and a standardised, periodically repeated dog census methodology — ideally harmonised with human census cycles — would materially improve MDV planning and coverage verification. Second, the true contribution of wildlife sylvatic cycles to human and livestock risk in India remains incompletely characterised and would benefit from systematic molecular epidemiological surveys linking canine, wildlife, and human viral isolates. Third, health-economic evaluations comparing ORV, ID-PEP, and mAb scale-up strategies under Indian cost structures are still sparse, limiting evidence-based prioritisation of limited public health budgets. Finally, as next-generation nucleic-acid vaccine platforms mature, India-specific feasibility and cold-chain-independence studies will be needed before these technologies can be meaningfully incorporated into national policy.

Conclusion:

Eliminating dog-mediated human rabies in India by 2030 is an achievable public health goal, and the most recent national burden estimates suggest the country is considerably closer to that goal than earlier figures implied — though a residual annual toll of several thousand entirely preventable deaths makes clear that the work is far from complete. Achieving elimination in full will require the national response to complete its transition from reactive medical therapy toward a genuinely proactive, integrated One Health paradigm. The demonstrated success of state-level models in Goa and Sikkim confirms that sustained mass dog vaccination above the 70% herd-immunity threshold, real-time digital surveillance, community wound-care education, and durable cross-sectoral governance can, together, sever the dog-to-human Lyssavirus transmission chain within the Indian context. The innovations reviewed here — Oral Rabies Vaccination for catch-resistant street dogs, recombinant human monoclonal antibodies, WHO-recommended intradermal PEP regimens, decentralised diagnostics, next-generation RNA vaccine platforms, and drone-assisted logistics — collectively provide India with the technological means to overcome its most entrenched ground-level operational bottlenecks. What remains is sustained political will, ring-fenced financing, and unambiguous inter-departmental accountability under NAPRE 2030, so that rabies can complete its transition from a neglected, fatal zoonosis to a documented Indian public health achievement.

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References:

- Abbas, S. S., Kakkar, M., & Rogawski, E. T. (2014). Expanding access to post-exposure management for rabies in India: Urgent need for a One Health approach. *Operations Research for Health Care*, 3(4), 202–207.
- Acharya, K. P., Acharya, N., Phuyal, S., Upadhyaya, M., & Luitel, S. (2020). One Health approach to eliminate rabies in South Asia. *Tropical Medicine and Infectious Disease*, 5(4), 165.
- Ashwini, M. A., Lodha, L., Ramachandran, A., Esther, A. J., & Mani, R. S. (2026). Laboratory diagnosis of rabies in an endemic country: Progress and challenges on the path to elimination. *Diagnostic Microbiology and Infectious Disease*, 114(2), 117123.
- Banyai, O., et al. (2018). Cold chain maintenance and vaccine logistics in low- and middle-income country settings. *Vaccine*, 36(42), 6251–6258.
- Banyard, A. C., et al. (2021). Lyssaviruses and bats: Emergence and public health risk. *Viruses*, 13(10), 1991.
- Bharti, O. K., et al. (2017). Local infiltration of rabies immunoglobulins without systemic administration is safe and effective in Category III animal bites. *WHO South-East Asia Journal of Public Health*, 6(2), 52–58.
- Chakraborty, S., et al. (2023). Drone-assisted transport of medical supplies and vaccines in remote healthcare settings: A feasibility analysis. *Journal of Public Health Policy*, 44(1), 89–102.
- Chatterjee, P., et al. (2016). India's progress toward rabies elimination: Strategic opportunities and structural challenges. *Infectious Diseases of Poverty*, 5(1), 1–9.
- Coleman, P. G., & Dye, C. (1996). Immunizing a reserve: How many dogs should be vaccinated to control rabies? *Vaccine*, 14(3), 185–186.
- Fang, Z., Yu, P., & Zhu, W. (2024). Development of mRNA rabies vaccines. *Human Vaccines & Immunotherapeutics*, 20(1), Article 2382499.
- Fooks, A. R., et al. (2017). Rabies. *Nature Reviews Disease Primers*, 3(1), 17091.
- Gibson, A. D., et al. (2018). Elimination of rabies — a One Health approach utilizing mobile technology in Goa, India. *Frontiers in Veterinary Science*, 5, 189.
- Gibson, A. D., et al. (2022). Sustainable mass dog vaccination campaigns achieving zero indigenous human rabies deaths in Goa, India. *Nature Communications*, 13(1), 4912.
- Gogtay, N. J., et al. (2018). A prospective study evaluating safety and immunogenicity of recombinant human monoclonal antibody (Rabishield) in Category III rabies exposures. *Human Vaccines & Immunotherapeutics*, 14(9), 2235–2242.

- Gongal, G., et al. (2022). One Health approach for rabies elimination in South-East Asia. *Veterinary Sciences*, 9(12), 682.
- Hampson, K., et al. (2015). Estimating the global burden of endemic canine rabies. *PLoS Neglected Tropical Diseases*, 9(4), e0003709.
- Head, J. R., et al. (2019). Feasibility and cost-effectiveness of oral rabies vaccination for free-roaming dogs in Asia and Africa. *Vaccine*, 37(Suppl A), A105–A115.
- Kansagra, K., et al. (2019). Clinical evaluation of Twinrab™: A cocktail of two monoclonal antibodies for post-exposure prophylaxis of rabies. *International Journal of Infectious Diseases*, 85, 112–118.
- Liu, C., Lv, X., Liu, S., Chen, Q.-J., Zhu, Z.-G., Yu, R., Yin, W.-W., & Wang, C.-L. (2025). Research trends in anti-rabies virus monoclonal antibody: A bibliometric analysis. *Human Vaccines & Immunotherapeutics*, 21(1), Article 2508559.
- Loveridge, R., et al. (2019). The Sikkim Anti-Rabies and Animal Health (SARAH) program: A sustainable One Health model. *Frontiers in Veterinary Science*, 6, 412.
- Maine, C. J., Picarda, G., Miyake-Stoner, S. J., Essink, B., Somodevilla, G., Sparks, J., Geall, A. J., Wang, N. S., Goldberg, Z., & Aliahmad, P. (2025). Durability of next-generation self-replicating RNA vaccine RBI-4000: A phase 1, randomized open-label clinical trial. *Communications Medicine*, 5, Article 147.
- Mani, R. S. (2025). Rabies elimination in India: Pathways from vision to reality [Editorial]. *Indian Journal of Medical Research*, 162(3).
- Menezes, R. (2010). Rabies in India: A common yet neglected disease. *International Journal of Infectious Diseases*, 14(4), e268–e270.
- Ministry of Health and Family Welfare (MoHFW) & Department of Animal Husbandry and Dairying (DAHD). (2021). National Action Plan for Rabies Elimination by 2030 (NAPRE 2030). Government of India, New Delhi.
- Mondal, T., & Sudarshan, M. K. (2025, March 13). Rabies in India: Current scenario and prospects of elimination. Policies for Equitable Access to Health (PEAH). <https://www.peah.it/2025/03/14477/>
- Muller, T., et al. (2015). Development of oral rabies vaccination for dogs: Challenges and future prospects. *Vaccine*, 33(38), 4720–4728.
- Phukan, P. (2026). One Health implementation for rabies elimination in India by 2030: Progress, governance, challenges, and policy alignment. *One Health*, 23, Article 101520.
- Rana, S. K., et al. (2019). Rabies in wildlife reservoirs in India: Epizootiological patterns and diagnostic challenges. *Indian Journal of Medical Research*, 150(4), 382–390.

- Reece, J. F., & Chawla, S. K. (2006). Control of rabies in Jaipur, India, by the sterilization and vaccination of neighbourhood dogs. *Veterinary Record*, 159(12), 379–383.
- Sambo, M., et al. (2018). Health-seeking behaviour and utilization of post-exposure prophylaxis following animal bites. *Vaccine*, 36(49), 7522–7529.
- Singh, A., et al. (2019). Community perception, practices and health-seeking behavior regarding animal bites in rural India. *Journal of Family Medicine and Primary Care*, 8(5), 1642–1648.
- Sparrow, E., et al. (2019). Passive immunization for rabies post-exposure prophylaxis: A review of monoclonal antibodies as alternatives to rabies immunoglobulin. *Vaccine*, 37(Suppl A), A125–A131.
- Sudarshan, M. K., et al. (2005). Assessing burden of rabies in India: WHO sponsored national multicentric rabies survey (2003). *Indian Journal of Community Medicine*, 30(3), 100–101.
- Suraweera, W., et al. (2012). Deaths from rabies in India: A national representative survey. *PLoS Neglected Tropical Diseases*, 6(3), e1521.
- Taylor, L. H., et al. (2017). The role of dog population management in rabies elimination. *Frontiers in Veterinary Science*, 4, 109.
- Tenzin, T., et al. (2015). Dog population management and rabies control. *Veterinary Sciences*, 2(4), 341–366.
- Thangaraj, J. W. V., Krishna, N. S., Devika, S., Egambaram, S., Dhanapal, S. R., Khan, S. A., Srivastava, A. K., Mishra, A., Shrinivasa, B., Gour, D., Madhukar, M., Verma, N., Sharma, P., Soni, R. K., Ramasamy, S., Mohandas, S., Baidya, S., Rehman, T., Yeldandi, V. V., ... Murhekar, M. V. (2025). Estimates of the burden of human rabies deaths and animal bites in India, 2022–23: A community-based cross-sectional survey and probability decision-tree modelling study. *The Lancet Infectious Diseases*, 25(1), 126–134.
- ThePrint. (2025). How close is India to the ‘Zero by 30’ rabies goal? <https://theprint.in/science/india-zero-by-30-rabies-goal/2900078/>
- Tiwari, H. K., et al. (2018). Knowledge, attitudes and practices regarding rabies among dog owners and non-dog owners in India. *Preventive Veterinary Medicine*, 159, 120–130.
- Warrell, M. J., et al. (2019). Economical intradermal post-exposure rabies vaccination regimens: Historical development and modern WHO guidelines. *Vaccine*, 37(Suppl A), A82–A89.
- World Health Organization (WHO). (2018). WHO Expert Consultation on Rabies: Third Report (WHO Technical Report Series No. 1012). WHO.
- Yale, G., et al. (2022). Feasibility of oral rabies vaccination for free-roaming dogs in Goa, India. *Frontiers in Veterinary Science*, 9, Article 882012.