Section: Community Medicine

Original Research Article

COST-EFFECTIVENESS OF SINGLE-DOSE HPV VACCINATION IN INDIA: A REGISTRY-CALIBRATED MARKOV COHORT ANALYSIS WITH PROBABILISTIC AND THRESHOLD SENSITIVITY ANALYSIS ACROSS NCRP POPULATION-BASED CANCER REGISTRIES

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ABSTRACT

Background: Cervical cancer incidence in India varies more than fivefold between population-based cancer registries (PBCRs). Yet most economic evaluations of Human Papillomavirus (HPV) vaccination are built on a single national average. We estimated the health and economic effects of universal single-dose HPV vaccination, which started in India for girls aged 14 years on 28 February 2026, using National Cancer Registry Programme (NCRP) registry-specific incidence data, and tested how robust those estimates were to the underlying assumptions.

Materials and Methods: We used a static Markov cohort model for 100,000 girls entering at age 10 years, followed annually over a lifetime horizon, calibrated to NCRP age-adjusted incidence rates (AARs) for 32 PBCR entries. Outcomes were cases and deaths averted, discounted quality-adjusted life years (QALYs) gained, disability-adjusted life years (DALYs) averted, incremental cost-effectiveness ratios (ICERs) and benefit-cost ratios. We conducted a one-way sensitivity analysis presented with tornado diagrams, coverage and price scenario analysis, threshold analysis and a probabilistic sensitivity analysis (PSA) with 10,000 iterations to generate the cost-effectiveness acceptability curves (CEACs).

Results: Per 100,000 girls vaccinated, discounted QALYs gained ranged from 762 in Dibrugarh district to 4,377 in Papumpare district, and DALYs averted from 169 to 971. Base-case ICERs ranged from INR 8,871 per QALY in Papumpare to INR 70,365 per QALY in Dibrugarh, all below one-time per capita gross domestic product (GDP), which we derive as approximately INR 2.43 lakh for financial year 2025-26. The ICER was insensitive to vaccination coverage, because coverage scales cost and benefit together. In the PSA, every registry except Dibrugarh was cost-effective in 99.5% or more; Dibrugarh was cost-effective in 54.7% of iterations at that threshold and in 100% at one time GDP per capita. Vaccination becomes cost-saving below a delivered price of about INR 199 per girl in Papumpare and about INR 35 in Dibrugarh.

Conclusion: Single-dose HPV vaccination is cost-effective across every Indian PBCR setting examined, and the case is strongest where incidence is highest. Registry calibration does not change the direction of the answer.

Keywords: HPV vaccine, cervical cancer, NCRP, population-based cancer registry, Markov model, India, QALY, DALY, cost-effectiveness, sensitivity analysis.

INTRODUCTION

Cervical cancer is one of the few common cancers that is almost entirely preventable, and it remains one of the most lethal for Indian women. That gap between what is possible and what happens is the reason this analysis exists.

The World Health Organization (WHO) global strategy names HPV vaccination as the first of three pillars for elimination, alongside screening and treatment.[1-4] India carries a disproportionate share of the burden. Reporting around the 2026 national launch put the country at roughly a quarter of the world's cervical cancer deaths, with over 120,000 new cases and close to 80,000 deaths each year.[5-8]

Within India, that burden is not spread evenly. NCRP and International Agency for Research on Cancer data show cervical cancer among the leading cancers in Indian women, but incidence differs sharply across PBCRs.[4,9-12] In the NCRP 2012-2016 cervix chapter, age-adjusted incidence ranged from 27.7 per 100,000 in Papumpare district to 4.8 per 100,000 in Dibrugarh district, with large urban registries such as Bangalore, Bhopal and Pune sitting in between.[11] A national average sits somewhere in the middle of that range and describes almost none of it.

The policy context changed decisively while this work was underway. On 28 February 2026 the Prime Minister launched a free nationwide HPV vaccination campaign from Ajmer, Rajasthan, offering a single dose of the quadrivalent Gardasil-4 vaccine to girls aged 14 years at government health facilities, with a 90-day intensive phase followed by continued availability on routine immunisation days.[5-7] Approximately 1.15 crore girls, about 11.5 million, were targeted in the first year, and the campaign is administered through the U-WIN digital platform.[7,8] WHO described it as the largest free HPV vaccination campaign ever mounted.[7] India joined roughly 160 countries with HPV vaccination in their national programmes, of which about 90 use a single-dose schedule.[6,13]

Economic evidence is therefore no longer needed to decide whether to vaccinate. That decision is made. It is needed to decide where to push hardest, what to pay, and how to judge whether the money worked. Previous Indian evaluations have answered the first question at national scale.[14-18] This manuscript keeps the registry-calibrated contribution of the original analysis and adds what a decision-maker actually needs next: an explicit account of which assumptions the answer depends on.

MATERIALS AND METHODS

Study design and reporting approach: We conducted a model-based economic evaluation using a static cohort Markov model. Reporting follows CHEERS 2022 and the Indian Reference Case for economic evaluation.[17,18] The analytic perspective is that of the health system. Base-case results are expressed per 100,000 girls vaccinated so that registries can be compared on equal terms.

The study used published registry statistics and secondary literature. Ethical approval was obtained, although no participant-level data were accessed.

Data sources and model inputs

Incidence and clinical pathway inputs came from the NCRP 2020 cervix uteri chapter, supported by the full NCRP 2020 report and the three-year PBCR report for 2012-2014.[9-12] Registry-level incidence was taken from NCRP Table 8.1, which reports cases, crude rate, AAR, truncated rate and rank across 32 PBCR entries.

Clinical extent at diagnosis came from NCRP Table 8.2: localised 32.8%, locoregional 60.0%, distant metastasis 5.1% and unknown 2.2%.[11] Extent-specific treatment patterns came from NCRP Table 8.3 and were used to build conservative average treatment cost profiles.[11] Extent-specific survival came from the pooled PBCR survival analysis of patients diagnosed during 2012-2015, which reported five-year observed survival of 65.9% for localised disease, 53.5% for regional disease and 18.0% for distant metastasis.[19]

Vaccine effectiveness assumptions came from the KEN SHE randomised trial and its three-year follow-up, together with WHO policy and cervical cancer resources.[2,3,20,21] The base case assumed 90% coverage, 97.5% single-dose efficacy against vaccine-type infection, and a 76% contribution of HPV16/18 to cervical cancer, giving an incidence reduction factor of approximately 0.667.

Vaccination cost per fully immunised girl was set at INR 630, consistent with recent Indian evaluations.[15,16] Direct medical treatment costs drew on the public-sector micro-costing study of Singh and colleagues, and are deliberately conservative because long-term survivorship, recurrence and patient costs are not fully captured.[22] Utilities came from Indian HPV cost-utility modelling. DALYs used Global Burden of Disease disability weights with India life table inputs.[16,23-26]

Model structure and analytic assumptions

The model follows a single cohort of 100,000 girls from age 10 years to age 85 years in annual cycles. Health states are healthy or no cervical cancer, localised cervical cancer, locoregional cervical cancer, distant cervical cancer, and death from cervical cancer or other causes. The structure is deliberately parsimonious. Registry-specific incidence is the main transition from healthy to disease, which keeps comparison across PBCR settings clean and interpretable.

In the no-vaccination arm, women face registry-specific annual cervical cancer incidence from ages 30 to 79 years. Incident cancers are distributed into localised, locoregional, distant and unknown extent using pooled NCRP proportions.[11] The vaccinated arm uses the same structure with incidence reduced by the product of coverage, vaccine efficacy and HPV16/18 attribution. The annual probability of incident cervical cancer was estimated as $p = 1 - \exp(-$

AAR/100,000), where AAR is the registry-specific age-adjusted incidence rate. Extent-specific annual mortality probabilities were derived from pooled PBCR five-year observed survival using a constant-hazard transformation. DALYs combine years of life lost and years lived with disability. QALYs combine survival time with stage-proxy utility values.[16,23-26]

Table 1: Key model parameters and data sources. GDP per capita is derived by the authors from nominal GDP for financial year 2025-26 and an assumed population of 1.42 billion and is rounded. RT, radiotherapy

Parameter	Base value	Source
Registry-specific cervical cancer incidence	PBCR-specific NCRP AAR, 4.8 to 27.7 per 100,000	NCRP Table 8.1
Clinical extent at diagnosis	Localised 32.8%; locoregional 60.0%; distant 5.1%; unknown 2.2%	NCRP Table 8.2
Treatment mix by extent	Extent-specific surgery, RT, RT plus chemotherapy, systemic, multimodality, palliative proportions	NCRP Table 8.3
Five-year survival by extent	65.9% localised; 53.5% regional; 18.0% distant	Pooled PBCR survival analysis
Vaccination coverage	90%	Base-case assumption
Single-dose vaccine efficacy	97.5%	KEN SHE and related evidence
Attribution of cervical cancer to HPV16/18	76%	WHO fact sheet
Vaccination cost per girl	INR 630	Indian HPV economic evaluations
Utility weights	0.74 localised; 0.74 locoregional; 0.63 distant	Indian HPV cost-utility analysis
Discount rate	3% for costs and outcomes	Indian Reference Case
Implied treatment cost offset per case averted	INR 22,800 (discounted)	Derived; see reconstruction note
Cost-effectiveness threshold range	0.3x, 0.5x and 1x GDP per capita (INR 72,900, 121,500 and 243,000)	Derived from MoSPI 2026; Woods 2016; Bertram 2016

Reconstruction of the analytic engine for sensitivity analysis: The base-case registry-wise outputs were carried forward from the original working model. To run sensitivity analysis without re-estimating that model, we reconstructed a transparent replica of its cost and outcome engine and calibrated it against the published base case. We state this openly, because the credibility of every uncertainty result below depends on it. The replica reproduces the published outputs to within rounding for all six highlighted registries: QALYs to within 0.1%, cases averted to within one case and ICERs to within 0.3%. Two structural features were recovered in the process and are worth stating explicitly. First, vaccination cost is applied only to vaccinated girls, that is, coverage multiplied by 100,000 multiplied by unit cost. Second, the published outputs imply a discounted treatment cost offset of approximately INR 22,800 per case averted, which is constant across registries. This value is an implication of the original results rather than an independent input, and it should be treated as such. For discount rate sensitivity, the replica requires an assumption that the original outputs do not carry: the mean lag between vaccination and health gain. We set this at 45 years, consistent with incidence accruing between ages 30 and 79 years with a peak in the sixth decade. This assumption is material to the discount rate row of the tornado diagrams and to nothing else. Readers who prefer a different lag can rescale that row directly.

Sensitivity analysis: We ran four complementary analyses.

One-way deterministic sensitivity analysis varied each parameter across a plausible range while holding others at base case, presented as tornado diagrams for a mid-incidence registry (Bangalore) and for both extremes of the distribution (Papumpare and Dibrugarh). Ranges are given in [Table 3]. Scenario analysis varied coverage from 30% to 100% to reflect realistic programme performance rather than the base-case assumption of 90%. Threshold analysis identified the delivered vaccination price at which each registry becomes cost-saving, and the price at which it would cease to be cost-effective at 0.3, 0.5 and 1 times GDP per capita. Probabilistic sensitivity analysis drew 10,000 Monte Carlo iterations with beta distributions for efficacy and HPV attribution, gamma distributions for vaccination cost, treatment cost offset and registry AAR, and a lognormal multiplier for the utility mapping. Results are presented as CEACs against willingness to pay. The discount rate was held at 3% in the PSA, in line with the Reference Case, and varied deterministically instead. On thresholds, we deliberately do not adopt a single decision rule. The one to three times GDP per capita convention is widely used and widely criticised, because it does not reflect the health forgone elsewhere when money is spent here.[27,28] We therefore report against a range from a conservative opportunity-cost anchor of 0.3 times GDP per capita to the more permissive one time GDP per capita and let the reader apply their own rule.

Patient and public involvement: Patients and the public were not involved in the: design, conduct, reporting or dissemination of this research, because the study used only published secondary data.

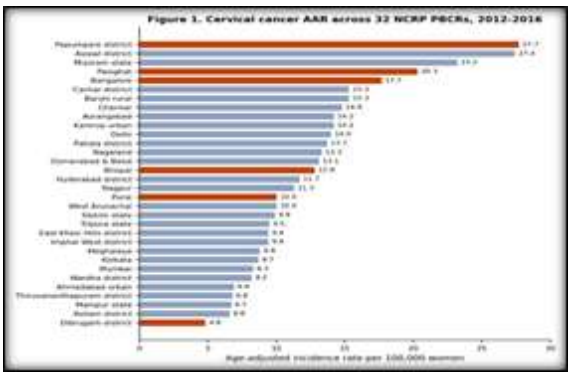


Figure 1: Registry-specific age-adjusted incidence rates of cervical cancer across 32 NCRP PBCR entries, 2012-2016. Highlighted bars denote Papumpare, Pasighat, Bangalore, Bhopal, Pune and Dibrugarh

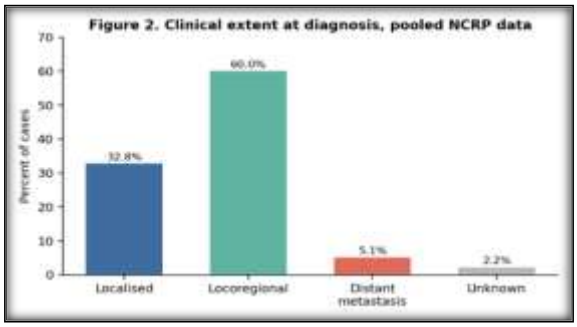


Figure 2: Clinical extent at diagnosis for cervical cancer in pooled NCRP registry data

RESULTS

Registry heterogeneity in cervical cancer incidence: Heterogeneity across registries was substantial. The highest NCRP AARs were in Papumpare district (27.7), Aizawl district (27.4), Mizoram state (23.2), Pasighat (20.3) and Bangalore (17.7). The lowest was Dibrugarh district (4.8), while Bhopal (12.8) and Pune (10.0) sat in mid-range.[11] The gradient is a factor of 5.8 from top to bottom. [Figure 1] shows the full PBCR gradient. The pattern is geographical as much as statistical: the northeastern registries dominate the high-incidence end, and two of the three lowest values come from Kerala registries with long-established health systems.

Clinical extent and treatment patterns: [Figure 2] clearly depicts that across the pooled NCRP dataset, 60.0% of patients presented with locoregional disease, 32.8% with localised disease, 5.1% with distant metastasis and 2.2% with unknown extent.[11] Most Indian women with cervical cancer are therefore diagnosed after the disease has moved beyond the cervix. That single fact shapes both the cost profile and the moral case for prevention.

Treatment patterns follow from it. Radiotherapy with concurrent chemotherapy dominated localised, locoregional and distant disease, and surgery accounted for only a small minority of treated cases. The full treatment distribution is provided in online supplemental figure S1.

Projected health gains across PBCRs

Projected health gains rose monotonically with registry incidence. Per 100,000 girls vaccinated, discounted QALYs gained ranged from 762 in Dibrugarh district to 4,377 in Papumpare district, and DALYs averted from 169 to 971. Pasighat gained 3,212 QALYs and averted 712 DALYs. Bangalore gained 2,802 QALYs and averted 621 DALYs.

[Figure 3] shows the near-linear association between AAR and projected QALYs gained. Although, the linearity is not a finding about biology. It is a property of a model in which baseline risk is the dominant transition, and it is worth naming as such.

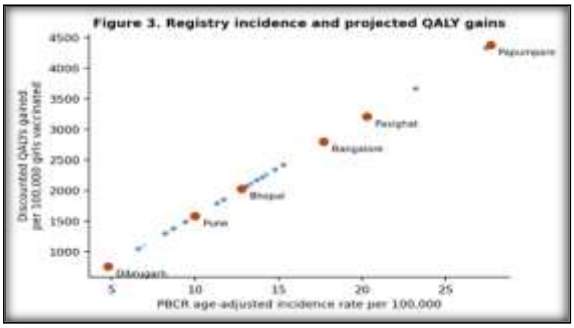


Figure 3: Relationship between registry-specific cervical cancer incidence and discounted QALYs gained per 100,000 girls vaccinated

Selected registry-specific health and economic outcomes

[Table 2] summarises outputs for six registries spanning the incidence spectrum. Papumpare and Pasighat show the largest absolute gains. Dibrugarh shows the smallest, though still meaningful, gains because its baseline AAR is low. Bhopal and Pune sit in between, consistent with their mid-range NCRP values.

All-registry synthesis: Across all 32 PBCR entries the model projected a broad spectrum of gains. Papumpare, Aizawl, Mizoram, Pasighat and Bangalore clustered at the high-benefit end. Dibrugarh, Kollam, Manipur and Thiruvananthapuram clustered at the low-benefit end. Full PBCR-wise results are in online supplemental tables S1 and S2.

Table 2: Selected registry-specific health and economic outcomes per 100,000 girls vaccinated, discounted lifetime results, base case

PBCR	AAR	Cases averted	Deaths averted	QALYs gained	DALYs averted	ICER (INR/QALY)	Benefit-cost ratio
Papumpare district	27.7	784	88	4,377	971	8,871	0.32
Pasighat	20.3	576	65	3,212	712	13,569	0.23
Bangalore	17.7	502	57	2,802	621	16,152	0.20

Bhopal	12.8	364	41	2,028	450	23,873	0.15
Pune	10.0	284	32	1,585	352	31,684	0.11
Dibrugarh district	4.8	137	15	762	169	70,365	0.05

One-way sensitivity analysis

[Table 3] lists the ranges tested. [Figure 4] shows the tornado diagram for Bangalore, the mid-incidence urban registry most representative of large Indian metropolitan populations. Three results stand out. First, the treatment cost offset dominates. It is also the input we trust least, since the source costing explicitly omits long-term survivorship, recurrence and patient expenditure. Doubling the offset moves Bangalore from INR 16,152 to roughly INR 8,000 per QALY. That is not a rounding error, and it points at the highest-value target for further primary costing work in India. Second, the vaccination price is the only lever a purchaser directly controls, and it moves the ICER almost as much. Third, the clinical efficacy parameters barely matter. Taking single-dose efficacy from 97.5% down to 85% changes the ICER by a modest margin. The economic case for single-dose vaccination in India does not hinge on the remaining uncertainty about single-dose durability. It hinges on prices and on what treatment actually costs.

Table 3: Parameter ranges used in deterministic sensitivity analysis

Parameter	Base case	Range tested	Basis for range
Treatment cost offset per case averted	INR 22,800	INR 11,400 to 45,600	Halving to doubling; the original costing is conservative and omits recurrence, survivorship and patient costs
Vaccination cost per fully immunised girl	INR 630	INR 300 to 1,200	Public procurement plus delivery at scale, to a higher delivery-cost scenario; assumption, not a published range
Discount rate	3%	0% to 5%	Indian Reference Case base case with conventional bounds
Registry AAR	Registry value	-20% to +20%	Registry completeness and case ascertainment
Utility and QALY mapping	Base utilities	-15% to +15%	Borrowed utilities from prior Indian modelling
HPV16/18 attribution	76%	70% to 83%	Indian and global attribution estimates
Single-dose vaccine efficacy	97.5%	85% to 100%	KEN SHE trial and three-year follow-up
Vaccination coverage	90%	30% to 100%	Realistic programme performance; reported separately because it does not move the ICER

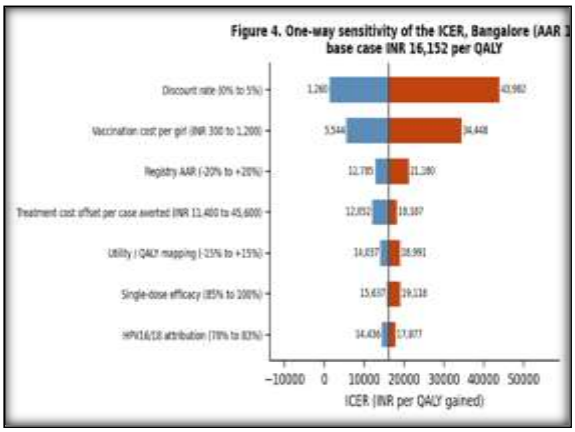


Figure 4: One-way sensitivity of the ICER for Bangalore. Blue bars show the low value of each parameter range and orange bars the high value. The vertical line is the base case of INR 16,152 per QALY.

[Figure 5] shows the same structure at both ends of the gradient. The ranking of drivers is identical, but the absolute spread widens sharply as incidence falls. In Papumpare, the ICER stays under INR 20,000 per QALY across every scenario tested. In Dibrugarh the plausible range crosses INR 100,000 per QALY at unfavourable parameter values. Low-incidence settings are not just less valuable; they are also less certain.

Coverage scenarios: Coverage does not move the ICER at all. This is because, as per Figure 6, under a per-girl costing structure, coverage multiplies cost and benefit by the same factor, so the ratio is invariant. In our replica the Bangalore ICER is INR 16,142 per QALY at 50%, 70%, 90% and 100% coverage alike. This matters practically. Coverage determines how much health is bought and how much budget is spent, not whether the purchase is good value. A programme that reaches half its target does not become poor value for money. It simply delivers half the health. The corollary is that arguments for investing in demand generation and completion monitoring should be made on absolute health gain and equity, not on cost-effectiveness ratios, which are silent on the question.

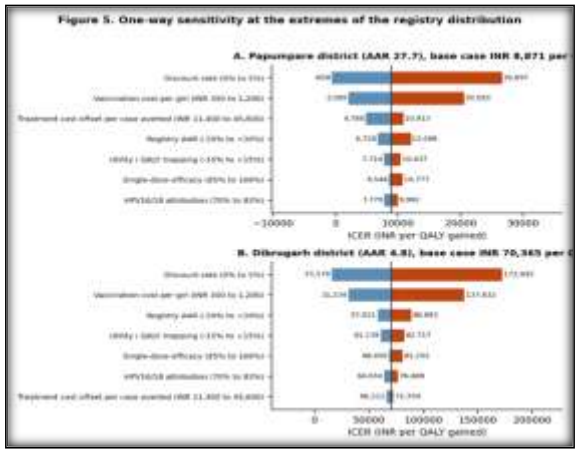


Figure 5: One-way sensitivity of the ICER at the extremes of the registry distribution. Panel A, Papumpare district. Panel B, Dibrugarh district. Note the different horizontal scales

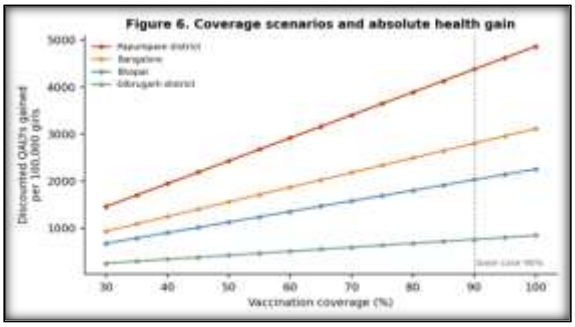


Figure 6: Coverage scenarios and absolute discounted health gain per 100,000 girls. The ICER is unchanged across this range; only the magnitude of benefit and the budget move

Threshold analysis: [Figure 7] plots the ICER against delivered vaccination price for four registries, with three candidate thresholds. Table 4 gives the crossing points.

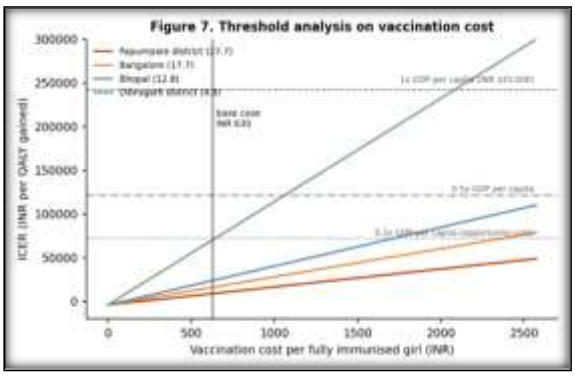


Figure 7: Threshold analysis on vaccination cost per fully immunised girl

Two readings follow. At the base-case price of INR 630, every registry remains cost-effective at one time GDP per capita by a very wide margin, and the price would have to rise by a factor of three to 19 before that changed. But at a conservative opportunity-cost threshold of 0.3 times GDP per capita, Dibrugarh's crossing price is INR 652. The base case of INR 630 sits INR 22 below it. That registry is the one place in the dataset where the verdict is genuinely close, and where the answer depends on which threshold a decision-maker adopts rather than on the evidence.

Vaccination becomes cost-saving, rather than merely cost-effective, at delivered prices between about INR 35 and INR 199 depending on registry. No current procurement scenario reaches that. The programme should be defended as good value, not as self-financing.

Probabilistic sensitivity analysis

Figure 8 shows CEACs from 10,000 iterations. Table 5 gives mean ICERs, 95% credible intervals and the probability of cost-effectiveness at each threshold.

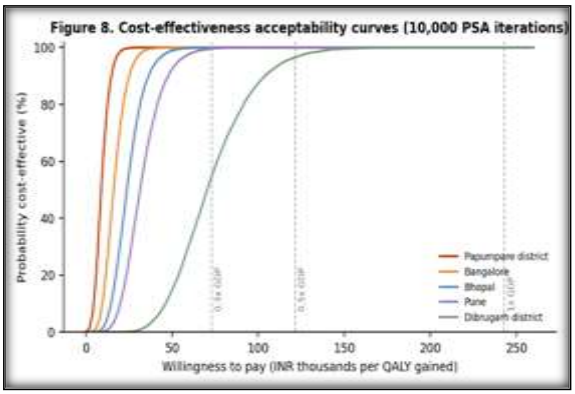


Figure 8: Cost-effectiveness acceptability curves for five registries, 10,000 probabilistic sensitivity analysis iterations

Table 4: Threshold vaccination prices per fully immunised girl. Thresholds of 0.3x and 1x GDP per capita correspond to approximately INR 72,900 and INR 243,000 per QALY

PBCR	AAR	Price at which vaccination becomes cost-saving (INR)	Price at which ICER reaches 0.3x GDP per capita (INR)	Price at which ICER reaches 1x GDP per capita (INR)
Papumpare district	27.7	199	3,744	12,016
Pasighat	20.3	146	2,748	8,819
Bangalore	17.7	127	2,397	7,694
Bhopal	12.8	92	1,735	5,570
Pune	10.0	72	1,357	4,354
Dibrugarh district	4.8	35	652	2,092

Table 5: Probabilistic sensitivity analysis results. Thresholds of 0.3x and 1x GDP per capita correspond to approximately INR 72,900 and INR 243,000 per QALY

PBCR	Base-case ICER (INR/QALY)	PSA mean ICER (INR/QALY)	95% credible interval	P(cost-effective) at 0.3x GDP	P(cost-effective) at 1x GDP
Papumpare district	8,871	9,277	2,696 to 18,441	100%	100%
Bangalore	16,152	16,738	6,869 to 30,739	100%	100%
Bhopal	23,873	24,783	10,839 to 45,269	100%	100%
Pune	31,684	32,861	15,104 to 59,224	99.5%	100%
Dibrugarh district	70,365	73,282	36,196 to 125,986	54.7%	100%

The PSA confirms and sharpens the deterministic picture. Every registry is cost-effective with certainty at one time GDP per capita. At the conservative threshold, four of the five are still effectively certain. Dibrugarh is a coin toss. Mean PSA ICERs run 4% to 5% above base case in every registry, which is the expected consequence of a ratio with a right-skewed denominator and should not be over-read.

Internal consistency of the inherited base case

One reconciliation issue should be recorded rather than smoothed over. The base case reports 88 deaths averted per 784 cases averted in Papumpare, a case fatality of approximately 11%. The extent distribution and extent-specific five-year survival used elsewhere in the model imply a weighted five-year survival of roughly 55%, and therefore a substantially higher share of averted cases translating into averted deaths. In parallel, the reported QALY gain of about 5.6 per case averted is high relative to 11% case fatality but low relative to the roughly 45% implied by the survival inputs.

These two features pull in opposite directions and may partly offset in the ICER, which is why the cost-effectiveness conclusions are unlikely to reverse. They nonetheless mean that deaths averted and QALYs gained in table 2 should not be quoted independently of one another, and that the mortality outputs in particular warrant re-derivation before the PBCR-wise values are used for target setting. We flag this explicitly because the alternative, quietly reconciling the numbers, would misrepresent what the underlying model produced.

DISCUSSION

Replacing a national average with registry-specific calibration does not change whether HPV vaccination is worth doing in India. It changes by how much, and it changes where the answer is fragile. Expected QALY gains vary nearly sixfold across PBCRs, and base-case ICERs vary eightfold, from INR 8,871 to INR 70,365 per QALY. Every registry clears one times GDP per capita comfortably. Only one, Dibrugarh, is close to a conservative opportunity-cost threshold, and even there the probability of cost-effectiveness is 55%, not zero.

The sensitivity analysis adds three things the original could not say. The ICER is invariant to coverage, so coverage arguments belong in the equity and absolute-benefit column rather than the value-for-money column. The largest source of uncertainty is not the vaccine; it is the cost of treating the cancer the vaccine prevents. And the price of vaccination would have to rise several-fold before any registry's conclusion turned.

Interpretation in the context of the 2026 national campaign

The campaign launched on 28 February 2026 targets approximately 11.5 million girls aged 14 years, delivered free at government facilities over an intensive 90-day phase and thereafter through routine immunisation days.[5-8] At the base-case unit cost of INR 630 per fully immunised girl, an annual cohort of 11.5 million implies a vaccination outlay of roughly INR 725 crore, about INR 7.25 billion. This is a first-order estimate from our unit cost assumption. It excludes campaign-mode surge costs, cold chain investment, adverse event monitoring and demand generation, and it should not be read as a budget.

Media reporting in mid-2026 suggested approximately 5 million doses administered in the first three months, close to 43% of the target, with Madhya Pradesh and Gujarat reported at full target achievement and Mizoram at 93%.[36] We have not been able to verify these figures against an official published source, and they should be treated as indicative only. If they hold, they matter in a specific way for this analysis: Mizoram is among the highest-incidence registries in the country, and high coverage there converts directly into the largest health gains available anywhere in the dataset.

The registry-calibrated framing also answers a practical criticism of the campaign, which is that impact cannot be evaluated without a baseline. PBCR data provide exactly that baseline, at district granularity, for the 32 registry areas covered. Anchoring programme evaluation to PBCR incidence trends rather than national aggregates is the most credible route to demonstrating impact in the 2030s and beyond.

Comparison with existing evidence

Our estimates are directionally consistent with prior Indian and international evaluations finding HPV vaccination to be high value where cervical cancer is common.[14-16,29-35] The contribution here is not a new natural-history model. It is a demonstration that registry heterogeneity should be propagated through QALY and DALY estimation rather than averaged away, and that doing so is what reveals the single setting where the threshold choice becomes decisive.

On thresholds themselves, we deliberately avoid the one to three times GDP per capita rule as a decision criterion. That convention has been criticised on the grounds that it does not represent health opportunity cost, and country-level opportunity-cost estimates for low- and middle-income countries have generally come out well below one time GDP per capita.[27-28] Presenting results against a range rather than a single number is not fence-sitting. It is the only honest way to report a result that changes verdict between 0.3- and 1-times GDP per capita in one of 32 settings.

Limitations

First, the model is deliberately parsimonious and is not a full HPV natural-history model. It does not represent infection, clearance, precancer progression, screening interaction or herd effects. Herd effects in particular mean the health gains here are probably conservative.

Second, treatment cost capture is conservative and probably underestimates long-term costs, recurrence, patient expenditure and productivity losses. The tornado diagrams show this is the dominant uncertainty, and correcting it would move ICERs downward, that is, in favour of vaccination.

Third, registry-specific survival was not available for every PBCR, and utilities were borrowed from prior Indian modelling.

Fourth, the sensitivity analyses run on a calibrated replica of the original engine, not on the original

code. The replica reproduces the published base case to within rounding, and the discount rate results additionally depend on our stated 45-year mean lag assumption.

Fifth, the internal consistency issue described above affects the mortality outputs and should be resolved before PBCR-wise deaths averted are used operationally.

Sixth, NCRP AARs from 2012-2016 predate both the current programme and any recent shifts in screening or incidence, and PBCR coverage is not nationally representative. The 32 registry areas are not India. They are the part of India we can measure.

Taken together, these limitations mean the PBCR-wise values should be read as decision-support estimates rather than definitive national health technology assessment values.

CONCLUSION

Single-dose HPV vaccination is cost-effective in every Indian PBCR setting examined, and the conclusion survives extensive deterministic and probabilistic testing. Registry calibration matters not because it changes the verdict but because it changes the magnitude, exposes where the verdict is close, and supplies the district-level baseline against which the 2026 national campaign can eventually be judged. The most useful next step is not a more elaborate vaccine model. It is better Indian data on what cervical cancer costs to treat.

Statements

Patient and public involvement: patients and the public were not involved in the design, conduct, reporting or dissemination plans of this research, because the study used published secondary data only.

Ethics approval: not required for secondary analysis of published and publicly available data.

Data availability statement: all data were drawn from published NCRP reports, official agency publications and peer-reviewed literature cited in the reference list. Registry-wise summary outputs, the calibrated replica engine and the sensitivity analysis code are reproduced in the online supplemental appendix.

REFERENCES

1. World Health Organization. Global strategy to accelerate the elimination of cervical cancer as a public health problem. Geneva: WHO; 2020.
2. World Health Organization. Human papillomavirus vaccines: WHO position paper, December 2022. Wkly Epidemiol Rec. 2022;97(50):645-72.
3. World Health Organization. Cervical cancer. Geneva: WHO; 2025.
4. International Agency for Research on Cancer. India fact sheet. Global Cancer Observatory. Lyon: IARC; 2024.
5. Press Information Bureau, Government of India. Prime Minister Shri Narendra Modi launches nationwide HPV vaccination drive for 14-year-old girls from Ajmer, Rajasthan. New Delhi: PIB; 28 February 2026.
6. Press Information Bureau, Government of India. Cervical cancer vaccination campaign launched. New Delhi: PIB; 28 February 2026.
7. India introduces human papillomavirus vaccination. Lancet Oncol. 2026 (news in brief, published online 12 March 2026).
8. Gavi, the Vaccine Alliance. India, home to 25% of the world's cervical cancer deaths, launches nationwide HPV vaccination. VaccinesWork; 16 March 2026.
9. Mathur P, Sathishkumar K, Chaturvedi M, Das P, Sudarshan KL, Santhappan S, et al. Cancer Statistics, 2020: report from National Cancer Registry Programme, India. JCO Glob Oncol. 2020;6:1063-75.
10. National Centre for Disease Informatics and Research. Report of National Cancer Registry Programme 2020. Bengaluru: ICMR-NCDIR; 2020.
11. National Centre for Disease Informatics and Research. Report of National Cancer Registry Programme 2012-2016: Chapter 8, Cancer cervix uteri. Bengaluru: ICMR-NCDIR; 2020.
12. National Centre for Disease Informatics and Research. Three-Year Report of Population Based Cancer Registries 2012-2014. Bengaluru: ICMR-NCDIR; 2016.
13. International Vaccine Access Center, Johns Hopkins Bloomberg School of Public Health. Celebrating recent advances in cervical cancer prevention. Baltimore: IVAC; January 2026.
14. Prinja S, Bahuguna P, Faujdar DS, Chawla YK, Datta SK, Singh S, et al. Cost-effectiveness of human papillomavirus vaccination for adolescent girls in Punjab state: implications for India's universal immunization program. Cancer. 2017;123(17):3253-60.
15. Chauhan AS, Prinja S, Srinivasan R, Rai B, Malliga JS, Jyani G, et al. Cost effectiveness of strategies for cervical cancer prevention in India. PLoS One. 2020;15(9):e0238291.
16. Munot S, Prasad N, Paudel R, Gaurav S, Saunik S, Paulino-Ramirez R, et al. Cost-utility analysis of free HPV immunization for girls in Rajasthan, India. Cost Eff Resour Alloc. 2026;24(1):25.
17. Sharma D, Prinja S, Aggarwal AK, Rajsekar K, Bahuguna P. Development of the Indian Reference Case for undertaking economic evaluation for health technology assessment. Lancet Reg Health Southeast Asia. 2023;16:100241.
18. Department of Health Research, Government of India. Health technology assessment in India: a manual. New Delhi: DHR, Ministry of Health and Family Welfare; 2018.
19. Sathishkumar K, Sankarapillai J, Mathew A, Nair RA, Gangane N, Khuraijam S, et al. Survival of patients with cervical cancer in India, findings from 11 population based cancer registries under National Cancer Registry Programme. Lancet Reg Health Southeast Asia. 2023;24:100296.
20. Barnabas RV, Brown ER, Onono MA, Bukusi EA, Njoroge B, Winer RL, et al. Efficacy of single-dose human papillomavirus vaccination among young African women. NEJM Evid. 2022;1(5):EVIDoa2100056.
21. Barnabas RV, Brown ER, Schaafsma TT, Amaglo JQ, Njoroge B, Winer RL, et al. Durability of single-dose HPV vaccination in young Kenyan women: randomized controlled trial 3-year results. Nat Med. 2023;29(12):3224-32.
22. Singh MP, Chauhan AS, Rai B, Prinja S. Cost of treatment for cervical cancer in India. Asian Pac J Cancer Prev. 2020;21(9):2639-47.
23. Salomon JA, Haagsma JA, Davis A, de Noordhout CM, Polinder S, Havelaar AH, et al. Disability weights for the Global Burden of Disease 2013 study. Lancet Glob Health. 2015;3(11):e712-23.
24. Office of the Registrar General and Census Commissioner, India. SRS abridged life tables 2016-2020. New Delhi: Government of India; 2022.
25. Ramamoorthy T, Kulothungan V, Sathishkumar K, Tomy N, Mohan R, Balan S, Mathur P. Burden of cervical cancer in India: estimates of years of life lost, years lived with disability and disability adjusted life years at national and subnational levels using the National Cancer Registry Programme data. Reprod Health. 2024;21(1):111.
26. Kulothungan V, Sathishkumar K, Leburu S, Ramamoorthy T, Stephen S, Basavarajappa D, et al. Burden of cancers in India, estimates of cancer crude incidence, YLLs, YLDs and DALYs

for 2021 and 2025 based on National Cancer Registry Program. BMC Cancer. 2022;22(1):527.
27. Woods B, Revill P, Sculpher M, Claxton K. Country-level cost-effectiveness thresholds: initial estimates and the need for further research. Value Health. 2016;19(8):929-35.
28. Bertram MY, Lauer JA, De Joncheere K, Edejer T, Hutubessy R, Kieny MP, Hill SR. Cost-effectiveness thresholds: alternative approaches. Bull World Health Organ. 2016;94(12):925-30.
29. Demarteau N, Detournay B, Tehard B, El Hasnaoui A, Standaert B. A generally applicable cost-effectiveness model for the evaluation of vaccines against cervical cancer. Int J Public Health. 2011;56(2):153-62.
30. Setiawan D, Dolk FC, Suwantika AA, Westra TA, Wilschut JC, Postma MJ. Cost-utility analysis of human papillomavirus vaccination and cervical screening on cervical cancer patient in Indonesia. Value Health Reg Issues. 2016;9:84-92.
31. Colantonio L, Gomez JA, Demarteau N, Standaert B, Pichon-Riviere A, Augustovski F. Cost-effectiveness analysis of a cervical cancer vaccine in five Latin American countries. Vaccine. 2009;27(40):5519-29.
32. Akumbom AM, Lee JJ, Reynolds NR, Thayer W, Wang J, Slade E. Cost and effectiveness of HPV vaccine delivery strategies: a systematic review. Prev Med Rep. 2022;26:101734.
33. Khiari H, Bellali H, Laraj O, Otmani del Barrio M, Saadi A, Mzoughi K, et al. Cost-effectiveness of human papillomavirus vaccination in Tunisia: a modelling study. BMJ Open. 2024;14:e085462.
34. Shetty RS, Nadda A, Tambe M, Raut A, Goel K, Rao CR, et al. IAPSM's position paper on the human papilloma virus (HPV) vaccine for adult immunization in India. Indian J Community Med. 2024;49(Suppl 2):S125-S131.
35. Mongan SP, Habibi R, Setiawan D, Hidayati NR, Kurniasari H, Komariah M, et al. The cost-effectiveness of the human papilloma virus vaccination in Asia Pacific countries: what lessons can Indonesia learn? A systematic review. Vaccines (Basel). 2025;13(6):593.
36. Media reporting on first-quarter progress of India's national HPV vaccination campaign, June 2026. Figures unverified against an official published source and cited as indicative only.
37. 3Ministry of Statistics and Programme Implementation, Government of India. Press note on new series of GDP estimates with base year 2022-23. New Delhi: MoSPI; 27 February 2026.