

Cold Chain Management Practice, Vaccine Wastage, and Mitigation Strategies in Primary Healthcare Facilities: A Systematic Review

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Abstract

Background: Vaccine wastage remains an ongoing challenge to the efficiency of immunization programs in primary health care facilities, and the primary contributing factor is cold chain management. **Objective:** This systematic review summarizes the evidence on cold chain management practices related to vaccine wastage in primary health care facilities and identifies mitigation strategies reported to be effective. **Methods:** A systematic search was conducted in PubMed, Scopus, ScienceDirect, and Google Scholar in accordance with the 2020 PRISMA guidelines, using the Population-Exposure-Outcome framework. Eligible articles were those published between 2016 and 2026 that focused on cold chain practices and vaccine wastage in primary health care facilities. We assessed study quality using the JBI critical appraisal checklist. **Results:** Of the 432 studies identified, 22 met all eligibility criteria for synthesis, covering various regions across Africa, Asia, the Middle East, and Southeast Asia. Vaccine wastage and the quality of cold chain management are driven by four main factors: weak infrastructure, adherence to standard operating procedures, resources, and training of health workers. Strategies for implementing immunization services in the field indicate that wastage rates can be measured. **Conclusion:** Vaccine wastage in primary health care facilities occurs due to recurring factors; improvements in infrastructure- such as solar-powered cold chains-and regular training for health care workers are mitigation strategies supported by the best available evidence, although neither of these measures alone is adequate to achieve the 80% target set by the WHO's EVM standards.

Keywords: cold chain, vaccine wastage, primary healthcare, immunization logistics, systematic review

1. INTRODUCTION

Immunization is the most cost-effective public health intervention for preventing vaccine-preventable diseases. The effectiveness of vaccines depends on maintaining their potency from the production stage through to administration to the target population. Vaccines are biological products that are highly sensitive to temperature fluctuations and exposure to light during distribution. Vaccines must be maintained within a cold chain system to preserve their effectiveness [1].

According to Lloyd & Cheyne, consistent failures to maintain the cold chain can lead to a permanent loss of vaccine potency, which in turn can result in the failure of the entire immunization program [2]. A review by Hanson et al. found that vaccine wastage caused by temperature exposure during storage accounted for 33% of wastage in high-income countries and 37.1% in low-income countries. The review also found that wastage occurred during the transportation process to primary health care facilities, at rates of 38% and 19.3%, respectively [2].

Vaccine wastage also occurred with open-vial vaccines, specifically 21.2% of pentavalent vaccines and 72.6% of BCG vaccines, due to administration methods, package sizes, and service strategies at primary and secondary health facilities in Nigeria [3]. In Papua New Guinea, the Outbreak Response Immunization program also reported that 55% of the distributed measles vaccines were damaged due to cold chain failures [4].

In addition to reports on the causes of vaccine wastage, several studies conducted at 576 primary and secondary

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health facilities also showed that providing training to health workers in Uganda successfully improved cold chain management, although it still fell short of the minimum 80% target set by the WHO [5]. Kapuria B also found that the use of solar-powered refrigeration equipment in Lebanon can reduce vaccine wastage and improve temperature stability [6]. In Egypt, administering immunizations per session from an open vial reduces vaccine wastage and cost wastage [7].

Existing systematic reviews on vaccine cold chain, notably McCarney et al. and a more recent meta-analysis restricted to knowledge among health professionals in Ethiopia, have not specifically synthesized evidence linking cold chain management practices to wastage outcomes across multiple countries in primary healthcare settings [8,9]. This review addresses that gap, by specifically investigating what and how cold chain management practices contribute to vaccine wastage at primary health care facilities, as well as which mitigation strategies have been reported to be effective in addressing both issues.

In Indonesia specifically, pharmaceutical distribution and storage practise are governed by Good Distribution Practice (CDOB) standards, though compliance has been reported to vary accros pharmaceutical wholesalers [10], and implementation of pharmaceutical service standards at the primary care lever – covering both clinical pharmacy and management of pharmaceutical supplies – has similarly shown incomplete to national regulations [11].

2. METHODS

2.1. Study Design

This study, which employs a systematic review design, follows the PRISMA 2020 guidelines and is structured according to the Population-Exposure-Outcome (PEO) framework: the population consists of primary health care facilities and health workers who manage vaccines; vaccine management practices serve as the exposure; and the outcomes are vaccine wastage rate and/or cold chain management compliance scores..

2.2. Eligibility Criteria

Primary studies were included if they met the following criteria: (1) original quantitative, qualitative, or mixed-methods research; (2) conducted in primary healthcare facilities (e.g., Puskesmas, health posts, or primary clinics); (3) published in peer-reviewed journals between January 2016 and July 2026; and (4) written in English or Indonesian. Non-primary studies (editorials, review articles) and grey literature (un-peer-reviewed theses or conference abstracts) were excluded.

2.3. Search Strategy

Systematic searches were conducted across PubMed, Scopus, ScienceDirect, and Google Scholar, with the final update search in July 2026. Searches yielded 432 records; after duplicate removal ($n = 34$), 398 records were screened by title and abstract. Full-text assessment was conducted for 37 records, of which 15 were excluded (table 1), including five grey-literature dissertations without a corresponding peer-reviewed version and two records found to report the same study. Supplementary citation tracking identified three additional candidate studies from Indonesia, of which two met eligibility criteria. Ultimately, 22 studies met all eligibility criteria for qualitative synthesis.

Table1. Search keywords

No	Sources	Boolean
1	Scopus	"cold chain" AND "vaccine" AND "waste" AND "management"
2	Pubmed	"cold chain management" AND "knowledge and practice" AND "primary health care"
3	ScienceDirect	"vaccine wastage" AND "cold chain management" AND "primary health care" AND "practice"
4	Google Scholar	"cold chain" "vaccine wastage" ("primary health care" OR "primary healthcare" OR Puskesmas)

2.4. Quality Assesment and Data Synthesis

Methodological quality was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Tool and the Mixed Methods Appraisal Tool (MMAT), which was applied to mixed-methods studies. The findings were then

synthesised narratively and grouped according to the domains of infrastructure, human resources, compliance with standard operating procedures (SOPs), and distribution or governance policies.

3. RESULT

Figure 1 illustrates the search and screening process: of the 22 papers included, 8 studies measured the level of vaccine wastage (Stream A), whilst 14 studies evaluated the quality of cold chain management practices (Stream B). These articles covered twelve countries in Sub-Saharan Africa, the Middle East, South Asia, South-East Asia and the Pacific.

Table 2. Summary of Included Study Characteristics

No	Author	Country	Design	Stream	Key Findings
1	Sinnei et al. (2023)[12]	Kenya	Cross-sectional	B	Cold Chain Equipment preventive maintenance gaps; Funding Constraints & Technicians
2	Ali Qanbar et al. (2023)[13]	Irak	Cross-sectional	B	Poor management of vaccines/diluents; Cold chain fair in the majority of facilities
3	Adebimpe & Adeoye (2021)[14]	Nigeria	Cross-sectional	B	Knowledge of vaccination logistics varies between PHC health workers
4	Daniel et al. (2024)[5]	Uganda	Cross-sectional	B (mitigation)	Cold chain score of 65.3% (below the EVM target of 80%); Multi-modality training improves scores
5	Geneti et al. (2024)[15]	Ethiopia (Sheger)	Cross-sectional multicenter	B	Variation in knowledge/practice related to the availability of training & infrastructure
6	Iwu et al. (2020)[16]	Afrika Selatan (OR Tambo)	Cross-sectional	B	Stock-out & stock management are the main challenges
7	Feyisa et al. (2022)[17]	Ethiopia (Silt'e)	Cross-sectional	B	Compliance with WHO storage codes varies between facilities
8	Ergetie et al. (2023)[18]	Ethiopia (Northwest)	Observational (self-report vs actual)	B	Gap between self-reported practices vs. actual practices
9	Feyisa (2021)[19]	Ethiopia (Jimma)	Mixed-method multicenter	B	Cold chain maintenance & stock management varies between facilities
10	Kapuria et al. (2024)[6]	Lebanon	Multi-phase implementation	A (mitigation)	Cold chain solarization lowers wastage & stabilizes storage temperature
11	Osei et al. (2019)[20]	Ghana (Tolon)	Descriptive (WHO-EVM)	B	Temperature control score, stock, distribution all below WHO standard 80%
12	Kamac et al. (2017)[4]	Papua New Guinea	Descriptive (outbreak response)	A	55% of doses wasted (85,236 doses) due to multiple cold chain logistics failures
13	Buledi et al. (2017)[21]	Pakistan (Quetta)	Cross-sectional	B	The status of the cold chain of EPI was assessed at the routine immunization center
14	Mohammed & Workneh (2021)[22]	Ethiopia (Oromia)	Qualitative phenomenology	A	Wastage contributing factors: logistics, practices, vial size, HR, institutions
15	Lambo et al. (2024)[3]	Nigeria	National mixed-methods study	A	Open-vial wastage 21.2% (pentavalent)-72.6% (BCG); determinants: vial size, service strategy, HR
16	Nestory et al. (2022)[23]	Tanzania (Morogoro, n=77 fasilitas)	Cross-sectional	B	84% of facilities have functional refrigerators; The knowledge of health workers is generally good
17	Radwan et al. (2020)[7]	Mesir	Cross-sectional	A	The practice of managing vaccination sessions is directly related to wastage rate and cost
18	Mohammed et al. (2022)[24]	Ethiopia (Oromia Special Zone)	Explanatory sequential mixed-methods	A	Comprehensive wastage contributing factors (follow up to 2021 phenomenological study)

19	Asamoah et al. (2021)[25]	Ghana (Sekyere Central)	Mixed-method concurrent	B	Knowledge and good attitude, but weak association with actual practice
20	Rahmat et al. (2023)[26]	Indonesia (Kupang, 11 Puskesmas)	Cross-sectional	B	8 of the 27 storage criteria & 3 of the 8 distribution criteria have not been met; Thermometer calibration & SOP in the spotlight
21	Sambara et al. (2018)[27]	Indonesia (Kupang, 2 Puskesmas)	Descriptive observational	B	Storage profiles are generally available; One facility has no freeze tag/freeze watch and backup generator
22	Syakur et al. (2021)[28]	Indonesia (Jember)	Descriptive qualitative	B	Cold chain facilities are available; Vaccine logistics management is still considered not optimal

Across the 22 included studies, cold chain management practices and vaccine wastage were shaped by four recurring determinant domains: infrastructure and equipment, human resources and training, SOP compliance, and service delivery strategy. Table 2 summarizes the characteristics of all 22 include studies, including country, study design, outcome stream, and key findings.

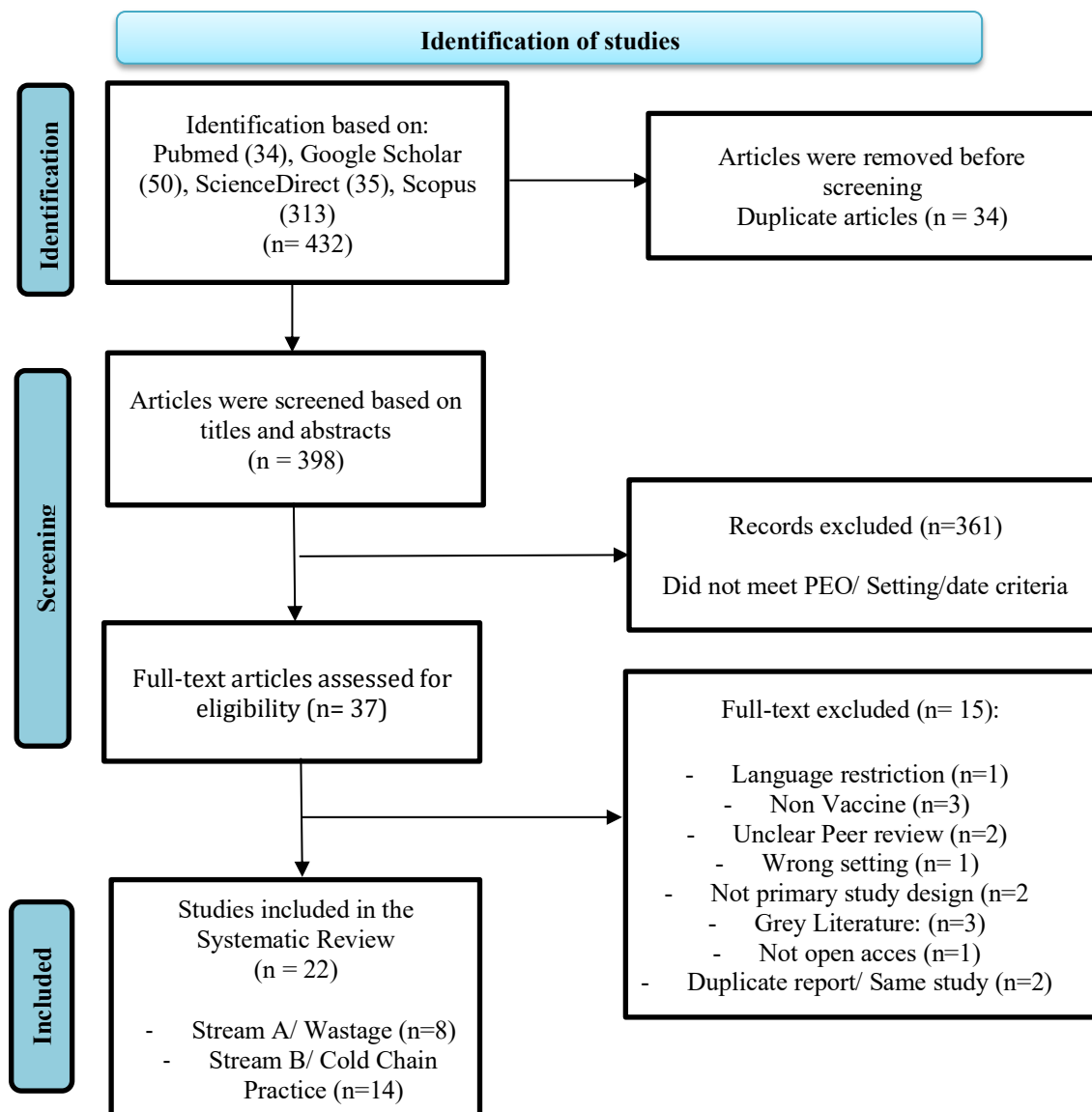


Figure 1. Diagram PRISMA 2020

3.1. Equipment and Infrastructure: Necessary but Not Sufficient

A high-quality vaccine refrigerator can ensure safe storage, but it is not the only factor. In Kenya, most health care facilities have vaccine refrigerators that function properly, but maintenance is not performed according to schedule, making them vulnerable to sudden and undetected equipment failure [12]. In the OR Tambo District of South Africa, vaccine stockouts did not occur due to a lack of vaccine refrigerators but rather due to poor distribution scheduling [16]. In Papua New Guinea, vaccine wastage occurred during a measles emergency, resulting in 55% of vaccine doses being damaged during distribution [4]. These infrastructure-related losses demonstrate that ensuring equipment resilience during periods of high pressure and surges in demand requires separate planning beyond routine operational activities.

3.2. Staff Capacity: Training Alone Does Not Bridge the Gap

Training for healthcare workers has yielded better results, but has not yet closed the gap regarding vaccine management standards. In Uganda, training successfully improved the cold chain management score to 65.3%, but it remains below the WHO's Effective Vaccine Management (EVM) standard of 80% [29]. Scores for temperature control, stock management, and distribution in Ghana are also below the EVM standard despite training having been provided to healthcare workers [20]. However, the situation in Tanzania indicates that high levels of knowledge do not necessarily translate into good practice. Health facilities with vaccine refrigerators and good knowledge accounted for 84%, yet this was not reflected in the actual waste observed [23]. A study in Ethiopia comparing self-reported data with direct observations of health workers found significantly different results. Self-reports overestimated staff compliance rates [18]. A similar pattern emerged in Ghana, where healthcare workers demonstrated excellent knowledge and positive attitudes, but their daily practices were poor [25].

3.3. SOP Compliance and Session-Level Realities

The conduct of immunization sessions by health workers has a direct impact on vaccine wastage. In Iraq, researchers found that the management of immunization sessions in most health facilities was very poor [13]. In Egypt, direct observations demonstrated that mismanagement correlates with higher levels of wastage and also leads to a surge in costs. This serves as evidence that vaccine storage temperature in vaccine management is a determining factor in vaccine wastage from an economic perspective.

An assessment in Nigeria supports these findings; wastage of open-vial vaccines was more than three times higher depending on the vaccine type, ranging from 21.2% for Pentavalent to 72.6% for BCG. This is influenced by how vaccines are administered; vaccination conducted in the field results in greater wastage compared to vaccination services at health facilities [4]. In Oromia, Ethiopia, it was concluded that vaccine wastage is influenced by a combination of logistics, the implementation of vaccination sessions, vial size, healthcare workers' knowledge, and management support [22,24].

3.4. Proven Mitigation Strategies

These studies demonstrate that interventions are effective in reducing vaccine wastage. In Lebanon, the shift to solar-powered vaccine refrigerators successfully stabilized storage temperatures, thereby reducing vaccine wastage in healthcare facilities [6]. Similar results were observed in Uganda, where more structured training proved more effective than standard orientation in enhancing the capacity of healthcare workers [5]. These findings suggest that improving infrastructure and building capacity are strategies that can yield better results.

Overall, the thematic synthesis of the 22 reviewed studies is illustrated in Figure 2 below, which shows how these determining factors collectively influence the quality of cold chain management practices and vaccine wastage, while also illustrating the role of the reported mitigation strategies.

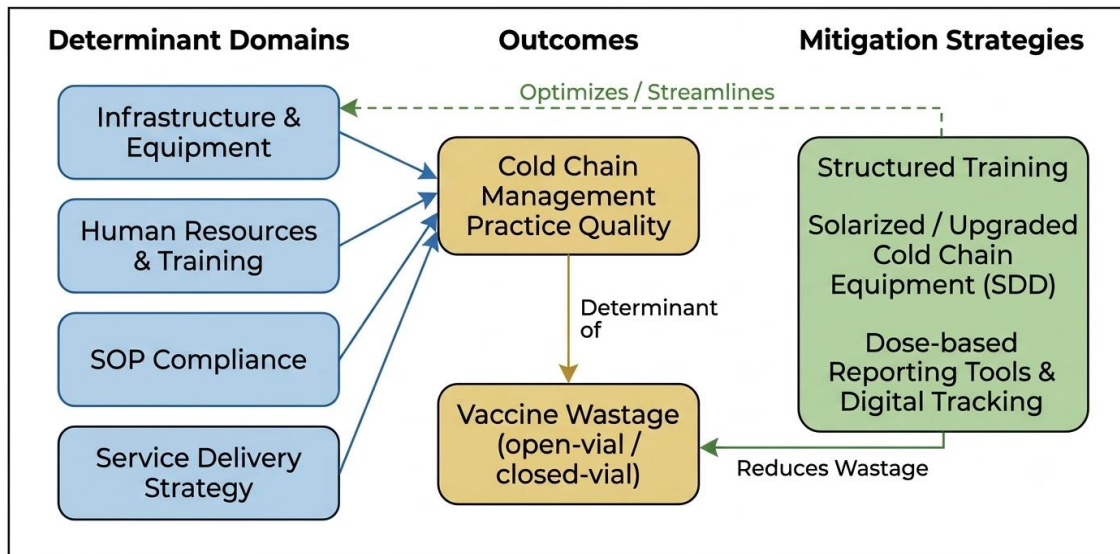


Figure 2. Conceptual synthesis framework: Determinant Domains, Outcomes, Mitigation Strategy

4. DISCUSSION

Vaccine wastage in health facilities, as identified in this review, results from a combination of infrastructure limitations, human resource capacity constraints, and vaccination practices in the field. This pattern is consistent across various geographic contexts and health systems in different regions. A meta-analysis found that healthcare workers in Ethiopia had knowledge of cold chain management but did not examine whether this was related to vaccine wastage. This review provides broader evidence by synthesizing data from twelve countries that examined both practices and outcomes related to vaccine wastage [9]. In addition, a key issue in the literature that needs to be highlighted is that most studies evaluating cold chain quality rely on self-reported data or written knowledge tests rather than observing the behavior of healthcare workers or physically measuring wastage. When researchers compare what healthcare workers report with their actual practices, a more significant gap in compliance becomes apparent. The high knowledge scores in some studies are described as overly optimistic and do not automatically reduce vaccine wastage [23,25]. Only four studies Sayet, Lambo et al., and those from the Oromia region link daily cold chain management practices to measurable levels of wastage. Meanwhile, other studies merely considered self-reported knowledge or practices of healthcare workers as the final outcome [3,7,22,24]. Figure 2 summarizes how the four determinant domains identified across the included literature relate to these two outcome streams and to the mitigation strategies reported effective in this review.

4.1. Connecting Global Evidence to the Indonesian Context

The evidence in this review was dominated by African countries, and only three articles on health facilities in Indonesia also found non-compliance with vaccine storage and distribution guidelines. These local findings align closely with the global evidence synthesized in our framework. For instance, a recent evaluation at the primary healthcare level in Indonesia revealed that despite high physical infrastructure compliance, critical technical vulnerabilities remain—including temperature monitoring devices that had never been calibrated since procurement, the absence of specific maintenance SOPs for vaccine refrigerators, a lack of local spare parts, and hazardous practices such as sharing electrical outlets between vaccine refrigerators and loggers, which elevates short-circuit risk [30].

These facility-level operational gaps are further amplified by macro-level supply chain challenges. According to Indonesia's National Immunization Strategy, supply chain monitoring received the lowest score among all vaccine management indicators aligned with the EVM. This poor performance is related to the implementation of an integrated logistics management system as well as nationwide shortages of essential vaccines. In addition, healthcare workers' compliance with the national logistics platform (SMILE) remains uneven, and data is rarely entered in real time [31].

Indonesia's geographical conditions which include an archipelago and hard to reach areas contribute to vaccine wastage. According to the National Immunization Strategy, distribution delays occur in remote areas, and the Ministry of Health recommends maintaining a reserve stock for remote and isolated regions. Ensuring vaccine integrity involves not only monitoring vaccine refrigerators but also ensuring that distribution via land and water routes is equipped with vaccine carriers. When vaccines arrive at health facilities, power outages are a frequent challenge; in addition, health facilities also face staff turnover or transfers of healthcare workers[31].

If national policies fail to account for these challenges, even the "last mile" of immunization programs will be disrupted, leading to the failure to achieve herd immunity. Basic immunization coverage in 2024 reached only 63.6% of the national target of 75%, and there were 131 diphtheria outbreaks in 25 provinces and 53 measles outbreaks in 16 provinces (27). This serves as evidence of coverage gaps and vaccine supply chain failures occurring nationwide. Vaccine wastage requires an approach that goes beyond static, facility-based audits. We must prioritize distribution resilience, solar-powered vaccine refrigerators for health facilities with limited electricity supply, and the implementation of more observational supervision and direct on-site monitoring.

4.2. Study Limitations

First, pronounced heterogeneity in study design, outcome definition, and wastage measurement methodology precluded meta-analytic pooling; findings were therefore synthesized narratively, which, while appropriate given the evidence base, limits the precision of any cross-study effect comparison. Second, restricting eligibility to English- and Indonesian-language, peer-reviewed journal articles - deliberately excluding grey literature such as theses and dissertations, may have omitted relevant programmatic evaluations, particularly from countries where doctoral research is not routinely converted into journal publications; five studies were excluded from synthesis on this basis alone. Third, the predominance of cross-sectional designs across Stream B studies limits causal inference regarding the direction of association between practice and wastage; only the Lebanon and Uganda studies employed implementation designs capable of supporting stronger causal claims regarding mitigation effectiveness [5,6].

5. CONCLUSION

We summarized findings from 22 articles across twelve countries to identify how cold chain management practices influence vaccine wastage occurring in primary health care facilities. We found that vaccine wastage is influenced by infrastructure, health worker training, compliance with SOPs, and vaccination implementation. Of these four factors, daily practices during service sessions and the selection of service strategies have a direct and measurable impact on the level of vaccine wastage.

Although infrastructure provisions such as solar-powered vaccine refrigerators and health worker training have the strongest evidence of success, these two interventions are the only ones that can meet the standards for effective vaccine management in accordance with WHO standards.

For Indonesia itself, simply issuing standard guidelines is not enough; policy makers must actively build distribution resilience in remote health facilities. Crucial steps to reduce vaccine wastage and close immunization gaps include providing solar-powered vaccine refrigerators, implementing real time digital tracking through SMILE, and improving compliance checklists for healthcare workers that are directly observed and monitored.

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