Increasing the Coverage and Quality of Immunization Programs by Implementing Effective Vaccine Management (EVM) in Central Java

Novia Handayani[1*], *Ayun* Sriatmi[2], *Martini* Martini[3], *Aditya* Kusumawati[1], and *Erlin* Friska[4]

[1]Department of Health Promotion and Behavioral Sciences, Faculty of Public Health, Universitas Diponegoro, Semarang, Indonesia
[2]Department of Administration and Health Policy, Faculty of Public Health, Universitas Diponegoro, Semarang, Indonesia
[3]Department of Epidemiology and Tropical Disease, Faculty of Public Health, Universitas Diponegoro, Semarang, Indonesia
[4]Center of Health Research, Institute for Research and Community Service, Universitas Diponegoro, Semarang, Indonesia

Abstract. Immunization programs are highly dependent on an effective and efficient supply chain system for storing, transporting, and distributing vaccines. This ensures that the right products are available in the right place, at the right time, and under the right conditions to provide efficient health services to the public. This study aims to evaluate the implementation of Effective Vaccine Management (EVM) in Central Java and identify its obstacles. This study used a quantitative method with a cross-sectional approach. A descriptive analysis of vaccine management was carried out in 35 regencies/cities in Central Java. The population comprised EVM programmers in Central Java selected using the total sampling technique. Data were collected using the World Health Organization (WHO) assessment tools and in-depth interviews with pharmacy departments or person in charge of immunization programs in each regency/city. The results showed that five of the 35 regencies/cities had an average score of 80% and above across nine assessment indicators, but no region met the WHO standards of 80% across all the criteria assessed. The overall EVM assessment revealed that 20% of the regencies/cities fell into the low category, 65.7% in the medium category, and 14.3% in the high category. Each region had different problems in fulfilling the nine criteria of EVM assessment, such as inadequate infrastructure, lack of periodic vaccine stock recording, absence of standard operating procedures, and insufficiently trained officers. Therefore, support is needed from the Central Java Provincial Government in providing support to the regions with regular

*Corresponding author: novia.handayani@live.undip.ac.id

monitoring and evaluation of the EVM implementation. Additionally, officers need to be trained regarding proper vaccine management.

1 Introduction

Immunization coverage in Indonesia has experienced significant fluctuations from 2019 to 2023, largely influenced by the COVID-19 pandemic. In 2019, immunization rates were relatively stable, but the pandemic caused a dramatic decrease in coverage due to disruptions in healthcare services. By 2020, the coverage of fully immunized children had dropped to 84.2%, and the number of zero-dose children increased to 26% by 2021. To address this situation, the Indonesian Government initiated the *Bulan Imunisasi Anak Nasional* (National Immunization Month for Children/BIAN) catch-up immunization campaign in 2022, which improved coverage to 94.6%, exceeding the national target [1,2].

In Central Java, the province has mirrored national trends. It was among the provinces most affected by disruptions to immunization services during the pandemic. In 2021, the coverage of fully immunized children was only 88.2% [3]. Efforts, including the catch-up campaigns and targeted provincial strategies, were implemented to restore immunization levels. By 2022, the province had resumed much of its immunization activities, aiming to reduce the gap in coverage caused by the pandemic [4].

Previous evaluations of immunization programs in Indonesia have revealed several factors contributing to the suboptimal quality of these programs. Key issues include inadequate training for healthcare workers, insufficient cold chain management, and poor community outreach efforts. For example, a study highlighted the challenges in vaccine logistics and stock management, which directly impacted immunization coverage [5]. The success of immunization programs depends greatly on organized and efficient supply chain systems. These systems are responsible for storing, transporting, and distributing vaccines and medical supplies, ensuring that the right products are available at the right time and under the right conditions to provide communities with reliable healthcare [6].

A strong vaccine supply system is a vital element of immunization programs, ensuring that vaccines reach their destinations in suitable condition for use.7 The Effective Vaccine Management (EVM) initiative, launched in 2010 by the World Health Organization (WHO) and United Nations Children's Fund (UNICEF), provides a comprehensive assessment of vaccine supply management systems in low- and lower-middle-income countries. Its objective is to pinpoint gaps in supply chain performance and lay the groundwork for necessary improvements [8]. EVM helps in improving the quality of cold chain vaccines within immunization programs [9].

The EVM initiative evaluates nine criteria for effective vaccine management, ranging from national systems to service delivery points, and compares their performance to global standards. These criteria include: (i) vaccine arrival procedures to ensure every shipment from manufacturers reaches national stores in optimal condition; (ii) temperature monitoring to ensure vaccines and diluents are stored and distributed within recommended temperature ranges; (iii) adequate cold storage, dry storage, and transport capacity for vaccines and immunization supplies; (iv) suitability of buildings, cold chain equipment, and transport systems; (v) maintenance of buildings, cold chain equipment, and vehicles; (vi) stock management systems; (vii) vaccine distribution across all levels of the supply chain; (viii) implementation of appropriate vaccine management policies; and (ix) effective information systems and supportive management functions [8,10]. The EVM initiative is vital for assessing supply chain performance, identifying weaknesses, improving vaccine quality and availability, strengthening training and capacity building, and guiding policy and program improvements [11]. However, the implementation of EVM in Central Java has not been monitored and evaluated. Therefore, it is crucial to optimize supply chain management to support full basic immunization coverage in Central Java through EVM. This study aims to evaluate the implementation of EVM in vaccine management in Central Java and identify its obstacles.

2 Materials and Methods

This study used a descriptive method with a cross-sectional approach conducted in Central Java Province, Indonesia, in May 2023, to evaluate vaccine management knowledge and practices. A total of 35 regions were involved, and various healthcare facilities were surveyed using the WHO's EVM tools. All healthcare workers responsible for vaccine handling were interviewed, including 70 immunization program managers from regency/city health offices.

This study used the EVM assessment tool developed by the WHO and UNICEF in 2010. This Windows-based program evaluates supply chain systems through standardized questions in Excel workbooks, assessing each level of the supply chain, from national systems to service delivery points. The tool sets standards for nine aspects of vaccine management based on quality management principles, including vaccine arrival procedures, storage temperature, storage capacity, buildings, equipment, transportation, maintenance, stock management, distribution, vaccine management practices, information systems, and management support. Healthcare workers responsible for vaccine management at all levels used to the tool to assess these aspects. In addition to interview, observations of cold chain facilities and a desk review of relevant documents were conducted. Data were categorized into three levels based on the WHO standards: low (<61), medium (61-79), and high (>79) [12]. The data were analyzed descriptively using univariate analysis.

3 Results

3.1 Summary of Consolidated EVM Scores

The WHO recommends a minimum score of 80% for each criterion of EVM.11 Out of the 35 regencies/cities in Central Java, 7 (20%) fell into the low category, 23 (65.71%) into the medium category, and 5 (14.29%) into the high category. Brebes Regency had the highest average score at 86%, while Boyolali Regency had the lowest average score at 49%, as shown in Table 2. Table 1 shows that no region met the WHO standards across all criteria. However, certain regions met the standards of specific individual criteria.

3.2 Temperature

Scores for temperature control ranged from 56% to 100%, with 12 regions failing to meet the WHO standards. The issues identified included the limited number of temperature monitoring devices. Ideally, each cold chain facility should be equipped with a temperature monitoring device that can be checked continuously. In several regions, temperature data analysis was not performed. As a result, deviations and their causes were not identified. Additionally, vaccine managers in some regions, such as Kendal Regency and Tegal City, lacked awareness of the correct storage temperatures required for different vaccine.

Maintaining the correct temperature for vaccines is essential because vaccines are sensitive biological products that can lose their efficacy if exposed to inappropriate conditions. Most vaccines are vulnerable to heat and freezing, and deviations from the recommended temperature range of +2°C and +8°C can lead to a reduction in their potency. When potency is compromised, the vaccines may fail to induce the necessary immune response, rendering them ineffective in preventing diseases [13,14] Awareness of freezing temperatures remains a major issue in the supply chain, affecting both developing and developed countries [15].

3.3 Storage Capacity

In terms of storage capacity, 21 out of 35 regions in Central Java met the WHO standards. Rembang Regency had the lowest score at an average of 39%. Factors contributing to non-compliance with the standards included a lack of dedicated cold chain equipment for the production of cold and freeze boxes, the absence of standard operating procedures (SOPs) for managing emergency vaccine situations in several areas, and a lack of dedicated personnel to handle such conditions.

If the storage capacity does not meet EVM standards, it can pose significant challenges in vaccine distribution and safety. Insufficient storage capacity can cause overcrowding in vaccine refrigerators, which risks inappropriate temperature control [16].

3.4 Buildings, Equipment, Transport

The scores for buildings, equipment, and transport across the regencies/cities in Central Java ranged from 55% to 100%, with 11 regions failing to meet the WHO standards. These regions include Banyumas, Kebumen, Kendal, Pemalang, Temanggung, Blora, Boyolali, Demak, Sragen, Sukoharjo, and Salatiga. The issues identified include the lack of refrigerated vehicles, deteriorating buildings, insufficient generators to power all equipment at vaccine storage sites, freezers not connected to stabilizers, the lack of fire extinguishers, poorly maintained program vehicles, and absence of service logbooks.

Maintaining buildings, equipment and transport is essential because failure to meet EVM standards can severely compromise vaccine safety and distribution. Inadequate building infrastructure, such as poorly designed storage facilities with inadequate insulation or unreliable temperature control, can expose vaccines to temperature fluctuations, risking their potency. Similarly, failure to comply with transport standards can result in vaccines being exposed to unsafe conditions during transit, such as excessive heat or freezing [17].

3.5 Maintenance

In the maintenance criterion, 27 regions did not meet the WHO standards, with scores ranging from 13% to 100%, indicating diverse conditions in Central Java. The regions with the lowest scores were Demak Regency (13%), followed by Boyolali (35%) and Jepara (38%). Focus group discussion (FGD) results showed that resources for maintenance were limited, both in terms of budget and human resources. Additionally, there was a lack of documents and documentation for building and cooling equipment maintenance, including missing maintenance plans. Therefore, it is necessary to develop a maintenance plan for buildings, cooling equipment, and vaccine transport vehicles.

3.6 Stock Management

A total of 20 regencies/cities met the standards for this criterion, with Magelang and Semarang City achieving perfect scores of 100%. The scores ranged from 52% to 100%, with Banyumas having the lowest score. Issues related to stock management include the absence of solvent reports, untrained staff, incomplete labeling and vaccine stock records, discrepancies between the number of vaccines and solvents, vaccine stockouts, and failure to follow the FEFO (First Expired, First Out) method for inventory management.

These findings are consistent with the findings of studies in Nigeria and Ghana, where stock management had an average score of 32% [18,19]. Effective vaccine stock management and procedures are essential for the vaccine supply chain system. This includes proper vaccine handling, accurate physical inventory, effective stock control systems, appropriate stock level management, good warehousing practices, and proper disposal of damaged or expired vaccines, all in accordance with global standards. Failure to meet these standards can result in critical issues such as overstocking, stockouts, and wastage.

3.7 Distribution

Vaccine distribution in Central Java begins with collection from the Provincial Health Office, with each region scheduled for collection once a month. A total of 24 regencies/cities met the standards for this criterion, while 11 regions scored below 80%. Challenges faced by the regency/city health offices include the lack of refrigerated vehicles for vaccine distribution, insufficient allocation of vaccines with healthcare facilities required to independently collect them from district vaccine warehouses, staff unawareness of the proper use of cool packs and cool boxes, lack of distribution schedules to healthcare facilities (using a request-based system instead), and the absence of SOPs for vaccine packaging during distribution.

These findings are consistent with the findings of studies in Nigeria and Ghana where average distribution scores remained below standard (80%), with Nigeria scoring 27% and Ghana scoring between 13% and 46% [18,19]. Without adherence to these standards, vaccines may be exposed to inappropriate temperatures, such as excessive heat or freezing, during transportation, reducing their efficacy or rendering them unusable. This can result in increased vaccine wastage, delays in reaching healthcare facilities, and missed vaccination opportunities, particularly in remote or underserved areas [14].

3.8 Vaccine Management

Vaccine management is equally important to consider, but the conditions in Central Java showed that 21 out of 35 regencies/cities did not meet the standards for this criterion. The scores ranged from 41% to 100%, with Grobogan Regency scoring the lowest at 41%, while Brebes and Surakarta City achieved perfect scores of 100%. Issues encountered in the field include staff unawareness of the shake test, incomplete record-keeping, no calculation of vaccine wastage during the assessment period, no posters or stickers about reading Vaccine Vial Monitors (VVMs) in vaccine collection areas, and not receiving supportive supervision visits.

These findings are consistent with the findings of studies in Nigeria and Ghana where the vaccine management scores also failed to meet EVM standards. In Nigeria, the average score for vaccine management was 16%, while in Ghana, it was 53% [17,18]. Poor vaccine management can lead to inadequate stock control, improper storage conditions, and ineffective distribution, all of which compromise vaccine potency and availability. This increases the likelihood of vaccine wastage, stockouts, and delays in vaccination efforts.

3.9 Management Information System (MIS) and Supportive Function

Scores for this criterion varied significantly across regencies/cities in Central Java, ranging from 9% to 100%. Salatiga City had the lowest score at 9%, while several areas achieved 100%, including Semarang City, Surakarta City, Sukoharjo, Pati, Blora, Temanggung, Wonosobo, and Pemalang. Factors contributing to not meeting the standards include failure to use vaccination coverage data and the previous year's usage index for vaccine needs estimation, incomplete SOPs for vaccine management, and the absence of methods for calculating the number of syringes and safety boxes. The scores for vaccine management and information systems in Ghana was approximately 16%. Inadequate MIS and poor supportive function could negatively impact immunization programs due to inaccurate vaccine forecasting, avoidable stockouts, and inefficient management of vaccine waste [17].

Table 1. Average EVM scores by category in Central Java

Category	Frequency	%	Mean	SD
Low (<61)	7	20%	70.23	9.065
Middle (61-79)	23	65,71%		
High (>79)	5	14,29%		
Total	35	100%		

Table 2. Summary of consolidated EVM scores by region in Central Java

District	E1	E2	E3	E4	E5	E6	E7	E8	E9	Mean
Banjarnegara	0%	67%	100%	92%	81%	66%	80%	77%	77%	71%
Banyumas	0%	72%	67%	73%	45%	52%	71%	70%	23%	53%
Batang	0%	100%	100%	94%	95%	89%	97%	99%	45%	80%
Brebes	0%	100%	100%	100%	97%	95%	95%	100%	90%	86%
Cilacap	0%	86%	75%	80%	42%	70%	100%	88%	91%	70%
Kebumen	0%	67%	75%	75%	69%	73%	65%	60%	45%	59%
Kendal	0%	72%	83%	77%	46%	82%	95%	94%	91%	71%
Pemalang	0%	81%	83%	73%	65%	77%	74%	87%	100%	71%
Purbalingga	0%	100%	67%	94%	71%	90%	100%	88%	89%	78%
Rembang	0%	86%	39%	84%	71%	71%	59%	90%	90%	66%
Semarang	0%	100%	100%	97%	79%	100%	95%	76%	43%	77%
Temanggung	0%	67%	100%	79%	45%	55%	40%	50%	100%	60%
Wonosobo	0%	81%	92%	99%	68%	75%	100%	85%	100%	78%
Tegal	0%	94%	92%	96%	90%	82%	86%	88%	55%	76%
Pekalongan City	0%	100%	83%	91%	77%	88%	95%	76%	91%	78%
Tegal City	0%	89%	78%	82%	62%	82%	63%	89%	100%	72%
Blora	0%	86%	100%	71%	78%	56%	86%	47%	100%	69%
Boyolali	0%	67%	58%	55%	35%	57%	52%	68%	46%	49%
Demak	0%	81%	67%	67%	13%	72%	69%	45%	89%	56%
Grobogan	0%	67%	78%	93%	55%	81%	94%	41%	91%	67%
Jepara	0%	100%	67%	100%	38%	86%	42%	83%	89%	67%
Karanganyar	0%	61%	100%	90%	70%	95%	96%	77%	77%	74%
Klaten	0%	81%	92%	89%	76%	80%	88%	49%	89%	72%
Kudus	0%	100%	75%	100%	83%	90%	56%	60%	89%	73%
Magelang	0%	100%	100%	98%	100%	84%	96%	73%	55%	78%
Pati	0%	86%	100%	98%	58%	84%	93%	98%	100%	80%
Pekalongan	0%	56%	58%	80%	39%	58%	58%	68%	55%	52%
Purworejo	0%	94%	100%	86%	64%	88%	89%	55%	32%	68%
Sragen	0%	100%	92%	75%	73%	100%	95%	73%	32%	71%

District	E1	E2	E3	E4	E5	E6	E7	E8	E9	Mean
Sukoharjo	0%	94%	33%	78%	67%	71%	93%	76%	100%	68%
Wonogiri	0%	67%	75%	97%	60%	85%	88%	75%	89%	71%
Magelang City	0%	100%	92%	96%	70%	75%	89%	87%	45%	73%
Salatiga City	0%	72%	100%	65%	56%	76%	99%	55%	9%	59%
Semarang City	0%	72%	100%	97%	100%	88%	100%	73%	100%	81%
Surakarta City	0%	100%	100%	91%	96%	83%	83%	100%	100%	84%

E1: vaccine arrival; E2: temperature; E3: storage capacity; E4: buildings, equipment, transport; E5: maintenance; E6: stock management; E7: distribution; E8: vaccine management; E9: MIS, supportive functions

4 Discussion

Vaccines are biological substances that can lose their effectiveness if they get exposed to inappropriate temperatures, either too hot or too cold. To prevent this, they must be stored at specific temperatures using a cold chain system [20]. All individuals involved in vaccine handling are responsible for maintaining proper temperature control. They must have the necessary knowledge to do this effectively.5,20 In this study, 12 regions still scored below the standards (<80%). The issues identified include the limited number of temperature monitoring devices. Ideally, each cold chain should be equipped with temperature monitoring devices that can be checked continuously. In several regions, temperature recording analysis was not performed. As a result, deviations and their causes were not identified. A previous EVM assessment in Ghana revealed similarly poor temperature control practices, even at the national level. Several factors contributed to this include a lack of training, insufficient temperature monitoring devices, and inadequate knowledge about vaccine management [21]. Healthcare workers often lacked an understanding of critical temperature control measures, including the use of Vaccine Vial Monitors (VVMs), the shake test, and the multi-dose vial policy, which likely contributed to the observed deficiencies in maintaining proper temperature control. This finding is consistent with assessments in Tanzania and Cameroon, where 28,3% of personnel were unaware of the correct vaccine storage temperature. The major challenges were the lack of training and low levels of knowledge about vaccine management practices [22,23].

Vaccines are costly, and if they lose their potency, it cannot be restored. This makes the vaccines useless, and recipients of vaccines that have lost potency due to improper storage may not be fully protected against the diseases they are designed to prevent [10]. A study in Ghana similarly highlighted the lack of organization and management of vaccines and immunization supplies, emphasizing the urgent need for practical solutions to address these problems [21]. Vaccine management involves both managerial and operational tasks to ensure a steady supply of high-quality vaccines for effective immunization services [8]. This study found that staff in some areas were unaware of the shake test, incomplete record-keeping, no calculation of vaccine wastage during the assessment period, no posters or stickers about reading VVMs in the vaccine collection area, and not receiving regular supportive supervision visits. These negatively impact vaccine storage conditions, potentially compromising their safety and potency, necessitating immediate and pragmatic measures to address the issue [24]. Therefore, protocols for ordering, storing, and handling vaccines should be readily available in the workplace to ensure that health workers use them, thereby improving vaccine management practices [7].

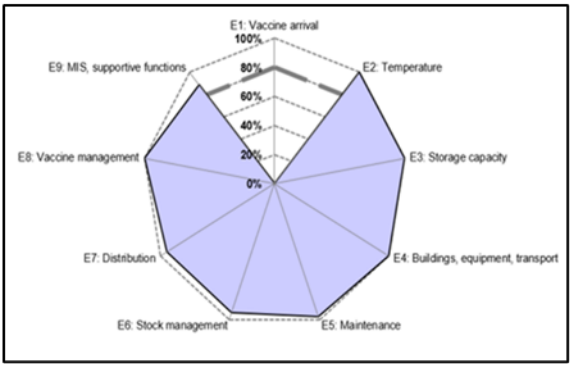

Fig. 1. EVM scores of Brebes

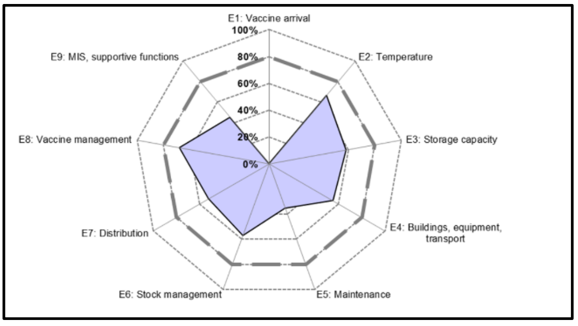

Fig. 2. EVM scores of Boyolali

Effective vaccine stock management and procedures are essential for the vaccine supply chain system. This includes proper vaccine handling, accurate physical inventory, effective stock control systems, appropriate stock level management, good warehousing practices, and proper disposal of damaged or expired vaccines, all in accordance with global standards [25]. This aligns with the findings of a 2014 study by the International

Federation of Pharmaceutical Manufacturers and Associations (IFPMA), which revealed that less than a quarter of countries met the minimum EVM standards for stock maintenance and management [26]. To improve vaccine stock management, it is essential to identify and address bottlenecks throughout the entire supply chain.

Vaccines and supplies need to be transported efficiently across different levels of the supply chain. This involves using passive containers correctly, packing things properly, and having plans in place for unexpected transportation issues to keep vaccines safe during transport [5]. In this study, several issues related to vaccine distribution were identified, such as the lack of refrigerated vehicles for transporting vaccines, staff unawareness of the standards for using cool packs and cool boxes, and the absence of SOPs related to vaccine packaging during distribution.

Effective information systems and supportive management functions, including the use of SOPs, are crucial for the successful operation of immunization programs [5]. In this study, the performance of this criterion was severely lacking across all the facilities evaluated. This inadequacy impacts vaccine requirements and other essential resources, potentially harming the immunization program. It may also result in inaccurate vaccine forecasting, avoidable stockouts, and poor management of vaccine wastage [25].

5 Conclusion

Increasing vaccine coverage should not only be assessed quantitatively by the number of targets achieved, but must also ensure that the vaccines provided are of high quality to maximize their benefits. To address this, the WHO and UNICEF introduced the Effective Vaccine Management (EVM) to manage vaccines effectively and efficiently. However, the implementation of EVM still requires considerable attention, as the 2023 EVM assessment results in Central Java were not optimal. Scores below the standards were still found across all criteria in the 35 regencies/cities of Central Java. Each region had different problems in fulfilling the nine criteria of EVM assessment, such as inadequate building facilities, lack of periodic vaccine stock recording, absence of standard operating procedures, and insufficiently trained officers. Therefore, support is needed from the Central Java Provincial Government in providing support to the regions, with regular monitoring and evaluation of the EVM implementation. Additionally, officers need to be trained regarding proper vaccine management.

References

1. World Health Organization (WHO), Indonesia Targets Low Vaccination Areas to Tackle Decline in Childhood Immunization. [online] https://www.who.int/indonesia/news/detail/03-05-2023-indonesia-targets-low-vaccination-areas-to-tackle-decline-in-childhood-immunization (2023).
2. World Health Organization (WHO), Expanded Programme on Immunization (EPI) Factsheet 2023: Indonesia. [online] https://www.who.int/publications/i/item/Indonesia-EPI-Factsheet-2023 (2023).

3. Central Java Provincial Health Office, Immunization Data of Central Java Province (2023).
4. World Health Organization (WHO), Indonesia Targets Low Vaccination Areas to Tackle Decline in Childhood Immunization. Indonesia [online] https://www.who.int/indonesia/news/detail/03-05-2023-indonesia-targets-low-vaccination-areas-to-tackle-decline-in-childhood-immunization (2023).
5. Department of Immunization, V. and B. W., Immunization Supply Chain and Logistics: A Neglected but Essential System for National Immunization Programs. (Geneva, 2014).
6. J. Chiodini, Safe Storage and Handling of Vaccines (2014).
7. J. Chiodini, Safe Storage and Handling of Vaccines. Nursing Standard. **28**, 45–52 (2014).
8. WHO and UNICEF, Achieving Immunization Targets with the Comprehensive Effective Vaccine Management (CEVM) Framework (2016).
9. P. Kumar Bhatnagar et al., Evaluation of Effective Vaccine Management at Cold Chain Points in Urban Meerut, Uttar Pradesh, India. [online] www.wjpls.org (2018).
10. S. K. Diamenu, G. Bosnu, F. Abotsi, A. K. Achiano, & F. Sarpong, Why Conduct Effective Vaccine Management (EVM) Assessment? Int J Vaccine Immunizat. 1 (2010).
11. World Health Organization, EVM Model Standard Operating Procedures Consolidated Version, with User Guide Effective Vaccine Management Initiative (2013).
12. World Health Organization, World Health Organization Effective Vaccine Management (EVM) EVM Assessment Tool Version 1.0.9-User Guide (2013).
13. World Health Organization, Temperature Monitoring Study: A Fully Documented Process to Detect Weaknesses in the Supply Chain (2017).
14. World Health Organization, How to Temperature Map Cold Chain Equipment and Storage Areas (2022).
15. C. M. Hanson, A. M. George, A. Sawadogo, & B. Schreiber, Is Freezing in the Vaccine Cold Chain an Ongoing Issue? A Literature Review. Vaccine. **35**, 2127–2133 (2017).
16. D. Feyisa, F. Ejeta, T. Aferu, & O. Kebede, Adherence to WHO Vaccine Storage Codes and Vaccine Cold Chain Management Practices at Primary Healthcare Facilities in Dalocha District of Silt'e Zone, Ethiopia. Trop Dis Travel Med Vaccines. **8** (2022).
17. Q. Lin, Q. Zhao, & B. Lev, Cold Chain Transportation Decision in the Vaccine Supply Chain. Eur J Oper Res. **283**, 182–195 (2020).
18. O. T. Oyadiran, S. A. Usman, M. E. Osoba, S. O. Olukorode, & D. E. Lucero-Prisno, Towards Effective and Efficient COVID-19 Vaccination in Nigeria. J Glob Health Rep. 5 (2021).
19. E. Osei, M. Ibrahim, & G. K. Amenuvegbe, Effective Vaccine Management: The Case of a Rural District in Ghana. Adv Prev Med. 2019, 1–8 (2019).
20. M. Zaffran et al., The Imperative for Stronger Vaccine Supply and Logistics Systems. Vaccine. 31 (2013).

21. E. Osei, M. Ibrahim, & G. K. Amenuvegbe, Effective Vaccine Management: The Case of a Rural District in Ghana. Adv Prev Med. 2019, 1–8 (2019).
22. G. Sadru et al., Assessment of Vaccine Management Performance in Health Facilities of Mwanza Region, Tanzania: A Cross-Sectional Study. J Pharm Policy Pract. 16 (2023).
23. M. N. Yakum, J. Ateudjieu, E. A. Walter, & P. Watcho, Vaccine Storage and Cold Chain Monitoring in the North West Region of Cameroon: A Cross-Sectional Study. BMC Res Notes. 8 (2015).
24. D. M. Dairo, & O. E. Osizimete, Factors Affecting Vaccine Handling and Storage Practices among Immunization Service Providers in Ibadan, Oyo State, Nigeria. Afr Health Sci. **16**, 576–583 (2016).
25. UNICEF, Effective Vaccine Management-Gujarat (2011).
26. IFPMA, The Complex Journey of a Vaccine: Immunization Supply Chain, Delivery Innovation, and Regulatory Requirements, UNICEF, USA (2014).