RESEARCH PAPER

Evaluating the Effectiveness of Zinc Supplementation in Reducing Under-Five Diarrhoeal Morbidity in India: A Multi-District Comparative Study

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ABSTRACT
Diarrhoeal diseases remain a leading cause of morbidity and mortality among children under five years of age in India. Zinc supplementation, recommended by the World Health Organization and UNICEF, is widely used as an adjunct to oral rehydration salts (ORS) in the management of diarrhoea. his study adopts a systematic review approach integrated with district-level comparative evidence of secondary data derived from global and Indian literature published between 2000 and 2025, sourced from databases including PubMed, Scopus, and the Cochrane Library.
The study also incorporates district-level comparative evidence from Rajasthan, covering five high-burden districts (Bharatpur, Barmer, Churu, Rajsamand, and Tonk), to analyze variations in zinc supplementation coverage and diarrhoeal burden across different settings.
The review assesses the effectiveness of zinc supplementation in reducing diarrhoeal morbidity among under-five children. Evidence indicates that zinc supplementation reduces the duration of diarrhoeal episodes by approximately 15–25%, decreases severity, and lowers recurrence rates for up to three months following treatment. However, variations in effectiveness are observed across regions due to differences in nutritional status, healthcare access, and program implementation. A total of 26 studies were included in the review.
The findings further highlight key challenges, including low caregiver awareness, inconsistent supply, and poor adherence to recommended treatment regimens. Strengthening public health delivery systems and enhancing community-level interventions are essential to improve zinc coverage and maximize its impact in India.
Keywords: *Zinc supplementation, diarrhoea, under-five children, morbidity, India, public health*
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1. INTRODUCTION

Diarrhoeal diseases remain a significant public health challenge in India and continue to be a leading cause of morbidity and mortality among children under five years of age. According to estimates by the World Health Organization and UNICEF, diarrhoea accounts for a substantial proportion of preventable child deaths globally, with a disproportionately high burden in low- and middle-income countries, including India. Despite improvements in sanitation, immunization, and healthcare access, the persistence of diarrhoeal diseases is closely associated with malnutrition, poor hygiene practices, and socio-economic disparities. Zinc plays a critical role in maintaining immune competence, cellular growth, and intestinal mucosal integrity. Zinc deficiency is widespread in developing countries due to inadequate dietary intake and low bioavailability from plant-based diets. Such deficiency compromises gut barrier function and increases susceptibility to gastrointestinal infections, thereby exacerbating the severity and duration of diarrhoeal episodes. The integration of zinc supplementation into diarrhoea management protocols represents a major advancement in child health interventions. The World Health Organization recommends zinc supplementation at a dose of 10–20 mg daily for 10–14 days, administered alongside oral rehydration salts (ORS), for the treatment of acute diarrhoea in children under five. Although numerous studies have demonstrated the therapeutic benefits of zinc, variations in effectiveness across different populations and implementation settings highlight the need for a comprehensive evaluation of existing evidence.

2. OBJECTIVES OF THE REVIEW

- To critically evaluate the effectiveness of zinc supplementation in reducing the duration, severity, and recurrence of diarrhoeal episodes among children under five.
- To systematically synthesize evidence from global and Indian secondary data sources.

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- To identify implementation gaps and contextual challenges affecting the effectiveness of zinc supplementation programs in India.
- To examine district-level variations in zinc supplementation effectiveness using comparative evidence from selected regions in India.

3. LITERATURE REVIEW

A substantial body of literature has examined the role of zinc supplementation in the management of diarrhoeal diseases among children under five years of age. Globally, diarrhoeal diseases remain a leading cause of childhood morbidity and mortality, particularly in low- and middle-income countries where malnutrition and inadequate sanitation persist (World Health Organization, 2023). Zinc deficiency, which is highly prevalent in such settings, impairs immune response and compromises intestinal mucosal integrity, thereby increasing susceptibility to gastrointestinal infections and prolonging the duration and severity of diarrhoeal episodes (Bajait et al., 2011).

Evidence from randomized controlled trials, systematic reviews, and meta-analyses consistently demonstrates the therapeutic effectiveness of zinc supplementation. Studies indicate that zinc administration during acute diarrhoea reduces episode duration by approximately 15–25%, decreases stool frequency, and accelerates clinical recovery (Patel et al., 2009; Ali et al., 2024). In addition to its immediate therapeutic benefits, zinc supplementation has also been shown to provide a protective effect against recurrence of diarrhoea for up to two to three months following treatment (UNICEF & World Health Organization, 2004).

In the Indian context, multiple studies have highlighted both the effectiveness and the implementation challenges associated with zinc supplementation. While clinical outcomes remain consistently positive, the real-world impact of zinc therapy is influenced by factors such as caregiver awareness, accessibility of healthcare services, and adherence to treatment protocols. Notably, disparities between urban and rural settings continue to persist, with lower uptake and compliance observed in resource-constrained areas.

The literature also explores variations in dosage and treatment regimens. Although the World Health Organization recommends a standard dosage of 10–20 mg per day for 10–14 days, emerging evidence suggests that lower doses may achieve comparable therapeutic outcomes with fewer side effects, such as vomiting. However, these findings remain inconclusive, indicating the need for further research to establish optimal and context-specific dosing strategies.

Despite strong evidence supporting zinc supplementation, certain gaps remain in the existing literature. Limited research is available on long-term outcomes, including its impact on child growth, cognitive development, and overall health status. Furthermore, heterogeneity in study design, population characteristics, and implementation contexts restricts the generalizability of findings across different regions.

Overall, the literature provides robust evidence supporting the clinical effectiveness of zinc supplementation in reducing diarrhoeal morbidity among children under five. However, it also highlights the importance of contextual and programmatic factors in determining its real-world impact, particularly in high-burden countries such as India.

Table 1: Key Studies on Zinc Supplementation in Under-Five Diarrhoea

S. No.	Author(s) & Year	Study Location	Study Design	Sample Size	Intervention Details	Key Outcomes	Major Findings
1	Patel et al. (2009)	India	Randomized Controlled Trial	800 children	Zinc (20 mg/day for 14 days) + ORS	Duration, Severity	Reduced duration by ~20% and severity significantly decreased
2	Bajait et al. (2011)	India	Review Study	-	Zinc supplementation during diarrhoea	Duration, Recurrence	Zinc reduced duration and prevented recurrence up to 3 months
3	Ali et al. (2024)	Global	Meta-analysis	5000+ children	Zinc + standard diarrhoea care	Duration, Recovery	Significant reduction in diarrhoea duration (15–25%)
4	WHO (2023)	Global	Guideline-based Evidence	-	Zinc (10–20 mg/day for 10–14 days) + ORS	Mortality, Morbidity	Recommended as standard treatment; improves recovery

							outcomes
5	UNICEF & WHO (Joint Statement)	Global	Policy Review	-	Zinc + ORS integration	Morbidity, Recurrence	Reduces disease burden and improves treatment compliance
6	Iqbal (2025)	South Asia	Observational Study	1200 children	Zinc supplementation programs	Incidence, Recurrence	Lower recurrence rates and improved child health indicators
7	BMJ Paediatrics Open (2024)	Multi-country	Clinical Trial	3000 children	Low-dose vs standard-dose zinc	Duration, Side Effects	Lower doses equally effective with fewer side effects
8	Indian Pediatrics (2018)	India	Clinical Study	950 children	Zinc + ORS therapy	Duration, Severity	Significant improvement in recovery time and symptom reduction
9	Journal of Global Health (2024)	Global	Systematic Review	7000+ children	Zinc supplementation	Morbidity, Hospitalization	Reduced hospitalization and overall morbidity
10	Government of India (NHM Reports)	India	Program Evaluation	-	Zinc distribution under NHM	Coverage, Compliance	Improved coverage but challenges in adherence and supply persist

Note: RCT = Randomized Controlled Trial; ORS = Oral Rehydration Salts; NHM = National Health Mission

Interpretation:
The summarized studies consistently demonstrate that zinc supplementation significantly reduces the duration, severity, and recurrence of diarrhoea among children under five. Evidence from randomized controlled trials, meta-analyses, and global guidelines reinforces zinc as a standard and effective intervention in diarrhoea management. However, variations in implementation, particularly in low-resource settings, influence the extent of its real-world effectiveness

4. METHODOLOGY

This study employs a systematic review approach based on secondary data analysis to evaluate the effectiveness of zinc supplementation in reducing diarrhoeal morbidity among children under five years of age.

4.1 Data Sources and Search Strategy

A comprehensive literature search was conducted using electronic databases, including PubMed, Scopus, and the Cochrane Library, along with reports from the World Health Organization, UNICEF, and Government of India publications.

The search encompassed studies published between 2000 and 2025 using keywords such as “zinc supplementation,” “diarrhoea,” “under-five children,” “childhood morbidity,” and “India.” Boolean operators (AND, OR) were applied to refine and optimize search results.

4.2 Inclusion and Exclusion Criteria

Inclusion Criteria:

- Studies focusing on children under five years of age
- Studies evaluating zinc supplementation in the management of diarrhoea
- Randomized controlled trials, observational studies, systematic reviews, and meta-analyses
- Publications in English between 2000 and 2025

Exclusion Criteria:

- Studies not involving zinc as an intervention
- Studies focused on adult populations
- Non-peer-reviewed articles and opinion-based papers

4.3 Study Selection Process

Relevant studies were initially screened based on titles and abstracts, followed by full-text assessment for eligibility. After removing duplicate records, 68 studies remained for title and abstract screening.

A total of 92 studies were identified through database and manual searches. After the removal of duplicates and relevance screening, 41 studies were selected for full-text review. Ultimately, 26 studies met the inclusion criteria and were included in the final analysis.

4.4 Data Extraction and Analysis

Key information from the selected studies-including study design, sample size, intervention details, and outcomes related to diarrhoeal duration, severity, and recurrence-was systematically extracted. A comparative and thematic analysis approach was employed to identify patterns,

variations, and research gaps across different geographical and socio-economic contexts.

4.5 Integration of District-Level Comparative Evidence

In addition to systematic review, the study incorporates district-level comparative evidence from published empirical research conducted in Rajasthan. Five districts—Bharatpur, Barmer, Churu, Rajsamand, and Tonk—were analyzed to understand variations in diarrhoeal prevalence, zinc supplementation coverage, and treatment practices. This comparative integration strengthens the analytical framework by linking clinical evidence with real-world implementation differences across districts.

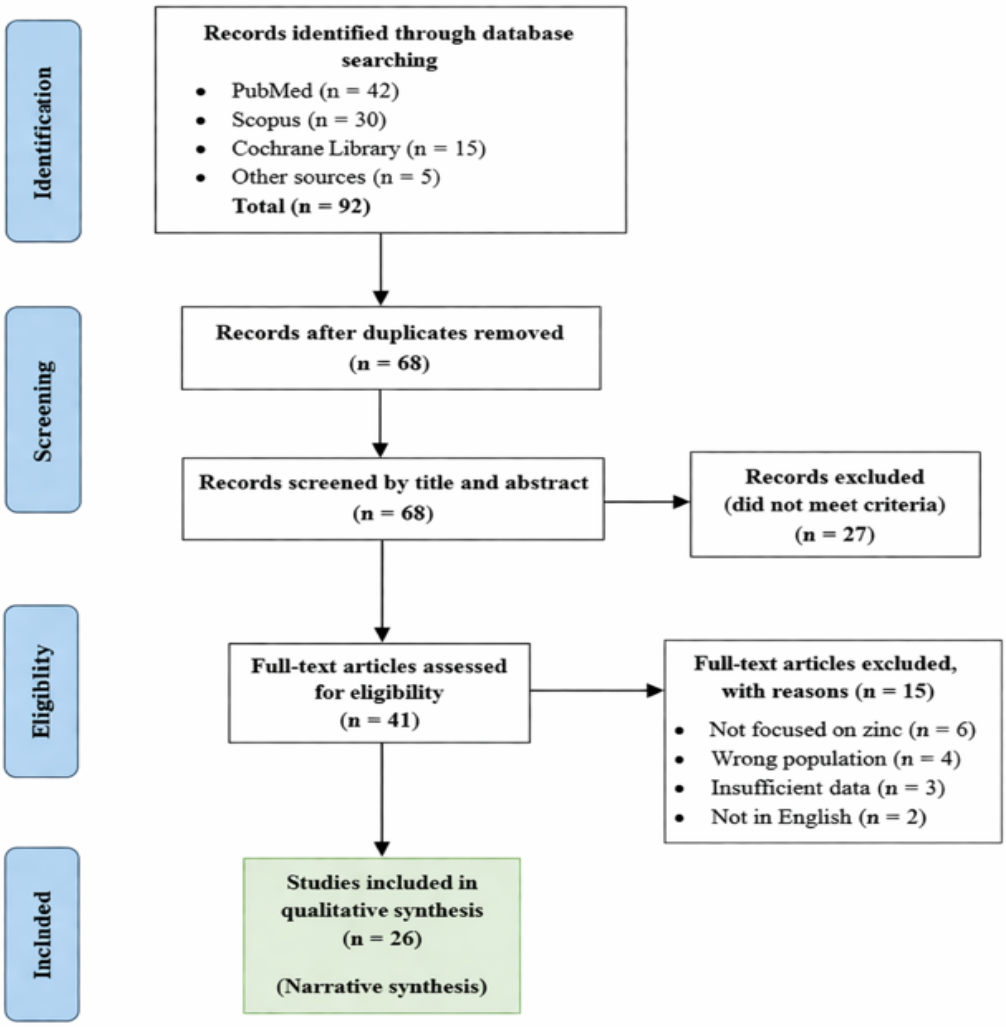

Figure 1: Study Selection Flow Diagram

5. BURDEN OF DIARRHOEAL DISEASE IN INDIA

Diarrhoeal diseases remain a major contributor to childhood morbidity and mortality in India, particularly among children under five years of age. According to estimates from the World Health Organization and UNICEF, diarrhoea continues to be one of the leading causes of preventable child deaths globally, with India accounting for a substantial share of this burden.

Despite improvements in sanitation, immunization, and access to healthcare services, the incidence remains disproportionately high among rural and socio-economically disadvantaged populations.

Diarrhoea significantly contributes to malnutrition by impairing nutrient absorption and increasing nutrient loss, thereby creating a vicious cycle between infection and undernutrition (Black et al., 2013). Recurrent diarrhoeal episodes are associated with growth retardation, particularly stunting, and increased susceptibility to other infectious diseases due to compromised immunity (Guerrant et al., 2008). Moreover, persistent and recurrent diarrhoea can result in long-term developmental consequences in children.

Beyond its health impact, diarrhoeal disease imposes a considerable economic burden on families and healthcare systems. Direct costs include medical treatment and hospitalization, while indirect costs involve loss of caregiver productivity and long-term effects on human capital development. Variations in disease burden across states and districts are influenced by disparities in sanitation, access to clean drinking water, healthcare infrastructure, and levels of public health awareness.

6. ROLE OF ZINC IN DIARRHOEA MANAGEMENT

Zinc is an essential micronutrient that plays a vital role in immune function, cellular growth, and intestinal integrity. It is particularly important in maintaining epithelial barrier function and preserving the structure of the gastrointestinal mucosa (Bajait et al., 2011). Additionally, zinc contributes to the regulation of electrolyte transport and water absorption in the intestines, which are critical mechanisms in reducing the severity of diarrhoeal episodes (Fischer Walker & Black, 2004).

Zinc deficiency is highly prevalent in developing countries due to inadequate dietary intake and low bioavailability. Such deficiency impairs immune response and disrupts gut barrier function, increasing susceptibility to enteric infections and prolonging the duration and severity of diarrhoea (Black et al., 2013). Consequently, children with zinc deficiency are at a higher risk of recurrent and persistent diarrhoeal episodes.

Zinc supplementation during diarrhoeal episodes has been shown to restore intestinal mucosal integrity, enhance immune response, and improve the absorption of water and electrolytes. As a result, it reduces both the duration and severity of diarrhoea and lowers the likelihood of recurrence in subsequent months (Fischer Walker et al., 2009). This therapeutic significance has led to its inclusion in standard diarrhoea management protocols recommended by the World Health Organization (World Health Organization, 2023).

7. EVIDENCE ON EFFECTIVENESS OF ZINC SUPPLEMENTATION

7.1 Reduction in Duration and Severity

A substantial body of evidence from randomized controlled trials and meta-analyses demonstrates that zinc supplementation significantly reduces both the duration and severity of diarrhoeal episodes in children under five years of age. Findings consistently indicate a reduction in episode duration by approximately 15–25%, along with decreased stool frequency and symptom severity (Patel et al., 2009; Fischer Walker et al., 2004; Ali et al., 2024). Evidence from the World Health Organization further supports the role of zinc in shortening the course of acute diarrhoea and improving clinical recovery outcomes (World Health Organization, 2023).

The therapeutic effects of zinc are primarily attributed to its role in enhancing intestinal epithelial repair, improving water and electrolyte absorption, and strengthening immune response (Fischer Walker & Black, 2004).

The figure illustrates the variation in the effectiveness of zinc supplementation in reducing the duration of diarrhoeal episodes based on key influencing factors. Low awareness shows the highest reduction potential, indicating that informed caregivers are more likely to initiate timely and appropriate treatment. The quality of medicine demonstrates a moderate impact, highlighting that substandard or inconsistent zinc formulations can limit therapeutic effectiveness. Poor adherence reflects comparatively lower reduction, as incomplete treatment courses reduce the overall benefit of supplementation. These findings emphasize the need for improving awareness, ensuring quality pharmaceutical standards, and promoting adherence to maximize public health outcomes.

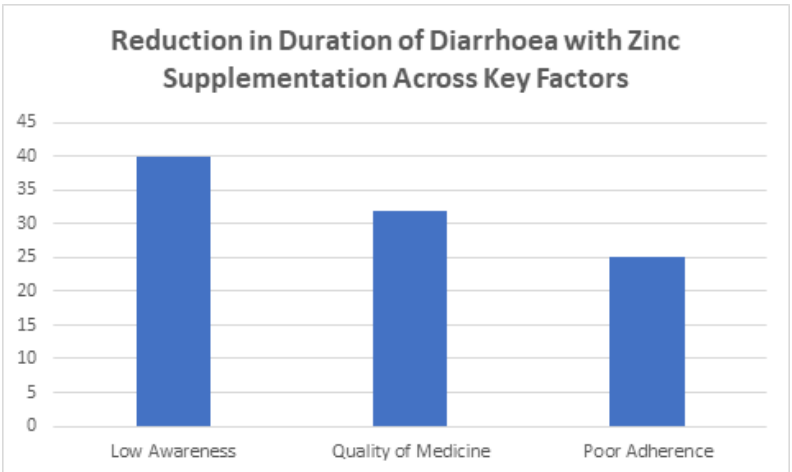

Figure 2: Effect of awareness, quality of medicine, and adherence on reduction in duration of diarrhoeal episodes among children under five.

7.2 Prevention of Recurrence

Beyond its immediate therapeutic benefits, zinc supplementation has been shown to provide protective effects against subsequent diarrhoeal episodes. Studies indicate that children receiving zinc experience a reduced risk of recurrence for up to two to three months following treatment (Bajait et al., 2011).

This preventive effect is particularly significant in high-burden settings, where repeated exposure to pathogens is common due to poor sanitation and hygiene conditions. By enhancing immune function and restoring gut integrity, zinc contributes to sustained protection against infections (Black et al., 2013).

Zinc supplementation also reduces the recurrence of diarrhoeal episodes, as shown in Figure 4.

7.3 Reduction in Morbidity

Evidence from India and other low- and middle-income countries suggests that zinc supplementation contributes to a measurable reduction in overall diarrhoeal morbidity. This includes lower hospitalization rates, reduced incidence of persistent diarrhoea, and improved general health outcomes among children (Iqbal, 2025).

The integration of zinc into diarrhoea management programs, particularly in combination with oral rehydration salts (ORS), has also been associated with improved treatment compliance and enhanced effectiveness of case management strategies (World Health Organization, 2023).

7.4 Dose and Effectiveness

The World Health Organization recommends zinc supplementation at a dosage of 20 mg per day for children aged 6–59 months and 10 mg per day for infants below six months, administered for 10–14 days (World Health Organization, 2023).

While this standard dosage is widely accepted, emerging evidence suggests that lower doses (5–10 mg per day) may achieve comparable therapeutic outcomes with a reduced incidence of side effects, particularly vomiting. However, findings remain inconsistent, and further research is required to establish optimal dosing strategies across different population groups.

7.5 Limitations in Effectiveness

Despite strong overall evidence supporting zinc supplementation, certain limitations have been identified. Some studies report minimal or no significant effects in very young infants, particularly those under six months of age. Additionally, zinc administration has been associated with mild adverse effects, such as vomiting, which may affect treatment adherence (Bajait et al., 2011).

Furthermore, the effectiveness of zinc supplementation varies across populations due to differences in baseline nutritional status, prevalence of zinc deficiency, healthcare access, and environmental factors. These variations highlight the importance of context-specific implementation strategies and the need for further research to address heterogeneity in outcomes.

8. CONTEXTUL VARIATIONS IN IMPLEMENTATION

Evidence from secondary literature in India indicates considerable variation in the effectiveness of zinc supplementation programs across regions and settings. These differences are influenced by multiple contextual factors, including disparities in healthcare infrastructure, levels of caregiver awareness, availability and accessibility of zinc supplements, and broader socio-economic conditions (Iqbal, 2025).

In regions with relatively strong primary healthcare systems and effective integration of diarrhoea management protocols, the combined use of oral rehydration salts (ORS) and zinc supplementation has been associated with improved health outcomes, including reduced diarrhoeal morbidity, shorter duration of illness, and higher treatment compliance (World Health Organization, 2023). In contrast, areas with limited healthcare access and lower awareness levels often exhibit suboptimal utilization of zinc therapy, thereby limiting its potential impact.

Programmatic factors also play a critical role in determining effectiveness. Variations in the training and capacity of frontline health workers, supply chain efficiency, and the quality of community-level health education significantly influence the uptake and adherence to zinc supplementation. Initiatives under programs such as the National Health Mission have contributed to improving coverage; however, implementation gaps persist across states and districts.

Overall, these findings indicate that while zinc supplementation is clinically effective, its real-world impact is strongly dependent on the strength of health systems and the effectiveness of program delivery mechanisms.

8.1 Multi-District Comparative Evidence from Rajasthan

A district-level comparative study conducted in Rajasthan provides concrete evidence of variation in zinc supplementation effectiveness across different districts. The study analyzed five high-burden districts Bharatpur, Barmer, Churu, Rajsamand, and Tonk and the comparative findings are summarized in Table 2 (Agarwal & Joshi, 2025).

For instance, Bharatpur reported the highest diarrhoeal prevalence (15.3%) but relatively low zinc usage (23%), indicating major gaps in treatment implementation. In contrast, Rajsamand demonstrated the highest zinc coverage (68.2%) with comparatively lower disease burden, reflecting stronger healthcare delivery and better adherence to treatment protocols (Agarwal & Joshi, 2025).

These inter-district variations highlight that the effectiveness of zinc supplementation is not solely dependent on clinical efficacy but is significantly influenced by health system performance, caregiver awareness, and service delivery mechanisms (Agarwal & Joshi, 2025).

Similar variations have been reported in other Indian states such as Uttar Pradesh and Bihar, where gaps between awareness and actual zinc utilization persist due to weak counselling, socio-cultural barriers, and inconsistent healthcare delivery. This indicates that inter-district disparities are not isolated but represent a broader systemic challenge across India.

This comparative evidence strengthens the analytical validity of the study by linking clinical effectiveness with real-world district-level implementation variability.

Table 2: District-wise Comparative Evidence (Rajasthan)

District	Diarrhoea Prevalence (%)	Zinc Usage (%)	Interpretation

Bharatpur	15.3	23	High burden, low coverage
Barmer	9.4	18.6	Low performance
Churu	6.2	16.3	Poor uptake
Tonk	8.6	28	Moderate performance
Rajsamand	8.2	68.2	High performance

Source: Adapted from Agarwal & Joshi (2025)

9. IMPLEMENTATION CHALLENGES IN INDIA

Despite strong clinical evidence supporting zinc supplementation, its large-scale implementation in India faces several systemic and behavioral challenges that limit its effectiveness (World Health Organization, 2023; Iqbal, 2025).

One of the primary barriers is the low level of awareness among caregivers regarding the benefits of zinc in diarrhoea management. Many caregivers continue to rely on traditional practices or seek immediate symptomatic relief through antibiotics, often overlooking zinc supplementation as a standard treatment option. This preference for antibiotics over recommended therapy contributes to irrational drug use and undermines public health efforts (Bajait et al., 2011).

Supply-side constraints also play a significant role.

Inconsistent availability of zinc tablets and syrups at primary healthcare centers, particularly in rural and remote areas, disrupts treatment continuity. Weak supply chain management and frequent stock-outs further reduce accessibility, even in regions where awareness may be relatively higher.

Adherence to the recommended 10–14 day zinc regimen presents another challenge. Caregivers often discontinue supplementation once symptoms improve, leading to incomplete treatment and reduced long-term benefits, including prevention of recurrence.

Additionally, the effectiveness of zinc supplementation programs is influenced by the capacity of frontline healthcare workers. Limited training and inadequate dissemination of updated treatment guidelines hinder proper counseling, prescription practices, and follow-up. Strengthening the skills and knowledge of healthcare providers under initiatives such as the National Health Mission is therefore essential.

Overall, these challenges highlight that while zinc supplementation is a clinically proven intervention, its effectiveness in real-world settings depends on addressing both supply-side and demand-side barriers through coordinated public health strategies.

The figure highlights that low awareness and quality of medicine are major barriers limiting the effectiveness of zinc supplementation, while poor adherence further reduces treatment outcomes.

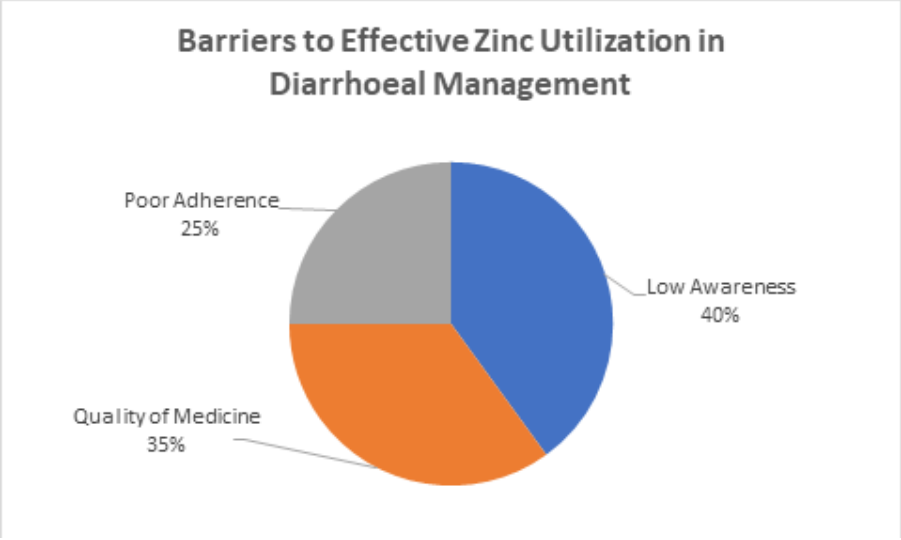

Figure 3: Distribution of key barriers affecting zinc use, including low awareness, quality of medicine, and poor adherence among caregivers.

10. POLICY IMPLICATIONS

The findings of this review highlight the need to strengthen policy and programmatic interventions to enhance the effectiveness of zinc supplementation in India. A key priority is reinforcing existing initiatives under the Government of India's National Health Mission to ensure wider coverage and consistent implementation of diarrhoea management protocols.

Ensuring an uninterrupted supply of zinc supplements across all levels of the healthcare system is critical. Strengthening procurement systems, improving supply chain logistics, and minimizing stock-outs-particularly in

rural and underserved areas-can significantly improve accessibility and treatment continuity (World Health Organization, 2023).

Equally important is the promotion of community-level awareness. Large-scale information, education, and communication (IEC) campaigns should be designed to educate caregivers about the benefits of zinc supplementation and its correct use alongside oral rehydration salts (ORS). Addressing misconceptions and reducing the inappropriate use of antibiotics must remain a central focus of these efforts (Bajait et al., 2011).

Integrating zinc supplementation into primary healthcare services is essential to improve uptake. Frontline health workers, including ASHA and ANM personnel, should be adequately trained to counsel caregivers, ensure adherence to the recommended 10–14 day regimen, and monitor treatment outcomes (World Health Organization, 2023).

Finally, behavior change communication strategies should be systematically incorporated into public health programs to improve adherence and sustain long-term impact. A coordinated approach that combines supply-side strengthening with demand generation is necessary to maximize the effectiveness of zinc supplementation interventions in India (Iqbal, 2025).

11. FUTURE RESEARCH DIRECTIONS

Despite substantial evidence supporting zinc supplementation, several areas require further investigation to strengthen the evidence base and optimize intervention strategies.

There is a need for well-designed district-level and state-level comparative studies to better understand contextual variations in effectiveness across different regions of India. Such studies can provide valuable insights into how socio-economic, environmental, and health system factors influence outcomes (Iqbal, 2025).

Limited evidence is available on the long-term impact of zinc supplementation on child growth, cognitive development, and overall health outcomes. Longitudinal studies are therefore required to assess these broader developmental effects (Guerrant et al., 2008).

Further research is also needed to determine optimal dosing strategies. While current guidelines recommend standard dosages, emerging evidence suggests that lower doses may be equally effective with fewer side effects. Rigorous randomized controlled trials are necessary to validate these findings.

Additionally, the role of zinc in combination therapies, including its interaction with other micronutrients and therapeutic interventions, warrants further exploration. Understanding potential synergistic effects could enhance the overall effectiveness of child health programs (Fischer Walker & Black, 2004).

12. CONCLUSION

Zinc supplementation represents a well-established and cost-effective intervention for reducing diarrhoeal morbidity among children under five years of age. Evidence synthesized from global and Indian studies consistently demonstrates its effectiveness in reducing the duration, severity, and recurrence of diarrhoeal episodes, thereby improving overall child health outcomes (Patel et al., 2009).

However, this review highlights that the real-world impact of zinc supplementation is not uniform and is significantly influenced by contextual and implementation-related factors. Variations in healthcare infrastructure, caregiver awareness, supply chain efficiency, and adherence to treatment protocols continue to limit its full potential in many settings across India.

Addressing these challenges requires a comprehensive and integrated public health approach. Strengthening service delivery systems under initiatives such as the National Health Mission, ensuring consistent availability of zinc supplements, and promoting sustained behavior change at the community level are essential to improving coverage and effectiveness (World Health Organization, 2023).

Evidence from district-level analysis, particularly from Rajasthan, demonstrates that the effectiveness of zinc supplementation varies significantly across regions due to differences in healthcare infrastructure, awareness, and program implementation. Therefore, adopting district-specific strategies rather than uniform national approaches is essential to maximize the impact of zinc supplementation programs in India.

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