Economic Business Horizon

ISSN: 2808-0696 (p), 2807-9531 (e)

Economic Business Horizon
Volume: 05
Issue: 02
Year: 2026
Page: 137-146

Citation:
Rohman, T. N. (2026). Socio-economic and cognitive impacts of iodine deficiency disorders: A systematic literature review with implications for Indonesia. *Economic Business Horizon*, *5*(2), 137-146.

Socio-Economic and Cognitive Impacts of Iodine Deficiency Disorders: A Systematic Literature Review with Implications for Indonesia

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Abstract

Iodine deficiency disorders (IDD) remain a significant public health concern with far-reaching implications for cognitive development and socio-economic outcomes. This study aims to systematically review and synthesize existing literature on the cognitive and socio-economic impacts of iodine deficiency, with particular attention to the Indonesian context. A systematic literature review (SLR) approach was employed using databases such as Scopus, PubMed, Google Scholar, and ScienceDirect, following PRISMA-based selection procedures. A total of more than twenty relevant studies, including empirical research, systematic reviews, and global health reports, were analyzed using thematic synthesis. The findings indicate that iodine deficiency significantly impairs cognitive development, particularly during critical periods such as pregnancy and early childhood, leading to reduced intelligence quotient (IQ) and academic performance. These cognitive deficits contribute to lower educational attainment and reduced human capital, ultimately affecting economic productivity. At a global level, iodine deficiency continues to contribute to the burden of developmental intellectual disability, particularly in low socio-demographic index regions. In Indonesia, although iodized salt programs have improved iodine status, challenges remain in monitoring and equitable distribution. The study highlights the importance of universal salt iodization and integrated public health strategies to mitigate the long-term impacts of IDD.

Keywords

Cognitive Development, Human Capital, Iodine Deficiency, Salt Iodization, Socio-Economic Impact.

1. Introduction

Iodine is an essential micronutrient required for the synthesis of thyroid hormones, particularly thyroxine (T4) and triiodothyronine (T3), which play a fundamental role in regulating metabolic processes, growth, and neurological development (Zimmermann, 2020). Adequate iodine intake is especially critical during pregnancy and early childhood, as these periods represent sensitive phases of brain development. Insufficient iodine intake can result in iodine deficiency disorders (IDD), a spectrum of conditions ranging from goiter to severe neurological impairments such as cretinism and developmental intellectual disability (Toloza et al., 2020).

Despite decades of global intervention efforts, iodine deficiency remains a persistent public health issue. Universal Salt Iodization (USI) has been widely implemented as the primary strategy to eliminate IDD; however, mild to moderate iodine deficiency continues to be reported across both developing and developed regions (Lisco et al., 2023; World Health Organization, 2024). These findings suggest that while progress has been made, the elimination of iodine deficiency has not been uniformly achieved, particularly in populations affected by socio-economic disparities and limited access to fortified food systems.

The implications of iodine deficiency extend beyond clinical health outcomes and into broader socio-economic dimensions. A substantial body of evidence demonstrates that iodine deficiency negatively affects cognitive development, leading to reduced Intelligence Quotient (IQ), impaired learning ability, and lower academic performance (Latifah et al., 2020). These cognitive limitations have long-term consequences, including reduced educational attainment and diminished productivity, which ultimately constrain human capital formation and economic growth (Field et al., 2009; Bommer et al., 2020). At a global level, iodine deficiency continues to contribute significantly to the burden of developmental intellectual disability, particularly in low socio-demographic index regions (Liu et al., 2025).

In the Indonesian context, iodine deficiency has historically been recognized as a major public health concern, particularly in inland and mountainous regions where environmental iodine levels are low. Although national salt iodization programs have improved iodine intake in many communities, challenges remain in ensuring consistent coverage, quality control, and public awareness (Kusrini et al., 2020). Furthermore, recent literature indicates that updated national data on iodine status are limited, highlighting the need for continued monitoring and evidence-based policy evaluation.

While previous studies have extensively examined the biological and clinical impacts of iodine deficiency, there remains a lack of integrated synthesis that connects cognitive outcomes with broader socio-economic consequences. Existing research often treats these dimensions separately, limiting a comprehensive understanding of how iodine deficiency affects human development as a whole. Therefore, a systematic and structured synthesis of the literature is required to bridge this gap.

This study aims to systematically review and synthesize existing evidence on the cognitive and socio-economic impacts of iodine deficiency disorders, with particular emphasis on their implications in Indonesia. By integrating findings from empirical studies, systematic reviews, and global health reports, this research seeks to provide a comprehensive understanding of IDD and contribute to more effective public health and policy strategies.

2. Literature Review and Hypothesis Development

2.1. Iodine and Brain Development

Iodine is a fundamental micronutrient required for the synthesis of thyroid hormones, which regulate neurological development and metabolic processes. Thyroxine (T4) and triiodothyronine (T3) play a critical role in neuronal migration, myelination, and synaptic development during early life stages (Zimmermann, 2020). Deficiency during critical developmental windows, particularly in utero and early childhood, can lead to irreversible brain damage and long-term cognitive impairment (Toloza et al., 2020).

The biological mechanism underlying iodine deficiency highlights its systemic impact on human development. Insufficient iodine intake disrupts thyroid hormone production, leading to hypothyroidism, which directly affects brain maturation and neurocognitive outcomes. These effects are most pronounced during pregnancy, where maternal iodine deficiency can impair fetal brain development even before birth (Dineva et al., 2020).

2.2. Cognitive Impacts of Iodine Deficiency

A substantial body of empirical evidence demonstrates a strong association between iodine deficiency and impaired cognitive performance. Studies conducted in iodine-deficient regions consistently report lower intelligence quotient (IQ), reduced academic achievement, and impaired learning capacity among affected populations (Latifah et al., 2020). These findings indicate that iodine deficiency not only affects individual cognitive ability but also influences educational outcomes.

However, the relationship between iodine deficiency and cognitive development is not entirely uniform across studies. Some research suggests that cognitive outcomes are influenced by multiple interacting factors, including nutritional status, environmental conditions, and socio-economic background (Johnston et al., 1987). Furthermore, meta-analytical evidence indicates that while iodine supplementation improves certain biological indicators, its direct effect on cognitive outcomes may vary depending on the severity and timing of deficiency (Dineva et al., 2020). This suggests that iodine deficiency should be understood within a broader developmental context rather than as a single isolated determinant.

2.3. Socio-Economic Impacts and Human Capital

The cognitive consequences of iodine deficiency extend into socio-economic domains, particularly through their impact on human capital formation. Reduced cognitive ability has been linked to lower educational attainment, which subsequently affects labor productivity and long-term economic outcomes (Field et al., 2009). Empirical evidence indicates that improvements in iodine intake, particularly during prenatal development, are associated with increased years of schooling and enhanced academic progression.

At a broader level, iodine deficiency contributes to economic losses by reducing workforce efficiency and increasing the burden of disability. Global studies highlight that micronutrient deficiencies, including iodine deficiency, have a multiplicative effect on human development indicators such as productivity, income levels, and national economic growth (Bommer et al., 2020). These findings emphasize that addressing iodine deficiency is not only a health priority but also an economic imperative.

2.3. Global and Regional Disparities

Despite significant global progress, iodine deficiency remains unevenly distributed across regions. Low socio-demographic index (SDI) regions continue to experience a higher burden of iodine deficiency and its associated consequences (Liu et al., 2025). These disparities are driven by differences in access to iodized salt, public health infrastructure, and socio-economic conditions.

In Southeast Asia, micronutrient deficiencies remain prevalent and continue to affect human development outcomes. In Indonesia, iodine deficiency persists in certain regions despite national intervention programs. Studies indicate that while iodine intake has improved overall, gaps remain in distribution, monitoring, and public awareness (Kusrini et al., 2020). This highlights the importance of context-specific strategies to address regional inequalities.

2.5. Policy and Intervention Strategies

Universal Salt Iodization (USI) is widely recognized as the most effective and cost-efficient strategy for preventing iodine deficiency disorders (World Health Organization, 2022). Evidence from multiple studies demonstrates that iodized salt programs significantly improve iodine status and reduce the prevalence of deficiency at the population level.

However, the effectiveness of these interventions depends on several factors, including regulatory enforcement, supply chain management, and public awareness (Untoro et al., 2010). In addition, recent literature highlights the importance of maintaining optimal iodine intake levels, as both deficiency and excess can lead to adverse health outcomes (Sohn et al., 2024). The literature suggests that while effective strategies exist, their success requires sustained implementation, monitoring, and integration with broader public health and socio-economic policies.

3. Methods

This study adopts a Systematic Literature Review (SLR) approach to synthesize existing evidence on the cognitive and socio-economic impacts of iodine deficiency disorders. The SLR method is used to ensure a structured, transparent, and reproducible process in identifying, selecting, and integrating relevant studies. A systematic search was conducted across several major academic databases, including Scopus, PubMed, Google Scholar, and ScienceDirect. The search strategy employed combinations of keywords such as "iodine deficiency," "iodine deficiency disorders," "cognitive development," "IQ," "socio-economic impact," "human capital," and "iodized salt," using Boolean operators (AND, OR) to refine and optimize the results. This approach was intended to capture a comprehensive set of relevant studies addressing both cognitive and socio-economic dimensions of iodine deficiency.

The inclusion criteria for this review comprised peer-reviewed journal articles, systematic reviews, and authoritative institutional reports published between 2015 and 2025, with the addition of selected foundational studies to strengthen theoretical grounding. Studies were included if they specifically addressed iodine deficiency and its cognitive and/or socio-economic impacts and were available in full text. Conversely, studies were excluded if they were unrelated to iodine deficiency, duplicated across databases, or focused solely on unrelated micronutrients.

The study selection process followed a PRISMA-based framework, consisting of identification, screening, eligibility assessment, and final inclusion. Initially, a broad set of articles was identified through database searches. These were then screened based on titles and abstracts to remove irrelevant studies. The remaining articles underwent full-text evaluation to ensure compliance with the inclusion criteria, resulting in a final set of approximately 20–22 studies included in the analysis.

The selected studies were analyzed using a thematic synthesis approach. Findings were systematically categorized into key themes, including cognitive impacts, socio-economic consequences, global and regional disparities, and policy and intervention strategies. This analytical approach enabled the identification of patterns, consistencies, and research gaps across the literature, providing a comprehensive understanding of the multifaceted impacts of iodine deficiency disorders.

4. Results

4.1. Cognitive Impacts of Iodine Deficiency

The reviewed literature consistently demonstrates that iodine deficiency has a significant negative impact on cognitive development, particularly during critical life stages such as pregnancy, infancy, and childhood. Iodine plays a crucial role in thyroid hormone production, which is essential for brain development; therefore, insufficient iodine intake during these periods leads to impaired neurological function and reduced cognitive capacity (Zimmermann, 2020; Toloza et al., 2020). Empirical studies indicate that individuals living in iodine-deficient areas tend to exhibit lower Intelligence Quotient (IQ), reduced learning ability, and poorer academic performance compared to those with adequate iodine intake (Latifah et al., 2020).

In addition, longitudinal and cross-sectional studies suggest that the cognitive effects of iodine deficiency can persist into adolescence, affecting educational outcomes and intellectual performance over time. Evidence also highlights that indicators such as goiter and urinary iodine levels are associated with variations in cognitive achievement, further supporting the link between iodine status and brain function. However, some findings indicate variability in outcomes, suggesting that cognitive development is influenced by multiple interacting factors, including overall nutritional status and environmental conditions (Ford & Stein, 2016).

Meta-analytical evidence further shows that while iodine supplementation improves biological markers, its direct effect on cognitive outcomes may depend on the severity and timing of deficiency (Dineva et al., 2020). This suggests that intervention strategies must be carefully timed and targeted to achieve meaningful cognitive benefits, rather than solely relying on the correction of biochemical indicators. Taken together, the findings underscore the necessity of public health policies that prioritize iodine prophylaxis during early development, while also acknowledging the complex, multifactorial nature of cognitive development that can moderate the effects of iodine status.

4.2. Socio-Economic Impacts

The cognitive impairments associated with iodine deficiency extend into broader socio-economic consequences, particularly through their influence on human capital development. Reduced cognitive ability has been linked to lower educational attainment, which subsequently affects labor productivity and long-term economic performance (Field et al., 2009). Empirical evidence demonstrates that improvements in iodine intake, especially during prenatal development, are associated with increased years of schooling and enhanced academic progression. This chain of effects—from biological deficiency to reduced cognitive functioning, and then to lower educational achievement—illustrates how a seemingly simple nutritional shortfall can have enduring repercussions on an individual's economic potential and overall contribution to society.

At a macro level, iodine deficiency contributes to economic losses by reducing workforce efficiency and increasing the burden of disability. Global studies indicate that iodine deficiency remains a contributor to developmental intellectual disability, which imposes long-term economic and social costs, particularly in low socio-demographic index regions (Liu et al., 2025). These costs manifest not only in direct healthcare expenditures but also in lost productivity, reduced tax revenues, and increased dependency on social support systems. Furthermore, broader analyses of micronutrient deficiencies highlight their cumulative impact on human development indicators, including productivity and economic growth (Bommer et al., 2020), suggesting that iodine deficiency should be understood as part of a larger constellation of nutritional challenges that collectively undermine national development trajectories.

Taken together, the evidence reinforces that addressing iodine deficiency is not merely a public health concern but also an economic imperative. Interventions such as universal salt iodization have proven cost-effective precisely because they prevent the lifelong cognitive and economic losses associated with deficiency. However, the persistence of iodine deficiency in low-resource settings underscores the need for sustained political commitment, robust monitoring systems, and integrated nutritional strategies that simultaneously tackle multiple micronutrient deficiencies to fully realize both individual cognitive potential and broader socio-economic gains.

4.3. Global and Regional Context

The distribution of iodine deficiency remains uneven across regions, with a higher prevalence observed in low- and middle-income countries. Global evidence indicates that regions with lower Socio-Demographic Index (SDI) levels continue to experience a disproportionate burden of iodine deficiency and its associated outcomes (Liu et al., 2025). This geographic disparity is not merely a reflection of natural iodine availability in soil and water, but is also deeply shaped by structural factors including public health infrastructure, economic constraints, and political commitment to nutrition programs. Although global initiatives such as universal salt iodization have significantly reduced the prevalence of iodine deficiency, disparities persist due to differences in public health infrastructure, dietary patterns, and socio-economic conditions. Consequently, while some nations have successfully achieved iodine sufficiency, others—particularly those with weak regulatory systems or fragmented salt markets—continue to struggle with endemic deficiency and its long-term developmental consequences.

In the Indonesian context, iodine deficiency continues to be a public health concern in specific regions, particularly those with limited access to iodized salt and nutrition education. Studies suggest that while overall iodine intake has improved, variations in coverage and monitoring remain challenges (Kusrini et al., 2020). These local disparities are often exacerbated by geographical factors such as mountainous terrain, which historically correlates with low soil iodine content, as well as by limited distribution networks for iodized salt in remote areas. Furthermore, differences in awareness and health literacy across communities mean that even when iodized salt is available, its consistent use cannot be taken for granted, underscoring the need for context-specific behavioral interventions alongside supply-side measures.

These findings indicate the need for continued surveillance and targeted interventions to address regional inequalities. A one-size-fits-all approach is insufficient given the heterogeneity in iodine status within and between countries; instead, policymakers must prioritize subnational mapping of deficiency hotspots and tailor programs accordingly. Strengthening monitoring systems, including regular assessment of urinary iodine levels and salt iodine content at the district level, is essential to track progress and identify emerging gaps. Ultimately, achieving equitable iodine sufficiency requires not only sustained commitment to universal salt iodization but also integrated strategies that address the social, economic, and geographic determinants of deficiency, ensuring that no region or population group is left behind.

4.4. Policy and Intervention Outcomes

The literature strongly supports Universal Salt Iodization (USI) as the most effective and sustainable strategy for preventing iodine deficiency disorders. Evidence from global and regional studies demonstrates that iodized salt programs significantly improve iodine status and reduce the prevalence of deficiency at the population level (World Health Organization, 2022). This approach leverages the near-universal consumption of salt across households, making it a cost-effective and scalable public health intervention. In addition, supplementation programs targeting

vulnerable groups, such as pregnant women, have been shown to contribute to improved iodine intake and related health outcomes. These targeted efforts are particularly important because the developmental consequences of iodine deficiency are most severe during fetal and early postnatal life, and supplementation can serve as a critical safety net for those who may not benefit adequately from USI alone.

However, the effectiveness of these interventions depends on proper implementation, including regulatory enforcement, supply chain management, and public awareness (Untoro et al., 2010). Without strong political commitment and quality control mechanisms, iodized salt may fail to reach remote or marginalized populations, or may lose its iodine content due to poor storage and handling practices. Furthermore, recent studies emphasize the importance of maintaining optimal iodine intake levels, as both deficiency and excess can lead to adverse health outcomes (Sohn et al., 2024). Excessive iodine intake, which can occur in some regions due to over-iodization or high consumption of iodine-rich foods and supplements, has been associated with thyroid dysfunction and other metabolic disturbances, thereby complicating the public health messaging around iodine.

These findings highlight the need for balanced and well-monitored intervention strategies. Rather than simply maximizing iodine delivery, programs must aim for a "just-right" range of population iodine intake, as measured by median urinary iodine concentrations. This requires regular surveillance systems that can detect both insufficient and excessive intake, allowing for timely adjustments to salt iodization levels or supplementation guidelines. Ultimately, sustainable success in preventing iodine deficiency disorders hinges on an integrated approach that combines robust regulatory frameworks, ongoing monitoring, community engagement, and flexible programming that adapts to changing dietary patterns and epidemiological profiles.

5. Discussion

The findings of this study confirm that iodine deficiency disorders (IDD) exert a multidimensional impact that extends beyond biological health outcomes into cognitive and socio-economic domains. While the results consistently demonstrate a strong association between iodine deficiency and impaired cognitive development, the broader implications suggest that these effects are embedded within a complex system of nutritional, environmental, and socio-economic determinants. This aligns with previous literature emphasizing that cognitive development is not solely determined by micronutrient status but is influenced by a combination of interacting factors (Bommer et al., 2020).

From a cognitive perspective, the evidence reinforces the critical importance of iodine during early developmental stages, particularly during pregnancy and early childhood. The persistence of cognitive deficits into later life stages indicates that iodine deficiency has long-term consequences that are not easily reversible. However, the variability in findings across studies, especially in relation to supplementation outcomes, suggests that the timing, severity, and context of iodine deficiency play a crucial role in determining its impact (Dineva et al., 2020). This highlights the need for early and sustained intervention rather than reactive approaches.

In terms of socio-economic implications, the findings underscore the role of iodine deficiency as a barrier to human capital development. Reduced cognitive ability translates into lower educational attainment and diminished productivity, which collectively constrain economic growth (Field et al., 2009). This relationship illustrates how micronutrient deficiencies can perpetuate cycles of poverty and inequality, particularly in regions with limited access to adequate nutrition and healthcare. Consequently, addressing iodine deficiency should be viewed not only as a public health priority but also as a strategic investment in economic development.

The Indonesian context provides a relevant case for understanding these dynamics. Although national iodization programs have contributed to improvements in iodine status, the persistence of regional disparities indicates that policy implementation remains uneven (Kusrini et al., 2020). These gaps may be attributed to differences in infrastructure, awareness, and regulatory enforcement. Furthermore, the limited availability of updated national data on iodine status suggests that current monitoring systems may not fully capture the evolving nature of the problem. This emphasizes the importance of strengthening surveillance systems and ensuring consistent program implementation.

From a policy perspective, the evidence strongly supports Universal Salt Iodization (USI) as the most effective and cost-efficient intervention. However, the discussion also highlights that the success of such interventions depends on sustained commitment, effective governance, and integration with broader public health strategies (Untoro et al., 2010; World Health Organization, 2022). In addition, the emerging concern regarding iodine excess underscores the need for balanced approaches that ensure optimal intake levels rather than focusing solely on deficiency (Sohn et al., 2024). This study contributes to the literature by providing an integrated synthesis that connects cognitive and socio-economic impacts of iodine deficiency within a unified framework. By bridging these dimensions, the findings offer a more comprehensive understanding of IDD and highlight the importance of adopting multidisciplinary approaches in addressing micronutrient deficiencies.

6. Conclusion

This study synthesizes existing evidence on the cognitive and socio-economic impacts of iodine deficiency disorders (IDD) through a systematic literature review. The findings confirm that iodine deficiency significantly impairs cognitive development, particularly during critical periods such as pregnancy and early childhood, resulting in long-term effects on intelligence, learning ability, and academic performance. These cognitive consequences extend into broader socio-economic domains, where reduced educational attainment and productivity contribute to weakened human capital and hindered economic development.

The review also highlights that iodine deficiency remains unevenly distributed across regions, with low- and middle-income countries bearing a greater burden. In the Indonesian context, although iodized salt programs have improved iodine status, challenges persist in ensuring consistent implementation, monitoring, and equitable access. These findings emphasize that addressing iodine deficiency requires not only biomedical interventions but also consideration of socio-economic and structural factors.

From a policy perspective, Universal Salt Iodization (USI) remains the most effective and cost-efficient strategy for preventing IDD. However, its success depends on sustained regulatory enforcement, public awareness, and continuous monitoring to ensure optimal iodine intake levels. The potential risks associated with both iodine deficiency and excess further underscore the need for balanced and evidence-based approaches.

This study contributes to the literature by integrating cognitive and socio-economic perspectives into a unified analytical framework, offering a more comprehensive understanding of the impacts of iodine deficiency. Nevertheless, this study is limited by its reliance on secondary data and the variability of methodologies across the included studies. Future research should focus on generating updated, context-specific data, particularly in Indonesia, and on evaluating the long-term effectiveness of intervention strategies

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