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Iodine in Nigeria: A Review of Concepts; Prevalence, and Effect on Brain Cognitive Potential

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ABSTRACT / ABSTRAK

The issue of iodine deficiency is a historic threat that affects all regions of the world. Iodine is a critical element belonging to the halogens that is used to make vital hormones (thyroid hormones) for the proper functioning of the human or mammalian body. Iodine is obtained from the diet of either plant or animal origin or water. Iodine for plants uptake is obtained from soil, which is affected by the nature of the environment such as climate, locations, topography, iodine fixation potential, proximity to sea and relations. The failure of the proper iodine cycling spurs a poor intake by humans. Poor dietary intake of iodine occurs at different levels, but the entire complex dealing with poor iodine intake is termed as iodine deficiencies, such as goiter, cretinism, hypothyroidism, and hyperthyroidism. Effects resulting from iodine deficiency are many and enormous. The iodine deficiency among other things affect the brain (nervous system functioning) probably because it affects the whole body metabolism when thyroid hormones are insufficient, and neurotransmitters and oxidative stress regulations are limited. It is important to deliberately educate the public, fortify foods properly, give iodine supplements, monitor iodine deficiencies, and utilize diverse foods; because IDD cause mental retardation among other things.

INTRODUCTION

Iodine has an atomic number of 53, and an atomic weight of about 126.9. Iodine is the heaviest as well as stable member of the halogen group in the periodic table. It makes diatomic molecule (I2) and behave as solid entity contrary to other members of halogens, and it is volatile at ordinary room temperature (Fuge & Johnson, 2015). Iodine is an essential trace (micro) nutrient that serve as a non-negotiable component of thyroid hormones (thyroxine and triiodothyronine) (). Deficiency or insufficient level of iodine affects thyroid gland directly and in turn, the mammalian (human) body is generally affected in many regions (Fuge & Johnson, 2015). Iodine is found in the environment as iodate in many regions of Nigeria and is affected or depleted by processes such as flooding, glaciation, and erosion happening in soils (Zimmermann, 2010). Soil of this type is typically depleted, and in turn the growing plants (crops) will contain insufficient iodine levels; a situation that affect humans as the ultimate consumers (Wang et al., 2021). Albeit, all people are concerned, effects of iodine deficiency are mostly felt in pregnant women, children, unborn babies, and breastfeeding mothers (Fan etal.

2020; Habib et.al., 2021). Other people at the risk of iodine deficiency include, people who consumed single diet, malnourished individuals, people who consumed certain drugs, people in poverty, people in poor countries (areas), people living in deficient soils (environments), and illiterate people (Zia et al., 2014; Katongo et al., 2017; Appiah et al., 2020; Haritha et al., 2022).

However, the exact specific examples of iodine deficiency effects include, irreversible brain damage in children, stillbirths, miscarriages, low birth weight, goiter, cretinism, poor productivity, and poor learning (Zimmermann, 2007; Zimmermann, 2010; Fuge & Johnson, 2015; Duborska et al., 2022). Iodine's role in the body is enormous indeed. Ideally, it shows abnormalities into the body's central nervous system (brain) functioning because of its disparate roles in metabolism, and the ability of iodine deficiency to escalate homocysteine level (Emelike et al., 2017). The role of iodine in the body can be for instance pointed based on its participation as component of thyroid hormones (thyroxine/T4; and triiodothyronine/T3). The thyroid hormones regulate several important biochemical processes such as protein synthesis, enzymes activities. Furthermore, the thyroid hormones are needed for central nervous system development, and skeletal development in children (Delange, 2000; Fuge & Johnson, 2015; Sarkingobirr et al., 2022; Umar et al., 2023).

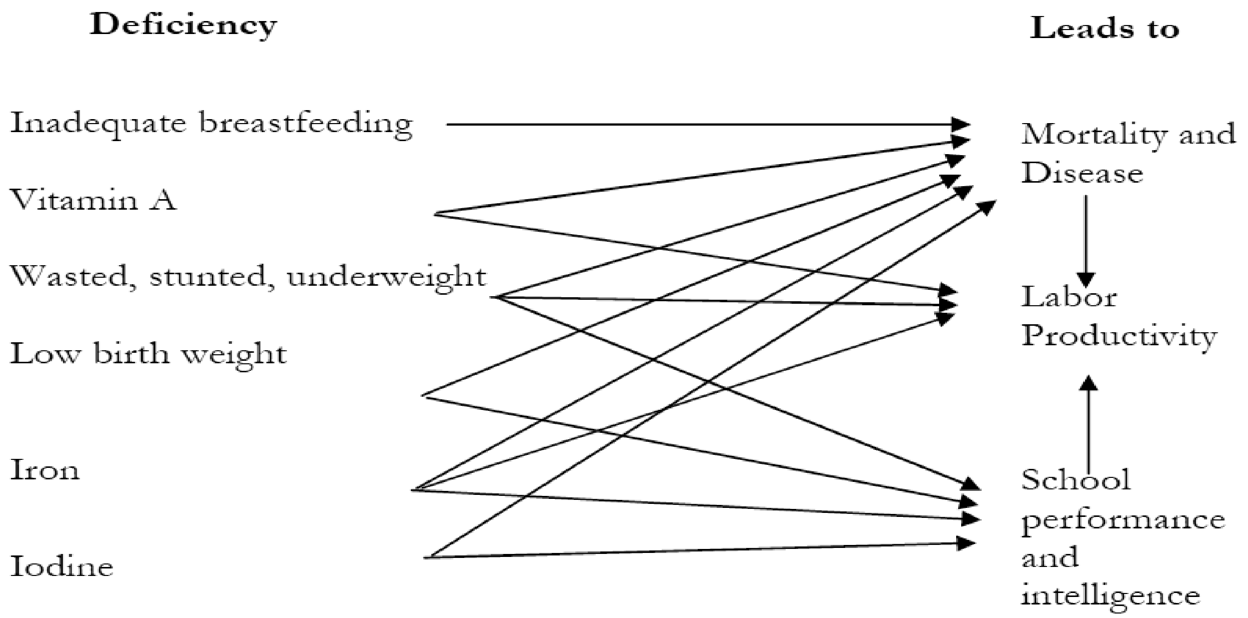

Figure 1: An overview of how nutrition deficiencies affect the prospects of young Children. Source: TFNC, World Bank and UNICEF, (2007).

Iodine

Iodine is a member that chemically belongs to halogens, a group of elements with seven valence electrons. Halogens make their octet state by sharing electrons and formation of halide. However, iodine is the least chemically reactive member among them. Iodine is a rare element and is essentially needed by the body to construct thyroid hormones. The production of hormones is undertaken at the butterfly-shaped area situated in the front of the neck; the gland consists of two loves attached to each side of the windpipe. After the synthesis of thyroid hormones, they are supposed to travel to the blood where they control disparate processes affecting body parts. Essentially, thyroid hormones are around for normal functioning of body's energy, and for development (Johnson, 2003). Everyday an adult, children, infants, pregnant women, and lactating women need; 150ug, 90ug, 120ug, 200ug, respectively (Zimmermann, 2008; Zimmermann, 2010).

Consequences of iodine insufficiency

Health effects that are consequential on other aspects occur due to iodine deficiency (little iodine); some of the effects are:

Goiter- Goiter is a situation when the thyroid gland is enlarged above normal. When iodine is low, thyroid activity slows, in turn, the pituitary gland (in the brain) secrete thyroid stimulating hormone to agitate thyroid gland produce more hormones. This increased agitation, albeit, an adaptation tactic, caused goiter (enlarged gland). Sometimes goiter constrict windpipe and trigger chocking (Johnson, 2003; Zimmermann, 2010).

Hypothyroidism- In this term, the thyroid hormone reaching the body is insufficient. The situation is tested by showing low level of thyroid hormones in the blood. Hypothyroidism cause dry skin, constipation, cold intolerance, and sluggishness. Particularly, in children, other important effects of hypothyroidism are the mental retardation, growth derangement (Wisnu, 2008; UNICEF, 2008).

Cretinism- Cretinism is a severe situation of hypothyroidism happening during fetal or neonatal period causing the affected person to suffer irreversible mental retardation, deaf mutism, musculoskeletal defects, and short stature (Hernando, 2015).

Reproductive problem-Women with severe iodine deficiency show more stillbirths, miscarriages, decreased fertility.

Childhood mortality in children- Iodine insufficiency lead to death on many occasions haply due to poor immunity (Bouga et al., 2015; Adekunle et al., 2019).

Socioeconomic problem- Iodine insufficiency lead to emergence of mentally-deranged children that are less-likely to learn properly or contribute to the economy when grown-up (either at individual or societal level); and require much from the economy for their care (Zimmermann, 2010; Emilike et al., 2017).

Prevalence and Indicators of Iodine Insufficiency

Indications had revealed that IDD and determinants are rampant in various parts of Nigeria over the past years (as revealed in Tables 1-4).

Table 1: WHO Global Database (1988) On Iodine Deficiency Before Initiation of USI In Nigeria

Year	States	Goiter Prevalence (%)
1988	Enugu	36
	C/River	34
	Edo	19
	Benue	28
	Oyo	24
	Ondo	26
	Plateau	16

Source: WHO (2007)

Table 2: WHO Global Database (1993) On Iodine Deficiency Before Initiation of USI in Nigeria.

Year	States	Goiter Prevalence (%)
1993	Enugu	67
	Cross River	62
	Edo	32
	Benue	60
	Oyo	36
	Plateau	26
	Ekiti	38
	Katsina	11
	Kano	13
	Zamfara	22

Source: WHO (2007)

Table 3: WHO Global Database (1998) On Iodine Deficiency After Initiation of USI in Nigeria

Year	States	Goiter Prevalence (%)	Median Urinary Iodine (μg/L)
1998	Enugu	9.8	146.0
	C/River	14.9	148.0
	Edo	30.4	147.0
	Benue	9.4	146.5
	Oyo	16.2	106.0
	Plateau	4.7	92.0
	Ekiti	33.3	140.0
	Katsina	2.9	126.0
	Kano	4.1	156.5
	Zamfara	2.9	155.0

Source: WHO (2007)

Table 4: WHO Global Database (2001) On Iodine Deficiency After Initiation of USI in Nigeria.

Year	States	**Urinary iodine (μg/L)**						**Median**
		Distribution (%)					Prevalence (%)	
		<20	20-49	50-99	100-299	>300	<100	
2001	Nasarawa	7.0	16.6	19.1	42.7	14.7	42.7	119.2
	Taraba	6.6	11.5	14.1	44.1	23.8	32.2	158.0
	Borno	4.2	4.2	10.4	38.0	43.2	18.8	237.1
	Kaduna	3.7	12.2	21.5	31.8	30.8	37.4	163.2
	Kebbi	4.3	4.6	9.1	52.2	22.7	18.0	152.8
	Kano	1.0	1.4	5.7	40.9	50.9	8.1	310.0
	Osun	1.5	8.5	15.8	47.5	26.8	25.8	173.4
	Edo	0.5	4.8	18.5	43.4	32.8	23.8	199.1
	Kwara	1.8	9.9	16.9	47.3	23.9	28.6	183.8
	Imo	2.7	5.3	17.1	40.3	34.6	25.1	208.4
	Bayelsa	0.6	2.4	11.4	49.6	35.9	14.4	231.4
	AkwaIbom	4.6	8.7	15.8	45.4	25.5	29.1	187.3

Source: WHO (2007)

Emenwanne & Akinyele (2000) in a southeastern study shows that none of the children examined had normal iodine and 44.0% of the collected households salts were iodized at 30ppm level, 19.0% of the samples were never iodized.

Salau et al., (2011) in an evaluative study of iodine in selected vegetables and fruits in Nigeria (Ogun state) obtained a result showing that, only few sampled plant-based foods had sufficient iodine. Olife et al., (2013) studied iodine status in Anambra State, Nigeria, and the populations examined are at the risk of iodine deficiency disorders.

Uniquely, in a goiter endemic region of southeast Nigeria; nutritional and iodine investigation among schooling children in a community in Enugu state Nigeria, shows that, about 8.8 percent of the children are iodine deficient, and that could be attributed to availability of iodine in salts (94.2‰) (Nwamarah et al., 2015). Musa et al., (2015) studied the levels of urinary iodine in students of Maiduguri University and result revealed mild deficiency that needs intervention.

Ekotti & Etukundo (2017) observed in a study of iodine stability of sold salts in Nigeria that, Dangote salt lost 20.13% iodine after heating at 40oC, Mr Chef salt and Royal salt lost 36.50 %, and 100% respectively. This strongly advocate for proper idolization and storage of salts considering the climate of various regions of the country.

Adekunle et al., (2019) examined the levels of acceptance of iodized tomato in Abeokuta, Nigeria; therewith, the findings show that, price is a major determinant that will prevent the public in using the tomato. Yetunde et al., (2020) observed iodine levels of primary school pupils in Ilorin (northern Nigeria) and found a quarter of the pupils had mild iodine deficiency.

Azubuike et al., (2021) in their work reiterated how low iodine levels are surfacing among primary school children in southeast Nigeria. There were high iodine levels, low iodine deficiency. Thus, iodine deficiency interventions should be done carefully. Orisa et al., (2022) analyzed iodine among preschool children in Rivers state, Nigeria; and the result show that, none of the children were deficient. Therefore, this indicates success in iodine status interventions among the given population observed. John et al., (2022) assessing iodine deficiency in a University of Portharcourt Hospital and observed that, iodine deficiency was prevalent among population of women attending antenatal care more than other women. This finding is an indicator of needs for supplementation among other strategies.

Kareem et al., (2023) assessed factors that associate with inadequate iodized salt intake among pregnant and lactating women in Nigeria; and revealed 35.2% prevalence of inadequate iodine in the subjects, due to poverty, non-formal education. Enhanced economy and health promotion interventions are suggested in acting upon the trend. Izuagba et al. (2023) in a study of iodine status among communities in Imo state, Nigeria found a prevalence of 7.8% among 386 study participants involved.

Nwabugo et al., (2023) examined levels of iodine and potassium iodide in sold salts in Enugu market and the results show iodine is sufficient, while many of the samples are containing potassium iodide below standard. Edah et al., (2023) assessed the types of thyroid disorders in a higher level of healthcare facility in Jos, Nigeria; the results show that thyroid disorders are prevalent, and could be linked to poor iodine intake among the adults (18-78 years) observed. Nevertheless, the past studies had revealed that iodine IDD is still an issue in the country more efforts should be garnered to surmount the monster.

Control Strategies for Iodine Deficiency Disorders (IDD)

The following are basic strategies for intervening against IDD:

Supplementation

Iodine supplementation is quite advantageous over iodization due to some areas that are remote where small scale mode of salts is made at local levels following and implementation of laws and policies is low (Muleta & Kibatu, 2016; Maduforo et al., 2023). Thus, method of supplementation can be achieved in various forms. Iodization of oil (through emulsification of vegetable oils) is given orally or intramuscular. Furthermore, iodine is supplemented as KIO3 or KI drops, tablets, and drinking water. Parable, girl or women of childbearing age supposed to be supplemented with single oral 400 mg dose annually; children at the age range of 7 to 24 months supposed to receive an annual single dose of 200 mg of iodine; children at 0-6montgs supposed to be supplemented when their mothers have not been earlier supplemented or if the baby is not receiving breastfeeding (Zimmermann, 2007: Gwarzo, 2012; Ojuwundu et al., 2011; Tuncalp et al., 2020; Umar et al., 2021).

Fortification through Salt

Iodate and Iodine are utilized to fortify sat in the form of potassium salt. Iodate behavior is less soluble in water and resist oxidation or evaporation more than iodide. Salt iodization globally is termed as universal salt iodization. This universal practice is peculiar because mostly the entire people use salt, few sources make salt, technique is cheap, and easy to monitor, and salt consumption is throughout the year. After drying salt, iodine is added through KIO3 dripping or spraying by passing the salt on conveyer belt; this is wet method. Dry method, rather involved adding KI or KIO3 powder been sprinkled on dry salt. To avoid loss of iodine, salt is supposed to be kept dry and packages properly, example in high density polyethylene bag because, humid storage could dissipate 30% of iodine content of the salt (Zimmermann, 2007). Ideally, there are other vehicles for fortification such as bread, milk and water. KI or KIO3 should be added daily to public water (Onyeaghala et al., 2007; Zimmerman, 2010; Ekotti & Etukundo, 2017).

Monitoring

Effective monitoring systems to checkmate non-compliance to iodine iodization is necessary. Likewise, monitoring is important to diagnose gaps with a view to fill. Monitoring levels of goitrogens in foods consumed by humans, iodine levels in human population, are key methods (UNICEF, 2008; Doku & Bortey, 2018). Health education methods should be applied to make wise decisions on foods; including views and ways to reach all. When people are aware, believed in iodization is improved (UNICEF, 2008; Enechi etal., 2013).

Dietary Diversification

Ideally, there is no catch-it-all food that contains all the required nutrients for human consumption, unless in rare cases. Thus, instead of people to rely on single food like rice in the Northern Nigeria, Garri (cassava) in the Southern Nigeria, and many other typical regional foods; it is pertinent to disclose that people should diversify their first isn't locally available cheap sources (Egubute et al., 2002; Ajayi et al., 2015; Adekunle et al., 2019).

Iodine Deficiency and Brain Functioning

Long ago, it was realized that children who were exposed to IDD at critical stages of life experience various forms of mental retardation (Tina, 2001). A link between iodine and mental state was once demonstrated that, iodine status increase performance of children subjected to mental tests (Delange, 2000; Tina, 2001). In other parable work, Leny et al., (2020) show that IDD affects cognition in an experimental study in Indonesia. Micronutrients (including iodine) make up building block of nervous system functioning. Empirical works elucidated how people that are improperly fed show negative behaviors, poor emotional health, and disparate array if consequences (Umar, 2019). Iodine is a parcel of thyroid hormones (T3 and T4). These two hormones are significant for differentiation, metabolism, growth, and physiology if tissues of the human body; especially relating to the issues affecting brain, bones, heart, liver, pituitary, muscles, and fat tissues. Thyroid hormones are responsible for stimulating enzymes and RNA/protein synthesis. They are significant in their role of impacting the growth, as well as maturation of brain cells and brain metabolism. In youngsters, the needs for iodine is more crucial; because lack of iodine delays mental development ((Diosady et al., 1997; Ahad & Ganie, 2010; Umar, 2019). The concentration of iodine in the brain, substantia nigra, cerebrospinal fluid, and breast milk, indicates the emphatic significance of iodine for biological system especially with regards to children. Indeed, in the first 12 weeks of gestation, a fetus is entirely dependent for iodine source from the mother. Thyroid hormones must be sufficient for normal maturation (especially myelination) of nervous cells. Specifically, in the brain, thyroid hormones made from iodine instigate differentiation, maturation, synaptogenesis, neurite outgrowth, gangliogenesis, cell migration, cerebellar neurogenesis, as well as myelination of neurons. The effects of thyroid hormones are directly felt through their ability of regulating gene expression of processes (such as myelin gene expression, genes for cell signaling, neuronal growth factor gene, etc) (Umar, 2019). Furthermore, thyroid hormones directly and indirectly regulate body's normal growth and development; and play role in diverse metabolic processes. Additionally, iodine was reported to act as antioxidant. Therefore, in a nutshell, iodine deficiency may affect brain (nervous system) ability in learning through the influences including, effects on morphology, functioning, energy metabolism, excess homocysteine, oxidative stress in the brain or the body (Diosady et al., 1997; Ahad & Ganie, 2010; Umar, 2019; Abu Bashar & Begam, 2020).

Dietary Iodine Insufficiency in the Context of Nigerian Population: A review

Model for Understanding Iodine in Soil

In any soil, iodine is better understood by considering the principal factors that bring iodine to the soil, including the locational factors, anthropogenic factors, iodine fixation potential, pathways, and anthropogenic impact. These various factors involved in influencing the soil iodine are discussed below:

- Locational factors include, climate, parent material, soil topography, iodine fixation potential, etc. Parent material is a raw material for making soils, and it is of different types; therefore, definitely affecting the contents of soils. A soil made from weathering of different rocks contain different materials subject to the nature of deposition materials received. Igneous rocks (such as granite, volcanic glasses, basalts, intrusives, other volcanics) may have less iodine content (0.2ug/g) than sedimentary rocks having about (1.2ug/g).

Examples of iodine enriched sedimentary rocks include shales, sandstones, limestone, etc. However, despite contents of the parent rock of the soil, processes that add organic matter, concentrate finer minerals, or add seawater to soil help to enrich the soil with iodine. Contrary processes reduce iodine levels of soils.

- Climate- Climate (example temperature, precipitation) influence soil formation. Parable, heavy rain cause flooding, and leaching of available iodine and affect the food chain iodine.
- Topography-Mountainous areas are iodine deficient, lowlying place close to the sea supposed to be iodine-rich.
- Proximity to the sea- Much of the iodine is derived from the sea; therefore, areas that are close to the sea have more iodine in soils than others.
- Ability of soil to fix iodine- A soil despite its parent material, should be able to fix external iodine, so as to be enriched. Iodine fixation potential was defined as" the total amount of iodine that can be fixed by various fractions in a soil and is a characteristic of a soil in a given environment." An iodine level of soil is given by its fixation potential and iodine supply.
- Pathways bring iodine to the soil- Pathways include precipitation, weathering, volcanic activity, combustion, etc (Johnson, 2003; Moyib, 2018; Naeem etal., 2021).

Iodine Biogeochemical Cycling

Iodine Biogeochemical Cycling is depicted in the steps below:

1. Conversion of iodate (most stable in sea water) to iodide in ocean surface. This is believed to be due to phytoplankton or bacteria biological activity.
2. Seaweed and phytoplankton take in iodide to be released as CH3I and CH2I2.
3. The formed organic iodine gases are divulged to the air and due to sunlight iodine is released
4. Iodine affects ozone.
5. In the air forma of iodine include, inorganic iodate, inorganic iodite, soluble fractions insoluble fractions others
6. Further return of iodine to Earth's surface because of rainfall and deposition (Paz etal., 2018; Sorrenti et al., 2021).

Iodine Uptake by Plants

Usually, iodine uptake by plants is considered using a transfer factor; therewith, high transfer factor relates high iodine uptake in plants. However, iodine sticks very well to soils, therefore, have low transfer factor. Indeed, soil contribution of iodine through plants may be limiting (except in anoxic soils) (Daniel, 2009; The Jivita Journal, 2012).

Iodine Deficiency Disorders (IDD)

IDD is a collective spectrum of adverse health consequences or effects that are precipitated by intake of diet lacking enough iodine or poor iodine level in the body (as shown in Table 6) (Tina, 2001; Oladejo et al., 2018; Sarkingobir et al., 2023).

Effects of IDD and Vulnerability

When there is short in the iodine needed by the body, the thyroid gland become enlarged in a bid to balance between iodine short and thyroid hormones synthesis (this is dubbed as goiter) Other consequence is due to low thyroid hormones known as hypothyroidism, a condition that spur weight gain, intolerance to cold, lethargy, elevated blood cholesterol, reduces heart work, mental sluggishness. Specifically, children, infants, babies, could suffer goiter or IDD badly, leading to cretinism. Cretinism is characterized with mental retardation, apathy, stunting, impaired movement, impaired speech or hearing (Zimmermann, 2007; Oruma et al., 2021).

Women of childbearing age, breastfeeding mothers, and pregnant mothers are vulnerable to IDD more than others. IDD causes poor reproduction, infertility, miscarriage, stillbirth, abortion, and permanent mental retardation (in babies, and children) (Hernando et al., 2015; Zimmermann, 2010).

Table 5. The Health Consequences of Iodine Deficiency by Life Stage

Life stage	Health consequences of iodine deficiency
All ages	• Goitre • Hypothyroidism • Increased susceptibility to nuclear radiation
Foetus	• Spontaneous abortion • Stillbirth • Congenital anomalies • Perinatal mortality
Neonate	• Endemic cretinism including mental deficiency with a mixture of mutism, spastic diplegia, squint, hypothyroidism and short stature • Infant mortality
Child and adolescent	• Impaired mental function • Delayed physical development • Iodine-induced hyperthyroidism
Adults	• Impaired mental function • Iodine-induced hyperthyroidism

Source: Hetzel, (1983) and World Health Organization, (2007)

Food Sources of Iodine

Iodine contents of foods vary markedly. General idea believed that iodine is richer in iodized salt, seafood, some bakery foods, fresh fish, garlic, sardine oil, lettuce, potatoes, green beans, tomatoes, yoghurt, prunes, onions, cow milk, eggs, pineapple (Zia et al., 2014; Hernando et al., 2015; Cvijanovi et al., 2021).

CONCLUSION

Based on the current situation, IDD affects all parts of the world, and mostly all categories of people could be inflicted directly or indirectly. The IDD situation in the country (Nigeria) is enormous because of determinants such as poverty, poor soils, poor health education, disease burdens, non-enforcement of iodine policies, among others. The situation has put pregnant women, unborn children, breastfeeding mothers and their kids, adults, and children at risks. The academic and productivity potentials of many youngsters could be deteriorated due to iodine micronutrient deficiency. Therefore, all hands should be put on deck to ensure nutritional education, biofortification, iodization, and supplementation.

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