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Is iodine deficiency still a problem in sub-Saharan Africa?: a review

Sanjoy Saha[1], Brenda A. Z. Abu[2], Yasaman Jamshidi-Naeini[1], Upasana Mukherjee[1], Makenzie Miller[1], Li-Ling Peng[1] and Wilna Oldewage-Theron[1]*
[1]*Department of Nutritional Sciences, College of Human Sciences, Texas Tech University, Texas, USA*
[2]*Wegmans School of Health and Nutrition, Rochester Institute of Technology, New York, USA*

Iodine is an essential trace mineral, vital for its functions in many physiological processes in the human body. Both iodine deficiency (ID) and excess are associated with adverse health effects; ID and excess iodine intake have both been identified in sub-Saharan Africa (SSA). The review aims to (1) review the iodine status among populations in SSA until October 2018, and (2) identify populations at risk of excess or inadequate iodine intakes. A systematic search of relevant articles was carried out by a seven-member research team using PubMed, Science Direct and Scopus. A total of twenty-two articles was included for data extraction. Of the articles reviewed, the majority sought to determine the prevalence of iodine status of the study populations; others measured the impact of uncontrolled and unmonitored salt iodisation on iodine excess and tested the effectiveness of water iodisation. Although iodine status varied largely in study populations, ID and excessive iodine intake often coexisted within populations. The implementation of nutrition interventions and other strategies across SSA has resulted in the reduction of goitre prevalence. Even so, goitre prevalence remains high in many populations. Improvements in access to iodised salt and awareness of its importance are needed. The emerging problem of excess iodine intakes, however, should be taken into consideration by policy makers and programme implementers. As excessive iodine intakes may have adverse health effects greater than those induced by iodine deficient diets, more population-based studies are needed to investigate iodine intakes of the different population groups.

Iodine: Deficiency: Excess: Sub-Saharan Africa

Iodine (I_2), present in food as iodide (I^-), is mainly found in saltwater fish, iodised salt, molasses, seaweed and the leaves of plants growing close to the sea. Iodine is an essential trace mineral particularly vital for its function in the synthesis of thyroid hormones that aid the regulation of metabolic activities and the development of the central nervous system and the brain. It is also involved, importantly, in a number of physiological processes[1,2]. The Dietary Reference Intakes recommend an estimated average requirement of 90 µg/l for children 3–8 years old, 120 µg/l for boys aged 9–13 years and men older than 70 years old, and 150 µg/l for boys aged 14–18 years, girls aged 9–18 years, men aged 19–70 years and women aged 19 years and older. During pregnancy and lactation 220 and 290 µg/l is recommended, respectively[1].

Both iodine deficiency (ID) and excess are associated with adverse health effects[3–5]. Inadequate intake of iodine causes mental and health disorders, collectively known as iodine deficiency disorders (IDD). IDD include goitre, cretinism, deafness, motor disabilities, hypothyroidism and mental retardation resulting from damage during brain development[6,7]. Beyond the adverse

Abbreviations: ID, iodine deficiency; IDD, iodine deficiency disorder; SSA, sub-Saharan Africa; UIC, urinary iodine concentration.
***Corresponding author:** Wilna Oldewage-Theron, email wilna.oldewage@ttu.edu

physiological effects, inadequate iodine intake can also result in negative social outcomes. Individuals with goitre may face social discrimination, which can cause psychological tension, reduced opportunity for marriage and lowered participation in social events[8,9]. Conversely, excessive iodine intake can block thyroid hormone synthesis and release and thus increase the risk of thyroiditis, goitre, hypothyroidism and possibly fatal iodine-induced hyperthyroidism[6,10], and may possibly cause autoimmune diseases[10–13]. Balancing iodine intakes is thus necessary since inadequate and excessive intakes lead to adverse health outcomes[11,12]. Pregnant women require additional iodine for the development of the fetus and to compensate for the increased iodine excretion during pregnancy[14]. Adequate iodine intake is especially important during pregnancy and infancy. ID can cause abortions, stillbirths, perinatal and infant mortality, as well as irreversible brain damage and impaired psychomotor development among children[15].

The WHO indicated that 42·6 % of the African population had insufficient iodine intakes in 2004[13]. At the same time, thirteen countries had insufficient iodine intake, eleven countries had adequate intake, nine had a risk of high iodine intake and three countries had excessive intakes. Data were not available for twelve of the sub-Saharan Africa (SSA) countries. A decade (1993 to 2003) of trend analyses indicated that the total goitre prevalence increased from 15·6 to 28·3 %[13]. More recently, a global report from the Iodine Global Network reported that out of 139 countries, nineteen countries still experienced inadequate iodine intake, 110 countries had optimal intake and ten countries were classified as at risk of excessive intake. This report also indicated that the majority of countries in most of the regions on the African continent, such as Burkina Faso, Burundi, Mali (Western Africa), Mozambique (Southern Africa), South Sudan and Sudan (Northern Africa), showed sufficient intakes of iodine[16]. Moreover, a number of African countries are experiencing both inadequate and excess iodine intakes[13,16,17]. The lack of dietary diversity in the diets of most African countries and the fact that women often become pregnant at an early age, may contribute to inadequate dietary intakes[9,18]. ID interventions include food fortification, supplementation and promotion of consumption of iodine-rich foods. Iodine-related interventions mainly target pregnant women, lactating mothers and children because these groups are more vulnerable to IDD, and thus leading to their exposure to/participation in more than one intervention at the same time[4,19].

There have been significant efforts to reduce ID and goitre in the world, especially in Africa. However, several research investigations have found the existence of not only inadequate, but also excess iodine intakes. To date, no Africa-wide review has been carried out about iodine intake or status in SSA. Thus, this paper aims to (1) review the iodine status among populations in SSA until October 2018, and (2) identify populations at risk of excess or inadequate iodine intakes.

Methods

Search strategies

A team of seven members was involved in this review. The peer-reviewed articles were systematically selected but not evaluated for scientific rigour. The principal investigator guided the team members in searching, checking inclusion and exclusion criteria, and data extraction from the selected peer-reviewed articles. Research questions, objectives, search engines and key words aligning with the objectives for searching were decided in several group meetings at the beginning of the review process. All the authors independently reviewed the included articles and analysed them. The final results were the outcome of group discussions of each individual's analysis and consensus in findings.

A systematic and structured search in PubMed, ScienceDirect and Scopus was conducted using an advanced search process in April 2017. The research team made another search in October 2018 to include updated research articles in this review. For this review, six key words were used to identify relevant articles: 'iodine intake', 'iodine status', 'excess of iodine', 'hyperthyroidism', 'hypothyroidism', 'Sub-Saharan Africa' and various combinations of the name of each country situated in SSA. Limitation on the year of published articles was not accounted for as we aimed to assess iodine status over time in SSA. Three authors independently searched articles using the selected archives and transferred all outputs to an Excel spreadsheet. A final Excel spreadsheet of searched outputs was prepared by resolving disagreements and reaching consensus of the outputs.

Screening and selection

The research team initially found a total of 499 outputs during the search for research articles using the selected key words and combinations. Articles included were based on the eligibility criteria, namely: (a) original research article, (b) research conducted on human subjects, (c) research conducted in any part of the SSA countries, (d) published abstract available in English and (e) studies focusing on the assessment of iodine status using urinary iodine concentration (UIC), dietary intake or the prevalence or association of hypothyroidism or hyperthyroidism with iodine intake or status. Studies focusing on unnatural sources of iodine, one subject-based case studies, radiation or medication were excluded in the screening process. All the searched articles were listed in an Excel spreadsheet. Five authors of the team independently screened the titles and abstracts of all the articles to eliminate duplicates and checked for eligibility to be included in this review. Any disagreements among the authors regarding eligibility of articles were resolved through group discussions to reach a consensus.

Extraction of data

Three authors (S. S., Y. Z-N. and U. M.) independently read through all the twenty-three peer-reviewed articles that passed the eligibility criteria, to make sure of the eligibility for inclusion in this review. Afterwards, S. S., Y. Z-N. and U. M. independently read all the articles to extract data. Basic information of the article, study period, study objective/s, target population, study design, sample size, measurement method of exposure and outcome, intervention (if it was an interventional study), confounders, and main results prevalence, or percentage of ID or excess iodine intakes and measures related to association or determinants, were recorded. Key contents of the published articles were extracted and transferred to an Excel spreadsheet. The main results were prepared and discussed for each article. Afterwards, two other authors (B. A. Z A. and W. O-T.) independently reviewed all twenty-three articles and extracted data as part of cross-checking. The research team held group discussions to resolve disagreements to reach a consensus on the extracted data. Fig. 1 represents the flow chart of the selection process for the published articles.

Indicators to assess iodine status

The four recommended indicators to assess iodine nutritional status are: UIC or urinary iodine excretion, goitre rate, serum thyroid stimulating hormone level and serum thyroglobulin level[2]. UIC is measured using individual urine or urine spot samples[2,20]. Goitre rate is measured by visual observation, palpation or through the less-commonly used ultrasonography[6,20,21]. Serum thyroid stimulating hormone and serum thyroglobulin are thyroid hormones that can be measured in blood samples and used as determinants of thyroid function and iodine nutrition[2,15]. Other thyroid hormones, such as free thyroxine 4 and free triiodothyronine 3, may also be used as indicators, but are considered less reliable[2]. Although total goitre prevalence, UIC, thyroid stimulating hormone, and dietary iodine recall intakes have been used to measure iodine status or iodine intake among general populations[13,16,22], analysis of blood and urine samples are the most commonly used methods to estimate iodine intake in a population[10]. Urinary iodine excretion, via the kidneys, is considered an effective biochemical indicator of recent iodine intake[4]. The cut-off value for IDD is a median UIC level lower than 100 μg/l. IDD is further classified as severe (<20 μg/l), moderate (20–49 μg/l) and mild (50–99 μg/l)[23,24]. If more than 20 % of the UIC levels of a population are below 50 μg/l, it meets one of the requirements for sustainable elimination of IDD[4]. UIC above 300 μg/l is considered excessive iodine intake. According to the WHO/UNICEF/International Council for Control of Iodine Deficiency Disorders classification, indicators for assessing IDD, the percentage of subjects with UIC less than 50 and 100 μg/l should be less than 50 and 20 %, respectively, in order for the population to be iodine sufficient[23,24]. For the purpose of this review, UIC and goitre results are reported. UIC is less subjective as it measures current iodine states (over the last few days before sampling) whereas a physical goitre reflects a considerably longer history[7].

Results

The twenty-three studies included and information collected in this review were conducted in the following countries: Central Africa (Cameroon, Central African Republic, Democratic Republic of the Congo)[20,25], Eastern Africa (Djibouti, Ethiopia, Kenya, Tanzania)[4,8,9,20,22,26,27], Northern Africa (South Sudan, Sudan)[6,7,10,28,29], Southern Africa (Lesotho, Mozambique, South Africa, Zambia, Zimbabwe)[14,15,18,20,21,30–32] and Western Africa (Benin, Burkina Faso, Cameroon, Ghana, Mali, Nigeria, Togo)[20,33–35]. Three studies were conducted in multiple countries[20,26,34]. None of the articles reported national studies except for one study[27]. The majority of included studies were peer-reviewed and contained sub-national research. Many studies were not recent, ranging from as early as 1986 to only eight studies dated 2010 and later[4,7,9,10,18,26,27,33]. The most recent studies (*n* 2) were published in 2017[9,26]. Eleven of the studies included had the objective to determine the prevalence of IDD and iodine status of the study populations[6–9,14,18,21,22,27,32,35]. Five studies measured the impact of uncontrolled and unmonitored salt iodisation on iodine excess[8,20,30,31,34]. Among these, the purposes of three studies were to determine the prevalence of ID and its relationship with goitre, and other potential goitre-causing risk factors[8,20,30]. Six of the studies included iodine status during pregnancy[4,9,14,15,26,29]. Two tested the effectiveness of water iodisation and whether water is an alternative vehicle for iodisation[27,28]. The most common nutrition intervention and strategy for treating ID is the Universal Salt Iodisation programme. Table 1 presents a summary of all the included studies in this review.

Urinary iodine concentration and goitre in sub-Saharan Africa

From the two Central Africa studies[20,25], the first study reported median UIC showing excessive iodine intakes in both northeast and southeast regions of the Democratic Republic of Congo. However, the prevalence of goitre still ranged between 16 and 32 %[20]. In Central African Republic with 437 school children and 187 households, the median UIC indicated mild IDD in the households and severe IDD in the school children. Crude goitre rates of 50 % were observed among the households, including all members older than 6 years. In addition, the goitre prevalence was 28 % among school children in rural and 22 % in urban areas[25].

In Eastern Africa, seven studies were included[4,8,9,20,22,26,27]. In Ethiopia, the prevalence of goitre was 39·9 % for children aged 6–12 years in 2007, and 46 and 23 % of the children suffered from severe and moderate IDD, respectively[8]. IDD seems to be a persistent problem in Ethiopia as Keno and co-authors reported 72·6 % IDD in school children aged 6–12 years and 80 % IDD in pregnant women in 2017[9]. Goitre was observed in 21·3 % and 32·0 % of school children in the Unguja and Pemba islands, respectively[22]. In 1999, the goitre

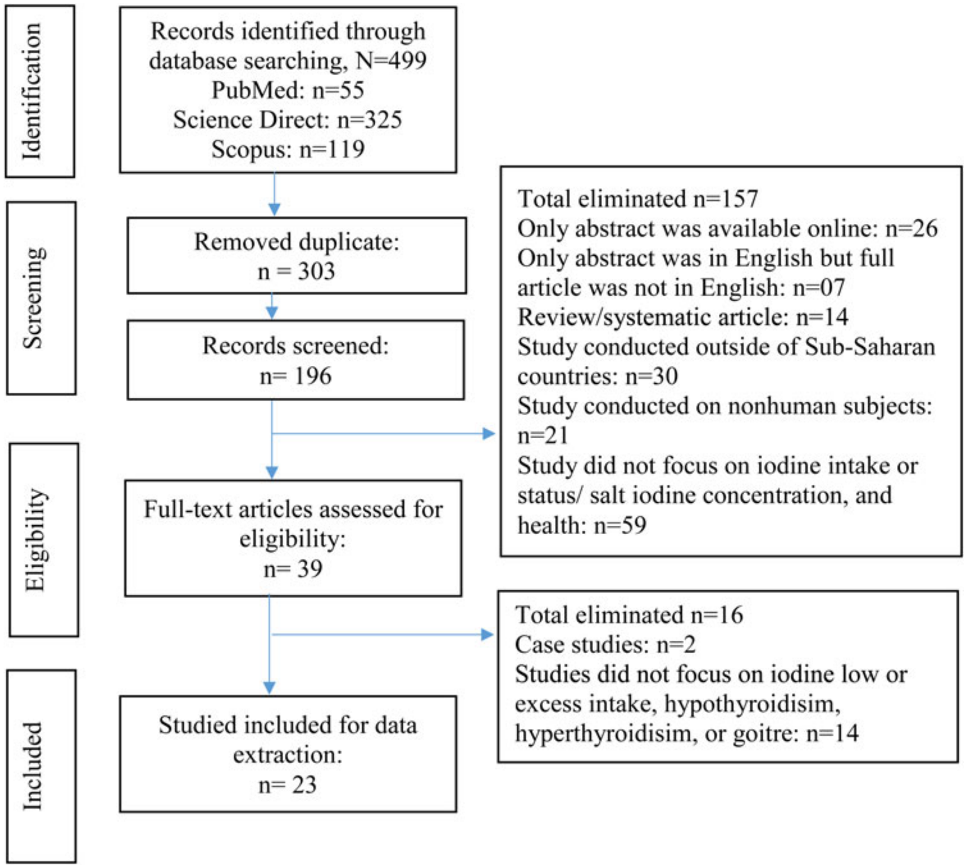

Fig. 1. (Colour online) Flow chart of the article selection process.

prevalence ranged from 9 to 14 % among school children aged 6–14 years in Kenya and 31–61 % in Tanzania[20]. This seems to have been addressed as a recent study reported excessive iodine intakes in school children and pregnant women in Kenya[4,26], Tanzania and Djibouti[26]. Excessive intakes were also reported for school children and women (>40 %) in Somalia[28], school children in Ethiopia (7·5 %)[9], rural dwellers and Somali refugees (71 %) in Kenya[4].

Four studies conducted in Northern Africa were implemented in Sudan[6,10,28,29] and one in South Sudan[7]. All the studies reported excess and/or inadequate status of iodine[6,7,10,28,29]. In one study, excess iodine intake was observed among 77·4 % participants in Port Sudan (*n* 31 school children)[10]. Furthermore, a higher prevalence of excess iodine levels (75 %) was also observed in a similar study conducted in 2006 (*n* 141 children)[6]. The authors emphasised that lack of regulation and monitoring of salt fortification could be the possible reason for excess iodine status among the study population[6]. A study in Western Sudan reported the efficiency of water sources containing iodine-saturated silicon matrices for providing adequate iodine supply to an iodine deficient population (*n* 2786). The prevalence of goitre decreased from 69 % (baseline) to 17 % (post-intervention) after a 2-year implementation[28]. In a study conducted in South Sudan among patients with endemic goitre (*n* 286), 54·5 % of the respondents had grade 1 goitre and 45·5 % grade 2 goitre. Goitre was more prevalent among women[7]. Furthermore, in another study, it was found that pregnant women (*n* 50) had significantly lower UIC levels than non-pregnant women[29].

From Southern African countries, eight published papers were included in this review[14,15,18,20,21,30–32]. A study undertaken in 924 (including sixty-four pregnant) women and 912 children in Lesotho showed median UIC indicating normal iodine intakes. However, 36 % of the children and 47·2 % of the women had excessive UIC. The study also showed that 21·5 % of the children and 17·9 % of the women had UIC lower than 100 µg/l[31]. In South Africa, a cross-sectional survey among 127 mothers with 149 children aged 6–11 years as well as 304 primary school children (6–14 years old) in rural Kwazulu-Natal showed a goitre prevalence of 28·3 % among mothers and 21·6 % among their children. The school children had a goitre prevalence of 29·6 %. Based on the UIC levels, 85 % of the household members and 97 % of the school children had IDD[21]. In many other studies, IDD still existed in the same populations, with visible goitre, especially among adolescent girls in Mozambique[18], pregnant women in Zimbabwe[14] and children in Zimbabwe[32], and Zambia[20].

In the Western Africa region, four studies reported excessive intake of iodine[20,33–35]. A study was conducted among 250 Ghanaian school children and

Table 1. List and details of research articles included in this review

Region	Author (year), country, reference	Objective/s	Target population and size sample size	Median UIC (μg/l) (range)	Goitre prevalence rate	ID/IDD/excess iodine prevalence rate based on UIC	Salt iodine concentration (mean/median) ppm or ppm (% of samples)	Legislated iodisation standard ppm/mg/kg	Access to iodised salt
Central Africa	Delange *et al.* (1999), Democratic Republic of Congo[20]	To assess the present iodine intake and prevalence of hyperthyroidism after the introduction of iodised salt in areas which were affected by ID in the past	313 SC aged 6–14 years	300–360	16–32 %	–	44 ppm at production 50–60 ppm in household	100 ppm	–
	Peterson *et al.* (1995), Central African Republic[25]	To estimate thiocyanate contents in cassava to deteriorate IDD in the western Central African Republic	152 SC >6 years old and 84 adults (western village) 101 SC >6 years old and 103 adults (central village) 184 primary SC (Bangui)	–	28 % (central area) 50 % (Western area) 22 % (Bangui)	79 % IDD in children (western) 88 % IDD in children (central) 59 % IDD in children (Bangui) 76 % adults (western) 86 % adults (central)	–	–	–
Eastern Africa	Abuye *et al.* (2007), Ethiopia,[8]	To examine the distribution and degree of severity of IDD and proportion of households with iodised salt	10 965 children aged 6–12 years 10 894 households salt samples	245	39·9 % 12·2 % for visible goitre	46 % severe ID 23 % moderate ID 17 % mild ID	–	–	4·2 %
	Assey *et al.* (2006), Tanzania[22]	To estimate the prevalence of IDD in the Unguja and Pemba islands	11 967 SC 80 salt samples from shops	127·5 (total sample) 186·0 (Unguja) 53·0 (Pemba)	21·3 % in Unguja 32·0 % in Pemba islands	8 % IDD in Unguja 47 % IDD in Pemba	10·3 ppm Unguja 2·9 ppm Pemba	≥37·5 ppm retail	1·0 % in Pemba 63·5 % in Unguja
	Delange *et al.* (1999), Kenya[20]	Mentioned earlier	866 SC aged 6–14 years	120–580	9–14 %	–	51 ppm at production 63–68 ppm in household	100 mg/kg from 1990–2009 Adjusted to 30–50 mg/kg 2010	–
	Delange *et al.* (1999), Tanzania,[20]		713 SC aged 6–14 years	150–160	31–61 %	–	28 ppm at retail 20 ppm in household	-75–100 ppm	–

Farebrother *et al.* (2018), Kenya[26]	To determine the effects of a chronic excessive iodine intakes on thyroid hormone functions, and subclinical and overt thyroid disorders	1390 SC, women of reproductive age, including PW and LW, breast-feeding and weaning infants	424 (SC) 289 (women of reproductive age) 337 (PW) 245 (LW) 546 (breastfed infants) 250 (weaning infants)	–	–	43 mg/kg	100 mg/kg from 1990–2009 30–50 mg/kg 2010	71·0 %
Farebrother *et al.* (2018), Tanzania[26]		2048 SC, women of reproductive age, PW, LW, breastfed and weaning infants	520 (SC) 473 (women of reproductive age) 422 (PW) 192 (LW) 515 (breastfed infants) 528 (weaning infants)	–	–	44 mg/kg	20–80 mg/kg	84·0 %
Farebrother *et al.* (2018), Djibouti[26]		985 (SC) 213 (PW)	334 (SC) 264 (PW)	–	–	Iodine detected in only 9 % of households salt samples Median 10 mg/kg Only 1·6 % of salt samples adequately iodised	-15–40 mg/kg	–
Kassim *et al.* (2010), Kenya[4]	To determine the adequacy of iodine intake in UIC between women receiving and not receiving the supplement attending antenatal care clinics	74 PW 63 non-PW (control)	730 (total group) 845 (PW) 660 (non-PW)	–	71 % had excessive UIC	50·7 ppm	100 mg/kg from 1990–2009 30–50 mg/kg 2010	–

Table 1. (*Cont*.)

Region	Author (year), country, reference	Objective/s	Target population and size sample size	Median UIC (μg/l) (range)	Goitre prevalence rate	ID/IDD/excess iodine prevalence rate based on UIC	Salt iodine concentration (mean/median) ppm or ppm (% of samples)	Legislated iodisation standard ppm/mg/kg	Access to iodised salt
	Kassim *et al*. (2014), Somalia[27]	To assess the iodine status and determinant of iodine status among the population of Somalia	1838 women aged 15–19 years 756 children aged 6–11 years 2345 household salt samples	329 (152–721) among women 416 (200–1110) among children	3·3 % in Northwest zone and 1·4 % in South Central zone among women 1·3 % in Northwest zone and 0·3 % in South Central zone among children	>40 % of both group of participants had excessive iodine intake		≥15 mg/kg	7·7 %
	Keno *et al*. (2017), Ethiopia[9]	To examine the iodine status of PW and SC, and iodine content in household salt in west Ethiopia	73 SC aged 6–12 years 40 PW	–	–	72·6 % IDD in SC 80 % IDD (PW) 2·7 % excess iodine intakes in children 7·5 % excessive iodine intakes	<15 ppm (67·0 %) > 15 ppm (33·0 %)	40 ppm	–
Northern Africa	Chuot *et al*. (2014), South Sudan[7]	To assess the prevalence of IDD among goitre patients	286 adult goitre patients	–	54·5 % grade 1 goitre 45·5 % grade 2 goitre	25 % moderate to severe IDD 23 % excess iodine excretion	–	–	38 % 62 % of participants consumed non-iodised salt
	Elnagar *et al*. (1997), Sudan[28]	To evaluate the effectiveness of iodinated silicon matrices in providing an adequate iodine supply to the population in a moderately severe ID area	2786 local inhabitants aged 1–72 years from four villages at baseline 2310 after 2 years post-intervention	13·9–25·3 (baseline) 37·9–256·9 (post-intervention)	69 % at baseline 49 % visible goitre at baseline 17 % after 2 years 11 % visible goitre after 2 years	93·8 % IDD at baseline 58·5 % after 2 years	–	–	–
	Eltom *et al*. (2000), Sudan[29]	To understand the persistence or otherwise of the pregnancy-related changes in the iodine metabolism and thyroid function	47 PW in third trimester aged 23–34 years 40 non-PW (control) aged 23–34 years	38·0 (third trimester) 50·7 (3 months postpartum) 30·4 (6 months postpartum) 63·3 (9 months postpartum) 75·9 (non-pregnant control)	–		–	–	–

	Izzeldin *et al.* (2007), Sudan[6]	To measure the iodine status of children who obtained school rations containing iodine	141 SC aged 6–12 years old	–	17 % visible goitre	75 % excess iodine intakes	>140 mg/kg (100 %)	20–40 mg/kg	–
	Medani *et al.* (2012), Sudan[10]	To explore the correlation between iodine intake and water chemicals and the thyroid gland status of SC	360 children, namely 31 from Port Sudan and 329 from other cities	464 (Port Sudan) 70·1 (other cities)	34·9 % (Port Sudan)	77·4 % excessive intakes (Port Sudan) 38·7 % hypothyroidism (Port Sudan)	–	–	–
Southern Africa	Benadé *et al.* (1997), South Africa[21]	To estimate the prevalence of goitre and ID in a rural area of KwaZulu-Natal in South Africa	127 mothers 149 children aged 6–11 years in household 304 children aged 6–14 years in schools Salt samples from three community shops	45·0 (children in households) 24·0 (children in schools)	28·3 % mothers 21·6 % children in households 29·6 % children in schools	85 % IDD in household children 97 % IDD in children in schools	–	–	Iodised salt was not available in any of the three community shops
	Delange *et al.* (1999), Zimbabwe[20]	Mentioned earlier	329 SC aged 6–14 years	450	9 %	–	50 ppm in household	30–90 ppm	–
	Delange *et al.* (1999), Zambia[20]		865 SC aged 6–14 years	180–260	3–16 %	–	59 ppm at retail 34–61 ppm in household	80–100 ppm	–
	Chinyanga and Dako (1989), Zimbabwe[14]	To assess the iodine status and the severity of ID in PW	100 PW and non-PW	–	16 % visible goitre in PW	40 % ID in PW	–	–	–
	Chinyanga *et al.* (2006), Zimbabwe[15]	To evaluate mothers who received antenatal care from hospital, whether met the increased need of iodine	100 PW 80 infants 80 LW 18 non-PW	115·5 (PW and LW) 271 (full term infants) 185 (non-PW)	–	>90 % of infants had sufficient iodine intakes (>100 μg/l) 60 % of PW had sufficient iodine intakes 60 % of LW had sufficient iodine intakes	–	–	–
	Gomo *et al.* (1999), Zimbabwe[30]	To evaluate urine iodine excretion as an indicator of iodine intake of adults living in an area of previous ID	734 adults aged ≥35 years (253 men and 480 women)	600 rural 440 urbans 680 (≤60 years of age) 480 (>60 years of age)	–	3 % hypothyroidism	–	–	–

Table 1. (*Cont.*)

Region	Author (year), country, reference	Objective/s	Target population and size sample size	Median UIC (μg/l) (range)	Goitre prevalence rate	ID/IDD/excess iodine prevalence rate based on UIC	Salt iodine concentration (mean/median) ppm or ppm (% of samples)	Legislated iodisation standard ppm/mg/kg	Access to iodised salt
	Korkalo *et al.* (2015), Mozambique[18]	To examine the biochemical status, prevalence of deficiency, dietary intake among adolescent girls	551 adolescent girls 14–19 years old	55 (non-pregnant, non-lactating) 54 (pregnant) 43 (non-pregnant, lactating)	IDD (pregnant and lactating girls) Moderate IDD (rural areas) Mild to moderate IDD (urban areas)	–	–	–	18·0 %
	Sebotsa *et al.* (2007), Lesotho, South Africa[31]	To measure the sustainability of the salt iodisation programme in Lesotho, 2 years after promulgation of the universal salt iodisation legislation	924 women 912 children	214·7 (women)	–	36 % children with excessive iodine intakes 47·2 % of women with excessive iodine intakes 21·5 % IDD in children 17·9 % IDD in women	38·5 ppm	>15 ppm	86·9 %
	The Chinamora research team (1986), Zimbabwe[32]	To determine the prevalence of goitre, iodine status of the population	3841 rural dwellers including children	–	29 %	Moderate IDD	–	–	–
Western Africa	Abizari *et al.* (2017), Ghana[33]	To measure the potential contribution of bouillon cubes to total iodine intakes in SC	250 SC aged 6–13 years 100 households salt samples	241·9	–	10·1 % IDD 35·4 % excess iodine intakes	< 5 mg/kg (72 %) 5–14·9 mg/kg (6·0 %) 15–40 mg/kg (4·0 %) >40 mg/kg (18 %)	≥15 ppm	–
	Delange *et al.* (1999), Cameroon[20]	Mentioned earlier	747 SC aged 6–14 years	100–120	21–23 %	–	14 ppm at production 31 ppm at retail 8 ppm in household	100 ppm	–
	Delange *et al.* (1999), Nigeria[20]		590 SC aged 6–14 years	260–370	26–40%	–	19 ppm at production 16 ppm at retail 21 ppm in household	50 ppm	–
	Delange *et al.* (2002), Benin[34]	To evaluate the present status of iodine nutrition in West Africa	1116 SC aged 6–12 years	293	1·2 %	9·3 % IDD 48·8 % excess iodine intakes	–	–	97·9 %

Delange *et al.* (2002), Burkina Faso[34]		1001 SC aged 6–12 years	114	22·4 %	60·4 % IDD 12·8 % excess iodine intakes	–	–	97·8 %
Delange *et al.* (2002), Mali[34]		901 SC aged 6–12 years	151	13·4 %	43·8 % IDD 21·9 % excess iodine intakes	–	–	94·2 %
Delange *et al.* (2002), Togo[34]		993 SC aged 6–12 years	116	4·3 %	53·6 % IDD 13·4 % excess iodine intakes	–	–	83·7 %
Torheim *et al.* (2004), Mali[35]	To measure iodine status and its determinants in women of childbearing age	423 women aged 15–45 years	27	60 % visible goitre	75 % IDD (<50 μg/l)	0 ppm (61 %) 25 ppm (19 %) >25 ppm (20 %)	–	61 % of households used salt with no iodine (tested)

ID, iodine deficiency; IDD, iodine deficiency disorder; LW, lactating women; ppm, part per million; PW, pregnant women; SC, school children; UIC, urinary iodine concentration.

reported that about a third (35·4 %) of the children had high UIC compared with only 10·1 % with insufficient iodine intakes[33]. In Mali, a study among 423 women showed that 35 % of the women had severe and 40 % moderate IDD. Only 6 % of the women had adequate iodine intakes. While 60 % of the women had visible goitre, only 9 % were classified as without goitre (Table 1)[35]. Among 590 Nigerian children, the median UIC levels were high. However, the prevalence of goitre was 26 and 40 % in the two areas respectively despite the high UIC levels[20]. In addition, the goitre prevalence among children (n 747) was 20 and 23 % in two areas respectively in Cameroon[20].

Multi-country study

In total three studies were conducted in multiple countries[20,26,34]. A study was conducted in three countries in East Africa by Farebrother and co-authors, and recruited a total of 4636 participants from these three countries. Excess iodine intakes were found among the participants from Kenya and Tanzania[26]. In a multicentre study by Delange and co-authors in four countries in West Africa, namely Benin, Burkina Faso, Mali and Togo, the highest rate of IDD (32·4 %) was found in Burkina Faso and excess iodine intakes (48·8 %) in Benin. The average median UIC was within normal range in four countries; however, still one-third of the participants had UIC levels below the acceptable range. The authors remarked on improvement in iodine status among the population; however, improved monitoring is needed in order to ensure quality of iodine concentration in salt[34]. Fig. 2 represents that two studies in Central Africa[20,25], five studies in Eastern Africa[8,9,20,22,27], four studies in Northern Africa[7,28,6,10], six studies in Southern Africa[14,18,20,21,31,32] and four studies in Western Africa[20,33–35] found ID. However, iodine excess was also reported in all regions, except for Central Africa. Although more studies reported IDD, excess iodine intakes should be noted and given attention in future studies.

Iodine deficiency disorders interventions and iodine from food sources in sub-Saharan Africa

Salt iodisation is the most effective strategy for addressing IDD globally and also in Africa. However, the success of the iodisation fortification programmes is highly dependent on household coverage[33]. Compulsory salt iodisation was introduced in most of the SSA countries as early as the 1970s in Kenya[26], and most other countries during the 1990s, for example Tanzania[26], Mali[35], Zimbabwe[14,30], South Africa[21], Ethiopia[9], Lesotho[31], Sudan[10] and Ghana[35]. Some countries also obtained iodised salt from their neighbours, for example Djibouti from Kenya[26]. The WHO recommended level is 20–40 and 15–40 mg iodine per kg salt respectively, at the production level and household level[19]. Not all the studies reported the iodine concentration and access to iodised salt. In addition, many

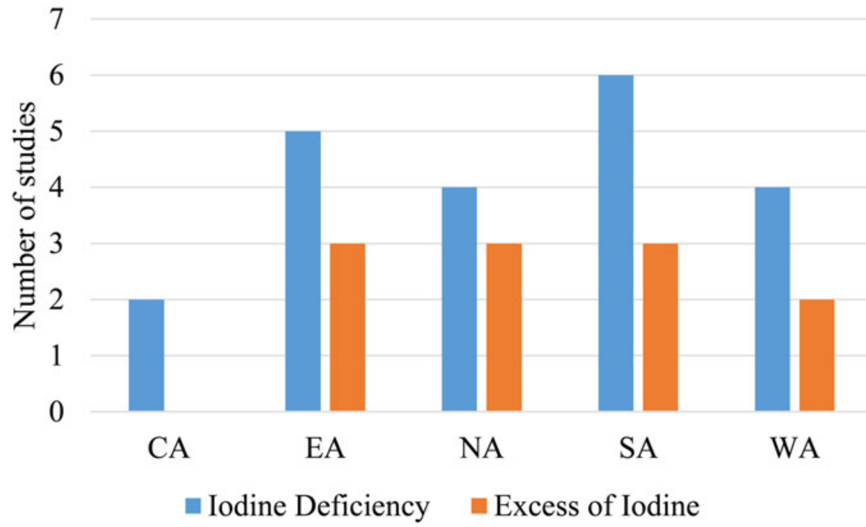

Fig. 2. (Colour online) Number of studies found iodine deficiency and iodine excess in Africa sub-regions. CA, Central Africa; EA, Eastern Africa; NA, Northern Africa; SA, Southern Africa; WA, Western Africa.

countries in SSA have their own legislation guidelines. In one study from Sudan, 100 % of the salt samples showed high iodine levels of >140 mg/kg, three times as high as the legislated amount[6]. From the results it is clear that most of the salt samples that were analysed had low iodine levels compared with the individual country's legislated amounts, except for Lesotho[31], Zimbabwe[20], Tanzania[26] and Kenya[4,26] that had optimum salt iodine levels. Interestingly, the same countries showed higher household access of iodised salt compared with those with low salt iodine levels. In the multi-country study from West Africa, high access levels of iodised salt, ranging from 83·7 % in Togo to 97·9 % in Benin, were also reported[34]. The goitre patients in three South Sudanese counties (*n* 286) were mostly the rural poor and all reported sorghum and maize as their predominant food. Only 38 % reported consuming iodised salt[7]. Some neighbouring countries in the region, such as Kenya, have over 90 % of their populations consuming iodised salt[26]. Chuot and co-authors also showed that despite the consumption of iodised salt, some individuals were still suffering from IDD. Contrary to this, only 50 % of the respondents that consumed non-iodised salt were iodine deficient. The reason for this apparent discrepancy may be that IDD is influenced by differences in diet[7].

Many food sources of iodine exist in SSA. Many food processors use iodised salt in foods, oils and blended cereal products. However, in these products, iodine levels are largely unmonitored[6]. In Ghana, it was estimated that two-thirds of the dietary iodine intake was from bouillon cubes manufactured with iodised salt[33]. Other sources of iodine include excess fluoride levels in drinking-water[10], water iodination using silicon matrices[28], supplementation and intake of fortified food[4], high consumption of dairy products[33] and groundwater[26]. Water is an essential nutrient consumed by all on a daily basis and is thus a good alternative for iodine supplementation. In fact, silicon matrices containing sodium iodide in well water sources were used in a study in Sudan in 1997[28]. Plants, such as cassava as well as low iodine content in the soil of Central Africa, have been known to impact IDD[25]. In Ethiopia, cassava consumption may have contributed to the regional variation in the IDD prevalence[8]. Cassava, a staple in Central and West Africa, is widely consumed in some parts of the country. It contains a goitrogenic substance known as cyanogenic glucoside, which upon conversion to thiocyanate in the body exacerbates ID when iodine intake is marginal or low[8,25].

Iodine-testing kits and titration may be used to test household salt iodine levels. In a multi-centre study in four African countries, iodine-testing kits overestimated the absence and the elevated content of iodine. As a result, the percentage of salt samples meeting the legal requirements of at least 50 ppm was about two-thirds (64·3 %) according to the kits but only about one-third (36·3 %) according to titration. Therefore, titration seems to be a more accurate method. Based on titration, iodine was undetectable in 0·5 % of the samples; its content was 1–14 ppm in 17·3 %, 15–49 ppm in 37·4 %, 50–100 ppm in 36·3 % and above 100 ppm in the last 8·5 %, including 0·5 % in which it was above 200 ppm. The access to iodised salt at the household level in the four countries varied from 83·7 to 97·8 %, with a global value of 94·3. It was above 90 % in three of them[34].

Although many studies from most countries still reported the prevalence of IDD and goitre, excessive iodine intakes have been observed in some countries, namely Somali refugee women in Kenya (71·5 %)[4], Sudan (>33 %)[6], Ghana (35·4 %)[33], Somalia (40 %)[27], Benin (48·8 %)[34], Mali (21·9 %)[34], Togo (13·4 %)[34] and Burkina Faso (12·8 %)[34]. Research indicates that children and women who are pregnant and lactating are the most at risk populations for IDD because of an increase in iodine excretion during pregnancy[31]. Thus, pregnant and lactating women are required to have their iodine levels monitored to prevent complications of ID[15]. WHO, UNICEF and International Council for Control of Iodine Deficiency Disorders published a supplementation recommendation statement that pregnant and lactating women should consume 250 mg iodine daily[23]. Many refugee camps in Africa, including the one in Kenya where the women had excessive intakes, adopted this statement and rely on international organisations to provide food items for these refugees. While the iodine amounts of these donated food items are unknown, they are expected to provide 150–200 mg iodine per 8786·4 kJ daily. No adverse health consequences have been reported among Somali refugees in Kenya, but the health concerns of taking excessive iodine among refugees in Africa still remains[4].

Conclusions

Salt iodisation has been recognised as a sustainable and cost-effective universal strategy to combat IDD[36]. In low-resource countries the implementation of salt iodisation may cause significant changes in the marketing and distribution channels. Elnagar and co-authors predicted that it might take years to achieve universal fortification and reduction of IDD[28]. In Africa, almost 33 % of the total population was affected by ID in 1990. In the most severely affected African countries, IDD has improved through household utilisation of iodised salt, iodised oil and iodised water[4,25,34]. Earlier studies reported more IDD and higher prevalence rates of goitre whereas the more recent studies (2010 and later) reported excessive intakes and a lower prevalence of goitre[4,7,9,10,18,26,27,33]. In most of the countries it appears that the iodised salt fortification has made a considerable impact on the prevalence of IDD and goitre, but it is clear that none of the WHO indicators for achieving sustainable elimination of IDD have been fulfilled in SSA. There are also some countries that still have a high prevalence of IDD. In Ethiopia, for example, 72·3 % of the children and 80 % of pregnant women are still suffering from IDD[9]. Similarly in Mozambique, a recent study has shown IDD in adolescent girls[18]. Therefore, improvements in access to iodised salt and awareness of its importance are needed with a special focus on the rural population in these countries[18].

Furthermore, in most countries, the salt iodine levels were lower than the legislated standards and household access to iodised salt was also low. This indicates that other food and water sources are likely contributing to the excessive intakes observed in the more recent studies[7,9,26,33]. Although the results indicate that IDD is still a concern in some SSA countries, the emerging problem of excess iodine intakes should be a warning for policy makers and programme implementers to critically consider iodine fortification levels, and not to implement blanket additional supplementation to avoid hyperthyroidism without regular routine iodine assessments. Excessive iodine intakes may have adverse health impacts on the thyroid gland greater than those induced by iodine deficient diets. There is thus an urgent need to conduct further population-based studies to investigate iodine intakes of different population groups. It is important to provide a fortification/supplementation strategy to meet the optimal dietary iodine supplemental needs of each country. Also, effective efficacy and safety monitoring is needed to prevent under or over iodisation at the production level, and iodine losses during distribution, and storage of salt in order to reach adequate iodine levels in salt for household use. Moreover, in IDD populations, awareness programmes should be implemented to raise awareness of the importance of using iodised salt at the household level. Variations of the geology and iodine-rich food resources in the different SSA countries are evident, requiring that programme implementers take this into account as well as existing iodine-related interventions to address IDD effectively without exposing the regularly targeted women and children to excess iodine intake levels.

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