Factors Associated with Urinary Iodine Concentration among Women of Reproductive Age, 20–49 Years Old, in Tanzania: A Population-Based Cross-Sectional Study

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ABSTRACT

Background: Universal salt iodization (USI) is the most feasible and cost-effective, and equitable, approach to prevent iodine deficiency. Severe maternal iodine deficiency during pregnancy is associated with serious adverse gestational and birth outcomes.

Objectives: The aim was to assess iodine status and identify independent factors associated with urinary iodine concentration (UIC) among women of reproductive age in Tanzania.

Methods: This was a weighted, population-based, cross-sectional study in 2985 women of reproductive age (20–49 y) in Tanzania who participated in the Demographic and Health Surveys in 2015–2016 (DHS 2015–2016) and had measured UIC. Multivariable generalized linear regression was used to identify potential factors that were associated with UIC.

Results: The median UICs among women consuming inadequately iodized salt (93.6 μg/L; 25th and 75th percentiles: 43.1, 197.9 μg/L) and women in the lowest socioeconomic status (92.3 μg/L; 45.6, 194.4 μg/L) were below the WHO-recommended ranges (≥150 μg/L for pregnant women and ≥100 μg/L for nonpregnant women). The results of multivariable models indicated that pregnant women had 1.21 μg/L lower UIC than nonpregnant women (β = −1.21; 95% CI: −3.42, −0.12), breastfeeding women had 1.02 μg/L lower UIC than nonbreastfeeding women (β = −1.02; 95% CI: −2.25, −0.27), and women with no education had a 1.88 μg/L lower UIC compared with those with secondary/highest education (β = −1.88; 95% CI: −4.58, −0.36). Women consuming inadequately iodized salt had 6.55 μg/L lower UIC than those consuming adequately iodized salt (β = −6.55; 95% CI: −9.24, −4.33). The median UIC varied substantially across geographic zones, ranging from 83.2 μg/L (45.9, 165.3) in the Western region to 347.8 μg/L (185.0, 479.8) in the Eastern region.

Conclusions: Our findings indicated a great heterogeneity in median UIC across regions of Tanzania among women of reproductive age. Poverty, consuming inadequately iodized salt, and lack of education appeared to be the driving factors for lower UIC in Tanzania.

Introduction

There has been outstanding global progress towards the eradication of iodine deficiency disorders (IDDs) over the last 2 decades through the scale-up of universal salt iodization (USI) programs (1). The number of countries previously classified as iodine deficient decreased from 113 to only 20 (2). A previous study found that 37% (88/237) of pregnant women and 33% (24/73) of lactating mothers had iodine deficiency in India (3). In developing countries including sub-Saharan Africa (SSA), ~38 million newborn infants are at risk of the devastating consequences of iodine deficiency every year (4). In 1980, it was estimated that 41% of the population in Tanzania lived in certain geographical regions subject to iodine deficiency (5). A national survey conducted in 2004 in Tanzania to assess the extent to which iodized salt was used and its apparent impact on the total goiter prevalence (TGP) and urinary iodine concentrations (UICs) among schoolchildren after the initiation of USI showed that TGP had decreased from 61% in the 1980s to 12.3% in 2004 (6). Despite legislation to implement USI in all salt for human

Keywords: sub-Saharan Africa, adequate iodized salt, iodine, pregnant women, breastfeeding

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Abbreviations used: DHS, Demographic and Health Survey; IDD, iodine deficiency disorder; IRB, Institutional Review Board; ppm, parts per million; SSA, sub-Saharan Africa; TDHS, Tanzanian Demographic and Health Survey; TFNC, Tanzania Food and Nutrition Center; TGP, total goiter prevalence; UIC, urinary iodine concentration; USI, universal salt iodization.
consumption in early 1994, Tanzanians still suffer from mild to severe iodine deficiency. Pregnant and lactating women are the most vulnerable population to iodine deficiency (6). Insufficient iodine intake during pregnancy has a long-term impact on child normal growth, brain development, and intelligence quotient scores (7–10). Furthermore, iodine deficiency is considered to be a major cause of the most preventable mental impairment worldwide (11, 12). Inadequate iodine intake during pregnancy has been associated with maternal hypothyroxinemia, impaired brain growth, cognitive psychomotor deficits in neonates, and impaired neurodevelopment in infants and children (13–18). Iodine deficiency during pregnancy can cause serious health conditions such as spontaneous abortion, neurological impairment, congenital hypothyroidism, stillbirth, low birth weight, poor cognitive functioning, decrease in intelligence, and delay in mental development among infants and children (11, 12, 16, 19). Public awareness about the benefits of iodine nutrition in women of reproductive age is lacking (20). A recent report published by UNICEF recommends assessing the adequacy of iodine intake among different subgroups, such as by geographic region and socioeconomic status (1). Factors associated with UIC among women of reproductive age in Tanzania, however, have not been well studied. Previous studies highlighted the need for data assessing iodine status among this population in Tanzania (6, 21–23). To the best of our knowledge, there are no recent studies that have assessed iodine status among women of reproductive age in Tanzania using UIC. To fill this gap in the literature, we used the most recent national survey, the Tanzania Demographic and Health Survey 2015–2016 (TDHS 2015–2016), to conduct a population-based cross-sectional analysis to assess iodine status and to identify independent factors associated with UIC among women of reproductive-age (20–49 y) in Tanzania.

Methods

Data source and participants
This study analyzed the most recent round of national survey data from the TDHS 2015–2016, which is a nationally representative survey among childbearing-age women 20–49 y old to examine iodine deficiency. The survey was conducted using a multistage cluster-sampling scheme based on the Tanzania Census with a stratified design to collect information on population demographics and health. The surveys include detailed information such as family planning methods, maternal and child health, pregnancy and breastfeeding, biomarker measures, salt test for iodine content, and childhood immunization. We extracted household salt and UIC information from the household survey, and then linked these variables to women's record data, using the Demographic and Health Surveys (DHSs) merging guideline. The survey response rate among women was 97%. The present analysis included a total of weighted 2985 women aged 20–49 y with complete UIC tested results.

Ethical considerations
Written request to access the survey data was made and granted to DHS. Procedures and questionnaires for standard DHSs have been reviewed and approved by the ICF Institutional Review Board (IRB) and the IRBs of the host countries. The TDHS 2015–2016 was administered by the National Bureau of Statistics and Office of the Chief Government Statistician, Zanzibar, in cooperation with the Ministry of Health and Social Welfare–Mainland and the Ministry of Health, Zanzibar. The survey was funded by the Government of Tanzania, US Agency for International Development (USAID), Global Affairs Canada, Irish Aid, UNICEF, and United Nations Population Fund and implemented by ICF International (24). Written and oral informed consent was obtained from each study participant before beginning each survey and/or conducting biomarker tests. All of the data are Health Insurance Portability and Accountability Act (HIPAA) protected and de-identified. The ethical issues were handled by the ICF IRB and the IRBs of the host countries who conducted the primary surveys and not by the authors of this article. No further IRB approval was needed by the institutions of the authors of this article.

Assessment of iodine deficiency (outcome)
During data collection through questionnaires, interviewers requested women respondents to provide a spot urine sample for subsequent testing for urinary iodine content. Women who provided informed consent were given a small plastic cup for collection of a spot urine sample, and the urine samples were transferred from the plastic cup via a vacuum method into small tubes with tightly fitted caps. The urine samples were then transported to the Tanzania Food and Nutrition Center (TFNC) laboratory for testing for UIC using ammonium persulfate digestion with spectrophotometric detection of the Sandell-Kolhoff reaction (25). UIC has been considered as the most reliable biomarker to assess iodine adequacy from the diet at the population level because 90% of dietary iodine intake is excreted directly in the urine (26). It is commonly measured in spot urine samples and expressed as a median as a result of the high variability of spot urine samples (27). The WHO/UNICEF/International Council for Control of Iodine Deficiency Disorders (ICCIDD) recommend using the median UIC of a population to determine reference criteria to assess iodine status as follows: in nonpregnant women, median UIC <20 μg/L is indicative of insufficient iodine intake (severe iodine deficiency), 20–49 μg/L indicates moderate iodine deficiency, 50–99 μg/L indicates mild iodine deficiency, 100–199 μg/L indicates adequate intake, 200–299 μg/L indicates intakes above requirements, and 300 μg/L indicates excessive intake. During pregnancy, iodine requirements increase: a median UIC <150 μg/L is indicative of insufficient iodine intake, 150–249 μg/L indicates adequate intake, 250–499 μg/L indicates intakes above requirements, and 500 μg/L indicates excessive intake (28–31). For this study, the outcome of interest was UIC, which was square-root transformed to guarantee the normality of UIC distribution in the multivariable regression analysis. Women with excess iodine intake were kept in the present study because UIC depends on dietary iodine and varies greatly from day to day within individuals (1, 32). This variation is more likely to increase the spread of the distribution causing a different level of UIC in a population. Therefore, there will be always some individuals with higher UICs.

Assessment of factors associated with UIC (explanatory variables)
We investigated the following explanatory variables to assess whether they were associated with UIC: age, pregnancy status, breastfeeding status, educational status, marital status, wealth index status, iodine content in salt, place of residence, employment status, and...
geographic zones. Previous studies reported that these aforementioned sociodemographic/economic factors affect dietary iodine intake in Tanzania (6, 29). In every third sampled household, TDHS field teams asked the women respondents to provide a slightly larger sample of household salt for quantitative analysis of iodine content by titration methods at the TFNC laboratory (25). Educational status was broken down into 3 categories as done by a previous study (no education, primary education, secondary/higher education) (33). According to previous research, we re-categorized wealth index from 5 quintiles into 3 categories by combining poorest and poorer into 1 category (called “lowest”), the middle wealth level into the second category (called “middle”), and richer and richest into the third category (called “highest”), as previous researchers have done (34–36). Iodine content in salt was categorized into 2 categories—inadequately iodized salt (<15 parts per million (ppm)) and adequately iodized salt (≥15 ppm)—as done by previous researchers (37). The age of the respondent at the time of the DHS interview was originally measured as a continuous variable and was categorized into 3 categories: 20–30, 31–40, and 41–49 y old. The geographic zones of the country included 8 categories—Western, Northern, Central, Southern Highlands, Lake, Eastern, Southern, and Zanzibar—as previous researchers have done (29).

Statistical analysis

Univariate analyses were used to describe the characteristics of the study population. Summary statistics were presented as the proportion for the overall sample and medians with 25th and 75th percentiles. Multivariable analysis was performed using a generalized linear model in SAS (PROC GLM; SAS Institute) to explore the association between the explanatory variables and UIC adjusting for age, pregnancy status, breastfeeding status, educational status, marital status, wealth index status, iodine content in salt, place of residence, employment status, and geographic zone. After further examining the data, we noticed that the distribution of UIC was severely right-skewed. The log transformation did not improve the normality of UIC distribution. Therefore, we adopted a square-root transformation to guarantee the normality of UIC distribution in women as done by previous researchers (32, 38). After the transformation, we ran the fully adjusted model by including the square root of the UIC ($\sqrt{\text{UIC}}$) as the outcome, while all other parameters remained unchanged. Analyses were conducted using SAS version 9.4 (SAS Institute), and R software version 3.4.3 (R Foundation for Statistical Computing) was used to generate Figures 1 and 2. Multivariable regression results are presented with regression coefficients ($\hat{\beta}$) with 95% CIs. Eastern zone was selected as the reference geographic zone because it was the zone with the highest median UIC. We conducted a subgroup analysis stratified by nonpregnant women (Supplemental Table 1) versus pregnant status (Supplemental Table 2). Women from a household where salt was not tested for iodine content were considered as missing by the TDHS field team and were not included in the analysis of multivariable linear regression. Statistical significance was assessed at $P < 0.05$. 

FIGURE 1 Weighted median (25th and 75th percentiles) urinary iodine concentration according to pregnancy status, wealth status, breastfeeding status, and educational status.
Results

Table 1 presents the summary statistics of the demographic characteristics of the study population. The mean (SD) age was 31.9 (8.4) y. More than half of the study participants used adequately iodized salt (≥15 ppm; 66.7%); approximately half were between the ages of 20 and 30 y (49.4%) and from highest socioeconomic households (45.4%). Also, 8.9% of the survey respondents were pregnant at the time of the DHS, breastfeeding (31.2%), and had a primary education (64.4%) (Table 1). The median UICs among pregnant women (median: 156.1 μg/L; 25th and 75th percentiles: 64.6, 260.4) and uneducated women (104.3 μg/L; 46.4, 212.6) were on the edge of the recommended ranges. Women who consumed inadequately iodized salt (93.6 μg/L; 43.1, 197.9) and women in the lowest socioeconomic status (92.3 μg/L; 45.6, 194.4) were below the recommended ranges (≥150 μg/L for pregnant women and ≥100 μg/L for nonpregnant women) by the WHO. Also, the median UIC varied substantially across geographic zones, ranging from 83.2 μg/L (45.9,165.3) in the Western region to 347.8 μg/L (185.0, 479.8) in the Eastern region. (Table 1, Figures 1 and 2).

To identify independent factors associated with UIC, we used a multivariable generalized linear regression model as presented in Table 2. Pregnant women had a 1.21-μg/L lower UIC than nonpregnant women (β = −1.21; 95% CI: −3.42, −0.12); breastfeeding women had a 1.02-μg/L lower UIC than nonbreastfeeding women (β = −1.02; 95% CI: −2.25, −0.27); women consuming inadequately iodized salt had a 6.55-μg/L lower UIC than those consuming adequately iodized salt (β = −6.55; 95% CI: −9.24, −4.33); women with no education had a 1.88-μg/L lower UIC compared with those with secondary/highest education (β = −1.88; 95% CI: −4.58, −0.36); women of the lowest socioeconomic status had a 1.61-μg/L lower UIC compared with those of the highest socioeconomic status (β = −1.61; 95% CI: −3.61, −0.41). Also, living in a rural area and living in other geographic zones compared with the Eastern zone were associated with significantly lower UICs. Subgroup analysis showed that inadequately iodized salt and being of a lower socioeconomic status were significantly associated with lower UIC among pregnant women (Supplemental Table 2).

Discussion

This population-based cross-sectional study in >2500 women of reproductive age in Tanzania assessed the magnitude of iodine deficiency using the UIC and its association with sociodemographic factors. Approximately one-third of women were consuming inadequately iodized salt. In the multivariable linear regression model, independent factors associated with UIC included currently pregnant and breastfeeding, consuming inadequately iodized salt, coming from a lowest or middle wealth index household, lack of education, and living in rural areas. Findings from our study show the existence of heterogeneity and inequalities of the UIC in Tanzania. The median UIC varied significantly across geographical regions of Tanzania. Our findings are of public health and clinical significance because iodine is one of the most critical and significant micronutrients required for the synthesis of thyroid hormones and fetal brain development (7). The negative significant association between pregnant and breastfeeding women and UIC is concerning and indicates that their unborn children and infants are still in danger of IDD. Mild to severe iodine deficiency during pregnancy can trigger serious maternal and fetal hypothyroxinemia and
impaired neurological development (39). Previous studies have shown that mild-to-moderate iodine deficiency during pregnancy can have a serious impact on children's intelligence quotient and cognitive functioning in offspring (7, 40–42). Furthermore, the most consequential effects of severe maternal iodine deficiency in the offspring are congenital hypothyroidism, which results in growth retardation including physical and intellectual developmental delay (40, 43). The negative association between pregnant women and UIC in Tanzania was not surprising. A previous study reported an iodine deficiency prevalence of 54% among pregnant women using the 2010 TDHS data (29). Our analysis showed a strong negative association between lack of adequately iodized salt consumption and UIC. In addition, a subgroup analysis stratified by non-pregnant compared with pregnant status also showed that inadequately iodized salt consumption was associated with lower UIC. Previous studies have indicated that consuming adequately iodized salt was associated with a decreased risk of developing subclinical iodine deficiency among pregnant women in Tanzania (29). USI, through fortification of salt, remains the most reliable method for sustainable elimination of iodine deficiency among women of reproductive age (30, 40, 43). The iodization of salt remains the main strategy and the most cost-effective for achieving sustained IDD control, with a cost of only US$0.02–0.05 per individual per year (1, 12). However, the full implementation of USI is still a big challenge in many SSA countries where noniodized salt is still being sold for human consumption, which may cause a lack of access to adequately iodized salt for women of reproductive age and pregnant women (40). In addition, one of the key problems in the prevention of IDD in

### Table 1: Sociodemographic characteristics of the weighted survey participants

| Characteristics                  | Overall (n = 2985) | Median | 25th, 75th percentiles |
|----------------------------------|--------------------|--------|------------------------|
| Mean (SD) age, y                 | 31.9 (8.4)         |        |                        |
| Age group, n (%)                 |                    |        |                        |
| 20–30 y                          | 1474 (49.4)        | 171.1  | 68.6, 322.6            |
| 31–40 y                          | 928 (31.1)         | 143.3  | 66.7, 305.0            |
| 41–49 y                          | 583 (19.5)         | 133.8  | 63.1, 290.7            |
| Pregnancy status, n (%)          |                    |        |                        |
| Pregnant                         | 266 (8.9)          | 156.1  | 64.6, 260.4            |
| Not pregnant                     | 2719 (91.1)        | 152.6  | 66.7, 315.9            |
| Breastfeeding status, n (%)      |                    |        |                        |
| Breastfeeding                    | 930 (31.2)         | 117.3  | 51.2, 262.1            |
| Not breastfeeding                | 2055 (68.9)        | 174.0  | 76.0, 328.1            |
| Iodine content in salt, n (%)    |                    |        |                        |
| Inadequately iodized salt (<15 ppm) | 804 (33.3)   | 93.6   | 43.1, 197.9            |
| Adequately iodized salt (≥15 ppm) | 1613 (66.7)     | 226.9  | 112.9, 1369.0          |
| Educational status, n (%)        |                    |        |                        |
| No education                     | 507 (17.0)         | 104.3  | 46.4, 212.6            |
| Primary education                | 1923 (64.4)        | 144.3  | 64.6, 303.6            |
| Secondary/higher                | 555 (18.6)         | 239.8  | 121.9, 395.2           |
| Wealth index status, n (%)       |                    |        |                        |
| Lowest                           | 1100 (36.9)        | 92.3   | 45.6, 194.4            |
| Middle                           | 530 (17.8)         | 113.7  | 51.1, 233.4            |
| Highest                          | 1355 (45.4)        | 243.9  | 125.1, 403.9           |
| Place of residence, n (%)        |                    |        |                        |
| Urban                            | 993 (33.3)         | 261.3  | 140.8, 414.4           |
| Rural                            | 1992 (66.8)        | 108.0  | 50.2, 234.2            |
| Employment status, n (%)         |                    |        |                        |
| Employed                         | 2396 (80.3)        | 144.3  | 62.8, 291.4            |
| Unemployed                       | 589 (19.7)         | 195.8  | 87.0, 371.6            |
| Geographic zone, n (%)           |                    |        |                        |
| Western                          | 306 (10.2)         | 83.2   | 45.9, 165.3            |
| Northern                         | 355 (11.9)         | 224.2  | 99.4, 401.2            |
| Central                          | 304 (10.2)         | 167.4  | 73.4, 317.9            |
| Southwest/Southern Highlands    | 482 (16.2)         | 141.0  | 54.3, 271.4            |
| Southern                         | 161 (5.4)          | 103.0  | 53.5, 173.4            |
| Lake                             | 817 (27.4)         | 116.3  | 48.3, 232.7            |
| Eastern                          | 468 (15.7)         | 347.8  | 185.0, 479.8           |
| Zanzibar                         | 92 (3.1)           | 178.5  | 94.1, 279.9            |

1 n = 2985. ppm, parts per million; UIC, urinary iodine concentration.

2 We categorized wealth index from 5 quintiles into 3 categories by grouping poorest and poorer into 1 category as lowest, middle, and richer and richest into another category as highest (lowest, middle, and highest).

3 Geographic zone was categorized from 9 zones into 8 zones by grouping Southern and Southwest Highlands zone into Southwest/Southern Highlands (Western, Northern, Central, Southwest/Southern Highlands, Southern, Lake, Easter, and Zanzibar) (29).
Despite having a USP policy in place since early 1994, Tanzania still struggles with full implementation due to political instability, famine, poverty, and conflict (6, 29). Interestingly, there were some outliers in our data with a higher UIC. This could be due to the fluctuation of the iodine concentration at the individual level, which can vary from day to day and sometimes within the same day. However, this variation averaged out when measuring UIC at the population level (46). Poor and uneducated women were more likely to have lower UICs during our study compared with those with a higher income and education. This was not surprising because women of a lower socioeconomic status are more likely to have access to salt that was inadequately fortified with iodine or with no iodine content and may be dependent on available household salt as the main dietary salt source (1). These findings were also consistent with a previous study that found that women belonging to the lowest socioeconomic categories had higher odds of subclinical iodine deficiency in Tanzania (29). This may be due to the inability to buy iodized salt and lack of knowledge about the benefits of iodized salt (47). Previous studies have indicated that women of higher socioeconomic status are more likely to access iodized salt than those of the lowest socioeconomic status in SSA (48). This could also be explained by the higher cost of purchasing adequately iodized salt compared with noniodized salt (49–51).

### Table 2

Regression coefficients (95% CIs) and P values in the association between explanatory variables and UIC.

| Characteristics                  | Coefficients (β) | 95% CI          | P    |
|----------------------------------|------------------|-----------------|------|
| Age (y)                          | −0.0004          | −0.0016, 0.0001 | 0.25 |
| Pregnancy status                 |                  |                 |      |
| Pregnant                         | −1.21            | −3.42, −0.12    | 0.004|
| Not pregnant                     | Reference        |                 |      |
| Breastfeeding status             |                  |                 |      |
| Breastfeeding                    | −1.02            | −2.25, −0.27    | <0.0001|
| Not breastfeeding                | Reference        |                 |      |
| Iodine content in salt           |                  |                 |      |
| Inadequately iodized salt (<15 ppm) | −6.55           | −9.24, −4.33    | <0.0001|
| Adequately iodized salt (≥15 ppm) | Reference       |                 |      |
| Educational status               |                  |                 |      |
| No education                     | −1.88            | −4.58, −0.36    | 0.0005|
| Primary education                | −0.45            | −1.54, −0.01    | 0.02 |
| Secondary/higher                | Reference        |                 |      |
| Wealth index status              |                  |                 |      |
| Lowest                           | −1.61            | −3.61, −0.41    | <0.0001|
| Middle                           | −1.72            | −3.88, −0.44    | <0.0001|
| Highest                          | Reference        |                 |      |
| Place of residence               |                  |                 |      |
| Rural                            | −0.42            | −1.42, −0.01    | 0.02 |
| Urban                            | Reference        |                 |      |
| Employment status                |                  |                 |      |
| Employed                         | −0.20            | −0.96, 0.01     | 0.09 |
| Unemployed                       | Reference        |                 |      |
| Geographic zone                  |                  |                 |      |
| Central                          | −9.61            | −16.81, −4.37   | <0.0001|
| Lake                             | −19.98           | −27.77, −13.40  | <0.0001|
| Northern                         | −7.13            | −12.89, −3.06   | <0.0001|
| Southern                         | −12.11           | −24.11, −4.24   | <0.0001|
| Southern Highlands               | −23.43           | −31.81, −16.24  | <0.0001|
| Western                          | −26.63           | −37.70, −17.39  | <0.0001|
| Zanzibar                         | −11.02           | −17.98, −5.71   | <0.0001|
| Eastern                          | Reference        |                 |      |

1Model fully adjusted for age, pregnancy status, breastfeeding status, educational status, wealth index status, iodine content in salt, place of residence, employment status, and geographic zone. ppm, parts per million; UIC, urinary iodine concentration.
adequate potassium iodate to the salt. Regions with a low median UIC could learn from regions with high median UICs such as Pwani and Tanga.

**Study strengths and limitations**

The strength of our study is the analysis of a nationally representative sample with a high response rate of UIC testing for iodine deficiency. Another strength of this study is the use of a biomarker (UIC), which is considered an excellent indicator for the assessment of iodine status and iodine deficiency in the population (53). Most of the previous national studies investigated the use of iodized salt consumption instead of the biomarker as done in this TDHS. However, the study has some limitations that need to be addressed. The cross-sectional nature of the survey does not allow for the determination of a temporal or causal relation between the explored variables and iodine deficiency among women. In addition, there was no follow-up for those who were consuming inadequately iodized salt. Second, only women’s household salt was measured during this survey. TDHS field teams did not ask about the source of the salt (where the salt was purchased) during the survey. Besides these limitations, this study provides crucial information concerning the use of adequately iodized salt among women of reproductive age. In particular, this study identifies which regions in Tanzania may need enhanced efforts to improve access to iodized salt to all individuals.

**Conclusions**

Iodine deficiency is still a significant public health problem in Tanzania. The findings from our study showed great heterogeneity in the median UIC across regions of Tanzania and in relation to women’s sociodemographic characteristics. Pregnancy and breastfeeding, consuming iodized salt inadequately fortified, being of a lower socioeconomic status, having a lack of education, living in rural areas, and living in certain geographical zones were significantly associated with lower UICs among women of reproductive age in Tanzania. The findings of this study demonstrate an urgent need to strengthen the national USI program, which was introduced in early 1994 to reduce iodine deficiency among reproductive-age women in Tanzania. The findings also highlight the need for collaborative efforts from stakeholders, health care providers, and government officials to combat iodine deficiency among pregnant and breastfeeding women in Tanzania through full implementation and enforcement of USI and health education programs about the consequence of iodine deficiency.

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**References**

1. UNICEF. Guidance on the monitoring of salt iodization programmes and determination of population iodine status. 2018. [cited 2019 Dec 23] [Internet]. Available from: https://www.unicef.org/nutrition/files/Monitoring-of-Salt-Iodization.pdf.
2. Iodine Global Network. Global scorecard of iodine nutrition in 2017 in the general population and in pregnant women (PW) [Internet]. Zurich (Switzerland): Iodine Global Network; 2017. Available from: https://www.ign.org/cm_data/IGN_Global_Scorecard_AllPop_and_PW_May2017.pdf. [Accessed 2019 Dec 23].
3. Majumder A, Jaiswal A, Chatterjee S. Prevalence of iodine deficiency among pregnant and lactating women: experience in Kolkata. Indian J Endocrinol Metab 2014;18(4):486–90.
4. UNICEF. Sustainable elimination of iodine deficiency. New York: UNICEF; 2008.
5. Kavishe F, Malentelem T. Iodine deficiency disorders in the region Eastern, Central and Southern Africa. Vol. NIN/ICFSEN public no. 5. In: van de Haar F, Kavishe F, editors. Iodine deficiency disorders in Tanzania. Wageningen (Netherlands): International Nutrition Institute/International Course in Food Science and Nutrition; 1997:51–65.
6. Assey VD, Peterson S, Kimboka S, Ngemera D, Mgoba C, Ruhije DM, Ndosii GD, Greiner T, Tylleskär T. Tanzania National Survey on iodine deficiency: impact after twelve years of salt iodation. BMC Public Health 2009;9(1): 319.
7. Simpong DL, Adu P, Bashiru R, Morna MT, Yeboah FA, Akakpo K, Ephraim RK. Assessment of iodine status among pregnant women in a rural community in Ghana—a cross sectional study. Arch Public Health 2016;74(8).
8. Gebrebiadaksan TM, Troen AM. Progress and challenges in eliminating iodine deficiency in Ethiopia: a systematic review. BMC Nutr 2016;2(1):12.
9. Darnton-Hill I, Mkparuc UC. Micronutrients in pregnancy in low- and middle-income countries. Nutrients 2015;7(3):1744–68.
10. Qian M, Wang D, Watkins WE, Gbeshi V, Yan YQ, Li M, Chen ZP. The effects of iodine on intelligence in children: a meta-analysis of studies conducted in China. Asia Pac J Clin Nutr 2005;14(1):32–42.
11. Ahad F, Ganie SA. Iodine, iodine metabolism and iodine deficiency disorders revisited. Indian J Endocrinol Metab 2010;14(1):13–7.
12. Zimmermann MB, Jooste PL, Pandav CS. Iodine-deficiency disorders. Lancet North Am Ed 2006;372(9645):1251–62.
13. de Benoist B, McLean E, Andersson M, Rogers L. Iodine deficiency in 2007: global progress since 2003. Food Nutr Bull 2008;29(3):195–202.
14. Gernand AD, Schulze KJ, Stewart CP, West KP Jr, Christian P. Micronutrient deficiencies in pregnancy worldwide: health effects and prevention. Nat Rev Endocrinol 2016;12(5):274–89.
15. Azizi F. Iodine nutrition in pregnancy and lactation in Iran. Public Health Nutr 2007;10(12a):1596–9.
16. Skeaff SA. Iodine deficiency in pregnancy: the effect on neurodevelopment in the child. Nutrients 2011;3(2):265–73.
17. Nutrient Reference Values for Australia and New Zealand including Recommended Dietary Intakes. Canberra (Australia). Commonwealth Department of Health and Ageing, Ministry of Health, National Health and Medical Research Council, Commonwealth of Australia and New Zealand Government; 2006.
18. Melse-Boonstra A, Jaiswal N. Iodine deficiency in pregnancy, infancy and childhood and its consequences for brain development. Best Practice & Research Clinical Endocrinology & Metabolism 2010;24(1):29–38. https://doi.org/10.1016/j.beem.2009.09.002.
19. Verbeesen RH, Schweitzer CM. Iodine deficiency, more than cretinism and goiter. Med Hypotheses 2008;71(5):645–8.
20. Leung AM, Braverman LE, Pearce EN. A dietary iodine questionnaire: correlation with urinary iodine and food diaries. Thyroid 2007;17(9):755–62.
21. WHO/UNICEF. Joint statement by the World Health Organization and the United Nations Children’s Fund: reaching optimal iodine nutrition in pregnant and lactating women and young children. Geneva (Switzerland): WHO; UNICEF; 2007.
22. Sundqvist J, Wijetunga M, Assey V, Gebre-Medhin M, Peterson S. Salt iodation and risk of neonatal brain damage. Lancet North Am Ed 1998;352(9121):34–5.
23. Sullivan K, Suchdev P, Grummer-Strawn L. Achieving and sustaining USI: doing it well through quality assurance, monitoring and impact evaluation.
SCN News. United Nation's Standing Committee on Nutrition. No 35 end-2007 ISSN 1564-3743.

24. Ministry of Health and Social Welfare (Tanzania Mainland); Ministry of Health (Zanzibar); National Bureau of Statistics; Office of the Chief Government Statistician; ICF International. Tanzania Service Provision Assessment Survey (TSPA) 2014–15. Dar es Salaam (Tanzania) and Rockville (MD): Ministry of Health and Social Welfare; Ministry of Health; National Bureau of Statistics; Office of the Chief Government Statistician; ICF International; 2015.

25. The Demographic and Health Surveys Program. Tanzania DHS, 2015–6. [cited 2019 Oct 30] [Internet]. Available from: https://dhsprogram.com/publications/publication-FR321-DHS-Final-Reports.cfm.

26. World Health Organization. Trace elements in human nutrition and health. Indicators for assessing iodine deficiency disorders and their control through salt iodization. Geneva (Switzerland); WHO; 1996.

27. Solid OP. Controversies in urinary iodine determinations. Clin Biochem 2002;35(8):575–9.

28. von Oettingen JE, Brathwaite TD, Carpenter C, Bonnell R, He X, Braverman LE, Pearce EN, Larco P, Larco NC, Jean-Baptiste E, et al. Population survey of iodine deficiency and environmental disruptors of thyroid function in young children in Haiti. J Clin Endocrinol Metab 2017;102(2):644–51.

29. Mtumwa AH, Ntwenya JE, Paul E, Huang M, Vuai S. Socio-economic and spatial correlates of subclinical iodine deficiency among pregnant women age 15–49 years in Tanzania. BMC Nutr 2017;3(1):47.

30. WHO/UNICEF. Reaching optimal iodine nutrition in pregnant and lactating women and young children. Joint Statement of the World Health Organization and the United Nations Children's Fund. Geneva (Switzerland): World Health Organization; 2007.

31. World Health Organization; United Nations Children's Fund; International Council for the Control of Iodine Deficiency Disorders. Assessment of iodine deficiency disorders and monitoring their elimination: a guide for programme managers. 3rd ed. Geneva (Switzerland): World Health Organization; 2007. [cited 2019 Jun 19] [Internet]. Available from: http://whqlibdoc.who.int/publications/2007/9789241595827_eng.pdf.

32. Ji X, Liu P, Sun Z, Su X, Wang W, Gao Y, Sun D. Intra-individual variation in urinary iodine concentration: effect of statistical correction on population distribution using seasonal three-consecutive-day spot urine in children. BMJ Open 2016;6(2):e010217–e.

33. Ba DM, Ssentongo P, Kjerulff KH, Na M, Liu G, Gao X, Du P. Adherence to iron supplementation in 22 sub-Saharan African countries and associated factors among pregnant women: a large population-based study. Curr Dev Nutr 2019;3(12). doi: 10.1093/cdn/nzz120.

34. Lunani LL, Abasa A, Omosa-Mayonyi G. Prevalence and factors associated with contraceptive use among Kenyan women aged 15–49 years. AIDS Behav 2018;22(Suppl 1):125–30.

35. Titilayo A, Palamuleni ME, Olaoye-Oyesola JO, Owoeye OM. Religious perceptions and attitudes of men towards discontinuation of female genital cutting in Nigeria: evidence from the 2013 Nigeria Demographic and Health Survey. Afr J Reprod Health 2018;22(1):20–8.

36. Hassen HT, Beyene M, Ali JH. Dietary pattern and its association with iodine deficiency among school children in southwest Ethiopia: a cross-sectional study. PLoS One 2019;14(8):e0221106.

37. Wirth JP, Leyvraz M, Sodani PR, Aaron GJ, Sharma ND, Woodruff BA. Coverage of adequately iodized salt is suboptimal and rice fortification using public distribution channels could reach low-income households: findings from a cross-sectional survey of Anganwadi center catchment areas in Telangana, India. PLoS One 2016;11(7):e0158554.

38. Rohner F, Wirth JP, Woodruff BA, Chiwile F, Yankson H, Sesay F, Koroma AS, Petry N, Pyne-Bailey S, Dominguez E, et al. Iodine status of women of reproductive age in sierra leone and its association with household coverage with adequately iodized salt. Nutrients 2016;8(2):74.

39. Thilly CH, Delange F, Lagasse R, Boudourx P, Ramioul L, Berquist H, Ermans AM. Fetal hypothyroidism and maternal thyroid status in severe endemic goiter. J Clin Endocrinol Metab 1978;47(2):354–60.

40. Zimmermann MB. Iodine deficiency in pregnancy and the effects of maternal iodine supplementation on the offspring: a review. Am J Clin Nutr 2009;89(2):668S.

41. Trumpf C, De Schepper J, Tafooreau J, Van Oyen H, Vanderfaeille J, Vandevijvere S. Mild iodine deficiency in pregnancy in Europe and its consequences for cognitive and psychomotor development of children: a review. J Trace Elem Med Biol 2013;27(3):174–83.

42. Bath SC, Rayman MP. A review of the iodine status of UK pregnant women and its implications for the offspring. Environ Geochem Health 2015;37(4):619–29.

43. Zimmermann MB. The effects of iodine deficiency in pregnancy and infancy. Paediatr Perinat Epidemiol 2012;26(Suppl 1):108–17.

44. Okosieme OE. Impact of iodination on thyroid pathology in Africa. J R Soc Med 2006;99(8):396–401.

45. Ekpechil OL. Iodine deficiency disorders in Africa. In: Hetzel BS, Dunn JT, Stanbury JB, editors. The prevention and control of iodine deficiency disorders. Amsterdam: Elsevier Science Publishers (Biomedical Division); 1987. pp. 219–36.

46. Mannar MV. Making salt iodization truly universal by 2020. IDD News 2014;42:12–5.

47. Gwatkin DR, Rutstein S, Johnson K, Suliman E, Wagstaff A, Amouzou A; HNP/Poverty Thematic Group. Socio-economic differences in health, nutrition and population in Cote d’Ivoire. Health Population and Nutrition Group. Washington (DC): World Bank; 2000.

48. Knowles JM, Garrett GS, Gorstein J, Kupka R, Situma R, Yadav K, Yusufali R, Pandav C, Aaron GJ. Household coverage with adequately iodized salt varies greatly between countries and by residence type and socioeconomic status within countries: results from 10 national coverage surveys. J Nutr 2017;147(5):1004s–14s.

49. Sen TK, Das DK, Biswas AB, Chakrabarty I, Mukhopadhyay S, Roy R. Limited access to iodized salt among the poor and disadvantaged in North 24 Parganas district of West Bengal, India. J Health Popul Nutr 2010;28(4):369–74.

50. Rasheed S, Hanifi MA, Iqbal M, Nazma N, Bhuiya A. Policy of universal salt iodization in Bangladesh: do coastal people benefit? J Health Popul Nutr 2001;19(2):66–72.

51. Agarwal S, Sethi V, Sharma D, Vaid M, Agrnihotri A, Sindhwiani A, Patra P. Consumption of iodized salt among slum households of North-East Delhi, India. Indian J Comm Med 2009;34(4):368–9.

52. Assery VD, Tylleskär T, Momburi PB, Maganga M, Mlingi NV, Reilly M, Greiner T, Peterson S. Improved salt iodation methods for small-scale salt producers in low-resource settings in Tanzania. BMC Public Health 2009;9(1):187.

53. Zimmermann M. Methods to assess iron and iodine status. Br J Nutr 2008;99(5):S2–S9.