Iodine status in western Kenya: a community-based cross-sectional survey of urinary and drinking water iodine concentrations

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Abstract

Spot urinary iodine concentrations (UIC) are presented for 248 individuals from western Kenya with paired drinking water collected between 2016 and 2018. The median UIC was 271 μg L^{-1}, ranging from 9 to 3146 μg L^{-1}, unadjusted for hydration status/dilution. From these data,12% were potentially iodine deficient (<100 μg L^{-1}), whilst 44% were considered to have an excess iodine intake (>300 μg L^{-1}). The application of hydration status/urinary dilution correction methods were evaluated for UICs, using creatinine, osmolality and specific gravity. The use of specific gravity correction for spot urine samples to account for hydration status/urinary dilution presents a practical approach for studies with limited budgets, rather than relying on unadjusted UICs, 24 hour sampling, use of significantly large sample size in a cross-sectional study and other reported measures to smooth out the urinary dilution effect. Urinary corrections did influence boundary assessment for deficiency-sufficiency-excess for this group of participants, ranging from 31 to 44% having excess iodine intake, albeit for a study of this size. However, comparison of the correction methods did highlight that 22% of the variation in UICs was due to urinary dilution, highlighting the need for such correction, although creatinine performed poorly, yet specific gravity as a low-cost method was comparable to osmolality corrections as the often stated 'gold standard' metric for urinary concentration. Paired drinking water samples contained a median iodine concentration of 3.2 μg L^{-1} (0.2-304.1 μg L^{-1}). A weak correlation was observed between UIC and water-I concentrations (R = 0.11).

Keywords: Urinary Iodine Concentrations; iodine excess; hydration status corrections

Introduction

Approximately 2 billion people are estimated to be at risk of iodine deficiency disorders (IDD) worldwide (WHO, 2004; Andersson et al. 2012), for which the most severe consequences occur during foetal and early childhood development and can later manifest as goitre and impaired cognitive development (Obican et al. 2012; Bath et al. 2013). The Iodine Global Network estimated that 19 countries remain at risk of IDD whilst 10 countries have excess iodine intake (IGN, 2017). Excess intake of iodine (I) can cause hyper- or hypo-thyroidism, thyroid autoimmunity or euthyroid goitre (Burgi et al. 2010; Leung et al. 2014). Rohner et al. (2013) provided a comprehensive review of health consequences of I-deficient or excess intake and an evaluation of biomarkers to define I-status. The I-status of populations was traditionally quantified based on the prevalence of goitres, but the the use of urinary iodine concentration (UIC) measured in spot urine samples is now considered standard practice given the subjective nature of goitre classification and the more widespread availability of laboratories capable of urinary iodine analyses (UNICEF, 2007). In addition, over 90% of ingested iodine is rapidly excreted in the urine over 24-48 hours allowing for reliable estimates of iodine intake, as well as providing ease and cost effectiveness of collection with few limitations (Zimmerman et al. 2008; Zimmermann & Andersson 2012; Rohner et al. 2013; WHO 2013). UIC are normally expressed as a population median in μg L^{-1}, since assessment of individual status using single spot samples is not recommended due to high intra-diurnal variations in iodine intake (Vejbjerg et al. 2009; Knudsen et al 2009; König et al. 2011; Zimmermann & Andersson 2012, Rohner et al. 2013).

The highest prevalence of iodine deficiency is in the African region, as measured using school age children (SAC), at 39.3% (58 million) (Andersson et al. 2012). For example, in Malawi, 35% of the population (calculated from SAC) present a UIC of <100 μg L^{-1}, representing a population risk of inadequate iodine intakes, whilst the same 2010 Malawi Demographic and Health Survey (NSO, 2012) also reported that 62% of households were consuming adequately iodised salt. Further, Farebrother et al. (2018) described the history of the successful salt iodisation programme in Kenya which recorded a national median UIC in SAC of 118 μg L^{-1} in 2004, though regional variations in UIC were wide with values as high as 477 μg L^{-1}, which resulted in a reduction in salt-I concentration from 100 to 30-50 mg kg^{-1} in 2010 (Kenya Ministry of Health, 2011). Yet, the Kenyan National Micronutrient Survey reported in 2011 a median UIC of 208 μg L^{-1} in SAC, of which 30% were considered to have excess-I intake at >300 μg L^{-1} (Kenya Ministry of Health, 2011). These examples show that often the success of salt iodisation strategies is not maintained through lack of consistent and sustained monitoring of iodinated salt alongside UIC, which can be problematic for assessment of both deficiency and excess I-intakes.

The Estimated Average Requirement (EAR) for iodine in children, adults and pregnant women is 64, 107 and 143 μg *capita* d^{-1}, respectively (WHO, 2004). The Tolerable Upper Limit (TUL) is defined as the level of iodine intake at which there is no demonstrable evidence of toxicity and for adults is 600 and 1,100 μg *capita* d^{-1} in the EU and USA, respectively (Zimmerman 2008; Leung et al 2015). Excess iodine intake can result in thyroid disorders, but little data is available of the effects in vulnerable groups (Farebrother 2018), although a healthy thyroid can tolerate I-intakes in excess of the EAR (Burgi et al. 2010; Leung et al. 2015; Katagiri et al. 2017). Reports identifying excess I-intake are becoming more common, with I-intake now being a problem of both deficiency and excess in many regions, often at a local scale. For example, in some regions in Argentina (Watts 2009), Algeria (Barikmo et al. 2011), Somalia (Kassim et al. 2014), Malawi (Watts 2015) and Ghana

(Simpong et al. 2016; Abu et al. 2018), although Farebrother et al. (2018) reported a generally low prevalence of thyroid dysfunction across the study population in Kenya. On the basis of I status defined as 'inadequate' if the median UIC is <100 μg L^{-1}, sufficient 100-300 μg L^{-1} and excess >300 μg L^{-1} (WHO/ICCIDD 2007), Watts et al. (2015) reported 12 and 33% of a study in Malawi to have a risk of moderate deficiency (50-100 μg L^{-1}) and excess, similarly in Lesotho, 18 and 47% at risk of deficiency and excess, respectively (Sebotsa et al. 2005). The 2017 Iodine Global Scorecard (IGN 2017) classified 7 of 47 mainland African countries as having 'more than adequate' I intake, 14 with no data and four as 'excessive' on the basis of UIC in School Age Children (SAC). Such variances may be due to differences in dietary intake given that plant based foods are generally low in I content compared to the, consumption of iodised salt, increasingly processed foods (e.g. stock cubes) or availability of I-rich fish (Rohner et al. 2013; Watts et al. 2015; Abizari et al. 2017). Additional uncertainty could be derived from cooking processes, for example, 6 to 51% of I is reportedly lost from iodised salt when cooking (Rana & Raghuvanshi 2013). A review of cross-sectional studies by Katagiri et al. (2017) revealed the sources of excess I to be mainly from iodised salt or drinking water. Rohner et al. (2013) also referred to studies reporting the contribution of I-intake from groundwater sources in China and Algeria (Andersen et al. 2009; Henjam et al. 2010).

Drinking water-I can vary in concentration according to the source; Reimann et al. (2003) reported 0.3-961 μg L^{-1} (median 11 μg L^{-1}) from spring, well and river sources along the Ethiopian Rift Valley. Aakre et al. (2015) reported a median water-I concentration of 102 μg L^{-1} (80-255 μg L^{-1}) in Algerian refugee camps, which correlated with UIC, but also coupled with high milk-I and salt-I consumption resulted in thyroid dysfunction after excessive I-intake over several years. Farebrother et al. (2018) reported median water-I concentrations of 92 μg L^{-1} for Kenya, Tanzania and Djibouti although no correlation was observed with UIC.

Concentrations of spot urinary analyte concentrations, I included, require correction for hydration-driven dilution variation (Middleton et al. 2016). However, corrections of UIC are not commonly reported in the literature, with largley uncorrected UIC available for comparison of datasets. The routine aproach to dilution correction in the wider biomonitoring discipline is creatinine correction, the validity of which has been questioned (Nermell et al. 2008). For a correction method to perform properly, it must satisfy a number of prerequisites. Firstly, the metric used should be an accurate physicochemical marker of urinary dilution and it has long been recognised that urinary osmolality, the proxy for which is specific gravity (SG) is far more reliable that creatinine. Creatinine, the breakdown product of muscular creatinine phosphate, is subject to appreciable variation, more so than osmolality (Yeh et al. 2015) from demographic factors, particularly in developing countries owing to varying intake of protein and water and the existence of malnutrition, as well as age-sex cut-ff points (Knudsen et al. 2000; Vejberg et al. 2009; Jooste et al. 2010; Cockell 2015). Secondly, the application of the metric must be mathematically robust and representative of underlying physiological changes in analyte excretion in relation to fluctuations in urinary flow rate (Araki et al. 1986). Several criteria have previously been proposed (Middleton et al. 2016) to assess the performance of urinary dilution corrections, one of which is the removal of dilution variation from samples, crudely assessed by plotting corrected concentrations against the measurement used to correct them.

This paper aims to: (1) evaluate a sample population for I status using UIC measurements in western Kenya; (2) comparatively assess the use of creatinine, osmolality and specific gravity as effective dilution corrections in comparison to uncorrected UIC (as is commonly reported) and potential influence on boundary assessment for deficiency-sufficiency-excess, and (3) explore whether drinking water influences UIC.

Methods

Study setting

Sample collection was part of a wider project as described in Watts et al. (pending), which collected soil, crops, drinking water and a urine sample from households. Each household is shown in Figure 1, including Bomet, Bungoma, Elgoyo Marakwet, Kakamega, Kisumu, Nandi Hills, Siaya, Uasin Gishu counties in Western Kenya.

Collection of urine

This paper describes the urinary iodine concentrations (UICs) and paired drinking water iodine from each household. Adult and consenting volunteers at each site were requested for a urinary sample following an explanation of the study and why samples were being collected. In general, we attempted to collect from a minimum of 30 different sites that were spread out evenly across each county, representing rural land-use, although the geographic size and accessibility resulted in slight variation in numbers per county. One sample was generally collected from each household, a second volunteer provided a sample in <10% of households. Ethical approval was obtained from the Institutional Research and Ethics Board of Moi University (000921). Volunteers above the age of 18 were requested. Pregnant and lactating women excluded. Volunteers were asked to urinate into a 30 mL nalgene LDPE bottle, which was hygienically capped and transported in a coolbox (Ca 4ºC) and subsequently filtered into an 8 mL nalgene LDPE bottle using a nylon 0.45 µm syringe filter at the end of each day, followed by storage in a coolbox and freezing at -80ºC on return to the University of Eldoret laboratory in Kenya. Urines were transported frozen to the UK for elemental analyses, including I and urinary dilution measurements for subsequent corrections.

Collection of water

Generally, only drinking water was collected and filtered (nylon, 0.45 µm) on-site into a 30 mL nalgene LDPE bottle to be used for anion, organic carbon and pH/alkalinity measurements and a 15 mL nalgene LDPE bottle to be acidified on return to the UK with 1% HNO_3/0.5% HCl for elemental analyses by inductively coupled plasma mass spectrometry (ICP-MS) (Watts et al. pending), although iodine analyses were performed on the filtered unacidified portion owing to the requirement of an alkaline matrix (Tetramethylammonium Hydroxide-TMAH). Additional data was collected regarding the source (rain, river, borehole, well), any treatment, reliability and field parameters, including conductivity, pH, temperature and total dissolved solids.

ICP-MS analyses for iodine

Urine samples were analysed with a x20 dilution in 0.5% TMAH solution prior to analyses by ICP-QQQ-MS (Agilent 8900) with the collision cell in no gas mode, Rf power 1550 W, nebuliser flow rate of 0.4 ml min^{-1}, providing a limit of detection (LOD) of 0.2 µg L^{-1} (3SD blanks). Tellurium was used as an internal standard to correct for minor signal drift. Measurements below the LOD were attributed a value half of the LOD. Water samples were analysed separately to urines, but using the same method. Certified reference materials were measured giving iodine concentrations of 114 ± 2 µg L^{-1} (recovery: 109%; n = 15) for Seronorm™ Trace Elements Urine L-1 (Sero, Norway) and 39.7 ± 3.0 µg L^{-1} (recovery: 99%; n = 21) for a spiked SLRS-2 Riverine Water.

Urinary dilution corrections

Urinary creatinine was determined using a Randox liquid assay kit and a Randox RX Imola chemistry analyser. Osmolality was measured by freezing-point osmometry using a Gonotect Osmomat 030 (Gonetec, Germany). Specific gravity was measured with a PAL-10-S digital refractometer (Atago, Japan) prior to filtration. Creatinine, SG and osmolality corrections were performed using Equation 1:

$$UIC_{cor} = UIC_{vol} \times (D_{ref})/(D_{meas}), \quad (1)$$

where UIC_{cor} is dilution corrected urinary iodine concentration; UIC_{vol} is the measured, volume-based urinary iodine concentration (in µg/L); D_{ref} is the reference value to which UIC concentrations are scaled to and D_{meas} is that measured in the given specimen (note: D_{ref}-1 and D_{meas}-1 are used for SG correction). D_{ref} was 1 g L^{-1} for creatinine – synonymous with the conventional division-based correction and yielding results in µg g creatinine^{-1}; and, for both SG and osmolality, the study group medians were selected: 1.017 (unitless) and 581 mOsm kg^{-1}, respectively.

Statistical analysis

Summary statistics (arithmetic mean, median, standard deviation (SD), minimum and maximum) were calculated for UICs – uncorrected and corrected by various dilution metrics. Pearson correlation coefficients (R) and significance tests (P-values) were calculated on natural log-transformed variables due to the positively skewed distributions of UIC concentrations. All statisitcal analyses and graphics were performed in R version 3.4.3 and the RStudio GUI.

Results & Discussion

Urinary iodine concentrations

Urinary iodine concentrations (UIC) for 248 adults are summarised in Table 1. Uncorrected UIC values, which are commonly compared across studies provided a mean of 321 ± 280 µg L^{-1} and median of 271 µg L^{-1}, with a wide range of UIC values from 9-3146 µg L^{-1}. Whilst only 12% of the measured population were considered to be iodine deficient (<100 µg L^{-1}) according to UIC, 44% were above 300 µg L^{-1}, indicating excessive iodine intake. These UIC data are comparable to other studies reporting the prevalence of excess I intake, according to UIC and other urinary biomarkers. For example, Farebrother et al. (2018) reported uncorrected median UICs in non-pregnant, non-lactating women elsewhere in Kenya of 289 µg L^{-1} (IQR 173, 458 µg L^{-1}), and coastal Tanzania, of 473 µgL-1 (IQR 321, 689 µg L^{-1}). Median uncorrected UIC's reported in Malawi (Watts et al. 2015) were 221 µg L^{-1} (141-344 µg L^{-1}); in Port Sudan 464 and 561 µg L^{-1}, Medani et al. (2012) and Hussein et al. (2012), respectively. In Somalia non-pregnant women provided a median of 329 µg L^{-1} (Kassim et al. 2014) and in Lesotho median UIC of 280 µg L^{-1}, with 21 and 47% of women considered either deficient or excess following two years after introducing a salt iodisation programme (Sebotsa et al. 2005). Additionally, the median uncorrected UIC of 271 µg L^{-1} in this study is high when compared to data summarised in the Iodine Global Scorecard (IGN, 2017), median uncorrected UICs were 215, 175, 66 and 118 µg L^{-1} for Lesotho, Malawi, Sudan and Kenya, respectively in the general population.

Table 1: Summary statistics for uncorrected and dilution corrected urinary iodine concentrations (UIC), comparison to World Health Organisation (WHO) guidance values and to the Hays et al. (2018) Biomonitoring Equivalents (BE) – displayed as number of individuals and in brackets as (%) of group below BE.

UIC (μg L^{-1})	**Uncorrected**	**Osmolality-corrected**	**Creatinine-corrected**	**Specific Gravity-corrected**
n	246	242	230	246
Median	271	285	232	299
Arithmetic mean	321	325	395	321
SD	280	278	655	279
Range	9-3146	14-3870	6-4771	9-3149
Percentiles (25, 75)	163, 403	205, 382	149, 359	190, 404
Number	246	242	230	246
WHO Values, *n* (%)				
Extreme deficiency (<50 μg L^{-1})	9 (4)	1 (0)	9 (4)	8 (3)
Mild deficiency (<100 μg L^{-1})	30 (12)	6 (2)	23 (10)	30 (12)
Sufficient (100-300 μg L^{-1})	107 (43)	129 (53)	130 (57)	106 (43)
Excess (>300 μg L^{-1})	109 (44)	107 (44)	78 (34)	108 (44)
Hays et al. (2018) BE's, *n* (%)*				
EAR cut-off (60 μg L^{-1})	11 (4)	2 (1)	9 (4)	11 (4)
RDA (100 μg L^{-1})	30 (12)	6 (2)	23 (10)	30 (12)
UL (730 μg L^{-1})	11 (4)	6 (2)	17 (7)	11 (4)
MRL (450 μg L^{-1})	51 (21)	32 (13)	37 (16)	51 (21)

* Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA) and for toxicity, Tolerable Upper Intake Level (UL) and Minimal Risk Level (MRL)

Hays et al. (2018) recently proposed new boundaries for determining iodine deficiency, sufficiency and excess according to UIC by deriving Biomonitoring Equivalents (BEs). Established exposure and guidance criteria were used, such as the Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA) and for toxicity, Tolerable Upper Intake Level (UL) and Minimal Risk Level (MRL). For UIC, BE's were derived for adults as follows; 60,100, 730 and 450 μg L^{-1}, respectively. Zimmerman et al. (2016) also employed EAR and UL cutoff points to improve spot UIC to adjust I-intake distributions from UIC surveys where single sample per subject is collected. Whilst these approaches have not yet appeared in abundance for other studies in the literature, they are likely to gain greater interest to improve the validity of UIC spot measurements as cost effective survey tools. When considering Hays et al. (2018) BE's, for this study, using uncorrected UICs the proportion of volunteers <EAR, <RDA, >UL and > MRL, were 4, 12, 4 and 21%, respectively. Little difference in the proportion of UIC deficiencies results from these BE's, but excess is reduced from 44% for both the UL and MRL criteria.

Influence of urinary dilution corrections

For UICs with dilution correction, creatinine is the most commonly reported correction method, although has fallen out of favour (Cockell 2015). In this paper, creatinine corrected UIC (μg g^{-1}) provided a median of 232 μg L^{-1}, which was significantly higher than 203 μg L^{-1} reported in Malawi (Watts et al. 2015), but presented a higher proportion of individuals with a

UIC in a range of sufficiency. Meanwhile, the number of volunteers exhibiting excess UIC reduced to 34 with creatinine adjustment from 44% (uncorrected) in this study.

Table 1 summarises the UIC data and influence of correction methods on the proportion of volunteers considered to have excess I-intake ranging between 31 to 44%, with 44% of volunteers in excess when using uncorrected UICs. No clear pattern can be discerned as to the influence of each method of correction on changes to numbers of individuals within each boundary for UICs for a study group of this size. Therefore, further analyses were undertaken to evaluate the validity of each correction method, in comparison to a UIC uncorrected for dilution.

Figure 2 shows each of the three dilution measurements in relation to one another. Expectedly, a strong positive correlation (R=0.82) was observed between osmolality and SG (Figure 2A), albeit a number of possible outliers - interferences on SG measurement by refractometry are possible in the presence of large urinary solutes (i.e. proteinuria) (Imran et al. 2010). Conversely, a weaker correlation was observed for creatinine in relation to both osmolality (Figure 2B, R=0.47) and SG (Figure 2C, R=0.48). If, as is widely cited (Imran et al. 2010), it is assumed that osmolality is the most robust measure of urinary dilution, creatinine was a poor marker of urinary dilution in the present dataset, with only 22% of variation explained by osmolality. This finding was markedly different when compared with two western populations: 48% variation in creatinine was explained by osmolality in a set of 2151 samples from the US NHANES survey (CDC, 2018) and 67 % in a UK survey of 202 adults (Middleton et al. 2016a). This may indicate the particularly poor utility of creatinine in an African population.

Figure 3 shows the correlations between both uncorrected (A-C) and corrected (D-F) UICs and each dilution metric. Uncorrected concentrations showed positive correlations with each metric, demonstrating the necessity of correcting to remove hydration-driven dilution variation. As evident in Figure 3B, almost a quarter of variation in UICs was attributable to sample dilution alone. This was less evident for creatinine (Figure 3A) reiterating its poor reflection of urinary dilution. Figure 3 D-E show the efficacy (no correlation desired) of each correction method in removing dilution variation from the sample set. No significant correlation remained following correction by osmolality (Figure 3E) and SG (Figure 3F) – an indication of their good performance. However, creatinine (Figure 3D) resulted in an apparent over-correction, of a magnitude consistent with previous findings in relation to this performance criterion (Middleton et al. 2016). It is possible to compensate for this over-correction by modifying correction equations with a coefficient reflecting the disparity in excretion slopes between creatinine and the analyte under investigation (Vij & Howell, 1998). However, the apparent variation in creatinine concentrations is not explained by dilution in the present dataset and would make any such improvements misleading indicators of performance.

Finally, given the relative paucity of studies utilising alternative correction methods to creatinine, there is a lack of consistency as to the reference values (D_{ref} in Equation 1) used to normalise/scale datasets. This has profound implications when comparing between populations and to published referenced values. Firstly, comparing distributions of uncorrected values between populations assumes that they do not differ by hydration status. However, the median osmolality of the present study group was 581 mOsm kg^{-1}; compared to 730 mOsm kg^{-1} in the US NHANES data (Centers for Disease Control and Prevention, 2015). Secondly, using the median osmolality of the present study group as D_{ref} yielded a median UIC of 285 µg L^{-1}, whereas using the NHANES median yielded a median UIC of 358 µg L^{-1} – an increase of 25%. To ensure that studies are comparing like-for–like, standardised

guidelines on the proper use of dilution corrections, and the appropriate dilution reference values, are urgently needed.

Drinking water and comparison to UIC

Drinking water concentrations for 268 samples provided a median of 3.2 μg L^{-1} (0.2-304.1 μg L^{-1}) and mean of 12.3 ± 33.3 μg L^{-1}. Whilst the median water-I concentration was not high compared to other studies, the range was comparable, for example, in Denmark <1.0 to 139 μg L^{-1} (Pedersen et al. 1999) and 55 to 545 μg L^{-1} in Algeria (Barikmo et al. 2011). Almost no correlation of UIC (uncorrected) with drinking water was observed (R = 0.11), unlike other studies that observed a much stronger correlation (Hussein et al. 2012; Aakre et al. 2015). Kassim et al. (2014) reported variations in Somalian UICs according to the source of drinking water, with a greater association with borehole water, although the concentration of I in water was not measured. In contrast to these studies, the maximum water-I concentration reported in the USA was only 18 μg L^{-1} (WHO, 2003). Given a typical water consumption of 1.8 L day^{-1} (Beal et al. 2017), drinking water could assist in preventing I-deficiency, but may also contribute to I-excess intake above upper tolerable limits of 1100 μg day^{-1} (Leung et al. 2015) where water-I is high. For example, in this study the mean water-I concentration would contribute an intake of 22 μg day^{-1} and at the maximum water-I range, 547 μg day^{-1}. There is currently no defined guideline for iodine in drinking water (WHO, 2003).

Conclusion

Whilst 24 hour urinary collection is cited as ‘ideal’ for UIC measurements, UIC single spot analyses are generally used in studies for practical reasons in the field. Often the sample size of 300 or 500 subjects is referred to for smoothing out differences in hydration (Andersen et al. 2008; Konig et al. 2011; Rohner et al. 2013). Creatinine correction for hydration status has been repeatedly reported as unsuitable for UIC in a developing country scenario where malnutrition may be a problem, although there appears to be a lack of published quantitative evidence to reinforce this widely held view in the literature. Correction for hydration status should be reconsidered, especially given the robustness, simplicity and low cost of specific gravity measurements, which are comparable to the gold standard/osmolality (Middleton et al. 2015). Use of specific gravity adjustments for spot urine samples to account for urinary dilution presents an opportunity for studies with limited budgets and studies that are most commonly reported to have less than the 300+ recommended number of subjects and for practical reasons where repeat sampling of individuals may not be possible.

This study adds to the growing awareness of excess I-intake according to UIC since Anderson et al. (2012) reported an increase from 5 to 11 countries between 2003 and 2011 in which the national median UIC was >300 μg L^{-1}. Whilst no correlation with drinking water was observed in this study, further research to establish the association between water-I concentration, physical and chemical parameters, alongside depth of boreholes, lithology and extraction rates from aquifers is required. In combination with UIC, dietary and physiological studies, a guideline value for water-I should be established to inform national programmes for monitoring and alleviating iodine deficiency and preventing any adverse health effects secondary to chronic excessive iodine intakes.

Figure legends

Figure 1 Map illustrating location of household collection points in western Kenya.

Figure 2 Scatterplots showing the relationship between urinary osmolality and creatinine (A), urinary osmolality and specific gravity (B) and urinary specific gravity and creatinine (C). Pearson correlation coeficients are signifcant to P<0.001.

Figure 3 Scatterplots of urinary iodine against dilution measurements both pre- (A-C) and post- (D-F) correction by each method investigated. ** and * denote statistical significance to P<0.001 and <0.05, respectively.

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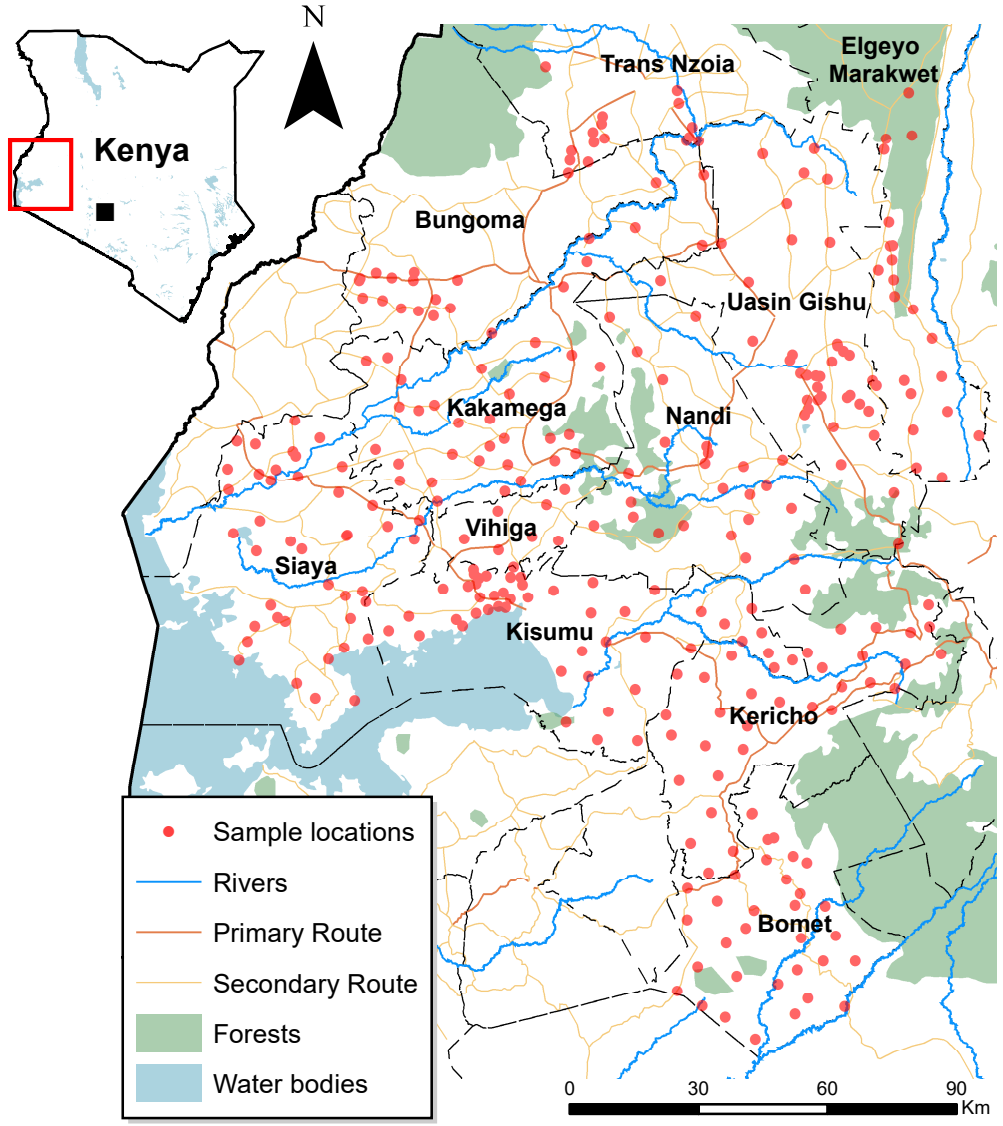
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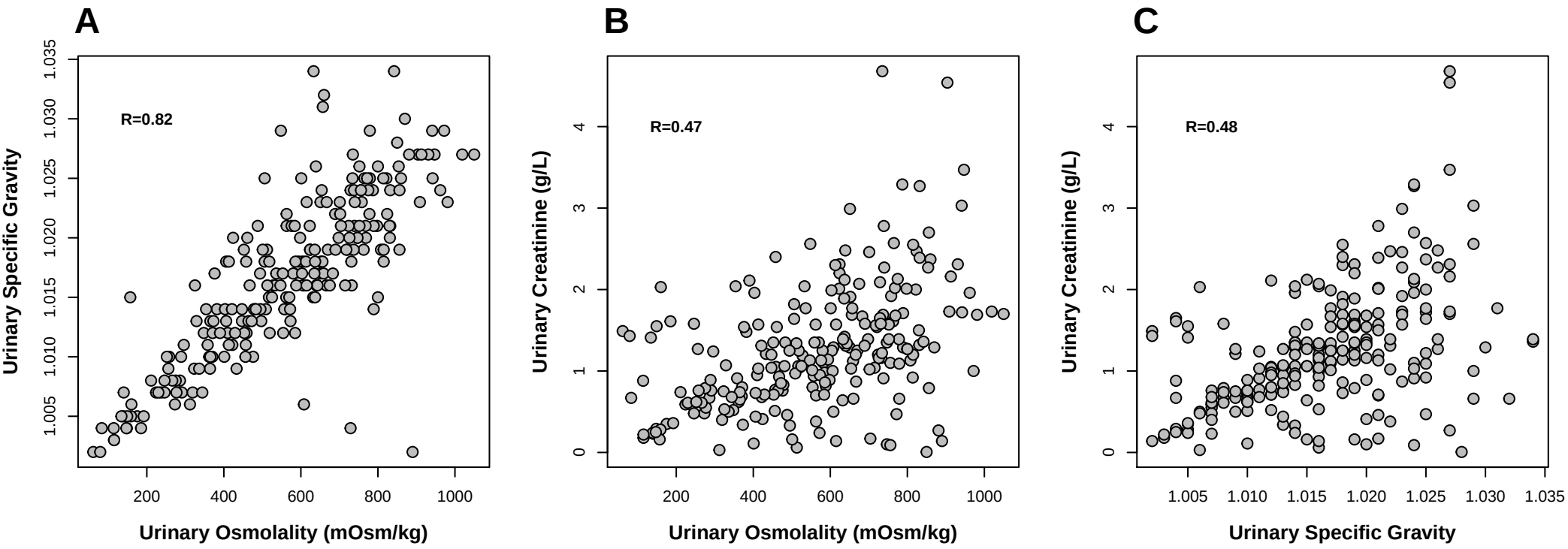
A
R=0.82
Urinary Specific Gravity
1.005
1.010
1.015
1.020
1.025
1.030
1.035
200
400
600
800
1000
Urinary Osmolality (mOsm/kg)
B
R=0.47
Urinary Creatinine (g/L)
0
1
2
3
4
200
400
600
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1000
Urinary Osmolality (mOsm/kg)
C
R=0.48
Urinary Creatinine (g/L)
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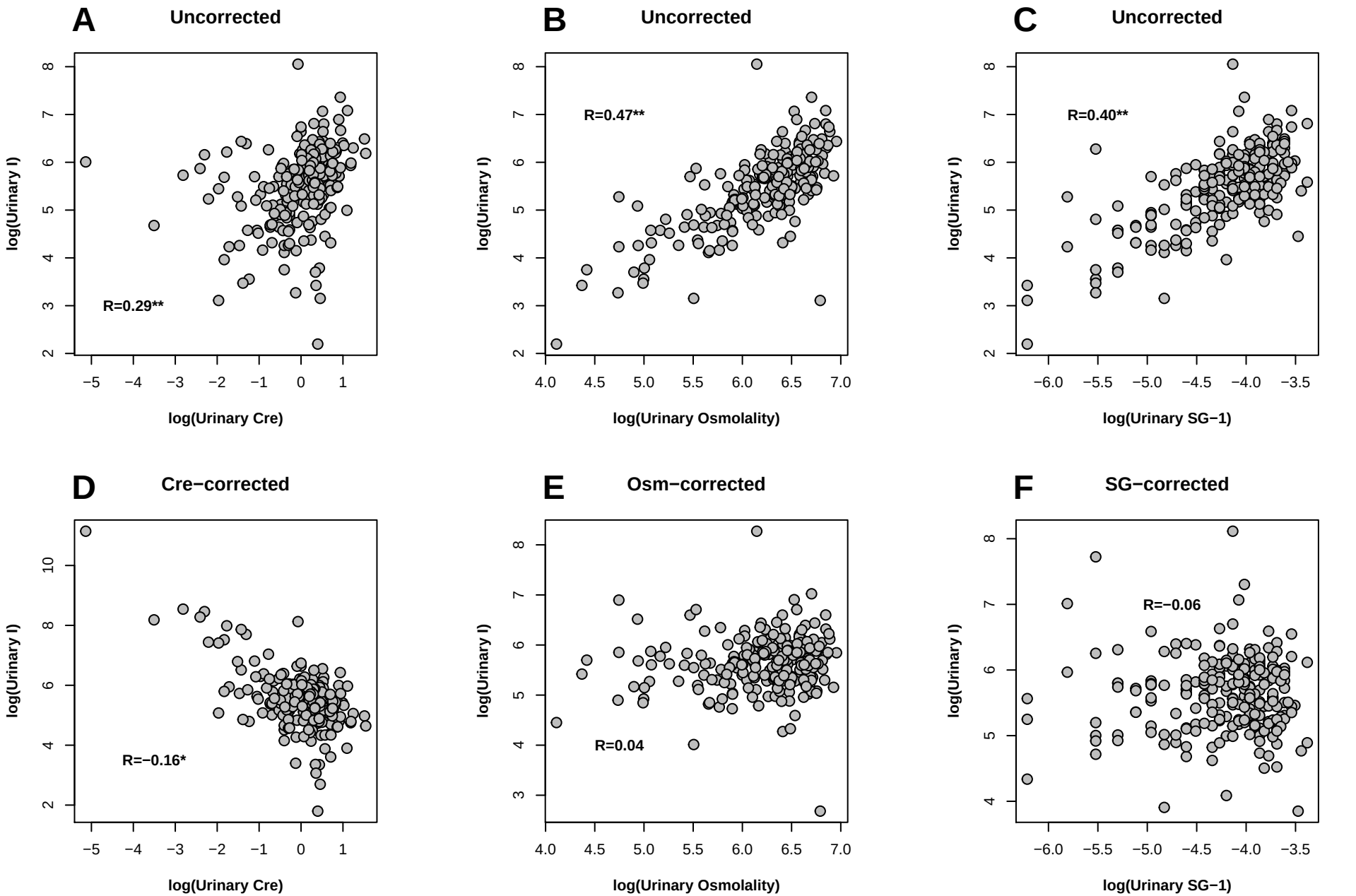
Urinary Specific Gravity


A
Uncorrected
log(Urinary I)
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R=0.29**
B
Uncorrected
log(Urinary I)
log(Urinary Osmolality)
R=0.47**
C
Uncorrected
log(Urinary I)
log(Urinary SG−1)
R=0.40**
D
Cre−corrected
log(Urinary I)
log(Urinary Cre)
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E
Osm−corrected
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log(Urinary Osmolality)
R=0.04
F
SG−corrected
log(Urinary I)
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