Paper for Submission to The Science of the Total Environment

Selenium and iodine in soil, rice and drinking water in relation to endemic goitre in Sri Lanka.

Fiona M. Fordyce[a], Chris C. Johnson[b], Udaya R. B. Navaratna[c], J. Don Appleton[b] and Chandra B. Dissanayake[c]

[a] British Geological Survey, West Mains Road, Edinburgh, EH9 3LA, UK
[b] British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
[c] Department of Geology, University of Peradeniya, Kandy, Sri Lanka

Corresponding Author:

Fiona Fordyce
British Geological Survey
West Mains Road
Edinburgh
EH9 3LA

Tel: + 44 (0)131 650 0393
Fax: + 44 (0) 131 668 2683
E-mail: f.fordyce@bgs.ac.uk

Selenium and iodine in soil, rice and drinking water in relation to endemic goitre in Sri Lanka.

Fiona M. Fordyce[a], Chris C. Johnson[b], Udaya R. B. Navaratna[c], J. Don Appleton[b] and Chandra B. Dissanayake[c]

[a] British Geological Survey, West Mains Road, Edinburgh, EH9 3LA, UK
[b] British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
[c] Department of Geology, University of Peradeniya, Kandy, Sri Lanka

Abstract

Endemic goitre has been reported in the climatic Wet Zone of south-west Sri Lanka for the past 50 years, but rarely occurs in the northern Dry Zone. Despite government sponsored iodised salt programmes, endemic goitre is still prevalent. In recent years, it has been suggested that Se deficiency may be an important factor in the onset of goitre and other iodine deficiency disorders (IDD). Prior to the present study, environmental concentrations of Se in Sri Lanka and the possible relationships between Se deficiency and endemic goitre had not been investigated. During the present study, chemical differences in the environment (measured in soil, rice and drinking water) and the Se-status of the human population (demonstrated by hair samples from women) were determined for 15 villages. The villages were characterised by low (< 10 %), moderate (10 – 25 %) and high (> 25 %) goitre incidence (NIDD, MIDD and HIDD respectively). Results show that concentrations of soil total Se and iodine are highest in the HIDD villages, however, the soil clay and organic matter content appear to inhibit the bioavailability of these elements. Concentrations of iodine in rice are low (≤58 ng/g) and rice does not provide a significant source of iodine in the Sri Lankan diet. High concentrations of iodine (up to 84 µg/l) in drinking water in the Dry Zone may, in part, explain why goitre is uncommon in this area. This study has shown for the first time that significant proportions of the Sri Lankan female population may be Se deficient (24 %, 24 % and 40 % in the NIDD, MIDD and HIDD villages respectively). Although Se deficiency is not restricted to areas where goitre is prevalent, a combination of iodine and Se deficiency could be involved in the pathogenesis of goitre in Sri Lanka. The distribution of red rice cultivation in Sri Lanka is coincident with the HIDD villages. Varieties of red rice grown in other countries contain anthocyanins and procyanidins, compounds which in other foodstuffs are known goitrogens. The potential goitrogenic properties of red rice in Sri Lanka are presently unknown and require further investigation. It is likely that the incidence of goitre in Sri Lanka is multi-factorial, involving trace element deficiencies and other factors such as poor nutrition and goitrogens in foodstuffs.

Keywords: Iodine deficiency disorders, selenium deficiency, Sri Lanka, environmental geochemistry and health, soil, rice, water, hair, goitre, goitrogens

1. Introduction

The trace elements iodine and selenium are essential to human and other animal health in small doses. Iodine forms an important constituent of the thyroid hormones thyroxine (T4, also known as tetraidothyronine) and triiodothyronine (T3). These hormones play a fundamental biological role controlling growth and development (Hetzel and Maberly, 1986). The discovery of the link between iodine deficiency and goitre probably represents the first recognised association between trace element concentrations in the environment and human health.

If the amount of utilisable iodine reaching the thyroid gland is inadequate, or if the thyroid gland is not functioning as it should, then hormone production is reduced and results in a group of conditions in man, collectively referred to as Iodine Deficiency Disorders (IDD) (Fernando et al., 1987). Goitre, the most obvious manifestation of iodine deficiency, is an enlargement of the thyroid gland in an attempt to make more efficient use of the inadequate levels of iodine available. Goitres can vary in size, from small-nodular to monstrous. In more extreme cases, IDD include cretinism, mental retardation, deafness and retarded growth (WHO, 1996).

Although IDD are often associated with poor, remote mountainous regions in the developing world, the diseases have also been reported in many developed countries such as Germany and Italy. Indeed, countries where IDD have been recorded account for 90 % of the world’s population (Dunn, 1996). Extensive dietary supplementation programmes, often based on the addition of iodised oil, iodised salt or iodination of irrigation water (DeLong et al., 1997) have successfully lowered the incidence of IDD in countries such as China, the USA, Switzerland, Papua New Guinea and India. Despite the success of these programmes, endemic IDD remain a serious global health issue affecting 1.6 billion people world-wide (WHO, 1993). Although endemic IDD are attributed mainly to iodine deficiency, other factors such as goitrogens, other trace elements, and genetic factors have been implicated in the aetiology of these diseases (Gaitan and Dunn, 1992).

In recent years, it has been suggested that Se deficiency may be an important factor in the onset of IDD. The selenoenzyme, type 1 iodothyronine deiodinase (IDI), is responsible for the conversion of the prohormone T4 to the active hormone T3 which exerts a major influence on cellular differentiation, growth and development, especially in the foetus, neonate and child. Selenium deficiency inhibits the conversion of T4 to T3 adversely affecting the thyroid hormone metabolism (Arthur and Beckett, 1994; Arthur et al., 1999).

Endemic goitre has been reported in Sri Lanka for the past 50 years. The oceans are the major sink of iodine in the environment which is volatilized from seawater and deposited on land during precipitation (Fuge, 1996). Sri Lanka has a maritime climate and the supply of iodine in the environment should be adequate. Therefore, the simple explanation that iodine deficiency leads to endemic goitre and other IDD is open to much debate and for this reason other causative factors are being investigated.

A number of epidemiological studies have been carried out since 1947 and demonstrate that goitre incidence is much greater in the centre and south-west of the country than in the north (Deo and Subramanian, 1971; Fernando et al., 1987; Mahadeva et al., 1968;). The pattern of endemic goitre closely follows the climato-topographic regions of Sri Lanka which is characterised by a flat-lying Dry Zone in the north and a more rugged Wet Zone in the centre and south-west of the island (Figure 1). One of the more recent surveys estimated that 10 million people were at risk from goitre (Fernando et al., 1987). Although some of these studies included the determination of iodine in foodstuffs and drinking water, no systematic investigations into iodine concentrations in soils had been implemented. Prior to the present study, the concentrations of Se in the environment in Sri Lanka and the possible relationships between Se deficiency and endemic goitre had not been explored.

The current study was designed to address these knowledge gaps and to use the new information on Se and iodine geochemistry to recommend possible remediation strategies. Results relating to soil chemistry will be reported elsewhere (Johnson et al., ‘Iodine and selenium in Sri Lankan soils’, In Prep.). This paper presents a summary of the iodine and Se results for soil and their inter-relationships with rice, drinking water and hair data.

2. Methods

2.1. Sampling strategy

Fifteen villages with differing IDD rates were selected on the basis of previous goitre-prevalence investigations (Table 1). Although the goitre incidence rates for each village were not determined consistently, they provided a useful guide for the selection of target villages and were confirmed by “on-the-ground” visible-goitre observations whilst sampling. The villages were characterised by low (< 10 %), moderate (10 – 25 %) and high (> 25 %) goitre incidence (NIDD, MIDD and HIDD respectively) (Dr A B C Amarasinghe and Dr L Watawana, University of Peradeniya, pers. commun., IDD in Sri Lanka).

The villages with low goitre incidence rates lie within the Dry Zone around Anuradhapura and the moderate and high goitre incidence rate villages are located in the Wet Zone around Kalutara and Kandy (Figure 1). For the purposes of this study, the Wet and Dry Zones are defined on the basis of the 2000 mm rainfall isohyet. Although all the villages are underlain by a sequence of highly folded Precambrian rocks, soil types vary markedly between climato-topographic. In the Dry Zone around Anuradhapura, reddish-brown-earths predominate whereas in the Wet Zone around Kandy and Kalutara red-yellow-podzolic soils and to a lesser extent, mountain regosols and soft or hard laterite and bog soils are developed (Survey Dept., 1988).

Chemical differences in the environment (measured in soil, staple foodstuffs (rice) and drinking water) and the Se-status of the human population (demonstrated by hair samples from women) were determined for each village. Goitre affects more women than men in Sri Lanka (Fernando et al., 1987) hence women were chosen for the survey.

Five composite near-surface (10-30 cm, below A_0) soil samples were collected from each village (Fordyce et al, 1998). Sample sites were selected to represent the cultivated paddy fields around each village managed by different farmers. Duplicate samples were collected from 1 in 25 sample sites.

Rice (red and white varieties) is the most important staple food crop grown in the areas of study and is cultivated on irrigated plains in the Anuradhapura and Kalutara regions and in valley bottoms in the rugged terrain around Kandy. Five rice samples were collected from different grain stores in each village corresponding, where possible, to farms where soils had been collected. Duplicate samples were collected from 1 in 25 rice stores.

The majority of villages were supplied by shallow drinking water wells. In each village, one well was sampled and duplicate samples were collected at 1 in every 5 wells. The following suite of water samples were collected at each well: (i) three 30 ml 0.45 µm filtered water samples for trace element analysis (ii) one 30 ml unfiltered water sample for pH and Eh analysis and (iii) one 250 ml unfiltered water sample for bicarbonate and conductivity determinations.

Samples collected for trace element and Se analysis were acidified by the addition of 0.3 ml ARISTAR grade nitric acid and hydrochloric acid respectively thus preventing adsorption of dissolved metals to the interior walls of the storage bottle and minimising post-sampling microbial activity. Eh, pH, bicarbonate and conductivity determinations were carried out at the end of each day's sampling.

In all villages, hair samples (from the nape of the neck) were collected from five women from different families corresponding to the farms where soil and rice samples had been collected. Their age, health, disease and medication details were recorded (Fordyce et al., 1998).

2.2. Analysis

Soil samples were dried at a low temperature of 35 °C for 6 - 12 hours to avoid loss of Se and iodine through volatilisation. The soils were disaggregated to pass a 2 mm nylon sieve mesh and were ground in an agate vibrating-cup mill to < 150 µm. Total (hydrofluoric-nitric-perchloric digestion), water-soluble and phosphate-extractable Se in soils were determined by hydride generation Atomic Fluorescence Spectrometry (AFS). Total iodine in soils was determined by an automated colorimetric method at the University College of Wales, Aberystwyth (Fuge et al., 1978).

Following removal of the husks, rice grains were milled in an agate vibrating-cup for 3 minutes to produce a powder with a nominal particle size of 150 µm. Total Se concentrations were determined by AFS following a nitric-perchloric digestion.

A sub-sample (20 g) of rice powder from each of the samples from a village was selected and homogenised in an agate mill to produce one large 100 g composite sample for each village. The total iodine content of composite rice samples was determined on 1 g of sample powder by epithermal Neutron Activation Analysis at the Environmental Analysis Section, Imperial College Centre for Environmental Technology, Silwood Park.

After initial acidification, water samples underwent no further treatment prior to AFS analysis for Se. Chloride, NO_3 and SO_4 were determined in the unacidified samples by ion chromatography. Total iodine concentrations in water were determined by automated colorimetry (Fuge et al., 1978).

All the women sampled during the present study had long hair. In order to test whether there was significant variation in Se concentration along the length of the hair, 7 samples were selected and cut into 5 cm lengths starting from the hair root.

Each length was analysed separately. In addition, the possible effects of surface contaminants on the hair were investigated. The 5 cm sections of three of the samples were divided in two. Half the hair was washed in deionised water and the other half in Neutracon® anionic surfactant. In general, the hairs showed little variation in Se concentration with length or with washing solution (Fordyce et al., 1998). On the basis of this information, hair samples were washed in deionised water prior to analysis and the entire hair length was prepared and analysed in bulk. Following a nitric-perchloric digestion, total Se was determined by AFS.

Data quality was assured by selected repeat measurements and the inclusion of certified reference materials in the analytical runs (Fordyce et al., 1998). In general, the results show good agreement (> 85 % recovery) between the measured values and the certified reference values (Table 2). Limits of detection for iodine and Se are given in Table 3.

2.3. Data processing

For statistical analysis, determinations below detection were set to 2/3 of the detection limit. Spearman Rank correlation coefficients were calculated as these are less sensitive to outlying values than product moment (Pearson) correlation coefficients. Comparisons between various sample types are based on the village geometric mean values.

3. Se and iodine in the environment

3.1. Soil

Total concentrations of iodine and Se range from 0.13 - 10 µg/g and 0.113 - 5.238 µg/g respectively (Table 4 and Figure 2) and are comparable to values reported for soils in other regions of the world (Fordyce et al., 1998).

On the basis of research in China, threshold levels in various sample types indicative of Se deficiency and toxicity diseases have been defined (Tan, 1989). Applying these thresholds to the results for Sri Lanka, 36 % of the soils in the NIDD villages are deficient or marginal in total Se, however, the majority of soils cannot be considered deficient (Table 5). One in five soils in the NIDD and HIDD villages and two in five soils in the MIDD villages are marginal in water-soluble Se. Soil iodine and Se concentrations in the study areas can therefore be described as average to marginal when compared with soils from other regions.

Soil iodine concentrations are similar in all three village-groups and concentrations in the goitre prevalent (MIDD/HIDD) villages are no lower than in the non-goitre (NIDD) villages (Figure 2).

The highest concentrations of total and readily-extractable (water-soluble + phosphate-extractable) Se occur in the HIDD and MIDD villages in the Wet Zone and the lowest concentrations are found in the NIDD villages in the Dry Zone (Figure 2). This is the opposite of what would be expected if soil Se concentrations are a causative factor in goitre incidence**.** However, many other soil properties can affect the uptake of Se and iodine into plants and the relationship between soil and rice samples requires careful examination in order to define the controls on Se and iodine bioavailability in the Sri Lankan environment.

3.2. Rice

Although total iodine concentrations were determined in composite rice samples from all 15 villages, only the results for Ihala Kagama (NIDD4) (58 ng/g) and Kiralesssa (NIDD5) (45 ng/g) are above the limit of detection (38 ng/g). These values do not correspond to the highest iodine concentrations in soil.

Muramatsu et al. (1995) have shown that the soil-to-plant transfer factor for iodine in rice is very low compared to green leafy vegetables and that iodine in soil can be volatilized off as organic/methyl iodine as a result of rice cultivation. In addition, the atmosphere is an important source of iodine in plants and atmospheric adsorption rather than soil - root uptake may contribute to rice iodine concentrations. As a consequence, concentrations of iodine in rice are often very low (Table 6) compared to soils and to other crops.

Total Se concentrations in rice range from <0.1 to 776 ng/g (Table 4 and Figure 2). The mean values for NIDD, MIDD and HIDD villages are very similar despite the higher total and extractable Se concentrations in HIDD soils noted in Section 3.1. These results suggest better transfer of Se from soil to rice in the NIDD villages and reduced availability of Se in the soils of the HIDD villages. This is best demonstrated by the ratio of rice total Se/ soil total Se. The lowest ratios (i.e. the poorest uptake of

Se) occur in the HIDD villages whereas the highest ratios are for the NIDD villages (Figure 2). A comparison of the geometric mean values for each village shows there are no significant (95 % confidence level) correlations between rice Se concentrations and water-soluble or phosphate-extractable Se concentrations in soil (Table 7).

Although concentrations of Se and iodine in soil are higher in the Wet Zone than in the Dry Zone, they are less available for plant uptake. This is due to the marked contrast in soil chemistry between the two climatic regions. Soils in the MIDD and HIDD villages have higher organic matter, gibbsite and goethite contents and lower pH than soils in the NIDD villages that contain more illite. Thus Se and iodine in the Wet Zone (MIDD and HIDD) are adsorbed onto clay minerals and organic matter in the soil, inhibiting bioavailability (Fordyce et al., 1998; Johnson et al., 'Iodine and selenium in Sri Lankan soils', In Prep).

Despite average to marginal Se concentrations in soils, more than a third of the rice samples in all three village groups (32 % NIDD, 44 % MIDD, 42 % HIDD) are below the Se deficient/marginal thresholds described by Tan (1989) for grains in China (Table5).

3.3. Water

Shallow well water samples from the NIDD (Dry Zone) villages have a markedly different chemistry (higher pH , conductivity and bicarbonate) than the MIDD and HIDD (Wet Zone) villages reflecting the different climatic regimes in the north and south-west of the country (Table 8).

Iodine concentrations in waters from the Dry Zone (NIDD) (53 to 84 µg/l) are distinctly higher than those from the MIDD and HIDD villages (3.3 - 23.5 µg/l) and are comparable to results reported by other investigators (Table 6). Concentrations in the NIDD waters exceed the range in most shallow waters, which normally contain less than 15 µg/l iodine (Fuge and Johnson, 1986).

Se concentrations range from 0.06 - 0.24 µg/l (Table 4, Figure 2) and are similar for the three goitre-incidence village groups. However, the NIDD samples show a much wider range of values. The reported range is not dissimilar to concentrations quoted for surface waters (0.14 - 0.21 µg/l, McNeal and Balistrieri, 1989).

4. Se status of the population

4.1. Se status shown by hair

Total Se concentrations in hair range from 104 - 2652 ng/g (Table 4, Figure 2). These are nominally higher than values reported for Se-deficient areas of China (Fordyce et al., 2000; Johnson et al., 2000, Table 6). However, approximately 24 % of the samples in the NIDD and MIDD groups are below the marginal threshold described by Tan (1989) for hair in China and the highest percentage of marginal and deficient samples (40 %) occurs in the HIDD village group (Table 5).

Hair Se values show no significant (95 % confidence level) correlation with Se in soil, water or rice samples (Table 7). The higher Se values in soil and rice noted in

Navinna (MIDD5) are not manifested in the hair samples from this village. It is likely that food sources other than rice and drinking water contribute to the Se intake of the population as concentrations of Se in both these foods are low.

Se concentrations in hair do not correlate significantly (95 % confidence level) with age (r_{sp} 0.088, n = 78) or with number of years of residency (r_{sp} = -0.15, n = 48) or with the percentage of local rice consumed (r_{sp} = 0.06, n = 65).

4.2. Se status in relation to goitre incidence

No marked variation in hair Se values between women currently known to be suffering goitre or who have a history of goitre in the family and those who do not is evident (Figure 3). Furthermore, hair Se concentrations show no relationship with the number of years a woman has suffered from goitre (Figure 3).

The results for total Se in hair suggest that a substantial proportion of the sampled population are at risk from Se deficiency, however, there are no clear differences in Se status between women in the HIDD/MIDD villages and the NIDD villages (Figure 2). Although, these results show that Se deficiency is not restricted to the endemic goitre areas, it may still have an effect on goitre incidence as it is clearly prevalent in the goitre-affected villages.

5. Discussion

5.1. Dietary intake

Mahadeva et al. (1968), measured the iodine content and the amount of different foodstuffs consumed by rural populations in Sri Lanka and estimated that the daily intake of iodine per person per day was 300 - 350 µg in the Wet Zone and 850 µg in the Dry Zone. These values exceed the recommended daily requirements for adults of 150 µg/day and 200 µg/day for pregnant women (WHO, 1996). The daily consumption of rice seems generous (284 g per day, 95 g per meal) which may also account for the high estimates of daily iodine intake. Conversely, the estimate that 1 litre of water is drunk per day seems rather low.

Assuming that these figures are correct, the intake of iodine and Se from rice and water measured during the present study can be calculated for each village group on the basis of geometric mean values (Table 9). The concentrations of iodine and Se provided by rice and water samples alone fall well below the recommended daily intake of these elements, however, it is evident that in the Dry Zone, drinking water is a far more important source of iodine in the diet than rice. The level of Se in the diet provided by rice in the HIDD villages is approximately half that provided in the MIDD and NIDD villages (Table 9).

Although the iodine status of individuals was not measured during the current study, it is clear that concentrations in the staple food (rice) are very low. Unless other sources of iodine are included in the diet, such as fish or iodised salt, it is likely that the population will continue to be at risk from iodine deficiency. Similarly, the concentrations of Se in rice and water are very low and a lack of Se rich foods, such as fish and red meat, in the diet may result in Se deficiency.

It is possible that low levels of dietary iodine coupled with low Se intake in the MIDD and HIDD villages contribute to the occurrence of goitre. Although Se intake in the NIDD villages is also low, iodine intake from drinking water is higher and this, in part, may help to prevent goitre.

5.2. Goitrogens

Whereas iodine deficiency is accepted as the main environmental determinant in the pathogenesis of endemic goitre, there are large numbers of naturally occurring and artificial agents that are known to adversely affect the function of the thyroid gland and interfere with the process of hormone synthesis. These agents are usually called goitrogens. When people are exposed to these agents in food or water, they may exert a significant antithyroidal and/or goitrogenic effect. Sartelet et al. (1996), demonstrated the antithyroid effects of flavonoids in Fonio millet. Pearl millet contains a number of flavonoids including thiomide, C-glycosylflavones and glycosylvitexin that inhibit thyroid peroxidase, the enzyme catalysing hormone system in the thyroid. They also interact with iodothyronine deiodinase enzymes, inhibiting the peripheral metabolism of thyroid hormones (Gaitan et al., 1995).

Little is known about the possible influence of goitrogens on goitre incidence in Sri Lanka. Dissanayake and Chandrajith (1996) suggested that goitrogens may be a factor influencing goitre incidence without specifying which goitrogens might be involved.

Hjelle et al. (1994) found no significant relationship between goitre status and the average monthly consumption of goitrogen containing vegetables in a study of pregnant women in the Galle District, south-western Sri Lanka.

It is well known that high concentrations of flavonoids occur in tannins and pigments in a variety of staple foods including millet, sorghum, beans and ground nuts. During the present survey, it was observed that a large proportion (15 out of 25) of the rice samples collected from rural communities in the HIDD villages were red. Only 4 out of 25 rice samples from the MIDD villages and none of the rice samples from the NIDD villages were red. Red rice cultivation is concentrated in a few districts of Sri Lanka and is prevalent in two areas (Kalutara and Galle) with relatively high goitre incidence rates (Dr S Abeysiriwardena, Rice Research and Development Institute, Sri Lanka, pers. commun., red rice cultivation). Aromatic red rice used for wine making in Japan contains anthocyanins of which the major pigment was identified as cyanidin 3-glucoside (Terehara et al., 1994). Red rice (Oryza rufipogon Griff) is found in most countries that grow rice (O. sativa*)* and is considered a weed pest in some. Red rice is also found among O. glaberrima varieties in Africa where it is reported that the rice bran contains a number of procyanidins (Dr J Wood, NRI, pers. commun., goitrogens in foodstuffs). It has also been suggested that the red pigmentation may be caused by tannins (Dr J Wood, Natural Resources Institute (NRI) pers. commun., goitrogens in foodstuffs). Anthocyanins are flavonoid compounds (Prof E Gaitan, University of Mississippi, pers. commun., goitrogens in foodstuffs) therefore red rice may have goitrogenic properties.

Parboiling rice (boiling before the bran is removed) is a common practice in Sri Lanka. Parboiling and boiling of potentially goitrogenic anthocyanins in red rice may have a number of actions depending on whether the goitrogen is thermolabile or thermostable and whether it is chemically bound within the bran or contained within the grain kernel (Fordyce et al., 1998). Parboiling could induce some leaching of goitrogens from the rice grain or lock it into the grain during starch gelatinisation (Dr J Wood, NRI, pers. commun., goitrogens in foodstuffs). An apparent increase of antithyroid activity has been reported on heating, boiling and storage of pearl millet (Gaitan, 1996) therefore parboiling and cooking of red rice may produce similar effects should the anthocyanin pigments prove to be goitrogenic.

The presence of goitrogenic substances in red rice requires further investigation before conclusions can be drawn as to the role they play in the pathogenesis of goitre in Sri Lanka.

5.3. Risk assessment and potential remediation strategies

Hair Se determinations have shown for the first time that a significant proportion of the Sri Lankan population may be at risk from Se deficiency. Options available for dealing with Se deficiency include, increasing the amount of Se rich foods such as fish and meat in the diet; supplementation with Se tablets; and the application of Se fertilisers to soil or food crops.

The intake of organic Se in food is more natural and possibly more beneficial than using supplementation tablets containing sodium selenite, for example. The majority of villagers already use nitrogen-phosphorous-potassium (NPK) fertiliser and it may be possible to enhance the Se levels of the fertiliser used. However, Se fertiliser added to the soil may have little effect, particularly in the Wet Zone where soils have a high capacity to adsorb more Se (Fordyce et al., 1998.). Direct application of Se to plant foliage has been shown to be more efficient than soil applications as the problem of Se immobilisation in the soil is avoided (Watkinson and Davies, 1967). Factors such as local humidity and time between spraying and rainfall events can give variable results from this method and recoveries are poor (4.2 - 8.1 % of Se added) (Haygarth, 1994). In the Wet Zone of Sri Lanka, however, this method may avoid the problem of Se fixation by the soil.

The government in recent years has carried out the introduction of iodised salt to the population of Sri Lanka. Although a high proportion of the women sampled in the present study use iodised salt, the majority add the salt before cooking. Much of the iodine added in this way may be lost to the atmosphere during the cooking process. It is recommended that an education programme be initiated to increase the effectiveness of the iodised salt programme making people aware that to store iodised salt for long periods or to add it to food before cooking may reduce its effectiveness.

Another possible intervention may be the iodinaton of irrigation water. Jiang et al. (1997) found that the irrigation method, rather than iodised salt, successfully raised the iodine status of subsistence-farming based populations in China. Before this method could be applied to Sri Lanka, however, field tests to assess its physiological and economic efficacy and social acceptability would be required.

6. Conclusions

1. Soil Se and iodine concentrations in the Sri Lankan environment are average to marginal compared to soils elsewhere. The highest values of Se and iodine in soil occur in the Wet Zone (MIDD/HIDD goitre-incidence village groups) of south-west Sri Lanka where goitre is prevalent. Although, concentrations of soil Se and iodine are higher in the Wet Zone than in the Dry Zone (NIDD goitre-incidence village group), they are less bioavailable due to the marked contrast in soil chemistry between the two climatic regions.

2. Iodine concentrations in rice are very low but are comparable to values reported from other areas of the world. Uptake of iodine into rice grains is generally very poor compared to other parts of the plant and rice does not provide a good source of iodine in the Sri Lankan diet. Iodine concentrations are ten times higher in the Dry Zone (NIDD) drinking waters than in the Wet Zone (MIDD/HIDD) and contribute more iodine to the diet than rice. This supply of iodine may, in part, explain why goitre is not common in the Dry Zone.

3. Despite average to marginal Se concentrations in soil, over a third of the rice samples in all three goitre-incidence village groups are deficient/ marginal in Se. Concentrations of Se in rice and drinking water are similar in the NIDD, MIDD and HIDD village groups. Estimates of daily dietary intakes show that Se from rice and water do not form an important source of Se in the diet.

4. This study has shown for the first time that significant proportions of the Sri Lankan female population may be Se deficient (24 %, 24 % and 40 % in the NIDD, MIDD and HIDD villages respectively). No difference in Se status was detected between women known to be suffering from goitre and those who were not and Se deficiency is not restricted to areas where goitre is prevalent. It is unlikely that Se deficiency is the main controlling factor in IDD but it could contribute to the onset of goitre along with iodine deficiency and other factors such as poor nutritional status and the presence of goitrogenic substances in the diet.

5. The distribution of red rice cultivation in Sri Lanka is coincident with high goitre-incidence villages. Although no studies have been carried out into the goitrogenic properties of Sri Lankan red rice, it is suspected that the rice may contain goitrogenic flavonoids (anthocyanins and/or procyanidins). In vitro and in vivo tests to ascertain the presence of flavonoids are recommended. These studies also need to examine whether goitrogens are concentrated in the bran or in the rice kernel and the likely effects of hulling and parboiling rice grains in the bran.

Acknowledgments

This study forms part of a British Government Department for International Development (DFID) Knowledge and Research (KAR) Project to determine methods of predicting and remediating human Se imbalances (Project R6227). The authors extend grateful thanks for the assistance of the following: Mr T Hewawasam, Prof. P A J Perera, Dr A B C Amarasinghe, Prof. Nugegoda, Mr A de Silva, Dr L Watawana, and Dr M Arseculeratne (University of Peradeniya); Mr S Burden, Mr P Blackwell, Dr M Cave, Mr M Allen, Dr V Hards and Dr P Smedley (BGS); Dr R Fuge and Dr R Benzing, Prof. G Fell, Prof. J Arthur, Dr J Wood, Prof. E Gaitan and Dr S Abeysiriwardena (for expert advice). Grateful thanks are also due to the village government officials and the women who took part in this study. This paper is published with permission from the Director of the British Geological Survey.

References

Arthur JR, Beckett GT. New metabolic roles for selenium. Proceedings of the Nutrition Society 1994; 53: 615-624.

Arthur JR, Beckett GJ, Mitchell JH. The interactions between selenium and iodine deficiencies in man and animals. Nutrition Research Reviews 1999; 12 (1): 55-73.

Balasuriya S, Perera PAJ, Herath KB, Katugampola SL, Fernando SL. Role of iodine content of drinking water in the aetiology of goitre in Sri Lanka. Ceylon Journal of Medical Science 1992; 35: 45-51.

Chilean Iodine Education Bureau (CIEB). Iodine Content of Foods. Shenval Press, London, 1952.

DeLong GR, Leslie PW, Wang SH, Jiang XM, Zhang ML, Rakeman MA, Jiang JY, Ma T, Cao XY. Effect on infant mortality of iodination of irrigation water in a severely iodine-deficient area of China. Lancet 1997; 350 (9080): 771-773

Deo MG, Subramanian TAV. Iodine metabolism in children and women with endemic goitre in Ceylon. British Journal of Nutrition 1971; 25: 97-105.

Dissanayake CB, Chandrajith RLR. Iodine in the environment and endemic goitre in Sri Lanka. In: Appleton JD, Fuge R, McCall GJH, editors. Environmental Geochemistry and Health. Geological Society Special Publication No. 113, 1996, pp. 213-221.

Dunn JT. Seven deadly sins in confronting endemic iodine deficiency and how to avoid them. Journal of Clinical Endocrinology and Metabolism 1996; 81(4): 1332-1335.

Fernando MA, Balasuriya S, Herath KB, Katugampola S. Endemic goitre in Sri Lanka. In: Dissanayake CB, Gunatilaka L, editors. Some Aspects of the Environment of Sri Lanka. Sri Lanka Association for the Advancement of Science, Colombo, 1987, pp. 46-64.

Fernando MA, Balasuriya S, Herath KB, Katugampola S. Endemic Goitre in Sri Lanka. Asia-Pacific Journal of Public Health 1989; 3(1): 11-18.

Fordyce FM, Johnson CC, Navaratne URB, Appleton, JD, Dissanayake CB. Studies of Selenium Geochemistry and Distribution in Relation to Iodine Deficiency Disorders in Sri Lanka. British Geological Survey Overseas Geology Series Technical Report WC/98/23, 1998.

Fordyce FM, Zhang G, Green K, Liu X. Soil, Grain and Water Chemistry and Human Se Imbalances in Enshi District, Hubei Province, China. Applied Geochemistry 2000;15(1): 117-132.

Fuge R. Geochemistry of iodine in relation to iodine deficiency diseases. In: Appleton JD, Fuge R, McCall GJH, editors. Environmental Geochemistry and Health. Geological Society Special Publication. 113, 1996, pp. 201-212.

Fuge R, Johnson CC. The geochemistry of iodine – a review. Environmental Geochemistry and Health 1986; 8: 31-54.

Fuge R, Johnson CC, Phillips WJ. An automated method for the determination of iodine in geochemical samples. Chemical Geology 1978; 23: 255-265.

Gaitan E. Flavonoids and the thyroid. Nutrition 1996; 12 (2): 127-129.

Gaitan E, Dunn JT. Epidemiology of iodine deficiency. Trends in Endocrinology and Metabolism 1992; 3(5): 170-175.

Gaitan E, Cooksey RC, Legan J, Lindsay RH. Antithyroid effects in vivo and in vitro of vitexin: a c-glycosylflavone in millet. Journal of Clinical Endocrinology and Metabolism 1995; 80 (4): 1144-1147.

Haygarth PM. Global importance and global cycling of Se. In : Frankenberger WT, Benson S, editors. Selenium in the Environment. Marcel Dekker Inc., New York, 1994, pp. 1-28.

Hetzel HS, Maberly GF. Iodine. In: Mertz W, editor. Trace Elements in Human and Animal Nutrition. Academic Press, London, 1986, pp. 139-197.

Hjelle AK, Neggers YH, Wikramanayake TW, Bindon R. Dietary intake and the prevalence of goitre among pregnant women on the south-western coast of Sri Lanka. Ceylon Journal of Medical Science 1994; 37: 31-38.

Jiang XM, Cao XY, Jiang JY, Ma T, James DW, Rakeman MA, Dou ZH, Mamette M, Amette K, Zhang ML, DeLong GR. Dynamics of environmental supplementation of iodine: Four years' experience of iodination of irrigation water in Hotien, Xinjiang, China. Archives of Environmental Health 1997; 52 (6): 399-408.

Johnson CC, Ge X, Green KA, Liu X. Selenium distribution in the local environment of selected villages of the Keshan Disease belt, Zhangjiakou District, Hebei Province, People’s Republic of China. Applied Geochemistry 2000; 15 (3): 385-401.

Koch GS, Link RF. Statistical Analysis of Geological Data. John Wiley and Sons, New York, 1970.

MAFF. Dietary intake of Se. Food Surveillance Information Sheet. No. 126. Ministry of Agriculture, Fisheries and Food, 1997.

Mahadeva K, Senthe Shanmuganathan S. The problem of goitre in Ceylon. British Journal of Nutrition 1967; 21: 341-352.

Mahadeva K, Seneviratne DA, Jayatilleke DB, Senthe Shanmuganathan S, Premachandra P, Nagarajah M. Further studies on the problem of goitre in Ceylon. British Journal of Nutrition 1968; 22: 527-534.

McNeal JM, Balistrieri LS. Geochemistry and occurrence of selenium: an overview. In: Jacobs LW, editor. Selenium in Agriculture and the Environment. SSSA Special Publication 23, 1989, pp. 1-14.

Muramatsu Y, Yoshida S, Ban-nai T. Tracer experiments on the behaviour of radioiodine in the soil-plant-atmosphere system. Journal of Radioanalytical and Nuclear Chemistry 1995; 194 (2): 303-310.

Sartelet H, Serghat S, Lobstein A. Flavonoids extracted from Fonio millet reveal potent antithyroid properties. Nutrition 1996; 12: 100.

Survey Department. The National Atlas of Sri Lanka. Survey Department of Sri Lanka, 1988.

Tan J, editor. The Atlas of Endemic Diseases and Their Environments in the People's Republic of China. Science Press, Beijing, 1989.

Terahara N, Siagusa N, Ohba R, Ueba S. Composition of anthocyanin pigments in aromatic red rice and its wine. Journal of the Japanese Society for Food Science and Technology 1994; 1 (7): 519-522.

Watkinson JH, Davies EB. Uptake of native and applied Se by pasture species. 4. Relative uptake through foliage and roots by white clover and browntop. Distribution of Se in white clover. New Zealand Journal of Agricultural Research 1967; 10: 122-1.

World Health Organisation. Global Prevalence of Iodine Deficiency Disorders. UNICEF/ International Council for the Control of Iodine Deficiency Disorders, WHO, Geneva, 1993.

World Health Organisation. Trace Elements in Human Nutrition and Health. World Health Organisation, 1996.

Yuita, K. Overview and dynamics of iodine and bromine in the environment. 1. Dynamics of iodine and bromine in the soil-plant system. Japan Agricultural Research Quarterly, 1994; 28 (2): 90-99.

Table 1

Goitre incidence rates for the 15 villages sampled during the present study.

Village	IDD Code	Pop.	Goitre Rate %	Goitre Ref.	Location
Upuldenya	NIDD1	1300	nd	8	Upuldenya
Manankattiya	NIDD2	1300	nd	8	Manankattiya
Polambayagama	NIDD3	800	7.3	3,6	Polambayagama
Ihala Kagama	NIDD4	700	nd	8	Ihala Kagama
Kiralessa	NIDD5	650	6.5	3,6	Matale District
Dehideniya	MIDD1	nd	22	2	Dehideniya
Kobbekaduwa	MIDD2	1250	17	2	Kobbekaduwa
Ambepussa	MIDD3	nd	23.7	4	Warakapola District
Debagama	MIDD4	950	18.3	4	Dehiowita District
Navinna	MIDD5	119	12.5	4	Kalutara District
Agunawala	HIDD1	nd	40	1	Agunawala
Kurunduwatte	HIDD2	nd	42	2	Kurunduwatte
Olaboduwa North	HIDD3	1471	44.9	3,6	Horana District
Pelenwatte	HIDD4	3000	53.6	3,4,5	Pelenwatte
Gurudola	HIDD5	1500	50	7	Matugama District

Goitre Ref. = Goitre Incidence References: 1. Dissanayake and Chandrajith (1996), 2. Department Biochemistry, University of Peradeniya (Unpubl.), 3. Fernando et al. (1989), 4. Mahadeva and Senthe Shanmuganathan (1967), 5. Deo and Subramanian (1971), 6. Fernando et al. (1987), 7. Dr L Watawana, Dept. Nuclear Medicine, University of Peradeniya (pers. commun.), 8. Dr P Smedley, BGS (pers. commun.). Goitre rates % cited for villages were not determined consistently, details are given in the references listed. Location = geographic locations cited in references. Pop. = Population. nd = no data. NIDD = No/low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence.

Table 2

Total iodine and Se concentrations in international reference materials.

Reference Material	Certified Value µg/g	Measured Value µg/g	No. of Analyses	% Recovery
Se by AFS				
NRCCRM Soil GBW 07402	160	134	1	84
NRCCRM Soil GBW 07405	1822	1560	1	86
NRCCRM Tea GBW 8505	41	37.92 ± 3.46	2	92
WRC Aquacheck Water 121 5a	8.400	8.379 ± 0.65	10	99
NRCCRM Hair GBW 07601	600 ± 30	554.4 ± 43.55	5	92
NRCCRM Hair GBW 09101	580 ± 50	513	1	88
Iodine by NAA				
SRM 1572 Citrus Leaves	1.84 ± 0.03	1.79 ± 0.6*	1	97

Water results = µg/l   *95% confidence based on counting statistics

Table 3

Limits of detection for iodine and Se in each sample type.

Sample Type	Se LOD ng/g	I LOD ng/g
Soil	5	200#
Soil Water Soluble	0.05	
Soil Phosphate Extractable	0.05	
Rice	5	38∝
Water	0.2	1#
Hair	10	

Se analysed by AFS # Automated Colorimetry

∝ Epithermal NAA Results for water = μg/l

Table 4

Summary of iodine and Se determinations in all sample types in each goitre incidence village group.

Group	Sample Type	Min Se	Max Se	Geomean Se	Number	Min Iodine	Max Iodine	Geomean Iodine	Number
NIDD	Soil ng/g	113	663	226	25	130	10 000	2260	25
	Rice ng/g	6.8	150	42	25	45	58	51	5
	Water µg/l	0.06	0.24	0.11	5	53	84	66.5	5
	Hair ng/g	104	765	294	25	nd	nd	nd	
MIDD	Soil ng/g	310	5238	875	24	130	6600	2008	25
	Rice ng/g	0.1	776	55	25	<38	<38	<38	5
	Water µg/l	0.06	0.09	0.07	5	3	23.5	5.5	5
	Hair ng/g	118	2652	389	25	nd	nd	nd	
HIDD	Soil ng/g	276	3947	1124	25	1000	9600	3914	25
	Rice ng/g	0.1	127	25	25	<38	<38	<38	5
	Water µg/l	0.06	0.09	0.07	5	3.3	20.2	7.02	5
	Hair ng/g	111	984	302	25	nd	nd	nd	

NIDD = No/low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence. nd = no data

Table 5

Percentage of deficient and marginal Se concentrations in soil, grain and hair samples from the NIDD, MIDD and HIDD villages.

	Threshold	Percentage of Samples		
	Se ng/g*	NIDD	MIDD	HIDD
Deficient				
Soil Total Se	< 125	8		
Soil Water-soluble Se	< 3			
Grain Total Se	< 25	24	16	42
Hair Total Se	< 200	24	16	24
Marginal				
Soil Total Se	< 125 - 175	28		
Soil Water-soluble Se	< 3 - 6	20	40	20
Grain Total Se	25 - 40	8	28	
Hair Total Se	200 - 250		8	16

* Thresholds from Tan (1989).

Table 6

Iodine and Se concentrations in sample types from the present study compared to results from other investigations.

Region	Sample Type	I ng/g	Se ng/g	Reference
NIDD, SL	Rice	45 – 58		Current Study
Dry Zone, SL	Rice	880		Mahadeva et al. (1968)
Wet Zone, SL	Rice	43		Mahadeva et al. (1968)
IDD Region, China	Rice	20 – 120		Tan (1989)
Chile	Rice	25		CIEB (1952)
Japan	Rice	25 – 55		Yuita (1994)
NIDD, SL	Water	53 – 84	0.06 – 0.24	Current Study
Anuradhapura, SL	Water	7 - 206		Dr P Smedley (pers. commun.*)
Dry Zone, SL	Water	83		Mahadeva and Senthe S (1967)
Dry Zone, SL	Water	119		Balasuriya et al. (1992)
MIDD/HIDD, SL	Water	3.3 – 23.5	0.06 – 0.09	Current Study
Kandy/Kalutara, SL	Water	2 – 11		Mahadeva and Senthe S (1967)
Kandy, SL	Water	15 – 150		Dissanayke and Chandrajith (1996)
World	Surface water		0.14 – 0.21	McNeal and Balistrieri (1989)
Sri Lanka	Hair		104 – 2652	Current Study
Zhangjiakou, China	Hair		94 – 359	Johnson et al. (2000)
Enshi, China	Hair		170 - 853	Fordyce et al. (2000)

SL = Sri Lanka   Water = µg/l

NIDD = No/ low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence

* Iodine in Sri Lankan groundwater

Table 7

Spearman Rank correlation coefficients for selected parameters in soil, rice, water and hair samples.

	Rice Se	Hair Se
Soil I	0.289	-0.086
Soil Se	0.561	0.229
Soil pH	-0.220	-0.297
Soil Ex Se	0.370	0.263
Soil WSe	0.322	0.259
Soil PSe	0.405	0.018
Soil TOC	0.310	0.242
Water Se	-0.046	0.155
Water I	-0.247	-0.316
Water pH	-0.554	-0.079
Hair Se *	-0.050	

Based on village geometric mean values n = 15, r95% = 0.441

* Based on individual results n = 74, r95% = 0.194 (Koch and Link, 1970)

WSe = water soluble Se PSe = phosphate extractable Se

Ex = Extractable (WSe + PSe) TOC = total organic carbon

Table 8

Summary of parameters determined in shallow well water samples from the NIDD, MIDD and HIDD villages.

	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Temp (°C)	pH	Eh (mV)	Bicarbonate (mg/l$CaCO_3$)	Conductivity (µS)
NIDD (n = 5)								
Minimum	0.07	10.37	0.07	26.4	7.26	212	129.0	712
Maximum	125.43	29.56	24.82	29.7	7.57	243	214.0	1760
MIDD (n =5)								
Minimum	4.54	0.70	1.46	27.9	4.82	230	5.0	68
Maximum	32.00	3.21	21.99	29.8	7.02	278	18.0	222
HIDD (n = 5)								
Minimum	3.19	0.68	0.54	27.6	4.76	232	1.7	49
Maximum	33.50	25.20	12.40	31.0	6.62	293	59	484

NIDD = No/low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence

Table 9

Estimates of daily dietary iodine and Se intake from drinking water and rice based on results from the present study.

	Daily intake µg Iodine		Daily intake µg Se	
	Rice	Water	Rice	Water
NIDD	14.5	66.5	11.9	0.11
MIDD	< 10.8*	5.5	15.6	0.07
HIDD	< 10.8*	7.0	7.1	0.07
Recommended daily intakes	150 – 200~		60 - 75^	

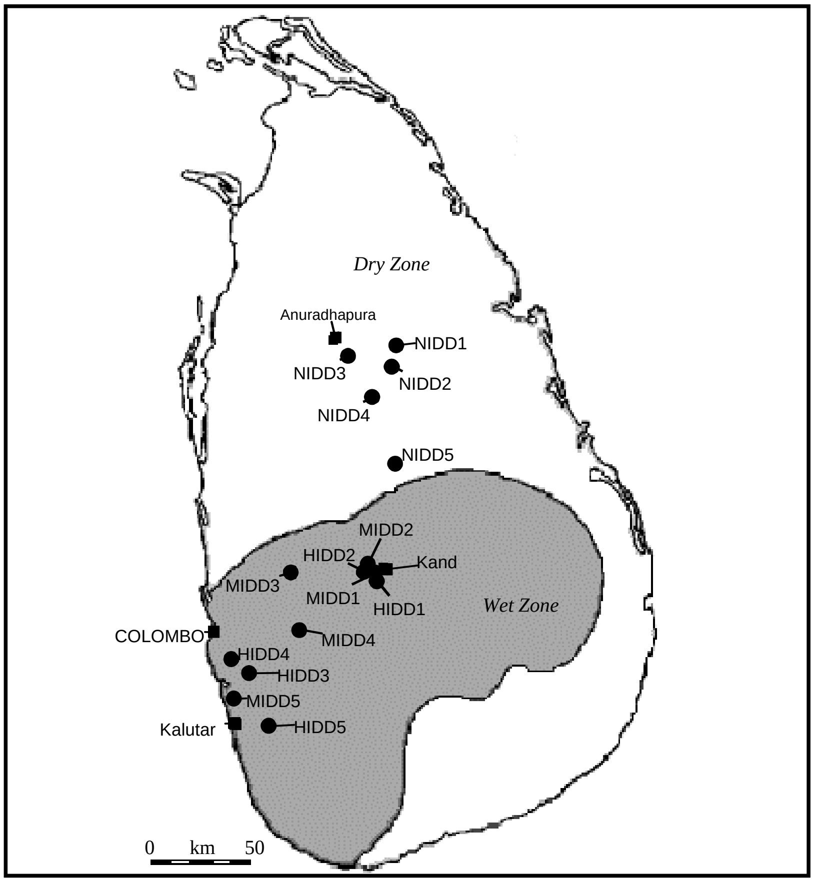
NIDD = No/low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence

~WHO (1996) ^MAFF (1997) * Calculated on the basis of the detection limit

Fig. 1. Sketch map showing the location of the 15 study villages, the Wet Zone/ Dry Zone demarcation used in the present study is based on the 2000 mm isohyet.

Fig. 2. Box and whisker plots of the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of iodine and Se distributions in soil, rice, water and hair samples classified by goitre incidence.

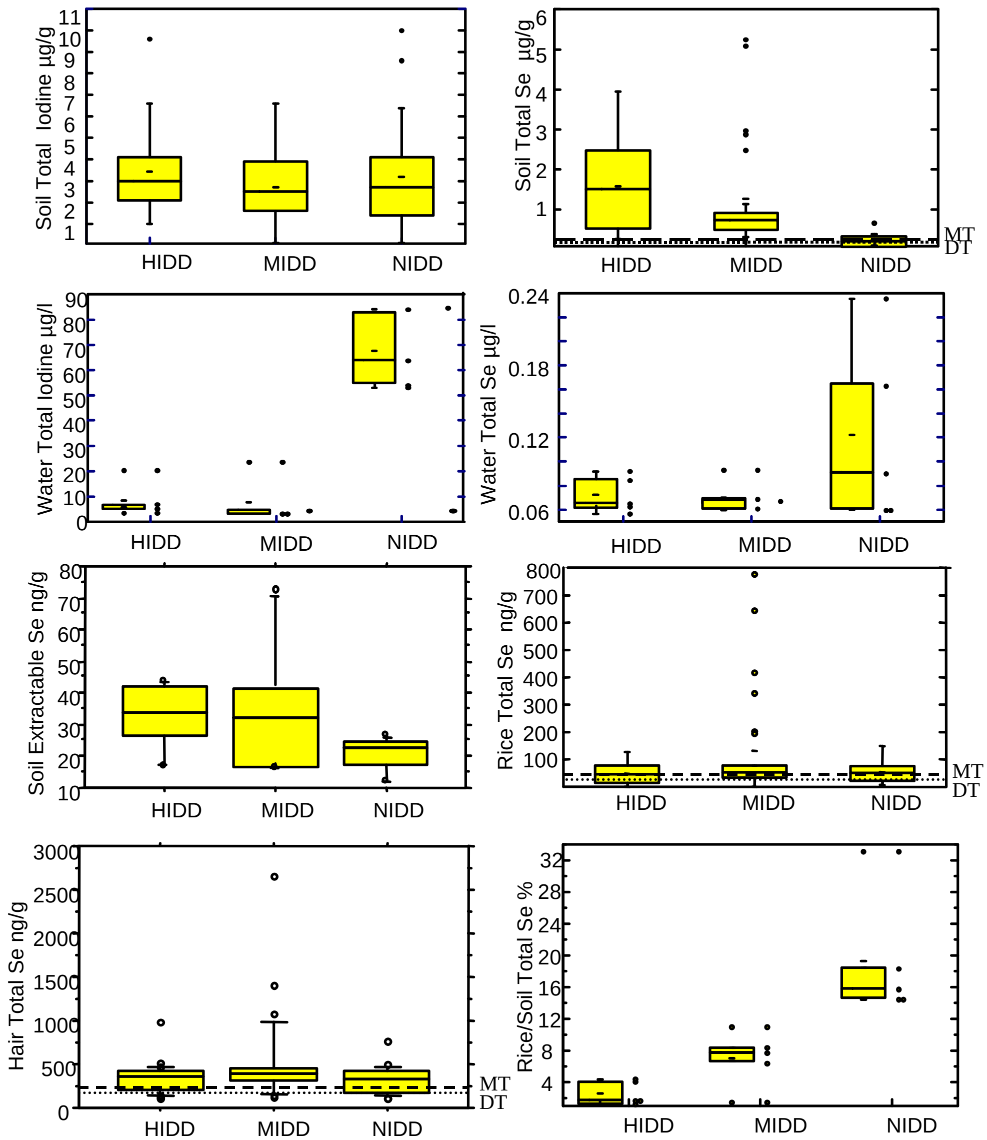
Fig. 3. Box and whisker plots of the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of hair total Se classified by goitre history.



Village Iodine Deficiency Disorders (IDD) codes:

No/low < 25% goitre incidence	Moderate 10 - 25% goitre incidence	High > 25% goitre incidence
NIDD1 Upuldenya	MIDD1 Dehideniya	HIDD1 Agunawala
NIDD2 Manankattiya	MIDD2 Kobbekaduwa	HIDD2 Kurunduwatte
NIDD3 Polambayagama	MIDD3 Ambepussa	HIDD3 Olaboduwa
NIDD4 Ihala Kagama	MIDD4 Debagama	HIDD4 Pelenwatte
NIDD5 Kiralessa	MIDD5 Navinna	HIDD5 Gurudola

Fig. 1.



NIDD = No/ low goitre incidence, MIDD = Moderate goitre incidence, HIDD = High goitre incidence

Se Deficiency and Marginal Thresholds for soil, grain and hair samples defined by Tan (1989): MT = Marginal Threshold, DT = Deficiency Threshold

Fig. 2.

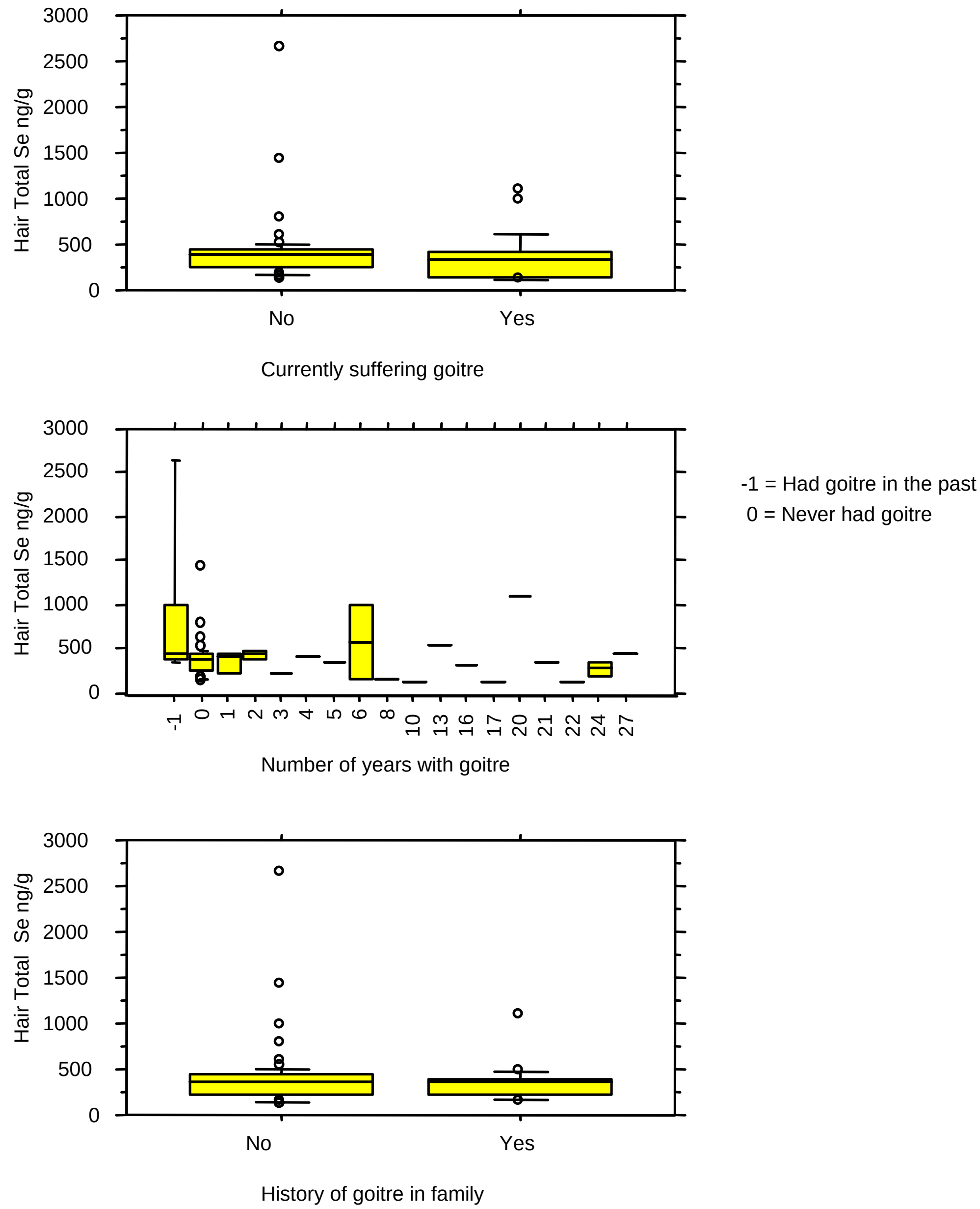

Hair Total Se ng/g
3000
2500
2000
1500
1000
500
0
No
Yes
Currently suffering goitre
Hair Total Se ng/g
3000
2500
2000
1500
1000
500
0
-1
0
1
2
3
4
5
6
8
10
13
16
17
20
21
22
24
27
Number of years with goitre
-1 = Had goitre in the past
0 = Never had goitre
Hair Total Se ng/g
3000
2500
2000
1500
1000
500
0
No
Yes
History of goitre in family

Fig. 3.