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Overseas Geology Series

STUDIES OF SELENIUM GEOCHEMISTRY AND DISTRIBUTION IN RELATION TO IODINE DEFICIENCY DISORDERS IN SRI LANKA

F M FORDYCE, C C JOHNSON, U R B NAVARATNE,
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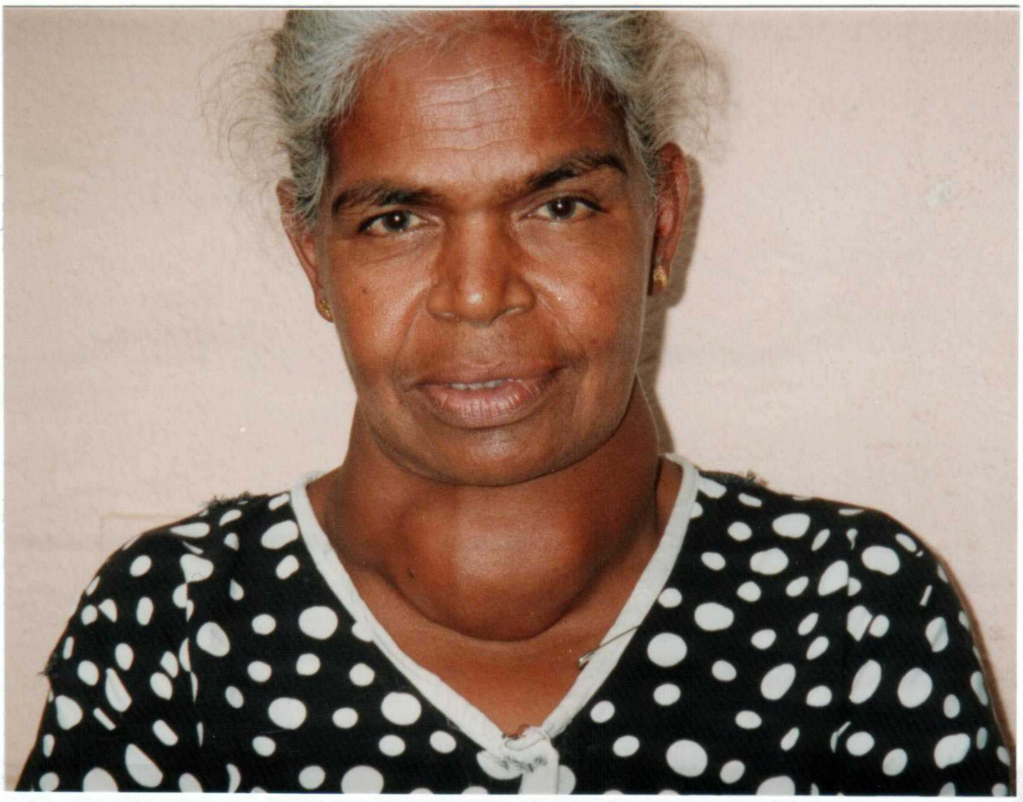

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WITH CONTRIBUTIONS FROM

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Front cover illustration: Woman suffering from goitre, one of the primary health effects of iodine deficiency disorders. (Photo: F Fordyce)

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EXECUTIVE SUMMARY

This report is intended for scientific and medical specialists, especially in Sri Lanka (and elsewhere in the world where iodine deficiency disorders and selenium deficiency are major problems). The main recommendations are detailed in the Executive Summary and in Chapter 14 of the text.

Several naturally occurring minerals and elements are essential to human health and well-being. These minerals are provided by the plants, animals and water that comprise the food supply, and through the ingestion and inhalation of particles derived from the environment. Animals and plants ultimately depend upon soil, water and rock for the provision of minerals hence the link between the geochemical environment and human health. This link is particularly important in developing countries where the poorest sectors of the population are often totally dependant on subsistence agriculture for their dietary needs. The inability of the local environment to provide the correct mineral balance can lead to serious health problems and disease thus inhibiting the wealth creation potential of individuals as well as impacting on their quality of life.

Selenium (Se), a naturally occurring metalloid element is found in all natural materials on earth including rocks, soils, waters, air, plant and animal tissues. Since the early 1930's, it has been recognised that Se toxicity causes hoof disorders and hair loss in livestock. Se was also identified as an essential trace element for humans and other animals in the late 1950's. It forms a vital constituent of the biologically important enzyme glutathione peroxidase which acts as an anti-oxidant preventing cell degeneration. Se deficiency has been implicated in the aetiology of several diseases including cancer, muscular dystrophy, muscular sclerosis and cystic fibrosis. In China, Se deficiency has been linked to an endemic degenerative heart disease known as Keshan Disease (KD) and an endemic osteoarthropathy which causes deformity of affected joints, known as Kaschin-Beck Disease.

Iodine (I) is also essential to health and forms an important constituent of the thyroid hormones thyroxine (T4, also known as tetraidothyronine) and triiodothyronine (T3) which play a fundamental biological role controlling growth and development.

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, referred to as Iodine Deficiency Disorders (IDD). The best known form of IDD is goitre which 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 inhibited growth.

IDD have been recorded in may areas of the world including South America (Ecuador, Peru, Bolivia, and Argentina), Africa (Zaire), Asia (India, Pakistan, Nepal, Bangladesh, China, Indonesia, Vietnam and Papua New Guinea) and historically in northern Italy, Switzerland, the UK and in Ohio in the USA.

Extensive dietary supplementation programmes in may areas of the world including China, the USA, Switzerland, Papua New Guinea and India have proved successful in lowering the incidence of cretinism and goitre. These programmes have generally involved the addition of iodised oil or iodised salt to the diet. Despite the success of these programmes, endemic IDD still occur in many areas of the world. The World Health Organisation (WHO) estimate that at least one billion people are at risk from IDD in the world today. 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.

It has recently 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.

Endemic IDD in the form of goitre has been reported in Sri Lanka for the last 50 years. The island of Sri Lanka has a maritime climate and should not therefore experience low environmental iodine levels as the majority of iodine in the environment is derived from sea water. Iodine is volatilized from the sea and deposited on land during precipitation. Despite the maritime climate and government sponsored iodised salt programmes, endemic goitre is still prevalent in the south and west of the country. The simple explanation that iodine deficiency leads to endemic goitre and other IDD is open to much debate.

A number of epidemiological studies into the prevalence of goitre in Sri Lanka had been carried out since 1947. In one of the more recent surveys, it was estimated that 10 million people were at risk from IDD in Sri Lanka (Fernando et al., 1987). These studies established that goitre occurs in the centre and south-west of the country and is much less prevalent in the north. 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. It was suggested by previous epidemiological investigators that heavy rainfall in the south-west of the country washed iodine out of the soils leaving them iodine depleted. Although some work had been carried out on the levels of iodine in foodstuffs and drinking water, no investigations into iodine levels in soils had been carried out to support this theory.

Prior to the present study, there was no information on the levels of Se in the environment in Sri Lanka although Se deficiency is known to occur in animals. The possible relationships between Se deficiency and IDD in Sri Lanka had, therefore, yet to be established.

The Study

This report outlines the results of a collaborative study undertaken by the British Geological Survey (BGS), the Dept. of Geology, University of Peradeniya, Sri Lanka and the Institute of Fundamental Studies, Sri Lanka (IFS), to investigate the relationship between human and environmental Se status and IDD in Sri Lanka. The present study forms part of a British Government Department for International Development (DFID) Knowledge and Research (KAR) Project (R6227), the objectives of which are (i) to develop a methodology for delineating areas where Se deficiency or toxicity may pose a health risk and cause health disorders and (ii) mitigate problems of natural Se imbalances by designing and implementing land-use planning, crop and dietary supplementation methods.

The current study was designed to address the knowledge gaps in terms of Se and iodine levels in the Sri Lankan environment and their relationship to goitre in the human population and to recommend possible remediation strategies.

During the present study, fifteen villages were selected for sampling on the basis of the incidence of goitre in each village as follows: five no/low IDD incidence (NIDD) (< 10 % goitre), five moderate IDD incidence (MIDD) (10 - 25% goitre) and five high IDD incidence (HIDD) (> 25% goitre). The goitre incidence rates can only be used as a rough guide to indicate which villages have high, medium or low incidences of IDD on a local scale. The rates are drawn from different surveys and the criteria used for establishing them were not consistent.

This sampling strategy was designed to determine the chemical differences in the environment (demonstrated by soil, staple foodstuffs (rice) and drinking water samples) and the Se status of the human population (shown by hair samples) between villages of different IDD incidence. The villages were located in three regions, namely Anuradhapura in the Dry Zone, Kandy in the uplands of the Wet Zone and Kalutara in the coastal plain of the Wet Zone. Samples from each village were also considered in terms of their geographic location to determine differences in the chemical environment and human Se status between different regions.

Results

Hair from women was collected during the present study because it is mainly women who suffer from goitre in Sri Lanka. The majority of women had long hair that had not been cut for several years. Tests on a sub-set of samples revealed, no significant differences in Se levels in different lengths of the hair tresses in the majority of cases. A selection of hair samples were washed in an anionic surfactant to test whether the hair was contaminated with surface particles. No difference in Se levels between surfactant washed hair and hair washed in deionised water was evident. It was concluded that surface contaminants did not significantly affect the levels of Se in the hair. As a result of these tests, the whole hair length was selected for analysis and samples were washed in deionised water.

This study presents for the first time, information on levels of Se in soil, rice, water and hair samples and systematic data on the levels of iodine in soils and rice in Sri Lanka. Results show that soil iodine concentrations in the Wet and Dry Zones are similar, therefore the previous theory that iodine is washed out of soils in the Wet Zone by heavy rainfall is not borne out by the present study. Highest levels of iodine in soil occur in the Kalutara coastal region, an area where IDD is prevalent. Soils in the Kalutara region contain highest levels of organic matter and soil iodine concentrations in this region appear to correlate with organic matter content.

Levels of iodine in rice are very low (≤58 ng/g) but are comparable to levels of iodine in rice reported from other areas of the world. Uptake of iodine into rice grains is generally very poor compared to other parts of the plant. It is unlikely that rice provides a good source of iodine in the Sri Lankan diet. Levels of iodine in rice are only marginally higher in the Dry Zone than the Wet Zone but a marked contrast is seen between levels of iodine in drinking water between the two climatic regions. Levels of iodine are ten times higher in the Dry Zone waters and contribute more iodine to the diet than rice. This supply of iodine may, in part, explain why IDD is not common in the Dry Zone.

Soil total and extractable (water soluble + phosphate extractable) Se levels are highest in the Kalutara region. All the soils in the Kalutara (MIDD-HIDD) region have high to excessive Se concentrations whereas a significant proportion of the soils in the Anuradhapura (NIDD) region are Se deficient. Although levels of Se in soil are higher in the Wet Zone than in the Dry Zone, a greater proportion of Se is taken up into rice in the Dry Zone as the Se is more readily available for plant uptake.

This is due to the marked contrast in soil chemistry between the two climatic regions. Soils in the Kalutara and Kandy regions have higher organic matter, gibbsite and goethite contents and lower pH than soils in the Anuradhapura region which contain more illite. Se adsorption studies carried out by Navaratne (In Prep) have shown that gibbsite and goethite are stronger adsorbers of Se than illite especially at low pH. Thus Se in the Wet Zone (Kalutara and Kandy) is held in clay minerals and organic matter in the soil and is not readily available for plant uptake. In the Kalutara region, soil total Se levels are five times higher than in the Kandy region and despite adsorption by clay minerals and organic matter, the majority of rice Se levels are moderate to high whereas in the Kandy region 63% of rice samples are marginal or deficient in Se.

Levels of Se in drinking water are similar in the Kandy and Kalutara regions and lower in the Anuradhapura region. Estimates of daily dietary intakes show that Se from water does not form an important source of Se in the diet.

This study has shown for the first time that significant proportions of the Sri Lankan population may be Se deficient (34%, 22% and 28% in the HIDD, MIDD and NIDD villages respectively). Although it is not the case that Se deficiency only occurs in areas where IDD is prevalent, these results show that a combination of iodine and Se deficiency could be involved in the etiopathogenesis of goitre in Sri Lanka. Although no difference in Se status was detected between women suffering from goitre and those who were not, the highest hair Se values were determined in women not suffering from goitre. 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 in general and the presence of goitrogenic substances in the diet.

Although iodine deficiency is accepted as the main environmental determinant in the aetiology of endemic goitre, there are a large number of naturally occurring and artificial agents which 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. Previous studies by other investigators have shown the presence of goitrogenic substances in many food crops such as millet, cassava and leafy vegetables. It is well known that high concentrations of certain goitrogenic compounds occur in tannins and pigments. The results of the present study have shown that the distribution of red rice cultivation in Sri Lanka is coincident with high IDD incidence regions. No studies have been carried out into the goitrogenic properties of red rice therefore it is not possible to assess the impact of this potential source of goitrogens on IDD in Sri Lanka.

Levels of total Se and iodine in Sri Lankan soils are not low compared to other areas of the world where IDD do not occur. However, the results of this study have demonstrated the important role that geochemical factors, such as soil pH and organic matter and clay content, play in controlling the amount of Se and iodine available for plant uptake. Sri Lanka is a relatively small island and yet there is a marked contrast in soil chemistry between the Wet and Dry Zones due to different geological, geochemical, climatological, topological and vegetative conditions. An understanding of these controls on element bioavailability in soil is fundamental to the assessment of deficiency risk and the selection of appropriate remediation strategies.

Recommendations

Comparisons between regions with different IDD prevalence and between people suffering or not suffering IDD were hampered in the present study due to the lack of systematic information on the occurrence of IDD in Sri Lanka. **It is recommended** that further investigations involving geochemists, medical doctors and nutritionists are required to elucidate the extent and nature of IDD and Se deficiency in Sri Lanka.

Should Se deficiency prove to be a significant problem, **it is recommended** that levels of Se in the diet should be enhanced by encouraging people to increase the quantity of Se rich foods such as fish and meat in the diet. It is recognised, however, that small scale farmers may not have the economic means to diversify their diet in this way. Alternatively the levels of Se in foodstuffs could be enhanced by the application of Se fertiliser. Villagers already apply NPK fertiliser routinely in Sri Lanka. However, the results of this study have shown that soils, particularly in the Kandy area, have a high capacity to adsorb more Se, and Se fertiliser added to the soil may not enhance Se levels in crops as expected due to adsorption of Se onto organic matter and clay minerals. Direct application of Se fertiliser to plant foliage may prove a more effective method of increasing crop Se levels.

The introduction of iodised salt to the population of Sri Lanka has been carried out by the government in recent years. 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 is lost to the atmosphere during the cooking process. **It is recommended** that an education programme is initiated to increase the effectiveness of the iodised salt programme making people aware that to store iodised salt for long periods or add it to food before cooking greatly reduces it's effectiveness.

It is recommended that in *vivo* and in *vitro* tests (similar to those applied to millet) should be carried out to determine whether red rice contains goitrogens. 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 husk.

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ABBREVIATIONS USED IN THIS REPORT

AFS	Atomic Fluorescence Spectrometry
BGS	British Geological Survey
CIEB	Chilean Iodine Education Bureau
DFID	Department for International Development
DOH	Department of Health
GSH-Px	Glutathione-peroxidase
IC	Ion Chromatography
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IDD	Iodine deficiency disorders
IFS	Institute of Fundamental Studies, Kandy
IGCP	International Geological Correlation Programme
KAR	Knowledge and Development
KD	Keshan Disease
LOD	Limit of Detection
MAFF	Ministry of Agriculture, Fisheries and Food
NAA	Neutron Activation Analysis
NERC	Natural Environmental Research Council
NRCCRM	National Research Centre for Certified Reference Materials
NRI	Natural Resources Institute
TOC	Total Organic Carbon
UCW	University College Wales
WHO	World Health Organisation
WRC	Water Research Council

1. INTRODUCTION

Plants, humans and other animals require small doses of several naturally occurring trace elements and minerals to maintain health. Elements can be assimilated by humans via several pathways including the food chain, drinking water and the inhalation and ingestion of particles from the atmosphere. Animals and plants in the food chain ultimately depend upon soil, water and rock in the environment for the provision of essential minerals. This link between the environment and the food chain is particularly important in developing countries where people are often totally dependent on subsistence agriculture for their dietary needs. The inability of the local environment to provide the correct mineral balance can lead to serious health problems and disease.

Selenium (Se) is a naturally occurring metalloid element which is essential to human health in small doses (deficiency level < 0.04 μg/day,) but can be toxic in excess (> 900 μg/day) (Yang & Xia, 1995). Se plays a vital role in many metabolic functions and is an essential component of the biologically important glutathione peroxidase enzymes (GSH-Px) which act as anti-oxidants preventing the degeneration of biological membranes. Se deficiency has been implicated in the aetiology of several diseases including cancer, muscular sclerosis and muscular dystrophy (Levander, 1986). In China, Se deficiency has been linked to an endemic degenerative heart disease known as Keshan Disease (KD) and an endemic osteoarthropathy which causes deformity of affected joints, known as Kaschin-Beck Disease (Tan et al., 1989).

In humans and other animals, iodine (I) is also essential to health and 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 & Maberly, 1986). The discovery of the link between iodine deficiency and goitre (swelling of the thyroid gland in the neck) 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, referred to as Iodine Deficiency Disorders (IDD) (Fernando et al., 1987).The best known form of IDD is goitre which 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. One of the earliest investigations to confirm the link between endemic goitre and iodine deficiency was the work of Marine & Kimbal (1920) who showed dietary iodide supplementation dramatically reduced the incidence of goitre among school children in Ohio, USA.

IDD have been recorded in may areas of the world including South America (Ecuador, Peru, Bolivia, and Argentina), Africa (Zaire), Asia (India, Pakistan, Nepal, Bangladesh, China, Indonesia, Vietnam and Papua New Guinea) and historically in northern Italy, Switzerland, the UK and in Ohio in the USA. Extensive dietary supplementation programmes in may areas of the world including China, the USA, Switzerland, Papua New Guinea and India have proved successful in lowering the incidence of cretinism and goitre. These programmes have generally involved the addition of iodised oil or iodised salt to the diet. Despite the success of these programmes, endemic IDD still occur in many areas of the world. The World Health Organisation (WHO) estimate that at least one billion people are at risk from IDD in the world today. 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 (Koutras, 1980).

It has recently 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 & Beckett, 1994).

The majority of iodine in the environment is derived from sea water (Fuge, 1996). Iodine is volatilized from the sea and deposited on land during precipitation. The island of Sri Lanka has a maritime climate and should not therefore experience low environmental iodine levels. No systematic measurements of levels of iodine in the Sri Lankan environment have, however, been determined. Despite the maritime climate and government sponsored iodised salt programmes, endemic goitre is still prevalent in the south and west of the country. 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 actively being investigated.

The geology and geochemical conditions prevalent in the south and west of Sri Lanka indicate that Se is likely to be deficient. Prior to the present study there was no information on the levels of Se in the environment in Sri Lanka although Se deficiency is known to occur in animals (Dr Arseculeratne, Dept. of Physiology, University of Peradeniya pers. commun.). The possible relationships between Se deficiency and IDD in Sri Lanka have, therefore, yet to be established.

The present study forms part of a British Government Department for International Development (DFID) Knowledge and Research (KAR) project to investigate methods of predicting and remediating human Se imbalances (Project R6227). During the first phase of the project, investigations concentrated on Se deficiency in relation to Keshan Disease and cancer in China (Johnson, et al., 1996; Fordyce et al., 1998 and Appleton et al., In prep). This report outlines the results of the second phase of the project, investigating the relationships between human Se status and IDD in Sri Lanka. This is a collaborative study between the Department of Geology, University of Peradeniya, Kandy, Sri Lanka, the Department of Environmental Sciences, Institute of Fundamental Studies (IFS), Kandy and the British Geological Survey (BGS, NERC, UK).

2. OBJECTIVES AND SCOPE OF THIS REPORT

The overall objectives of the project are to:

(i) develop a methodology for delineating areas where Se deficiency or toxicity may pose a health risk and cause health disorders and

(ii) mitigate problems of natural Se imbalances by designing and implementing land-use planning, crop and dietary supplementation methods.

The objectives for the Sri Lanka study area in particular are as follows:

(i) Establish the relationship between the human Se status of communities (represented by hair samples) and their dietary Se intake (represented by grain and drinking water samples) to the local geochemical environment characterised by Se in cultivated soils.

(ii) Relate the Se status of the population (represented by hair samples) and their dietary iodine intake (represented by grain and drinking water samples) to the local geochemical environment characterised by iodine in cultivated soils.

(iii) Identify the effects, if any, of environmental Se and iodine on the development of IDD in Sri Lanka.

3. SELENIUM CHEMISTRY

Se belongs to group VIA of the periodic table and has chemical and physical properties that are intermediate between metals and non-metals. The chemical behaviour of Se resembles that of sulphur and like sulphur, Se can exist in the 2^-, 0, 4^+ and 6^+ oxidation states. As a result of this complex chemistry, Se is found in all natural materials on earth including rocks, soils, waters, air, plant and animal tissues (Table 1). The main natural sources of Se in the environment are bedrock weathering, volcanic emissions and metal sulphide deposits. Anthropogenic sources of Se include coal and oil power stations and Cu processing plants.

Table 1. Se concentrations in selected materials (modified from McNeal & Balistrieri, 1989).

Material	Se (µg/g)	Material	Se(µg/g)
Earth's Crust	0.05	Lake Michigan	0.0008 - 0.01
Granite	0.01 - 0.05	Sea water	0.000009
Limestone	0.08		
Sandstone	< 0.05	USA plants	
Shale	0.06	Grasses	0.01 - 0.04
Phosphate rock	1 - 300	Clover & alfalfa	0.03 - 0.88
Soil		Barley	0.2 - 1.8
USA	< 0.1 - 4.3	Oats	0.15 - 1
England/Wales	< 0.01 - 4.7		
Seleniferous	1 - 80, < 1200	Algae	
Coal	.46 - 10.65	Marine	0.04 - 0.24
Atmospheric dust	0.05 - 10	Freshwater	< 2
River water		Whole fish	
Mississippi	0.00014	Marine	0.3 - 2
Amazon	0.00021	Freshwater	0.42 - 0.64
Colorado (alkaline)	0.01 - 0.4	Animal tissue	0.4 - 4

3.1 Geochemistry

During volcanic activity, Se escapes as high temperature volcanic gases therefore Se concentrations in volcanic rocks are generally low. The average crustal abundance of Se is 0.05 - 0.09 µg/g and average concentrations in magmatic rocks rarely exceed these values (Table 1). In sedimentary rocks, Se is associated with the clay fraction and is found in greater concentrations in shales than in limestones or sandstones. Relatively high concentrations (≤ 300 µg/g) of Se have been reported in some phosphate rocks which is particularly important because of the wide-spread use of phosphate fertilisers. Se concentrations in coal can be high relative to other rock types and typically range from 1 to 20 µg/g (Mayland et al., 1989). Se is a chalcophile element and elemental Se^0 is occasionally associated with sulphide mineralisation. More commonly, however, Se substitutes for sulphur in sulphide minerals due to the similarity in crystallography of these two elements.

3.2 Soil Chemistry

The Se concentration of most soils ranges from 0.01 - 2 µg/g (world mean 0.4 µg/g (Fergusson, 1990)) but high concentrations of up to 1200 µg/g have been reported in some seleniferous areas (Mayland et al., 1989).

The main factors controlling Se availability in soils are pH and redox conditions, Se speciation, soil texture and mineralogy, organic matter content and the presence of competitive ions. The theoretical speciation of Se in soils is shown in Figure 1. In acid and neutral soils, inorganic Se occurs as very insoluble Se^{4+} complexes of oxides and oxyhydroxides of ferric Fe. Se^{6+}, the predominant oxidation state in neutral and alkaline soils, is generally soluble, mobile and readily available for plant uptake. Se^{4+} is adsorbed onto soil particle surfaces with greater affinity than Se^{6+} and this behaviour coupled with lower solubility makes Se^{4+} less bioavailable than Se^{6+} (Mikkelsen et al., 1989). Bisbjerg & Gissel-Nielsen (1969) found that addition of Se^{6+} to soils resulted in ten times more plant uptake than addition of Se^{4+}.

Native Se (Se^0), metal Se^{2-} and Se-sulphide salts form in reduced soil conditions and the low solubility and oxidation potential of these element species make them largely unavailable to plants and animals (McNeal & Balistrieri, 1989).

Soil pH also influences the capacity of clays and ferric oxides to adsorb Se. Research has shown that Se^{4+} adsorption by clays reaches a maximum between pH 3 - 5 and decreases with increasing pH (Mikkelsen et al. 1989).

The bioavailable Se content of soil generally correlates negatively with clay content due to increased adsorption of Se onto clay minerals. Bisbjerg & Gissel-Nielsen (1969) found that Se uptake in plants grown on loamy soils was half that of plants grown on sandy soils and that vermiculite had a greater Se^{4+} adsorption capacity than montmorrilonite. However, adsorption by Fe oxides was greater than adsorption by the clay minerals tested.

Howard (1977) demonstrated that Fe exerts a major control on Se soil chemistry as both elements are affiliated under oxidising and reducing conditions. In addition, soil organic matter has a large capacity to remove Se from solution possibly as a result of fixation by organometallic complexes. Bisbjerg and Gissel-Nielsen (1969) reported ten times greater plant uptake of Se^{6+} added to mineral soils than organic rich soils.

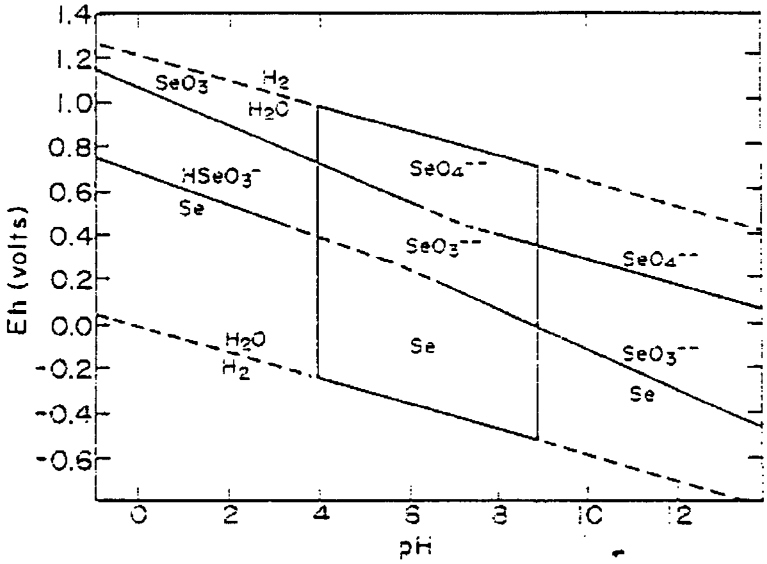


Figure 1. Eh - pH diagram of Se in soils (from Mayland et al., 1989).

The presence of ions such as SO_4^{2-} and PO_4^{3-} can influence Se accumulation in plants by competing with Se ions for fixation sites in the soil and plants or diluting the concentration of Se in the plants by increasing plant growth. SO_4^{2-} inhibits the uptake of Se by plants and has a greater effect on the uptake of Se^{6+} than Se^{4+}. Addition of PO_4^{3-} to soils has been shown to increase Se uptake by plants as the PO_4^{3-} ion is readily adsorbed in soils and displaces Se^{4+} from fixation sites making it more bioavailable. Conversely, increasing the levels of PO_4^{3-} in soils can dilute the Se content of vegetation by inducing increased plant growth.

Addition of $BaCl_2$ to seleniferous soils has been shown to reduce Se^{6+} uptake in plants more effectively than the addition of SO_4^{2-} probably due to the formation of $BaSeO_4$ which is barely soluble (Mikkelsen et al., 1989).

3.3 Water Chemistry

The chemical speciation of Se in water is largely dependent on the pH and redox conditions. The theoretical speciation of Se in water is shown in Figure 2. Se forms a very minor component of natural waters and rarely exceeds the World Health Organisation (WHO) drinking water maximum acceptable limit of 10 µg/l in concentration. Waters containing 1000 µg/l Se have been recorded in seleniferous areas in Montana (Mayland et al., 1989).

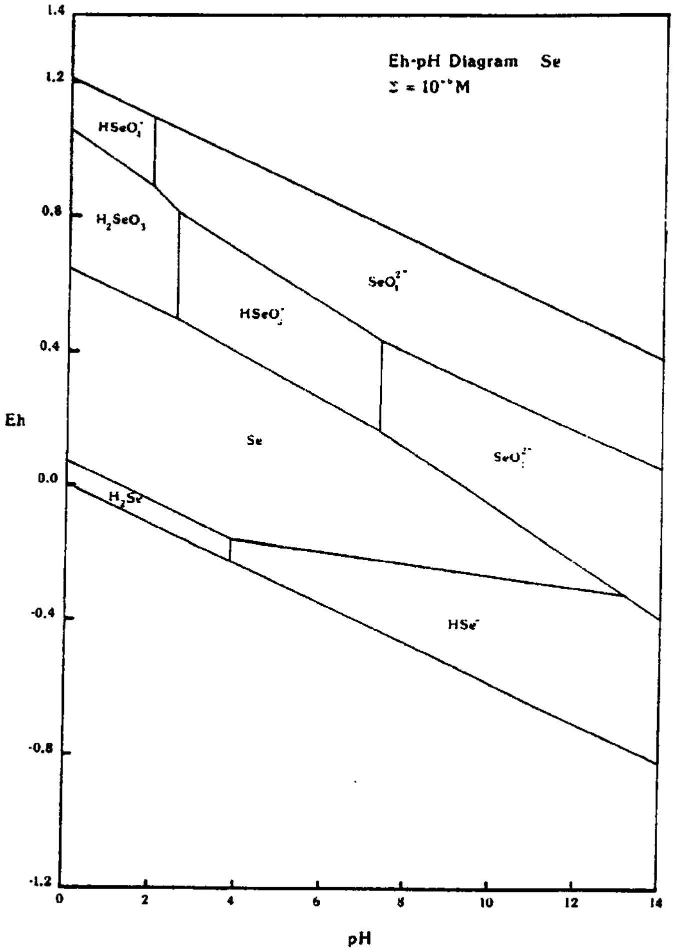


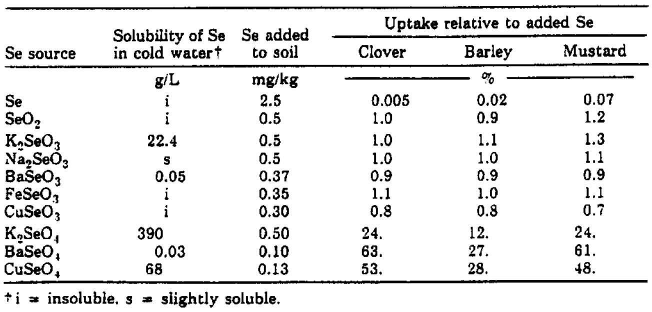
Figure 2. Eh - pH diagram of Se in waters (from McNeal & Balistrieri, 1989).

3.4 Selenium in Plants

Se is not an essential element for plant growth and Se concentrations in plants generally reflect the levels of Se in the environment. Plants are often classified according to their ability to accumulate Se when grown on seleniferous soils. Se accumulator plants can absorb > 1000 µg/g Se whereas secondary Se absorbers rarely concentrate more than 50 - 100 µg/g. The third group, which includes grains and grasses, usually accumulate less than 50 µg/g Se. Some examples of uptake of Se in different plants are given in Table 2. Much of the Se in non-accumulator plant species is found in the form of protein-bound selenomethionine whereas Se in accumulator plants is mostly water-soluble. Plants suffer Se toxicity as a result of interference with the sulphur metabolism. Exclusion of Se from the proteins of accumulator plants is thought to be the basis of Se tolerance (Mayland et al., 1989).

Se concentrations in food crops vary greatly between plant species. On average, root crops contain highest Se concentrations. Mikkelsen et al. (1989) report average concentrations of 0.407 µg/g Se in root crops from around the world whereas the concentration in field crops such as rice and wheat is 0.279 µg/g. Levels of > 3 - 5 µg/g in plants have been shown to induce Se toxicity in animals (Jump & Sabey, 1989).

Table 2. Se solubility in water and relative uptake in plants (from Mayland et al., 1989).



Se source	Solubility of Se in cold water†	Se added to soil	Uptake relative to added Se		
			Clover	Barley	Mustard
	g/L	mg/kg	%		
Se	i	2.5	0.005	0.02	0.07
SeO_2	i	0.5	1.0	0.9	1.2
K_2SeO_3	22.4	0.5	1.0	1.1	1.3
Na_2SeO_3	s	0.5	1.0	1.0	1.1
$BaSeO_3$	0.05	0.37	0.9	0.9	0.9
$FeSeO_3$	i	0.35	1.1	1.0	1.1
$CuSeO_3$	i	0.30	0.8	0.8	0.7
K_2SeO_4	390	0.50	24.	12.	24.
$BaSeO_4$	0.03	0.10	63.	27.	61.
$CuSeO_4$	68	0.13	53.	28.	48.

† i = insoluble. s = slightly soluble.

4. IODINE CHEMISTRY

Iodine is a naturally occurring halide element (group V11A of the periodic table) which is widely dispersed in nature (Table 3). Iodine was present during the primordial development of the earth but subsequent weathering and leaching by snow, glacial ice, rain and water carried iodine to the sea (Hetzel & Maberly, 1986). The ocean has become the primary reservoir of iodine. Volatilisation of iodine from sea water possibly as elemental iodine or as organically-bound iodine is the main source of the element in the environment (Fuge, 1996). Every year 400 000 tons of iodine escape from the surface of the oceans (Hetzel & Maberly, 1986). The geochemical cycle of iodine involving its easy transfer to the atmosphere and its mechanical removal from soils are critically important in determining its distribution in the environment.

Table 3. Iodine concentrations in selected materials.

Material	I µg/g	Material	I µg/g
Sea water*	0.050 - 0.060	Sedimentary Rocks†	2
Sea water†	0.058	Carbonates†	2.7
Rain water†	0.005	Shales†	2.3
Rain water*	0.0018 - 0.0085	Sandstones†	0.8
Coastal rain water†	0.005 - 0.006 (Wales)	Recent sediments†	5 - 200
Inland rain water†	0.002 (Wales)		
Surface waters+	0.015 (maximum)	Soils+	<0.1 - >100 (range)
Iodine deficient waters*	< 0.002	Soils^	5
		Soils∝	2.8
Earth's crust*	0.3	Soils†	4 - 8
		USA Soils∂	0.75
Igneous Rocks†	0.24		
Granite+	0.25	Air*	70
Other Intrusive Rocks+	0.22		
Basalt+	0.22	Terrestrial Plants∗	1.8 - 6.9
		Grain and Bread`	0.02 - 0.07
Other Extrusive Rocks+	0.24	Marine Plants#	47 - 5600
Volcanic glasses+	0.52	Plankton*	0.03 - 1.5

* Hetzel & Maberly (1986) + Fuge (1996) ∝ Kabata-Pendias & Pendias (1984)
† Fuge & Johnson (1986) ^ Vinogradov (1959) ∂ Shacklette & Boerngen (1984)
∗ Shacklette & Cuthbert (1967) # Saenko et al. (1978) ` Chilean Iodine Educational Bureau (1952)

4.1 Geochemistry

Due to its large ionic radius, iodine is seldom found in primary minerals and has a low crustal abundance of 0.3 µg/g (Table 3). The low concentration of iodine in primary minerals is reflected in the generally low and uniform concentrations in most igneous rock types. Iodine concentrations in sedimentary rocks are more variable. Marine sediments generally contain more iodine than non marine sediments and shales tend to have higher concentrations than sandstones (Table 3). Some limestones are relatively enriched in iodine, however, greatest enhancement occurs in organic-rich sediments (> 40 µg/g) (Fuge, 1996).

4.2 Soil Chemistry

The iodine content of soils is generally controlled by the quantity of the element in the environment and the ability of the soil to fix iodine - the Iodine Fixation Potential (Figure 3) (Fuge & Johnson, 1986). The major source of iodine in soils is wet and dry deposition from the atmosphere. The iodine content of rocks generally contributes little during weathering to soils and soil iodine levels tend to be greater than that of the parent materials. In general, coastal soils contain more iodine than continental soils. In regions where there is high rainfall, iodine tends to be enriched in soils as it is flushed out of the atmosphere on a regular basis (Fuge, 1996).

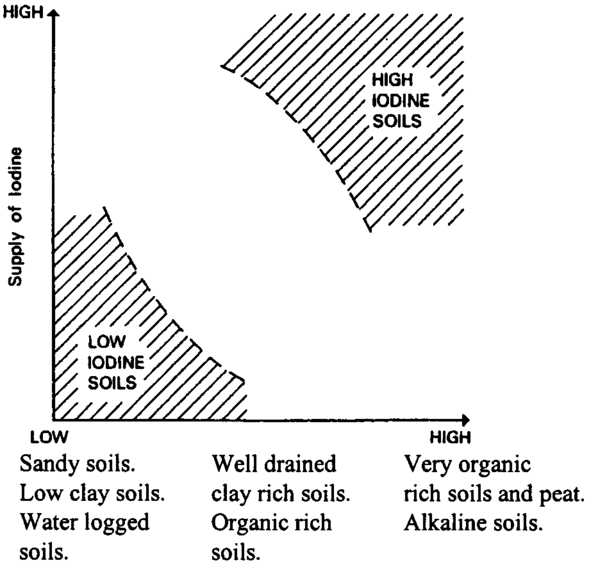


Figure 3. Simple model for the iodine content of soils based on supply and fixation potential (Fuge & Johnson, 1986).

Several factors control the retention of iodine in soils. Organic rich soils have been show to contain higher levels of iodine than other soils. Johnson (1980) demonstrated that iodine was associated with organic matter in top soil samples (0 - 20 cm) but showed no relationship with organic matter in deeper soils (> 20 cm). Organic matter plays an important role in fixing iodine in the upper layers of soil exposed to the atmosphere. Whitehead (1984) demonstrated that soil iron (Fe) and aluminium (Al) oxyhydroxides also play an important role in the sorption of iodine. Clay minerals also retain iodine in soils but this fixation mechanism is thought to be less important than organic matter and Fe and Al oxyhydroxides.

Iodine sorption onto Fe and Al oxyhydroxides and clay minerals is greatest in acid conditions and no sorption takes place under neutral and alkaline conditions.

However, neutral to alkaline soils developed over limestones are often much richer in iodine than acid soils from adjacent areas. Fuge (1996) accounts for this phenomenon in terms of the recycling of iodine in the soil environment. Although the volatilisation of iodine from the marine environment and subsequent transfer on land represents the most important stage of the iodine chemical cycle, the zone of iodine enrichment in soils close to the coast is relatively narrow (~ 20 km in the UK). It is therefore unlikely that much of the marine derived iodine directly reaches central continental areas. The gaseous iodine found in continental atmospheres is probably derived from the revolatilisation of iodine from soils in a step-wise progression from the marine environment across the continental interior. Under oxidising acid soil conditions, iodide (I^-) is converted to I_2 (Figure 4) which is gaseous and readily lost to the atmosphere to be carried by the prevailing wind and redeposited during precipitation. However, in neutral and alkaline soils, iodate (IO_3^-) is the stable form which is not readily converted to volatile I_2, thus the iodate will remain in the soil.

Fuge (1996) proposes the following controls on iodine in soils. Iodine added to soils from precipitation can be in the forms I^- or IO_3^-. A proportion of these ions will be adsorbed in the soil by organic matter, Fe and Al oxyhydroxides and clay minerals. The amount of sorption will be controlled by a number of factors including the abundance of these soil components and the soil pH. However, some of the iodine will remain in a mobile form and the fate of this iodine will be determined by the Eh-pH regime of the soil. In acid oxidising soils the IO_3^- will be converted to volatile I_2 and lost to the atmosphere whereas in neutral and alkaline soils I^- will be converted to IO_3^- and retained in the soil. Organic rich and alkaline soils therefore pose a barrier to the migration of iodine in the terrestrial environment.

Farming processes can also affect the retention of iodine in soil. Ploughing, draining and liming practices during improvement of upland soils in the UK, are thought to have reduced the capability of soil to retain iodine in a bioavailable form and resulted in the incidence of goitre in cattle (Lidiard, 1995).

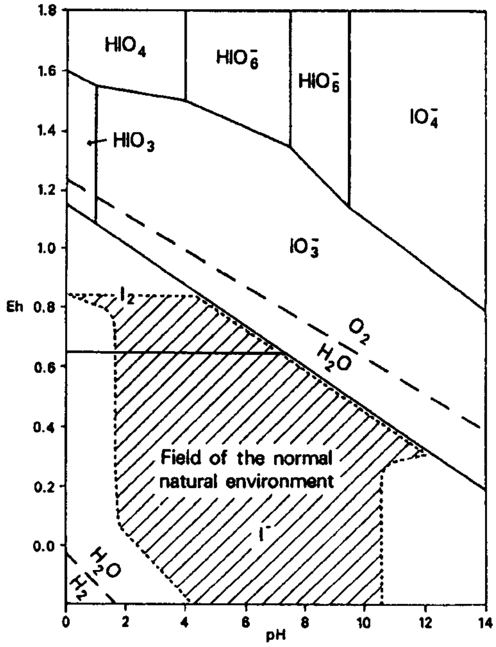


Figure 4. Eh-pH diagram for iodine (Fuge, 1996)

4.3 Water Chemistry

In oceanic waters, the iodine content can vary with salinity and depth. The mean iodine content of sea water has been estimated at 58 µg/l (Fuge & Johnson, 1986). The stable form of iodine in sea water is IO_3^-. The iodine content of surface waters is highly variable but generally does not exceed 15 µg/l. Regional variations are dependent on the proximity to the sea, surface run-off, geology and anthropogenic sources. Sugawara & Terada (1957) suggested that 90% of the iodine in surface waters is in the I^- form, however, in alkaline waters IO_3^- may be more dominant as this ion is stable in high pH environments (Figure 4). Groundwaters generally contain higher levels of iodine than surface waters (Fuge, 1996). Iodine concentrations in rainwater are higher at the onset of precipitation than at the end of precipitation as would be expected as rain washes iodine from the atmosphere. Intense rainfall washed out iodine more efficiently than light precipitation. Dean (1963) demonstrated that 40% of the iodine in New Zealand rainwater was organically bound.

4.4. Iodine in Plants

In the UK, several historical endemic areas of IDD were not associated with inadequate levels of iodine in soil (Fuge, 1996). This may be because plants do not necessarily uptake significant quantities of iodine from soils into the food chain (Al-Ajely, 1985). Absorption of iodine from the atmosphere by plant leaves may be a more important mechanism for plant uptake (Whitehead, 1984). However, iodine rich fertilisers applied to soils have been shown to double or triple the levels of iodine in food crops and pastures (Hetzel & Maberly, 1986). Gerevich (1964) demonstrated that the iodine concentration in vegetable and cereal crops increased 10 - 100 times following applications of seaweed and fish products. Barakat et al., (1972) found significant variations in iodine concentration in samples of the same vegetables. The iodine content of cabbage ranged from 0 - 950 ng/g. Hartmans (1974) reported 60 - 140 ng/g iodine in pasture grasses and 160 - 180 ng/g in white clover (dry weights).

There is, as might be expected, a marked contrast in the iodine content of terrestrial plants (1800 - 6900 ng/g (dry matter) (Shacklette & Cuthbert, 1967) (Table 3). Saenko et al. (1978) and Shacklette & Cuthbert (1967) report high levels of iodine in seaweeds up to 8800 µg/g (dry matter).

5. PHYSIOGRAPHY, GEOLOGY AND SOILS OF SRI LANKA

Sri Lanka comprises a highland massif situated in the south-centre of the island which is surrounded by an intermediate zone of upland ridges and valleys. The intermediate zone is in turn surrounded by a zone of lowlands and a coastal fringe of sandbars and lagoons (Figure 5a). Three agro-ecological zones are defined in the country on the basis of rainfall, elevation and soil type. The Wet Zone comprises the south-west quadrant of the island which receives a mean annual rainfall of over 2500 mm with no rain-shadow effect. The Intermediate Zone receives a mean annual rainfall of 1750-2500 mm with or without rain-shadow effects. The Dry Zone demarks the north and eastern sectors of the island which receive less than 1750 mm annual rainfall with a marked dry season (Survey Dept, 1988) (Figures 5b and 5c). The villages with low IDD incidence rates selected for the present study lie within the Dry Zone around Anuradhapura and the moderate and high IDD incidence rate villages are located in the Wet Zone around Kalutara and the Wet to Intermediate Zone around Kandy (Figure 6). For the purposes of this study, the Wet and Dry Zones are defined on the basis of the 2000 mm rainfall isohyet.

Rice, coconut palms and rubber are the main crops grown in these areas. In the coastal zone around Kalutara and in the northern zone around Anuradhapura, the terrain is flat to slightly undulating. Rice cultivation is concentrated in irrigated plains surrounded by villages situated in coconut palm plantations. In the Kandy area the terrain is more rugged with steep, densely wooded valley sides and narrow, flat bottomed valleys. Rice cultivation is restricted to the irrigated valley bottoms and villages ascend the steep valley sides (Plates 1 and 2). In non-irrigated areas only one rice crop per year is grown whereas in irrigated areas, two crops per year are produced in September-October and January-February. In the Dry Zone, irrigation is based upon an ancient system of numerous small reservoirs known as tanks. However, after several years of drought, many of these tanks are dry, greatly reducing the area of cultivated land.

The study area is underlain by a sequence of highly folded Precambrian rocks. The Highland Complex, which comprises granulite-grade metasediments (quartzites and carbonates), charnokitic orthogneisses, granitoid rocks and subordinate metabasic intrusives, extends across the centre of Sri Lanka from the south-west to the north-east (Figure 5d). The south-west of the Highland Complex is dominated by Al-rich corderite-bearing pelitic paragneisses and wollastonite-bearing calc-gneisses. It is not clear whether this sequence is a facies variant of the main Complex or whether it represents a different depositional basin (Geological Survey, 1995). Cooray (1984) defines these rocks as a separate sequence called the Southwestern Group. The structural relationship between the Wanni Complex and the Highland Complex is not yet known, however, it is significantly younger than the Highland Complex. The Wanni Complex comprises amphibolite-grade migmatitic, granitic, and granodioritic gneisses, dioritic orthogneisses and minor gabbros. The Kadugannawa Complex, which outcrops in the Kandy area, comprises hornblende-biotite calc-alkaline gneisses predominately tonalite and granodiorite (Geological Survey, 1995).

The distribution of soil types in Sri Lanka closely follows the Wet Zone, Intermediate Zone and Dry Zone demarcation. In the Dry Zone around Anuradhapura, reddish-brown-earths with low humus content and gley soils predominate. In the Kandy area, the Intermediate Zone is characterised by red-yellow-podzolic soils and mountain regosols. In the Wet Zone between Kandy and Kalutara, red-yellow-podzolic soils predominate although reddish-brown-latosols and immature brown-loams are developed in the hill terrain around Kandy. Along the south-west coastal plain near Kalutara red-yellow-podzolic soils with soft or hard laterite and bog soils are developed (Survey Dept., 1988). The mineralogy of soils in the Dry Zone is dominated by kaolinite with minor illite whereas in the Wet Zone, soil clays comprise kaolinite, gibbsite and goethite. In the upland areas around Kandy, gibbsite and goethite are present in trace amounts only whereas the soils of the Kalutara area are rich in gibbsite (Navaratne, 1992).

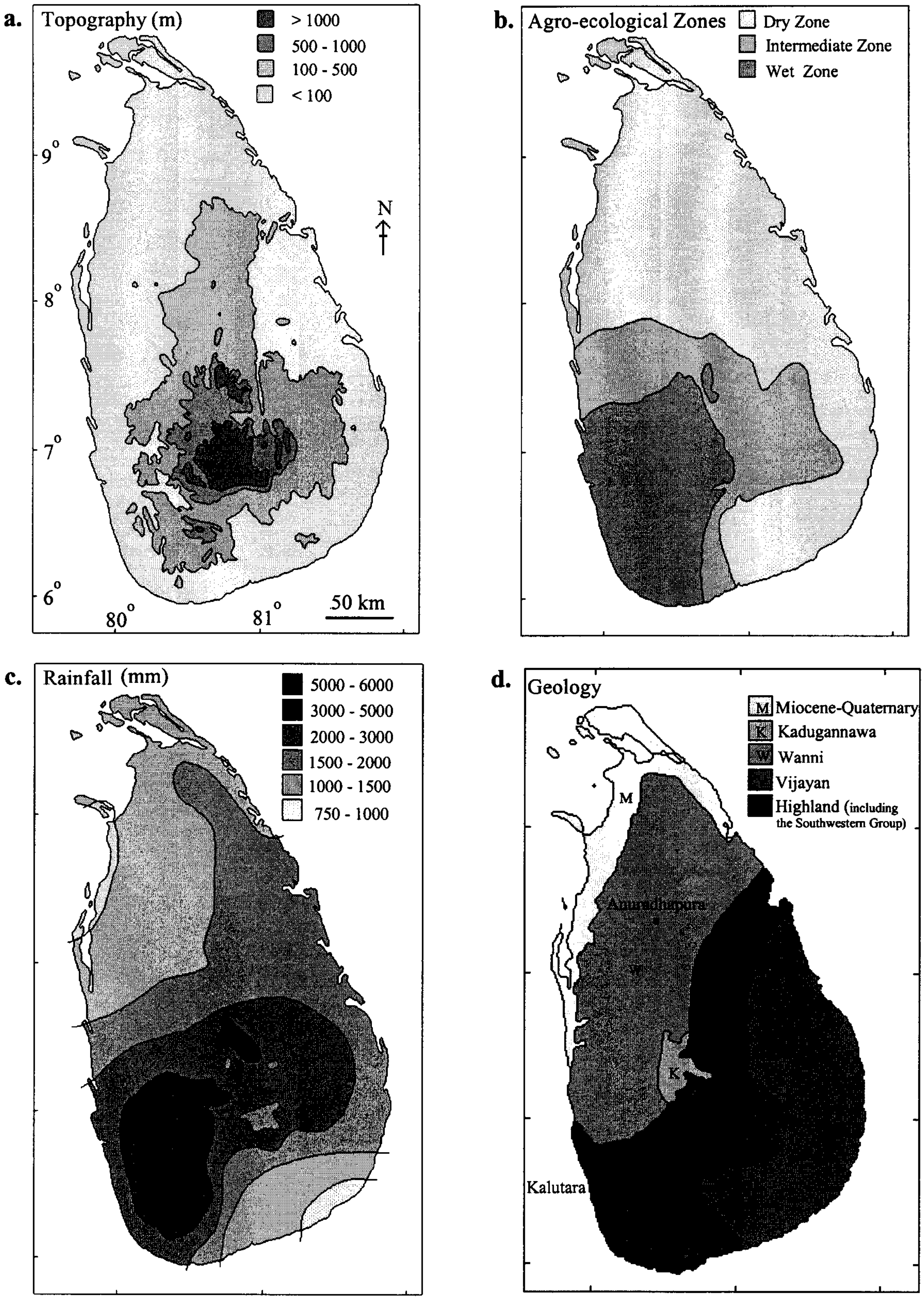
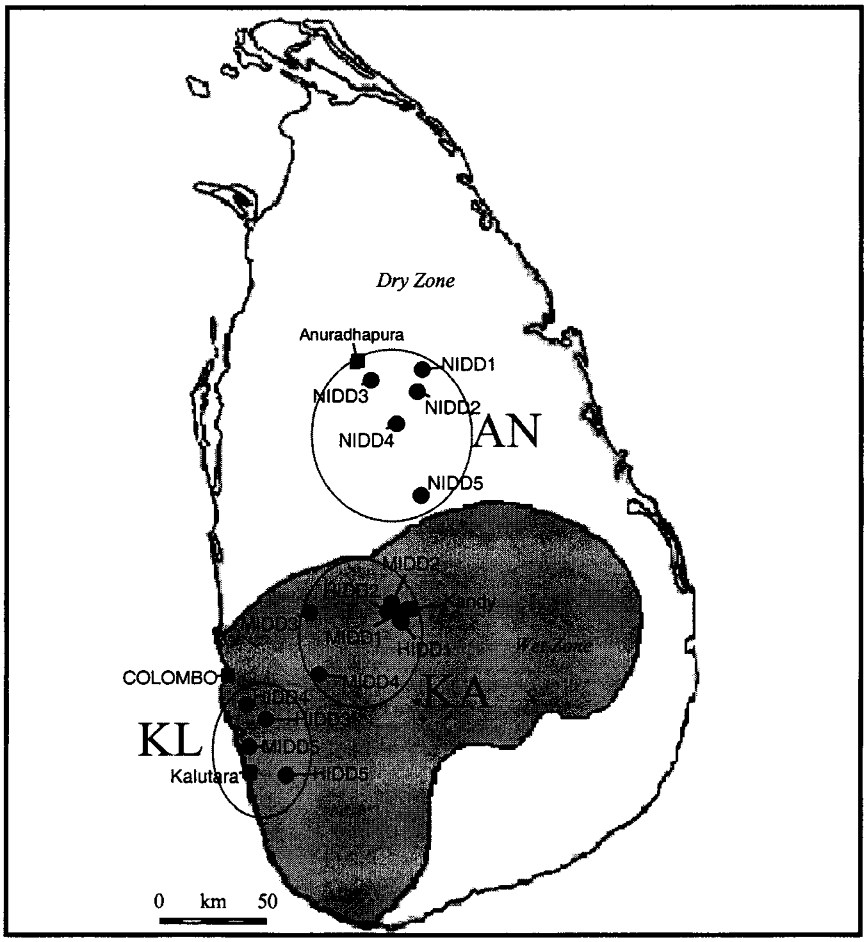


Figure 5. Sketch maps showing **a.** topography (from Survey Dept., 1988); **b.** agro-ecological zones (from Survey Dept., 1988); **c.** rainfall (from Survey Dept., 1988) and **d.** geology (From Cooray, 1984; Cooray, 1994; Geological Survey, 1995) of Sri Lanka.



Village Iodine Deficiency Disorders (IDD) codes:

High Incidence IDD	*Moderate Incidence IDD*	*No/Low Incidence IDD*
> 25% goitre	*10 - 25% goitre*	*< 10% goitre*
HIDD1 Agunawala (KA1)	MIDD1 Dehideniya (KA3)	NIDD1 Upuldenya (AN1)
HIDD2 Kurunduwatte (KA2)	MIDD2 Kobbekaduwa (KA4)	NIDD2 Manankattiya (AN2)
HIDD3 Olaboduwa (KL1)	MIDD3 Ambepussa (KA5)	NIDD3 Polambayagama(AN3)
HIDD4 Pelenwatte (KL2)	MIDD4 Debagama (KA6)	NIDD4 Ihala Kagama (AN4)
HIDD5 Gurudola (KL3)	MIDD5 Navinna (KL4)	NIDD5 Kiralessa (AN5)

See Section 8 for an explanation of regional codes in brackets: AN = Anuradhapura, KA = Kandy, KL = Kalutara

Figure 6. Sketch map showing the location of the 15 study villages in region AN Anuradhapura; region KA = Kandy and region KL = Kalutara. The Wet Zone/ Dry Zone demarcation used in the present study is based on the 2000 mm isohyet.

Plate 1. Typical village in the Kandy area (Kobbekaduwa, MIDD2), rice cultivation is concentrated in the valley bottom and the village is situated in the coconut plantations on the valley sides.

Plate 2. Typical village located in a coconut plantation (Pelenwatte, HIDD4).

6. PREVIOUS INVESTIGATIONS INTO IDD IN SRI LANKA

The occurrence of goitre in Sri Lanka appears to be a relatively modern phenomenon and Mahadeva & Shanmuganathan (1967) cite references to support this claim.

The first comprehensive survey of goitre in Sri Lanka was carried out in 1947 in which nearly 50,000 people were examined (Wilson, 1950; Mahadeva & Shanmuganathan, 1967). Goitre was found to be endemic in the south-west of the island in the Wet Zone. The highest incidence of goitre was at Wetera, Horana Region (3.3%), a village 12 km from the coast, north-north-east of Kalutara. Atmospheric volatilisation of iodine from sea-water is the major source of the element in the environment and the high incidence of IDD near the coast is surprising.

A second survey was carried out in 1963 in nine of the Wet Zone villages from the previous study (Mahadeva & Shanmuganathan, 1967). This survey noted a significant increase in the incidence of goitre, particularly amongst females, and all surveys have shown females to be very much more affected than males. Studies in other areas of the world have proved that pregnant women are most at risk from IDD. Mahadeva & Shanmuganathan (1967) also presented data on the goitre incidence of mothers at ante-natal clinics which confirmed the Horana area as a high incidence region (34.8% of mothers had goitre). Mahadeva & Shanmuganathan (1967) suggested that IDD was prevalent in the Wet Zone due to persistent heavy rainfall leaching the iodine from soils.

In further studies, Mahadeva et al. (1968) investigated the iodine and calcium content of food from endemic and non-endemic areas. They found that the iodine content of food grown in non-endemic areas was, in most instances, considerably higher than in endemic areas. However, the dietary iodine content in areas of endemic goitre was surprisingly high at 300 - 350 µg per person per day (186 - 215 µg per person per day allowing for 38% loss during cooking). Recommended iodine intake is of the order of 100 µg per day (Beckers & Delange, 1980) but depends on the age and status of the individual. Mitchel (1974), for example, recommends 35 mg per day for 0-6 month-old children and 125-150 µg per day during pregnancy and lactation.

A more recent study of endemic goitre was that of Fernando et al. (1987; 1989) in which 59,158 children from 87 schools in 17 districts in Sri Lanka were examined for goitre. The work of Fernando et al. (1987; 1989) was a useful source of information regarding the selection of villages for this current study although incidence rates are based on districts rather than villages. Some additional information concerning the schools sampled enabled specific villages to be targeted.

Fernando et al. (1987) defined a goitre belt across the south-west of Sri Lanka estimating that 10 million people within the belt were at risk of goitre (out of a total national population of 17 million). Highest prevalence rates of over 30% were observed in the Kalutara District confirming the results of earlier investigators (Fernando et al, 1989). A wide range of prevalence rates were reported within each district. In Kandy District, for example, prevalence ranged from 4.4% to 38.8% between schools suggesting that the endemicity occurs in pockets and is not uniform. Table 4 shows the prevalence rates by thyroid grade and district (both sexes). This survey adopted a stricter procedure than earlier surveys for goitre definition based on the WHO classification (Perez et al., 1960). It is difficult to collate the endemic goitre data currently available for Sri Lanka due to differing definitions of goitre, varying sample sizes and different sample targets (e.g. schools and ante-natal clinics).

Deo & Subramaniam (1971) give further data on the prevalence of goitre in school children. The Horana District (Pelenwatte village) is recorded as a high incidence area although the highest incidence rate occurs in Kandy District (Gampola village 54%). It is not clear from this study how the school children were selected for the investigation.

Dissanayake & Chandrajith (1993, 1996) is the only investigation which has considered the goitre problem from the point of view of the distribution of iodine in the geochemical environment. They found no clear correlation between the iodine content of soil and water and the endemicity of goitre in Sri Lanka and as a result, they suggest a multi-factorial aetiology which may include goitrogens.

The Faculty of Medicine, University of Peradeniya, are currently conducting small scale studies relating to endemic goitre in the Kandy area. This unpublished data was also used in selecting village targets for the present study in the Kandy District although caution should be exercised in the interpretation of prevalence rates. Firstly, the areas were all within close proximity to the University of Peradeniya giving a false impression of the distribution of high endemic goitre prevalence and secondly, incidence rates were generally based on a small sample size of 40 families chosen at random. Nevertheless, these prevalence data provided a useful guide for the present study and were confirmed by "on-the-ground" observations whilst sampling.

The Department of Nuclear Medicine, University of Peradeniya are investigating possible genetic controls on the incidence of IDD in Sri Lanka as it is common for women in the same family to suffer from IDD (Dr Watawana pers commun.).

Table 4. IDD prevalence rates in Sri Lanka by thyroid grade and district (both sexes) from Fernando et al (1989).

District	Prevalence Rate (%)		
	1a	1a≥	1b≥
Kalutara	19.8	30.2	10.4
Moneragala	19.7	28.2	8.5
Nuwara Eliya	19.4	27.6	8.2
Ratnapura	18.3	24.7	6.4
Badulla	15.3	22.4	7.1
Kegalle	15.1	21.2	6.1
Kandy	16.0	20.8	4.8
Hambantota	16.0	19.7	3.7
Galle	12.8	17.8	5.0
Gampaha	13.0	17.1	4.1
Matara	12.4	16.2	3.8
Kurunegala	9.5	11.9	2.4
Puttalam	8.4	10.4	2.0
Colombo	8.2	9.2	1.0
Polonnaruwa	7.2	8.5	1.3
Anuradhapura	6.6	7.3	0.7
Matale	4.9	6.5	1.7
All Districts	*13.9*	*18.8*	*4.9*

Grade 1a goitre -	thyroid distinctly palpable and definitely larger than normal and not visible with the head in the normal or extended position.
Grade 1b goitre -	thyroid easily palpable and visible with the head in the extended position including subjects with discrete nodular goitre.

7. SAMPLE COLLECTION

7.1 Sampling Design

The sample collection strategy applied in Sri Lanka is similar to that employed during the first three phases of the project in China (Johnson et al., 1996; Fordyce et al., 1998; Appleton et al., In Prep.). The fifteen villages selected for the study were coded according to the following scheme:

NIDD 1 - 5	Low/ low IDD incidence < 10% goitre rate
MIDD 1 - 5	Moderate IDD incidence 10-25% goitre rate
HIDD 1 - 5	High IDD incidence > 25% goitre rate

Although the IDD incidence rates are based on communities which may be a collection of villages spread over an area of 30 km^2, a single village was chosen to represent a community.

No comprehensive information on current IDD incidence rates is available for Sri Lanka. Villages were selected for the present study on the basis of several previous investigations into IDD (Appendix A). The IDD incidence rates cited for each village were not determined consistently, details are given in the references cited in Appendix A. Nevertheless, the prevalence data provided a useful guide for the selection of target villages for this study and was confirmed by "on-the-ground" observations whilst sampling.

For the purposes for statistical analysis, the villages were assigned a second code related to the region in which the samples were collected, namely, Anuradhapura, Kandy or Kalutara (Section 8).

Samples were coded SL for Sri Lanka and numbered according to a random number list (Plant, 1973). Sample details were recorded on field cards and an epidemiological field sheet. Village and sample details are summarised in Appendices A-E. Where possible, samples were collected in accordance with the recommendations of the IGCP 259 Final Report (Darnley et al. 1995). Field sampling equipment is listed in Appendix F.

7.2 Soil Sampling

All soils collected were from rice paddies and were a mixture of paddies that had just been harvested or paddies with near-ripe rice crops. With the exception of village NIDD1 where the drought prevented operation of the irrigation system, all samples were collected from wet paddy fields. Fields were selected such that soil samples were moist to wet rather than water-logged as this made sampling easier and enforced a consistency between sample sites. All samples were collected from within the ploughed horizon and no distinctive soil horizon profile development was observed due to the cultivated nature of the soils. Visible organic content varied greatly between fields. In some areas, rice stubble was ploughed back into the soil following the rice harvest whilst in other areas, burnt stubble and chaff and charcoal fragments were evident in the soil.

A close relationship between bedrock lithology and soil mineralogical content was observed in areas where bedrock existed near the surface. For example, the outcrop of bands of biotite gneiss corresponded to large and abundant flakes of biotite in the soil. Variations of this type were very localised and resulted in a contrast between soil mineral clasts within fields of the same village.

7.2.1 Sampling Strategy

- five composite samples were collected from each targeted village from rice paddies used to provide the village food supply.
- sites were selected so as to cover all the topographic aspects of rice paddy land around the village.
- duplicate samples were collected from 1 in 25 sample sites.
- near surface samples (10-30 cm; below Ao) were collected
- in order to carry out Se speciation studies at the BGS it was important that the soils retained their moisture content therefore the samples were collected in plastic securitainers.

7.2.2 Collection (Plate 3)

1. All sampling equipment (Dutch soil auger and plastic sheet) was cleaned before use.
2. Using the assembled sectional soil auger, four auger holes were made at the corners of a 20 m square and the fifth hole in the centre of the square. The top c.10 cm organic rich layer was discarded. The five auger samples were placed on a plastic sheet.
3. Any large rootlets and stones were hand picked from the sample and discarded.
4. The accumulated sample was homogenised on the plastic sheet.
5. The sample was coned and quartered to produce a split of two samples (minimum 100g). One split was placed in a grey securitainer (49 x 75 mm) and the other split in a 6"x10" Kraft sample bag. A black waterproof marker pen was used to write the number carefully on the Kraft bag and on the top, side and bottom of the securitainers (to avoid the number being rubbed off during transport). Sample containers were also coded with the letter S to indicate they contained a soil sample. The grey securitainer samples were transported back to the UK for analysis by BGS and the Kraft bag samples remained at the University of Peradeniya.
6. Sample field cards were completed at each site noting site characteristics (Appendix B).
7. Duplicate soil samples were collected in the same way, from five different holes in the same field as the original sample.

7.3 Rice Sampling

Rice was the predominant grain crop grown in all areas sampled. In several areas rice had just been harvested at the time of sampling therefore samples were collected from village rice stores. The rice collected was generally from the harvest of October 1996 (in areas where the 1997 crop was not ready) or the harvest of January-February 1997. Rice is stored in four forms all of which were sampled during the field programme:

In the husk without boiling
In the husk boiled to draw the goodness of the husk into the rice
De-husked without boiling
De-husked after boiling in the husk

Rice still in the husk is called paddy.

7.3.1 Sampling Strategy

- 5 rice samples were collected from 5 different rice stores in each target villages so as to represent the staple diet of the residents.
- the rice samples were collected from villagers that farmed the fields sampled for soils
- duplicate samples were collected from 1 in 25 rice stores.

7.3.2 Collection

1. The house of the farmer that worked the fields sampled for soil was located.
2. Dehusked rice samples were collected in 49 x 75 mm securitainers whereas husked samples were collected in 6"x10" Kraft paper bags as more sample material was required to allow for loss during dehusking.
3. A black waterproof marker pen was used to write the sample number clearly on the securitainer or Kraft bag which were also labelled with the letter G to indicate a grain sample.
4. Usage of fertiliser and harvest-date details were recorded on field sheets (Appendix C).
5. All rice samples were transported to the UK for analysis by the BGS.

7.4 Water Sampling

The majority of villages sampled during the field programme were supplied by well water. Most villages contained several wells and the well serving the most people in each village was sampled.

7.4.1 Sampling Strategy

- water samples were collected to represent the drinking water supplies of each of the 15 villages sampled.
- duplicate samples were collected from 1 in 5 sample sites.

7.4.2 Collection (Plate 4)

1. At each site, the following suite of water samples were collected:
   - Three 30 ml filtered water samples collected in trace element free polyethylene Nalgene® bottles.
   - One 30 ml unfiltered water sample collected in a polystyrene Steralin® vial for pH and Eh determinations.
   - One 250 ml unfiltered water sample collected in a polyethylene bottle for bicarbonate and conductivity determinations.
2. A waterproof black marker pen was used to write the sample number clearly on the sides of the bottles. Numbers were also written on the lids and bottom of the 30 ml Nalgene® bottles to avoid the numbers being rubbed off during transport. The 30 ml Nalgene® bottles were labelled to indicate which samples would be acidified as follows:

   UA = unacidified
   HA = acidified with hydrochloric acid
   NA = acidified with nitric acid

3. Each filtered water sample was collected using a 25 ml plastic syringe and a Swinnex® filter cartridge pre-loaded with a 0.45µm Millipore® cellulose filter. A new filter cartridge was used for each site to avoid any possible cross-contamination between sites.
4. At each site the filtered water samples were collected first avoiding disturbance to sediment in the bottom of the spring-fed water reservoir.
5. Water was drawn into the syringe which was rinsed out twice. The syringe was filled with water again and connected to the filter cartridge which was also rinsed out twice. The syringe was refilled and the sample bottle was rinsed out twice with filtered water prior to being filled. The 30 ml Nalgene® bottles were filled to the shoulder.
6. Both the 30 ml Steralin® vial and the 250 ml polyethylene bottle were rinsed out twice in the water reservoir. Where possible, the vial and the bottle were both submerged underwater whilst the caps were secured making sure that no air was trapped in the sample container. This minimises the degassing of HCO_3 in the samples.
7. Care was taken to keep all bottles and filters clean and uncontaminated by human touch.
8. 30 ml samples collected for trace element analysis were acidified within 4 hours of the end of fieldwork each day. NA and HA samples were acidified by the addition of 0.3 ml (8 drops) ARISTAR grade nitric and hydrochloric acid respectively. Addition of 1% vol/vol acid reduces the pH of the samples to approximately 1.0, thus preventing adsorption of dissolved metals to the interior walls of the storage bottle and minimising post-sampling microbial activity.
9. Care was taken to avoid introducing contamination through the plastic dropping pipettes, each of which were stored in a plastic self-seal bag and did not come into contact with bench surfaces.
10. Eh and pH measurements, bicarbonate and conductivity determinations were also carried out at the end of each day's sampling. Procedures are detailed in Appendix G and results are listed in Appendix D. Following the measurements, these samples were discarded and the sampling containers reused.
11. Two field-blank UA, HA and NA samples were made up near the start and end of fieldwork. 30 ml Nalgene® bottles were rinsed twice with filtered deionised water, filled to the shoulder with filtered deionised water and acidified in the same way as the samples. The field-blanks were numbered in the same way as the samples according to the random list.
12. At all stages great care was taken to ensure that sample bottle tops were securely tightened.
13. The UA, HA and NA water samples were transported back to the UK for analysis by the BGS.

7.5 Hair Sampling

Hair samples were collected from the inhabitants of the 15 villages to represent the Se status of the local population. In all villages, women were sampled as IDD affects women more than men in Sri Lanka. One man suffering from nodular goitre was sampled in NIDD5. The majority of men in Sri Lanka have very short hair and were unwilling to have their hair cut even shorter.

7.5.1 Sampling Strategy

- hair samples were collected from 5 women in each village to represent the Se status of the local population.

Plate 4. Collection of a filtered water sample from the shallow drinking water well in Polambayagama (NIDD3).

Plate 5. Collection of a hair sample from the nape of the neck of a woman suffering from goitre (Kurunduwatte, HIDD2).

- where possible women from different families were selected for sampling
- whenever possible women from farms where rice and soil samples had been collected were sampled
- women of a range of ages were sampled and age, health, disease, medication, diet and residency details were recorded on field sheets (Appendix F).

7.5.2 Collection (Plate 5)

1. Individuals to be sampled were identified with the assistance of the local guides.
2. Samples of long hair tresses were collected by cutting hair across the nape of the neck using stainless steel scissors.
3. Approximately 10 g of sample was collected and placed in a small plastic self-seal bag. The bag was numbered in a similar way to the soil and rice samples using a waterproof black marker pen.
4. A field sheet was completed for each individual sampled (Appendix E).
5. Hair samples were transported to the UK for analysis at the BGS.

Plate 3. Soil sampling with a Dutch auger. Field observations were recorded on field data cards (Pelenwatte, HIDD4).

8. ANALYTICAL METHODS AND DATA PROCESSING

8.1 Introduction

Total Se, total iodine, total organic carbon (TOC), pH, Al, Ca, Cu, Fe, Mn, Ni, and Zn were determined in all soil samples. Investigations into the Se adsorption capacity of soils were also carried out on all soil samples. Semi-quantitative XRD mineralogical analysis was carried out on six selected soil samples, representing a variety of total Se concentrations from the three regions (AN, KA and KL). Water extractable and phosphate extractable Se concentrations and were determined on 15 composite soil samples, one from each village. Water soluble iodine concentrations were carried out on 12 selected soil samples representing a range in total iodine concentration. Total Se concentrations were determined in all rice samples and total iodine concentrations in 15 composite samples, one from each village. Total Se and Cl, NO_3, SO_4 concentrations were determined in water samples. Total Se concentrations were determined in hair.

Se in all samples types was analysed by Atomic Fluorescence Spectrometry (AFS) whereas multi-element analysis and water extractable iodine concentrations in soils were based on ICP-AES techniques. Total iodine concentrations in rice were determined by automated colorimetry and total iodine in rice were determined by Neutron Activation Analysis (NAA).

Data quality was assured by the inclusion of analytical replicates, field duplicate samples and international reference standards in the analytical runs.

8.2 Sample Preparation

8.2.1 Sample Preparation for ICP-AES, AFS, Colorimetry and TOC Analysis in Soils

All samples were homogenised and cone and quartered and one half was retained in the original container for reference. Samples were dried at a low temperature of 35 °C for 6 - 12 hours to avoid loss of Se 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.

8.2.2 Sample Preparation of Soil Samples for Extractable Se Analyses

The five soil powders (< 150µm) from each village were selected. 1 g of each sample was weighed into a centrifuge tube and put through the extraction procedure. All samples had been thoroughly ground and homogenised during the first powder preparation therefore they were not ground again prior to the extraction process.

8.2.3 Sample Preparation of Rice Samples for AFS Analysis

Rice husks were removed by gently grinding the grains in an agate mortar and pestle. After 1-2 minutes the separated husks and seeds were allowed to fall across the front of a modified dust extraction intake covered by clean 500 micron sieve mesh. This separated the husks by retaining them on the vertical nylon mesh with approximately 90% efficiency. The seeds were then milled in an agate vibrating-cup for 3 minutes to produce a powder with a nominal maximum particle size of 150 µm.

8.2.4 *Sample Preparation of Rice Samples for NAA Analysis*

The five rice powders prepared for AFS analysis from each village were selected. 20 g of rice powder from each sample in a village was selected and homogenised in an agate mill to produce one large 100 g composite sample for each village.

8.2.5 *Sample Preparation of Hair Samples for AFS Analysis*

The majority of women sampled had long hair. In order to test whether there were longitudinal differences in hair Se content and whether washing hair samples in water or anionic surfactant would affect the results, seven hair samples were selected for washing and cutting tests. The results of these tests are presented in Section 12 and showed no consistent differences between Se contents of different hair lengths. Washing in anionic surfactant made little difference to the results. On the basis of these tests, samples were washed in 100 ml of deionised water twice by shaking in a new 250 ml Nalgene® bottle (rinsed twice with deionised water before use) before cutting into 1 - 2 mm lengths. The finely cut hair was then homogenised whilst still damp, by repeatedly folding it in a paper towel for 1 - 2 minutes followed by careful mixing using gloved hands for a further 1 - 2 minutes. The samples were then covered and dried on clean paper towelling over-night. Washed disposable gloves were used at all stages of preparation.

8.3 Analysis

8.3.1 *Analysis of Soil Samples by ICP-AES and AFS*

Total (hydrofluoric-nitric-perchloric digestion) and water soluble Se in soil samples were determined by hydride generation AFS according to the methods detailed in Appendix G. Phosphate extractable Se was determined on the residue after water soluble Se had been removed according to the methods of Martens & Suarez (1997). Total (hydrofluoric-nitric-perchloric) soil Al, Ca, Cu, Fe, Mn, Ni and Zn concentrations were determined by ICP-AES (Appendix G). Water soluble iodine concentrations were determined by leaching 5 g of soil in 30 ml of deionised water for 60 minutes. Analysis of the resultant solutions was carried out on the same day by iodine vapour generation ICP-AES.

8.3.2 *Analysis of Soil Samples by Automated Colorimetry*

Total iodine in soil samples was determined by an automated colorimetric method at the University College of Wales, Aberystwyth (Fuge et al., 1978). The method is based on the catalytic action of iodine on the reaction between arsenic and cerium (Appendix G).

8.3.3 *Analysis of Soil pH*

Soil pH was determined by adding 4 g of each sample to 10 ml of 0.1M $CaCl_2.2H_2O$. The mixture was shaken and left overnight. The mixture was reshaken just prior to analysis by pH electrode (Rowell, 1994). This method of soil pH determination generally gives lower results (0.5 pH units) than water based methods.

8.3.4 *Analysis of TOC in Soils*

Determinations of TOC in soil samples was carried out using a wet oxidation-titrimetric method (Ministry of Agriculture Fisheries and Food (MAFF) Method No. 56., Rowell, 1994) at Intertek Testing Services (Environmental Laboratories). 1 g of < 150 µm soil powder was gently boiled for 2 hours at 130 - 135_ in 40 ml of acid dichromate solution to oxidise the soil organic carbon. Excess dichromate was determined by titration with ferric sulphate.

8.3.5 *Bulk Mineralogical Determinations in Soils*

Details of semi-quantitative XRD analysis to determine soil bulk mineralogy are given in Appendix B.

8.3.6 *Selenium Adsorption Studies in Soil*

0.05 g of soil sample was added to 25 ml of 200 ng/g sodium selenite solution (pH = 4.02). Samples were placed in a mechanical shaker for 24 hours. Samples were centrifuged and the decanted solutions were analysed for Se by AFS (Appendix G). The percentage of Se adsorption was then calculated.

8.3.7 *Analysis of Rice Samples by NAA*

The total iodine content of rice village composite samples was determined at the Environmental Analysis Section, Imperial College Centre for Environmental Technology, Silwood Park, Ascot by epithermal NAA on 1 g of sample powder.

8.3.8 *Analysis of Selenium in Rice, Water and Hair Samples by AFS*

Sample preparation procedures for the determination of total Se content were based on a nitric-perchloric attack in rice and hair samples. Detailed methods and limits of detection for AFS analysis of rice, water and hair samples are given in Appendix G.

8.3.9 *Ion Chromatography Determinations in Waters*

Cl, NO_3 and SO_4 concentrations in water samples were determined by ion chromatography (IC) (Appendix G).

8.4 Data Processing

For the purposes of statistical analysis, determinations below the detection limit were set to 2/3 of the detection limit. Analytical replicate results and field duplicate results were removed from the data set prior to statistical processing. Statistical analyses and plots have been produced using UNISTAT (version 4.5), Statview (version 4.0) and Systat (version 5.2.1). Box and whisker plots are used to present the ranges associated with various classifications of the data. On these box and whisker plots, the bottom line of the box represents the lower quartile, the middle line shows the median and the upper quartile is the top of the box. The lower and upper whiskers represent the lower/upper quartile plus 1.5 times the inter-quartile range. Any values lying outside this range plot as individual points. The dash in the box represents the arithmetic mean value. Spearman Rank correlation coefficients were calculated as these are less influenced by outlying values than Pearson (Product Moment) correlation coefficients. Figures showing the data as classified symbol plots on a background map of Sri Lanka have been produced using MapInfo (version 4.1). Comparisons between the various sample types are based on the geometric mean value for the 15 villages as different numbers of each sample type were collected from each village.

Villages and samples have be classified in three ways. Firstly using the IDD codes based on goitre incidence rates (Section 6), namely:

NIDD	Low/ low IDD incidence	< 10% goitre rate
MIDD	Moderate IDD incidence	10-25% goitre rate
HIDD	High IDD incidence	> 25% goitre rate

Secondly, samples are considered in terms of the Wet Zone/ Dry Zone demarcation based on annual rainfall data from the Sri Lanka National Atlas (Survey Department, 1988) (Figure 6).

Lastly, initial interpretations suggested that a regional classification would be useful in assessing the results and so samples have also been classified as belonging to the Kalutara coastal region (KL), the Kandy highland region (KA), or the Anuradhapura (AN) lowland region. The latter region includes all samples from the Dry Zone whereas the Kalutara and Kandy regions are sub-sets of the Wet Zone.

The IDD and regional codes for each village are listed in Appendix A and shown on Figure 6.

9. SOIL RESULTS

9.1 Introduction

Seventy nine soil samples were collected, three of which were field duplicates (22 [68], 78 [86] and 81 [76] - original sample given in square brackets), and one sample (20) was from a village initially targeted but not selected. The duplicate samples and the extra sample have been removed from the data set and 75 samples from the 15 targeted villages have been considered in this interpretation. Soil analytical results are listed in Appendix B. In this account, results for total iodine, water soluble iodine, total Se, water soluble Se, phosphate extractable Se, pH, total organic carbon (TOC), and Se adsorption studies are discussed. Results for Al, Ca, Cu, Fe, Mn, Ni, and Zn (determined by ICP-AES) are also presented.

9.2 Quality Control

Total iodine analytical replicates show good agreement between both sets of results and analysis of internal standards produced satisfactory values (Appendix G), However, the field duplicates (Table 5) do indicate significant within-site variability and this must be taken into account when discussing the results.

Table 5. Comparison of results for soil field duplicate samples.

Duplicate Pairs	pH	Se ng/g	TOC (%)	I µg/g	Ca µg/g	Mn µg/g	Fe µg/g	Al µg/g	Ni µg/g	Cu µg/g	Zn µg/g
68	4.63	2494	4.8	3.90	362	105	16,238	60,815	31.6	12.6	46.1
22	4.34	2606	4.8	5.00	496	119	18,876	84,997	34.8	12.4	52.2
86	4.90	553	1.3	3.20	1,489	414	60,483	55,735	30.4	33.4	73.1
78	4.63	586	1.3	7.10	1,628	439	71,351	61,081	34.5	35.8	83.3
76	6.35	213	0.8	4.40	6,809	1,460	46,115	62,003	29.4	26.6	55.9
81	6.11	200	0.9	3.20	6,660	1,507	44,473	60,693	29.0	26.3	60.0

Analytical replicate results for total Se are shown in Figure 7 and show good correlation. International reference materials determined for Se gave results that were comparable with recommended values (Appendix G). Field duplicate results for total Se show good compatibility between samples from the same field (Table 5).

Analytical replicates for elements determined by ICP-AES show good reproducibility of the results (Appendix G). Results for field duplicate samples also show good compatibility between soils collected from the same field (Table 5).

No analytical replicate results are available for soil pH determinations, however, field duplicate pH results show good agreement (Table 5).

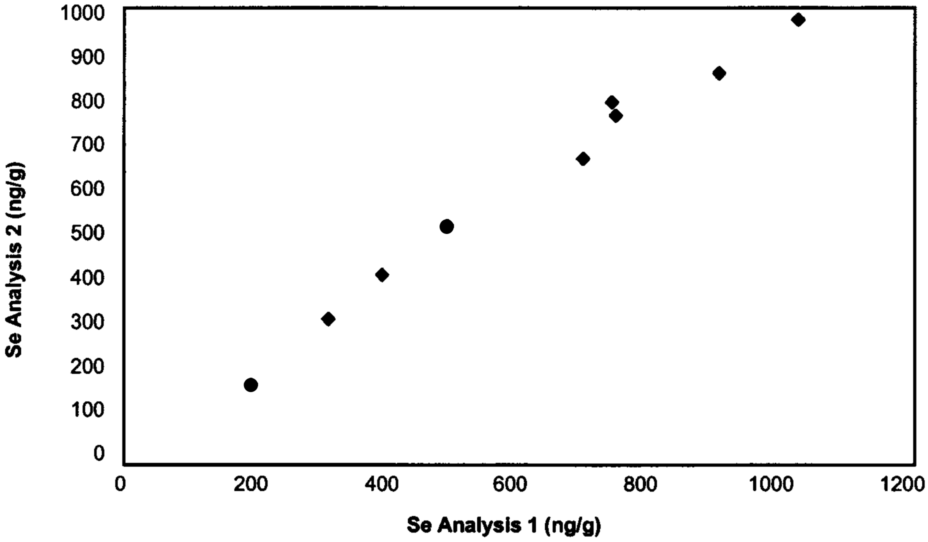
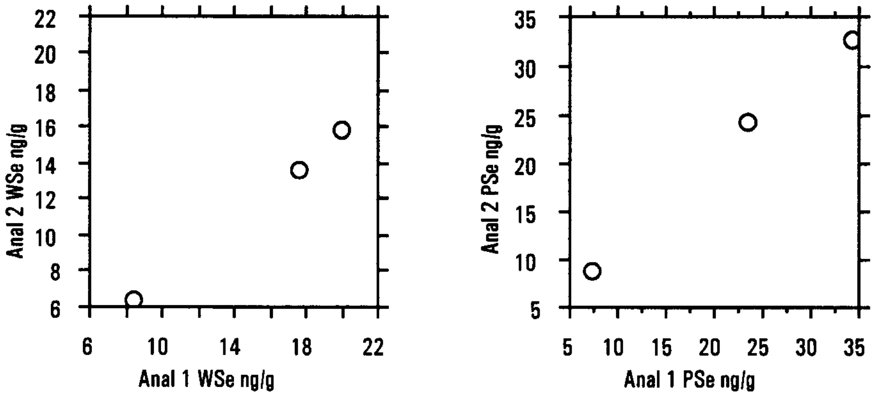


Figure 7. Replicate analyses for soil Se results.

Analytical replicates for water soluble and phosphate extractable Se based on village composite samples show good reproducibility of results, however, the second set of water soluble results are consistently lower than the first set (Figure 8). All water soluble iodine determinations in soil were below the detection limit (Section 9.5).



Anal = analysis WSe = water soluble Se PSe = phosphate extractable Se

Figure 8. Analytical replicate results for soil water soluble and phosphate extractable Se.

9.3 Soil Type

All soils collected were cultivated paddy soils and, with the exception of the samples collected at the first village (NIDD1 Upuldenya, Figure 6), were from irrigated paddy fields. Therefore, the samples were generally damp or wet when collected. In general, cultivated soils were paler in colour (i.e. more gleyed by repeated water-logging) than uncultivated soils. Soils are classified by their dry soil colour (Appendix B) but do not show the same degree of contrast as soils from the Zhangjiakou study area in China (Johnson et al., 1996). The eight dark grey soils come from just two villages (Pelenwatte (HIDD4) and Gurudola (HIDD5)) both from the Kalutara region (Figure 9). This figure also shows all the Dry Zone/Anuradhapura region soils are pale grey-yellow or grey yellow in colour.

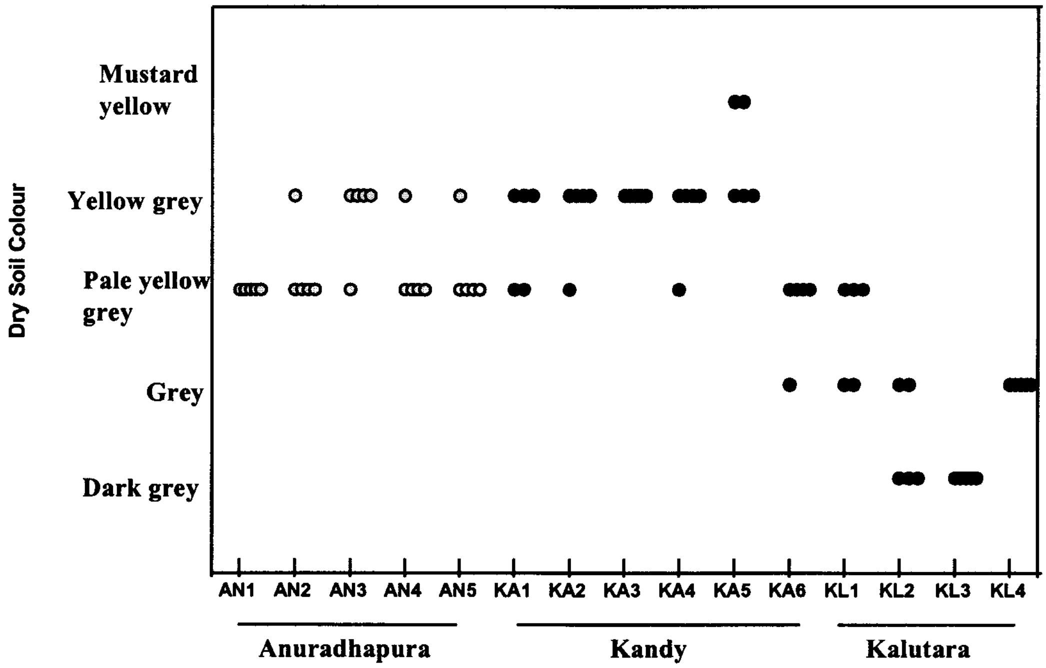


Figure 9. Plot of dry soil colour versus region. Hollow dots indicate samples from the Dry Zone, filled dots indicate samples from the Wet Zone.

A map of village geometric means for soil pH (Figure 10) shows that in the Wet Zone (Kalutara and Kandy regions) the soils are strongly acidic (pH < 4.80) whilst in the Dry Zone (Anuradhapura region) they are less acidic (pH 5.84 - 6.38). The box and whisker plot (Figure 11) shows this bimodal distribution between results in the Wet and Dry Zones. It should, however, be taken into consideration that the $CaCl_2$ method used to determine soil pH generally gives lower results (0.5 pH units) than water based soil pH methods (Section 8).

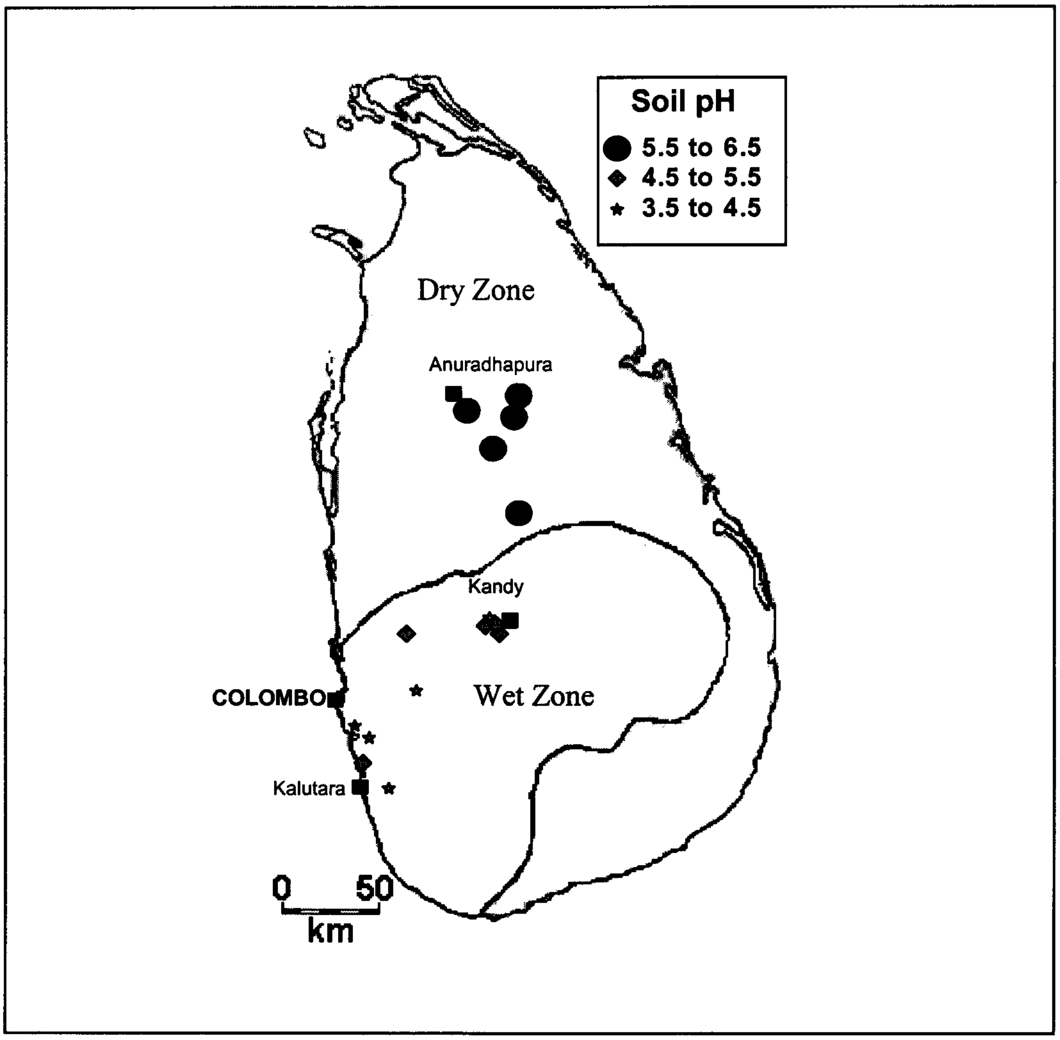


Figure 10. Map showing the pH of soils from the fifteen targeted villages based on village geometric mean values.

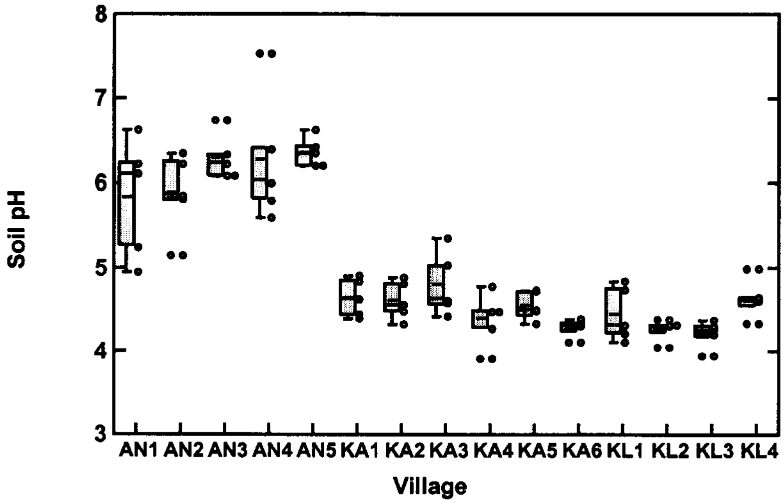


Figure 11. Box and whisker plot of soil pH for each village classified by region. Acutal results are plotted as dots to the right of each box and whisker. (AN = Anuradapura, KA = Kandy, KL = Kalutara)

9.4 Total Iodine

Total iodine ranges from 0.13 - 10 µg/g with an arithmetic mean of 3.11 µg/g and a geomean of 2.37 µg/g (Table 6). The geometric means for each village are plotted on Figure 12. These results are generally higher than the 0.04 - 6.6 (mean 1.9) µg/g iodine results for soils from Angunawala (Dissanayake & Chandrajith, 1996). There is surprisingly little data on iodine in Sri Lankan soils considering the numerous IDD case histories (e.g. Wilson (1950) and Mahadeva & Shanmuganathan (1967)). Fuge & Johnson (1986) list results for iodine in soils from many parts of the world - an average value of 4 - 8 µg/g is suggested. Vinogradov (1959) cites an average for iodine in soils of 5 µg/g. Levels of total iodine in Sri Lankan soils are therefore comparable to levels reported in soils from other regions of the world.

Table 6. Summary statistics for selected soil parameters in the Anuradhapura, Kandy and Kalutara regions and in the dataset as a whole.

	Iodine µg/g	Se ng/g	pH	% Se Adsorption	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	TOC %
Anuradhapura (AN)												
Number	25	25	25	25	25	25	25	25	25	25	25	25
Average	3.19	246	6.13	88.3	7,831	597	30,936	57,862	21.8	14.6	42.4	0.6
Geomean	2.26	226	6.11	87.2	7,490	550	29,435	57,045	21.3	13.0	41.5	0.6
Min	0.13	113	4.94	51.8	3,242	280	18,479	38,414	19.4	5.3	29.0	0.1
Max	10.00	663	7.53	99.9	13,308	1,460	59,116	77,628	44.9	26.6	55.9	1.4
Range	9.87	550	2.59	48.1	10,066	1,180	40,637	39,213	25.5	21.2	26.9	1.3
Kandy (KA)												
Number	30	30	30	30	30	30	30	30	30	30	30	30
Average	2.20	586	4.55	96.9	4,524	405	47,506	67,765	35.4	36.8	71.7	1.1
Geomean	1.77	545	4.54	96.6	3,488	364	43,254	64,812	32.5	31.1	69.0	1.0
Min	0.13	276	3.91	69.2	450	144	10,961	32,939	20.0	7.5	42.6	0.3
Max	4.60	1149	5.35	99.9	12,041	817	92,850	113,323	102.5	152.1	112.4	2.1
Range	4.47	873	1.43	30.8	11,591	673	81,889	80,384	82.5	144.5	69.8	1.8
Kalutara (KL)												
Number	20	20	20	20	20	20	20	20	20	20	20	20
Average	4.38	2690	4.40	88.3	480	78	19,928	92,482	37.1	17.3	51.2	5.2
Geomean	3.91	2435	4.39	86.4	444	73	16,776	88,376	35.8	16.4	49.6	4.7
Min	1.00	730	3.95	50.1	161	32	5,866	38,307	20.0	6.9	32.6	1.7
Max	9.60	5238	4.99	99.9	857	129	39,754	133,382	55.6	28.3	73.8	10.8
Range	8.60	4508	1.04	49.8	696	97	33,888	95,075	35.6	21.4	41.3	9.1
All Samples												
Number	75	75	75	75	75	75	75	75	75	75	75	75
Average	3.11	1034	5.04	91.8	4,548	382	34,628	71,056	31.3	24.2	56.4	2.0
Geomean	2.37	605	4.97	90.6	2,597	272	29,554	67,467	29.0	19.6	53.4	1.3
Min	0.13	113	3.91	50.1	161	32	5,866	32,939	19.4	5.3	29.0	0.1
Max	10.00	5238	7.53	99.9	13,308	1,460	92,850	133,382	102.5	152.1	112.4	10.8
Range	9.87	5125	3.62	49.8	13,147	1,428	86,984	100,442	83.2	146.7	83.4	10.7

% Se Adsorption = % residual Se adsorption

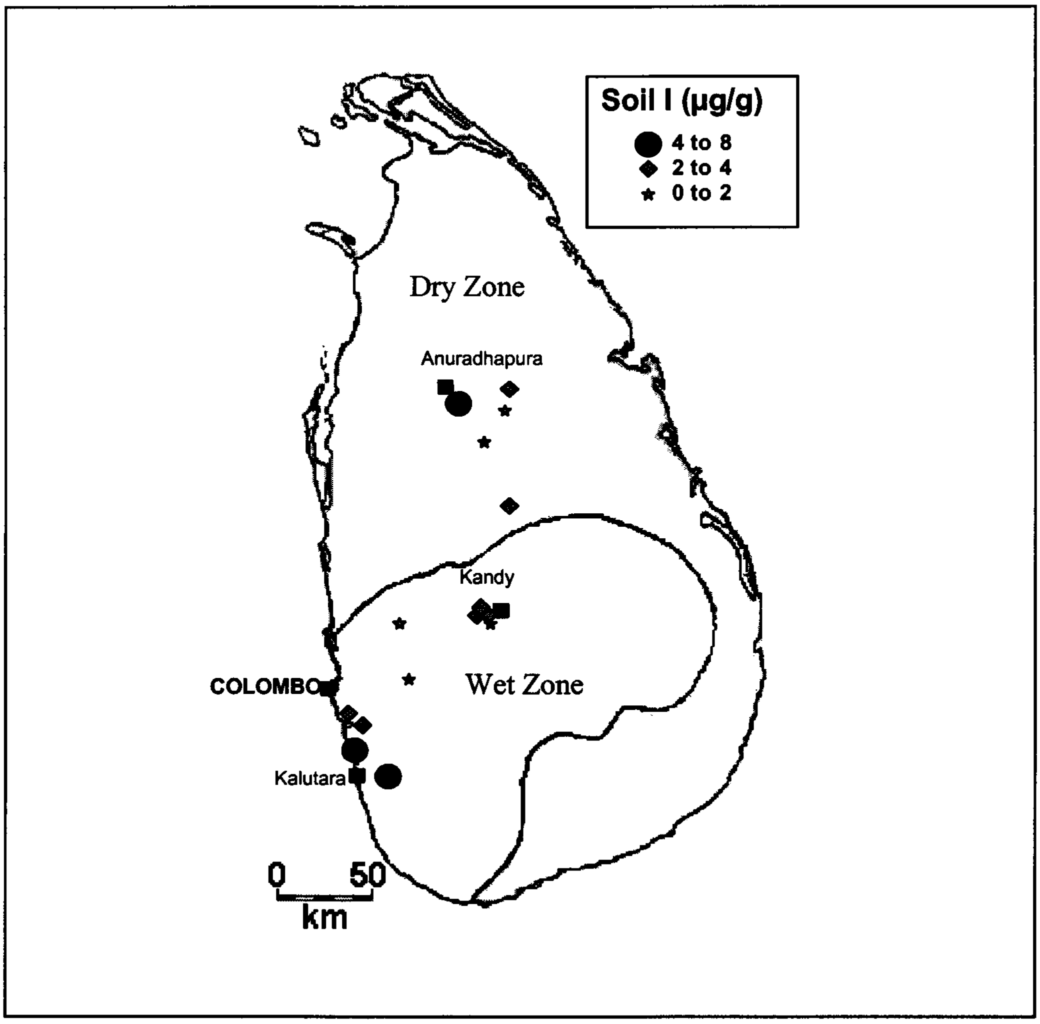


Figure 12. Map showing the total iodine content of soils from the fifteen targeted villages based village geometric means values.

Figures 13 and 14 (cumulative probability plot and histogram) show that the iodine results can be modelled as two overlapping lognormal populations - Population A (60%) mean c. 2 µg/g and Population B (36%) mean c. 3.5 µg/g - with three high outlying results that are > 8 µg/g. Two of these high results (10 and 8.6 µg/g) are from Polambayagama (NIDD3) and the third (9.6 µg/g) from Gurudola (HIDD5).

The box and whisker plot of soil iodine grouped by IDD incidence (Figure 15) shows no discernible trend with IDD incidence. A plot of village results classified by region does not show any clear trends between the regions and indicates a within village range of 2 - 3 µg/g (Figure 16).

A box and whisker plot based on the Anuradhapura, Kandy and Kalutara regions (Figure 17) suggests the Kalutara coastal region is relatively enriched in iodine, an observation that might be expected in view of the marine influence and likely high input of iodine originating from sea-spray or localised volatilisation from sea water. The relative order of total iodine in soils for the three regions is as follows (geomean in brackets):

Kalutara (3.91 µg/g) > Anuradhapura (2.26 µg/g) > Kandy (1.77 µg/g).

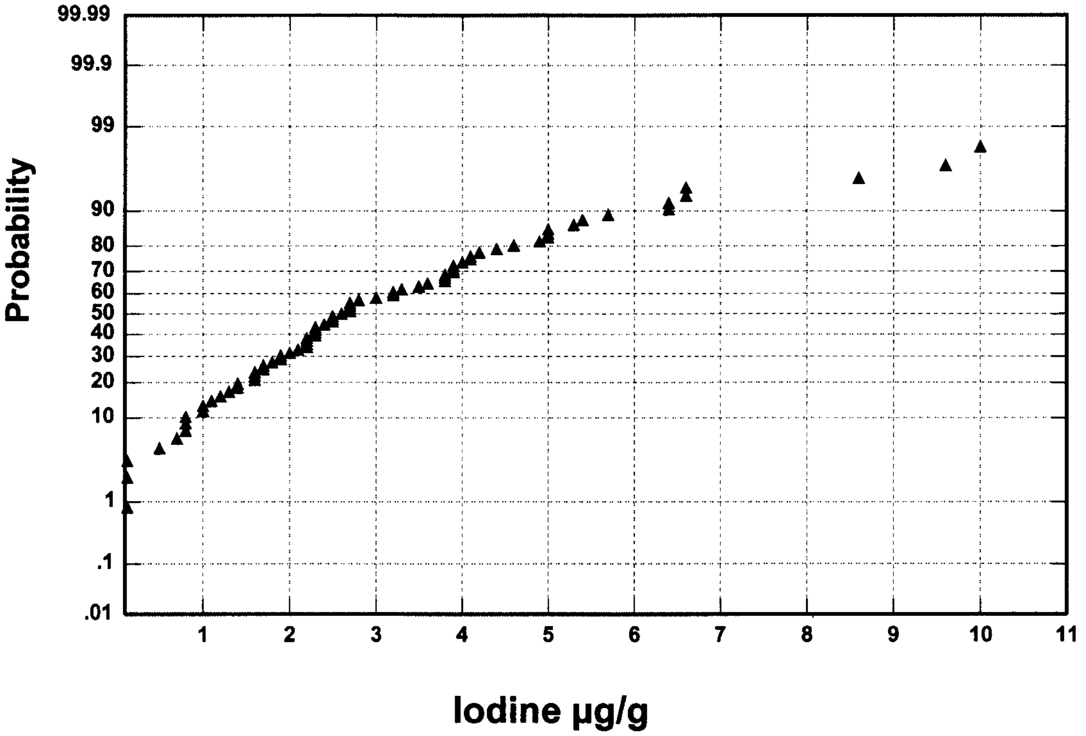


Figure 13. Cumulative probability plot of total iodine in soils.

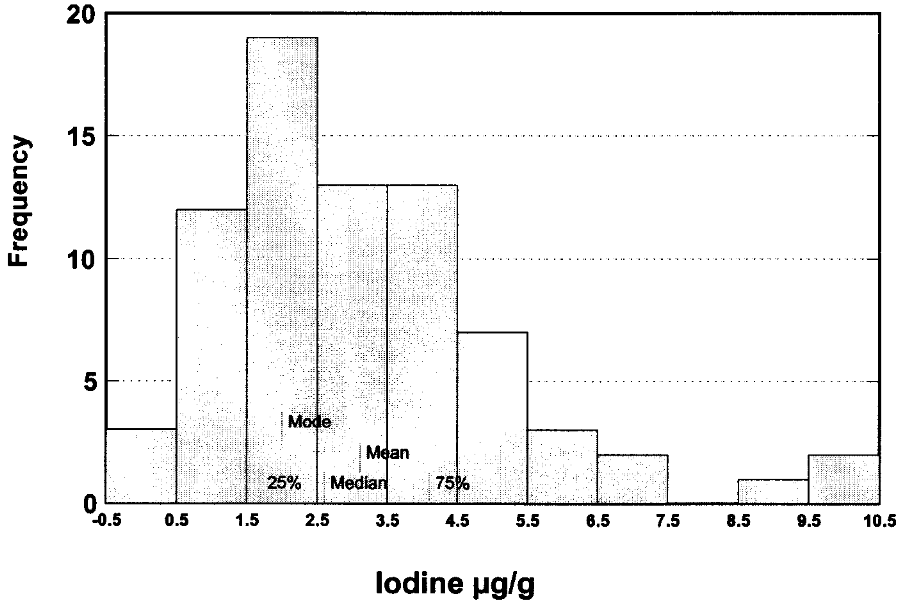


Figure 14. Histogram of total iodine in soils.

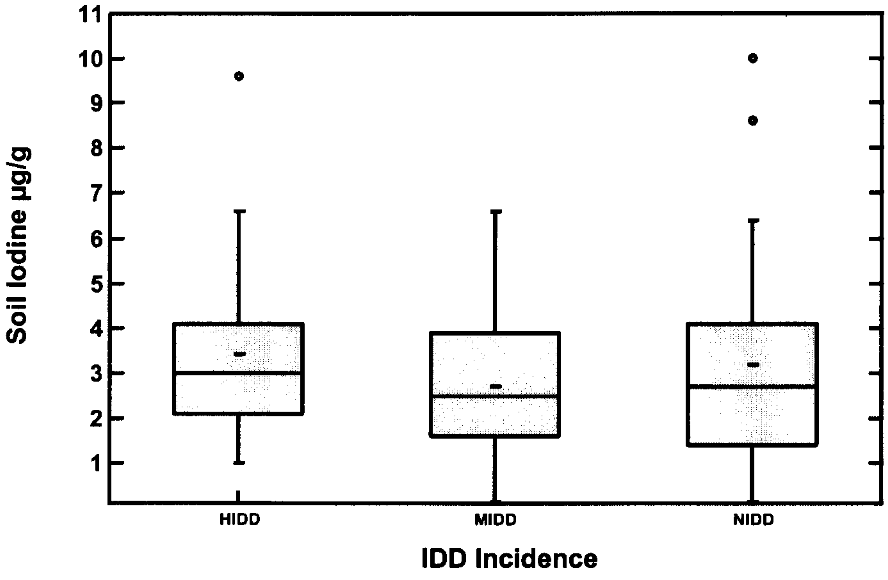


Figure 15. Box and whisker plot of soil total iodine classified by IDD incidence. (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence)

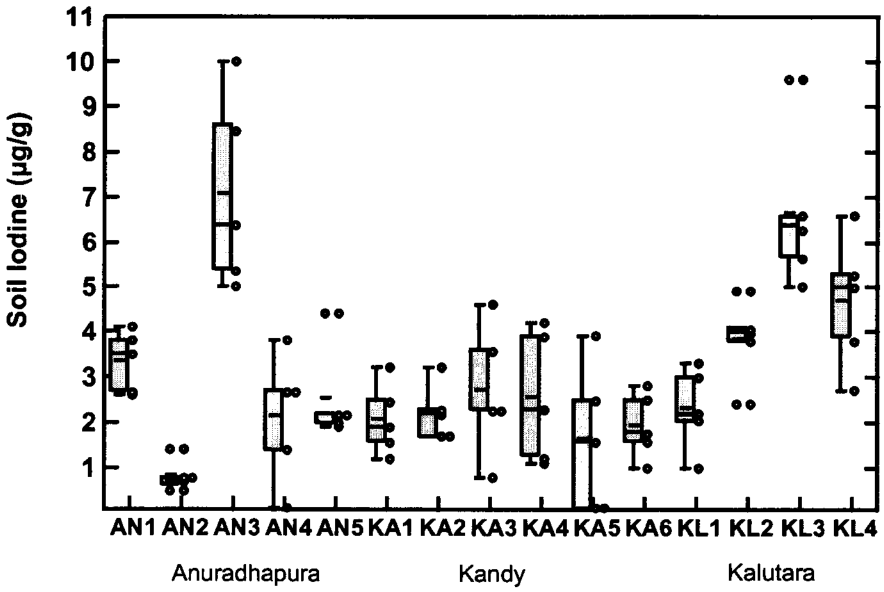


Figure 16. Box and whisker plot of soil total iodine for each village classified by region. Actual results are plotted as dots to the right of each box and whisker.

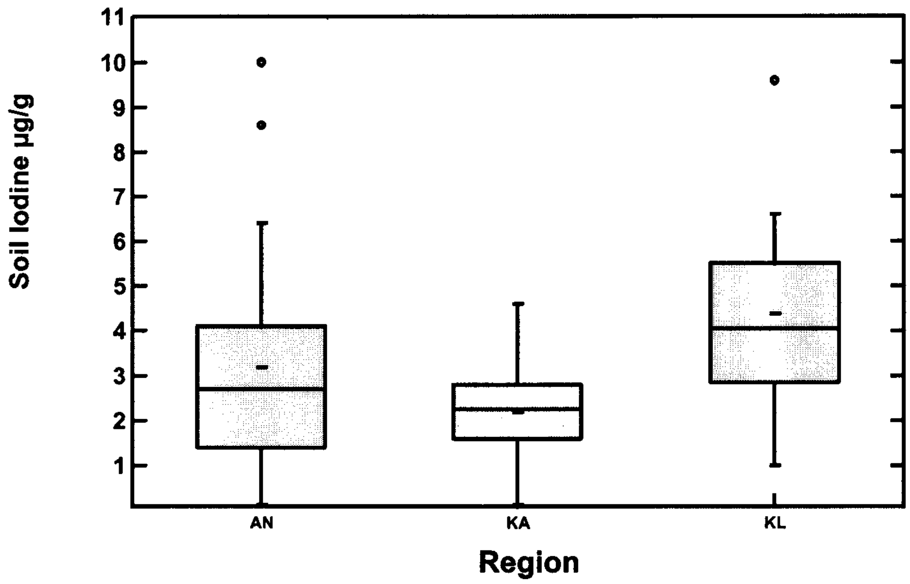


Figure 17. Box and whisker plot for soil total iodine classified by region. (AN = Anuradhapura, KA = Kandy, KL = Kalutara)

There is also no discernible difference between total iodine levels in the Wet and Dry Zones (Figure 16 - all AN samples are from the Dry Zone). There is a broad range of iodine values from low to high in villages of the Dry Zone. Village NIDD3/AN3 (Polambayagama) has particularly high iodine results whereas the results for Manankattiya (NIDD2/AN2) are low. The reasons for this are not known.

9.5 Water Soluble Iodine

Water soluble iodine contents were determined in 12 soils representing a range of total iodine contents in each region. In all cases the levels of water soluble iodine were below the detection limit (1177 ng/g, Appendix B). Results for Sri Lankan soils are generally much lower than those reported by Johnson (1980) for Welsh soils, ranging from 300 ng/g (soil with 4200 ng/g total iodine and 12.5% organic matter) to 8500 ng/g (soil with 41600 ng/g total iodine and 7.5% organic matter). However, levels of total iodine in soils in the Johnson (1980) study were significantly higher than those recorded in Sri Lankan soils. Several studies have shown that the percentage of water soluble iodine in soils is generally low (< 24%). Highest percentages of water soluble iodine occur in soils with low organic matter content (Johnson, 1980).

9.6 Total Selenium

Total Se values range from 0.112 - 5.24 µg/g with an arithmetic mean and geomean of 1.034 and 0.605 µg/g respectively (Table 6). These are much higher than the Keshan Disease area of Zhangjiakou, China, where soil Se ranged between 0.04 - 0.263 µg/g with an arithmetic mean and geomean of 0.136 and 0.127 µg/g respectively (Johnson et al., 1996).

The range of Se results is shown in the cumulative probability plot (Figure 18) and histogram (Figure 19). The data has a skewed distribution with 75% of results below 1 µg/g. The cumulative probability plot shows two distinct inflection points dividing the data into approximately three equal populations.

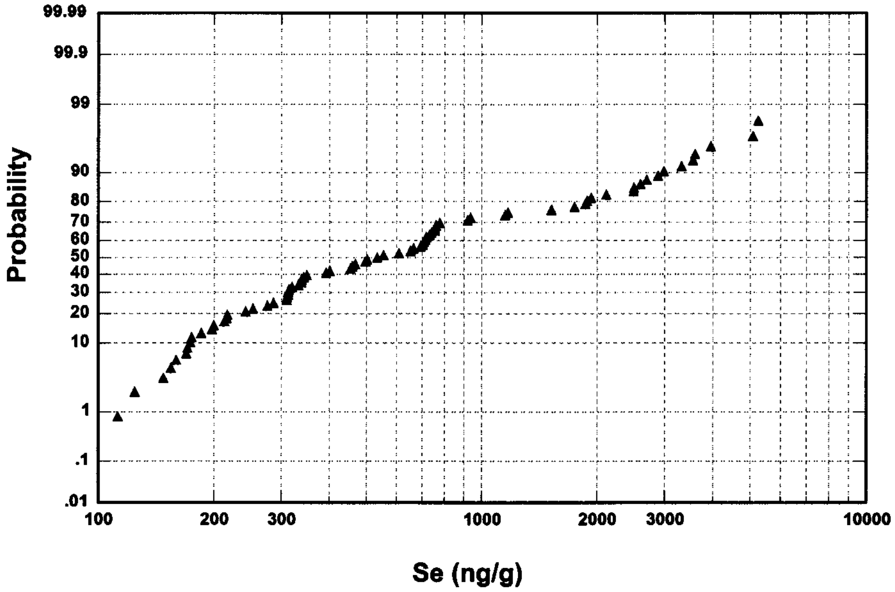


Figure 18. Cumulative probability plot for total Se in soils.

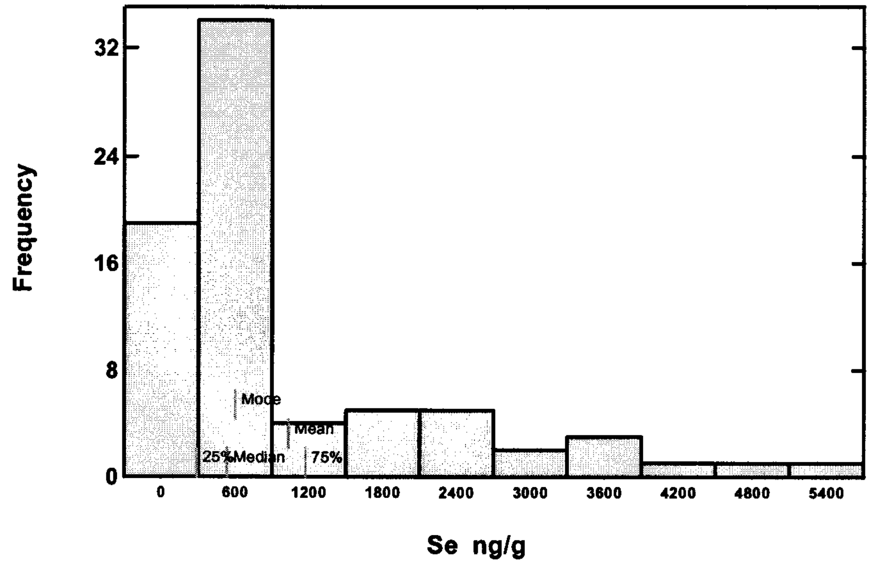


Figure 19. Histogram for total Se in soils.

The box and whisker plots (Figures 20 and 21) do show an apparent relationship between high incidence IDD areas and high levels of Se, this is the opposite to what would be expected if Se deficiency is a causative factor in IDD incidence. However, these are total Se not bioavailable levels and although total soil Se may be high, it may not be available for plant and human uptake.

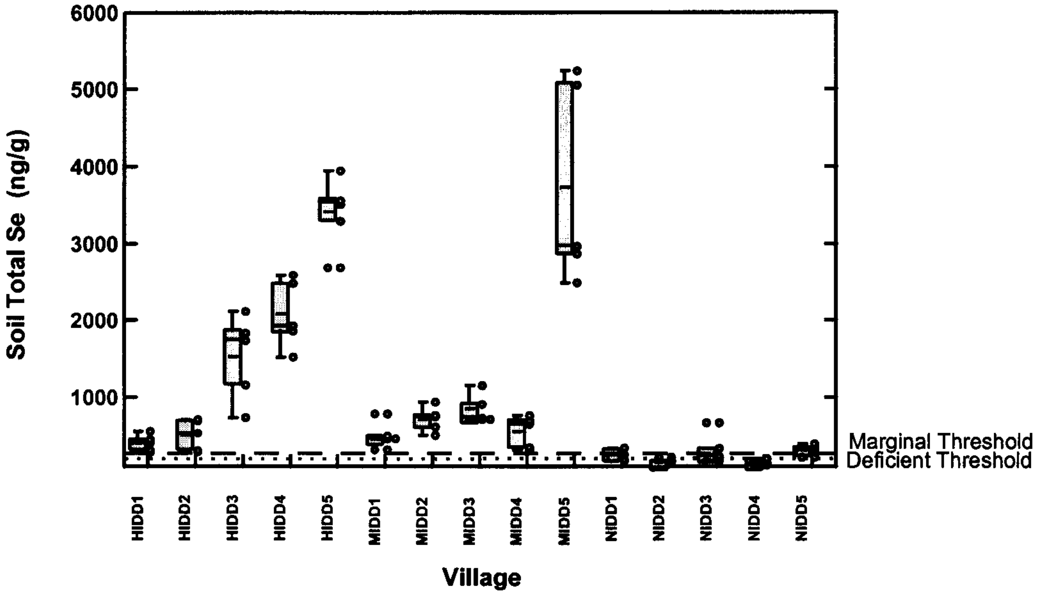


Figure 20. Box and whisker plot for soil total Se in each village classified by IDD incidence. Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in soil levels from Tan (1989). (HIDD = High IDD incidence, MIDD = Moderate IDD incidence and NIDD = Low/no IDD incidence)

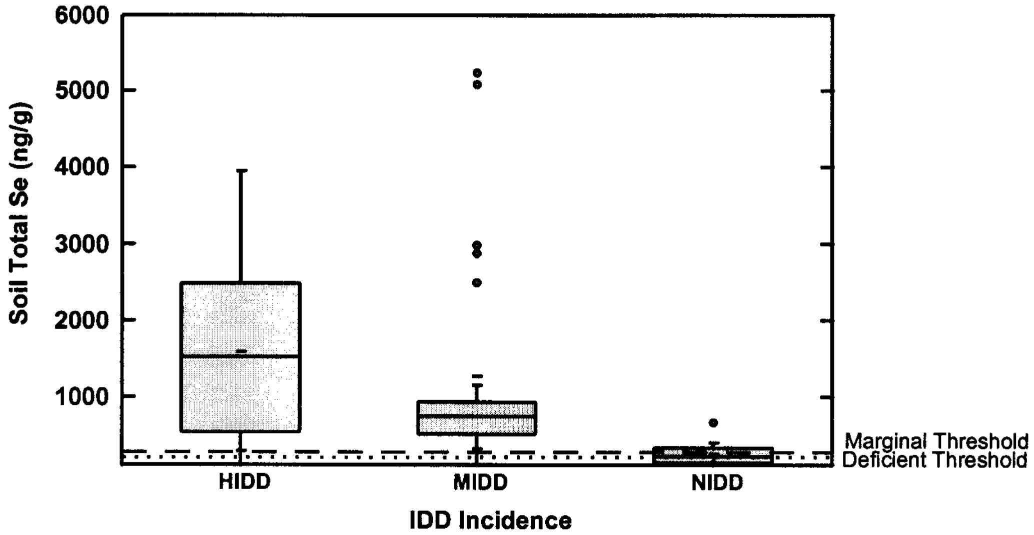


Figure 21. Box and whisker plot for total Se in soils classified by IDD incidence. Marginal and deficient total Se in soil levels from Tan (1989). (HIDD = High IDD, MIDD = Moderate IDD, NIDD = No/low IDD)

Figures 22 and 23 show that there is a very strong partitioning of the data between the Dry Zone, where the Se levels in the cultivated top soils are low, and the Wet Zone where the Se levels are much higher. Furthermore, the Se levels in the soils of the Kalutara coastal region are distinctly higher than those collected from elsewhere, and this could be a result of the differing clay mineral provinces which correspond closely to the main climatic zones of the island. The Kalutara region soils are dominated by kaolinite and gibbsite ($Al(OH)_3$) with minor goethite (FeO.OH) whereas the Kandy region soils comprise kaolinite with minor gibbsite and goethite and the Anuradhapura soils comprise kaolinite with illite (Section 5).

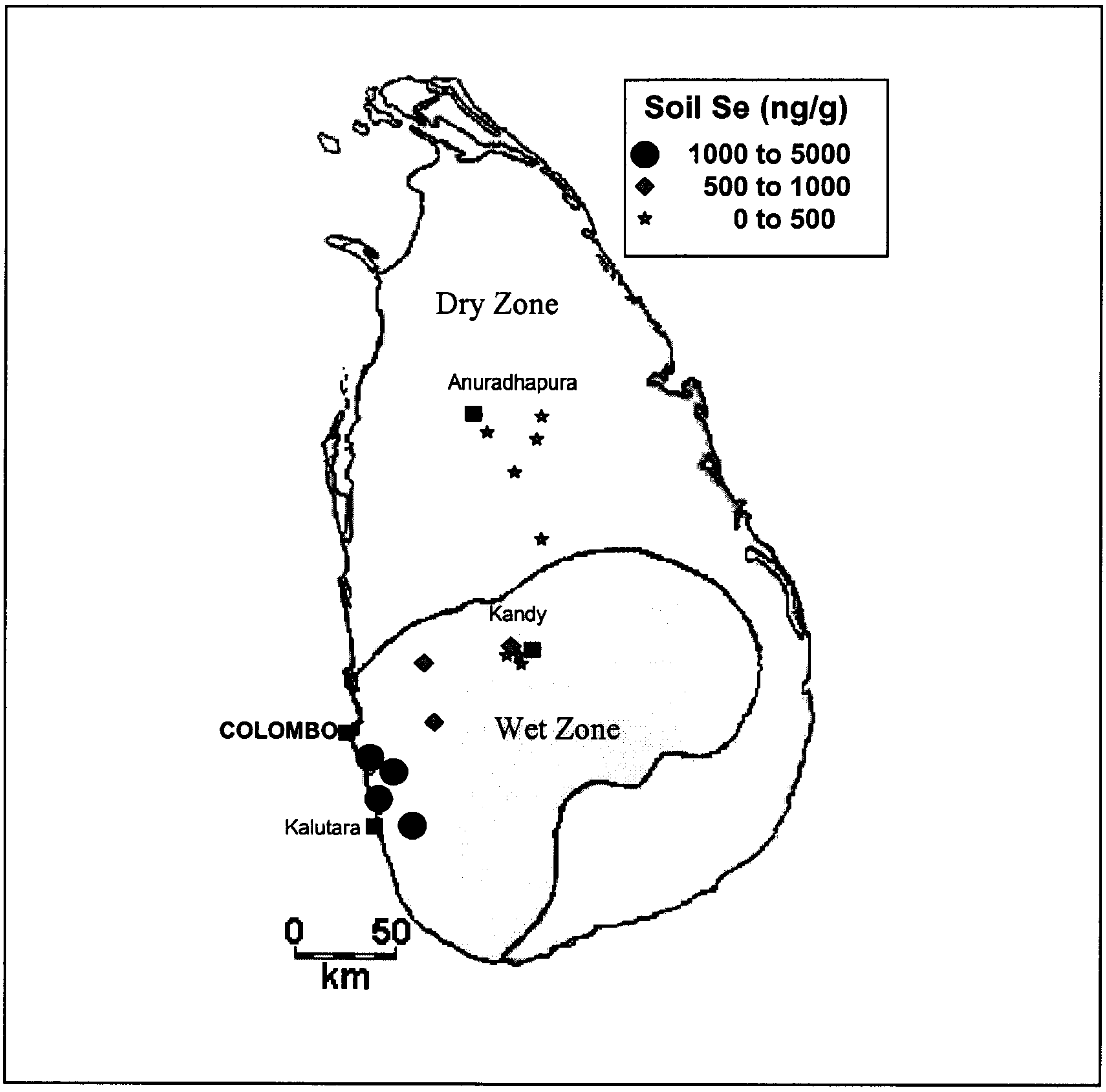


Figure 22. Map showing the total Se content of soils from the fifteen targeted villages based village geometric means values.

9.7 Water Soluble and Phosphate Extractable Selenium

Water soluble and phosphate extractable Se concentrations were determined on composite soil samples from each village. Both these measurements give an indication of the loosely bound Se content in soil which should be readily available for plant uptake. Water soluble Se concentrations range from 4.9 - 42.3 ng/g (geometric mean 10.3 ng/g; arithmetic mean 12.7 ng/g) and phosphate extractable concentrations range from 7.2 - 34.2 ng/g (geometric mean 14.5; arithmetic mean 16.4) (Appendix B).

No clear relationship between water soluble or phosphate extractable Se with IDD incidence is evident (Figure 25). Water soluble Se is generally lower in the Kandy soils than in Kalutara or Anuradhapura soils whereas phosphate extractable Se is highest in the Kalutara villages and Ambepussa (KA5) and Kobbekaduwa (KA4) (Figure 25). Trends in the water soluble Se content of soils in the Kandy and Kalutara regions mirror trends in the total Se content (Figure 23), however this is not the case in the Anuradhapura region.

Water soluble Se concentrations correlate negatively (95% confidence level) with Mn and Fe in soils. This suggests that Fe and Mn oxides and oxyhydroxides may inhibit the availability of Se in soil.

Phosphate extractable Se concentrations correlate significantly (95% confidence level) with soil total Se, Ni and organic matter (TOC) contents and negatively with soil pH, Ca and Mn (Table 7). The correlations with total Se and TOC suggest both these soil parameters exert a significant control on Se availability. Se availability is enhanced by higher total Se levels in soil which may in turn be due greater concentrations of organic matter, holding Se in the soil. The correlation with Ni probably represents geological associations between Ni and Se in the Kandy and Kalutara regions (Section 9.12). The negative correlation with Mn may indicate the inhibition of Se mobility by Mn oxides.

Table 7. Spearman Rank correlation coefficients for extractable Se and geometric mean soil parameters in the 15 study villages.

	Extra Se	WSe	PSe
WSe	0.725		
PSe	0.726	0.185	
I	0.005	0.03	0.090
Se	0.664	0.209	0.822
pH	-0.484	-0.054	-0.662
%Se Adsorption	0.026	-0.270	0.142
Ca	-0.603	-0.211	-0.676
Mn	-0.696	-0.472	-0.560
Fe	-0.302	-0.459	-0.158
Al	0.336	0.261	0.283
Ni	0.512	0.041	0.578
Cu	0.043	-0.266	0.169
Zn	-0.054	-0.202	0.131
TOC	0.596	0.246	0.665

n = 15 r95% = 0.441 (Koch & Link, 1970) WSe = water soluble Se PSe = phosphate extractable Se
Extra Se = water soluble + phosphate extractable Se % Se Adsorption = % residual Se adsorption

In general, Se availability is enhanced in alkaline conditions (Mikkelsen et al., 1989). The negative correlations between phosphate extractable Se and pH and Ca in Sri Lankan soils probably reflects the inverse relationship between soil organic matter and pH. Soil pH is lowered as the organic matter (and associated Se) content of soil increases. Similar controls on soil chemistry were found in the low Se environment of Enshi District, China (Fordyce et al., 1998). These negative relationships may also be due to differences in soil chemistry between the Wet and Dry Zones. Wet Zone soils (Kalutara and Kandy) have lower pH and Ca and higher organic matter content than soils of the Dry Zone (Anuradhapura) (Section 9).

The water soluble and phosphate extractable Se contents added together give an indication of the water soluble and loosely adsorbed Se content. Combined results range from 12.1 - 73.4 ng/g Se (arithmetic mean 29 ng/g; geometric mean 26 ng/g).

As Figure 26 shows, no clear relationship between Se availability and IDD incidence is evident, however, the greater availability of Se in soils in the Kalutara region and in Ambepussa (KA5) is apparent (Figures 26 and 27). Highest extractable Se levels occur in Navinna (MIDD5), the village which contains the highest levels of soil total Se. The combined extractable Se correlates negatively (95% confidence levels) with Mn, pH and Ca, this again may indicate the inhibition of Se availability by Mn oxides and the low levels of Ca in Kalutara soils (Table 7). Positive correlations with total Se, TOC and Ni indicate geological and organic matter associations in a similar way to phosphate extractable correlations.

It is also interesting to consider the combined water soluble and phosphate extractable results as a percentage of the total Se content of the soils. Figure 28 shows the percentage of extractable Se in each village classified by IDD incidence and by region. It is clear that although the Anuradhapura soils (all NIDD and Wet Zone soils) contain less extractable Se on average than the Kalutara soils, a greater proportion of the soil total Se is readily available in this region (Figure 28). In contrast, lowest percentages of extractable Se occur in the Kalutara region.

In summary, highest levels of readily available Se in soil are associated with highest total Se levels. Soil organic matter contents exert an important control on the amount of loosely adsorbed Se in soils from the 15 study villages. Complexing with and adsorption onto Fe and Mn oxides and oxyhydroxides also inhibits Se availability. The highest concentrations of readily extractable Se occur in the Kalutara region (Wet Zone) and the lowest concentrations are found in the Anuradhapura region (Dry Zone). However, a greater proportion of the soil total Se content is readily available for plant uptake in the Anuradhapura region than in the Kalutara region. Trends in extractable Se levels can be summarised as follows (geomeans in brackets):

1. Water Soluble Se (ng/g)	Kalutara (18) > Anuradhapura (10.4) > Kandy (7.1)
2. Phosphate Extractable Se (ng/g)	Kalutara (24.3) > Kandy (16.5) > Anuradhapura (9.3)
3. Extractable Se (1+2) (ng/g)	Kalutara (43.6) > Kandy (23.1) > Anuradhapura (19.9)
4. % Extractable Se	Anuradhapura (8.8) > Kandy (4.2) > Kalutara (1.8)

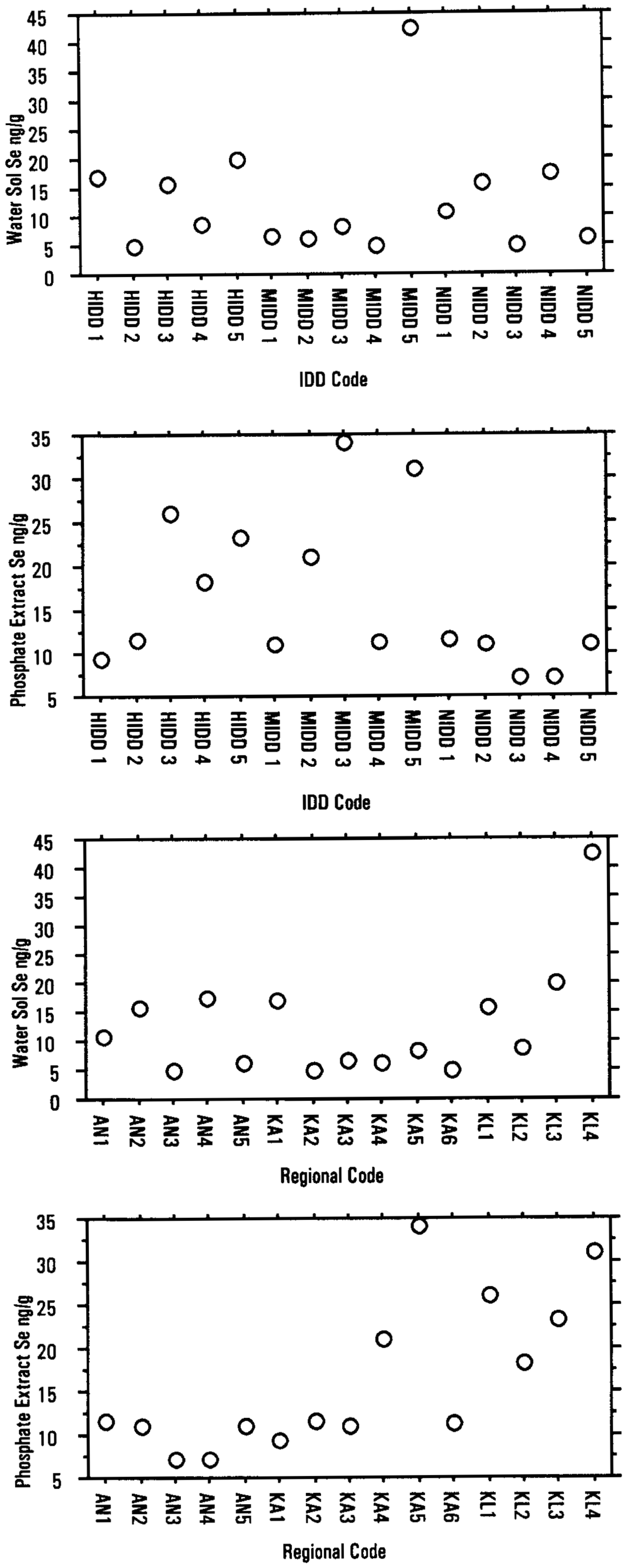


Figure 25. Water soluble Se and phosphate extractable Se concentrations in composite soil samples for each village classified by IDD incidence and region. (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence; AN = Anuradhapura, KA = Kandy, KL = Kalutara)

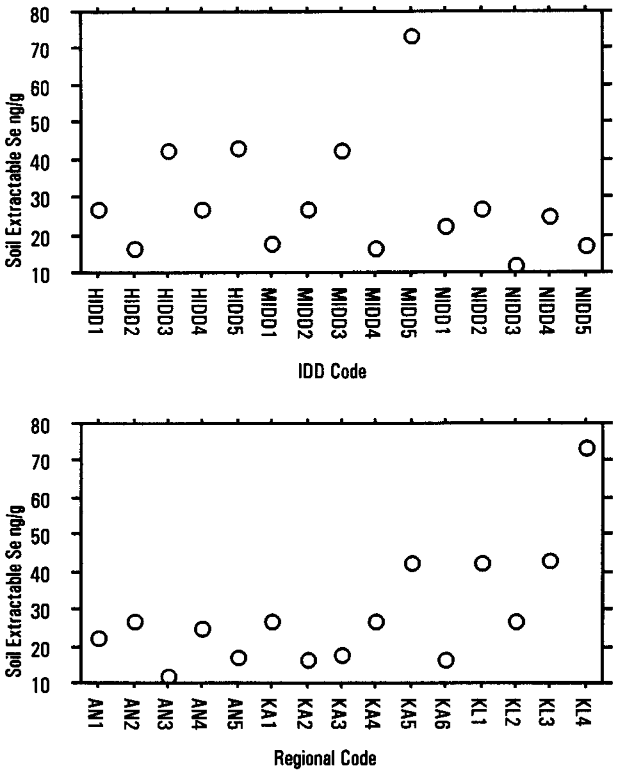


Figure 26. Combined water soluble and phosphate extractable Se in composite soil samples from each village classified by IDD incidence and region. (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence; AN = Anuradhapura, KA = Kandy, KL = Kalutara)

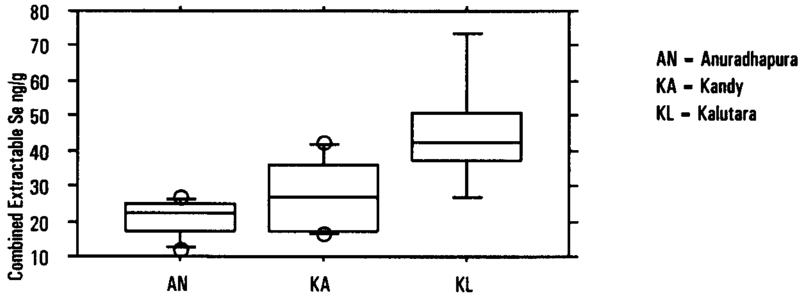
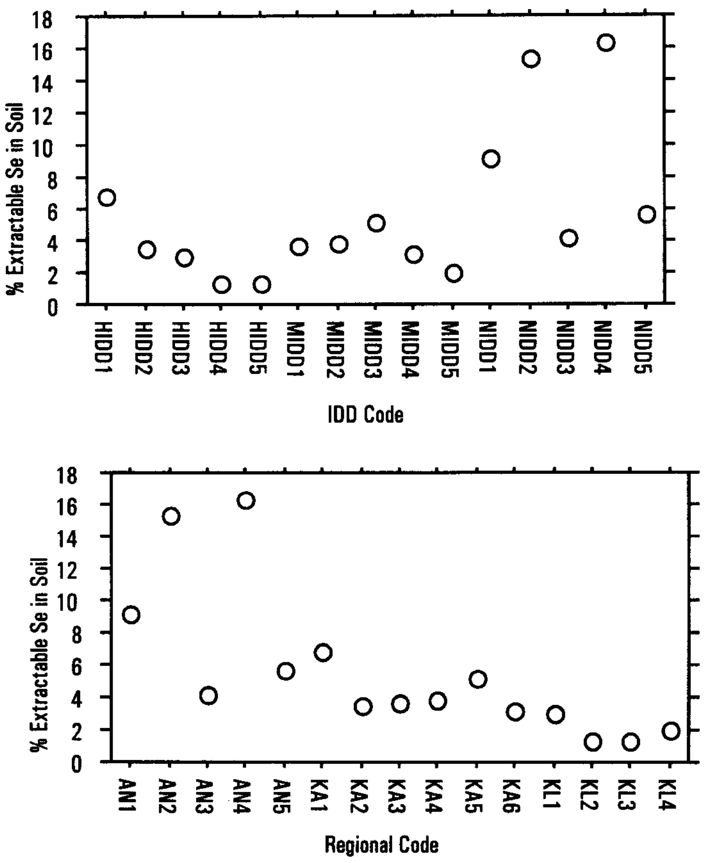


Figure 27. Combined water soluble and phosphate extractable Se in composite soil samples classified by region.



HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence; AN = Anuradhapura, KA = Kandy, KL = Kalutara

Figure 28. Extractable (water soluble + phosphate extractable) Se expressed as a percentage of total Se content in composite soil samples from each village classified by IDD incidence and region.

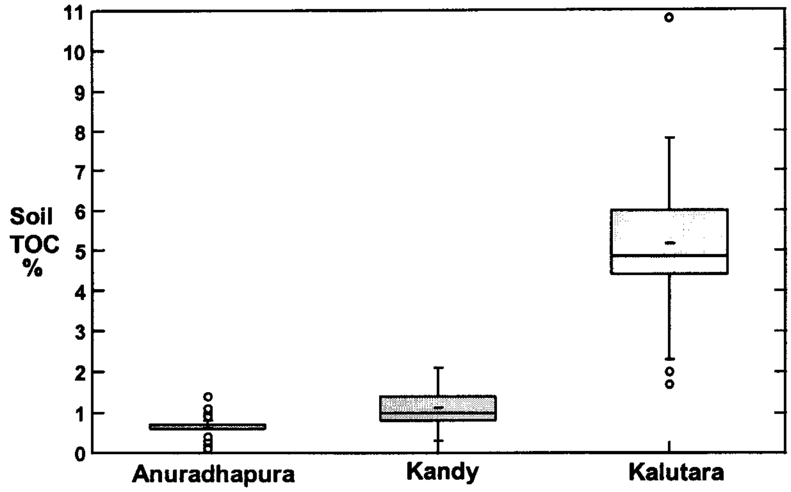
9.8 Total Organic Carbon

TOC results range from 0.1 - 10.8% (mean 2.0%, geomean 1.8%) with a strong partitioning of the results into the different regional groupings as shown by Figures 29 and 30. The Kalutara area has soils high in total organic carbon with all but one of the results being greater than 2% TOC. The Kandy soils have generally less than 2% TOC whereas the Anuradhapura soils have a narrow, low range 1.5 - 0.1%. The highest TOC sample (S42 from Gurudola, HIDD5) contained 10.8% TOC and it was noted at time of collection that the paddy field was very rich in organic matter because the farmer had dug straw into the field. The contrast between the organic matter content of the Wet and Dry Zone soils is probably due to the richness of the vegetation and greater biomass of the Wet Zone. Comparison between regional geometric mean results (in brackets) shows the following trend:

Kalutara (4.7%) > Kandy (1.0%) > Anuradhapura (0.6%)

Soils in HIDD villages have the highest organic matter content (Figure 29).

a)



b)

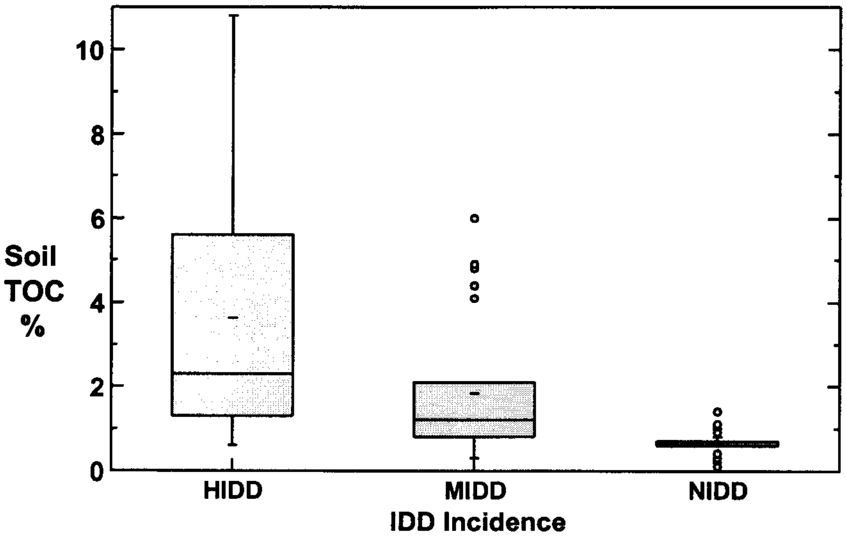


Figure 29. Box and whisker plot for total organic carbon in soils classified by a) region and b) IDD incidence.

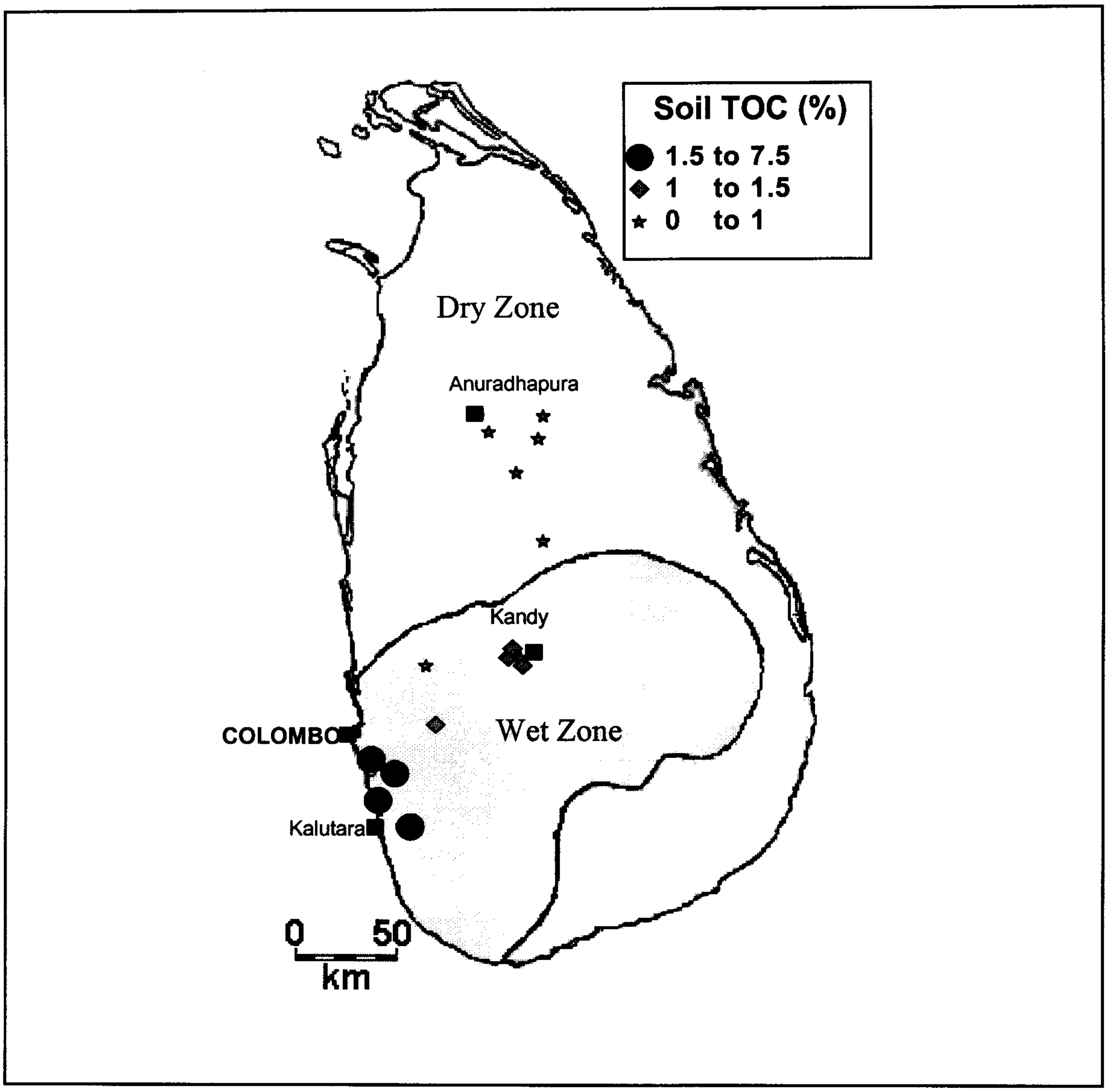


Figure 30. Map showing the total organic carbon (TOC) content of soils from the fifteen targeted villages based on village geometric mean values.

9.9 ICP-AES Results

Summary statistics for the elements determined (Al, Ca, Cu, Fe, Mn, Ni and Zn) are listed in Tables 6 and 8. As Table 8 shows, soils from all three regions (Anuradhapura, Kandy and Kalutara) are depleted in Ca, particularly in the case of the Kalutara soils. This is probably due to a combination of crystalline acid rocks making up the soil parent material and the washing of Ca from the soils in the tropical climate of Sri Lanka. Kalutara soils are also low in Mn and Fe compared to average soils but contain higher than average levels of Al. These results are consistent with lateritic soil development in the Kalutara coastal zone.

Table 8. Average concentrations of elements determined by ICP-AES in soils from Anuradhapura, Kandy and Kalutara compared to world average concentrations.

Region	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg
World Average *	19,600	761	32,000	66,500	34	25	59
Anuradhapura Average	7,831	597	30,936	57,862	22	15	42
Kandy Average	4,524	405	47,506	67,765	35	37	72
Kalutara Average	480	78	19,928	92,482	37	17	51
All Samples	4,548	382	34,628	71,056	31	24	56

*Bowen (1982)

Relative elemental levels reported by Navaratne (1992) for major and trace elements in the soils of the Central Province of Sri Lanka are generally comparable although the present study sampled paddy soils whereas Navaratne (1992) worked on soils from oxidised environments. Figure 31 presents the data as box and whisker plots which show how element distributions vary between the different regions. The Anuradhapura samples have the highest Ca and Mn but the lowest Al and Ni. Ca and Mn are very low in the Kalutara region and Al is high. The Kandy region is characterised by soils that have the highest Cu, Zn and Fe but intermediate amounts of Ca, Mn, Ni and Al. Figure 32 shows the data classified by IDD incidence. Soil Fe concentrations overlap between HIDD, MIDD and NIDD villages. NIDD soils have lowest Al, Ni, Cu and Zn concentrations but highest Ca and Mn contents. HIDD soils have highest Al concentrations and lowest Mn contents

In this study, and that of Navaratne (1992), Ca and Mn exhibit similar geochemical distribution patterns with respect to the intensity of rainfall. Low levels of these elements in Wet Zone soils are due to the high degree of leaching caused by heavy rainfall. Calcic plagioclase and hornblende are good sources of Ca in soils derived from rock types of the Dry Zone. Al concentrations show positive correlation with the intensity of rainfall. Minerals containing Al have a resistance to weathering and, because the alkali and alkaline earth metals are more soluble, Al is left behind and so is relatively enriched (Figure 33).

The Fe results in this report are contrary to those reported by Navaratne (1992) who found higher levels of Fe in the Dry Zone. This difference could be attributed to the fact that this study is looking at paddy soils which are dominated by reducing conditions (anaerobic environment) which favours the mobility rather than precipitation of oxides and hydroxides of Fe.

The elevated levels of Cu and Zn in the Kandy area, particularly some samples from Angunawala (HIDD1), are probably due to urbanisation although geology of the area could also be responsible for the higher levels of Cu and Zn. The Cu result for sample S3 from Angunawala, taken from a field adjacent to a telegraph support wire, was very high (152 mg/kg) and this outlier has been omitted from the Cu plots in Figures 31, 32 and 33.

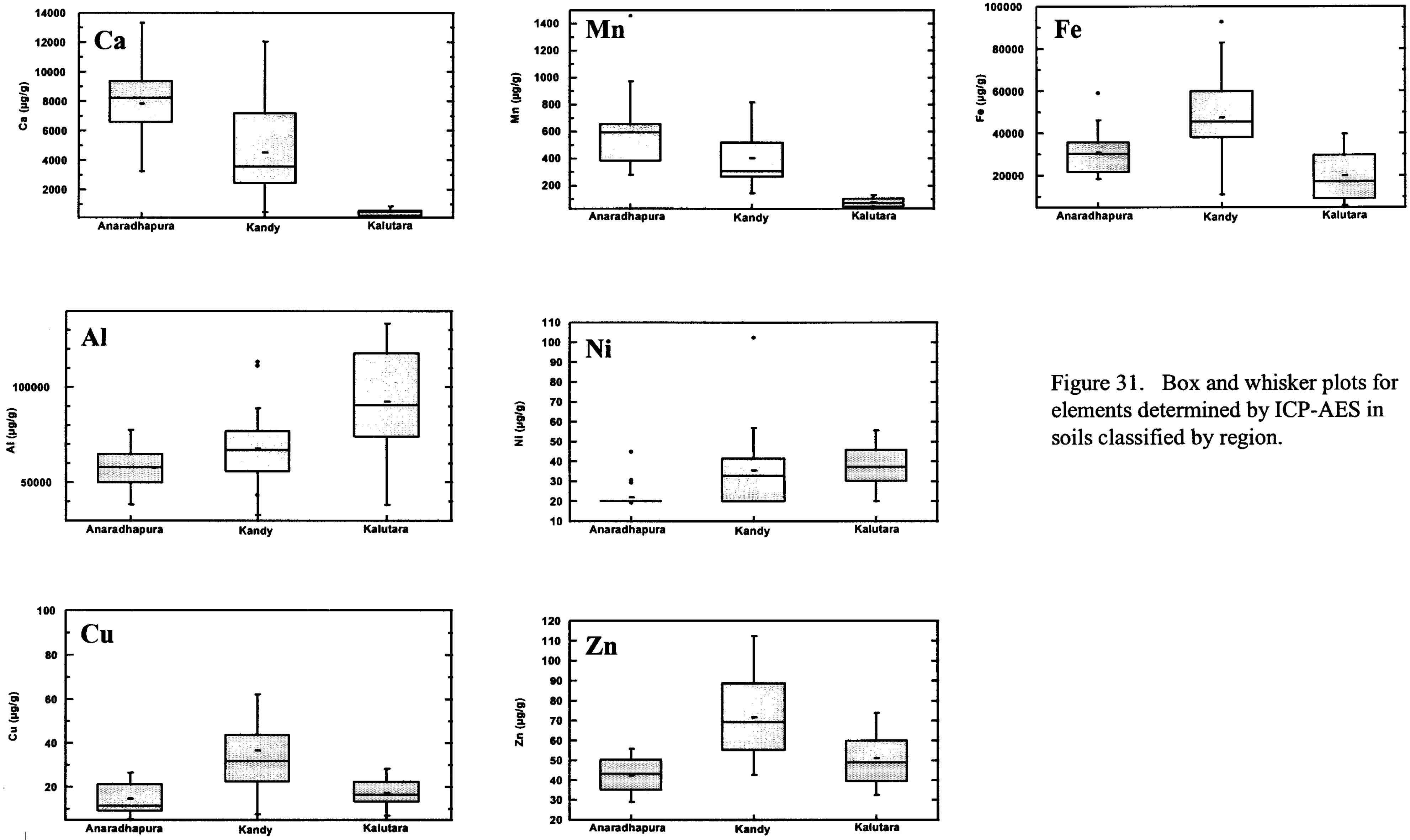


Figure 31. Box and whisker plots for elements determined by ICP-AES in soils classified by region.

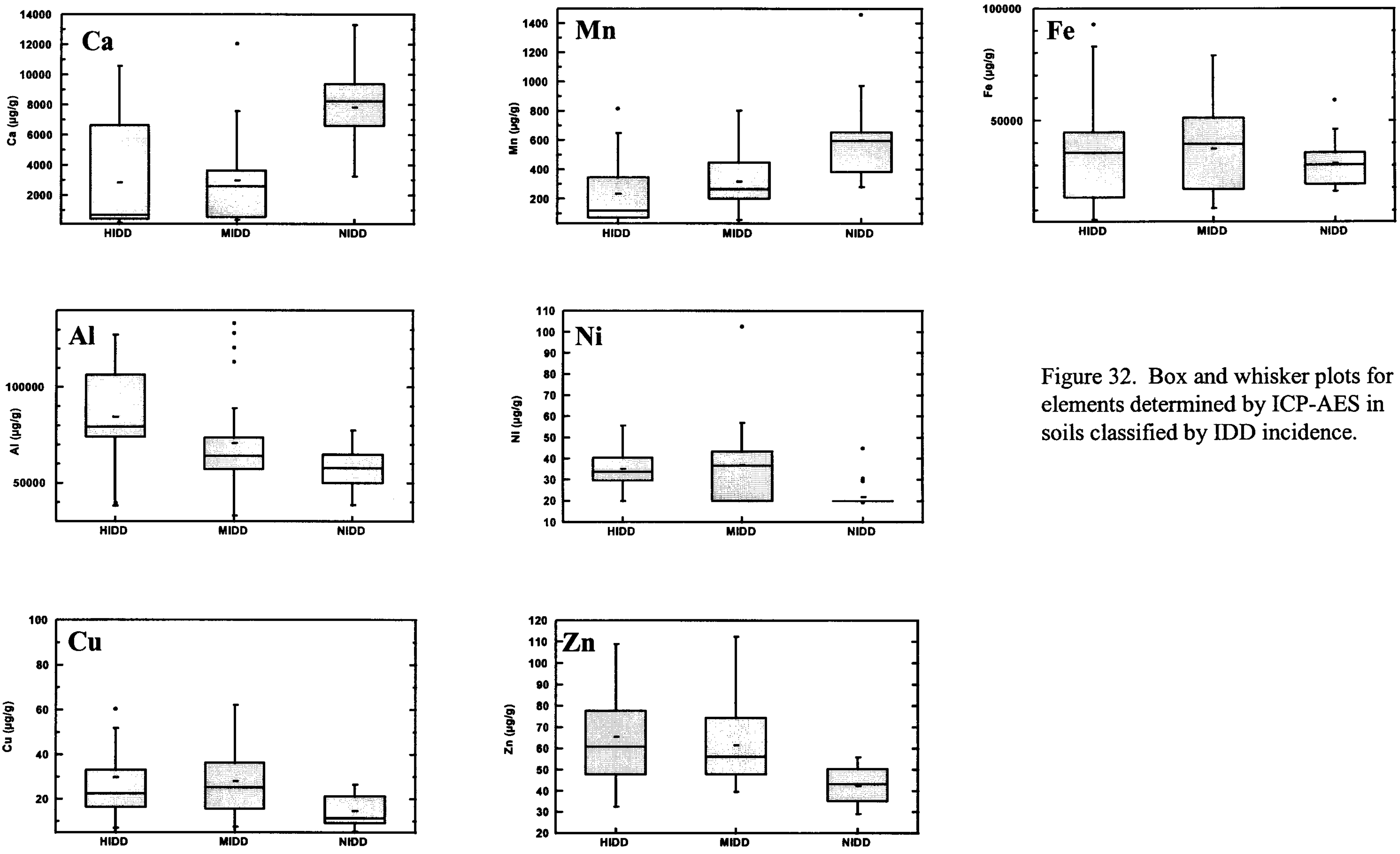


Figure 32. Box and whisker plots for elements determined by ICP-AES in soils classified by IDD incidence.

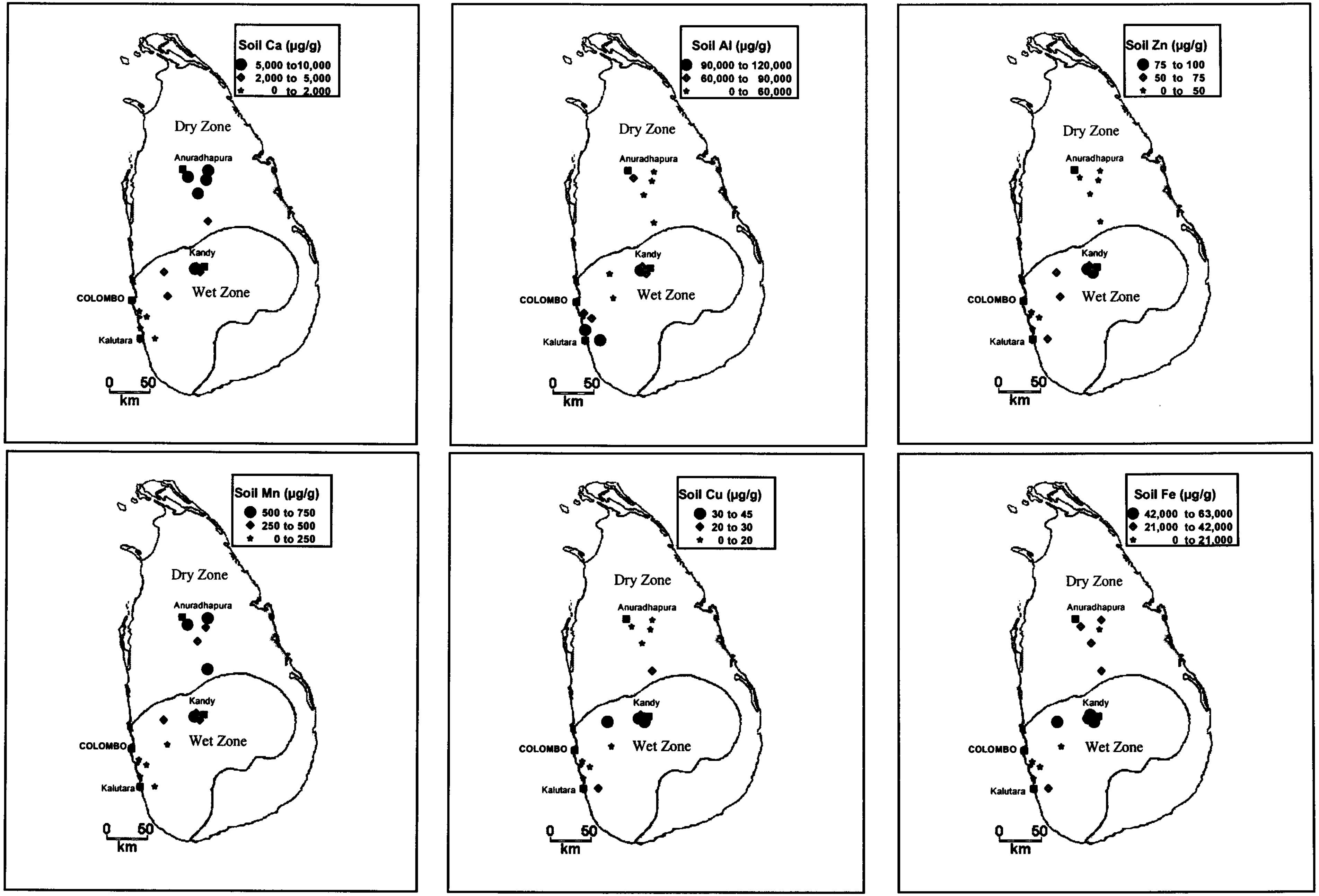


Figure 33. Maps showing concentration of elements determined by ICP-AES in soils from the fifteen targeted villages based village geometric mean values.

9.10 Selenium Adsorption Studies

Se (in the form of selenite) adsorption studies were carried out on the soils collected from the 15 villages (Navaratne, In Prep). Since the soils already contain a certain amount of Se, these studies test the ability of the soils to adsorb more Se or the residual Se adsorption capacity. Summary statistics for the percentage residual Se adsorption are given in Table 6. The average residual Se adsorption was 91.8% (geomean 90.6%) with a range of 50.1->99.75%. (Note that for statistical calculations values >99.75% have been substituted with a value of 99.9%). The majority of samples had the residual capacity to adsorb a high percentage of the Se. The geomean results for each of the 15 targeted villages are plotted on Figure 34. This shows that the soils around Kandy have the highest residual adsorption capacity but there appears to be no relationship with the Wet or Dry Zones.

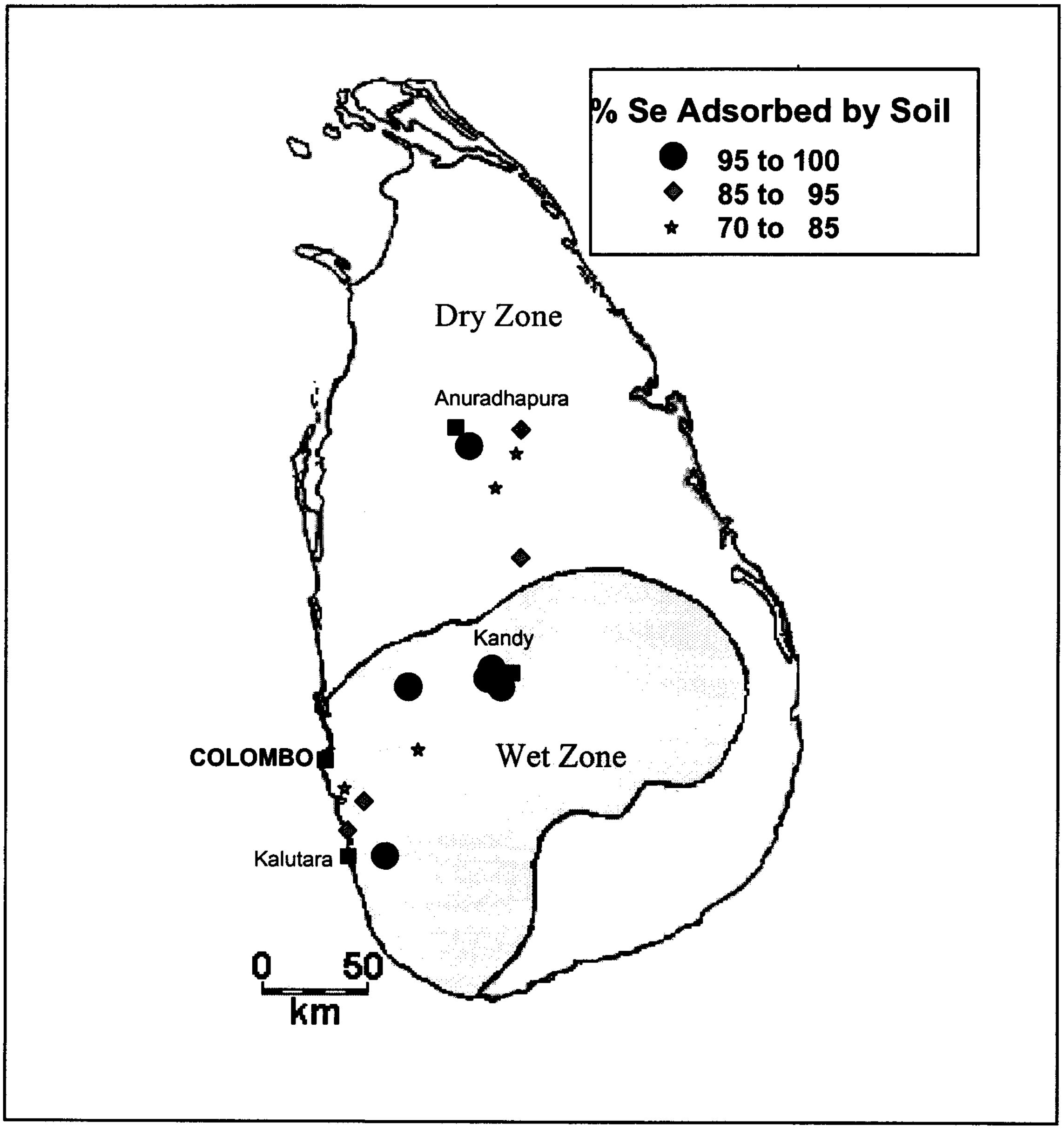


Figure 34. Map showing the percentage residual Se adsorption capacity of soils from the fifteen targeted villages based on village geometric mean values.

Figure 35 is a box and whisker plot of the residual adsorption results classified by region. This confirms that the Kandy region samples have the highest residual adsorption capacities although in all regions there is a wide range of results. Investigations into the Se adsorption capacities of the minerals goethite and gibbsite have shown that they are similar (Navaratne, In Prep). The levels of Fe (goethite) in soils in the Kandy region are three times that of the Kalutara region whereas the difference in Al (gibbsite) concentrations between the two regions is less marked (mean ~ 88,000 mg/kg Kalutara; mean ~64,000 mg/kg Kandy, Figure 31). The trends in residual Se adsorption capacity between regions (Figure 35) mirror the distribution of Fe and not Al. This suggests that the ability of the soils to adsorb more Se is controlled by goethite rather than gibbsite.

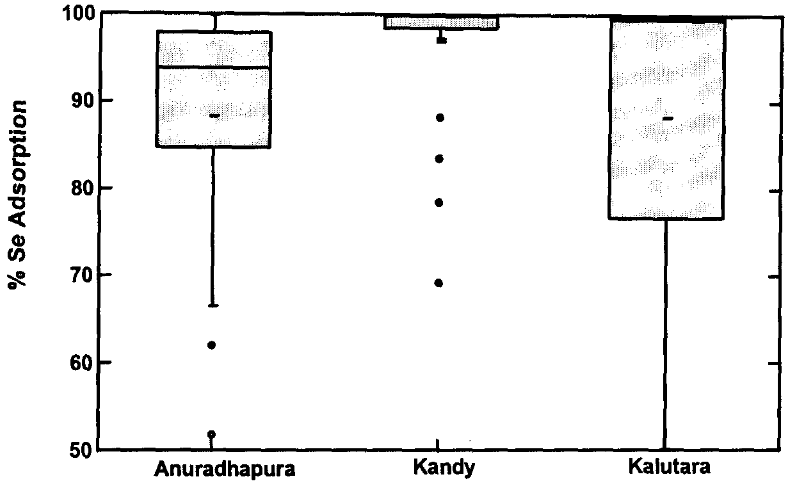


Figure 35. Box and whisker plot for the residual Se adsorption capacity of soils classified by region.

A comparison of the geomeans from the three regions (Table 6) shows the following trend in soil residual Se adsorption capacity:

Kandy (96.6%) > Kalutara (86.4%) ≈ Anuradhapura (87.2%)

A plot of the percentage Se adsorbed against the total Se content of the soil is shown in Figure 36. This does not show any clear relationship between soil total Se and residual Se adsorption capacity but the Spearman Rank correlation coefficient is significant at the 99.9% confidence level (r_{sp} = 0.350) (Section 9.12). Although in several cases, soils which already contain a high concentration of Se have the ability to adsorb significantly more, some of the soils high Se soils have a low residual Se adsorption capacity presumably because the majority of adsorption sites are already filled. Figure 36 also illustrates that the soils with the highest Se are darker in colour indicating a higher organic content.

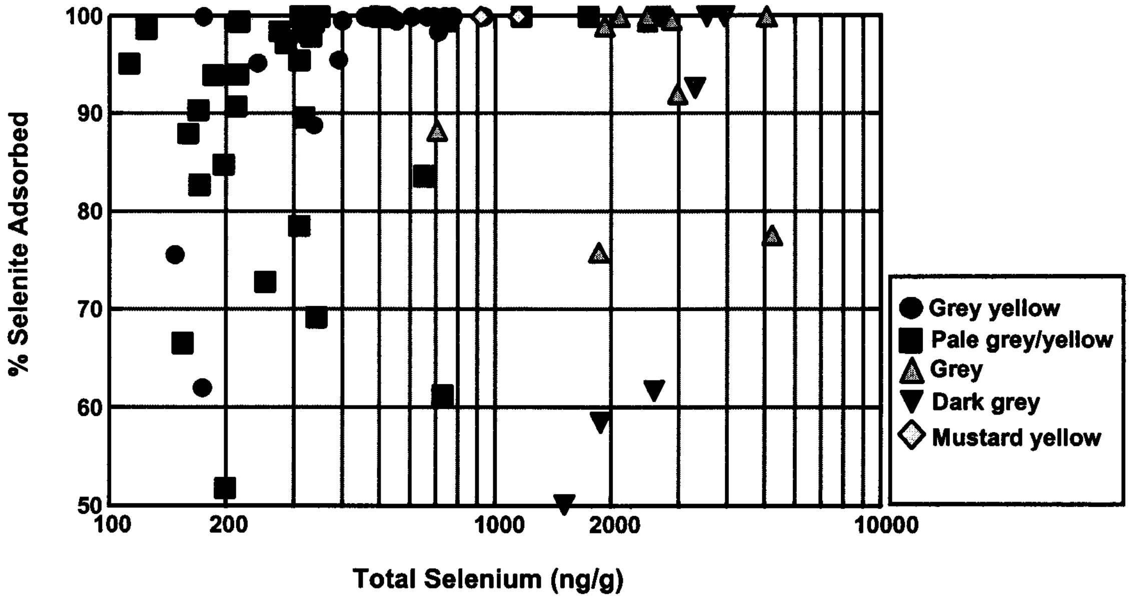


Figure 36. Plot of percentage residual Se adsorption versus total Se in soils classified by dry soil colour.

9.11 X-ray Diffraction Analysis of Six Soil Samples

Six of the soil samples were selected for mineralogical analysis (Appendix B). The results of a semi-quantitative XRD analysis are summarised in Table 9.

Table 9. Summary of semi-quantitative XRD bulk mineralogical determinations in six soil samples.

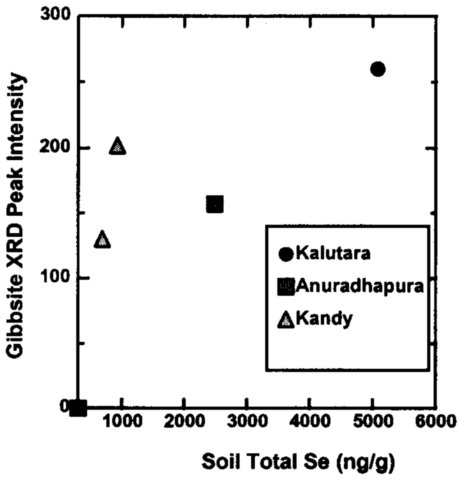
Sample Number	Village Code	Major	Minor	Trace	Total Se (ng/g)	% Residual Se Adsorption Capacity
SL-S-8	MIDD5 (KL4)	Quartz	Kaolinite (150)*†, gibbsite (260)*	Smectite (80)*†, albite	5079	>99.75
SL-S-25	NIDD5 (AN5)	Quartz	Gibbsite (511), kaolinite (157)	Smectite (30), albite, orthoclase	2489	99.4
SL-S-54	NIDD3 (AN3)	Quartz	Albite, orthoclase	Kaolinite (43), ?goethite	338	88.8
SL-S-61	MIDD2 (KA4)	Quartz	Gibbsite (202), Kaolinite (83)	Orthoclase, albite, hematite	935	>99.75
SL-S-65	NIDD5 (AN5)	Quartz	Orthoclase	Albite, kaolinite (53, amphibole, smectite (52)	309	95.4
SL-S-89	HIDD2 (KA2)	Quartz	Kaolinite (272)	Smectite (66), Gibbsite (130), orthoclase, albite, hematite, amphibole	692	>99.77

* Peak intensities measured: Kaolinite, d=7.14Å, Gibbsite d= 4.83Å, Smectite d=14.1Å

† Precise identification of the clay minerals species present from a bulk XRD trace is not possible

From a plot of the peak intensities for gibbsite (Figure 37) it is suggested that Se in the soil is related to the amount of gibbsite which is a strong adsorber of Se. During the XRD analysis, the main goethite line was obscured by the presence of a large proportion of quartz. Therefore, the detection of goethite was difficult (Appendix B). Adsorption of Se onto goethite is discussed in Section 9.12 in the context of correlations with the Fe analyses.

Figure 37. A plot of the gibbsite XRD peak intensity against the total Se content of the soil classified by region. The peak intensity is used as a semi-quantitative indication of the amount of gibbsite present.



9.12 Correlations and Geochemical Associations

9.12.1 Correlation Analysis

The Spearman Rank correlation matrix for soil analyses is given in Table 10. For 75 samples at a 99.9% confidence level, correlations above 0.37 are significant. Figure 38 shows the highest Spearman Rank correlation coefficients (i.e. > 0.59) in order to illustrate the main correlation groupings. Three distinct groupings are seen:

1. Fe-Cu-(Zn)-(% residual Se adsorption capacity)
2. TOC-Se-(Ni)-(Al)
3. Mn-Ca-(pH) (this group showing negative correlations with group 2)

Tables 11 to 13 give the Spearman Rank correlation coefficients for the three regional subsets of the data. These correlations show that, even with a small number of samples, there are highly significant correlations between the elements determined, emphasising the importance of some elements, particularly Al, Fe and Mn. The co-variation of these three elements with elements such as I, Se, Cu, Ni and Zn could be due to adsorption by Al, Fe and Mn oxides and oxyhydroxides or could be due simply to variation in bedrock composition.

The Kalutara region samples have many correlations in excess of 0.8 (total Se, total iodine and Ca, with Fe, Al, Ni, Cu, Zn and TOC).

The residual Se adsorption capacity correlates more significantly with Fe than with Mn or Al in all three regions and does not correlate significantly with TOC. This suggests that goethite exerts a greater control on potential for the soils to adsorb more Se within each region than Mn oxides, gibbsite or organic matter.

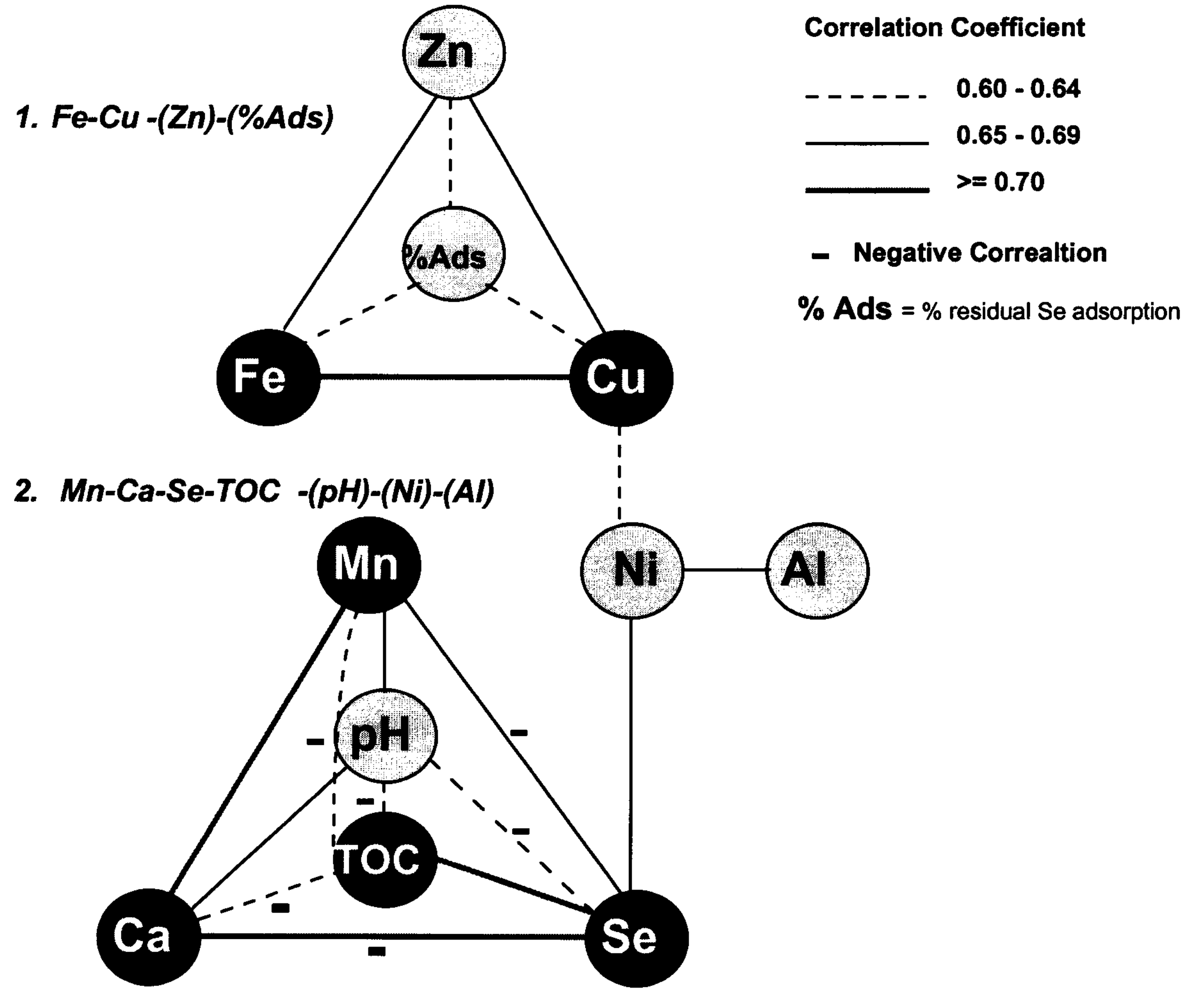


Figure 38. Diagram showing the highest Spearman Rank correlation coefficients in soils.

Although there is a positive correlation between Ca and pH and a negative correlation between pH and TOC in the whole dataset (Table 10), in the regional data sets similar correlations are lacking. This may be due to the anoxic environment of the paddy soils sampled in this study. Furthermore, the lack of correlation between pH and Ca may be a result of the generally low levels of Ca in Sri Lankan soils. Soil pH correlates positively with Fe, Mn, Ni, Cu and Zn in the Kandy region but exhibits no significant correlations in the other two regions. This may be due to the rock types of the Kandy area which are more mafic (Kadugannawa Complex) than the rocks surrounding Anuradhapura and Kalutara (Section 5).

A plot of the total Se in the soil against TOC (Figure 39) shows a good linear relationship ($r_{sp} = 0.78$, $n = 75$) and a very significant regional partitioning of the data. The Kalutara region samples plot as a distinct group with high TOC and high total Se. If the TOC versus Se plot is classified on the basis of dry soil colour (Figure 40) it can be seen that all the grey coloured soils, which occur in the Kalutara region, have highest TOC.

Table 10. Spearman Rank correlation matrix for all soil results (n = 75).

	Total I	Total Se	pH	% Se ads	Ca	Mn	Fe	Al	Ni	Cu	Zn
Total Se	0.4092										
pH	0.0270	-0.6388									
% Se ads.	0.1442	0.3536	-0.1725								
Ca	-0.1927	-0.7589	0.6545	-0.0938							
Mn	-0.0504	-0.6526	0.6892	0.0940	0.8011						
Fe	0.0602	-0.0821	0.1740	0.6278	0.3652	0.5928					
Al	0.5526	0.5563	-0.2829	0.3766	-0.2188	-0.2341	0.1179				
Ni	0.4038	0.6858	-0.3414	0.5865	-0.3193	-0.1704	0.3358	0.6924			
Cu	0.1068	0.3110	-0.1200	0.6133	-0.0034	0.2075	0.7536	0.3547	0.6087		
Zn	0.1849	0.2570	-0.3033	0.6019	-0.0217	0.1235	0.6458	0.4413	0.5256	0.6684	
TOC	0.4250	0.7785	-0.6052	0.2058	-0.6149	-0.6182	-0.1703	0.5700	0.5768	0.1815	0.3189

Correlations ≥ 99.9% confidence level are shaded grey. % Se ads = % residual Se adsorption

Table 11. Spearman Rank correlation matrix for Anuradhapura region soils (n =25).

	Total I	Total Se	pH	% Se ads	Ca	Mn	Fe	Al	Ni	Cu	Zn
Total Se	0.3294										
pH	0.2827	0.2569									
% Se ads.	0.3905	0.4319	0.1694								
Ca	0.0220	-0.3577	0.1208	-0.0901							
Mn	0.6329	0.1446	0.1985	0.4226	0.2208						
Fe	0.6263	0.4662	0.3546	0.6628	-0.3262	0.6000					
Al	0.7096	0.2031	0.3746	0.4373	0.2423	0.5354	0.5331				
Ni	0.4633	0.2385	0.3096	0.1411	0.2349	0.3397	0.2807	0.5722			
Cu	0.5724	0.6331	0.4731	0.5635	-0.2508	0.5592	0.8723	0.4846	0.2819		
Zn	0.6283	0.2485	0.2162	0.5804	-0.1838	0.6877	0.7800	0.4431	0.1349	0.6754	
TOC	0.1868	0.1566	0.1678	0.2964	0.2005	0.1698	0.1770	0.1463	0.0836	0.2156	0.2519

Correlations ≥ 99.9% confidence level are shaded grey. % Se ads. = % residual Se adsorption

Table 12. Spearman Rank correlation matrix for Kandy region soils (n = 30).

	Total I	Total Se	pH	% Se ads	Ca	Mn	Fe	Al	Ni	Cu	Zn
Total Se	0.3950										
pH	0.4311	0.1818									
% Se ads.	0.2587	0.4030	0.5034								
Ca	0.1008	-0.2111	0.2503	0.0492							
Mn	0.4298	0.1702	0.5982	0.4427	0.6418						
Fe	0.5252	0.3913	0.7775	0.6332	0.3321	0.8367					
Al	0.3595	-0.1034	0.3135	0.2856	0.6743	0.6009	0.4630				
Ni	0.4991	0.4400	0.5459	0.6867	0.2154	0.7710	0.8021	0.4805			
Cu	0.4237	0.1835	0.7148	0.5668	0.5021	0.8265	0.8323	0.4839	0.7205		
Zn	0.4996	-0.1786	0.3971	0.1233	0.5546	0.5689	0.4549	0.6859	0.4643	0.5146	
TOC	0.4491	0.1966	0.1098	0.0437	0.2274	0.3209	0.3124	0.2804	0.4091	0.2818	0.5351

Correlations ≥ 99.9% confidence level are shaded grey. % Se ads. = % residual Se adsorption

Table 13. Spearman Rank correlation matrix for Kalutara region soils (n = 20).

	Total I	Total Se	pH	% Se ads	Ca	Mn	Fe	Al	Ni	Cu	Zn
Total Se	0.7419										
pH	0.0391	0.1609									
% Se ads.	0.3368	0.3342	-0.1245								
Ca	0.6539	0.6767	-0.0782	0.4430							
Mn	-0.2709	-0.2211	0.2015	0.4225	0.1053						
Fe	0.4929	0.4842	-0.1654	0.7631	0.7534	0.5188					
Al	0.5290	0.8075	0.1504	0.3721	0.5519	-0.1624	0.4812				
Ni	0.4930	0.7883	0.0775	0.4637	0.5882	-0.2121	0.4633	0.9319			
Cu	0.5425	0.7835	-0.0030	0.3059	0.6241	-0.3639	0.3504	0.8060	0.8785		
Zn	0.5365	0.5323	-0.1594	0.7678	0.8286	0.3880	0.9368	0.5459	0.5604	0.5383	
TOC	0.8384	0.5992	-0.1039	0.2683	0.6165	-0.3779	0.3846	0.4102	0.4752	0.5924	0.5058

Correlations ≥ 99.9% confidence level are shaded grey. % Se ads. = % residual Se adsorption

The correlation between total iodine and TOC ($r_{sp} = 0.43$) is not as strong as the Se-TOC correlation but is significant at the 99.99% confidence level. Figure 41, a plot of total iodine against TOC reveals an interesting relationship not shown by the correlation result for the whole data set. The high organic soils of the Kalutara region do reveal a significant linear relationship with the total iodine ($r_{sp} = 0.84$, $n = 20$) whereas the low organic soils of the Anuradhapura region show no correlation at all ($r_{sp} = 0.019$). The iodine-TOC correlation for the Kandy region is also significant ($r_{sp} = 0.45$, $n = 30$) but not as strong as that found in the Kalutara area. It is evident that at low levels, organic matter exerts little control over soil iodine concentrations.

Figures 42 and 43 are plots of the Kalutara region soils ($n = 20$) showing that there is good correlation between Se, iodine and TOC, and between Se and Al and, to a lesser extent, between iodine and Al.

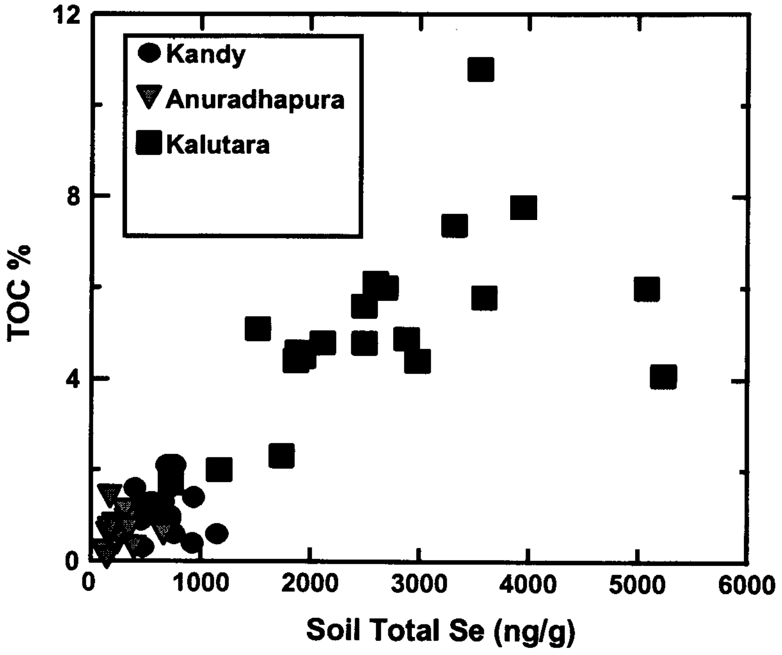


Figure 39. Plot of TOC against total Se for all soils classified by region.

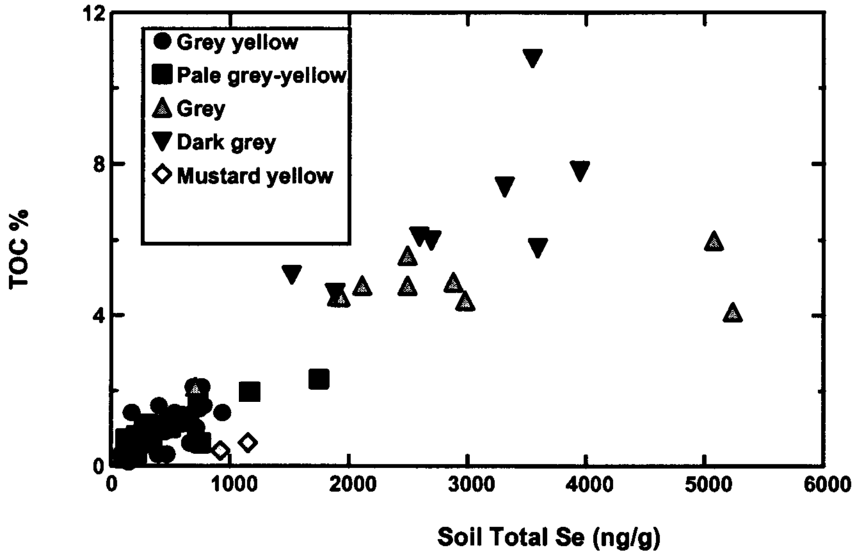
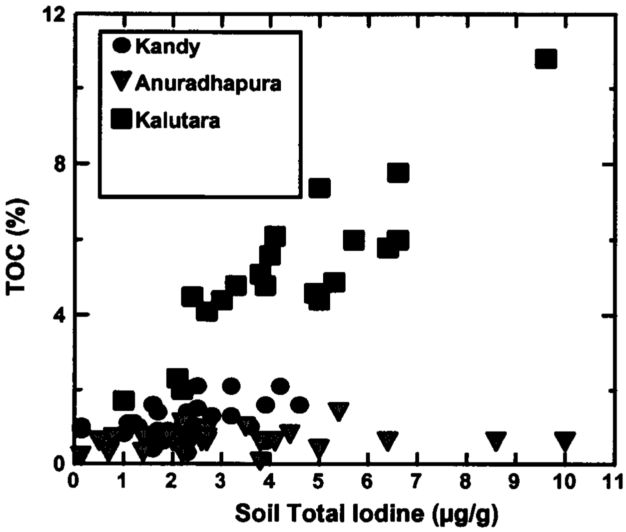


Figure 40. Plot of TOC against total Se classified by dry soil colour.

Figure 41. Plot of TOC against total iodine for all soil samples classified by region.



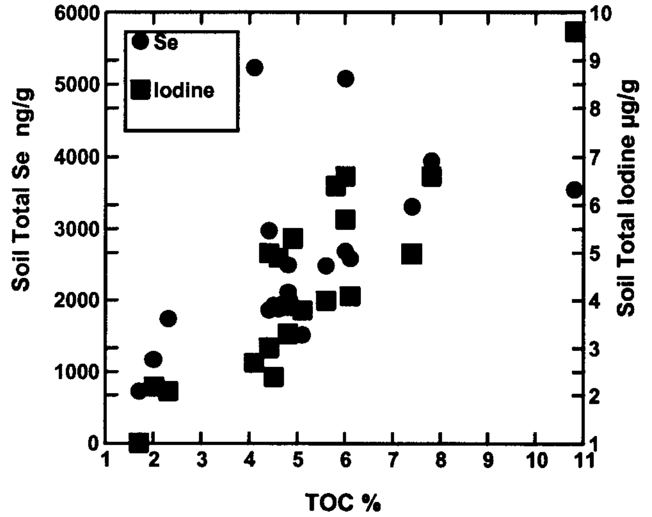
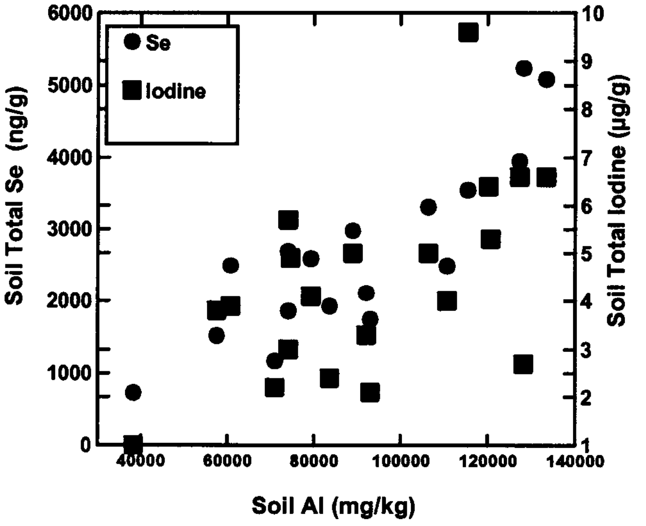


Figure 42. Plot of total Se and iodine against TOC for Kalutara region soils.

Figure 43. Plot of total Se and iodine against Al for Kalutara region soils.



9.12.2 Factor Analysis

Factor analysis is a further statistical tool that can be used to identify element associations. Table 14 gives the first three factors based on oblique factor scores from principal component analysis of all the soil samples.

From the table three factors are identified:

(i) I-Se-Al-TOC
(ii) Fe-(Ni)-Cu-Zn-(% residual Se adsorption)
(iii) pH-Ca-Mn

Table 14. Factors from Principal Component Analysis for all soils (oblique rotation factor matrix).

	Factor 1	Factor 2	Factor 3
Iodine µg/g	0.90	-0.05	0.30
Se ng/g	0.71	-0.09	-0.47
pH	0.13	-0.33	0.91
% Se ads.	0.09	0.65	0.06
Ca mg/kg	-0.13	0.11	0.81
Mn mg/kg	-0.03	0.29	0.85
Fe mg/kg	-0.03	0.84	0.31
Al mg/kg	0.78	0.32	-0.13
Ni mg/kg	0.49	0.62	-0.10
Cu mg/kg	-0.12	0.81	-0.05
Zn mg/kg	-0.01	0.89	-0.14
TOC %	0.71	-0.12	-0.46

% Se ads. = % residual Se adsorption

Tables 15 - 17 show oblique factor scores for the regional subsets of the soil data. Identified factors are (lower factor weightings in brackets):

Anuradhapura (a) (% residual Se adsorption)-Mn-Fe-Zn-(TOC)
(b) Ca-(Cu)-(Al)
(c) (Se)-I-Ni
(d) pH

Kandy (a) pH-% residual Se adsorption-Mn-Fe-(Al)-(Ni)-(Cu)
(b) I-(Ca)
(c) (Se)-(Zn)-TOC

Kalutara (a) Se-(I)-Al-Ni-Cu
(b) % residual Se adsorption-(Ca)-Mn-Fe-Zn
(c) pH-(TOC)

Using the criteria described by Howarth & Sinding-Larsen (1983) for interpreting element associations many of these factors would be rejected as they include several elements with relatively low factor weightings. However, it does show that there are different element groupings between the regions with the only consistent association being capacity to adsorb more Se -Mn -Fe.

Table 15. Factors from Principal Component Analysis for Anuradhapura soils (oblique rotation factor matrix).

	Factor 1	Factor 2	Factor 3	Factor 4
Se	0.3947	0.2319	-0.5759	0.0037
I	-0.0545	-0.2923	-0.8404	0.0549
pH	0.0238	-0.0736	-0.1705	0.9062
% Se ads.	0.6218	-0.1327	-0.2209	-0.4781
Ca	-0.0394	0.8902	-0.0882	0.0194
Mn	0.7524	0.0581	-0.1043	-0.0202
Fe	0.8158	-0.2192	-0.1702	0.1121
Al	0.4020	0.4997	-0.4929	0.1530
Ni	-0.0744	0.1737	-0.9270	0.0800
Cu	0.4129	-0.6063	-0.3705	0.2235
Zn	0.9081	-0.1132	0.0164	-0.1237
TOC %	0.6385	0.1345	0.2873	0.2101

% Se ads. = % residual Se adsorption

Table 16. Factors from Principal Component Analysis for Kandy soils (oblique rotation factor matrix).

	Factor 1	Factor 2	Factor 3
Se	0.3012	0.2790	0.6622
I	0.3578	0.8332	0.1444
pH	0.7449	0.0397	0.0667
% Se ads.	0.8304	0.1182	-0.3510
Ca	0.5319	-0.6135	0.0425
Mn	0.7614	0.0322	0.2760
Fe	0.8780	0.1314	0.1295
Al	0.6080	-0.3359	0.2885
Ni	0.6653	0.1233	0.3880
Cu	0.6066	-0.3592	-0.0270
Zn	0.2806	-0.5111	0.5684
TOC %	-0.1393	-0.0025	0.8857

% Se ads. = % residual Se adsorption

Table 17. Factors from Principal Component Analysis for Kalutara soils (oblique rotation factor matrix).

	Factor 1	Factor 2	Factor 3
Se	0.9523	0.0042	0.0806
I	0.5358	0.2196	-0.5110
pH	0.3284	0.0033	0.7319
% Se ads.	0.2162	0.7327	0.2420
Ca	0.4010	0.5528	-0.3477
Mn	-0.5995	0.7826	0.4012
Fe	0.0987	0.8481	-0.3598
Al	0.8914	0.1815	0.1144
Ni	0.9134	0.1513	0.2518
Cu	0.9322	-0.0233	-0.0270
Zn	0.2488	0.8163	-0.2600
TOC %	0.5377	0.1141	-0.5700

% Se ads. = % residual Se adsorption

10. RICE RESULTS

10.1 Introduction

Rice was only grain type sampled in the 15 study villages as it was the predominant cereal crop grown and is the major component of the staple diet of Sri Lankan villagers, Mahadeva et al., 1968). Seventy nine samples were submitted for analysis - this represents 75 samples collected from the 15 villages, 3 duplicate samples (81 [76], 22 [68] and 52 [79], original sample in brackets) plus one extra sample from Gurudola (HIDD5). Results for total Se in all rice samples and total iodine in composite rice samples from the 15 villages are presented.

10.2 Quality Control

Analytical replicate data and results for international reference materials show good agreement for Se (Appendix G). Field duplicate results are summarised in Table 18. The two duplicate pairs with lower levels of Se show good agreement. The rice duplicates with highest levels of Se are from (Navinna, MIDD5) the village with highest levels of Se in soils (Section 9). The difference between the two samples demonstrates a significant variability in Se between rice samples collected from the same grain store.

Table 18. Summary of total Se results for rice field duplicate pairs.

Sample No	Village Code	Total Se (ng/g)
22	MIDD5	777
68	MIDD5	417
86	HIDD1	12.9
78	HIDD1	10.9
81	NIDD5	57.7
76	NIDD5	58.6

Total iodine concentrations by NAA were reported within ± 0.017 standard deviations and a value of 1.79 µg/g was obtained for standard reference material SRM 1572 Citrus leaves (certified value 1.84 +/- 0.03 µg/g) (Appendix C). Levels of iodine above the limit of detection (38 ng/g) were recorded in two samples only.

10.3 Selenium

Total Se concentrations in rice range from <0.1 to 777 ng/g with a mean value of 46.5 ng/g (geometric mean 38.2 ng/g). Some rice samples and village averages are below the deficiency thresholds described by Tan (1989) for grains in China (deficient < 25 ng/g and marginal 25-40 ng/g) although only the Kandy regional average does not exceed these thresholds. Village means classified by IDD incidence are summarised in Table 19 and means for the Anuradhapura, Kandy and Kalutara regions are given in Table 20.

Table 19. Means and ranges for total Se in rice samples from each village classified by IDD incidence.

IDD Code	Regional Code	Village	Average Se ng/g	Geomean Se ng/g	Min Se ng/g	Max Se ng/g
HIDD1	KA1	Agunawala	16.8*	6.7*	0.1	53.9
HIDD2	KA2	Kurunduwatte	13.0*	5.6*	0.1	24.3
HIDD3	KL1	Olaboduwa N	64.8	62.1	44.8	90.4
HIDD4	KL2	Pelenwatte	84.4	82.4	64.7	120.1
HIDD5	KL3	Gurudola	64.3	55.8	24.5	127.2
HIDD	***All Villages***		***48.0***	***24.9***	***0.1***	***127.2***
MIDD1	KA3	Dehideniya	39.1*	37.4*	27.8	61.9
MIDD2	KA4	Kobbekaduwa	27.7*	10.0*	0.1	57.4
MIDD3	KA5	Ambepussa	57.4	55.3	38.1	78.5
MIDD4	KA6	Debagama	75.1	56.6	27.6	202.8
MIDD5	KL4	Navinna	403.5	296.7	49.7	776.5
MIDD	***All Villages***	***excl. Navinna***	***49.8***	***32.9***	***0.1***	***202.8***
	All Villages		***131.4***	***54.6***	***0.1***	***776.5***
NIDD1	AN1	Upuldenya	45.5	35.4*	6.8	75.2
NIDD2	AN2	Manankattiya	29.8*	27.4*	14.0	44.3
NIDD3	AN3	Polambayagama	53.9	42.5	11.1	108.0
NIDD4	AN4	Ihala Kagama	71.9	50.4	15.3	149.5
NIDD5	AN5	Kiralessa	65.7	57.2	20.2	130.0
NIDD	***All Villages***	***Villages***	***53.8***	***41.7***	***6.8***	***149.5***

* Marginal or deficient levels (< 40 ng/g) of Se in rice (based on Tan, 1989)

Table 20. Means and ranges for total Se in rice samples from the Anuradhapura, Kandy and Kalutara regions.

Regional Code	Average Se ng/g	Geomean Se ng/g	Min Se ng/g	Max Se ng/g
AN (Anuradhapura)	53.8	41.7	6.8	149.5
KA (Kandy)	37.5†	18.1†	0.1	202.8
KL (Kalutara)	161.5	98.5	24.5	776.5
*KL	70.5	65.1	24.5	127.2

* KL average and range excluding Navinna.

† Marginal or deficient levels (< 40 ng/g) of Se in rice (based on Tan, 1989)

The rice Se results are presented diagramatically as box and whisker plots in Figures 44 and 45. The rice samples from Navinna (MIDD5/KL4) are significantly higher than for other villages (Table 17) and have been excluded from the plots. The reason for the higher Se in the Navinna rice samples probably related to the fact that Navinna soils contained greater levels of total and extractable Se than other villages (Sections 9.6 and 9.7).

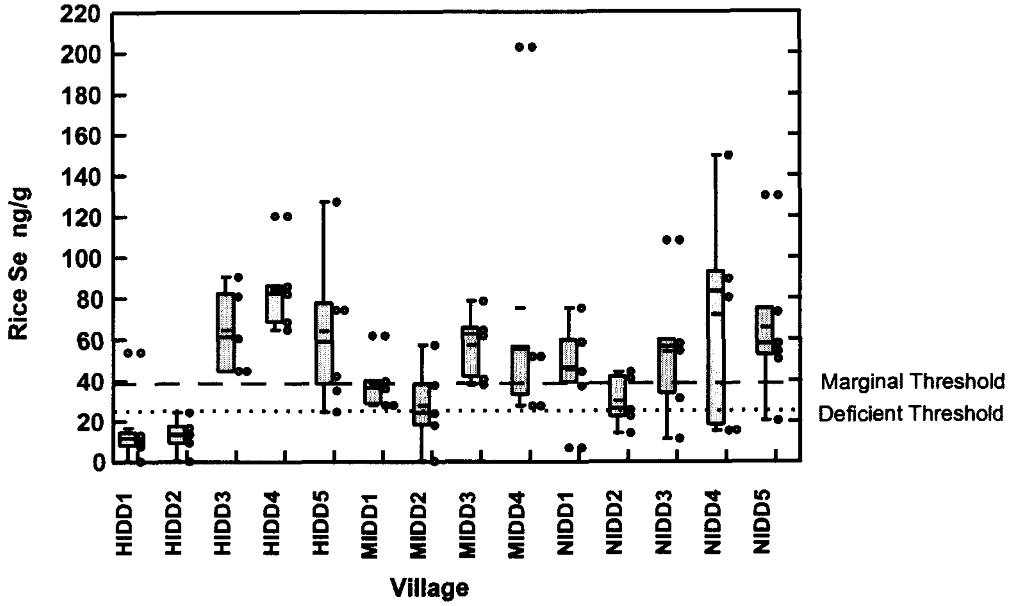


Figure 44. Box and whisker plot of rice total Se for each village classified by IDD incidence (excluding Navinna). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in grain levels from Tan (1989). (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence)

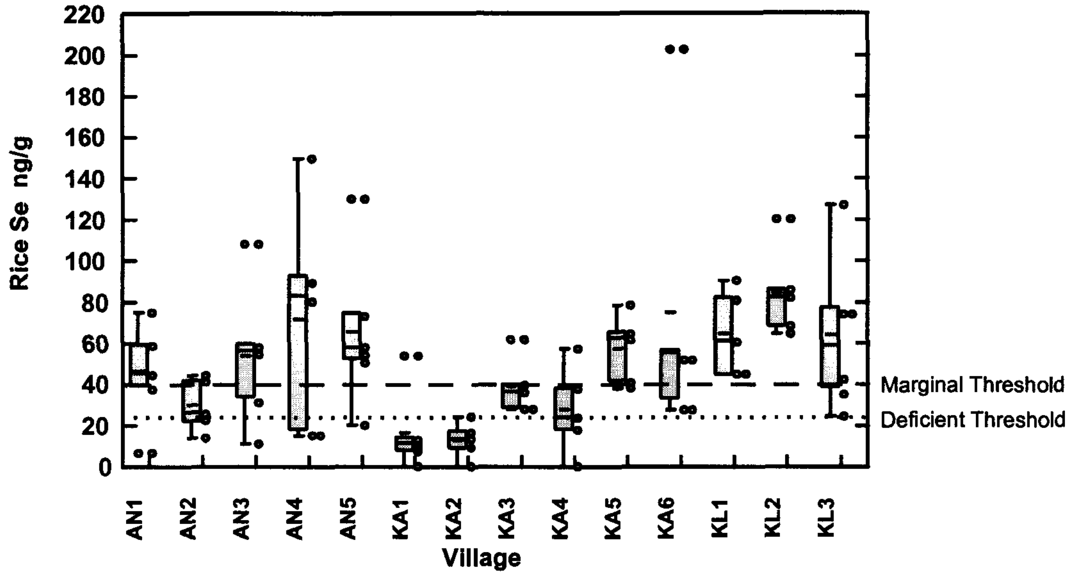


Figure 45. Box and whisker plot of rice total Se for each village classified by region (excluding Navinna). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in grain levels from Tan (1989). (AN = Anuradhapura, KA = Kandy, KL = Kalutara)

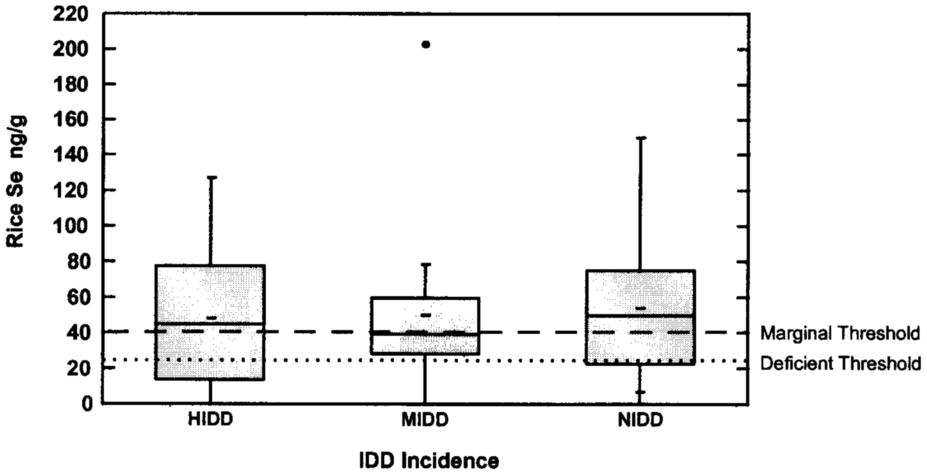


Figure 46. Box and whisker plot for total Se in rice classified by IDD incidence (excluding Navinna). Marginal and deficient total Se in grain levels from Tan (1989). (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence)

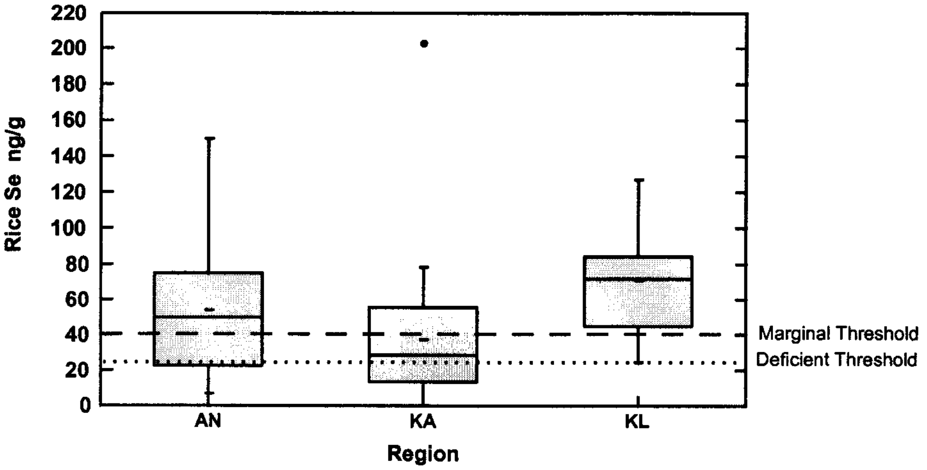


Figure 47. Box and whisker plot for total Se in rice samples classified by region (excluding Navinna). Marginal and deficient total Se in grain levels from Tan (1989). (AN = Anuradhapura, KA = Kandy, KL = Kalutara)

In soils, clear trends in total Se levels were seen for both the IDD grouping (Figure 21) and the regional grouping (Figure 24). Total Se levels in soils were much higher in Kalutara and HIDD villages than in Anuradhapura and NIDD villages. For the rice samples, the trends are different and not as distinct. When grouped by IDD incidence (Figure 46) the mean values for HIDD, MIDD and NIDD are very similar.

This suggests better transfer of Se from soil to rice in the NIDD area (Anuradhapura region) and reduced availability of Se in the soils of the HIDD villages. Results for extractable (water soluble + phosphate extractable) Se in soils (Section 9.7) showed that higher levels were found in the Kalutara region, however, a greater proportion of soil total Se content was available in the Anuradhapura region (Dry Zone) than in Kalutara (Wet Zone). Figure 47 is a box and whisker plot of rice Se levels for each region and this confirms the better mobility of Se from soil to rice in the Anuradhapura region. The Kandy region rice samples, on average, have the lowest Se levels suggesting that Se in soils in the Kandy area is less readily available. Regional variations in rice total Se content are shown on Figure 48. Trends in rice Se content between the three regions mirror the variations in soil water soluble Se content (Figure 25) rather than phosphate extractable (Figure 25) or extractable (water soluble + phosphate extractable, Figure 26) concentrations. This suggests that soil water soluble results may be a better indicator of plant available Se than phosphate extractable Se.

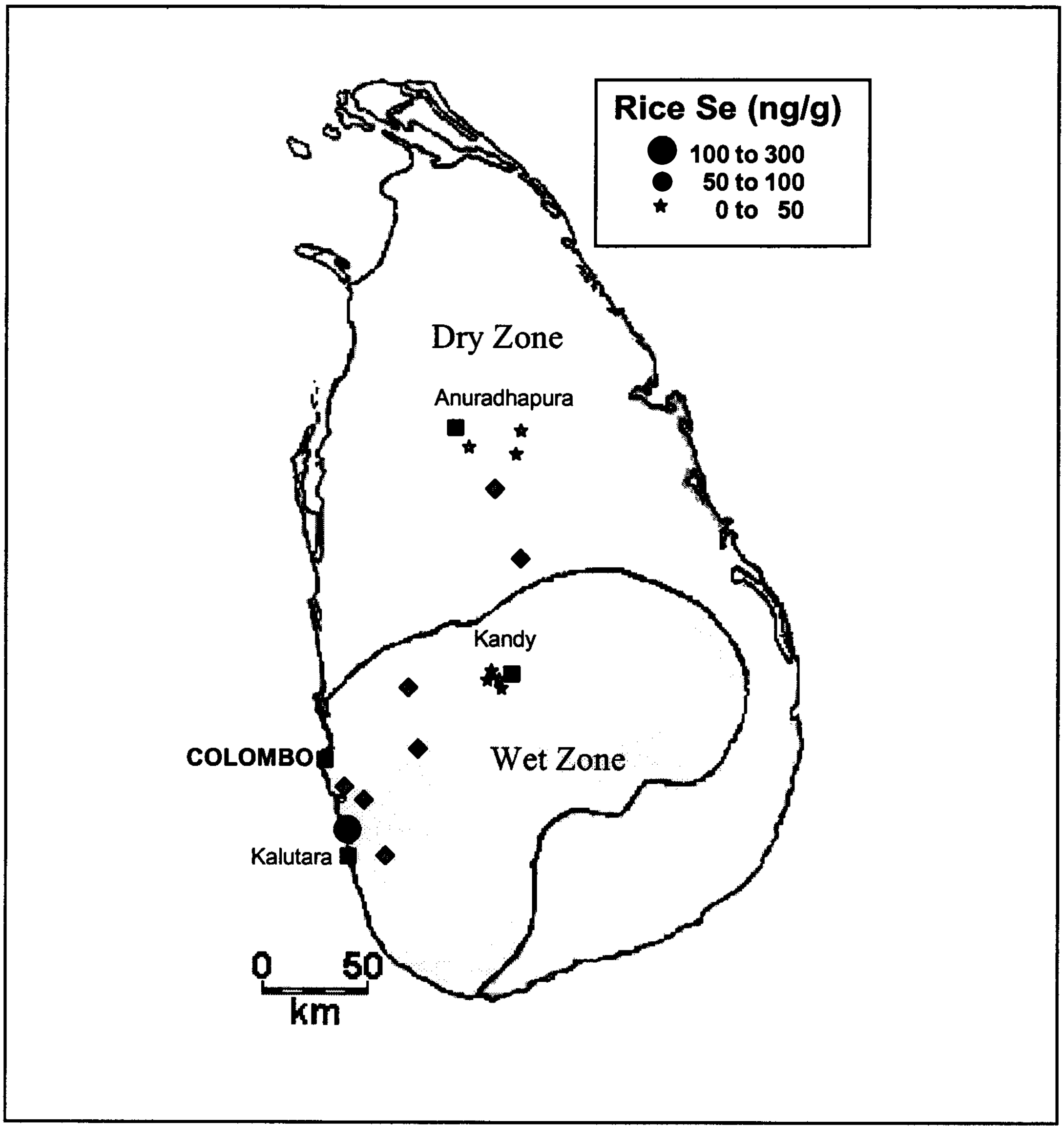


Figure 48. Map showing the total Se in rice from the fifteen targeted villages based on village geometric mean values.

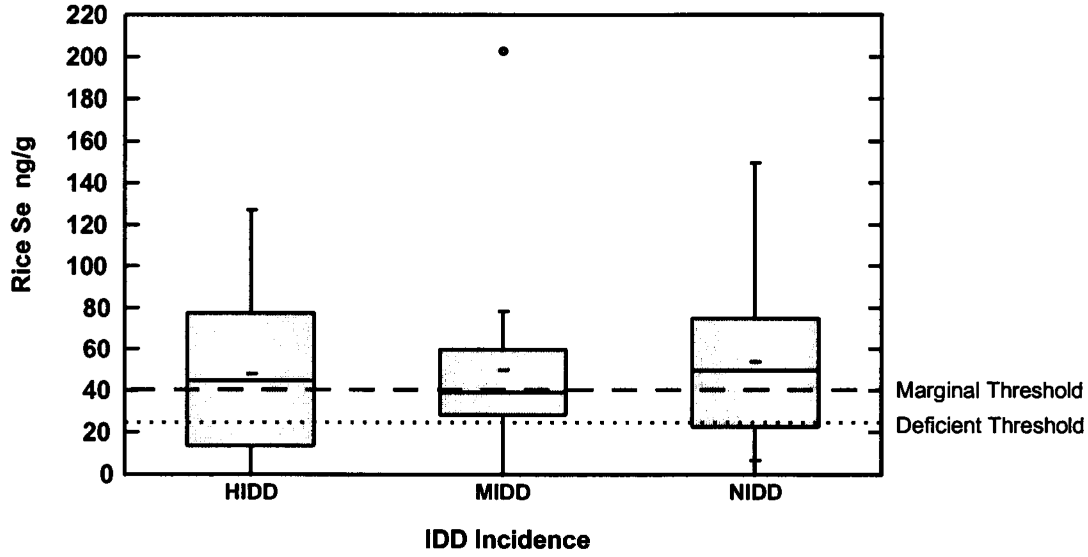


Figure 49. Box and whisker plot showing the levels of total Se in rice boiled in the husk and unboiled rice (excluding Navinna samples). Marginal and deficient total Se in grain levels from Tan (1989).

Figure 49 shows the variation in Se levels between rice boiled in the husk (11 samples) and unboiled rice (35 samples). The 27 "unknown" samples were collected before a distinction between the two methods of storage were made and are almost all from the Anuradhapura region. Villagers boil the rice in the husk to transfer nutrients from the husk to the grain. The results shown in Figure 49 do show an approximate increase of 10 ng/g Se in the boiled samples but this amount of Se is within the range of analytical variability. These results also take no account of possible regional variations. Furthermore, parboiling the rice may lead to the loss of volatile elements like Se and iodine rather than enhancing the levels in the rice grains.

When the rice samples were powdered, some distinct differences in the colour of the rice were noted. Rice powders were grouped into six colour categories: cream, fawn, white, yellow, pink and red. For interpretation two colour groups have been used, namely white and red. The white group includes the cream, fawn and yellow samples and the red group includes the pink samples. The red powders came predominately from the Kalutara region. Red rice is a different variety of rice from standard white rice varieties (Section 13). Figure 50 shows a plot of the rice colour against total Se (excluding the exceptionally high rice samples from Navinna which were predominantly red coloured). This figure shows slightly higher Se levels in the red rice but this can be attributed to the fact that all but one of the red rice samples come from the Kalutara region, an area shown to have higher levels of Se in the soil. It is difficult to make any judgement on differences in rice levels between the two different species as only 4 white rice samples were collected from the Kalutara region. However, as Figure 51 shows, the levels of Se in Kalutara white rice samples are similar to the levels found in red rice.

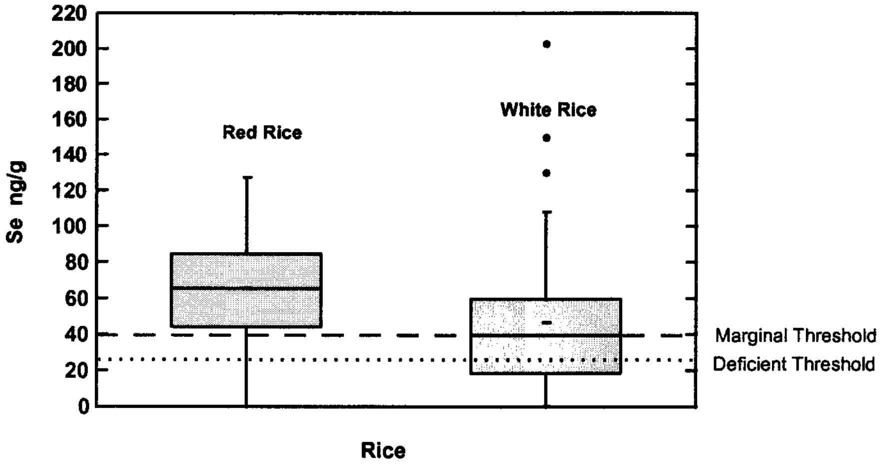


Figure 50. Plot of rice powder colour against total Se content (excluding Navinna samples).

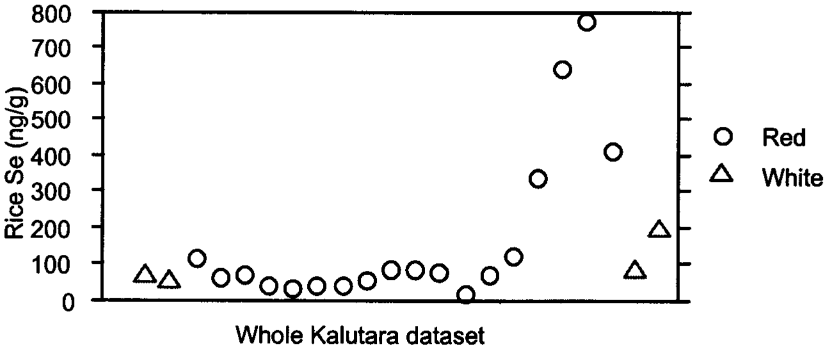


Figure 51. Comparison between total Se levels in red and white rice samples from the Kalutara region.

10.4 Relationships between Rice Selenium and Soil Selenium

As rice samples were not collected directly from the fields from which the soils were sampled, it is not possible to make a direct study between the Se in a sample of rice and the soil on which it was grown. However, by taking the geometric mean values of Se in the rice and soils from each village it is possible to investigate how levels of Se in the rice relate to the local environment in which they were grown.

Figure 52 is a plot of total Se in rice against total Se in soil for the fifteen villages. The Spearman Rank correlation coefficient for the rice to soil total Se result is 0.56 (significant at the 95% confidence level) (Table 21). However, this correlation is distorted by a few outlying results and for the majority of villages there appears to be little direct relationship between the Se content of the rice and the total Se content of the soils (Figure 52).

The Spearman Rank correlation coefficient between rice Se and soil Se residual adsorption capacity is significant at the 95% confidence level. The capacity of the soil to adsorb more Se is not, however, a measure of the availability of Se and the plot of rice Se against soil Se residual adsorption capacity shows no clear correlation (Figure 53).

Rice Se levels correlate negatively (95% confidence level) with soil Fe, Mn and Ca suggesting that Fe and Mn oxides and oxyhydroxides may inhibit the uptake of Se in rice. The negative relationship with Ca probably reflects geological differences in soil chemistry, soils higher in organic matter and Se are lower in Ca (Table 21).

There are no significant (95% confidence level) correlations between rice Se levels and water soluble or phosphate extractable Se concentrations in soil (Table 21). However, as Figure 54 shows, the highest Se in rice values correspond to the highest levels of extractable Se in soil in Navinna (MIDD5) and, in general, Kalutara samples are higher in both rice Se and soil extractable Se.

Table 21. Spearman Rank Correlation coefficients of village geometric mean values for Se content in rice compared to soil parameters.

	Rice Se
Soil I	0.289
Soil Se	0.561
Soil pH	-0.220
%Se Ads	-0.459
Soil Ca	-0.614
Soil Mn	-0.529
Soil Fe	-0.689
Soil Al	0.143
Soil Ni	-0.007
Soil Cu	-0.321
Soil Zn	-0.354
TOC	0.310
Extract Se	0.370
Soil WSe	0.322
Soil PSe	0.405

n = 15 r95% = 0.441 (Koch & Link, 1970) %Se Ads = Soil % residual Se adsorption capacity
WSe = water soluble Se soil PSe = phosphate extractable Se soil Extra Se = WSe + PSe soil

It is of particular interest to compare the levels of Se in rice to the levels of Se in the local soil. This is shown by the ratio of rice Se/soil total Se expressed as a percentage. Figure 55(a) shows that this ratio is significantly different for the Anuradhapura region where the Se appears to be more available for uptake by the rice crop, although levels of total Se in the soils of this area are lower than for other regions (Section 9.6). This confirms the results for extractable levels of Se in soils which showed that a greater proportion of soil total Se was available for plant uptake in the Anuradhapura region (Section 9.7).

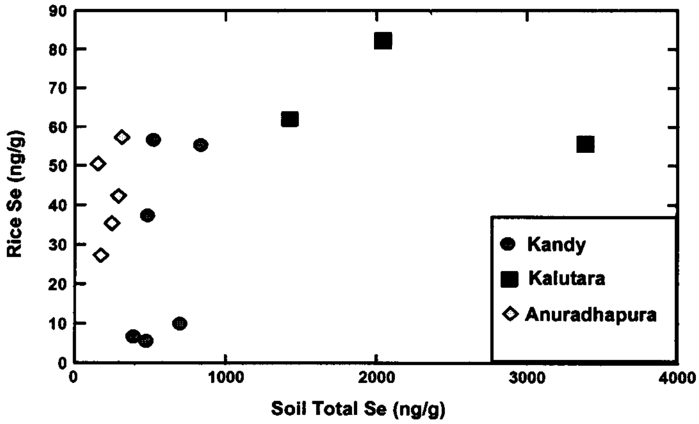


Figure 52. Plot of soil total Se against rice total Se based on village geometric mean values (excluding Navinna).

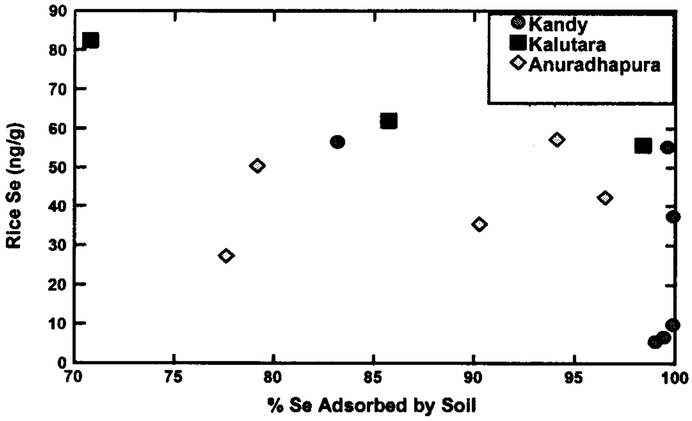


Figure 53. Plot of soil residual Se adsorption capacity against rice total Se based on village geometric mean values (excluding Navinna).

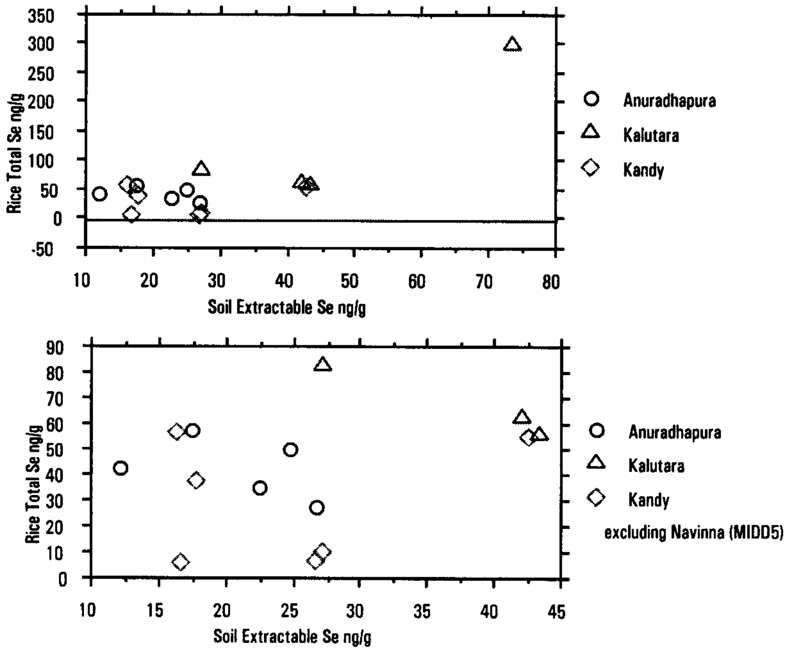


Figure 54. Plots of soil extractable (water soluble + phosphate extractable) Se against village geometric mean values for total Se in rice.

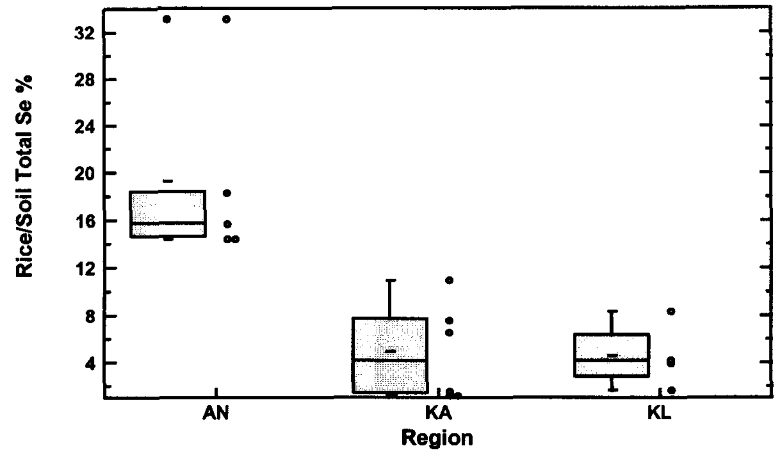


Figure 55. (a) Box and whisker plot for the rice/soil total Se ratio classified by region. (KA=Kandy, KL=Kalutara, AN=Anuradhapura)

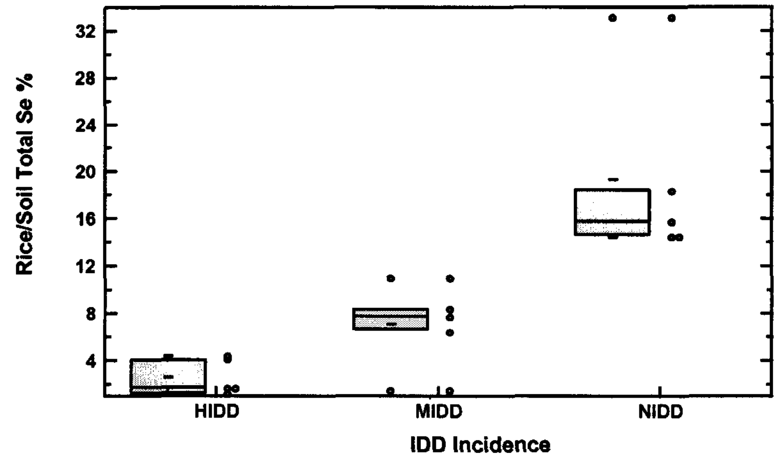


Figure 55. (b) Box and whisker plot for the rice/soil total Se ratio classified by IDD incidence.(NIDD=No/low IDD, MIDD=Moderate IDD, HIDD=High IDD)

The most significant trend shown by the rice/soil total Se ratio is for the different IDD groups (Figure 54(b)). The lowest ratios (i.e. the poorest uptake of Se)occur in the high incidence IDD villages whereas the highest ratios are for the no/low incidence IDD villages.

The rice/soil total Se ratios are plotted against soil pH in Figure 56. This again shows the Anuradhapura region and NIDD villages plotting as a distinct group with a high pH and high (generally 20%) rice/soil total Se ratios. On the basis of the regional classification, there is little distinction between the Kandy and Kalutara samples (Figure 56(a)), whereas the IDD classification shows the HIDD villages generally have lower rice/soil Se ratios than the MIDD villages (Figure 56(b)).

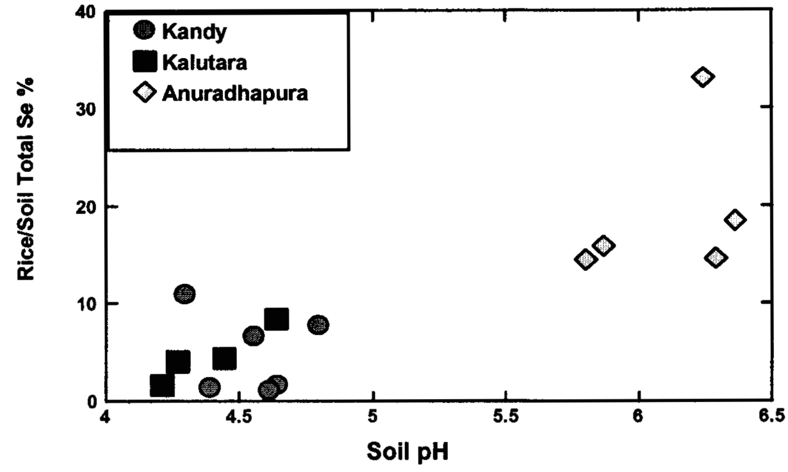


Figure 56. (a) Rice/soil total Se ratio plotted against soil pH classified by region based on village geometric mean values.

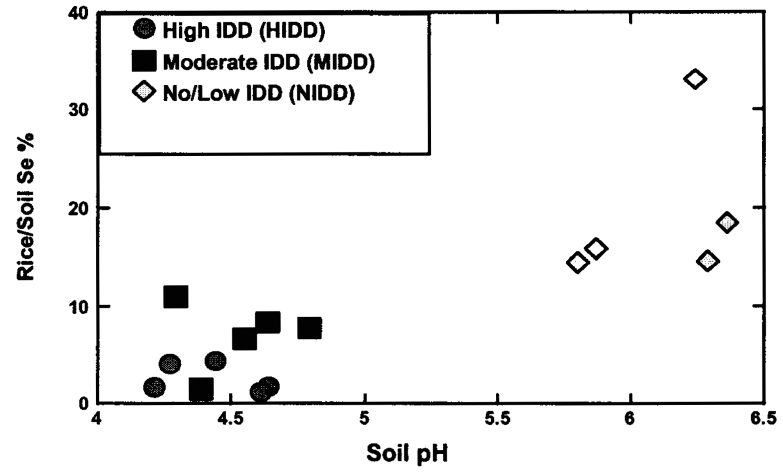


Figure 56. (b) Rice/soil total Se ratios plotted against soil pH classified by IDD incidence based on village geometric mean values.

10.5 Iodine

Total iodine concentrations were determined in 15 composite rice samples by NAA. In the majority of cases, values were below the detection limit but rice from Ihala Kagama (NIDD4) and Kiralessa (NIDD5), both in the Dry Zone, contained 58 ng/g and 45 ng/g iodine respectively (Appendix C). These values do not relate to highest total iodine concentrations in soils. The atmosphere is an important source of iodine in plants and adsorption of iodine from the atmosphere rather than via root uptake may contribute to rice total iodine levels. 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 as organic/methyl iodine as a result of rice cultivation. Levels of iodine in rice are therefore likely to be very low compared to levels in soil.

The results from the two villages are much lower than the levels reported by Mahadeva et al. (1968) for Dry Zone rice but are comparable to levels recorded in Uluvitike in the south-west of the Wet Zone (Table 22). They are also lower than levels reported in rice from paddy fields in Japan where iodine toxicity occurred in rice plants due to the dissolution of iodine in soils following the flooding of rice paddies (Table 22).

Information on iodine levels in rice is very limited in the literature, Tan (1989) reports 20 - 120 ng/g iodine in rice from an IDD region of China and CIEB (1952) report an average of 25 ng/g in rice from Chile (Table 22). Results from the present study are comparable to these values
and show that rice is a poor source of iodine in the Sri Lankan diet (Section 13).

Table 22. Total iodine concentrations in rice samples from the present study compared to other studies.

Country	Region	Location	Rice Iodine ng/g
Sri Lanka`	Dry Zone	Anuradhapura	< 38 - 58
	Wet Zone	Kandy	< 38
	Wet Zone	Kalutara	< 38
Sri Lanka*	Dry Zone	Jaffna	880
	Wet Zone	Pothupitiya	98
	Wet Zone	Uluvitike	43
	Wet Zone	Wetera	210
Japan†	Tochigi Ando Soil	Non-flooded paddy	25
	Tochigi Ando Soil	Flooded paddy	480
	Brown Forest Soil	Non-flooded paddy	27
	Brown Forest Soil	Flooded paddy	580
	Nagara River	Flooded paddy	55
China~	Heilongjiang	Huachan County	20 - 120
Chile^			25

` Present study results reported dry weight
† From Yuita (1994) results reported dry weight
~ From Tan (1989) results reported dry weight
* From Mahadeva et al. (1968) results reported wet weight
^ From Chilean Iodine Educational Bureau (CIEB) (1952) results reported dry weight

11. SHALLOW WELL WATER RESULTS

11.1 Introduction

Shallow well (< 15 m) water samples were collected from each of the 15 villages so as to represent the water drunk by the local population. Fifteen samples were collected plus three duplicate samples - the results are listed in Appendix D. Total Se, chloride, nitrate and sulphate concentrations were determined at BGS laboratories and iodine was determined at Aberystwyth University (Appendix G). These results have been combined with the field data (pH, bicarbonate, Eh and conductivity) for interpretation.

11.2 Quality Control

No analytical replicate data are available for water iodine results. There are no standards used to determine levels of iodine in waters. Check solutions were included in the analytical runs and produced satisfactory results (Dr R Fuge pers. commun.). No analytical replicate analysis were carried out during determinations of total Se. Results for standards show good precision of the data (+/- 2%) (Appendix G).

Results for field duplicates show excellent agreement for all parameters determined in water samples (Table 23).

Table 23. Analytical results for duplicate water sample pairs (duplicate samples are listed second in each case)

Sample Number	I µg/l	Cl mg/l	SO_4 mg/l	NO_3 mg/l	Se µg/l	pH	Eh mV	Conductivity µS	Alkalinity mg/l $CaCO_3$
W81	64	24.4	21.5	24.8	0.17	7.30	441	943	388
W76	65	24.2	21.4	25.1	0.18	7.28	428	935	380
W86	6.7	33.5	25.2	12.4	0.09	6.62	428	484	118
W78	6.8	33.4	25.2	12.5	0.08	6.60	428	478	120
W22		29.3	3.21	16.4	0.06	4.82	458	189	6.0
W68		29.3	3.24	16.1	0.06	4.77	456	188	5.6

11. 3 Field Results (Alkalinity, Conductivity and pH)

The field measurements of alkalinity, conductivity and pH show that waters from the three regions sampled (Anuradhapura, Kandy and Kalutara) have distinctly different geochemical characteristics, particularly the samples from the Dry Zone (Anuradhapura) (Table 24). This is illustrated by the plot of pH against conductivity classified by region (Figure 57) and the box and whisker plots (Figure 58). The Anuradhapura samples have a higher pH (7.3 - 7.6), conductivity and Eh as might be expected in a hot dry climate. In the Wet Zone, Kalutara waters have lower pH (4.8 - 5.6) and Eh than Kandy samples and slightly lower conductivity.

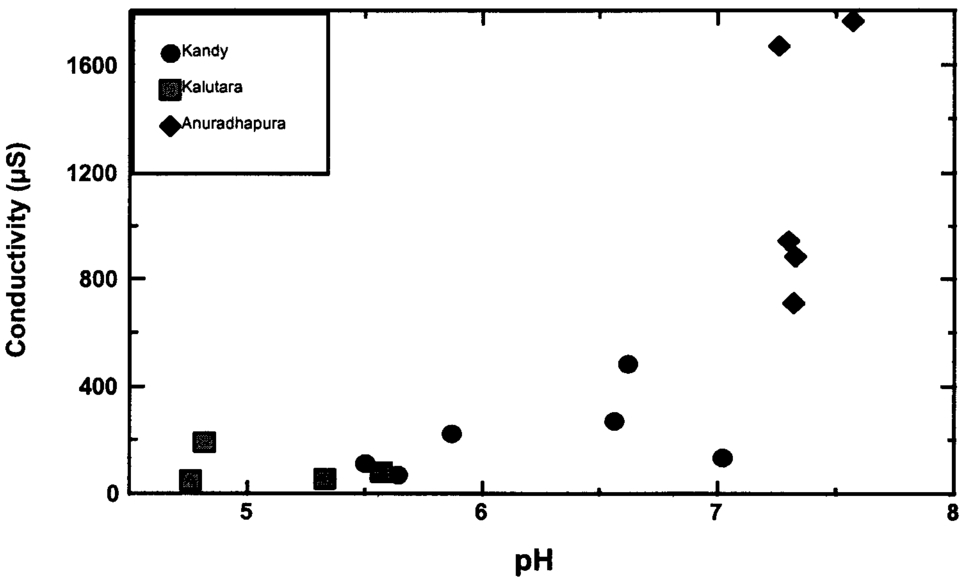


Figure 57. Plot of conductivity against pH of shallow well water samples classified by region.

11.4 Iodine

Iodine levels in the 15 water samples range from 3 - 84 µg/l with a mean of 28.05 µg/l (geomean 13.7 µg/l) (Table 24, Figures 58-60).

The results from the Dry Zone are distinctly higher than those from other regions ranging from 53 to 84 µg/l. These are within the range of iodine concentrations reported by Dr P. Smedley (BGS, pers. commun.) in Anuradhapura well waters and are comparable to mean values reported by Mahadeva & Shanmuganathan (1967) for drinking waters from the North Central Province (Dry Zone) (Table 25). Mean values from the present study are however, lower than those reported by Balasuriya et al. (1992) for this region.

Results from the Wet Zone range from 3.3 - 23.5 µg/l, highest values occur in Gurudola (HIDD5) and Dehideniya (MIDD1) (20.2 and 23.5 µg/l respectively), the reason for this is not known. Results for Kandy and Kalutara are generally comparable to values reported by Mahadeva & Shanmuganathan (1967) for the Central (Kandy) and Western (Kalutara) Provinces but are lower than results reported by Dissanayake & Chandrajith (1996) for waters around Kandy (Table 25). Results are comparable to levels of iodine reported in drinking waters from an IDD province of China (Tan, 1989, Table 25).

Table 24. Summary statistics for shallow well water samples.

All Samples	Iodine (µg/l)	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Se (µg/l)	Temp (°C)	pH	Eh (mV)	Bicarbonate (mg/l$CaCO_3$)	Conductivity (µS)
Number	15	15	15	15	15	15	15	15	15	15
Average	28.05	29.08	8.96	7.87	0.09	28.69	6.30	248.07	66.49	508.53
Geomean	13.70	12.30	4.03	2.30	0.08	28.66	6.22	246.91	22.16	263.27
Maximum	84.00	125.43	29.56	24.82	0.24	31.00	7.57	293.00	214.00	1760.00
Minimum	3.00	0.07	0.68	0.07	0.06	26.40	4.76	212.00	1.70	49.00
Standard Dev.	30.74	33.90	10.07	8.49	0.05	1.34	0.99	24.96	78.99	574.57

Anuradhapura	Iodine (µg/l)	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Se (µg/l)	Temp (°C)	pH	Eh (mV)	Bicarbonate (mg/l$CaCO_3$)	Conductivity (µS)
Number	5	5	5	5	5	5	5	5	5	5
Average	67.80	56.38	18.29	8.13	0.12	27.86	7.36	225.40	169.40	1193.60
Geomean	66.50	15.63	16.89	0.67	0.11	27.83	7.36	225.13	166.68	1117.47
Maximum	84.00	125.43	29.56	24.82	0.24	29.70	7.57	243.00	214.00	1760.00
Minimum	53.00	0.07	10.37	0.07	0.06	26.40	7.26	212.00	129.00	712.00
Standard Dev.	14.92	47.84	7.98	11.50	0.08	1.45	0.12	12.34	34.07	484.50

Kandy	Iodine (µg/l)	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Se (µg/l)	Temp (°C)	pH	Eh (mV)	Bicarbonate (mg/l$CaCO_3$)	Conductivity (µS)
Number	6	6	6	6	6	6	6	6	6	6
Average	8.00	18.38	6.13	8.86	0.07	28.37	6.20	252.50	22.82	214.83
Geomean	6.07	14.58	2.63	4.97	0.07	28.36	6.18	251.81	15.22	175.67
Maximum	23.50	33.55	25.17	21.99	0.09	29.30	7.02	278.00	59.00	484.00
Minimum	3.00	4.54	0.70	0.54	0.06	27.60	5.50	230.00	5.00	68.00
Standard Dev.	7.76	12.19	9.57	7.88	0.02	0.71	0.61	20.47	21.77	151.25

Kalutara	Iodine (µg/l)	Chloride (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Se (µg/l)	Temp (°C)	pH	Eh (mV)	Bicarbonate (mg/l$CaCO_3$)	Conductivity (µS)
Number	4	4	4	4	4	4	4	4	4	4
Average	8.43	11.00	1.54	6.08	0.07	30.20	5.12	269.75	3.35	92.75
Geomean	6.44	7.07	1.28	3.38	0.07	30.20	5.11	269.07	3.13	79.28
Maximum	20.20	29.28	3.21	16.38	0.09	31.00	5.57	293.00	4.80	189.00
Minimum	3.30	3.19	0.68	0.63	0.06	29.80	4.76	242.00	1.70	49.00
Standard Dev.	7.91	12.42	1.15	7.05	0.01	0.54	0.39	21.98	1.32	65.49

Standard Dev. = standard deviation

Table 25. Iodine levels in water samples from the present study compared to other studies.

Location	Region	Sample Type	No of Samples	Range (I µg/l)	Median (I µg/l)	Mean (I µg/l)
Sri Lanka>	Anuradhapura	Drinking water	5	53 - 84		66
Sri Lanka>	Kandy	Drinking water	6	3 - 24		6.1
Sri Lanka>	Kalutara	Drinking water	4	6 - 20		6.44
Sri Lanka*	Western Province	Drinking water	14	2 - 10		4
Sri Lanka*	Central Province	Drinking water	6	4 - 11		9
Sri Lanka*	North Central Province	Drinking water				83
Sri Lanka†	Kandy	Drinking water			19	31
Sri Lanka†	Kalutara	Drinking water			12	16
Sri Lanka†	Anuradhapura	Drinking water			101	119
Sri Lanka~	Kandy	Water		15 - 150		55
Sri Lanka^	Anuradhapura	Drinking water	123	7 - 206	41	52
UK+	England and Wales	Spring and wells	30	1 - 14		4
China`	Heilongjiang Province	Drinking water		3 - 9		

* Mahadeva & Shanmuganathan (1967)
~ Dissanayake & Chandrajith (1996)
>Present study
+ Fuge (1989)
` Tan (1989)
^ Dr P Smedely (pers. commun.)
† Balasuriya et al. (1992)

11.5 Selenium

Se results range from 0.056 - 0.235 µg/l with a mean value for the 15 villages of 0.088 µg/l (Table 24) (geomean 0.080 µg/l). There is no significant difference between Se levels from the three regions (Figure 58) or the three IDD groups (Figure 59). However, the Dry Zone samples from the Anuradhapura region do show a much wider spread of results and the two highest values come from this region (Upuldenya (NIDD1) and Kiralessa (NIDD5)). This range of results is low compared with the Keshan Disease areas of Zhangjiakou (geomean 0.144 µg/l, Johnson et al., 1996) and Enshi (geomean 0.168 µg/l, Fordyce et al., 1998) in China. Results are also low compared to concentrations quoted for surface waters (Section 3). The distribution of Se in village surface well waters is shown in Figure 60.

11.6 Chloride, Sulphate and Nitrate

Summary statistics for chloride, sulphate and nitrate concentrations in water samples are detailed in Table 24. The box and whisker plots (Figures 58 and 59) summarise the distributions of these anions between the different regions. Sulphate and chloride levels are higher in the Anuradhapura (Dry Zone) region than in the Kandy and Kalutara regions (Wet Zone) as expected. Nitrate results are variable for all three regions and may be influenced by the addition of fertilisers to the soil in all three regions rather than geochemical differences between the Wet and Dry Zones.

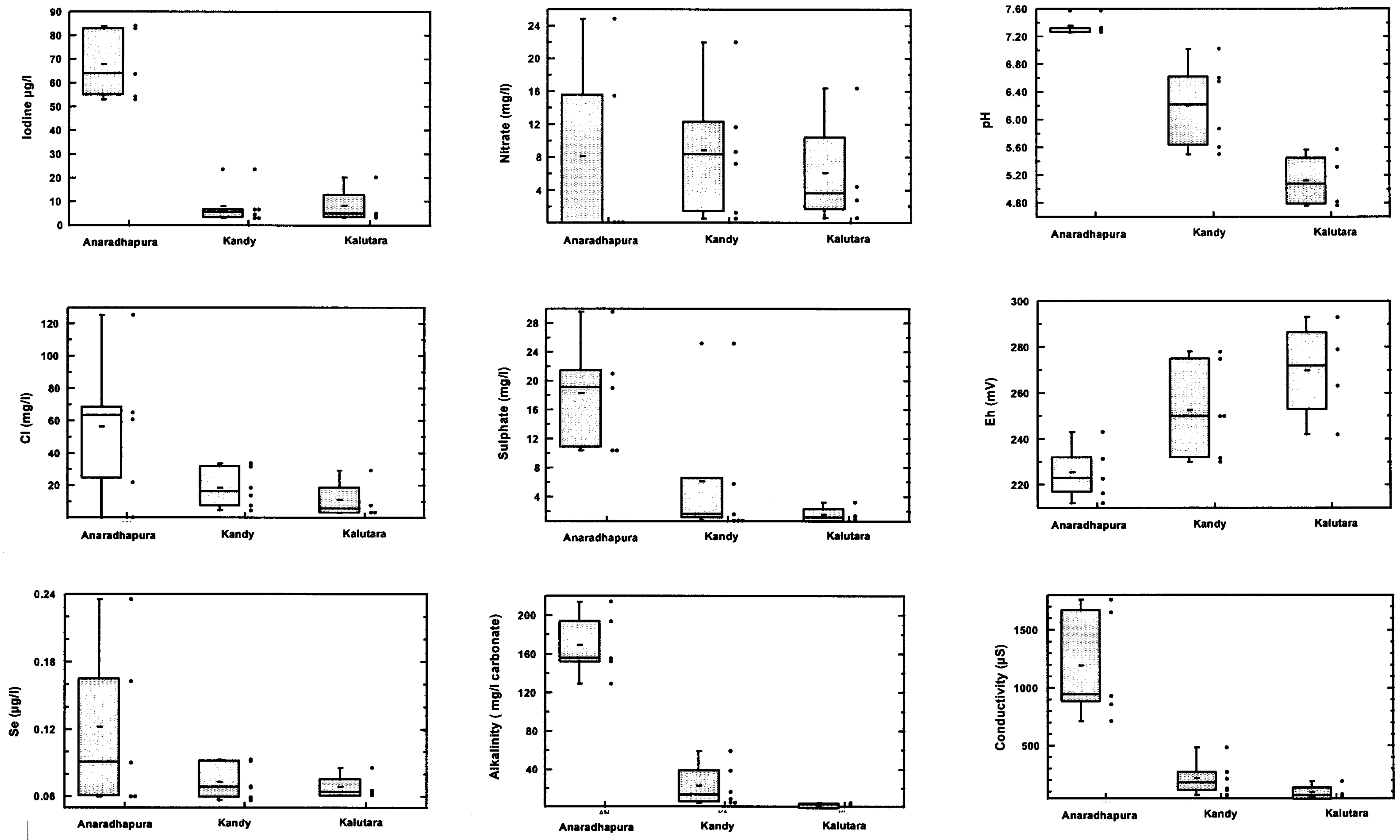


Figure 58. Box and whisker plots of well water parameters classified by region.

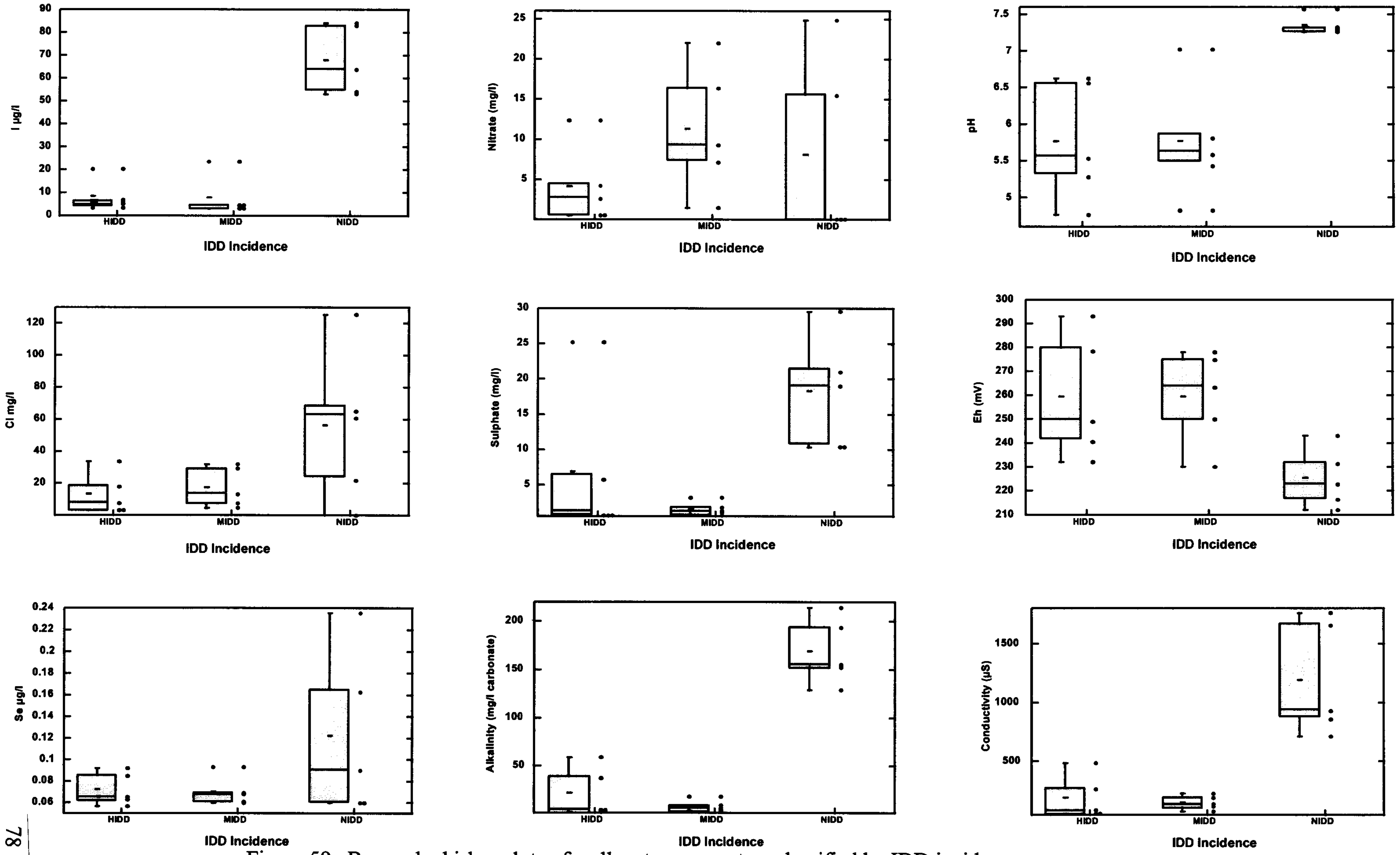


Figure 59. Box and whisker plots of well water parameters classified by IDD incidence.

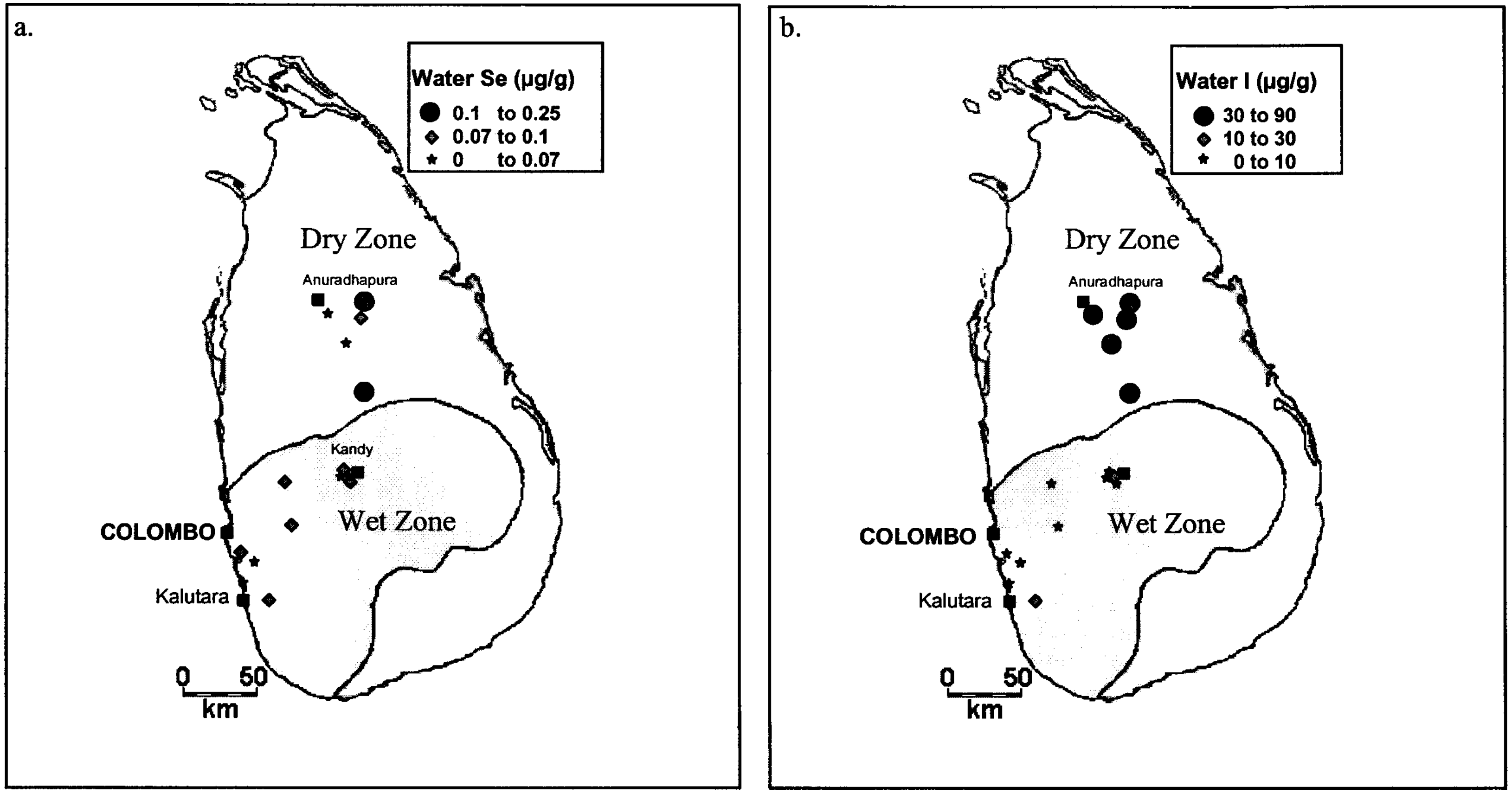


Figure 60. Maps showing (a) the Se concentration and (b) the iodine concentration of shallow well waters in the 15 villages.

11.7 Correlation Analysis

A Spearman Rank correlation matrix of water parameters and selected parameters in soil and rice is presented in Table 26. These correlations should, however, be treated with caution due to the small sample population (number = 15) and the fact that many of the results for the Anuradhapura region are distinctly different from the other regions giving outlying points that markedly improve the correlation coefficients.

Table 26. Spearman Rank correlation matrix for parameters in water, soil and rice.

	Rice Se	Soil I	Soil Tot Se	Soil pH	Soil %Se Ads	Water I	Water Cl	Water SO_4	Water NO_3	Water Se	Water pH	Water Eh	Water Bicarbonate
Soil I	0.289												
Soil Total Se	0.561	0.311											
Soil pH	-0.243	-0.036	-0.796										
Soil %Se Ads	-0.459	0.070	0.172	-0.050									
Water I	-0.247	-0.036	-0.772	0.794	-0.202								
Water Cl	-0.204	0.214	-0.468	0.618	0.161	0.370							
Water SO_4	-0.400	-0.064	-0.693	0.704	-0.057	0.638	0.482						
Water NO_3	0.154	0.154	0.312	-0.039	0.400	-0.357	0.158	0.036					
Water Se	-0.046	-0.054	-0.118	0.014	-0.088	-0.086	-0.100	0.354	0.566				
Water pH	-0.554	-0.164	-0.921	0.743	-0.130	0.665	0.368	0.629	-0.251	0.225			
Water Eh	0.497	-0.021	0.737	-0.610	0.148	-0.424	-0.422	-0.487	0.223	-0.208	-0.889		
Water Bicarbonate	-0.550	-0.129	-0.932	0.793	-0.066	0.731	0.507	0.768	-0.068	0.321	0.918	-0.730	
Water Conductivity	-0.479	-0.079	-0.861	0.879	-0.107	0.754	0.539	0.807	-0.050	0.229	0.868	-0.760	0.925

n =15 Correlation coefficients shaded in grey are significant to the 99.9 % confidence level

Correlations with soil and rice are based on village geometric mean values Soil % Se Ads = Soil % residual Se adsorption

Se in the water samples correlates significantly with nitrate. This correlation is strongly influenced by the results for Kiralessa (NIDD5) where both Se and nitrate are higher than in other water samples. Levels of sulphate and chloride, alkalinity and conductivity are also high in this village indicating a greater proportion of dissolved solids in the water. This may be related to the underlying calcareous (marble) geology (Appendix A). Iodine correlates with sulphate ($r_{sp} = 0.64$), pH ($r_{sp} = 0.66$), alkalinity ($r_{sp} = 0.73$), and conductivity ($r_{sp} = 0.75$) (all correlations significant at the 99.9% confidence level). These correlations are to be expected as, in the Dry Zone, evaporation exceeds precipitation thus concentrating dissolved ions in these waters relative to the Wet Zone. Selected village mean results for soil and rice samples are included in the Spearman Rank correlation matrix (Table 26). Rice Se levels correlate negatively with water pH and bicarbonate concentration and soil total Se shows strong negative correlations with water iodine, sulphate, pH, bicarbonate and conductivity. These correlations reflect high values of water parameters in the Anuradhapura compared to the Kalutara region and in contrast to higher soil and rice Se in the Kalutara region than around Anuradhapura (Section 9).

12. HAIR RESULTS

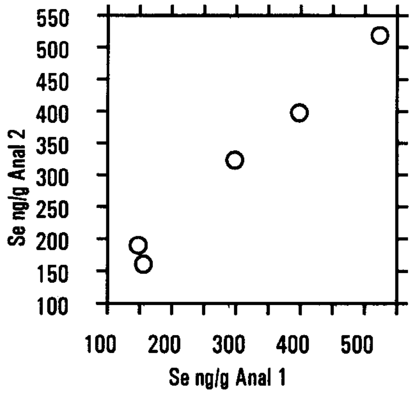
12.1 Introduction

In total, 78 hair samples were collected in the present study, 77 from women and 1 from a man. Samples were collected from a mixture of women who were suffering goitre and those who were not. Results from experiments to test the variation in total Se concentration along the length of hair samples and the effects of surface contaminants are presented in this section in addition to the results for total Se concentrations in hair determined by AFS.

12.2 Quality Control

Analytical replicates show good reproducibility of the methods (Figure 61) and results for international reference materials were within acceptable limits (Appendix G). No field duplicate samples were collected.

Figure 61. Analytical replicates for total Se in hair by AFS.



12.3 Variations in Selenium Concentration with Hair Length

All the women sampled during the present study had long hair which had not been cut short since teenage years. 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®.

With the exception of samples 26 and 69, the hairs show little variation in Se concentration with length (Figure 62). Assuming hair grows at a rate of 1 cm per month, the hairs sampled probably represent the Se status of the individual over the last two to two and a half years. The majority of water washed and Neutracon® washed samples showed little variation in Se content indicating that Se held in surface contaminants would not significantly affect the results (Figure 62). 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 (Section 8).

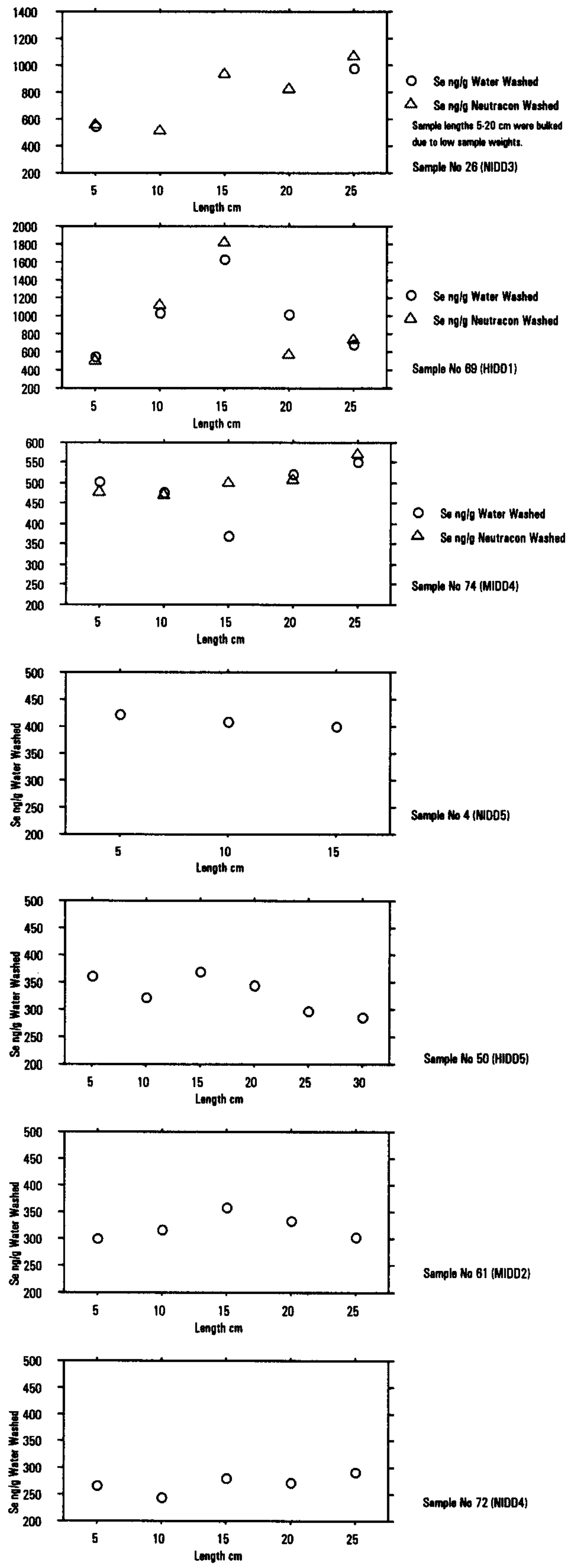


Figure 62. Total Se results in different lengths of selected hair samples and comparison between Neutracon® washed and deionised water washed hair for three samples.

12.4 Selenium

Total Se levels in hair range from 104 - 2651 ng/g (arithmetic mean 393 ng/g; geometric mean 326 ng/g). Village means classified by IDD incidence and region are summarised in Tables 27 and 28. These tables, and Figures 63 - 67, show total Se hair concentrations are similar for the three IDD groups and the three regions. Se concentrations vary markedly within villages. The three highest hair concentrations occur in MIDD4 (Debagama) (2652 ng/g and 1408 ng/g) and MIDD2 (Kobbekaduwa) (1077 ng/g). With the exception of the value of 2652 ng/g Se which does correspond to a high total Se concentration (203 ng/g) in rice, the reason for these high values is unknown. They do not relate to any specific population parameters such as the age of the women sampled (Appendix E) or to high levels of Se in soil or rice in these villages (Figures 20 and 44).

Levels of Se in hair in the HIDD and MIDD villages are on average (average and geomean values) slightly higher than in the NIDD villages which is the opposite to what would be expected if Se deficiency enhances IDD. Similarly, average hair Se levels in the Kalutara and Kandy regions are slightly higher (average and geomean values) than the Anuradhapura region Tables 27 and 28; Figures 63 - 67).

The distribution of village geometric mean Se concentrations in hair (excluding the three high values) is shown in Figure 68 which confirms that highest Se levels occur in the Kandy and Kalutara regions.

Table 27. Means and ranges for total Se in hair samples for each village classified by IDD incidence.

IDD Code	Regional Code	Village	Average ng/g	Geomean ng/g	Min ng/g	Max ng/g
HIDD1	KA1	Agunawala	503	462	363	984
HIDD2	KA2	Kurunduwatte	238	211	111	425
HIDD3	KL1	Olaboduwa N	255	237	155	471
HIDD4	KL2	Pelenwatte	326	296	0.4	141
HIDD5	KL3	Gurudola	404	398	330	520
HIDD	***All Villages***		***341***	***302***	***111***	***984***
MIDD1	KA3	Dehideniya	280	249	118	406
MIDD2	KA4	Kobbekaduwa	457	386	233	1077
MIDD3	KA5	Ambepussa	356	326	128	468
MIDD4	KA6	Debagama	1073	788	396	2652
MIDD5	KL4	Navinna	426	397	181	593
MIDD	***All Villages***		***509***	***389***	***118***	***2652***
NIDD1	AN1	Upuldenya	286	246	104	454
NIDD2	AN2	Manankattiya	382	357	173	499
NIDD3	AN3	Polambayagama	382	324	115	765
NIDD4	AN4	Ihala Kagama	309	305	259	414
NIDD5	AN5	Kiralessa	288	260	160	440
NIDD	***All Villages***	***Villages***	***328***	***294***	***104***	***765***

Table 28. Means and ranges for total Se in hair samples classified by region.

Region	Average ng/g	Geomean ng/g	Min ng/g	Max ng/g
Anuradhapura	328	294	104	765
Kandy	470	355	111	2652
Kalutara	353	324	141	593

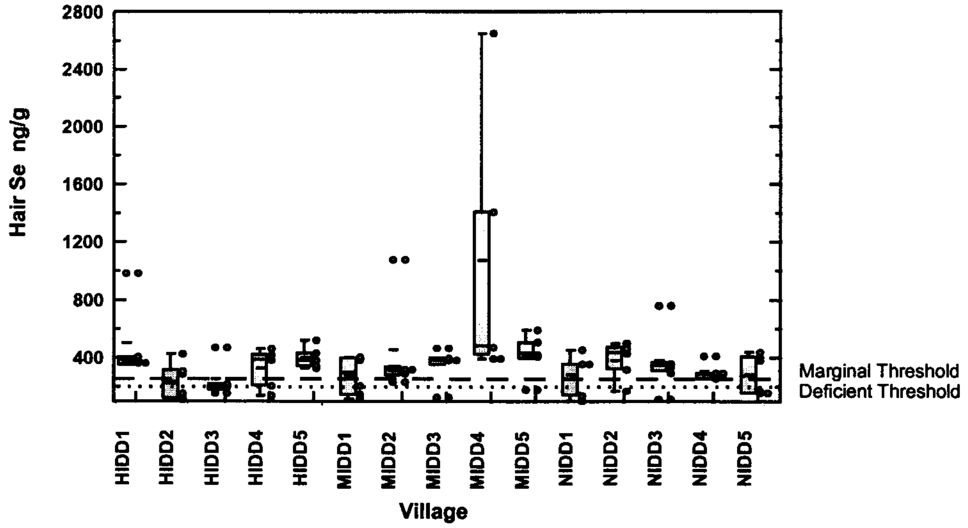


Figure 63. Box and whisker plot of hair Se for each village classified by IDD incidence. Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in hair levels from Tan (1989). (HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence)

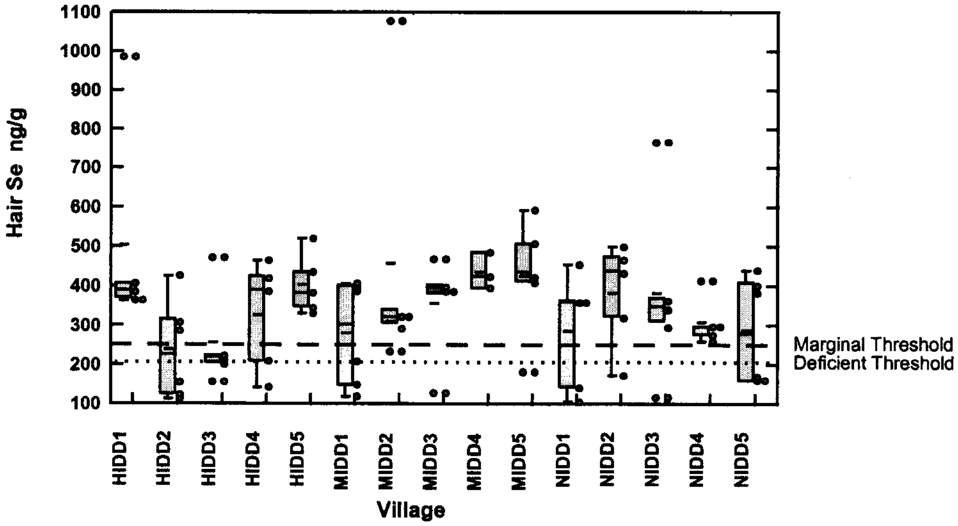


Figure 64. Box and whisker plot of hair Se for each village classified by IDD incidence (excluding 2 outlying values from MIDD4). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in hair levels from Tan (1989). (HIDD = High IDD, MIDD = Moderate IDD, NIDD = No/low IDD)

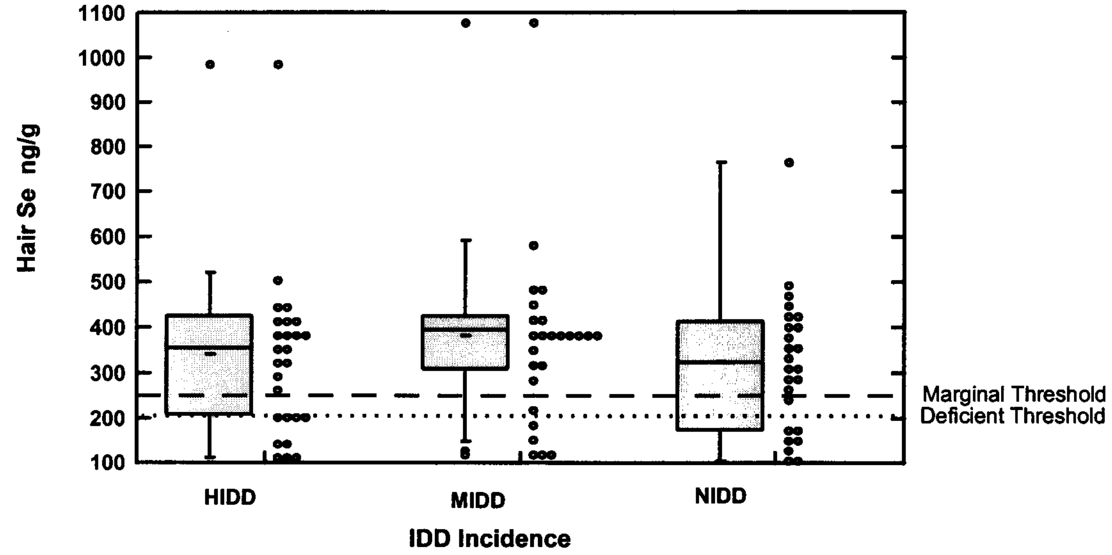


Figure 65. Box and whisker plot of hair Se classified by IDD incidence (excluding 2 outlying values from MIDD4). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in hair levels from Tan (1989). (HIDD = High IDD, MIDD = Moderate IDD, NIDD = No/low IDD)

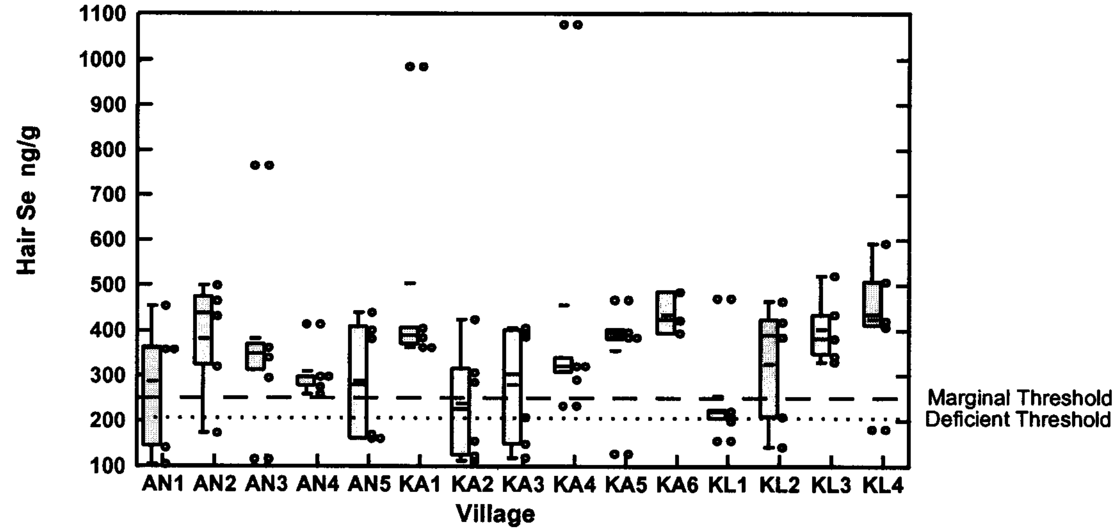


Figure 66. Box and whisker plot for hair Se from each village classified by region (excluding 2 outlying values from KA6). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in hair levels from Tan (1989).(AN = Anuradhapura, KA = Kandy, KL = Kalutara)

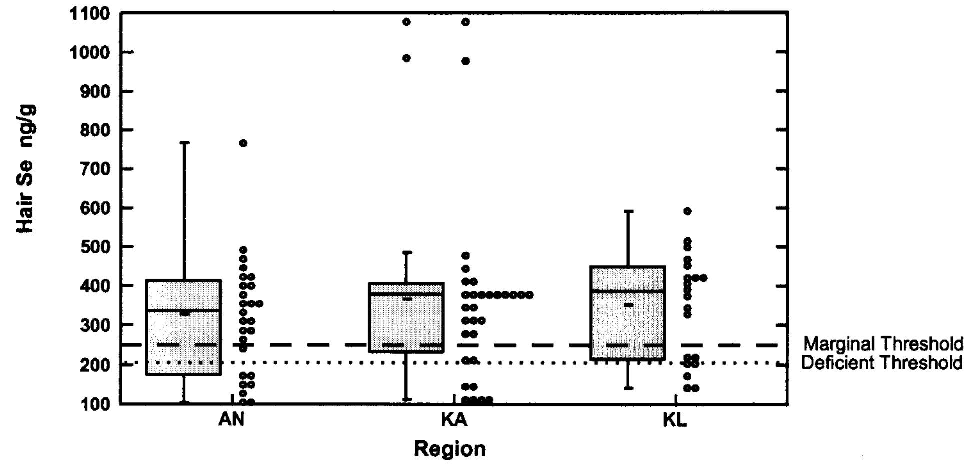


Figure 67. Box and whisker plot of hair Se classified by region (excluding 2 outlying values from KA6). Actual results are plotted as dots to the right of each box and whisker. Marginal and deficient total Se in hair levels from Tan (1989). (AN = Anuradhapura, KA = Kandy, KL = Kalutara)

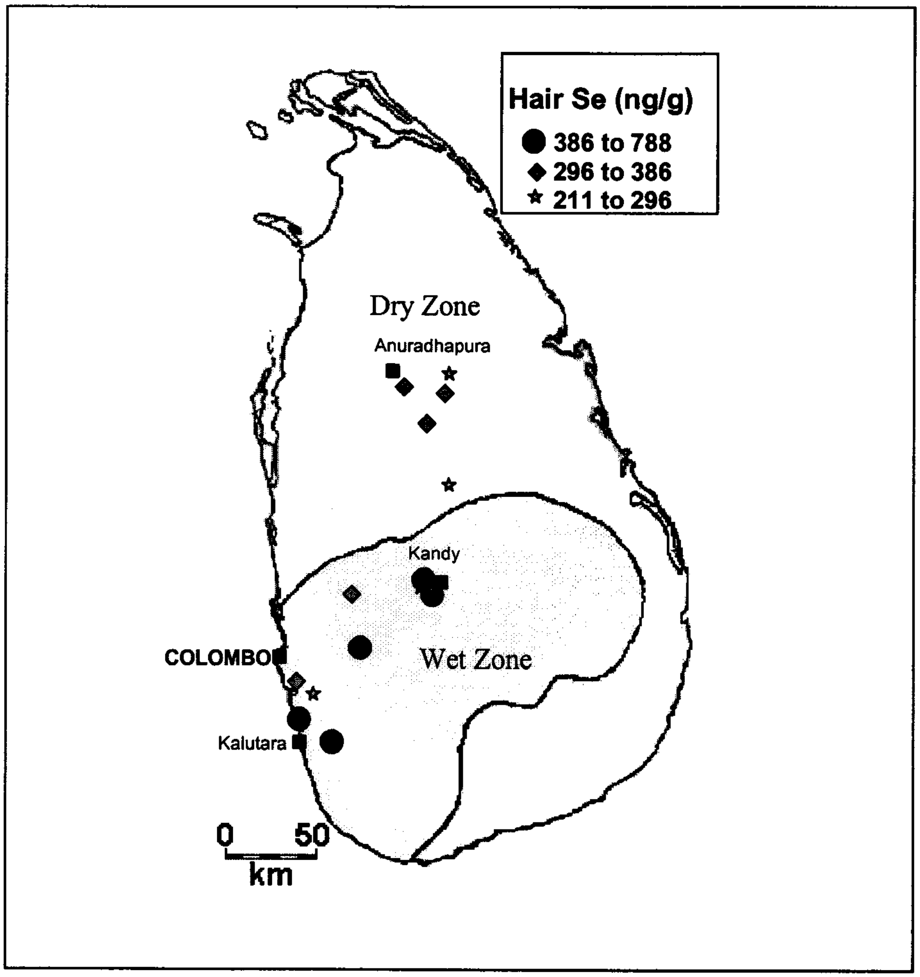


Figure 68. Map showing the Se content of hair for the fifteen targeted villages based on village geometric mean values.

Levels of Se in hair in the present study, are slightly higher (104 - 2659 ng/g, geomean 326 ng/g) than values reported for the Keshan Disease areas of Zhangjiakou (94 - 359 ng/g, geomean 206 ng/g, Johnson et al., 1996) and Enshi (170 - 853 ng/g, geomean 304 ng/g, Fordyce et al., 1998) in China.

Never the less, approximately 25 - 35 percent of the samples in each of the IDD groups and the regions are below the marginal threshold described by Tan (1989) for hairs in China (Table 29). Values range from deficient to high in both the IDD and regional grouping of villages (Table 29). Highest percentages of marginal and deficient samples (~35%) occur in the Kalutara and HIDD regions.

A broad range of Se values is evident within villages particularly in Navinna (MIDD4) and Polambayagama (NIDD3) (Table 29), demonstrating that the Se status of individuals within the same village can vary from deficient to high.

Table 29. Se levels in hair from the 15 targeted villages classified by Se threshold values.

Village Name	IDD Code	Region Code	% Deficient < 200 ng/g	% Marginal 200 - 250 ng/g	% Moderate 250 - 500 ng/g	% High 500 - 300
Agunawala	HIDD1	KA1			80	20
Kurunduwatte	HIDD2	KA2	50		50	
Olaboduwa N	HIDD3	KL1	20	60	20	
Pelenwatte	HIDD4	KL2	20	20	60	
Gurudola	HIDD5	KL3			80	20
Dehideniya	MIDD1	KA3	33	17	50	
Kobbekaduwa	MIDD2	KA4		20	60	20
Ambepussa	MIDD3	KA5	20		80	
Debagama	MIDD4	KA6			60	40
Navinna	MIDD5	KL4	20		40	40
Upuldenya	NIDD1	AN1	40		60	
Manankattiya	NIDD2	AN2	20		80	
Polambayagama	NIDD3	AN3	20		60	20
Ihala Kagama	NIDD4	AN4			100	
Kiralessa	NIDD5	AN5	50		50	
HIDD Region			*19*	*15*	*58*	*8*
MIDD Region			*15*	*7*	*59*	*19*
NIDD Region			*28*		*68*	*4*
Anuradhapura			*27*		*69*	*4*
Kandy			*19*	*6*	*63*	*12*
Kalutara			*15*	*20*	*50*	*15*

Deficient, marginal, moderate and high thresholds from Tan (1989)

12.5 Correlation Analysis

Se levels 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). No marked variation in hair Se levels between women currently suffering IDD and those who are not is evident (Figure 69). However, highest Se levels occur in women who have never suffered or no longer suffer from the disease. Hair Se levels show no clear relationship with the number of years a woman has suffered from IDD (Figure 69). There are no marked differences in hair Se levels between families with a history of IDD and those without, although the highest Se levels occur in women without a family history of IDD (Figure 69).

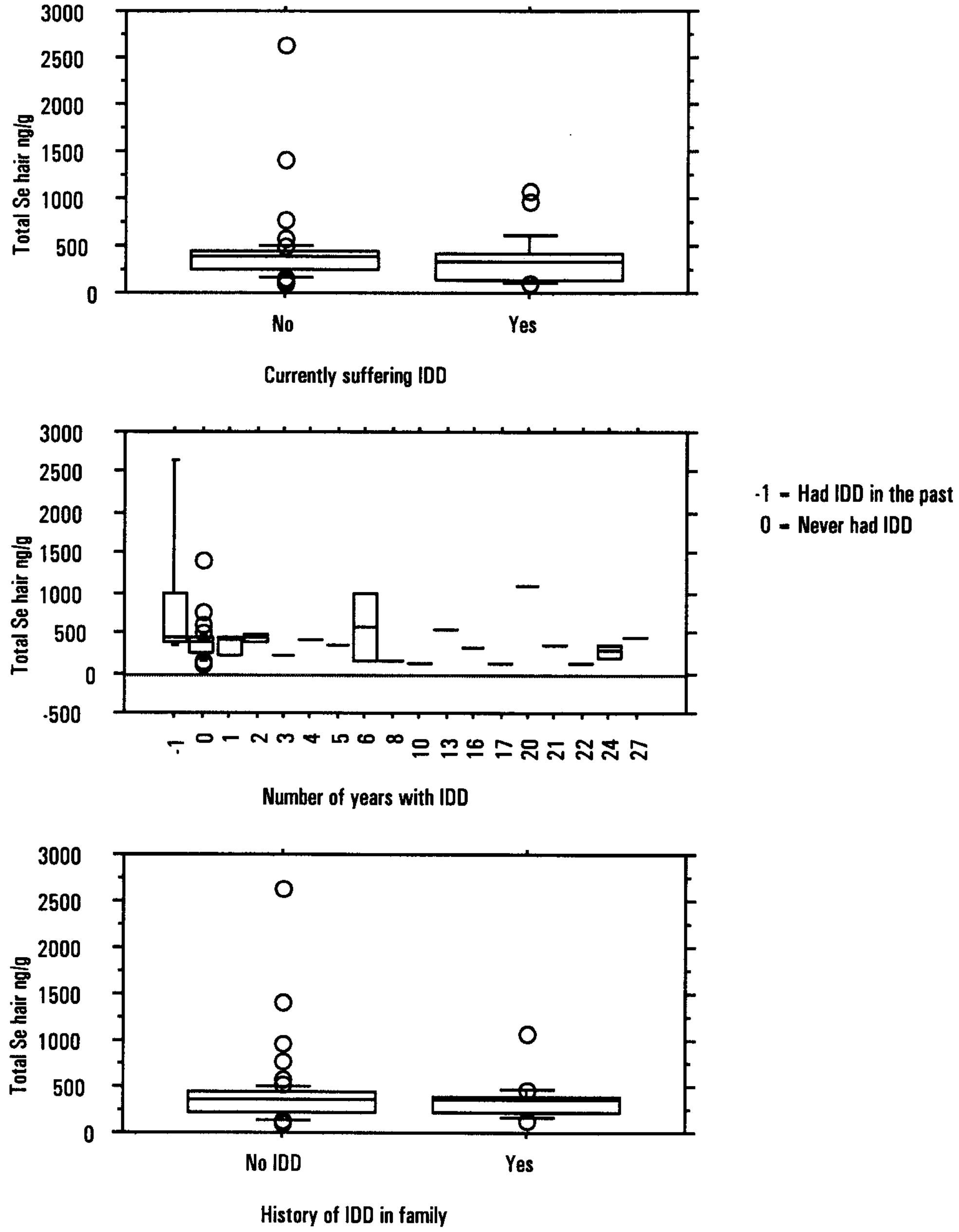


Figure 69. Box and whisker plots of hair Se classified by IDD history.

Locally grown rice samples were collected from the rice stores of women whose hair was sampled. It is therefore possible to make a direct comparison between total Se levels in hair and total Se levels in rice. However, water and soil samples were not necessarily collected from fields and wells belonging to the women whose hair was sampled therefore comparisons with these sample types are based on village geometric mean results.

Se concentrations in hair show no significant (95% level) correlation with the concentration in rice in the dataset as a whole (Table 30) or within each IDD group or region (Figure 70). The highest Se value in hair (2652 ng/g) from Debagama (MIDD4/KA6) does not correspond to the highest rice Se in the dataset as a whole, but does coincide with the highest Se level in rice from the Kandy region (Figure 70).

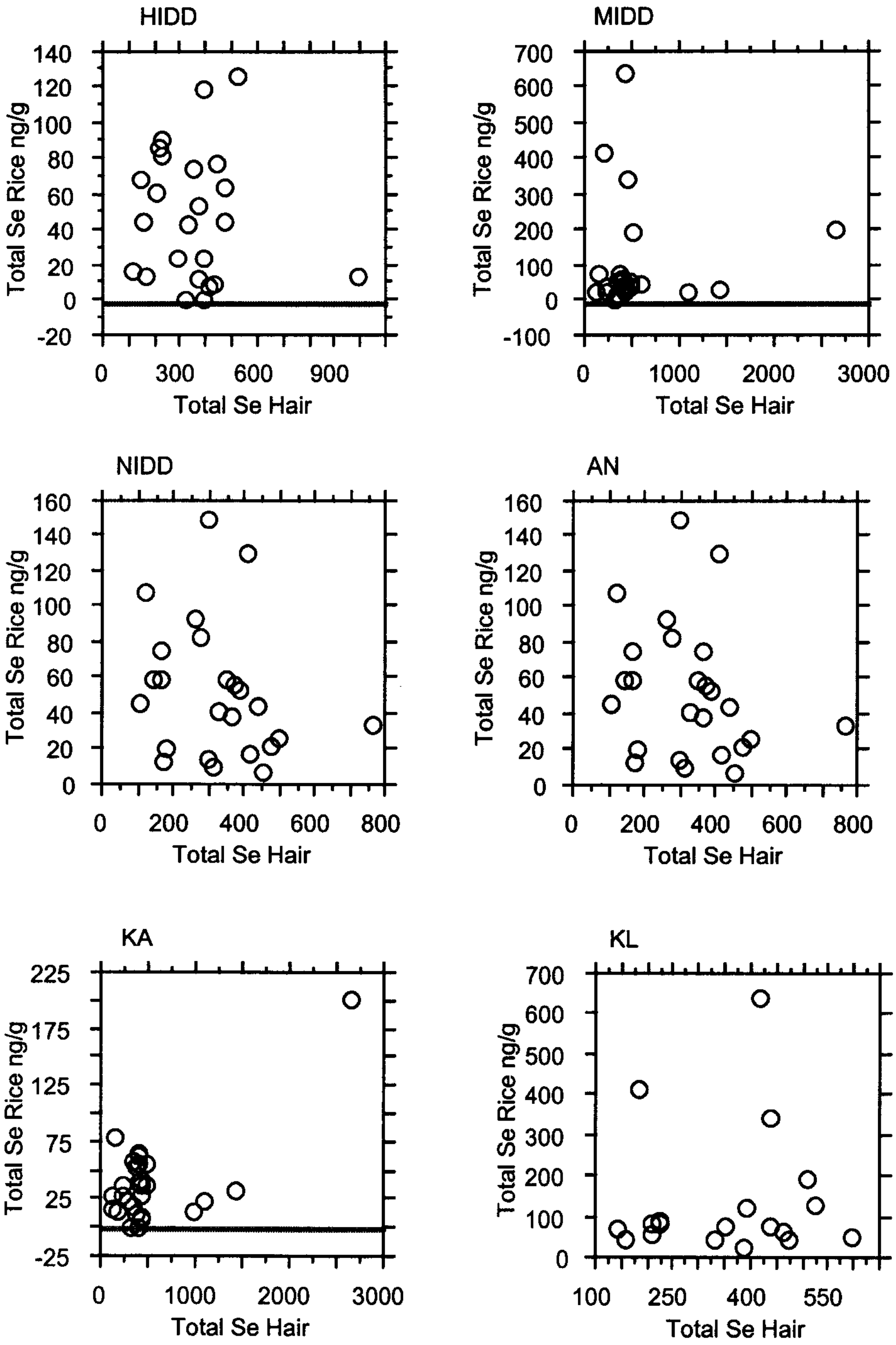
Table 30. Spearman Rank correlation matrix of village geometric mean values for total Se in hair and selected soil, rice and water parameters.

	Hair Se
Rice Se*	-0.050
Soil I	-0.086
Soil Se	0.229
Soil pH	-0.297
% Se ads	0.052
Soil Ca	-0.236
Soil Mn	-0.432
Soil Fe	-0.089
Soil Al	-0.179
Soil Ni	0.103
Soil Cu	0.071
Soil Zn	0.146
TOC	0.242
Water Se	0.155
Soil WSe	0.259
Soil PSe	0.018

n = 15 r95% = 0.441 (Koch & Link, 1970)
n = 74 r95% = 0.194
% Se ads = Soil % residual Se adsorption

Total hair Se concentrations do not correlate significantly (95% confidence level) with any soil parameters (Table 30). The higher Se values in soil and rice noted in Navinna (MIDD5) do not result in enhanced hair Se levels in this village. It is possible that food sources other than rice and drinking contribute to the Se intake of the population as levels of Se in both these foods are low.

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 regional differences in Se status between Dry Zone (AN), Wet Zone upland (KA) and Wet Zone coastal (KL) populations or between populations in high IDD incidence villages and no IDD incidence villages. The Se status of the population indicated by hair Se levels shows no clear relationship with Se in soil, water or rice samples. Although these results do not show a clear link between Se deficiency and IDD incidence, they do not disprove the effect Se deficiency may have on IDD as Se deficiency is clearly prevalent in IDD areas.



HIDD = High IDD incidence
MIDD = Moderate IDD incidence
NIDD = No IDD incidence

AN = Anuradhapura
KA = Kandy
KL = Kalutara

Figure 70. Comparisons between Se values in hair and rice samples in the three IDD incidence groups and the Anuradhapura, Kandy and Kalutara regions.

13. DISCUSSION

13.1 Classification of Target Villages

The initial classification used to group the targeted villages is based on IDD incidence as discussed in Section 8.4. The IDD incidence rates can only be used as a rough guide to indicate which villages have high medium or low incidences of IDD on a local scale. The rates are drawn from different surveys and the criteria used for establishing them are not consistent. The IDD rates show that within a region there is great variability of IDD incidence - one village may have high incidence whereas a neighbouring settlement may have low/no IDD. The causative factors suggested are numerous and a more detailed study is required to explain differences between neighbouring villages. The sampling strategy in this study is most useful in determining regional differences, and for this reason data is classified in several other ways in addition to the IDD classification.

Although the island of Sri Lanka is relatively small (area of 65,525 km^2, maximum length 432 km and maximum width 224 km, Survey Dept., 1988), there are marked climatic and topographic contrasts. Hence it is possible to classify the targeted villages on the basis of Wet or Dry Zone, or by upland or lowland (Figure 5). All the HIDD and MIDD villages fall within the Wet Zone, and all the NIDD villages are within the Dry Zone (in this report the 2000 mm isohyet is used to define the Zones - Figure 5). All the NIDD villages fall within the relatively flat area surrounding Anuradhapura whereas the MIDD and HIDD villages are located in the highlands of Kandy and the coastal plain around Kalutara respectively. A third classification that divides the settlements into the regions of Anuradhapura, Kandy and Kalutara is used to represent different climato-topographic regions in which geochemical and other factors can be contrasted in order to investigate the variable occurrence of IDD across the island of Sri Lanka.

13.2 Soil

In the Kandy region it was observed that banded variations in the underlying metamorphic rocks tended to contribute variable amounts of quartz and mica to the soil. However, in general, there were no major contrasts between the cultivated soils collected, except that in the Kalutara region the dry soil powders are greyer and darker (Figure 9) reflecting the greater amount of organic matter (confirmed by the TOC analyses (Figure 29)). Soil characteristics in the three climatic-topographic regions are summarised in Table 31.

Levels of iodine in the cultivated soils of the Wet Zone are no lower than those for the Dry Zone, so the suggestion that heavy rain produces iodine deficient soils in the Wet Zone (Mahadeva & Shanmuganathan, 1967) cannot be supported by the results of the present study. It is difficult to relate IDD incidence to levels of iodine in cultivated soils. Discussions on IDD incidence usually refer to drinking water levels of iodine. This is probably because it is much easier to determine iodine in water samples than in soil samples rather than any implied causative effect. Tan (1989) report levels of generally < 1 µg/g iodine in soils for the endemic goitre province of Heilongjiang in China, however, there is poor correlation with IDD incidence. Comparisons between the present study and Heilongjiang are difficult due to limited data available for China soils, however, on average, the Sri Lankan samples contain more than 1 µg/g iodine (Table 32). Dissanayake & Chandrajith (1996) report an average value of 1.9 µg/g iodine for the soils of the Angunawela-Daulagala endemic goitre area near Kandy which is very similar to that recorded in the present study (Table 32).

Iodine in Japanese flooded rice paddy soil is reported to be an order of magnitude more soluble than iodine in drained soil (Sheppard & Motycka, 1997). Action by the roots of rice plants or micro-organisms in flooded paddies can produce methyl iodide (CH_3I) which is volatile and lost to the atmosphere via the plant shoots (Muramatsu & Yoshida, 1995). This may explain why the levels of iodine recorded in Anuradhapura paddy soils in the present study are lower (2.26 ug/g) than levels reported for Dry Zone (Wariyapola) non-paddy soils (9.4 µg/g) by Dissanayake & Chandrajith (1996). This may also explain why no detectable levels of water soluble iodine were found in the Sri Lankan soils investigated in the present study.

Total Se levels are higher in the Sri Lankan soils than in the low Se Keshan Disease areas of Zhangjiakou and Enshi in China (Table 32). Water soluble Se levels are also higher in Sri Lanka than in the low Se region of Enshi. This is the first time that Se levels have been recorded in Sri Lankan soils therefore there are no previous results from Sri Lanka for comparison.

In China the deficiency threshold defined by Tan (1989) is <0.125 µg/g total Se in top soils. On this basis, the total Se levels in the majority of soils from Sri Lanka cannot be considered deficient, however, 36% of the soils in the Anuradhapura region are deficient or marginal in total Se (Table 33). The highest levels of Se are in the Kalutara coastal region (Figure 22). This is coincident with the band of extensively developed lateritic soils (Survey Dept., 1988). The higher Se from the Kalutara coastal area are spatially related to the south-west of the Highland Complex (Figure 5). The south-west differs from the rest of the Highland Complex because of the presence of wollastonite-bearing calc-gneisses and basic rocks (Cooray, 1994). The soils in Kalutara region all contain high or excessive levels of total Se according to the Chinese classification of Se in soils (Tan, 1989) (Table 33).

Significant proportions of the soils in Anuradhapura (20%) and Kandy (33%) have marginal water soluble Se contents but all the soils in the Kalutara region contain high or excessive levels of water soluble Se (Table 32). If soil geochemistry is controlling the amount of Se entering the food chain and the human population in Sri Lanka, these trends should be reflected in rice and hair samples.

The soils of the Kalutara region were generally darker in colour which was suggestive of a higher organic content. This was confirmed by the TOC results which showed the highest TOC results were for the dark grey/grey soils. Levels of TOC in Sri Lankan soils are generally higher than the Enshi area in China. TOC levels in Anuradhapura and Kandy soils are comparable to the Zhangjiakou area but Kalutara soils have significantly higher organic matter contents than either of the Chinese regions (Table 32).

Soil pH results in the Kandy region from the present study are comparable to those reported by Dissanayake & Chandrajith (1996) for the Kandy area (Table 32). Sri Lankan soil pH values are similar to those reported in Enshi but are significantly lower than the Zhangjiakou area in China (Table 32).

Table 31. Summary characteristics of soils in the three climatic- topographic regions.

	Kalutara	**Kandy**	**Anuradhapura**
Climatic Zone (Figure 6)	Wet	Wet	Dry
Topography	Flat coastal plain	Mountainous	Generally flat
Agriculture	Poor irrigation, one rice crop per year	Good natural irrigation in valley areas. Two crops per year.	Very dry and drought conditions exist. Large areas irrigated from reservoirs enabling two crops per year.
Geology	Highland Complex/ Southwestern Group. Dominated by Al-rich corderite pelitic gneisses and wollastonite calc-gneisses. Basic charnockites are rare; acid and intermediate types predominate. Absence of marbles. **Geological Survey (1995); Cooray (1984, 1994)**	Kadugannawa Complex. Hornblende-biotite calc-alkaline gneisses, tonalite and granodiorite. Wanni Complex amphibolite-grade migmatitic granitic and granodioritic gneisses diorites and minor gabbros. **Geological Survey (1995); Cooray (1994)**	Wanni Complex amphibolite-grade migmatitic granitic and granodioritic gneisses diorites and minor gabbros. **Geological Survey (1995); Cooray (1994)**
Soil Type (Survey Dept., 1988)	Red-yellow podzolic soils, lateritic and "bog" soils.	Red-brown latosols and immature brown loams. Red-yellow-podsols.	Red-brown earths (low humus content) and gley soils
Soil pH†	Low (3.95 - 4.99) (very acid)	Low (3.91 - 5.35) (very acid)	Moderate (4.94 - 7.53) (slightly acid - neutral)
Soil Maturity and Mineralogy†	Mature soil: kaolinite + gibbsite + goethite	Immature soil: rock forming minerals (micas) + kaolinite + (trace) goethite + gibbsite; may get increase of smectite and illite close to Wet Zone / Intermediate Zone boundary	Immature soil: kaolinite + illite + smectite. Clays have high cation exchange capacity.
Soil Chemistry†	Low Ca-Mn-Fe High Al	High Fe-Zn-Cu Intermediate Ca-Mn-Al-Ni	High Ca-Mn Low Ni-Al
Soil Organic Matter†	Relatively organic rich	Intermediate-low organic content	Low organic content
Predicted Se and I Adsorption Capacity	Strong adsorption onto surfaces of secondary Fe and Al oxides (goethite and gibbsite) and organic matter	Strong adsorption onto surfaces of secondary Fe and Al oxides (goethite + gibbsite), and organic matter.	Low adsorption capacity onto illite/ smectite.
Soil Residual Adsorption Capacity for Se and I†	High. Not as high as Kandy due to higher levels of Se already in soil and lower levels of Fe.	Very high. Due to moderate levels of Se and high levels of Fe. Many adsorption sites still available.	High. Not as high as Kandy or Kalutara due to lower organic matter and Al content.
Soil total I and Se Contents†	Se and I high due to adsorption capacity of soil, I high due to proximity to ocean	Moderate Se due to moderate adsorption, low I due to moderate adsorption	Low Se due to low adsorption capacity; moderate to high I due to capillary movement of I in Dry Zone soils
Se and I Availability in Soil† († from present study)	Highest extractable (water soluble + phosphate extractable)Se due to high total Se levels. I availability very low and percentage of Se availability relatively low due to adsorption of Se and I onto goethite, gibbsite and organic matter. However, water soluble (available) Se levels are similar to Kandy and Anuradhapura.	Moderate extractable Se due to moderate total Se levels. I availability very low and moderate percentage of Se availability due to adsorption of Se and I by goethite, gibbsite and organic matter. However, water soluble (available) Se levels are similar to Anuradhapura and Kalutara.	Lowest extractable Se due to low total Se levels. Highest percentage of Se availability due to moderate pH (6-7) and weaker adsorption by illite. I availability very low due to poor retention in soil However, water soluble (available) Se levels are similar to Kandy and Kalutara.

Table 32. Summary of iodine, Se, pH and TOC data ranges for soils classified by region compared to published results reported by previous investigators.

	Determinant	Range	Geometric Mean
Anuradhapura>	Total Iodine µg/g	0.13 - 10	2.26
Kandy>		0.13 - 4.6	1.77
Kalutara>		1.00 - 9.6	3.91
Kandy*		0.04 - 6.6	1.99
Wariyapola*			9
Heilongjiang~		<0.5 - >1	
Anuradhapura>	Total Se ng/g	113 - 663	226
Kandy>		276 - 1149	545
Kalutara>		730 - 5238	2435
Zhangjiakou†		40 - 263	127
Enshi^		34 - 228	99
Anuradhapura>	Water Soluble Se ng/g	4.89 - 17.6	10.4
Kandy>		4.88 - 17.2	7.1
Kalutara>		8.70 - 42.0	18.0
Enshi^		0.03 - 5.0	0.3
Anuradhapura>	pH	4.9 - 7.5	6.1
Kandy>		3.9 - 5.4	4.5
Kalutara>		4.0 - 5.0	4.4
Kandy*		3.8 - 6.8	5.2
Zhangjiakou†		6.8 - 9.2	7.9
Enshi^		4.2 - 6.9	5.3
Anuradhapura>	TOC %	0.10 - 1.40	0.6
Kandy>		0.30 - 2.10	1.0
Kalutara>		1.70 - 10.80	4.7
Zhangjiakou†		0.50 - 3.20	1.5
Enshi^		0.01 - 0.54	0.4

* Dissanayake & Chandrajith (1996) ^ Fordyce et al. (1998) † Johnson et al. (1996) ~ Tan (1989)
> Present Study

Table 33. Soil total Se and water soluble Se results from the three regions classified according to Se threshold values.

Region	Percentage of Samples									
	Deficient ng/g		Marginal ng/g		Moderate ng/g		High ng/g		Excessive ng/g	
	TSe	WSe	TSe	WSe	TSe	WSe	TSe	WSe	TSe	WSe
	< 125	<3	125-175	3-6	175-400	6-8	400-3000	8-20	>3000	>20
Anuradhapura	8		28	20	60	20	4	60		
Kandy				33	23	33	77	33		
Kalutara							70	75	30	25

TSe = Total Se WSe = Water soluble Se
Deficient, marginal, moderate, high and excessive thresholds from Tan (1989).

From the correlation and factor analysis distinctive elemental groupings are seen. Taking the data set as a whole, Se and iodine are grouped (from factor analysis) with Al and TOC. The association of Se and iodine with organic matter has been observed previously (for example, Se in the soils of Zhangjiakou (Johnson et al., 1996) and Enshi (Fordyce et al., 1998 and iodine in Welsh soils (Fuge & Johnson, 1986). Gibbsite (Al) in the lateritic soils of the Kalutara is a strong adsorber of Se in particular. The residual Se adsorption capacity of the soils correlates with the Fe-Zn-Cu grouping of elements that is a characteristic of the Kandy region soils. In this region it is possible that goethite exerts a greater control on the soil's ability to adsorb more Se whereas in the Kalutara region, gibbsite and organic matter are more important. These results have important implications if the Se status of the Sri Lankan population is to be enhanced by the addition of Se fertilisers to soil. In the Kandy region, it is likely that Se added to soil will be ineffective as the soils still have a high capacity to adsorb more Se making it less bioavailable.

The pH of the soil is an important factor in determining the mobility of the Se in the soil (Mikkelsen et al., 1989). In acid and neutral soils, inorganic Se occurs as insoluble Se^{4+} - complexes of oxides and oxyhydroxides of ferric Fe. Se^{4+} adsorption is at a maximum between pH 3 - 5. Se^{6+} the predominant oxidation state in neutral and alkaline soils, is generally soluble, mobile and readily available for plant uptake. Thus the more acidic soils of Kandy and Kalutara are likely to be better "fixers" of Se than the neutral soils of Anuradhapura.

Experiments investigating the Se adsorption capacity (based on selenite)of various clays (Navaratne, In Prep) show strong adsorption of Se by goethite and gibbsite, slightly lower adsorption capacity of illite, and low adsorption capacity of kaolinite (Figure 71). Adsorption is greatest at low pH. These results are consistent with the findings of the present study which suggest greatest adsorption of Se occurs in the Kalutara and Kandy soils which have lower pH and higher gibbsite and goethite contents than the Anuradhapura soils.

In summary total Se and iodine levels in Sri Lankan soils are highest in the Kalutara coastal region and lowest in the Dry Zone. Soil organic matter and clays (goethite and gibbsite) are strong adsorbers of Se in soil and inhibit Se availability for plant uptake. Levels of Se in a significant proportion of Anuradhapura and Kandy soils are marginal, however, in the high IDD region of Kalutara, levels of soil Se are high to excessive.

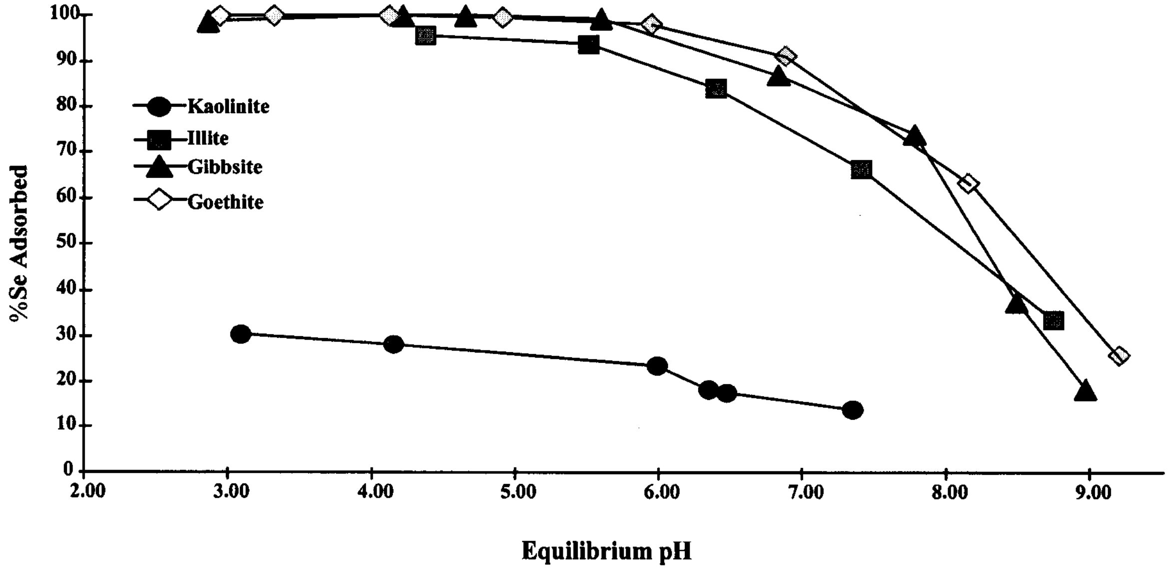


Figure 71. Adsorption of Se by different clay minerals at various pH's. (From Navaratne, In prep)

13.3 Rice

The box and whisker plots in Section 4 (Figures 44 to 50) show there is no identifiable trend in Se levels between the different villages classified by IDD incidence or by region. However, the rice samples of Navinna (MIDD5) are distinctly higher than any other village (50 - 777 ng/g) which was a reflection of the high level of Se in the soils. The reasons for the high levels of Se in the environment of Navinna are not known but may be related to possible lithological variations or fertiliser application. All the villages targeted used fertilisers and it is not known whether Navinna used a fertiliser that was any different.

No differences in Se concentrations were observed between rice boiled in the husk and unboiled rice or between red rice and white rice varieties.

There is a significant correlation between soil total Se and rice Se (based on village geometric means) at the 99.8% confidence level ($r_{sp} = 0.70$) (Figure 52), however, there is no significant correlation between soil extractable (water soluble + phosphate extractable) Se and rice Se levels (based in village geometric means) (Figure 54). Trends in rice Se levels mirror trends in soil water soluble Se concentration indicating that soil water soluble Se levels may give a better indication of the bioavailable Se than extractable Se levels (Section 9.7).

The Se levels in the rice samples range from deficient to high (based on the Chinese classification, Tan, 1989) in all three regions. However, in Anuradhapura (40%) and Kandy, (63%) significant proportions of the rice samples are marginal or deficient in Se whereas in the Kalutara region, the majority of samples (95%) are moderate to high in Se (Table 34). These results closely match the classifications of soil total and water soluble Se levels in Anuradhapura and Kalutara (Table 32), but in the Kandy region a greater proportion of rice samples have marginal Se levels compared to soil samples.

Geometric mean values for Se in rice in the three regions and IDD groups can be summarised as follows:

Kalutara	98 ng/g	>	Anuradhapura	42 ng/g	>	Kandy	18 ng/g
Kalutara*	65 ng/g	>	Anuradhapura	42 ng/g	>	Kandy	18 ng/g
MIDD	55 ng/g	>	NIDD	42 ng/g	>	HIDD	25 ng/g
NIDD	42 ng/g	>	MIDD*	33 ng/g	>	HIDD	25 ng/g

* Excluding outlying values from Navinna (MIDD5, KL4)

These trends confirm the results for extractable Se in soil and investigations into the ratios of Se in rice versus soil for each village (based on village geometric means). There is a clear distinction between the Wet and Dry Zone.

Higher levels of Se in rice relative to soils in the Dry Zone reflect the low adsorption capacity of the soils (due to lower organic matter, Fe and Al concentrations) and greater availability of Se due to higher soil pH in this region. However, the levels of Se in soils in the Dry Zone are so low, that a significant proportion of the rice grown in this region is Se deficient.

Wet Zone rice samples contain a much smaller percentage of Se relative to the soils than the Dry Zone samples (1-7% and 17-20% respectively). Se is less available in the more acid, more organic-rich and goethite and gibbsite rich soils. Therefore, despite higher soil total Se levels, rice in the Kandy region contains less Se than rice in Anuradhapura. This also explains why a high proportion of the rice samples grown in the Kandy area are deficient in Se compared to the proportion of Se deficient soils (Tables 33 and 34).

The levels of Se in Kalutara soils are five times higher than in Kandy soils and despite the strong adsorption of Se by gibbsite, goethite and organic matter in this region, greater amounts of Se are taken up by the rice.

On the basis of regional geometric mean values, there is a distinctive trend in rice Se levels which are lower in high IDD villages than in low/no IDD villages. Whether or not Se is implicated in causing IDD, it is certainly the case in the Kandy region that IDD is prevalent and Se uptake by rice is inhibited by the soil chemical processes. The incidence of IDD in the Kalutara region, however, does not correspond to low levels of Se in rice.

Table 34. Rice total Se results from the three regions classified according to Se threshold values.

Region	Percentage of Samples				
	Deficient Se ng/g <25	Marginal Se ng/g 25 - 40	Moderate Se ng/g 40 - 70	High Se ng/g 70 - 1000	Excessive Se ng/g > 1000
Anuradhapura	28	12	32	28	
Kandy	33	30	30	7	
Kalutara	5		37	58	

Deficient, marginal, moderate, high and excessive thresholds for Se in grain from Tan (1989).

Iodine concentrations in rice samples from the 15 villages are very low and only two samples from Dry Zone villages contained levels above the limit of detection. However, the levels reported for Sri Lankan samples are comparable to rice Se levels recorded in other areas of the world (Section 10.5). Levels of iodine in the grain of rice tend to be significantly lower than other parts of the rice plant. Muramatsu et al. (1995) showed that 1000 times more iodine was taken up in the leaves of rice plants than in the grain.

13.4 Drinking Water

The drinking water sample results emphasise the strong contrast in chemical environments between the Dry Zone in the north and the Wet Zone in the south-west of the island. Whilst significantly more iodine is available in the drinking waters of the NIDD villages, there was no significant difference in iodine concentration between the MIDD and HIDD villages of Kandy and Kalutara. Se levels in drinking water were similar whether classified by IDD incidence or region although highest values occurred in the Dry Zone (NIDD1 and NIDD5). Levels of Se in Sri Lankan waters are low compared to average surface water concentrations (Section 11.5). Levels of elements in water are generally lower than levels in food and therefore in the majority of cases do not contribute significantly to human dietary intake. However, it is possible that the higher concentrations of iodine in drinking water in the Dry Zone in Sri Lanka may help to prevent the occurrence of IDD in this region (Section 13.6). Geometric mean concentrations in the three regions can be summarised as follows:

Iodine ug/l Anuradhapura 66.5 > Kalutara 6.44 > Kandy 6.07
Se ug/l Anuradhapura 0.11 > Kalutara 0.77 = Kandy 0.77

13.5 Hair

Although the majority of women sampled during the present study had long hair that had not been cut since they were teenagers, in genreal, no significant differences in Se concentration were found in different lengths of the hair tresses. Washing the hair in anionic/ionic surfactant (Neutracon®) to remove possible surface contaminants also made little difference to the Se results compared to washing in deionised water.

Hair Se results are higher than those reported in Se deficient areas of China, however, significant proportions of the samples are below the marginal threshold defined by Tan (1989) for Se in hair (Anuradhapura 27%, Kandy 25% and Kalutara 35%). These results are in contrast to the proportion of deficient or marginal rice Se values for the three regions (Anuradhapura 32%, Kandy 63% and Kalutara 5%). Clearly people in the Kandy region obtain significant amounts of Se from sources other than locally grown rice as 60% of rice samples are marginal or deficient in Se and yet only 25% of the women sampled are marginal or deficient. Conversely, in Kalutara, only 5% of rice samples are marginal or deficient in Se whereas 35% of the sample population have marginal-deficient hair Se values. The results of the present study indicate that the natural environment and the rice grown on it are poor sources of Se in Sri Lanka. Although this study has not proved a direct link between Se deficiency and IDD, it has proved that significant proportions of the populations in IDD regions of Sri Lanka are Se deficient.

13.6 Dietary Intake

Mahadeva et al. (1968), measured the iodine content and the amount of different foodstuffs consumed by rural populations in Sri Lanka. Rice, pulses, leafy vegetables, fruit (with the exception of brinjal) and water showed a marked contrast in iodine concentrations between the Wet and Dry Zones. Foodstuffs grown in Jaffna (in the north of the Dry Zone) contained much higher levels of iodine than food stuffs grown in the south-west of the island in the Wet Zone (for example, rice 43 - 210 ng/g in the Wet Zone and 880 ng/g in the Dry Zone). Levels of iodine in water ranged from 4.4 - 4.6 µg/l in the Wet Zone to 182 µg/l in the Dry Zone. Differences in the iodine content of coconut, an important constituent of the Sri Lankan diet were less marked (1075 ng/g Wet Zone, 1660 ng/g Dry Zone). On the basis of daily dietary intakes of various food stuffs, the daily consumption of iodine in the Sri Lankan diet was estimated at 300 - 350 µg per person per day in the Wet Zone and 850 µg per person per day in the Dry Zone (Mahadeva et al.,1968). These values exceed the recommended daily requirements for humans of 160 µg/day and 200 µg/day for children and pregnant women (Hetzel & Maberly, 1986). However, up to 38% of the iodine can be lost during the cooking process which reduces these figures to 185 - 215 µg/ day in the Wet Zone and 530 µg/day in the Dry Zone (Mahadeva et al., 1968). 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 for dietary intake of rice and water are correct, the intake of iodine and Se from rice and water measured during the present study can be calculated for each region and IDD group on the basis of geometric mean values (Table 35). The levels 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 and may explain why IDD does not occur in this region of Sri Lanka. 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 35).

Although the iodine status of individuals was not measured during the current study, it is clear that levels 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 suffer from iodine deficiency.

The introduction of iodised salt to the population of Sri Lanka has been carried out by the government in recent years. Of 50 persons sampled in the present study, 4 had used iodised salt in the past, 32 were currently using iodised salt on a regular basis, 9 used the salt occasionally and 6 people didn't use it. Although these figures may seem encouraging, of the 45 people who had or were using the salt, 33 added it before cooking. The majority of iodine added in this way is lost to the atmosphere during the cooking process significantly reducing the effectiveness of the iodised salt programme.

There is currently no information on the Se status of the Sri Lankan population, the results of this study suggest that significant proportions of the population may be Se deficient. Levels 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 Kalutara and Kandy regions contribute to the occurrence of IDD. Although Se intake in the Anuradhapura region is also low, levels of dietary iodine are higher due to intake from drinking water and this may prevent IDD in this region.

Table 35. 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
Anuradhapura	14.6	66.5	11.8	0.11
Kandy	<10.8†	6.1	5.1	0.77
Kalutara	<10.8†	6.4	18.5*	0.77
HIDD	< 10.8†	7.0	7.1	0.07
MIDD	< 10.8†	5.5	14.1*	0.07
NIDD	14.6	66.5	11.8	0.11
Recommended daily intakes	160 - 200~		60 - 75^	

HIDD = High IDD incidence, MIDD = Moderate IDD incidence, NIDD = No/low IDD incidence
† Calculated on basis of limit of detection ~Hetzel & Maberly (1986) ^ UK Dept. of Health
* Excluding Navinna (MIDD5)

13.7 Summary

In summary, although the levels of total Se and iodine in soils are higher in the Wet Zone of Sri Lanka compared to the Dry Zone, the marked contrast in soil chemistry between the two climato-topographic regions means that the Se and iodine in the Wet Zone is less bioavailable. As a result, iodine concentrations in rice from both the HIDD and MIDD villages are below the analytical limit of detection (40 ng/g) and iodine was detected in only two of the five NIDD villages (45 and 58 ng/g). Similarly, deficient or marginal Se concentrations occur in rice in all three IDD regions although the Kandy area has the highest proportion of Se deficient rice samples. Iodine in drinking water is low (6 µg/l) in both the MIDD and HIDD villages and relatively high (66 µg/l) in the NIDD villages. The Se status of a proportion of the women in all three IDD regions is, determined by hair analysis, deficient or marginal based on thresholds established in China. In the HIDD region 34% of the women had deficient or marginal Se status. The corresponding figures for the MIDD and NIDD regions are 22% and 28%, respectively. It is clear from this information that a combination of iodine and Se deficiency could be involved in the etiopathogenesis of goitre in Sri Lanka. No systematic variation has been observed between the regions for either Se in rice or the Se status of the people. The only significant difference between the NIDD region compared with the MIDD and HIDD regions is that iodine in water is much higher and in rice is slightly higher in two of the IDD villages. Fish forms an important part of the Sri Lankan diet and is probably the best dietary source of iodine. There should not be, therefore, any iodine deficiency, except perhaps in the very poorest sections of the community. It is therefore necessary to consider other factors which may affect goitre incidence in Sri Lanka.

13.8 Other Factors

13.8.1 Goitrogens

Whereas iodine deficiency is accepted as the main environmental determinant in the aetiology of endemic goitre, there are a large number of naturally occurring and artificial agents which 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. The agents may amplify the effects of iodine deficiency leading to a greater incidence of goitre and other iodine deficiency disorders (Gaitan, 1989; 1997). Cyanogenic glycosides, which are precursors for thiocyanate which inhibits the iodine concentrating mechanism of the thyroid, occur in staple foods including cassava, maize, bamboo shoots, sweet potatoes and pearl millet. It is well known that exposure to cyanogenic glucosides in cassava (Delange, 1989) and to a combination of thiocyanate and flavonoids in millet (Gaitan et al., 1989; Gaitan 1996) enhances both the incidence and severity of goitre in Zaire and western Sudan, respectively. More recently Sartelet et al. (1996) demonstrated the antithyroid effects of flavonoids in Fonio millet, which is the staple food for people in the endemic goitre area of Guinea. Anthocyanins are a diverse range of pigments derived from flavonoids. Pearl millet contains a number of flavonoids, including thiomide, C-glycosylflavones and glycosylvitexin, and these induce goitre by inhibiting the normal conversion of thyroxine (T4) to triiodothyronine (T3) (Gaitan et al., 1995).

13.8.2 Goitrogens in Sri Lanka

Little is known about the possible influence of goitrogens on goitre incidence in Sri Lanka. Dissanayake & Chandrajith (1996) suggested that goitrogens may be a factor influencing goitre incidence without specifying which goitrogens might be involved. Hjelle et al. (1994) studied the relationship between intakes of dietary goitrogens and the prevalence of goitre among a select group of pregnant women in the Galle District, south-western Sri Lanka. The goitrogen containing foods included in the study were cassava, cruciferous vegetables (cabbage, beetroot, kohlrabi and turnips) and yams. However, no significant relationship was detected between goitre status and frequency and the average monthly consumption of goitrogen containing foods. Hjelle et al. (1994) concluded that goitre in the population studied was not associated with excessive goitrogen consumption.

13.8.3 Red Rice: A Potential Goitrogenic Agent

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 the majority of rice samples collected from rural communities in the Kalutara region (three HIDD and one MIDD villages) were of red rice. Only 2 out of 30 rice samples from the HIDD and MIDD villages of the Kandy area were red rice and none of the rice samples from the villages in the Anuradhapura (NIDD) area. Red rice cultivation is concentrated in a few districts of Sri Lanka (Table 36) and is prevalent in two areas (Kalutara and Galle) with relatively high goitre incidence rates.

Table 36. Extent of red rice cultivation in districts of Sri Lanka where it is predominantly grown (pers. comm. Dr S Abeysiriwardena, Rice Research & Development Institute, Sri Lanka)

District	Approximate % Extent Under Red Rice
Wet Zone	40
Kalutara	35
Colombo	30
Galle	
Dry Zone	
Hambantota	38

Dr. Sumith Abeysiriwardena (Rice Research & Development Institute, Sri Lanka) kindly provided the following information on red rice cultivation, use and cooking in Sri Lanka: *"Kalutara district has the highest percentage extent under red rice. However, this may not have a direct relationship with the red rice consumption pattern of the people in the Kalutara District. In the areas where there is a high demand for red rice, the price for red rice is higher by about Rs 1.00 than white rice so that farmers grow red rice in those areas. High demand for red rice is basically traditional and the people who prefer red rice say that the red rice meal is heavier and more nutritious than the white rice meal. Both red and white rices are cooked in the same way and the boiling time is the same. Red rice is not usually parboiled, which is the practice used to improve milling quality (increase total milled rice and head grain percentage) and keeping quality (increase storage time). People not only in Kalutara area, but also in Galle, Matara and Hambantota usually eat raw rice whereas people in Anuradhapura and Kandy area usually eat parboiled rice. However, there is no difference in cooking methods between different areas. Sometimes rice is cooked to produce* *'kiri bath' which is rice cooked in milk. In the areas where red rice is grown 'kiri bath' is predominantly made with red rice. In other areas 'kiri bath' is made with white rice."*

In Southeast Asia, some rice varieties have a red, purple or even black colouring due to anthocyanin pigments in the seed coat / pericarp, although it has been suggested also that the red pigmentation may be caused by tannins (pers. comm. Dr J Wood, Natural Resources Institute (NRI)). 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). Anthocyanins are flavonoid compounds (Gaitan, pers. comm.) so red rice may have goitrogenic properties. 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 (pers. comm., Dr J Wood, NRI).

Parboiling and boiling of potentially goitrogenic anthocyanins in red rice may have one of number of actions, or a combination of them all. If the potential goitrogen is thermolabile, it will be destroyed. If the goitrogen is thermostable but water soluble, it may leach into the par-boiling water rather than penetrate the endosperm of the rice as it cooks. If the goitrogen is thermostable but chemically or otherwise bound within the bran, then it will be removed in the milling and polishing processes, as with conventional rice milling. If the goitrogen is within the grain kernel, then bran removal will have little effect on the level of goitrogen in the consumed fraction of rice. Parboiling could induce some leaching of goitrogen from the rice grain or lock it into the grain during starch gelatinisation (pers. comm. Dr J Wood, NRI). An apparent increase of antithyroid activity has been reported on heating, boiling and storage of pearl millet (Gaitan, 1996) so 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 aetiology of IDD in Sri Lanka.

13.9 Risk Assessment and Potential Remediation Strategies

13.9.1 Risk Assessment

Levels of total iodine in soil are higher in Sri Lanka than in the endemic goitre region of China. However, the results of the present study have shown that it is important to consider the chemical controls on element bioavailability in soil in order to assess areas at risk from iodine deficiency. Iodine in soils of the goitrogenic Wet Zone of Sri Lanka is strongly adsorbed by organic matter and clay minerals and as a result, iodine contents in rice and water are low in this region. Rice or water samples may provide useful information on the likely risk of iodine deficiency in the human population. However, levels of iodine in rice, in general, are very low and it is unlikely that this foodstuff provides significant quantities of iodine to the diet unless consumed in very large quantities. It is therefore unlikely that sampling rice alone will give a good indication of the iodine status of the population and other foodstuffs should be sampled. The results of this study have shown that is important to consider the levels of iodine in drinking water in addition to staple foodstuffs as this may be an important source of iodine in the diet.

To assess the risk of Se deficiency in the human population, information on soil water soluble Se, extractable Se, Fe, Mn, Al and organic matter contents and soil pH are required to define more clearly, specific villages and populations at risk, on the basis of geochemical data. This method of assessing risk involves a number of analyses and careful interpretation of the results. However, it is important to understand the geochemical controls in the soil which prevent the uptake of elements into food crops in order to design effective remediation strategies.

Determinations of rice total Se levels did not provide a detailed indication of the likely human Se status. In the Kalutara region, only 5% of rice samples were marginal or deficient in Se whereas 36% of the women sampled had marginal or deficient Se levels in hair. Conversely, 63% of rice samples in the Kandy region were Se marginal or deficient but only 25% of women sampled had hair Se levels below the marginal threshold. These results suggest that other foodstuffs contribute to the Se status of the Sri Lankan population and more detailed dietary evaluations are required to assess deficiency risk.

13.9.2 Potential Remediation Strategies

Hair Se determinations have shown for the first time that significant proportions of the Sri Lankan population may be at risk from Se deficiency. Further investigations into the Se status of the Sri Lankan population are required to verify that Se deficiency is a problem. Should Se deficiency prove to be widespread, there are a number of options available for dealing with the problem. These include, encouraging people to increase 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. Furthermore, those at risk from iodine and Se deficiency are the poorest in the community and are unlikely to be able to afford Se supplementation tablets unless these are provided by government health programmes. It is also recognised that some small-scale farmers may not have the financial resources to diversify their diets in the manner recommended.

The majority of villagers already use 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 Kandy area where soils have a high capacity to adsorb more Se. The addition of Se in the form of fertiliser may be trapped by Fe and Al clays and organic matter in the soil, and may not increase crop Se levels.

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. Studies have shown that plant tissue Se concentrations were five times higher following foliar spraying of Se than when applied to soil (Watkinson & Davies, 1967). In general, Se^{6+} is more readily taken up by the plant than Se^{4+} and spraying late in the season results in higher Se concentrations due to greater leaf cover and slower plant growth (Mikkelsen et al., 1989). 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 organic matter in soil.

The presence of possible goitrogens in red rice, in particular, merits further study. Bibliographic searches indicate that the role of red rice in goitre has never been investigated. Detailed analysis of red rice grains to determine whether goitrogens are present mainly in the bran or the kernel is required. The goitrogenicity of red rice could be tested applying in *vitro* and in *vivo* tests previously used to evaluate goitrogens in millet (Gaitan et al., 1989; Gaitan, 1995). The in *vivo* test would involve 90 day rat/mouse studies, and an observation of goitre hyperplasia.

14. CONCLUSIONS AND RECOMMENDATIONS

1. The link between iodine deficiency and the onset of health problems such as goitre, mental retardation and cretinism (iodine deficiency disorders, IDD) has been established since 1895. The WHO currently estimate that 1 billion people in the world today are at risk from IDD. IDD and impairment of thyroid function can lead to problems of growth and body development making those affected less able to work and create wealth. People at risk are often the poorest members of the population who are totally dependent on subsistence agriculture for their dietary needs. The inability of their local environment to provide the correct mineral balance can lead to serious health problems. However, not all instances of IDD can be related to iodine deficiency and several other factors have been implicated in the aetiology of these disorders. It has recently been suggested that Se deficiency may exacerbate the effects of IDD as seleno-enzymes are required by the thyroid to process iodine effectively.

2. Previous and current medical investigations in Sri Lanka indicate that goitre is prevalent in the Wet Zone in the south-west of the country and is less prevalent in the Dry Zone to the north. Previous investigators assumed that iodine in the environment of the Wet Zone was washed out of soils resulting in lower levels than in the Dry Zone. Although measurements of iodine concentrations in water have been made in several previous studies, no systematic measurements of iodine levels in soils in the Wet and Dry Zones had been made. Similarly no information on Se levels in the environment or population of Sri Lanka were available prior to the present study. It was therefore not possible to establish the effects, if any of iodine and Se deficiency in the environment on IDD in Sri Lanka.

3. During the present study, fifteen villages were selected for sampling on the basis of the incidence of goitre in each village as follows: five no/low IDD incidence (NIDD) (< 10 % goitre), five moderate IDD incidence (MIDD) (10 - 25% goitre) and five high IDD incidence (HIDD) (> 25% goitre). This experimental design proved successful in determining chemical differences in the environment (demonstrated by soil, staple foodstuffs (rice) and water samples) and the Se status of the human population (shown by hair samples) between villages of different IDD incidence. The villages were located in three regions, namely Anuradhapura in the Dry Zone, Kandy in the uplands of the Wet Zone and Kalutara in the coastal plain of the Wet Zone. Samples from each village were also considered in terms of their geographic location to determine differences in the chemical environment and human Se status between different regions.

4. Hair from women was collected during the present study because it is mainly women who suffer from goitre in Sri Lanka. The majority of women had long hair that had not been cut for several years. Tests on a sub-set of samples, revealed no significant differences in Se levels in different lengths of the hair tresses in the majority of cases. A selection of hair samples were washed in an anionic surfactant to test whether the hair was contaminated with surface particles. No difference in Se levels between surfactant washed hair and hair washed in deionised water was evident. It was concluded that surface contaminants did not significantly affect the levels of Se in the hair. As a result of these tests, the whole hair length was selected for analysis and samples were washed in deionised water.

5. This study has presented for the first time, information on levels of Se in soil, rice, water and hair samples and systematic data on the levels of iodine in soils and rice in Sri Lanka. Results show that soil iodine concentrations in the Wet and Dry Zones are similar, therefore the previous theory that iodine is washed out of soils in the Wet Zone by heavy rainfall is not borne out by the present study. Highest levels of iodine in soil occur in the Kalutara coastal region, an area where IDD is prevalent. Soils in the Kalutara region contain highest levels of organic matter and soil iodine concentrations in this region appear to correlate with organic matter content. Levels of iodine in rice are very low but are comparable to levels of iodine in rice 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 it is unlikely that rice provides a good source of iodine in the Sri Lankan diet. Levels of iodine in rice are only marginally higher in the Dry Zone than the Wet Zone but a marked contrast is seen between levels of iodine in drinking water between the two climatic regions. Levels of iodine are ten times higher in the Dry Zone waters and contribute significant proportions of iodine to the diet. This supply of iodine may explain why IDD is not common in the Dry Zone.

6. Soil total and extractable (water soluble + phosphate extractable) Se levels are highest in the Kalutara region. All the soils in the Kalutara (MIDD-HIDD) region have high to excessive Se concentrations whereas a significant proportion of the soils in the Anuradhapura (NIDD) region are Se deficient. Although levels of Se in soil are higher in the Wet Zone than in the Dry Zone, a greater proportion of Se is taken up into rice in the Dry Zone as the Se is more readily available for plant uptake. This is due to the marked contrast in soil chemistry between the two climatic regions. Soils in the Kalutara and Kandy regions have higher organic matter, gibbsite and goethite contents and lower pH than soils in the Anuradhapura region which contain more illite. Se adsorption studies carried out by Navaratne (In Prep) have shown that gibbsite and goethite are stronger adsorbers of Se than illite especially at low pH. Thus, Se in the Wet Zone (Kalutara and Kandy) is held in clay minerals and organic matter in the soil and is not readily available for plant uptake. In the Kalutara region, soil total Se levels are five times higher than in the Kandy region and, despite adsorption by clay minerals and organic matter, the majority of rice Se levels are moderate to high whereas in the Kandy region 63% of rice samples are marginal or deficient in Se. Levels of Se in drinking water are similar in the Kandy and Kalutara regions and lower in the Anuradhapura region. Estimates of daily dietary intakes show that Se from water does not form an important source of Se in the diet.

7. Levels of total Se and iodine in Sri Lankan soils are not low compared to other areas of the world where IDD do not occur. However, the results of this study have demonstrated the important role that geochemical factors, such as soil pH and organic matter and clay content, play in controlling the amount of Se and iodine available for plant uptake. Sri Lanka is a relatively small island and yet there is a marked contrast in soil chemistry between the Wet and Dry Zones due to different geological, geochemical, climatological, topological and vegetative conditions. An understanding of these controls on element bioavailability in soil is fundamental to the assessment of deficiency risk and the selection of appropriate remediation strategies.

8. This study has shown for the first time that significant proportions of the Sri Lankan population may be Se deficient (34%, 22% and 28% in the HIDD, MIDD and NIDD villages respectively). Although it is not the case that Se deficiency only occurs in areas where IDD is prevalent, these results show that a combination of iodine and Se deficiency could be involved in the etiopathogenesis of goitre in Sri Lanka. Although no difference in Se status was detected between women suffering from goitre and those who were not, the highest hair Se values were determined in women not suffering from goitre. 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.

9. Comparisons between regions with different IDD prevalence and between people suffering or not suffering goitre were hampered in the present study due to the lack of systematic information on the occurrence of IDD in Sri Lanka. **It is recommended** that further investigations involving geochemists, medical doctors and nutritionists are required to elucidate the extent and nature of IDD and Se deficiency in Sri Lanka.

10. Should Se deficiency prove to be a significant problem, **it is recommended** that levels of Se in the diet should be enhanced by encouraging people to increase the quantity of Se rich foods such as fish and meat in the diet. It is recognised, however, that small scale farmers may not have the economic means to diversify their diet in this way. Alternatively the levels of Se in foodstuffs could be enhanced by the application of Se fertiliser. Villagers already apply NPK fertiliser routinely in Sri Lanka. However, the results of this study have shown that soils, particularly in the Kandy area, have a high capacity to adsorb more Se, and Se fertiliser added to the soil may not enhance Se levels in crops as expected due to adsorption of Se onto organic matter and clay minerals. Direct application of Se fertiliser to plant foliage may prove a more effective method of increasing crop Se levels.

11. The introduction of iodised salt to the population of Sri Lanka has been carried out by the government in recent years. 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 is lost to the atmosphere during the cooking process. **It is recommended** that an education programme is initiated to increase the effectiveness of the iodised salt programme making people aware that to store iodised salt for long periods or add it to food before cooking greatly reduces it's effectiveness.

12. Although iodine deficiency is accepted as the main environmental determinant in the aetiology of endemic goitre, there are a large number of naturally occurring and artificial agents which 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. Previous investigations have shown the presence of goitrogenic substances in many food crops such as millet, cassava and leafy vegetables. It is well known that high concentrations of certain goitrogenic compounds occur in tannins and pigments. The results of this study have shown that the distribution of red rice cultivation in Sri Lanka is coincident with high IDD incidence regions. However, no studies have been carried out into the goitrogenic properties of red rice. **It is recommended** that in *vivo* and in *vitro* tests (similar to those applied to millet) should be carried to whether red rice contains goitrogens. 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 husk.

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APPENDIX A: SUMMARY INFORMATION FOR THE 15 STUDY VILLAGES

Village	IDD Code	Region Code	Pop.	Map No.	Date Sampled	Geology*	Goitre Rate %	IDD Ref.	Location
HIGH INCIDENCE IDD									
Agunawala	HIDD1	KA1	nd	54	19/2/97	Charnockitic gneiss	40	1	
Kurunduwatte	HIDD2	KA2	nd	54	20/2/97	Granitic gneiss; hornblende gneiss; granodiorite	42	2	
Olaboduwa North	HIDD3	KL1	1471	73	22/2/97	Alluvium; poorly exposed charnockitic biotite gneiss with mafic layers	44.9	3,6	Horana District
Pelenwatte	HIDD4	KL2	c3000	66	22/2/97	Alluvium; poorly exposed gneiss	53.6	3,4,5	
Gurudola	HIDD5	KL3	c1500	80	23/2/97	Granitic gneiss; quartzo-feldspathic gneiss	50	7	Matugama District
MODERATE INCIDENCE									
Dehideniya	MIDD1	KA3	nd	54	19/2/97	Granitic gneiss; quartzite, biotite, charnockite and hornblende gneiss	22	2	
Kobbekaduwa	MIDD2	KA4	1250	54	20/2/97	Charnockitic gneiss; hornblende gneiss	17	2	
Ambepussa	MIDD3	KA5	nd	53	21/2/97	Hornblende gneiss; granitic gneiss	23.7	4	Warakapola District
Debagama	MIDD4	KA6	950	67	21/2/97	Charnockitic gneiss; corderite gneiss with mafic layers	18.3	4	Dehiowita District
Navinna	MIDD5	KL4	119	73	22/2/97	Sandy lateritic gravel; poorly exposed gneiss	12.5	4	Kalutara District
NO/LOW INCIDENCE IDD									
Upuldenya	NIDD1	AN1	1300	31	16/2/97	Biotite hornblende gneiss; pegmatitic granite	nd	8	
Manankattiya	NIDD2	AN2	1300	31	16/2/97	Biotite hornblende gneiss, pegmatitic granite	nd	8	
Polambayagama	NIDD3	AN3	800	31	17/2/97	Charnockitic biotite gneiss	7.3	3,6	
Ihala Kagama	NIDD4	AN4	700	36	17/2/97	Pegmatitic gneiss; hornblende gneiss	nd		
Kiralessa	NIDD5	AN5	650	42	17/2/97	Migmatitic gneiss; marble	6.5	3,6	Matale District

IDD References :

1 Dissanayake & Chandrajith (1996)

2 Department Biochemistry, University of Peradeniya (Unpubl.)

3 Fernando et al. (1989) with additional information on schools sampled

4 Mahadeva & Shanmuganathan (1967)

5 Deo & Subramanian (1971)

6 Fernando et al. (1987) with additional information on schools sampled

7 Dr L Watawana, Dept. Nuclear Medicine, University of Peradeniya (pers. commun.)

8 Iodine determinations in water carried out previously by Dr P Smedly (BGS)

(Note: goitre rates % cited for villages were not determined consistently. Details are given in the references cited.)

* From 1: 250 000 Sheet 13, Geological Survey and Mines Bureau (1995)

Pop. = Population nd = No data

Map No. = 1: 50 000 Topographic Map Sheet

Location = Geographic locations cited in references

APPENDIX B: LISTING OF SOIL RESULTS

(a) Field Data (flddata.xls)

Samp No	Village Name	IDD Code	Easting	Northing	Map Sheet	Date	Top (cm)	Bottom (cm)	Texture	Colour	State	Topography	Notes
001	ANGUNAWALA	HIDD1	18030	22625	54	2/19/97	10	30	SA-CL	RD-BR	WET	SLI TERR	ABUNDANT ANGULAR QTZ ON SURFACE < 1MM
003	ANGUNAWALA	HIDD1	18006	22629	54	2/19/97	10	30	SI-CL	GR-BR	WET	FLAT	V. MICACEOUS. FLAKES OF BIO 3MM. METAL TELEGRAPH SUPPORT IN FIELD
004	KIRALESSA	NIDD5	18875	28576	42	2/17/97	10	30	SI-CL	GR-BR	WET	FLAT	
005	NAVINNA	MIDD5	10976	16145	73	2/22/97	10	30	SI-CL	BR	DRY	FLAT	PORRLY IRRIGATED PADDY. FIELD QUITE DRY
007	DEHIDENIYA	MIDD1	17921	23023	54	2/19/97	10	30	SA-CL	GR-BR	WET	SLI TERR	
008	NAVINNA	MIDD5	10941	16094	73	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	
009	GURUDOLA	HIDD5	12734	14940	80	2/23/97	10	30	SI-CL	DRK BR	MOIST	FLAT	
013	AMBEPUSSA	MIDD3	13721	22684	53	2/21/97	10	30	SI-CL	OR-BR	MOIST	FLAT	QTZ CLASTS 0.05 - 8 MM
015	MANANKATTIYA	NIDD2	18643	33388	31	2/16/97	10	30	SA-SI	BR	WET	FLAT	
016	IHALA KAGAMA	NIDD4	17600	31850	36	2/17/97	15	35	SA-CL	BR	WET	FLAT	FE PPT ON WATER SURFACE IN CORNER OF PADDY
017	IHALA KAGAMA	NIDD4	17614	31868	36	2/17/97	10	30	SA-CL	BR	MOIST	FLAT	
018	UPULDENYA	NIDD1	18607	34510	31	2/16/97	10	30	SI-CL	BR	DRY	FLAT	GROUND VERY HARD
019	POLAMBAYAGAMA	NIDD3	16406	33834	31	2/17/97	10	30	SA-CL	RD-BR	WET	FLAT	SOME CHARCOAL PARTICLES IN SOIL
020	SIYAMBALAGODA		17426	23112	54	2/20/97	10	30	SI-CL	BR	MOIST	SLI TERR	THIS VILLAGE WAS NOT USED AS A TARGET. EXTRA SAMPLE
021	KURUNDUWATTE	HIDD2	17398	23033	54	2/20/97	10	30	SI-CL	BR	WET	FLAT	VERY MICACEOUS SOIL SAMPLE
022	NAVINNA	MIDD5											**DUPLICATE 0F 068**
023	DEBAGAMA	MIDD4	14172	19840	67	2/21/97	10	30	SI-CL	BR	MOIST	FLAT	ADJ. TO FLAT OUTCROP OF GARNETIFEROUS BIO HNB GNEISS
024	PELENWATTE	HIDD4	10800	18100	66	2/22/97	10	30	CL-SI	GR-BR	WET	FLAT	SOME CHARCOAL FRAGS IN SOIL
025	PELENWATTE	HIDD4	10800	18100	66	2/22/97	10	30	CL-SI	GR-BR	WET	FLAT	
026	POLAMBAYAGAMA	NIDD3	16422	33787	31	2/17/97	10	30	SA-SI	RD-BR	WET	FLAT	
028	POLAMBAYAGAMA	NIDD3	16448	33830	31	2/17/97	10	30	SI-CL	BR	WET	FLAT	EMPTY BOTTLE FOR PESTICIDE LYING IN PADDY
032	UPULDENYA	NIDD1	18945	34527	31	2/16/97	10	25	SI-CL	BR	DRY	FLAT	GROUND LIKE CONCRETE. SOME ASH IN 1 AUGER HOLE - REJECTED
033	GURUDOLA	HIDD5	12693	14870	80	2/23/97	10	30	CL-SI	GR-BR	MOIST	FLAT	
034	DEHIDENIYA	MIDD1	17920	23078	54	2/19/97	10	30	SI-CL	RD-BR	MOIST	SLI TERR	MICACEOUS
035	AMBEPUSSA	MIDD3	13735	22704	53	2/21/97	10	30	SI-CL	OR-BR	MOIST	FLAT	
036	DEBAGAMA	MIDD4	14170	19827	67	2/21/97	10	30	SI-CL	OR-BR	MOIST	FLAT	
037	KIRALESSA	NIDD5	18830	28577	42	2/17/97	10	30	SI-CL	BR	WET	FLAT	
038	DEHIDENIYA	MIDD1	17874	23095	54	2/19/97	10	40	CL-SI	RD-BR	WET	SLI TERR	CHARNOCKITE OUTCROP IN NEARBY STREAM
039	POLAMBAYAGAMA	NIDD3	16468	33846	31	2/17/97	10	30	SA-CL	BR	WET	FLAT	SOME RED PATCHES IN SOIL
040	KOBBEKADUWA	MIDD2	17551	23444	54	2/20/97	10	30		RD-BR	WET	TERR	MICACEOUS.
041	UPULDENYA	NIDD1	18925	34525	31	2/16/97	10	30	SI-CL	BR	DRY	FLAT	MICACEOUS. SI-SA AT SURFACE
042	GURUDOLA	HIDD5	12716	14874	80	2/23/97	10	30	CL-SI	DRK BR	WET	FLAT	RICH IN ORGANIC MATTER - FARMER DIGS STRAW BACK INTO FIELD
045	MANANKATTIYA	NIDD2	18631	33468	31	2/16/97	10	30	SI-SA	GR-BR	WET	FLAT	FE PPT ON SURFACE OF PADDY
046	UPULDENYA	NIDD1	18902	34550	31	2/16/97	10	30	SI-CL	GR-BR	DRY	FLAT	GROUND VERY HARD. SI-SA AT SURFACE
047	PELENWATTE	HIDD4	10800	18100	66	2/22/97	10	20	CL-SI	GR-BR	MOIST	FLAT	PALE GREY CLAY > 25 CM
048	AMBEPUSSA	MIDD3	13712	22700	53	2/21/97	10	30	SA-CL	OR-BR	MOIST	FLAT	BECOMING GREY AT DEPTH. QTZ FRAGS. MAGNETITE ON SURFACE
049	UPULDENYA	NIDD1	18775	34605	31	2/16/97	10	30	SI-CL	BR	DRY	FLAT	GROUND VERY HARD

Samp No	Village Name	IDD Code	Easting	Northing	Map Sheet	Date	Top (cm)	Bottom (cm)	Texture	Colour	State	Topography	Notes
050	GURUDOLA	HIDD5	12718	14898	80	2/23/97	10	30	CL-SI	GR-BR	MOIST	FLAT	SOME FLECKS OF OR-BR
051	AMBEPUSSA	MIDD3	13700	22668	53	2/21/97	10	30		OR-BR	MOIST	FLAT	FINE ANG. QTZ PLUS MAGNETITE ON SURFACE
052	OLABODUWA N	HIDD3	11723	17475	73	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	SOIL QUITE DRY AT DEPTH EVEN THOUGH PADDY WET AT SURFACE
054	POLAMBAYAGAMA	NIDD3	16440	33790	31	2/17/97	10	30	SI-CL	BR	WET	FLAT	
056	MANANKATTIYA	NIDD2	18579	33445	31	2/16/97	10	30	SA-SI	BR	WET	FLAT	SOIL Y-BR IN PATCHES
057	KOBBEKADUWA	MIDD2	17550	23462	54	2/20/97	10	30		BR	WET	FLAT	SMALL CLASTS OF QTZ < 3MM
059	DEBAGAMA	MIDD4	14190	19841	67	2/21/97	10	30	SA-SI	GR-BR	WET	FLAT	
060	NAVINNA	MIDD5	10953	16121	73	2/22/97	10	30	SI-CL	GR-BR	DRY	FLAT	
061	KOBBEKADUWA	MIDD2	17540	23469	54	2/20/97	10	30	SI-CL	OR-BR	MOIST	SLI TERR	
062	IHALA KAGAMA	NIDD4	17712	31879	36	2/17/97	10	30	SA-CL	BR	MOIST	FLAT	SURFACE SOIL WHITE AND SANDY
064	OLABODUWA N	HIDD3	11709	17472	73	2/22/97	10	30	CL-SI	BR	WET	FLAT	
065	KIRALESSA	NIDD5	18844	28597	42	2/17/97	10	30	SI-CL	GR-BR	WET	FLAT	
066	OLABODUWA N	HIDD3	11684	17462	73	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	
067	DEHIDENIYA	MIDD1	17917	23005	54	2/19/97	10	30	SI-CL	BR	WET	SLI TERR	
068	NAVINNA	MIDD5	10989	16118	73	2/22/97	10	30	SI-CL	DRK BR	DRY	FLAT	SOIL ORGANIC RICH
069	ANGUNAWALA	HIDD1	18015	22606	54	2/19/97	10	30	SA-CL	GR-BR	WET	FLAT	ABUND. QTZ AND MICA ON SOIL SURFACE. NOT AN IDEAL SITE CLOSE TO RAI
070	DEBAGAMA	MIDD4	14199	19828	67	2/21/97	10	30		DRK BR	MOIST	FLAT	SOIL ORGANIC RICH
071	KOBBEKADUWA	MIDD2	17566	23455	54	2/20/97	10	30	SI-CL	GR-BR	MOIST	SLI TERR	MICACEOUS. BECOMING PALE GREY CLAY AT> 30 CM
072	IHALA KAGAMA	NIDD4	17677	31847	36	2/17/97	10	30	SA-CL	GR-BR	WET	FLAT	SOME RUSTY COLOURED FLECKS
074	DEBAGAMA	MIDD4	14180	19856	67	2/21/97	10	30	SA-CL	GR-BR	WET	TERRACED	FLAKES OF BIOTITE ON SURFACE. ALSO QTZ SAND
076	KIRALESSA	NIDD5	18866	28596	42	2/17/97	10	30	SI-CL	BR	WET	FLAT	RUSTY BR FLECKS
077	PELENWATTE	HIDD4	10800	18100	66	2/22/97	10	30	CL-SI	DRK BR	WET	FLAT	SOIL ORGANIC RICH
078	ANGUNAWALA	HIDD1											**DUPLICATE 0F 086**
079	OLABODUWA N	HIDD3	11736	17483	73	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	QTZ SAND AT SURFACE
080	IHALA KAGAMA	NIDD4	17675	31830	36	2/17/97	10	20	SA-CL	OR-BR	MOIST	FLAT	SURFACE WHITE AND SANDY. AT 25 CM CHANGE TO GR COLOUR
081	KIRALESSA	NIDD5											**DUPLICATE 0F 076**
083	KURUNDUWATTE	HIDD2	17361	23060	54	2/20/97	10	30	SI-CL	BR	MOIST	SLI TERR	MICACEOUS. FLAKES ABUNDANT IN PATCHES
084	KURUNDUWATTE	HIDD2	17362	23020	54	2/20/97	10	30	SI-CL	RD-BR	DRY	FLAT	MICACEOUS
085	GURUDOLA	HIDD5	12721	14921	80	2/23/97	10	30	CL-SI	DRK BR	MOIST	FLAT	SURFACE STAINED WITH RED FE PPT
086	ANGUNAWALA	HIDD1	18041	22610	54	2/19/97	10	30	SA-CL	BR	WET	SLI TERR	MICACEOUS. QTZ FRAGS AT SURFACE
088	OLABODUWA N	HIDD3	11702	17490	73	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	
089	KURUNDUWATTE	HIDD2	17363	23030	54	2/20/97	10	30	CL-SI	RD-BR	MOIST	SLI TERR	MICACEOUS WITH ANG. QTZ CLASTS 5-9MM
090	KRALESSA	NIDD5	18887	28590	42	2/17/97	10	30	SI-CL	GR-BR	WET	FLAT	SOME ORGANIC MATTER
091	DEHIDENIYA	MIDD1	17895	23065	54	2/19/97	10	30	CL-SI	BR	WET	FLAT	VERY MICACEOUS
093	KOBBEKADUWA	MIDD2	17598	23451	54	2/20/97	10	30	SI-CL	BR	MOIST	TERRACED	VERY MICACEOUS. SOME CHARCOAL FRAGS. BECOMING GREY AT DEPTH
094	MANANKATTIYA	NIDD2	18647	33487	31	2/16/97	10	30	SI-SA	BR	WET	FLAT	
095	KURUNDUWATTE	HIDD2	17389	23046	54	2/20/97	10	30	SI-CL	BR	MOIST	SLI TERR	VERY MICACEOUS. SURFACE COVERED WITH MICA
096	NAVINNA	MIDD5	10966	16100	73	2/22/97	10	30	SI-CL	GR-BR	DRY	FLAT	BECOMING CL AT DEPTH > 25 CM
097	AMBEPUSSA	MIDD3	13706	22730	53	2/21/97	10	30	SI-CL	BR	WET	TERRACED	METAMORPHIC BEDROCK NEARBY
098	MANANKATTIYA	NIDD2	18583	33492	31	2/16/97	10	30	SA-SI	GR-BR	WET	FLAT	SOIL SURFACE SANDY
099	ANGUNAWALA	HIDD1	18005	22652	54	2/19/97	10	30	SI-CL	GR-BR	WET	FLAT	BETWEEN RAILWAY AND MAIN ROAD
100	PELENWATTE	HIDD4	10800	18100	66	2/22/97	10	30	SI-CL	BR	MOIST	FLAT	SOME BITS OF CHARCOAL

SI-CL=silty clay, SA-SI=sandy silt, SI-SA=silty sand, CL-SI=clay silt; BR=Brown, GR=Gray, RD=Red, OR=Orange, Y=Yellow; SLI=slight, TERR=terrace, PPT=precipitate, QTZ=quartz, BIO=biotite, HNB=hornblende, V=very, ANG=angular, ADJ=adjacent. Colour refers to sample when collected. Easting and Northing for Pelenwatte are estimated as the 1:50 000 topograhic map was not available.

(b) Laboratory Results

(i) Total Selenium (LabSeSoi.XLS) (determined at BGS laboratories, Keyworth, fmf 05388)

Sample Code	Sample Mass g	Se (solution) µg/l	Se in solid ng/g
SL - S - 01	0.1015	4.61	454
SL - S - 03	0.1034	3.23	312
SL - S - 04	0.1030	3.29	319
SL - S - 04 duplicate	0.1016	3.14	309
SL - S - 05	0.1071	31.93	2981
SL - S - 07	0.1038	3.26	314
SL - S - 08	0.1061	53.89	5079
SL - S - 09	0.1035	27.86	2692
SL - S - 13	0.1043	7.46	716
SL - S - 14	0.1064	2.37	223
SL - S - 15	0.1002	2.16	216
SL - S - 16	0.1040	1.17	113
SL - S - 17	0.1076	2.13	198
SL - S - 18	0.1007	1.87	185
SL - S - 19	0.1010	2.19	217
SL - S - 20	0.1034	3.45	334
SL - S - 21	0.0986	6.92	702
SL - S - 22	0.1021	26.61	2606
SL - S - 23	0.0994	6.48	652
SL - S - 24	0.1075	20.25	1884
SL - S - 25	0.1034	25.74	2489
SL - S - 26	0.1043	n/s	n/s
SL - S - 28	0.1050	6.96	663
SL - S - 32	0.1013	1.72	170
SL - S - 33	0.1091	39.21	3594
SL - S - 34	0.1079	5.36	497
SL - S - 35	0.1056	12.13	1149
SL - S - 36	0.1004	7.58	755
SL - S - 36 duplicate	0.1069	8.53	798
SL - S - 37	0.1080	4.23	392
SL - S - 38	0.1038	4.85	468
SL - S - 39	0.1046	2.53	242
SL - S - 40	0.1040	6.31	607
SL - S - 41	0.1003	2.54	253
SL - S - 42	0.1006	35.69	3548
SL - S - 43	0.1043	10.86	1041
SL - S - 43 duplicate	0.1022	10.08	986
SL - S - 45	0.1030	1.76	171
SL - S - 46	0.1018	3.44	338
SL - S - 47	0.1036	20.00	1931
SL - S - 48	0.1000	9.19	919
SL - S - 48 duplicate	0.1000	8.64	864
SL - S - 49	0.1054	3.50	332
SL - S - 50	0.1010	39.86	3947
SL - S - 51	0.1009	7.18	712
SL - S - 51 duplicate	0.1086	7.26	668

Sample Code	Sample Mass g	Se (solution) µg/l	Se in solid ng/g
SL - S - 52	0.1034	19.28	1865
SL - S - 54	0.1009	3.41	338
SL - S - 55	0.1040	2.11	203
SL - S - 56	0.1046	1.67	160
SL - S - 57	0.1088	8.27	760
SL - S - 57 duplicate	0.1026	7.89	769
SL - S - 59	0.0999	3.43	343
SL - S - 60	0.1040	54.47	5238
SL - S - 61	0.1023	9.57	935
SL - S - 62	0.1020	2.04	200
SL - S - 62 duplicate	0.1007	1.63	162
SL - S - 64	0.1045	22.07	2112
SL - S - 65	0.1009	3.12	309
SL - S - 66	0.0995	11.65	1171
SL - S - 67	0.1039	4.76	459
SL - S - 68	0.1010	25.19	2494
SL - S - 69	0.1014	2.79	276
SL - S - 70	0.1080	7.63	706
SL - S - 71	0.1068	5.36	501
SL - S - 71 duplicate	0.1071	5.52	516
SL - S - 72	0.1065	1.33	125
SL - S - 74	0.1014	3.15	310
SL - S - 76	0.1020	2.17	213
SL - S - 77	0.1020	26.45	2593
SL - S - 78	0.1048	6.14	586
SL - S - 79	0.1031	7.53	730
SL - S - 80	0.1082	1.60	148
SL - S - 81	0.1014	2.03	200
SL - S - 82	0.1024	1.17	114
SL - S - 83	0.1068	3.05	286
SL - S - 84	0.1017	5.43	534
SL - S - 85	0.1061	35.14	3312
SL - S - 86	0.1032	5.71	553
SL - S - 88	0.1030	17.98	1746
SL - S - 89	0.1041	7.20	692
SL - S - 90	0.1048	3.65	349
SL - S - 91	0.1009	7.84	777
SL - S - 93	0.1036	7.82	754
SL - S - 94	0.1032	1.60	155
SL - S - 95	0.1007	3.14	312
SL - S - 96	0.1007	28.99	2879
SL - S - 97	0.1048	7.75	740
SL - S - 98	0.1017	1.77	174
SL - S - 99	0.1031	4.14	401
SL - S - 99 duplicate	0.1034	4.23	409
SL - S - 100	0.1014	15.40	1519

(ii) Iodine (LabIsoil.xls) (determined at UCW Aberystwyth by Dr R Fuge)

SampNo	Iodine µg/g
1	1.9
3	2.5
4	2
5	5
7	0.8 , 1.0
8	6.6
9	5.7
13	<0.20
15	0.7
16	<0.20
17	1.4
18	4.1
19	10
20	1.9
21	2.3
22	5
23	2.8
24	4.9
25	4
26	5.4
28	8.6
32	3.8
33	6.4
34	3.6
35	3.9
36	1.8
37	2.2
38	2.3
39	5
40	1.1
41	2.6
42	9.6
45	0.8
46	3.5
47	2.4
48	1.6
49	2.7
50	6.6
51	<0.20
52	3

SampNo	Iodine µg/g
54	6.4, 6.1
56	0.5, 0.4
57	4.2
59	1.0, 1.0
60	2.7 , 2.9
61	2.3
62	2.7
64	3.3
65	2.2
66	2.2
67	2.3
68	3.9 , 4.0
69	1.2
70	2.5
71	1.3
72	2.7
74	1.6
76	4.4
77	4.1, 4.2
78	7.1
79	1
80	3.8
83	2.2, 2.5
81	3.2
84	1.7
85	5
86	3.2
88	2.1
89	3.2
90	1.9
91	4.6
93	3.9
94	1.4
95	1.7
96	5.3
97	2.5
98	0.8
99	1.6
100	3.8

(iii) Total Organic Carbon (LABTOC.XLS) (determined by Intertek Laboratories)

Our Ref : 97I05302.RES Code 1144

Lab Ref	Client Ref	TOC %	Lab Ref	Client Ref	TOC %
'056586	SLS01	0.9	56633	SLS64	4.8
'056587	SLS03	1	56634	SLS65	1.1
'056588	SLS04	0.6	56635	SLS66	2
'056589	SLS05	4.4	56636	SLS67	1.2
'056590	SLS07	0.6	56637	SLS68	4.8
'056591	SLS08	6	56638	SLS69	1.1
'056592	SLS09	6	56639	SLS70	2.1
'056593	SLS13	1	56640	SLS71	1
'056594	SLS15	0.3	56641	SLS72	0.7
'056595	SLS16	0.2	56642	SLS74	0.8
'056596	SLS17	0.3	56643	SLS76	0.8
'056597	SLS18	0.6	56644	SLS77	6.1
'056598	SLS19	0.6	56645	SLS78	1.3
'056599	SLS20	0.8	56646	SLS79	1.7
'056600	SLS21	0.6	56647	SLS80	0.1
'056601	SLS22	4.8	56648	SLS81	0.9
'056602	SLS23	1.3	56649	SLS83	1
'056603	SLS24	4.6	56650	SLS84	1.4
'056604	SLS25	5.6	56651	SLS85	7.4
'056605	SLS26	1.4	56652	SLS86	13
'056606	SLS28	0.6	56653	SLS88	2.3
'056607	SLS32	0.6	56654	SLS89	2.1
'056608	SLS33	5.8	56655	SLS90	0.7
'056609	SLS34	1	56656	SLS91	1.6
'056610	SLS35	0.6	56657	SLS93	1.6
'056611	SLS36	0.6	56658	SLS94	0.7
'056612	SLS37	0.3	56659	SLS95	0.9
'056613	SLS38	0.3	56660	SLS96	4.9
'056614	SLS39	0.4	56661	SLS97	1.5
'056615	SLS40	1.1	56662	SLS98	0.7
'056616	SLS41	0.6	56663	SLS99	1.6
'056617	SLS42	10.8	56664	SLS100	5.1
'056618	SLS45	0.6	56665	EN545	3.4
'056619	SLS46	1	56666	EN965B	0.5
'056620	SLS47	4.5	56667	EN705	1.7
'056621	SLS48	0.4	56668	C1	2.7
'056622	SLS49	0.9	56669	C2	4.7
'056623	SLS50	7.8	56670	C3	11
'056624	SLS51	0.9	56671	C4B	13.3
'056625	SLS52	4.4	56672	C5	3.7
'056626	SLS54	0.6	56673	C6	12.2
'056627	SLS56	0.6	56674	C7	40.4
'056628	SLS57	2.1	56675	C11	19
'056629	SLS59	0.8	56676	C13	41.6
'056630	SLS60	4.1	56677	C14	4
'056631	SLS61	1.4	56678	C15	2.7
'056632	SLS62	0.6			

(iv) Soil pH (LABpHsl.xls) (Determined by BGS laboratories fmf05408)

Sample Number	LIMS Code	pH
1	05408-00001	4.85
3	05408-00002	4.64
4	05408-00003	6.21
5	05408-00004	4.62
7	05408-00005	4.42
8	05408-00006	4.99
9	05408-00007	4.25
13	05408-00008	4.33
15	05408-00009	5.14
16	05408-00010	5.82
17	05408-00011	6.04
18	05408-00012	6.11
19	05408-00013	6.24
20	05408-00014	4.47
21	05408-00015	4.57
22	05408-00016	4.34
23	05408-00017	4.33
24	05408-00018	4.38
25	05408-00019	4.31
26	05408-00020	6.08
28	05408-00021	6.74
32	05408-00022	6.62
33	05408-00023	3.95
34	05408-00024	5.03
35	05408-00025	4.72
36	05408-00026	4.39
37	05408-00027	6.62
38	05408-00028	4.59
39	05408-00029	6.09
40	05408-00030	4.49
41	05408-00031	4.94
42	05408-00032	4.20
45	05408-00033	6.25
46	05408-00034	5.27
47	05408-00035	4.30
48	05408-00036	4.49
49	05408-00037	6.24
50	05408-00038	4.31
51	05408-00039	4.51
52	05408-00040	4.76
54	05408-00041	6.33
56	05408-00042	5.87
57	05408-00043	4.29
59	05408-00044	4.31
60	05408-00045	4.33
61	05408-00046	4.78
62	05408-00047	7.53
64	05408-00048	4.84
65	05408-00049	6.20
66	05408-00050	4.11
67	05408-00051	4.64
68	05408-00052	4.63
69	05408-00053	4.45
70	05408-00054	4.11
71	05408-00055	3.91
72	05408-00056	6.41
74	05408-00057	4.35
76	05408-00058	6.35
77	05408-00059	4.31
78	05408-00060	4.63
79	05408-00061	4.32
80	05408-00062	5.59
81	05408-00063	6.11
83	05408-00064	4.32
84	05408-00065	4.88
85	05408-00066	4.37
86	05408-00067	4.90
88	05408-00068	4.23
89	05408-00069	4.81
90	05408-00070	6.43
91	05408-00071	5.35
93	05408-00072	4.51
94	05408-00073	5.82
95	05408-00074	4.49
96	05408-00075	4.66
97	05408-00076	4.73
98	05408-00077	6.34
99	05408-00078	4.39
100	05408-00079	4.05

(v) ICP Analyses (LABICPsl.xls) (determined at BGS laboratories DA05637)

LIMS Code	Sample Number	Ca mg/kg	Mn mg/kg	Total Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg
05637-00001	1	2,445	305	59,824	48,182	29.8	33.1	77.7
05637-00002	3	8,104	432	43,114	75,639	31.8	152	109
05637-00003	4	3242	540	35,739	38,414	19.4	24.3	44.7
05637-00004	5	478	77.8	17,351	88,979	31.0	12.5	39.5
05637-00005	7	3,036	205	29,018	66,835	<27.8	22.5	55.3
05637-00006	8	541	65.5	17,005	133,382	55.6	25.3	57.2
05637-00007	9	717	68.9	29,274	74,073	34.6	17.2	60.8
05637-00008	13	3,485	299	46,201	50,082	29.1	38.0	46.4
05637-00009	14	3,019	344	22,903	60,215	<26.9	14.8	65.5
05637-00009 dup	14	3,203	339	22,999	64,770	<27.4	14.7	64.3
05637-00010	15	9,489	384	21,311	57,783	<26.5	9.28	34.6
05637-00011	16	6,599	328	21,642	45,801	<28.0	5.34	36.3
05637-00012	17	6,683	376	21,912	48,426	<27.4	9.20	35.2
05637-00013	18	8,976	881	28,996	65,826	<27.2	18.6	50.4
05637-00014	19	6,441	594	33,997	71,690	<28.0	9.91	46.4
05637-00015	20	10,504	500	51,569	79,175	45.2	35.0	76.6
05637-00016	21	6,642	649	82,884	88,922	44.7	40.9	90.3
05637-00017	22	496	119	18,876	84,997	34.8	12.4	52.2
05637-00018	23	2,134	200	22,694	57,136	<26.7	15.6	77.9
05637-00019	24	412	52.7	6,019	74,548	29.6	16.5	37.0
05637-00020	25	336	49.4	9,193	110,641	46.3	22.7	43.3
05637-00021	26	8,453	972	59,116	70,718	<27.6	11.9	53.6
05637-00022	28	10,901	787	43,163	77,628	44.9	25.9	43.5
05637-00023	32	10,399	688	32,545	53,286	<28.1	11.5	51.8
05637-00024	33	580	72.1	39,754	120,201	46.3	23.0	73.6
05637-00025	34	3,263	448	52,963	64,099	39.5	52.4	82.8
05637-00026	35	2,579	755	66,499	69,824	50.3	54.9	65.7
05637-00027	36	7,183	295	38,056	60,319	<27.4	19.7	47.8
05637-00028	37	4,489	936	42,024	61,408	<26.7	25.4	52.1
05637-00029	38	3,364	256	41,968	85,592	<27.6	17.4	57.1
05637-00030	39	5,185	638	41,844	59,146	<27.6	25.2	40.0
05637-00031	40	3,642	519	48,630	72,558	40.4	30.1	74.3
05637-00032	41	7,344	474	20,873	44,563	<27.6	8.17	39.8
05637-00033	42	857	70.2	37,141	115,415	40.1	22.2	73.8
05637-00034	43	25,508	591	36,076	73,038	33.0	29.7	79.8
05637-00035	45	8,273	441	18,560	48,768	<27.2	7.89	30.3
05637-00036	46	8,235	614	26,596	55,306	<27.8	11.3	51.8
05637-00037	47	206	49.8	7,797	83,580	31.9	14.9	36.2
05637-00038	48	1,392	226	40,652	36,314	34.6	25.2	46.0
05637-00039	49	9,608	651	28,169	54,591	<27.3	19.1	39.2
05637-00040	50	652	73.0	39,020	127,287	47.8	22.6	71.4
05637-00041	51	3,222	277	39,609	46,284	<27.6	31.1	42.6
05637-00042	52	484	112	15,699	74,102	28.8	14.2	47.8
05637-00043	54	6,990	607	34,672	73,259	30.6	14.1	43.2
05637-00044	55	3,420	751	32,854	71,751	31.0	15.6	74.0
05637-00045	56	9,837	603	22,446	58,696	<27.2	9.08	32.1
05637-00046	57	534	284	51,133	63,986	41.5	29.3	65.2

LIMS Code	Sample Number	Ca mg/kg	Mn mg/kg	Total Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg
05637-00047	59	1,358	144	10,961	32,939	<27.5	7.55	54.4
05637-00048	60	518	56.5	15,566	128,251	52.2	28.3	47.2
05637-00049	61	450	210	45,323	62,306	38.3	28.8	56.1
05637-00050	62	9,288	280	20,534	64,903	<28.0	9.51	32.7
05637-00051	64	420	119	20,486	92,108	37.2	16.5	58.7
05637-00052	65	5,357	285	37,020	57,811	<26.5	25.0	49.2
05637-00053	66	313	129	19,562	70,985	27.4	10.6	52.2
05637-00054	67	5,090	470	52,333	70,417	43.4	43.9	79.6
05637-00055 /1	68 /1	487	120	18,669	84,400	32.0	12.1	47.1
05637-00055d /1	68 dup /1	321	105	15,254	59,117	32.2	11.6	45.6
05637-00055 /2	68 /2	254	91	14,073	32,907	33.7	13.2	46.6
05637-00055d /2	68 dup /2	386	103	16,957	66,837	28.5	13.7	45.4
05637-00056	69	7,644	309	38,716	68,681	29.1	25.0	95.3
05637-00057	70	3,855	265	27,500	66,980	<27.2	13.8	94.4
05637-00058	71	1,533	292	25,795	58,850	36.9	20.4	49.2
05637-00059	72	13,308	655	32,249	69,026	<27.6	12.5	50.7
05637-00059 dup	72	12,786	614	31,074	64,198	<27.0	12.2	47.8
05637-00060	74	2,507	258	15,615	36,595	<26.8	12.0	55.4
05637-00061	76	6,809	1,460	46,115	62,003	29.4	26.6	55.9
05637-00062	77	548	52.3	8,094	79,254	37.5	18.0	39.7
05637-00063	78	1,628	439	71,351	61,081	34.5	35.8	83.3
05637-00064	79	250	102	9,153	38,307	<26.5	6.88	35.1
05637-00065	80	7,095	550	30,250	57,200	<27.5	10.2	44.6
05637-00066	81	6,660	1,507	44,473	60,693	29.0	26.3	60.0
05637-00067	82	29,108	466	26,946	62,651	<27.7	18.1	56.9
05637-00068	83	4,786	287	32,446	79,472	<27.4	30.5	58.3
05637-00069	84	7,074	587	73,981	111,242	55.6	60.4	98.0
05637-00070	85	686	80.4	35,610	106,348	38.3	20.0	61.9
05637-00071	86	1,489	414	60,483	55,735	30.4	33.4	73.1
05637-00072	88	562	118	30,139	93,086	40.4	15.3	59.1
05637-00073	89	7,756	817	92,850	111,420	47.3	51.8	88.8
05637-00074	90	4,991	363	34,680	50,882	<27.1	21.3	42.4
05637-00075	91	12,041	801	79,000	113,323	103	62.2	112
05637-00076	93	3,747	751	55,642	73,743	56.9	36.3	78.5
05637-00077	94	8,419	453	18,479	49,970	<27.3	6.18	29.4
05637-00078	95	10,555	480	45,682	76,962	30.6	32.9	59.9
05637-00079	96	510	71.3	19,586	120,698	45.2	14.4	50.3
05637-00080	97	7,573	555	60,804	51,186	36.8	48.4	56.8
05637-00081	98	9,370	366	20,459	49,456	<27.7	7.82	29.0
05637-00082	99	7,233	346	44,790	77,339	33.8	35.8	103
05637-00082 dup	99	7,643	337	44,764	78,610	32.4	36.3	99.6
05637-00083	100	161	32.0	5,866	57,583	<26.9	11.5	32.6
	GBW 7402	16,475	470	23,088	52,068	18.0	13.9	41.6
	GBW 7405	303	1,287	88,226	113,064	38.7	142	513
	GBW 7402	16,135	463	22,872	49,389	18.3	14.7	41.4
	GBW 7405	303	1,287	88,226	113,064	38.7	142	513
05637-00055 /1	68 /1	487	120	18,669	84,400	32.0	12.1	47.1
05637-00055d /1	68 dup /1	321	105	15,254	59,117	32.2	11.6	45.6
05637-00055 /2	68 /2	254	91	14,073	32,907	33.7	13.2	46.6
05637-00055d /2	68 dup /2	386	103	16,957	66,837	28.5	13.7	45.4
Mean	***68***	***362***	***105***	***16238***	***60815***	***31.6***	***12.6***	***46.1***

(vi) Water Soluble and Phosphate Extractable Se in Soil (Extr-Se.xls) (determined at BGS laboratories, Keyworth DA 05800)

LIMS No.	Customer ID	Se in solid		Notes
		Water Extract ng/g	Phosphate Extract ng/g	
05800~00001	HIDD 1	17.2	9.50	
05800~00002	HIDD 2	4.88	11.8	
05800~00003	HIDD 3	16.0	26.1	
05800~00004	HIDD 4	8.73	18.4	
05800~00005	HIDD 5	19.9	23.4	
05800~00006	NIDD 1	10.7	11.8	
05800~00007	NIDD 2	15.7	11.0	
05800~00008	NIDD 3	4.89	7.20	
05800~00009	NIDD 4	17.6	7.19	
05800~00010	NIDD 5	6.39	11.0	
05800~00011	MIDD 1	6.81	11.0	
05800~00012	MIDD 2	6.06	21.0	
05800~00013	MIDD 3	8.39	34.2	
05800~00014	MIDD 4	4.89	11.4	
05800~00015	MIDD 5	42.3	31.1	
05800~00005	HIDD 5	16.0	24.4	replicate
05800~00009	NIDD 4	13.7	8.88	replicate
05800~00013	MIDD 3	6.41	32.9	replicate
05800~Blank	n/a	<0.05	<0.05	blank

(vii) Water Soluble Iodine in Soil (SoilWatI.xls) (determined at BGS laboratories DA05794)

LIMS Code	Sample Code	Village	Weight Sample g	Weight Water g	I (In solution) µg/l	I (in soil) µg/kg
05794-00001	SL19	AN3	5.2203	28.6759	<20.0	<110
05794-00001 duplicate	SL19	AN3	4.698	26.8108	<20.0	<114
05794-00002	SL26	AN3	4.914	28.6329	<20.0	<117
05794-00003	SL33	KL3	0.79	6.6868	<20.0	<169
05794-00004	SL35	KA5	5.0038	28.801	<20.0	<115
05794-00005	SL42	KL3	0.5037	29.6382	<20.0	<1,177
05794-00006	SL45	AN2	5.0126	30.4049	<20.0	<121
05794-00007	SL54	AN3	2.4903	15.1271	<20.0	<121
05794-00007 duplicate	SL54	AN3	2.5001	15.1142	<20.0	<121
05794-00008	SL59	KA6	4.9884	29.1966	<20.0	<117
05794-00009	SL60	KL4	5.0658	27.8744	<20.0	<110
05794-00010	SL68	KL4	4.801	26.0234	<20.0	<108
05794-00011	SL83	KA2	4.9802	30.2595	<20.0	<122
05794-00012	SL91	KA3	5.0364	30.3035	<20.0	<120
05794-00012 duplicate	SL91	KA3	5.078	29.9053	<20.0	<118
05794-Blank 1	n/a	n/a	n/a	29.9887	<20.0	<20.000
05794-Blank 2	n/a	n/a	n/a	30.139	<20.0	<20.000

BRITISH GEOLOGICAL SURVEY
Mineralogy and Petrology Group
Short Report No. MPSR/97/51R

X-RAY DIFFRACTION ANALYSIS OF SIX SOIL SAMPLES

INTRODUCTION

Six soil samples were submitted for X-ray diffraction (XRD) analysis. by Dr. J. D. Appleton, Analytical and Regional Geochemistry Group, British Geological Survey (IR. 15027). Particular interest was expressed in the presence and relative abundances of kaolinite, gibbsite, goethite, illite and smectite.

LABORATORY METHOD

For bulk analysis, a representative subsample, ~3g, of the material was micronised under acetone for five minutes and the resulting powders dried at 55°C, before being back-loaded into standard aluminium sample holders.

XRD analysis was carried out using a Phillips PW1700 series diffractometer using Co-Kα radiation and operating at 45kV and 40mA. The micronised powder mounts were scanned over the range 2-50 °2θ at a scanning speed of 0.5 °2θ/minute. Diffraction data were analysed using Phillips APD1700 software coupled to a ICDD database running on a DEC Micro Vax 2000 micro-computer system.

RESULTS

Results of semi-quantitative XRD analysis are summarised in Table 1. Peak intensities above background are given in brackets for phases in which particular interest was expressed when present. Possible mineralogical groupings are suggested in relation to conditions of pedogenesis:

Wet climate = high kaolinite, gibbsite and smectite
?Intermediate = moderate kaolinite and gibbsite
Dry climate = low kaolinite

Illite is absent in all samples. Detection of goethite is difficult because its crystallinity is usually very poor and its main line at d = 4.18Å is close to one of the main quartz lines (d = 4.25Å). In the presence of a large proportion of quartz, as in this case, the main goethite line will be at least partially obscured. Where both kaolinite and smectite are present they give lines at around d = 14Å and d = 7Å, which can easily be confused with chlorite. Therefore, for better identification of clay mineral species, preparation of oriented clay fraction (<2μm) mounts is suggested.

Table 1. Results of semi-quantitative XRD analysis.

Sample	XRD code	Major	Minor	Trace	?Mineralogical Groupings
SL-S-8	H374	Quartz	Kaolinite (150)*†, gibbsite (260)*	Smectite (80)*†, albite	Wet climate
SL-S-25	H375	Quartz	Gibbsite (511), kaolinite (157)	Smectite (30), albite, orthoclase	Wet climate
SL-S-54	H376	Quartz	Albite, orthoclase	Kaolinite (43), ?goethite	Intermediate
SL-S-61	H377	Quartz	Gibbsite (202), Kaolinite (83)	Orthoclase, albite, hematite	Intermediate
SL-S-65	H378	Quartz	Orthoclase	Albite, kaolinite (53, amphibole, smectite (52)	Dry Climate
SL-S-89	H379	Quartz	Kaolinite (272)	Smectite (66), Gibbsite (130), orthoclase, albite, hematite, amphibole	Intermediate

* Peak intensities measured: Kaolinite, d=7.14Å, Gibbsite d= 4.83Å, Smectite d=14.1Å

† Precise identification of the clay minerals species present from a bulk XRD trace is not possible, see text.

(c) Data Used for Data Processssing (SOILRES.XLS)

Samp. No.	IDD Code	Region Code	Iodine µg/g	Se ng/g	pH	% Se Adsorption	Dry Colour	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	TOC %
004	NIDD5	AN5	2.00	319	6.21	89.5	3	3242	540	35,739	38,414	19.4	24.3	44.7	0.6
015	NIDD2	AN2	0.70	216	5.14	94.0	3	9,489	384	21,311	57,783	20.0	9.28	34.6	0.3
016	NIDD4	AN4	0.13	113	5.82	95.1	3	6,599	328	21,642	45,801	20.0	5.34	36.3	0.2
017	NIDD4	AN4	1.40	198	6.04	84.8	3	6,683	376	21,912	48,426	20.0	9.20	35.2	0.3
018	NIDD1	AN1	4.10	185	6.11	93.9	3	8,976	881	28,996	65,826	20.0	18.6	50.4	0.6
019	NIDD3	AN3	10.00	217	6.24	99.4	3	6,441	594	33,997	71,690	20.0	9.91	46.4	0.6
026	NIDD3	AN3	5.40	175	6.08	99.9	4	8,453	972	59,116	70,718	20.0	11.9	53.6	1.4
028	NIDD3	AN3	8.60	663	6.74	99.9	4	10,901	787	43,163	77,628	44.9	25.9	43.5	0.6
032	NIDD1	AN1	3.80	170	6.62	90.3	3	10,399	688	32,545	53,286	20.0	11.5	51.8	0.6
037	NIDD5	AN5	2.20	392	6.62	95.4	4	4,489	936	42,024	61,408	20.0	25.4	52.1	0.3
039	NIDD3	AN3	5.00	242	6.09	95.1	4	5,185	638	41,844	59,146	20.0	25.2	40.0	0.4
041	NIDD1	AN1	2.60	253	4.94	72.7	3	7,344	474	20,873	44,563	20.0	8.17	39.8	0.6
045	NIDD2	AN2	0.80	171	6.25	82.6	3	8,273	441	18,560	48,768	20.0	7.89	30.3	0.6
046	NIDD1	AN1	3.50	338	5.27	99.3	3	8,235	614	26,596	55,306	20.0	11.3	51.8	1
049	NIDD1	AN1	2.70	332	6.24	97.9	3	9,608	651	28,169	54,591	20.0	19.1	39.2	0.9
054	NIDD3	AN3	6.40	338	6.33	88.8	4	6,990	607	34,672	73,259	30.6	14.1	43.2	0.6
056	NIDD2	AN2	0.50	160	5.87	88.0	3	9,837	603	22,446	58,696	20.0	9.08	32.1	0.6
062	NIDD4	AN4	2.70	200	7.53	51.8	3	9,288	280	20,534	64,903	20.0	9.51	32.7	0.6
065	NIDD5	AN5	2.20	309	6.20	95.4	3	5,357	285	37,020	57,811	20.0	25.0	49.2	1.1
072	NIDD4	AN4	2.70	125	6.41	98.6	3	13,308	655	32,249	69,026	20.0	12.5	50.7	0.7
076	NIDD5	AN5	4.40	213	6.35	90.7	3	6,809	1,460	46,115	62,003	29.4	26.6	55.9	0.8
080	NIDD4	AN4	3.80	148	5.59	75.5	4	7,095	550	30,250	57,200	20.0	10.2	44.6	0.1
090	NIDD5	AN5	1.90	349	6.43	99.9	3	4,991	363	34,680	50,882	20.0	21.3	42.4	0.7
094	NIDD2	AN2	1.40	155	5.82	66.5	3	8,419	453	18,479	49,970	20.0	6.18	29.4	0.7
098	NIDD2	AN2	0.80	174	6.34	62.0	4	9,370	366	20,459	49,456	20.0	7.82	29.0	0.7
001	HIDD1	KA1	1.90	454	4.85	99.9	4	2,445	305	59,824	48,182	29.8	33.1	77.7	0.9
003	HIDD1	KA1	2.50	312	4.64	99.9	3	8,104	432	43,114	75,639	31.8	152	109	1
007	MIDD1	KA3	0.80	314	4.42	99.9	4	3,036	205	29,018	66,835	20.0	22.5	55.3	0.6

Samp. No.	IDD Code	Region Code	Iodine µg/g	Se ng/g	pH	% Se Adsorption	Dry Colour	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	TOC %
013	MIDD3	KA5	0.13	716	4.33	99.9	4	3,485	299	46,201	50,082	29.1	38.0	46.4	1
021	HIDD2	KA2	2.30	702	4.57	99.9	4	6,642	649	82,884	88,922	44.7	40.9	90.3	0.6
023	MIDD4	KA6	2.80	652	4.33	83.5	3	2,134	200	22,694	57,136	20.0	15.6	77.9	1.3
034	MIDD1	KA3	3.60	497	5.03	99.9	4	3,263	448	52,963	64,099	39.5	52.4	82.8	1
035	MIDD3	KA5	3.90	1149	4.72	99.9	5	2,579	755	66,499	69,824	50.3	54.9	65.7	0.6
036	MIDD4	KA6	1.80	755	4.39	99.5	3	7,183	295	38,056	60,319	20.0	19.7	47.8	0.6
038	MIDD1	KA3	2.30	468	4.59	99.9	4	3,364	256	41,968	85,592	20.0	17.4	57.1	0.3
040	MIDD2	KA4	1.10	607	4.49	99.9	4	3,642	519	48,630	72,558	40.4	30.1	74.3	1.1
048	MIDD3	KA5	1.60	919	4.49	99.9	5	1,392	226	40,652	36,314	34.6	25.2	46.0	0.4
051	MIDD3	KA5	0.13	712	4.51	98.4	4	3,222	277	39,609	46,284	20.0	31.1	42.6	0.9
057	MIDD2	KA4	4.20	760	4.29	99.9	4	534	284	51,133	63,986	41.5	29.3	65.2	2.1
059	MIDD4	KA6	1.00	343	4.31	69.2	3	1,358	144	10,961	32,939	20.0	7.55	54.4	0.8
061	MIDD2	KA4	2.30	935	4.78	99.9	4	450	210	45,323	62,306	38.3	28.8	56.1	1.4
067	MIDD1	KA3	2.30	459	4.64	99.9	4	5,090	470	52,333	70,417	43.4	43.9	79.6	1.2
069	HIDD1	KA1	1.20	276	4.45	98.5	3	7,644	309	38,716	68,681	29.1	25.0	95.3	1.1
070	MIDD4	KA6	2.50	706	4.11	88.2	2	3,855	265	27,500	66,980	20.0	13.8	94.4	2.1
071	MIDD2	KA4	1.30	501	3.91	99.9	3	1,533	292	25,795	58,850	36.9	20.4	49.2	1
074	MIDD4	KA6	1.60	310	4.35	78.5	3	2,507	258	15,615	36,595	20.0	12.0	55.4	0.8
083	HIDD2	KA2	2.20	286	4.32	97.3	3	4,786	287	32,446	79,472	20.0	30.5	58.3	1
084	HIDD2	KA2	1.70	534	4.88	99.9	4	7,074	587	73,981	111,242	55.6	60.4	98.0	1.4
086	HIDD1	KA1	3.20	553	4.90	99.5	4	1,489	414	60,483	55,735	30.4	33.4	73.1	1.3
089	HIDD2	KA2	3.20	692	4.81	99.9	4	7,756	817	92,850	111,420	47.3	51.8	88.8	2.1
091	MIDD1	KA3	4.60	777	5.35	99.9	4	12,041	801	79,000	113,323	103	62.2	112	1.6
093	MIDD2	KA4	3.90	754	4.51	99.9	4	3,747	751	55,642	73,743	56.9	36.3	78.5	1.6
095	HIDD2	KA2	1.70	312	4.49	98.2	4	10,555	480	45,682	76,962	30.6	32.9	59.9	0.9
097	MIDD3	KA5	2.50	740	4.73	99.9	4	7,573	555	60,804	51,186	36.8	48.4	56.8	1.5
099	HIDD1	KA1	1.60	401	4.39	99.5	4	7,233	346	44,790	77,339	33.8	35.8	103	1.6
005	MIDD5	KL4	5.00	2981	4.62	92.0	2	478	77.8	17,351	88,979	31.0	12.5	39.5	4.4
008	MIDD5	KL4	6.60	5079	4.99	99.9	2	541	65.5	17,005	133,382	55.6	25.3	57.2	6
009	HIDD5	KL3	5.70	2692	4.25	99.9	1	717	68.9	29,274	74,073	34.6	17.2	60.8	6

Samp. No.	IDD Code	Region Code	Iodine µg/g	Se ng/g	pH	% Se Adsorption	Dry Colour	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg	TOC %
024	HIDD4	KL2	4.90	1884	4.38	58.4	1	412	52.7	6,019	74,548	29.6	16.5	37.0	4.6
025	HIDD4	KL2	4.00	2489	4.31	99.4	2	336	49.4	9,193	110,641	46.3	22.7	43.3	5.6
033	HIDD5	KL3	6.40	3594	3.95	99.9	1	580	72.1	39,754	120,201	46.3	23.0	73.6	5.8
042	HIDD5	KL3	9.60	3548	4.20	99.9	1	857	70.2	37,141	115,415	40.1	22.2	73.8	10.8
047	HIDD4	KL2	2.40	1931	4.30	98.9	2	206	49.8	7,797	83,580	31.9	14.9	36.2	4.5
050	HIDD5	KL3	6.60	3947	4.31	99.9	1	652	73.0	39,020	127,287	47.8	22.6	71.4	7.8
052	HIDD3	KL1	3.00	1865	4.76	75.8	2	484	112	15,699	74,102	28.8	14.2	47.8	4.4
060	MIDD5	KL4	2.70	5238	4.33	77.5	2	518	56.5	15,566	128,251	52.2	28.3	47.2	4.1
064	HIDD3	KL1	3.30	2112	4.84	99.9	2	420	119	20,486	92,108	37.2	16.5	58.7	4.8
066	HIDD3	KL1	2.20	1171	4.11	99.9	3	313	129	19,562	70,985	27.4	10.6	52.2	2
068	MIDD5	KL4	3.90	2494	4.63	99.9	2	362	105	16,238	60,815	31.6	12.6	46.1	4.8
077	HIDD4	KL2	4.10	2593	4.31	61.7	1	548	52.3	8,094	79,254	37.5	18.0	39.7	6.1
079	HIDD3	KL1	1.00	730	4.32	61.2	3	250	102	9,153	38,307	20.0	6.88	35.1	1.7
085	HIDD5	KL3	5.00	3312	4.37	92.5	1	686	80.4	35,610	106,348	38.3	20.0	61.9	7.4
088	HIDD3	KL1	2.10	1746	4.23	99.9	3	562	118	30,139	93,086	40.4	15.3	59.1	2.3
096	MIDD5	KL4	5.30	2879	4.66	99.6	2	510	71.3	19,586	120,698	45.2	14.4	50.3	4.9
100	HIDD4	KL2	3.80	1519	4.05	50.1	1	161	32.0	5,866	57,583	20.0	11.5	32.6	5.1

APPENIDIX C: LISTING OF RICE RESULTS

(a) Field Data (fldgrain.xls)

No.	Date Sampled	Village Name	IDD Code	Grain Type	Harvest Date	Boiled or Unboiled	Last NPK + urea appl.	Colour of Dry Powder	Comments
1	2/19/97	Angunawala	HIDD1	Paddy	Sep. 1996	Unboiled	Jan. 1997	Red	
3	2/19/97	Angunawala	HIDD1	Rice	Sep. 1996	Boiled	Jan. 1997	Cream	
4	2/17/97	Kiralessa	NIDD5	Rice	Mar. 1996	Unknown	Unknown	Cream	
5	2/22/97	Navinna	MIDD5	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	
7	2/19/97	Dehideniya	MIDD1	Rice	Mar. 1996	Unboiled	Jan. 1997	Cream	
8	2/22/97	Navinna	MIDD5	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	
9	2/23/97	Gurudola	HIDD5	Rice	Sep. 1996	Unboiled	Jan. 1997	Pink	
13	1/21/97	Ambepussa	MIDD3	Paddy	Feb. 1997	Unboiled	Dec. 196	Cream	
15	2/16/97	Manankattiya	NIDD2	Rice	Mar. 1996	Unknown	Unknown	Cream	
16	2/17/97	Ihala Kagama	NIDD4	Rice	Jan. 1997	Unknown	Unknown	Cream	
17	2/17/97	Ihala Kagama	NIDD4	Rice	Jan. 1997	Unknown	Unknown	Cream	
18	2/16/97	Upuldenya	NIDD1	Rice	Mar. 1996	Unknown	Unknown	White	
19	2/17/97	Polambayagama	NIDD3	Rice	Mar. 1996	Unknown	Unknown	White	
21	2/20/97	Kurunduwatte	HIDD2	Rice	Oct. 1996	Unboiled	Jan. 1997	Cream	
22	2/22/97	Navinna	MIDD5	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	Duplicate of 68
23	1/21/97	Debagama	MIDD4	Rice	Feb. 1997	Unboiled	Nov. 1996	White	
24	2/22/97	Pelenwatte	HIDD4	Rice	Feb. 1997	Unboiled	Dec. 1996	Pink	
25	2/22/97	Pelenwatte	HIDD4	Rice	Feb. 1997	Unboiled	Nov. 1996	Pink	
26	2/17/97	Polambayagama	NIDD3	Paddy	Mar. 1996	Unknown	Unknown	Cream	
28	2/17/97	Polambayagama	NIDD3	Paddy	Mar. 1996	Unknown	Unknown	Cream	
32	2/16/97	Upuldenya	NIDD1	Paddy	Mar. 1996	Boiled	Unknown	Fawn	
33	2/23/97	Gurudola	HIDD5	Paddy	Feb. 1997	Unboiled	Dec. 1996	Red	
34	2/19/97	Dehideniya	MIDD1	Rice	Mar. 1996	Boiled	Unknown	Cream	
35	1/21/97	Ambepussa	MIDD3	Rice	Jul. 1997	Boiled	Nov. 1996	Cream	
36	1/21/97	Debagama	MIDD4	Rice	Feb. 1997	Boiled	Nov. 1996	Fawn	
37	2/17/97	Kiralessa	NIDD5	Rice	Sep. 1996	Unknown	Unknown	Cream	
38	2/19/97	Dehideniya	MIDD1	Rice	Mar. 1996	Unknown	Jan. 1997	White	
39	2/17/97	Polambayagama	NIDD3	Rice	Mar. 1996	Unknown	Unknown	White	
40	2/20/97	Kobbekaduwa	MIDD2	Paddy	Oct. 1996	Unboiled	Jan. 1997	Yellow	
41	2/16/97	Upuldenya	NIDD1	Rice	Jan. 1997	Unknown	Unknown	White	
42	2/23/97	Gurudola	HIDD5	Paddy	Feb. 1997	Unboiled	Dec. 1996	Red	
45	2/16/97	Manankattiya	NIDD2	Paddy	Mar. 1996	Unknown	Unknown	Cream	
46	2/16/97	Upuldenya	NIDD1	Paddy	Feb. 1997	Unknown	Unknown	Cream	
47	2/22/97	Pelenwatte	HIDD4	Paddy	Feb. 1997	Unboiled	Dec. 1996	Red	
48	1/21/97	Ambepussa	MIDD3	Rice	Sep. 1997	Boiled	Unknown	Pink	
49	2/16/97	Upuldenya	NIDD1	Paddy	Feb. 1997	Unknown	Unknown	Cream	
50	2/23/97	Gurudola	HIDD5	Rice	Sep. 1996	Unboiled	Jan. 1997	Pink	
51	1/21/97	Ambepussa	MIDD3	Paddy	Feb. 1997	Unboiled	Unknown	Cream	
52	2/22/97	Olaboduwa (N)	HIDD3	Rice	Feb. 1997	Unboiled	Nov. 1996	White	Same as 79
54	2/17/97	Polambayagama	NIDD3	Rice	Mar. 1996	Unknown	Unknown	White	Rice mixture from fields 0.8km apart
56	2/16/97	Manankattiya	NIDD2	Paddy	Apr. 1996	Unknown	Unknown	Cream	
57	2/20/97	Kobbekaduwa	MIDD2	Paddy	Mar. 1996	Unboiled	Jan. 1997	Cream	
58	2/23/97	Gurudola	HIDD5	Rice	Sep. 1996	Unknown	Jan. 1997	Pink	Extra sample
59	1/21/97	Debagama	MIDD4	Rice	Feb. 1997	Boiled	Nov. 1996	Cream	
60	2/22/97	Navinna	MIDD5	Paddy	Feb. 1997	Unboiled	Nov. 1996	Cream	
61	2/20/97	Kobbekaduwa	MIDD2	Rice	Mar. 1996	Boiled	Jan. 1997	Cream	

No.	Date Sampled	Village Name	IDD Code	Grain Type	Harvest Date	Boiled or Unboiled	Last NPK + urea appl.	Colour of Dry Powder	Comments
62	2/17/97	Ihala Kagama	NIDD4	Paddy	Jan. 1997	Unknown	Unknown	Cream	
64	2/22/97	Olaboduwa (N)	HIDD3	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	
65	2/17/97	Kiralessa	NIDD5	Rice	Sep. 1996	Unknown	Unknown	Cream	
66	2/22/97	Olaboduwa (N)	HIDD3	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	
67	2/19/97	Dehideniya	MIDD1	Rice	Mar. 1996	Unboiled	None	Cream	Straw fertiliser
68	2/22/97	Navinna	MIDD5	Paddy	Feb. 1997	Unboiled	Nov. 1996	Red	
69	2/19/97	Angunawala	HIDD1	Paddy	Sep. 1996	Unboiled	Jan. 1997	Cream	
70	2/21/97	Debagama	MIDD4	Paddy	Feb. 1997	Unboiled	Nov. 1996	Cream	
71	2/20/97	Kobbekaduwa	MIDD2	Rice	Mar. 1996	Boiled	Jan. 1997	Cream	
72	2/17/97	Ihala Kagama	NIDD4	Rice	Mar. 1996	Unknown	Unknown	Cream	
74	1/21/97	Debagama	MIDD4	Rice	Feb. 1997	Unboiled	Nov. 1996	Cream	
76	2/17/97	Kiralessa	NIDD5	Rice	Sep. 1996	Unknown	Feb. 1997	Cream	
77	2/22/97	Pelenwatte	HIDD4	Rice	Feb. 1997	Unboiled	Dec. 1996	Cream	
78	2/19/97	Angunawala	HIDD1	Paddy	Sep. 1996	Unboiled	Oct. 1996	Cream	
79	2/22/97	Olaboduwa (N)	HIDD3	Rice	Feb. 1997	Boiled	Nov. 1996	Red	Same as 52
80	2/17/97	Ihala Kagama	NIDD4	Paddy	Jan. 1997	Unknown	Unknown	Fawn	
81	2/17/97	Kiralessa	NIDD5	Rice	Sep. 1996	Unknown	Feb. 1997	Cream	Duplicate of 76
83	2/20/97	Kurunduwatte	HIDD2	Paddy	Sep. 1996	Unboiled	Jan. 1997	Cream	
84	2/20/97	Kurunduwatte	HIDD2	Rice	Sep. 1996	Unboiled	Jan. 1997	Cream	
85	2/23/97	Gurudola	HIDD5	Paddy	Feb. 1997	Unboiled	Jan. 1997	Red	
86	2/19/97	Angunawala	HIDD1	Paddy	Sep. 1996	Unboiled	Oct. 1996	Cream	Duplicate of 78
88	2/22/97	Olaboduwa (N)	HIDD3	Paddy	Feb. 1997	Unboiled	Unknown	Red	
89	2/20/97	Kurunduwatte	HIDD2	Paddy	Oct. 1996	Unboiled	Jan. 1997	Cream	
90	2/17/97	Kiralessa	NIDD5	Rice	Mar. 1996	Unknown	Unknown	Cream	
91	2/19/97	Dehideniya	MIDD1	Rice	Sep. 1996	Unboiled	Jan. 1997	White	
93	2/20/97	Kobbekaduwa	MIDD2	Paddy	Sep. 1996	Unboiled	Jan. 1997	Cream	
94	2/16/97	Manankattiya	NIDD2	Paddy	Mar. 1996	Unknown	Unknown	Yellow	
95	2/20/97	Kurunduwatte	HIDD2	Rice	Mar. 1996	Unboiled	Jan. 1997	Cream	
96	2/22/97	Navinna	MIDD5	Rice	Feb. 1997	Unboiled	Nov. 1996	White	
97	2/21/97	Ambepussa	MIDD3	Paddy	Feb. 1997	Unboiled	Nov. 1996	Cream	
98	2/16/97	Manankattiya	NIDD2	Paddy	Apr. 1996	Unknown	Unknown	Cream	
99	2/19/97	Angunawala	HIDD1	Paddy	Sep. 1996	Unboiled	Jan. 1997	Fawn	
100	2/22/97	Pelenwatte	HIDD4	Rice	Feb. 1997	Boiled	Oct. 1996	Red	

Paddy=rice in the husk, Rice=dehusked rice. Colour of Dry Powder referes to the ground rice sample.

(b) Laboratory Results

(i) *Total Iodine in Village Composite Samples (pf01-dat.xls) (determined by NAA at the Centre for Environmental Technology, Silwood Park)*

Customer : Dr J. D. Appleton

Organisation : British Geological Survey, Keyworth, Nottingham.

Samples received : 13-Jan-98

Report issued : 21-Jan-98

Our ref. : PF01

Samples analysed as received

Results are reported in mg/kg (ppm) and to 95% confidence based on counting statistics.

ASG Sample No.	Customer Sample No.	Total Iodine Concentration (mg/kg)	Uncertainty 2σ (mg/kg)
PF0101	HIDD 1	< 0.033	
PF0102	HIDD 2	< 0.029	
PF0103	HIDD 3	< 0.025	
PF0104	HIDD 4	< 0.025	
PF0105	HIDD 5	< 0.027	
PF0106	NIDD 1	< 0.032	
PF0107	NIDD 2	< 0.038	
PF0108	NIDD 3	< 0.025	
PF0109	NIDD 4	0.058	0.017
PF0110	NIDD 5	0.045	0.016
PF0111	NIDD 6	< 0.028	
PF0112	MIDD 1	< 0.025	
PF0113	MIDD 2	< 0.029	
PF0114	MIDD 3	< 0.023	
PF0115	MIDD 4	< 0.028	
PF0116	MIDD 5	< 0.021	
PF01Q1	SRM 1572 Citrus leaves	1.79	0.12

Certified iodine concentration for SRM 1572 Citrus leaves is 1.84 +/- 0.03 mg/kg

Copy no.	Name	Signature	Date
Prepared by	R. Benzing	[redacted]	[redacted]
Checked by	S. J. Parry	[redacted]	[redacted]

Note: NIDD6 is a replicate sample of NIID3

(ii) Total Selenium (fmf05389.xls) (determined at BGS laboratories, Keyworth fmf05389)

BGS Code	Customer ID SL-??-G	Se in Rice ng/g
05389~00001	3	53.9
05389~00002	4	130
05389~00003	5	341
05389~00004	6	52.7
05389~00005	7	27.8
05389~00006	8	643
05389~00007	9	74.9
05389~00008	13	42.2
05389~00009	14	2504
05389~00010	15	41.9
05389~00011	16	150
05389~00012	17	92.8
05389~00013	18	39.2
05389~00014	19	56.7
05389~00015	21	24.3
05389~00016	22	777
05389~00017	23	55.5
05389~00018	24	120
05389~00019	26	34.0
05389~00020	28	59.8
05389~00021	32	75.2
05389~00022	34	36.7
05389~00023	35	62.7
05389~00024	36	27.6
05389~00025	37	52.8
05389~00026	38	61.9
05389~00027	39	11.1
05389~00028	40	57.4
05389~00029	41	6.76
05389~00030	42	77.4
05389~00031	43	28.9
05389~00032	45	14.0
05389~00033	46	46.5
05389~00034	47	86.2
05389~00035	48	65.7
05389~00036	49	59.8
05389~00037	50	43.2
05389~00038	51	78.5
05389~00039	52	82.3
05389~00040	54	108
05389~00041	55	6653
05389~00042	56	22.6
05389~00043	58	38.5
05389~00044	59	203
05389~00045	60	49.7
05389~00046	61	18.3
05389~00047	62	83.2
05389~00048	64	44.9
05389~00049	65	20.2
05389~00050	67	28.8
05389~00051	68	417
05389~00052	69	14.4
05389~00053	70	33.1
05389~00054	71	38.3
05389~00055	72	15.3
05389~00056	74	56.6
05389~00057	76	58.6
05389~00058	77	68.7
05389~00059	78	10.9
05389~00060	79	61.5
05389~00061	80	18.4
05389~00062	81	57.7
05389~00063	82	36.7
05389~00064	83	9.32
05389~00065	84	13.6
05389~00066	86	12.9
05389~00067	87	8.15
05389~00068	88	90.4
05389~00069	89	17.6
05389~00070	90	75.0
05389~00071	91	40.1
05389~00072	93	24.2
05389~00073	94	26.4
05389~00074	96	193
05389~00075	97	38.1
05389~00076	98	44.3
05389~00077	99	8.22

(c) Data Used for Data Processing (SLGRAINS.XLS)

No	IDD Code	Region Code	Se (ng/g)	Type	State	NPK urea	Colour
1	HIDD1	KA1	0.1	Paddy	Unboiled	Jan. 1997	Red
3	HIDD1	KA1	53.9	Rice	Boiled	Jan. 1997	Cream
4	NIDD5	AN5	130	Rice	Unknown	Unknown	Cream
5	MIDD5	KL4	341	Paddy	Unboiled	Nov. 1996	Red
7	MIDD1	KA3	27.8	Rice	Unboiled	Jan. 1997	Cream
8	MIDD5	KL4	643	Paddy	Unboiled	Nov. 1996	Red
9	HIDD5	KL3	74.9	Rice	Unboiled	Jan. 1997	Pink
13	MIDD3	KA5	42.2	Paddy	Unboiled	Dec. 196	Cream
15	NIDD2	AN2	41.9	Rice	Unknown	Unknown	Cream
16	NIDD4	AN4	150	Rice	Unknown	Unknown	Cream
17	NIDD4	AN4	92.8	Rice	Unknown	Unknown	Cream
18	NIDD1	AN1	39.2	Rice	Unknown	Unknown	White
19	NIDD3	AN3	56.7	Rice	Unknown	Unknown	White
21	HIDD2	KA2	24.3	Rice	Unboiled	Jan. 1997	Cream
22	MIDD5	KL4	777	Paddy	Unboiled	Nov. 1996	Red
23	MIDD4	KA6	55.5	Rice	Unboiled	Nov. 1996	White
24	HIDD4	KL2	120	Rice	Unboiled	Dec. 1996	Pink
25	HIDD4	KL2	65	Rice	Unboiled	Nov. 1996	Pink
26	NIDD3	AN3	34.0	Paddy	Unknown	Unknown	Cream
28	NIDD3	AN3	59.8	Paddy	Unknown	Unknown	Cream
32	NIDD1	AN1	75.2	Paddy	Boiled	Unknown	Fawn
33	HIDD5	KL3	24.5	Paddy	Unboiled	Dec. 1996	Red
34	MIDD1	KA3	36.7	Rice	Boiled	Unknown	Cream
35	MIDD3	KA5	62.7	Rice	Boiled	Nov. 1996	Cream
36	MIDD4	KA6	27.6	Rice	Boiled	Nov. 1996	Fawn
37	NIDD5	AN5	52.8	Rice	Unknown	Unknown	Cream
38	MIDD1	KA3	61.9	Rice	Unknown	Jan. 1997	White
39	NIDD3	AN3	11.1	Rice	Unknown	Unknown	White
40	MIDD2	KA4	57.4	Paddy	Unboiled	Jan. 1997	Yellow
41	NIDD1	AN1	6.76	Rice	Unknown	Unknown	White
42	HIDD5	KL3	77.4	Paddy	Unboiled	Dec. 1996	Red
45	NIDD2	AN2	14.0	Paddy	Unknown	Unknown	Cream
46	NIDD1	AN1	46.5	Paddy	Unknown	Unknown	Cream
47	HIDD4	KL2	86.2	Paddy	Unboiled	Dec. 1996	Red
48	MIDD3	KA5	65.7	Rice	Boiled	Unknown	Pink
49	NIDD1	AN1	59.8	Paddy	Unknown	Unknown	Cream
50	HIDD5	KL3	43.2	Rice	Unboiled	Jan. 1997	Pink
51	MIDD3	KA5	78.5	Paddy	Unboiled	Unknown	Cream
52	HIDD3	KL1	82.3	Rice	Unboiled	Nov. 1996	White
54	NIDD3	AN3	108	Rice	Unknown	Unknown	White
56	NIDD2	AN2	22.6	Paddy	Unknown	Unknown	Cream
57	MIDD2	KA4	0.1	Paddy	Unboiled	Jan. 1997	Cream
58	HIDD5	KL3	38.5	Rice	Unknown	Jan. 1997	Pink
59	MIDD4	KA6	203	Rice	Boiled	Nov. 1996	Cream
60	MIDD5	KL4	49.7	Paddy	Unboiled	Nov. 1996	Cream
61	MIDD2	KA4	18.3	Rice	Boiled	Jan. 1997	Cream
62	NIDD4	AN4	83.2	Paddy	Unknown	Unknown	Cream
64	HIDD3	KL1	44.9	Paddy	Unboiled	Nov. 1996	Red
65	NIDD5	AN5	20.2	Rice	Unknown	Unknown	Cream
66	HIDD3	KL1	44.8	Paddy	Unboiled	Nov. 1996	Red
67	MIDD1	KA3	28.8	Rice	Unboiled	None	Cream
68	MIDD5	KL4	417	Paddy	Unboiled	Nov. 1996	Red
69	HIDD1	KA1	14.4	Paddy	Unboiled	Jan. 1997	Cream
70	MIDD4	KA6	33.1	Paddy	Unboiled	Nov. 1996	Cream
71	MIDD2	KA4	38.3	Rice	Boiled	Jan. 1997	Cream

No	IDD Code	Region Code	Se (ng/g)	Type	State	NPK urea	Colour
72	NIDD4	AN4	15.3	Rice	Unknown	Unknown	Cream
74	MIDD4	KA6	56.6	Rice	Unboiled	Nov. 1996	Cream
76	NIDD5	AN5	58.6	Rice	Unknown	Feb. 1997	Cream
77	HIDD4	KL2	68.7	Rice	Unboiled	Dec. 1996	Cream
78	HIDD1	KA1	10.9	Paddy	Unboiled	Oct. 1996	Cream
79	HIDD3	KL1	61.5	Rice	Boiled	Nov. 1996	Red
80	NIDD4	AN4	18.4	Paddy	Unknown	Unknown	Fawn
81	NIDD5	AN5	57.7	Rice	Unknown	Feb. 1997	Cream
83	HIDD2	KA2	9.32	Paddy	Unboiled	Jan. 1997	Cream
84	HIDD2	KA2	13.6	Rice	Unboiled	Jan. 1997	Cream
85	HIDD5	KL3	127.2	Paddy	Unboiled	Jan. 1997	Red
86	HIDD1	KA1	12.9	Paddy	Unboiled	Oct. 1996	Cream
88	HIDD3	KL1	90.4	Paddy	Unboiled	Unknown	Red
89	HIDD2	KA2	17.6	Paddy	Unboiled	Jan. 1997	Cream
90	NIDD5	AN5	75.0	Rice	Unknown	Unknown	Cream
91	MIDD1	KA3	40.1	Rice	Unboiled	Jan. 1997	White
93	MIDD2	KA4	24.2	Paddy	Unboiled	Jan. 1997	Cream
94	NIDD2	AN2	26.4	Paddy	Unknown	Unknown	Yellow
95	HIDD2	KA2	0.1	Rice	Unboiled	Jan. 1997	Cream
96	MIDD5	KL4	193	Rice	Unboiled	Nov. 1996	White
97	MIDD3	KA5	38.1	Paddy	Unboiled	Nov. 1996	Cream
98	NIDD2	AN2	44.3	Paddy	Unknown	Unknown	Cream
99	HIDD1	KA1	8.22	Paddy	Unboiled	Jan. 1997	Fawn
100	HIDD4	KL2	82.41	Rice	Boiled	Oct. 1996	Red

APPENDIX D: LISTING OF WATER RESULTS

(a) Field Data (FLDWATER.XLS)

Samp. No	Date Sampled	Village Name	IDD Code	Water Source	Sample Temp (°C)	pH	Field Eh (mV)	Corr. Eh (mV)	Conduct-ivity (µS)	Total Alkalinity (mg/l $CaCO_3$)	Comments
18	2/16/97	Upuldenya	NIDD1	Dug well 10 m deep in midwife's garden	29.7	7.26	232	426	1670	428	
45	2/16/97	Manankattiya	NIDD2	Dug well 6.6 m deep on road to dam	29.1	7.57	217	412	1760	312	
26	2/17/97	Polambayagama	NIDD3	Dug well 6.6 m deep on track into village from irrigation canal	27.1	7.32	212	409	712	258	
62	2/17/97	Ihala Kagama	NIDD4	Dug well 8 m deep at house opposite dam	27.0	7.33	223	420	883	308	
76	2/17/97	Kiralessa	NIDD5	Duplicate of 81	26.6	7.28	231	428	935	380	
81	2/17/97	Kiralessa	NIDD5	Dug well 8 m deep, first well to E of 3-way junction in village	26.4	7.30	243	441	943	388	
38	2/19/97	Dehideniya	MIDD1	Dug well 4 m to water table in agriculture student's garden	28.0	5.87	250	446	222	36	Orange ppt on filter
93	2/20/97	Kobbekaduwa	MIDD2	Spring water piped from 100 m above village house of D G Dingiriamma	27.9	7.02	230	426	133	18.4	Water polluted
48	2/21/97	Ambepussa	MIDD3	Dug well 8.25 m deep at house of P K Piyaratne	29.2	5.50	278	473	112	10	Yellow ppt on filter
74	2/21/97	Debagama	MIDD4	Dug well 5 m deep from 2nd house to west on S side of road	29.3	5.64	275	470	68	13	Yellow ppt on filter
22	2/22/97	Navinna	MIDD5	Well with pump head 6 m deep house of H Sunitha Mangalika	29.8	4.82	264	458	189	6	
68	2/22/97	Navinna	MIDD5	Duplicate of 22	30.0	4.77	262	456	188	5.6	Orange ppt on filter
78	2/19/97	Angunawala	HIDD1	Duplicate of 86	27.6	6.60	232	428	478	120	Orange ppt on filter
86	2/19/97	Angunawala	HIDD1	Dug well 10-15 m deep 3 m to water table at doctor's house.	27.6	6.62	232	428	484	118	Heavy rain am
89	2/20/97	Kurunduwatte	HIDD2	Dug well 2.,3 m deep house of T M Ariyawathi	28.2	6.56	250	446	270	78.4	Yellow ppt on filter
88	2/22/97	Olaboduwa N	HIDD3	Dug well 10 m to water table in front of headwoman's house	30.0	4.76	293	487	49	3.4	Well in bedrock
25	2/22/97	Pelenwatte	HIDD4	Dug well 8 m deep house of Sujatha Sumuduni	30.0	5.57	242	436	79	9.6	Colloidal, well in bedrock
9	2/23/97	Gurudola	HIDD5	Dug well 0.5 m to water table 3 m deep at village store.	31.0	5.33	280	473	54	7.8	Clear, yellow ppt on filter

(b) Laboratory Results

(i) Cl, SO_4, NO_3 and Se (fmf05394.xls) (determined at BGS laboratories, Keyworth fmf05394)

BGS Code	LIMS Code	Sample Number	Cl mg/l	SO4 mg/l	NO3 mg/l	Se µg/l
8781	05394-00001	9	3.19	1.40	0.63	0.07
8782	05394-00002	10	<0.10	<0.10	<0.10	0.09
8783	05394-00003	18	125.	29.6	15.6	0.24
8784	05394-00004	22	29.3	3.21	16.4	0.06
8785	05394-00005	25	8.28	0.68	2.81	0.09
8786	05394-00006	26	63.4	10.9	<0.10	0.06
8787	05394-00007	38	32.0	0.70	7.43	0.06
8788	05394-00008	45	<0.10	19.1	<0.10	0.09
8789	05394-00009	48	14.0	1.90	9.38	0.07
8790	05394-00010	62	68.6	10.4	<0.10	0.06
8791	05394-00011	68	29.3	3.24	16.1	0.06
8792	05394-00012	74	4.54	1.32	1.46	0.07
8793	05394-00013	75	<0.10	<0.10	<0.10	0.06
8794	05394-00014	76	24.2	21.4	25.1	0.18
8795	05394-00015	78	33.4	25.2	12.5	0.08
8796	05394-00016	81	24.4	21.5	24.8	0.17
8797	05394-00017	86	33.5	25.2	12.4	0.09
8798	05394-00018	88	3.24	0.88	4.51	0.06
8799	05394-00019	89	18.7	6.56	0.54	0.06
8800	05394-00020	93	7.54	1.13	22.0	0.09

(ii) Iodine (determined by Dr R Fuge, UCW Aberystwyth)

Water

Sample	I (µg l^{-1})
9	20.2
10	<1 (trace)
18	55
22	4.6
25	3.3
26	53
38	23.5
45	83
48	4.6
62	84
68	25
74	3.4
75	<1 (trace)
76	65
78	6.8
81	64
86	6.7
88	5.6
89	6.8
93	3.0

(c) Data Used for Data Processing (SLWATERS.XLS)

IDD Code	Iodine (µg/l)	Chlorine (mg/l)	Sulphate (mg/l)	Nitrate (mg/l)	Se (µg/l)	Temp (C)	pH	Eh (mV)	Bicarbonate (mg/l CaCO3)	Conductivity (mS)
HIDD1	6.8	33.4	25.2	12.5	0.08	27.6	6.60	232	60	478
HIDD1	6.7	33.5	25.2	12.4	0.09	27.6	6.62	232	59	484
HIDD2	6.8	18.7	6.56	0.54	0.06	28.2	6.56	250	39.2	270
HIDD3	5.6	3.24	0.88	4.51	0.06	30.0	4.76	293	1.7	49
HIDD4	3.3	8.28	0.68	2.81	0.09	30.0	5.57	242	4.8	79
HIDD5	20.2	3.19	1.40	0.63	0.07	31.0	5.33	280	3.9	54
MIDD1	23.5	32.0	0.70	7.43	0.06	28.0	5.87	250	18	222
MIDD2	3.0	7.54	1.13	22.0	0.09	27.9	7.02	230	9.2	133
MIDD3	4.6	14.0	1.90	9.38	0.07	29.2	5.50	278	5	112
MIDD4	3.4	4.54	1.32	1.46	0.07	29.3	5.64	275	6.5	68
MIDD5	4.6	29.3	3.21	16.4	0.06	29.8	4.82	264	3	189
MIDD5	25.0	29.3	3.24	16.1	0.06	30.0	4.77	262	2.8	188
NIDD1	55.0	125.	29.6	15.6	0.24	29.7	7.26	232	214	1670
NIDD2	83.0	<0.10	19.1	<0.10	0.09	29.1	7.57	217	156	1760
NIDD3	53.0	63.4	10.9	<0.10	0.06	27.1	7.32	212	129	712
NIDD4	84.0	68.6	10.4	<0.10	0.06	27.0	7.33	223	154	883
NIDD5	65.0	24.2	21.4	25.1	0.18	26.6	7.28	231	190	935
NIDD5	64.0	24.4	21.5	24.8	0.17	26.4	7.30	243	194	943

APPENDIX E: LISTING OF HAIR RESULTS

(a) Field Data (fldhair.xls)

Samp. No.	Date Sampled	Village Name	IDD Code	Gender	Age	Occupation	Current Health	Disease	Medication	Family Disease	Main Food	% Local	Eating rice/ paddy sample	Water Source	Use of iodised salt	Added before/ after cooking	Residency
1	19/2/97	Angunawala	HIDD1	F	25	None	Tennis ball size goitre	Had IDD for 2 years	Thyroxin tablets for last 3 months	Mother has IDD	Rice	0	None	Well	Not used for 1 year	N/A	Unknown
3	19/2/97	Angunawala	HIDD1	F	59	Housewife	Good	No IDD	None	Sister has IDD	Rice	> 50	Eating rice now	Well	Used regularly for 2-3 years	Before	Resident since birth
4	17/2/97	Kiralessa	NIDD5	F	30	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
5	22/2/97	Navinna	MIDD5	F	28	None	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Resident since birth
7	19/2/97	Dehideniya	MIDD1	F	36	Housewife	Slight neck swelling goitre, leg blister	Had IDD since 12 years old	Antibiotics for leg blister	No IDD	Rice	100	Eating rice now	Well	Used regularly for 2 years	Before	Born in Meda Mahanuwara 32 km E of Kandy. Resident here 16 years.
8	22/2/97	Navinna	MIDD5	F	34	Housemaid (Saudi Arabia)	Good	No IDD	None	No IDD	Rice	80	Not yet	Well	Used regularly for 3 years	Before	Born in Waskkaduwa 5 km away. Saudi Arabia 1993-1995. Resident here for 12 years
9	23/2/97	Gurudola	HIDD5	F	33	Housewife	Moderate neck swelling goitre	Had IDD since 14 years old	Thyroxin tablets 14-19 years old	No IDD	Rice	100	Eating rice now	Well	Used regularly whilst under treatment	Before	Resident since birth except 1.5 years in Matagama 3 km away
13	21/1/97	Ambepussa	MIDD3	F	42	Housewife	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	Used I and non I salt regularly for 3 years	Before	Born 11 km away. Resident here 20 years
15	16/2/97	Manankattiya	NIDD2	F	22	None	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
16	17/2/97	Ihala Kagama	NIDD4	F	36	Garment factory worker	Good	No IDD	None	No IDD	Rice	50	Eating rice now	Well	Unknown	Unknown	Unknown
17	17/2/97	Ihala Kagama	NIDD4	F	50	Housewife	Good	No IDD	None	No IDD	Rice	25	Eating rice now	Well	Unknown	Unknown	Unknown
18	16/2/97	Upuldenya	NIDD1	F	53	Housewife	Good	No IDD	None	No IDD	Rice	< 50	Drought, rice from market, normally local rice	Well	Unknown	Unknown	Unknown
19	17/2/97	Polambayagama	NIDD3	F	44	Housewife	Good	No IDD	None	No IDD	Rice	> 90	Eating rice now	Well	Unknown	Unknown	Unknown
21	20/2/97	Kurunduwatte	HIDD2	F	17	Student	Good	No IDD	None	Sister here has IDD	Rice	100	Eating rice now	Well	Used regularly for 5 years	After	Resident since birth
23	21/1/97	Debagama	MIDD4	F	39	Housewife	Suspected IDD, slight neck swelling	Recent IDD?	None	No IDD	Rice	60	Eating rice now	Well	Used regularly for 3 years	Before	Born 5 km from here. Resident here 18 years
24	22/2/97	Pelenwatte	HIDD4	F	14	Student	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Used regularly for 3 years	Before	Resident since birth
25	22/2/97	Pelenwatte	HIDD4	F	49	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Use non I salt and rarely I salt	Before	Resident since birth
26	17/2/97	Polambayagama	NIDD3	F	43	Housewife	Good	No IDD	None	No IDD	Rice	100	Local rice from elsewhere	Well	Unknown	Unknown	Unknown
28	17/2/97	Polambayagama	NIDD3	F	20	None	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
29	17/2/97	Kiralessa	NIDD5	M	55	Farmer	Pea size nodular goitre	Had IDD in the past which returned	Operation 1986	No IDD	Rice	< 50	No rice sample	Well	Unknown	Unknown	Resident of Walgamwewa 0.5 km away

Samp. No.	Date Sampled	Village Name	IDD Code	Gender	Age	Occupation	Current Health	Disease	Medication	Family Disease	Main Food	% Local	Eating rice/ paddy sample	Water Source	Use of iodised salt	Added before/ after cooking	Residency
32	16/2/97	Upuldenya	NIDD1	F	23	Wildlife Clerk	Dental fluorosis	No IDD	None	No IDD	Rice	> 80	Eating rice now	Well	Unknown	Unknown	Unknown
33	23/2/97	Gurudola	HIDD5	F	25	Housewife	Good	Had IDD 15-17 years old	Thyroxin tablets 15-17 years old	Mother here has IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Born near Kalutara. Resident here 15 years
34	19/2/97	Dehideniya	MIDD1	F	61	Housewife	Good	No IDD	None	No IDD	Rice	50-60	Eating rice now	Well	Unknown	N/A	Resident since birth
35	21/1/97	Ambepussa	MIDD3	F	55	Teacher	Pain in leg	No IDD	Unknown medication for leg pain	No IDD	Rice	100	Eating rice now	Well	Used I and non I salt regularly for 3 years	Before/after	Born near Gampa. Resident here 24 years
36	21/1/97	Debagama	MIDD4	F	42	Housewife	Good	No IDD	None	No IDD	Rice	80	Eating rice now	Well	Use I salt sporadically	After	Born in Gatahatta 25 km from here. Resident here 22 years
37	17/2/97	Kiralessa	NIDD5	F	26	Housewife	Good, 8 months pregnant	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
38	19/2/97	Dehideniya	MIDD1	F	47	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	None	N/A	Unknown
39	17/2/97	Polambayagama	NIDD3	F	49	Housewife	Poor, loss of appetite, dizziness	No IDD	Regularly takes unknown medication	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
40	20/2/97	Kobbekaduwa	MIDD2	F	41	Housewife	Moderate neck swelling goitre	Had IDD for 5 years	None	Sister here has IDD	Rice	100	Rice from market	Spring	Used regularly for 3 years	Before/after	Born in Peradeniya. Resident here 22 years
41	16/2/97	Upuldenya	NIDD1	F	60	Housewife	Good	No IDD	None	No IDD	Rice	< 50	Drought, rice from market, normally local rice	Well	Unknown	Unknown	Unknown
42	23/2/97	Gurudola	HIDD5	F	55	Housewife	Good	No IDD	None	No IDD	Rice	80	Not yet	Well	Used I and non I salt regularly for 3 years	Before	Born 5 km away. Resident here 35 years
44	20/2/97	Kurunduwatte	HIDD2	F	47	Housewife	Tennis ball size goitre, chest pains	Had IDD since 30 years old	None, refused operation 6 years ago	No IDD	Rice	22	Local rice until Jan. 1997, now from market	Well	Used regularly for 2 years	After	Resident since birth except 1972-1982 lived near Polgahawela
45	16/2/97	Manankattiya	NIDD2	F	31	Teacher	Dental fluorosis	No IDD	None	No IDD	Rice	95	Eating rice now	Well	Unknown	Unknown	Unknown
46	16/2/97	Upuldenya	NIDD1	F	46	Housewife	Good	No IDD	None	No IDD	Rice	75	Drought, rice from market, normally local rice	Well	Unknown	Unknown	Unknown
47	22/2/97	Pelenwatte	HIDD4	F	34	Housewife	High blood pressure	No IDD	None	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Resident since birth
48	21/1/97	Ambepussa	MIDD3	F	34	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	None	N/A	Resident since birth. Lived in Colombo for 2 years returned 3 years ago
49	16/2/97	Upuldenya	NIDD1	F	36	Teacher	Pains in joints	No IDD	None	No IDD	Rice	17	Drought, rice from market, normally local rice	Well	Unknown	Unknown	Unknown
50	23/2/97	Gurudola	HIDD5	F	27	Technical Officer	Good	Had IDD 15-18 years old	Thyroxin tablets 15-18 years old	No IDD	Rice	100	Eating rice now	Well	Used regularly for 3 years	Before	Resident since birth except 5 years study in Colombo
51	21/1/97	Ambepussa	MIDD3	F	42	Housewife	Moderate neck swelling goitre, cold	Had IDD since 18 years old	1980 thyroxin tablets for 1 year. Cold medication	Father's sister has IDD	Rice	100	Not yet	Well	Used regularly	Before	Born in Danowita 8 km away. Resident here since 1980
52	22/2/97	Olaboduwa (N)	HIDD3	F	14	Student	Slight neck swelling goitre	Had IDD since 11 years old	None	Mother's sister has IDD	Rice	100	Eating rice now	Well	Used regularly for 2 years	Before	Resident since birth

Samp. No.	Date Sampled	Village Name	IDD Code	Gender	Age	Occupation	Current Health	Disease	Medication	Family Disease	Main Food	% Local	Eating rice/ paddy sample	Water Source	Use of iodised salt	Added before/ after cooking	Residency
54	17/2/97	Polambayagama	NIDD3	F	37	Housewife	Good	No IDD	None	No IDD	Rice	100	Rice sample until Jan. 1997, now other local rice	Well	Unknown	Unknown	Unknown
56	16/2/97	Manankattiya	NIDD2	F	22	None	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
57	20/2/97	Kobbekaduwa	MIDD2	F	27	None	Good	No IDD	None	No IDD	Rice	100	Eating rice from market now as rice harvest failed	Well	Used regularly for 3 years	Before	Resident since birth
59	21/1/97	Debagama	MIDD4	F	36	Housewife	Good	Had IDD 23-30 years old	Operation 30 years old. Thyroxin tablets for 1 month around operation	No IDD	Rice	0	Eats local green vegetables	Well	Used I and non I salt regularly for 3 years	Before	Born in Gatahatta. Resident here 18 years
60	22/2/97	Navinna	MIDD5	F	24	Hairdresser/ seamstress	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Resident since birth
61	20/2/97	Kobbekaduwa	MIDD2	F	42	Housewife	Slight neck swelling goitre, amputated leg	Had IDD since 18 years old	Had irregular treatment until 1983. On thyroxin tablets since 1983	No IDD	Rice	90	Eating rice now	Spring	None	N/A	Resident since birth
62	17/2/97	Ihala Kagama	NIDD4	F	16	Student	Good	No IDD	None	No IDD	Rice	90	Eating rice now	Well	Unknown	Unknown	Unknown
64	22/2/97	Olaboduwa (N)	HIDD3	F	14	Student	No visible swelling goitre, arthritis	Had IDD since 13 years old	Thyroxin tablets for previous 7 months	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Resident since birth
65	17/2/97	Kiralessa	NIDD5	F	28	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
66	22/2/97	Olaboduwa (N)	HIDD3	F	48	Cafe owner	Slight neck swelling goitre	Had IDD for 6 years	Thyroxin tablets from 1995 until June 1996	No IDD	Rice	> 50	Not yet	Well	Used regularly for 3 years	Before	Born 5 km away. Resident here 18 years
67	19/2/97	Dehideniya	MIDD1	F	52	Housewife	Grapefruit size goitre	Had IDD for 22 years	None, refused operation	None	Rice	0	Local jack fruit, breadfruit and green vegetables eaten	Well	None	N/A	Resident since birth, lived in Jaffna for 20 years from age 12
68	22/2/97	Navinna	MIDD5	F	40	Housewife	Good	No IDD	None	No IDD	Rice	80	Not yet	Well	Used sporadically for 3 years	Before	Resident since birth
69	19/2/97	Angunawala	HIDD1	F	43	Housewife	Moderate neck swelling goitre	Had IDD since 1991	On thyroxin tablets, operation 1992	No IDD	Rice	0	None	Well	None	N/A	Unknown
70	21/2/97	Debagama	MIDD4	F	26	None	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	None	N/A	Resident since birth
71	20/2/97	Kobbekaduwa	MIDD2	F	51	Housewife	Good	No IDD	None	Sister-in-law has IDD	Rice	100	Eating rice now	Spring	Use I and non I salt, I salt rarely	Before	Resident since 1952
72	17/2/97	Ihala Kagama	NIDD4	F	44	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
73	19/2/97	Dehideniya	MIDD1	F	50	Housewife	Tennis ball size goitre	Had IDD for 1 year	None	No IDD	Rice	0	Local jack fruit, breadfruit and green vegetables eaten	Well	Used regularly for 1.5 years	Before	Resident for 30 years
74	21/1/97	Debagama	MIDD4	F	19	Garment factory worker	Slight neck swelling goitre	Had IDD since 17 years old	1 year ago thyroxin tablets for 3 months and operation	Father's sisters and sister have IDD	Rice	70	Eating rice now	Well	Used regularly	After	Resident since birth
76	17/2/97	Kiralessa	NIDD5	F	37	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown

Samp. No.	Date Sampled	Village Name	IDD Code	Gender	Age	Occupation	Current Health	Disease	Medication	Family Disease	Main Food	% Local	Eating rice/ paddy sample	Water Source	Use of iodised salt	Added before/ after cooking	Residency
77	22/2/97	Pelenwatte	HIDD4	F	33	Midwife	Slight neck swelling goitre	Had IDD since 25 years old	None	Mother and sister have IDD	Rice	0	Eats local vegetables	Well	Has used I salt in the past	Unknown	Born in Dehowita. Resident here 5 years
79	22/2/97	Olaboduwa (N)	HIDD3	F	32	Village Officer	Good	No IDD	None	Husbands brother's child has IDD	Rice	100	Eating rice now	Well	Used regularly for 2 years	Before	Resident since birth. Aunt of SL52.
80	17/2/97	Ihala Kagama	NIDD4	F	13	Student	Good	No IDD	None	No IDD	Rice	> 90	Eating rice now	Well	Unknown	Unknown	Unknown
83	20/2/97	Kurunduwatte	HIDD2	F	42	Housewife	Melon size goitre, neck pain	Had IDD since 1970	Herbal treatment for neck pain. Refused operation	No IDD	Rice	40-45	Rice from elsewhere	Well	Used regularly for 3 years	Before	Born in Gampola. Resident here since 1969
84	20/2/97	Kurunduwatte	HIDD2	F	65	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Used sporadically for 3 years	Before/after	Born here, lived in Colombo for 30 years, lived here last 10 years
85	23/2/97	Gurudola	HIDD5	F	27	Housewife	Moderate neck swelling goitre	Had IDD since 14 years old	None	No IDD	Rice	90	Not yet	Well	Used regularly for 3 years	Before	Resident since birth except 2 years in Colombo
86	19/2/97	Angunawala	HIDD1	F	37	Teacher	Egg size goitre, temporary paralysis in arm	Had IDD since 13 years old	Oral liquid at 13 years, operation 1987, on thyroxin tablets	3 family members also have IDD	Rice	0	None	Well	Used regularly	After	Unknown
88	22/2/97	Olaboduwa (N)	HIDD3	F	63	Housewife	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Born 5 km away. Resident here 40 years
89	20/2/97	Kurunduwatte	HIDD2	F	24	Student	Slight neck swelling goitre	Had IDD since 14 years old	None	No IDD	Rice	90	Eating rice now	Well	Used regularly from 16-18 years old now sporadically	Before/after	Resident since birth
90	17/2/97	Kiralessa	NIDD5	F	42	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
91	19/2/97	Dehideniya	MIDD1	F	42	Housewife	Slight neck swelling goitre	Had IDD for 4 years	None	Sister here has IDD	Rice	100	Eating rice now	Well	Used regularly	Before	Resident since birth
93	20/2/97	Kobbekaduwa	MIDD2	F	65	Housewife	Rugby ball size goitre, pain in hand	Had IDD for 20 years	On thyroxin tablets since 1989. Unknown medication for hand pains	Sister here had IDD (died)	Rice	80	Eating rice now	Spring	Used regularly	Before	Resident since birth
94	16/2/97	Manankattiya	NIDD2	F	?	Housewife	Good	No IDD	None	No IDD	Rice	100	Eating rice now	Well	Unknown	Unknown	Unknown
95	20/2/97	Kurunduwatte	HIDD2	F	38	Housewife	Moderate neck swelling goitre, joint pains	Had IDD since 22 years old	Thyroxin tablets from 26-28 years old, refused operation. On herbs for joint pains	Mother has IDD	Rice	100	Eating rice now	Well	Used regularly for 1 year	Before	Born in Kitulgala (Yatiyantota). At 18 moved to Makiyangana. Resident here 10 years
96	22/2/97	Navinna	MIDD5	F	35	Housewife	Good	No IDD	None	No IDD	Rice	100	Not yet	Well	Used regularly for 3 years	Before	Born 22 km away near Horana. Resident here 15 years
97	21/2/97	Ambepussa	MIDD3	F	45	Housewife	Good	No IDD	None	Daughter here has IDD	Rice	100	Not yet	Well	None	N/A	Born in Udukumburu 5 km away. Resident here 35 years
98	16/2/97	Manankattiya	NIDD2	F	15	Student	Good	No IDD	None	No IDD	Rice	90	Eating rice now	Well	Unknown	Unknown	Unknown
99	19/2/97	Angunawala	HIDD1	F	51	Housewife	Chest pains	No IDD	Unknown chest medication	No IDD	Rice	> 50	Eating rice now	Well	Used regularly for 6 years	Before	Unknown
100	22/2/97	Pelenwatte	HIDD4	F	20	None	Good	Had IDD when 15 years old	Thyroxin tablets for 3 months 3 years ago	Distant female relative here has IDD	Rice	0	Eats local green vegetables	Well	Used regularly for 4-5 years	Before	Resident since birth

(b) Laboratory Results

(i) Se in Different Sections of Hair Length, Hair Washed in Deionised Water and Hair Washed in Neutracon® (Hairwash1.xls) (determined at BGS laboratories fmf05432)

LIMS Code	Sample Code	Weight Hair g	Total Volume ml	Dilution	Se Solution ng/g	Se Solid ng/g
05432-00001 AW	26 AW	0.0369	10.2200	277	1.976	547
05432-00001 BW	26 BW	[illegible]				
05432-00001 CW	26 CW	Masses [illegible]				
05432-00001 DW	26 DW	01-BW=0.0098g 01-CW=0.0102 [illegible]				
05432-00001 EW	26 EW	0.0039	10.2200	2621	0.375	983
05432-00001 AN	26 AN	0.0417	10.2200	245	2.251	552
05432-00001 BN	26 BN	0.0200	10.2200	511	0.996	509
05432-00001 CN	26 CN	0.0043	10.2200	2377	0.394	936
05432-00001 DN	26 DN	0.0071	10.2200	1439	0.573	825
05432-00001 EN	26 EN	0.0043	10.2200	2377	0.447	1062
05432-00002 AW	69 AW	0.0505	10.2200	202	2.697	546
05432-00002 BW	69 BW	0.0511	10.2200	200	5.155	1031
05432-00002 CW	69 CW	0.0407	10.2200	251	6.521	1637
05432-00002 DW	69 DW	0.0421	10.2200	243	4.223	1025
05432-00002 EW	69 EW	0.0242	10.2200	422	1.609	680
05432-00002 FW	69 FW	n/s	n/s	n/s	n/s	n/s
05432-00002 AN	69 AN	0.0240	10.2200	426	1.169	498
05432-00002 BN	69 BN	0.0398	10.2200	257	4.363	1120
05432-00002 CN	69 CN	0.0456	10.2200	224	8.144	1825
05432-00002 DN	69 DN	0.0103	10.2200	992	0.568	564
05432-00002 EN	69 EN	0.0104	10.2200	983	0.753	740
05432-00002 FN	69 FN	0.0038	10.2200	2689	0.269	723
05432-00003 AW	74 AW	0.1013	10.2200	101	4.987	503
05432-00003 BW	74 BW	0.1140	10.2200	90	5.327	478
05432-00003 CW	74 CW	0.0483	10.2200	212	1.757	372
05432-00003 DW	74 DW	0.0423	10.2200	242	2.166	523
05432-00003 EW	74 EW	0.0158	10.2200	647	0.853	552
05432-00003 AN	74 AN	0.1059	10.2200	97	4.965	479
05432-00003 BN	74 BN	0.1289	10.2200	79	5.931	470
05432-00003 CN	74 CN	0.0842	10.2200	121	4.111	499
05432-00003 DN	74 DN	0.0556	10.2200	184	2.770	509
05432-00003 EN	74 EN	0.0173	10.2200	591	0.964	569
05432-Blank	n/a	n/a	10.2200	n/a	0.201	n/a
GBW 09101	n/a	0.0995	10.2200	103	4.992	513
GBW 07601	n/a	0.0993	10.2200	103	5.005	515

(ii) Se in Different Sections of Hair Length (Hairwash2.xls) (determined at BGS laboratories DA05625)

LIMS Code	Sample Code	Subsample	Se (solid) ng/g
05625-00001	SL-04-H	A	422
05625-00002	SL-04-H	B	407
05625-00003	SL-04-H	C	400
05625-00004	SL-50-H	A	360
05625-00005	SL-50-H	B	322
05625-00006	SL-50-H	C	369
05625-00007	SL-50-H	D	345
05625-00008	SL-50-H	E	297
05625-00009	SL-50-H	F	285
05625-00010	SL-61-H	A	300
05625-00011	SL-61-H	B	316
05625-00012	SL-61-H	C	357
05625-00013	SL-61-H	D	334
05625-00014	SL-61-H	E	304
05625-00015	SL-72-H	A	268
05625-00016	SL-72-H	B	245
05625-00017	SL-72-H	C	281
05625-00018	SL-72-H	D	273
05625-00019	SL-72-H	E	292

(iii) Se in Hair (FMF05676.XLS) (determined at BGS laboratories fmf05676)

LIMS Code	Customer ID SL~??~H	Se solid µg/kg	Recovery %
05676~00001	1	390	n/a
05676~00002	3	371	n/a
05676~00003	5	436	n/a
05676~00004	7	212	n/a
05676~00005	8	414	n/a
05676~00006	9	350	n/a
05676~00007	13	403	n/a
05676~00008	15	324	n/a
05676~00009	16	297	n/a
05676~00010	17	259	n/a
05676~00011	18	361	n/a
05676~00012	19	371	n/a
05676~00013	21	288	n/a
05676~00014	23	396	n/a
05676~00015	24	391	n/a
05676~00016	25	464	n/a
05676~00017	28	350	n/a
05676~00018	29	440	n/a
05676~00019	32	366	n/a
05676~00020	33	384	n/a
05676~00021	34	406	n/a
05676~00022	35	397	n/a
05676~00023	36	425	n/a
05676~00024	37	383	n/a
05676~00025	38	402	n/a
05676~00026	39	312	n/a
05676~00027	40	341	n/a
05676~00028	41	454	n/a
05676~00029	42	436	n/a
05676~00030	44	125	n/a
05676~00031	45	173	n/a
05676~00032	46	104	n/a
05676~00033	47	209	n/a
05676~00034	48	386	n/a
05676~00035	49	144	n/a
05676~00036	51	128	n/a
05676~00037	52	220	n/a
05676~00038	54	115	n/a
05676~00039	56	475	n/a
05676~00040	57	310	n/a
05676~00041	59	2,652	n/a
05676~00042	60	593	n/a
05676~00043	62	277	n/a
05676~00044	64	471	n/a
05676~00045	65	175	n/a
05676~00046	66	155	n/a
05676~00047	67	118	n/a
05676~00048	68	181	n/a
05676~00049	70	1,408	n/a

LIMS Code	Customer ID SL~??~H	Se solid µg/kg	Recovery %
05676~00050	71	233	n/a
05676~00051	73	148	n/a
05676~00052	76	160	n/a
05676~00053	77	141	n/a
05676~00054	79	206	n/a
05676~00055	80	414	n/a
05676~00056	83	426	n/a
05676~00057	84	164	n/a
05676~00058	85	521	n/a
05676~00059	86	363	n/a
05676~00060	88	223	n/a
05676~00061	89	111	n/a
05676~00062	90	160	n/a
05676~00063	91	393	n/a
05676~00064	93	1,078	n/a
05676~00065	94	499	n/a
05676~00066	95	316	n/a
05676~00067	96	508	n/a
05676~00068	97	468	n/a
05676~00069	98	439	n/a
05676~00070	99	407	n/a
05676~00071	100	425	n/a
05676~00072	Blank	<0.2	n/a
05676~00073	Blank	<0.2	n/a
05676~00074	Blank	<0.2	n/a
05676~00075	GBW 07601	576	96.07
05676~00076	GBW 07601	589	98.15
05676~00077	GBW 07601	592	98.63
05676~00078	GBW 07601	500	83.31
05676~00009dup	16	327	n/a
05676~00014dup	23	400	n/a
05676~00035dup	49	193	n/a
05676~00046dup	66	163	n/a
05676~00058dup	85	519	n/a

Sample Code		Se solution µg/kg	Recovery %
Aquacheck	129/5a	4.175	97.09
Aquacheck	129/5a	4.141	96.30
Aquacheck	129/5a	4.184	97.30
Aquacheck	129/5a	4.135	96.16
Aquacheck	129/5a	4.184	97.30
Aquacheck	129/5a	4.361	101.42
Aquacheck	129/5a	4.434	103.12
Aquacheck	129/5a	4.337	100.86
Aquacheck	129/5a	4.295	99.88
Aquacheck	129/5a	4.469	103.93
Aquacheck	129/5a	4.403	102.40

(c) Data Used in Data Processing (SLHAIR.XLS)

Samp. No.	IDD Code	Region Code	Se ng/g	Occupation	Current Health	Years of IDD	Current IDD	Current Medication	Family IDD	Current Use of I Salt	Salt Added to Cooking
1	HIDD1	KA1	390	None	Moderate goitre	2	Yes	Thyroxin	Yes	None	N/A
3	HIDD1	KA1	371	Housewife	Good	0	No	None	Yes	Regular	Before
4	NIDD5	AN5	410	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
5	MIDD5	KL4	436	None	Good	0	No	None	No IDD	Regular	Before
7	MIDD1	KA3	212	Housewife	Small goitre	24	Yes	Antibiotics	No IDD	Regular	Before
8	MIDD5	KL4	414	Housemaid	Good	0	No	None	No IDD	Regular	Before
9	HIDD5	KL3	350	Housewife	Moderate goitre	21	Yes	None	No IDD	None	Before
13	MIDD3	KA5	403	Housewife	Good	0	No	None	No IDD	Occasional	Before
15	NIDD2	AN2	324	None	Good	0	No	None	No IDD	Unknown	Unknown
16	NIDD4	AN4	297	Factory worker	Good	0	No	None	No IDD	Unknown	Unknown
17	NIDD4	AN4	259	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
18	NIDD1	AN1	361	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
19	NIDD3	AN3	371	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
21	HIDD2	KA2	288	Student	Good	0	No	None	Yes	Regular	After
23	MIDD4	KA6	396	Housewife	Small goitre	1	Yes	None	No IDD	Regular	Before
24	HIDD4	KL2	391	Student	Good	0	No	None	No IDD	Regular	Before
25	HIDD4	KL2	464	Housewife	Good	0	No	None	No IDD	Occasional	Before
26	NIDD3	AN3	765	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
28	NIDD3	AN3	350	None	Good	0	No	None	No IDD	Unknown	Unknown
29	NIDD5	AN5	440	Farmer	Small goitre	1	No	None	No IDD	Unknown	Unknown
32	NIDD1	AN1	366	Wildlife Clerk	Dental fluorosis	0	No	None	No IDD	Unknown	Unknown
33	HIDD5	KL3	384	Housewife	Good	0	No	None	Yes	Regular	Before
34	MIDD1	KA3	406	Housewife	Good	0	No	None	No IDD	Unknown	N/A
35	MIDD3	KA5	397	Teacher	Bad	0	No	Painkillers	No IDD	Occasional	Before/after
36	MIDD4	KA6	425	Housewife	Good	0	No	None	No IDD	Occasional	After
37	NIDD5	AN5	383	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
38	MIDD1	KA3	402	Housewife	Good	0	No	None	No IDD	None	N/A
39	NIDD3	AN3	312	Housewife	Bad	0	No	Herbal	No IDD	Unknown	Unknown

Samp. No.	IDD Code	Region Code	Se ng/g	Occupation	Current Health	Years of IDD	Current IDD	Current Medication	Family IDD	Current Use of I Salt	Salt Added to Cooking
40	MIDD2	KA4	341	Housewife	Moderate goitre	5	Yes	None	Yes	Regular	Before/after
41	NIDD1	AN1	454	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
42	HIDD5	KL3	436	Housewife	Good	0	No	None	No IDD	Occasional	Before
44	HIDD2	KA2	125	Housewife	Moderate goitre	17	Yes	None	No IDD	Regular	After
45	NIDD2	AN2	173	Teacher	Dental fluorosis	0	No	None	No IDD	Unknown	Unknown
46	NIDD1	AN1	104	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
47	HIDD4	KL2	209	Housewife	Bad	0	No	None	No IDD	Regular	Before
48	MIDD3	KA5	386	Housewife	Good	0	No	None	No IDD	None	N/A
49	NIDD1	AN1	144	Teacher	Bad	0	No	None	No IDD	Unknown	Unknown
50	HIDD5	KL3	330	Technical Officer	Good	0	No	None	No IDD	Regular	Before
51	MIDD3	KA5	128	Housewife	Moderate goitre	24	Yes	None	Yes	Regular	Before
52	HIDD3	KL1	220	Student	Small goitre	3	Yes	None	Yes	Regular	Before
54	NIDD3	AN3	115	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
56	NIDD2	AN2	475	None	Good	0	No	None	No IDD	Unknown	Unknown
57	MIDD2	KA4	310	None	Good	0	No	None	No IDD	Regular	Before
59	MIDD4	KA6	2652	Housewife	Good	0	No	None	No IDD	Occasional	Before
60	MIDD5	KL4	593	Hairdresser	Good	0	No	None	No IDD	Regular	Before
61	MIDD2	KA4	322	Housewife	Small goitre	24	Yes	Thyroxin	No IDD	None	N/A
62	NIDD4	AN4	277	Student	Good	0	No	None	No IDD	Unknown	Unknown
64	HIDD3	KL1	471	Student	Small goitre	1	Yes	Thyroxin	No IDD	Regular	Before
65	NIDD5	AN5	175	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
66	HIDD3	KL1	155	Cafe owner	Small goitre	6	Yes	None	No IDD	Regular	Before
67	MIDD1	KA3	118	Housewife	Large goitre	22	Yes	None	No IDD	None	N/A
68	MIDD5	KL4	181	Housewife	Good	0	No	None	No IDD	Occasional	Before
69	HIDD1	KA1	984	Housewife	Moderate goitre	6	Yes	Thyroxin	No IDD	None	N/A
70	MIDD4	KA6	1408	None	Good	0	No	None	No IDD	None	N/A
71	MIDD2	KA4	233	Housewife	Good	0	No	None	Yes	Occasional	Before
72	NIDD4	AN4	297	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
73	MIDD1	KA3	148	Housewife	Moderate goitre	1	Yes	None	No IDD	Regular	Before
74	MIDD4	KA6	485	Factory worker	Small goitre	2	Yes		Yes	Regular	After

Samp. No.	IDD Code	Region Code	Se ng/g	Occupation	Current Health	Years of IDD	Current IDD	Current Medication	Family IDD	Current Use of I Salt	Salt Added to Cooking
76	NIDD5	AN5	160	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
77	HIDD4	KL2	141	Midwife	Small goitre	8	Yes	None	Yes	None	Unknown
79	HIDD3	KL1	206	Village Officer	Good	0	No	None	Yes	Regular	Before
80	NIDD4	AN4	414	Student	Good	0	No	None	No IDD	Unknown	Unknown
83	HIDD2	KA2	426	Housewife	Large goitre	27	Yes	Herbal	No IDD	Regular	Before
84	HIDD2	KA2	164	Housewife	Good	0	No	None	No IDD	Occasional	Before/after
85	HIDD5	KL3	521	Housewife	Moderate goitre	13	Yes	None	No IDD	Regular	Before
86	HIDD1	KA1	363	Teacher	Moderate goitre	24	Yes	Thyroxin	Yes	Regular	After
88	HIDD3	KL1	223	Housewife	Good	0	No	None	No IDD	Regular	Before
89	HIDD2	KA2	111	Student	Small goitre	10	Yes	None	No IDD	Occasional	Before/after
90	NIDD5	AN5	160	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
91	MIDD1	KA3	393	Housewife	Small goitre	4	Yes	None	Yes	Regular	Before
93	MIDD2	KA4	1078	Housewife	Large goitre	20	Yes	Thyroxin	Yes	Regular	Before
94	NIDD2	AN2	499	Housewife	Good	0	No	None	No IDD	Unknown	Unknown
95	HIDD2	KA2	316	Housewife	Moderate goitre	16	Yes	Herbal	Yes	Regular	Before
96	MIDD5	KL4	508	Housewife	Good	0	No	None	No IDD	Regular	Before
97	MIDD3	KA5	468	Housewife	Good	0	No	None	Yes	None	N/A
98	NIDD2	AN2	439	Student	Good	0	No	None	No IDD	Unknown	Unknown
99	HIDD1	KA1	407	Housewife	Bad	0	No	Chest	No IDD	Regular	Before
100	HIDD4	KL2	425	None	Good	0	No	None	Yes	Regular	Before

APPENDIX F: SAMPLING EQUIPMENT

Supplied by the BGS Geochemistry Group:

- aluminium carrying case
- portable pH/Eh meter - (HI 9024/ HI 9025) Hanna Instruments Water-resistant Microprocessor
- portable conductivity meter - (HI 933100) Hanna Instruments Portable Microprocessor Conductivity Meter
- spare AAA meter batteries
- Eh electrode - (Model 96-78-00) Orion Research Platinum Redox Electrode
- temperature probe
- 2 pH electrodes - Russel pH Limited Combination pH Electrodes
- pH buffer solutions 4.01, 7.01 and 10.01.
- deionised water wash bottle
- sectional Dutch auger
- 200 grey 49x75 mm securitainers and white lids
- 85 30 ml Nalgene® bottles
- 5 250 ml polyethylene bicarbonate bottles
- 15 30 ml Steralin® tubes
- 4 plastic syringes
- 12 25 mm Swinnex® filter cartridges
- 100 0.45 μm Millipore® cellulose acetate filters
- digital titrator - (Model 16900-01) Camlab Hach
- bromocresol indicator
- 2 0.16N and 2 1.6N H_2SO_4 Camlab titrator cartridges
- 100 Kraft® paper soil bags
- 100 small self-seal plastic bags
- 100 large self-seal plastic bags
- box of tissues
- 100 blank fieldcards
- random number list
- 3 black marker pens
- compass and hand lens
- 1 roll laboratory towel
- 250 ml glass conical flask
- 100 ml plastic measuring cylinder
- Orion AgCl electrode filling solution 90-00-11
- 100 epidemiological fieldsheets

Supplied by J Wragg (AGG) in 60ml Nalgene® bottles:

- conductivity standard 12.86 mS/cm
- Zobelles Eh calibration solution
- pH electrode storage solution

Supplied by the University of Peradeniya:

- Concentrated ARISTAR grade HNO_3
- Concentrated ARISTAR grade HCl
- De-ionised water
- 1: 50 000 and 1 inch scale maps of field areas

Supplied by Dr C Johnson

- 1 pair stainless steel barber scissors

APPENDIX G: ANALYTICAL METHODS

G.1. Determination of Selenium by Hydride Generation Atomic Fluorescence Spectroscopy

G.1.1 Instrumentation

Measurements are made on a P.S. Analytical Excalibur™ Atomic Fluorescence Detector. The vapour generation system used is a P.S. Analytical-hydride system with a Type B gas/ liquid separator.

G.1.2 Theory

Selenium is analysed in a three stage process:

1. Selenium, in solution, is reduced to its 4^+ oxidation state using a combination of KBr + HCl at 80°C.

2. Gaseous selenium hydride is formed by reaction with sodium borohydride.

3. The hydride is atomised in a flame cell and determined by Atomic Fluorescence Spectroscopy (AFS).

Selenium hydride and hydrogen are formed in a continuous flow system by mixing the acidified sample with sodium borohydride. This gas liquid mixture is passed into a gas liquid separator where the gaseous selenium hydride and hydrogen are swept out of the mixture with Ar into a flame cell, and the gases are burnt as an air hydrogen flame. Within the flame, the selenium hydride is dissociated and Se atoms are formed. The atoms are excited by light emission from a Se hollow cathode lamp. The fluorescence emission is measured non-dispersively in a direction at right angles to the excitation source using a photomultiplier tube.

In atomic fluorescence, an intense light source, of a wavelength characteristic to the element of interest, is used to excite ground state atoms of the element through radiative absorption transitions. When these selectively excited atoms decay, the light emitted gives a measure of the element concentration. The intensity of the fluorescence emission is proportional to the element concentration.

G.1.3 Analytical Method

An acid carrier of 4 M HCl is required to produce sufficient hydrogen to sustain the atomisation flame. Therefore all samples are prepared in a 4 M acid matrix.

The reductant solution is prepared from 15 g $NaBH_4$ with 4 g sodium hydroxide (to stabilise the solution) made up to 1000 ml with deionised water.

Potassium bromide solution (50% w/v) is prepared using a reagent (50 g made up to 100 ml with de-ionised water).

At least four standards are prepared, using serial dilution from 1000 µg/g standard solution in 1% HCl, covering the range expected in the samples. A Se^{6+} standard is also prepared to check the efficiency of the reduction.

All standards, samples and check samples are reduced to ensure that all the selenium is in the form Se^{4+}. This is achieved by acidifying the samples and standards to match the acid concentration in the carrier and adding potassium bromide to make the samples 2% w/v KBr. The solutions are heated in loosely capped plastic containers at approximately 80°C for 30-40 minutes and left to cool for at least 30 minutes before analysis. Samples are analysed within 48 hours of reduction.

Data are captured by computer and concentrations calculated based on a calibration curve created by running known standards before and during each run.

G.1.4 Sample Preparation for Analysis of Water

Water samples are received preserved with 1% v/v HCl after filtration through 0.45 µm filters. Apart from the acidification and reduction procedure described in Section G1.3 no further preparation of the samples is carried out prior to analysis.

G.1.5 Sample Preparation for Analysis of Soil

0.1 g of soil is weighed into a uniquely labelled 15 ml PTFE test tube to which 1.0 ml of HF, 0.8 ml of concentrated HNO_3 and 0.4 ml of concentrated $HClO_4$ is added. The tubes are placed on a programmable heating block and are heated for three hours at 100°C, one hour at 140°C and ten hours at 190°C. Following digestion, the dry residue is dissolved in 4 M HCl at 50°C for one hour followed by the reduction procedure described in Section G1.3. Acid blanks and Water Research Council (WRC) Aquacheck reference samples are prepared with each batch of samples.

G.1.6 Sample Preparation for Analysis of Hair and Rice

0.1 g of grain or hair is weighed into a uniquely labelled 15 ml glass test tube to which 2.0 ml of concentrated HNO_3 and 0.4 ml of concentrated $HClO_4$ is added. The tubes are placed on a programmable heating block and are heated for one hour at 50°C, one hour at 85°C, two hours at 105°C, two hours at 125°C and eight hours at 200°C. Following digestion, the dry residue is dissolved in 4 M HCl at 50°C for 1 hour followed by the reduction procedure described in Section G1.3. Acid blanks and standard reference materials are prepared with each batch of samples.

G.1.7 Sample Preparation for Analysis of Water Soluble and Phosphate Extractable Se Concentrations in Soil

3 g of soil is weighed into a uniquely labelled 15 ml glass test tube into which 15 ml of deionised water is pipetted. The tubes are placed on a programmable heating block and are heated for 1 hour at 110°C. Following the hot water extraction, the samples are cooled, mixed on a vortex mixer and centrifuged. 10 ml of the supernatant liquid is collected to undergo the reduction method described in Section G1.3. Phosphate extractable Se is determined in the residue.

G.1.8 Data Quality

Se determinations in international reference materials from the Aquacheck scheme (WRC) UK and the National Research Centre for Certified Reference Materials

(NRCCRM), China are summarised in Tables A-D. In general, there is good agreement between the analytical results and the certified reference values.

The limits of detection (LOD) for the determination of Se in the various sample types by AFS are listed in Table E. LOD can vary depending on the sample matrix, the dilution required to give sufficient volume of solution for analysis, the current sensitivity of the instrument, the calibration range used and the level of Se found in the blank.

Replicate analytical results for Se in rice show good reproducibility of the method (Table F).

Table A. Total Se concentrations in international soil reference materials determined by AFS.

Reference Material	Certified Value Se µg/g	Measured Value Se µg/g
(NRCCRM) Soil GBW 07402	160	134
GBW 07405	1822	1560

Table B. Total Se concentrations in international vegetation reference material determined by AFS.

Reference Material	Certified Value Se µg/g	Measured Value Se µg/g
(NRCCRM) Tea GBW 8505	41	35.48 40.37

Table C. Total Se concentrations in national water reference materials determined by AFS.

Reference Material	Certified Value Se µg/1	Range Se µg/l	Number of Analyses
WRC Aquacheck Water Distribution 121 5a	8.400	8.326 - 8.441	4
		8.302 - 8.491	5

Table D. Total Se concentrations in international hair reference material determined by AFS.

Reference Material	Certified Value Se	Range Se	Number of Analysis	% Recovery
NRCCRM Hair				
GBW 07601	600 ± 30 µg/g	500 - 592 µg/g	4	83.31 - 98.63
GBW 07601	600 ± 30 µg/g	515 µg/g	1	85.8
GBW 09101	580 ± 50 µg/g	513 µg/g	1	88.4

Table E. AFS limits of detection for Se in various sample types

Sample Type	Se LOD ng/g
Soil	5
Soil Water Soluble Se	0.05
Soil Phosphate Extratable Se	0.05
Rice	5
Water	0.2
Hair	10

Table F. Analytical replicate results for Se in rice determined by AFS.

Sample Number	Se ng/g 1st Result	Se ng/g 2nd Result
22	777	753
81	58	59
86	13	13

G.2 Determination of Major Cations and Trace Elements in Soils by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)

G.2.1 Instrumentation

The ICP-spectrometer used to carry out this work is a Perkin-Elmer Plasma II sequential scanning system with twin 1 m vacuum monochromators. Monochromator A has a 3600 line/mm grating and wavelength range of 160-400 nm. The second monochromator (B) has a 1800 line/mm grating and wavelength range of 160-800 nm. The monochromator gratings, plasma power, plasma gas flows, plasma viewing height, 50-position auto-sampler and nebuliser peristaltic pump are all under computer control.

G.2.2 Theory

The nebulised sample is swept into the central channel of the inductively coupled plasma in a stream of argon carrier gas. On introduction to the plasma, the sample undergoes desolvation, evaporation, atomisation/ionisation and excitation. The atoms or ions decay from their excited state through radiative energy transitions, emitting light of specific energies (or wavelengths). The light emission from the plasma is separated into its component wavelengths by a monochromator, and a photomultiplier tube at the exit slit of the monochromator quantifies the light intensity at specific wavelengths. The intensity of the light emitted at the characteristic wavelength for a particular element is proportional to the amount of the element in the sample being sprayed into the plasma. The instrument is calibrated against standards containing known amounts of the elements to be analysed.

G.2.3 Analytical Method

Major and trace metals (Al, Ca, Cu, Fe, Mn, Ni and Zn) are determined directly by ICP-AES. Analysis is carried out on approximately 10-15 ml of sample acidified to 1-5% with respect to HNO_3 depending on the sample preparation. The instrument is standardised every 10 samples and quality control checks are run every 20 samples. The control standards are always analysed at the end of the run to check for drift. Reported measurements are based on the average of three replicate analyses.
Mixed standards, made up in the same acid matrix as the samples, are prepared from certified 1000 mg/l single element stock solutions.

G.2.4 Sample Preparation for Total Acid Digestion of Soils

0.1 g of soil is weighed into a uniquely labelled 15 ml PTFE test tube to which 1.0 ml of HF, 0.8 ml of concentrated HNO_3 and 0.4 ml of concentrated $HClO_4$ is added. The tubes are placed on a programmable heating block and heated for three hours at 100°C, one hour at 140°C and ten hours at 190°C. One ml of 50% v/v HNO_3 is added to the dry residue remaining after the digestion, and heated for 30 minutes at 50°C to bring the sample into solution. On cooling, the solutions are finally made up to 10 ml with deionised water and decanted into polystyrene screw top storage tubes. Acid blank samples and standard reference materials are prepared with each batch of samples.

G.2.5 Data Quality

A summary of the results found for two NRCCRM standard materials (two soils) taken through the total extraction procedure are shown in Table G. In general, results are comparable to the certified values.

The analytical replicate results in general show excellent agreement (Table H). Sample 68 was analysed in duplicate and the poor reproducibility of Al, Ca, Fe and Mn for this sample is probably due to the nature of the sample as the soil and resulting digest were noticebly darker in colour than the other samples. ICP-AES limits of detection are listed in Table I.

Table G. Total extraction analysis of international soil reference materials by ICP-AES.

	(NRCCRM) GBW 07402 Soil			(NRCCRM) GBW 07405 Soil		
	Range mg/kg	Number of Analyses	Certified Value mg/kg	Range mg/kg	Number of Analyses	Certified Value mg/kg
Al	49,389 - 52,068	2	54,572	113,064	2	114,225
Ca	16,135 - 16,475	2	16,866	303	2	678
Cu	13.9 - 14.7	2	16.3	142	2	144
Fe	22,872 - 23,088	2	24,622	88,226	2	88,277
Mn	463 - 470	2	510	1,287	2	1360
Ni	18.0 - 18.3	2	19.4	38.7	2	40
Zn	41.4 - 41.6	2	42.3	513	2	494

Table H. Analytical replicate results for ICP-AES soil analyses.

Sample Number	Ca mg/kg	Mn mg/kg	Fe mg/kg	Al mg/kg	Ni mg/kg	Cu mg/kg	Zn mg/kg
14	3,019	344	22,903	60,215	<26.9	14.8	65.5
14	3,203	339	22,999	64,770	<27.4	14.7	64.3
68 /1	487	120	18,669	84,400	32.0	12.1	47.1
68 dup /1	321	105	15,254	59,117	32.2	11.6	45.6
68 /2	254	91	14,073	32,907	33.7	13.2	46.6
68 dup /2	386	103	16,957	66,837	28.5	13.7	45.4
72	13,308	655	32,249	69,026	<27.6	12.5	50.7
72	12,786	614	31,074	64,198	<27.0	12.2	47.8
99	7,233	346	44,790	77,339	33.8	35.8	103
99	7,643	337	44,764	78,610	32.4	36.3	99.6

Table I. ICP-AES limits of detection for soil analyses.

Element	LOD ng/g
Al	100
Ca	250
Cu	25
Fe	50
I	20 µg/l (in solution)
Mn	5
Ni	500
Zn	25

G.3 Field Water Chemistry Methods

G.3.1 pH and Temperature

1. Remove the protective cap from the pH electrode and check that no air bubbles are trapped in the bulb at the end of the electrode. If air is present in the bulb, shake the electrode like a thermometer to remove the air. Connect the electrode and the temperature probe to the portable pH/Eh meter. Rinse the electrode and probe thoroughly with deionised water and dry them.

2. Switch on the meter holding the on/off button for a few seconds until the LCD display appears.

3. To calibrate the meter press the CAL button. The meter is now expecting the 4.01 calibration buffer solution. The first buffer solution measured during calibration is usually 7.01 therefore use the up arrow button to flick through the buffer solution options until 7.01 is selected. The meter is now ready to begin the calibration.

4. Place the pH electrode and the temperature probe in the first buffer (7.01) and wait for the reading to stabilise. The meter initially indicates that the reading is NOT READY and will flash a READY signal when the reading has stabilised. Once the READY signal has appeared and the reading is stable press the CFM (confirm) button. Record the pH and temperature readings.

5. The meter automatically expects the second buffer solution. Use the up and down arrow buttons to flick through the buffer solution options until the correct solution is selected (usually 4.01 for acid samples or 1.01 for alkaline samples). The meter is now ready to continue the calibration.

6. Rinse the electrode and temperature probe thoroughly in deionised water and dry them. Place the electrode and probe in the second buffer solution and wait for the READY signal before pressing the CFM (confirm) button. Note the pH reading. The calibration is now complete and the meter automatically switches to pH measurement mode.

7. To check the calibration, rinse the electrode and probe in deionised water, dry and return to the first buffer solution. The reading should stabilised around 7.01.

8. Rinse the electrode and temperature probe thoroughly in deionised water and dry them before measuring the first sample. Rinse the electrode and probe with some of the sample water in-between measuring each sample.

9. Store the pH electrode with the protective cap containing pH electrode storage solution over the end. Do not allow it to dry out. Care must be taken to avoid damage to the bulb at the end of the electrode.

10. If the electrode performance is not satisfactory on calibration try shaking it to remove any air from the bulb.

G.3.2 Redox Potential

1. Remove the protective cap from the redox (Eh) electrode and uncover the filling hole. Fill the electrode using Orion filling solution 90-00-11 to just below the filling hole. Empty the solution to waste by pushing the cap and body together and refill with solution ensuring that no bubbles are trapped around the electrode base. Connect the electrode and the temperature probe to the pH/Eh meter. Rinse the electrode and probe in deionised water and dry them.

2. Switch on the meter holding the on/off button for a few seconds until the LCD display appears.

3. Select the redox measurement function by pressing the RANGE button, mV will appear on the display.

4. To check the electrode performance place the electrode and probe in Zobelles solution. The value should settle between 200 and 250 mV, depending on the temperature.

5. Rinse the electrode and temperature probe thoroughly in deionised water and dry them before measuring the first sample. Rinse the electrode and probe with some of the sample water in-between measuring each sample.

6. The readings obtained require correction to redox potential relative to the standard hydrogen electrode according to the formula:

   Corrected Eh = Measured Eh + (224 - Temperature °C)

7. Prior to storage the electrode should be emptied and rinsed with deionised water. Store the electrode dry with the protective cap in place. A small amount of electrode storage solution should be added to the cap before storage.

G.3.3 Total Alkalinity

1. Select a sulphuric acid cartridge 1.6N or 0.16N according to the expected alkalinity of the samples.

2. Fit the cartridge to the hand held digital titrator and push the titrator piston down until it meets the top of the cartridge. Remove the cap from the cartridge and fit a feeder straw into the end of the cartridge. Wind the large wheel on the titrator until all the air is removed from the cartridge and the straw and a drop of acid leaves the end of the straw. Wipe the end of the straw to remove excess acid. Reset the titrator scale to zero by winding the small wheel to the left of the scale forwards.

3. Rinse the measuring cylinder and conical flask with deionised water prior to rinsing them with a small amount of the first sample. Using the measuring cylinder, measure 100 ml of the first sample into the conical flask.

4. Make sure the lid is securely tightened on the sample bottle in-between each stage of the measurements to reduce degassing of the samples.

5. Add a few (two) drops of bromocresol green indicator using a small pipette.

6. Add the acid using the large wheel on the titrator until the solution changes from blue to green-yellow and note the reading on the titrator scale when this occurs.

7. When the 0.16N cartridge is used the readings should be multiplied by 0.1.

8. The reading is the total alkalinity expressed as mg/l $CaCO_3$.

9. The titrator should be reset to zero and the conical flask and measuring cylinder rinsed in a small amount of the next sample prior to the next measurement.

10. Titrations should be carried out as quickly as possible to reduce degassing effects.

G.3.4 Conductivity

1. Remove the plastic cover from the conductivity probe and rinse the probe and the cover in deionised water. Dry the probe and the cover and replace the cover. Connect the conductivity probe to the conductivity meter.

2. Switch on the meter and place the probe in the 12.88 mS. calibration buffer solution making sure the solution covers the probe up to the join between the probe and the cover. The holes in the cover must be immersed in the solution.

3. Shake the probe in the solution to remove any air bubbles trapped between the probe and the cover. This is important as the probe measures conductivity in the volume of liquid defined by the cover therefore air trapped in the cover will affect the readings.

4. Press the CAL button and the 1413 µS indicator will be lit on the LCD display. Press the BUF button to change to the 12.88 mS calibration.

5. When the reading is stable and the calibration is within +/- 15% of the ideal value the BUF indicator on the display stops flashing and the CON indicator appears on the display. When the CON indicator appears press the CFM (confirm) button. The meter is now calibrated and will automatically return to measurement mode. To quit from calibration mode at any time press the CAL button.

6. Remove the plastic cover from the probe, rinse with deionised water and dry the probe and the cover prior to measuring each sample. Remember to cover the probe with sample up to the join between the cover and the probe and to remove air by shaking the probe.

7. The probe and cover should be rinsed in deionised water and dried before storage.

8. If the meter is difficult to calibrate try shaking the probe to remove air trapped under the cover.

G. 4 Determination of Major and Trace Anions by Ion Chromatography

Instrumentation

The ion chromatography system used for the anion analysis is a Dionex 2000i fitted with an auto sampler. An integral conductivity detection module and an additional on-line Philips PU4110 UV/VIS detector are used for analyte detection. The data were processed using a Dionex advanced computer interface and AI-450 data capture and manipulation software loaded onto a Dell personal computer

Theory

When a solvent containing dissolved anions is passed through a column of anion exchange resin, the progress of the anions through the column are retarded with respect to the solvent. Different anions are retained by different degrees according to their size and charge. The conductivities of the separated anions eluted from the column are detected as transient peaks and quantification may be achieved by comparing the peak area or peak height of the samples to those of known standards. For measurements to be accurate, the high background conductivity of the eluent is removed using chemical suppression. This relies on the exchange of sodium and hydrogen ions across a membrane to convert the sodium carbonate and sodium bicarbonate eluent to weakly conducting carbonic acid, and the weakly conducting anionic salts of the sample to more conductive anionic acids.

Analytical Method

Major and trace anions (Cl^-, SO_4^{2-}, NO_3^-) are determined using approximately 1 ml of unpreserved sample by ion chromatography. The instrument is calibrated at the start of the run and recalibrated after not more than 33 samples. Quality control check samples are analysed with each calibration and bracket the analytical samples. The analysis follows a pre-programmed schedule and the data are collected by the software with peaks identified by retention time. Quantification is performed by comparing peak areas against a quadratic calibration curve based on the peak areas of standards over an appropriate concentration range. All raw data are stored on the computer's hard drive and can, if required, be re-integrated, for example using different standards.

The method is limited by the number of exchange sites available within the column. With the injection loop and column used in this study, solutions with total anion concentrations of up to 500 mg/l can be analysed; above this the column becomes overloaded, causing poor peak shapes, variable retention times and thus unreliable results. To overcome this problem, more concentrated solutions are diluted. Dilution is also used to bring the analyte concentration within the concentration range covered by the standards and to reduce sample viscosity. The limit of detection for Cl, SO_4 and NO_3 was 0.1 mg/l

G.5 Iodine by Automated Colorimetry

Total iodine concentrations in soils and waters were determined at the Univeristy College of Wales, Aberystwyth. An automated colorimetric method was used that is based on the catalytic action of iodine on the reaction between As^{3+} and Ce^{4+} (Fuge et al., 1978). Iodine was extracted from soil samples by fusing 0.5 g of the sample with an alkaline flux. The limits of detection were 1 µg/l for water and 0.2 µg/g for soil.

There are no international reference materials available for iodine analysis. Results for internal soil standards are listed in Table J and show good agreement with the certified values.

Soil analytical replicate results show good reproducibility of the method (Table K).

Table J. Results for iodine in soil internal reference materials.

Reference Material	Batch Number	I µg/g Measured Concentration	I µg/g Certified Concentration
GSS-3	1	1.7	1.3
GSS-7	1	18.7	19.3*
GSS-3	2	1.1	1.3
GSS-7	2	18.6	19.3*
GSS-3	3	1.4	1.3
GSS-7	3	19.2	19.3*

* this is a suggested value, not certified.

Table K. Analytical replicate results for iodine in soils.

Sample Number	Batch Number	I µg/g Result 1	I µg/g Result 2
54	1	6.4	6.1
60	1	2.7	2.9
07	2	0.8	1.0
56	2	0.5	0.4
59	2	1.0	1.0
68	2	3.9	4.0
77	3	4.1	4.2
83	3	2.5	2.2

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