Impact of Intensive Vegetable Cultivation on Drinking Water Quality in the Upcountry Region of Sri Lanka

J. D. H. Wijewardena[10]

ABSTRACT

An investigation was conducted from February 1996 to January 1997 to study the extent of water contamination by plant nutrients due to fertilizer and manure use in 40 drinking water wells. Of these, 20 each were situated in the intensive vegetable growing areas in the upcountry intermediate zone (UCIZ) and the upcountry wet zone (UCWZ). Monthly water samples were analyzed for a period of 12 consecutive months for pH value, electrical conductivity (EC), Na, K, Ca, Mg, P, and NO_3-N. The pH values of well water in the UCIZ and the UCWZ ranged from 6.4 to 7.9 and from 4.9 to 7.2, respectively. However, the electrical conductivity (EC) of water in these two areas was low and it ranged from 0.082 to 0.356 dS/m and from 0.036 to 0.470 dS/m, in the UCIZ and the UCWZ, respectively. In general, the sodium content in both zones was high. The highest values in these two areas were 48.3 mg/l and 34.6 mg/l, respectively. Potassium levels in well waters of the UCIZ and the UCWZ ranged from 1.4 to 22.7 mg/l and from 1.2 to 52.4 mg/l, respectively. In general, the calcium content in drinking water was high in both zones and ranged from 6.2 to 16.4 mg/l and from 5.6 to 24.5 mg/l, respectively. Generally, the magnesium content in both zones was high ranging from 4.7 to 14.9 mg/l in the UCIZ and from 2.8 to 10.5 mg/l in the UCWZ. The pH value is extremely low in the well waters. In both zones phosphorous content in the well waters was below 1 mg/l. In general, the nitrate (NO_3-N) content was lower than the permissible level of 11.3 mg/l NO_3-N stipulated by WHO for drinking water. It ranged from 0.34 to 1.30 mg/l NO_3-N in the UCIZ and from 0.29 to 2.13 mg/l NO_3-N in the UCWZ. These results suggest the possibility that excessive quantities of plant nutrients contribute to the high concentration of some chemicals in drinking water in wells situated in the upcountry where intensive agriculture is being carried out.

INTRODUCTION

The UCIZ of Sri Lanka refers to the region that lies between 900 m and 1,400 m above mean sea level, receiving an annual rainfall ranging from 1,100 mm to 1,400 mm. The mean minimum and maximum temperatures are 15 °C and 27 °C, respectively. The UCWZ of Sri Lanka refers to the region that lies above 1,400 m above mean sea level. The mean air temperature in the UCWZ ranges from 8 °C to 20 °C receiving an annual rainfall of 2,500 mm. The landscape in both zones varies from undulating, rolling topography to hilly, steeply dissected mountainous terrain. The Ultisols are the predominant soils of these zones (Panabokke 1996) with a pH value of 4.0– 5.5 (Wijewardena, Yapa, and Yatagama 1996).

[10] Regional Agricultural Research & Development Center, Bandarawela.

The agriculture in the upcountry areas of Sri Lanka is intensive and highly commercialized. Potato and exotic vegetables are the predominant crops grown in this region throughout the year. In the UCWZ, the commonly grown vegetables are cabbage, leek, beet, carrot, and radish. These crops are grown in the form of mono-cropping or even in the form of mixed cropping. Carrot-beet, leek-beet, carrot-beet-leek are common mixed cropping combinations. In the UCIZ, the commonly grown vegetables are tomato, bean, cabbage, brinjal, and radish. Farmholdings are small ranging from about 0.3 to 0.5 hectare and farmers often cultivate more than 2 crops per year to make the maximum use of the available land. In the UCWZ, potato and vegetables are grown in upland conditions while, in the UCIZ vegetables are grown under upland rain-fed, irrigated, and lowland rice-based cropping systems. The lowland cropping system consists of three crops per year: rice during the wet season followed by potato and vegetable crops during the dry season. In the upland irrigated cropping systems, vegetables are cultivated throughout the year. In the upland rain-fed cropping system, potato is cultivated from about mid-October to January and the land lies fallow thereafter. The lowland cropping system is rice-based with an adequate water supply. It supports three crops a year: rice during the wet season (January to April) followed by potato (May to August) and vegetables (September to December) during the dry season.

The use of fertilizer mixtures containing nitrogen as urea or ammonium sulfate, phosphorous as triple superphospate, and potassium as muriate of potash is a common practice in the upcountry. In potato and vegetable cultivation, farmers apply potato or vegetable fertilizer mixtures in combination with organic manure. After an application of chemical fertilizer, if there is no rainfall, farmers irrigate once or twice before planting the crop. During the growing season, farmers top-dress their crops with a top dressing mixture (TDM) containing sodium and potassium or even with an NPK fertilizer mixtures. In addition, various types of liquid fertilizers are also used regularly as foliar sprays during the growing period of crops.

In the upcountry, potato and vegetables have been cultivated for several decades. Application of fertilizers, both organic and chemical, is based on this long experience. However, the rates applied by farmers in the upcountry region to each crop are much higher than the quantity recommended by the Department of Agriculture (Rezania, Yogaratnam, and Wijewardena 1989; Wijewardena 1996a). The levels of chemical fertilizer applied by farmers to potato and vegetable crops is almost double or treble the quantity recommended by the Department of (Rezania, Yogaratnam, and Wijewardena 1989). In addition, the use of animal manure in vegetable cultivation is also common in the upcountry region. While poultry manure is used in the UCIZ cattle manure is used in the UCWZ. Quantities added range from 10 to 15 t/ha of poultry manure and from 20 to 30 t/ha of cattle manure (Wijewardena 1993; Wijewardena 1995).

Vegetables produce a high biomass in a short time and remove large quantities of plant nutrients in their harvested portions, but vegetable-growing soils in the upcountry show an accumulation of plant nutrients rather than a depletion due to the excessive fertilizer usage (Jeevanathan, Seneviratne, and Eriyagama 1995; Wijewardena 1996a; Wijewardena, Yapa, and Yatagama 1996). Reasons for excessive application of both organic and chemical fertilizers are their relatively low cost compared to the profits generated from cultivation of high-value vegetable crops (Maraikar, Wijewardena, and Amarasiri 1996). Due to the hilly nature and high rainfall in the area, applied fertilizer could easily get washed out by rain and, therefore, there is much concern among scientists and the public that drinking well waters could be polluted with the many plant nutrients in the upcountry region. In addition, many of these wells are situated in the vegetable-growing lands and they are also not properly protected with cement walls. Hence, even the runoff water could easily pollute well waters in these areas.

However, monitoring of well waters has not been undertaken in the upcountry region of Sri Lanka where intensive vegetable cultivation is common. An investigation was, therefore, conducted to determine the extent of drinking water contamination due to fertilizer and manure use in 40 wells distributed equally in the UCIZ and the UCWZ. This paper reports the results of this study undertaken for 12 months from February 1996.

MATERIALS AND METHODS

Water samples were collected monthly from 40 wells, 20 each randomly selected in the UCIZ and the UCWZ in the intensive vegetable-growing lands (table 1). Water samples were collected approximately at 30-cm depths below the surface of water level for a period of 12 consecutive months beginning February 1996. Each sample was poured into a 500-ml polythene bottle after rinsing it twice or thrice with the same water and covered with a lid. Samples were then transported to the laboratory at the Regional Agricultural Research & Development Centre, Bandarawela, for chemical analysis.

No sooner the samples reached the laboratory, water was filtered and the filtrate was used for analysis. (In the case of water samples needing to be stored for long periods, a few drops of chloroform were added to prevent any algal growth and then stored in the refrigerator.) Immediately after this the pH values were taken using a glass electrode, and electrical conductivity using a conductivity meter. The nitrate content was determined colorimetrically using the Brucine method (Taras 1958). The pH value was also ascertained colorimetrically by molybdenum blue method using ascorbic acid (Watanabe and Olsen 1965). The sodium and potassium contents were determined using a Jenway Flame meter while calcium and magnesium contents were determined by an Atomic Absorption Spectrometer.

RESULTS AND DISCUSSION

The analyses of the water samples in the 40 wells, 20 each from the UCIZ and UCWZ are given in table 2.

Table 1. Sampling sites in UCIZ and UCWZ.

Well No.	UCIZ	UCWZ
01	Kahagolla	Seetha Eliya 1
02	Kubalwela 1	Seetha Eliya 2
03	Kubalwela 2	Magastota 1
04	Demodera	Seetha Eliya
05	Baddewela	Magastota 2
06	Haputalegama 1	Kadapola 1
07	Haputalegama 2	Kadapola 2
08	Haputalegama 3	Kadapola 3
09	Walgahawela	Kadapola 4
10	Bogahakubura	Kadapola 5
11	Erabadda	Kadapola 6
12	Idama 1	Shanthipura 1
13	Idama 2	Shanthipura 2
14	Mudanawa 1	Ruwan Eliya 1
15	Mudanawa 2	Ruwan Eliya 2
16	Ganetenna	Black Pool 1
17	Gabadagama	Black Pool 2
18	Kumarapattiya	Black Pool 3
19	Mirahawatta	Black Pool 4
20	Ellathota	Nuwara Eliya

pH Values

In general, pH values of well water in the UCIZ and UCWZ ranged from 6.4 to 7.9 and 4.9 to 7.2, respectively. The average pH value of drinking water in the UCIZ was 7.2 while that in the UCWZ was 6.4. However, in 1983, the National Water Supply and Drainage Board of Sri Lanka recommended a pH value of 6.5–9.0 as a suitable range for drinking water in Sri Lanka.

The low pH value in the drinking water, especially in the UCWZ may be attributed to the acidic nature of the soils in this region. In general, Ultisols, which constitute the main soil group in the upcountry is acidic and its pH value ranges from 4.0 to 5.5 (Wijewardena 1996a; Wijewardena, Yapa, and Yatagama 1996). Generally, rainfall is higher in the UCWZ than in the UCIZ. This may be a reason for the low pH value in drinking water in the UCWZ compared to that in the UCIZ. Amarasiri (1965; 1973) observed that a close relationship exists between the pH value of irrigation water and the degree of rainfall in irrigation tanks, which are situated in the dry zone of Sri Lanka.

Table 2. The pH value in drinking water (mean of 12 monthly samples).

Well No.	UCIZ			UCWZ		
	Mean	±	SD	Mean	±	SD
01	7.3	±	0.3	7.2	±	0.4
02	7.9	±	0.4	6.7	±	0.6
03	7.4	±	0.5	6.6	±	0.7
04	7.6	±	0.4	6.9	±	0.4
05	7.4	±	0.5	5.1	±	0.4
06	7.0	±	0.5	6.5	±	0.3
07	7.0	±	0.7	6.4	±	0.6
08	6.9	±	0.6	7.0	±	0.4
09	6.4	±	0.6	6.7	±	0.7
10	7.5	±	0.4	6.4	±	0.5
11	7.0	±	0.5	6.9	±	0.4
12	7.3	±	0.6	5.4	±	0.9
13	7.2	±	0.5	5.7	±	0.7
14	7.0	±	0.4	6.5	±	0.3
15	6.8	±	0.5	7.2	±	0.3
16	7.0	±	0.3	6.6	±	0.7
17	7.2	±	0.4	6.6	±	0.7
18	7.6	±	0.5	5.7	±	0.7
19	7.1	±	0.4	4.9	±	0.5
20	7.4	±	0.5	6.4	±	0.1
Average	7.2			6.4		

However, there is a higher acidity in the well waters in the UCWZ than in the UCIZ, which may perhaps be attributed to the rate of chemical fertilizer application by farmers in the UCWZ, which is higher than the corresponding application in the UCIZ (Rezania, Yogaratnam, and Wijewardena 1989). It is a well-known fact that the use of a high rate of chemical fertilizers tends to increase the soil acidity. Hence, the prevalence of high acidity in well waters in the UCWZ could be anticipated.

Electrical Conductivity (EC)

Drinking water contains salt in very low quantities (table 3). It ranged from 0.082 to 0.356 dS/m and 0.036 to 0.470 dS/m in the UCIZ and the UCWZ, respectively.

Generally, mean values of electrical conductivity in both zones were almost similar and it was 0.199 and 0.206 dS/m in the UCIZ and the UCWZ, respectively. This indicates that salt concentration in waters in both zones had similar quantities. Based on the standards reported

Table 3. EC (dS/m) in drinking water (mean of 12 monthly samples).

Well No.	UCIZ			UCWZ		
	Mean	±	SD	Mean	±	SD
01	0.105	±	0.004	0.419	±	0.034
02	0.262	±	0.034	0.470	±	0.041
03	0.126	±	0.005	0.116	±	0.013
04	0.314	±	0.035	0.036	±	0.019
05	0.083	±	0.009	0.198	±	0.058
06	0.174	±	0.017	0.392	±	0.128
07	0.152	±	0.041	0.120	±	0.024
08	0.271	±	0.016	0.161	±	0.038
09	0.141	±	0.023	0.079	±	0.033
10	0.231	±	0.014	0.189	±	0.082
11	0.179	±	0.014	0.399	±	0.030
12	0.356	±	0.060	0.307	±	0.146
13	0.255	±	0.024	0.242	±	0.076
14	0.175	±	0.014	0.073	±	0.005
15	0.082	±	0.010	0.171	±	0.070
16	0.192	±	0.026	0.100	±	0.022
17	0.251	±	0.013	0.112	±	0.006
18	0.350	±	0.024	0.230	±	0.055
19	0.149	±	0.017	0.110	±	0.017
20	0.139	±	0.013	0.189	±	0.208
Average	0.199			0.206		

by Nagarajah et al. (1988), the water of the majority of wells can be categorized as low-salinity water in the range of 0–0.25 dS/m. However, there were a few wells, which had water with medium salinity that ranged from 0.25 to 0.75 dS/m. Generally, low salinity of the drinking water could be attributed to the low salt concentration in the soil and the low infiltration rates of the Ultisols. However, electrical conductivity values in the upcountry well water were very much less compared to values reported in Jaffna (Nagarajah et al. 1988) and Kalpitiya (Kuruppuarachchi 1995).

Sodium

In general, the sodium (Na) content in both zones was high. It ranged from 6.0 to 48.3 mg/l and from 3.6 to 34.6 mg/l in the UCIZ and the UCWZ, respectively. Average sodium value of drinking water in the UCIZ was 17.1 mg/l while in the UCWZ it was 13.0 mg/l (table 4). The sodium (Na) values reported by Amarasiri (1965;1973), Nagarajah et al. (1988), and Kuruppuarachchi (1995) in irrigation waters were much lower than these values.

Table 4. Sodium (mg/l) content in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ Mean ± SD	UCWZ Mean ± SD
01	6.0 ± 1.0	8.3 ± 1.0
02	32.8 ± 4.8	34.1 ± 9.8
03	9.3 ± 0.7	6.8 ± 0.8
04	25.6 ± 7.0	3.6 ± 1.8
05	8.5 ± 0.8	24.5 ± 9.0
06	31.7 ± 4.4	33.6 ± 9.5
07	8.2 ± 1.6	7.8 ± 2.1
08	41.0 ± 16.8	8.8 ± 1.3
09	7.9 ± 2.5	5.7 ± 1.1
10	8.1 ± 0.6	8.0 ± 0.6
11	7.6 ± 0.6	34.6 ± 5.3
12	48.3 ± 16.1	24.2 ± 7.6
13	9.5 ± 0.5	8.1 ± 1.3
14	7.4 ± 2.2	7.6 ± 1.0
15	7.7 ± 0.8	6.1 ± 1.0
16	9.3 ± 1.3	8.0 ± 1.8
17	29.7 ± 13.3	8.3 ± 0.9
18	29.2 ± 9.4	9.2 ± 1.1
19	7.3 ± 0.5	6.3 ± 0.8
20	7.7 ± 1.5	6.5 ± 0.8
Average	17.1	13.0

Potassium

Potassium (K) levels in well waters ranged from 1.4 to 22.7 mg/l and 1.2 to 52.4 mg/l (table 5) in the UCIZ and the UCWZ, respectively. Mean potassium (K) content in well waters was 4.7 and 11.6 mg/l in the UCIZ and the UCWZ, respectively. In general, an appreciable amount of potassium (K) in drinking water in this area could be attributed to a high level of potassium fertilizer used for the crops grown in the upcountry. The level of fertilizer applied by farmers to vegetable crops is almost double or treble the quantity recommended by the Department of Agriculture (Rezania et al. 1990; Wijewardena 1996 b; Wijewardena and Amarasiri 1997). The high potassium content in the drinking water collected from the UCWZ may be attributed to the higher rate of organic and chemical fertilizer usage there when compared to that in the UCIZ. Generally, Ultisols are high in potassium (Wijewardena and Amarasiri 1993; Wijewardena 1996 b; Wijewardena and Amarasiri 1997). Hence, a high content of soil potassium could also be a reason for the high concentration of potassium (K) in drinking waters in this region. Potassium values reported in Kalpitiya (Kuruppuarachchi 1995) where water is believed to be polluted were much lower than in well waters in the upcountry region.

Table 5. Potassium (mg/l) content in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ			UCWZ		
	Mean	±	SD	Mean	±	SD
01	3.1	±	0.3	33.5	±	13.5
02	3.3	±	0.3	52.4	±	16.6
03	1.5	±	0.2	4.2	±	1.3
04	3.8	±	1.1	1.2	±	0.9
05	1.4	±	0.1	6.3	±	1.5
06	5.5	±	1.1	38.2	±	18.1
07	3.2	±	0.8	1.4	±	0.2
08	5.9	±	0.4	4.5	±	1.0
09	5.2	±	1.3	3.0	±	0.5
10	2.9	±	0.3	4.2	±	0.5
11	3.2	±	0.5	31.3	±	10.9
12	22.7	±	8.4	8.9	±	8.6
13	3.1	±	0.4	16.6	±	10.6
14	3.8	±	0.3	2.9	±	0.4
15	2.7	±	0.6	2.1	±	0.5
16	5.9	±	1.4	1.7	±	1.1
17	6.2	±	1.0	1.8	±	0.6
18	1.9	±	0.3	8.1	±	6.5
19	5.4	±	0.8	2.0	±	1.0
20	3.6	±	0.5	7.0	±	6.7
Average	4.7			11.6		

Calcium

Calcium content in drinking water was generally high in both zones and ranged from 6.2 to 16.4 mg/l and from 5.6 to 24.5 mg/l (table 6) in the UCIZ and the UCWZ, respectively. An appreciable amount of calcium in drinking water may be due to the use of liming materials such as dolomite and lime in upcountry farming. The application of lime and dolomite for potato and vegetable cultivation is a common practice in this region (Rezania, Yogaratnam, and Wijewardena 1989; Wijewardena 1996a).

Poultry manure is also a common feature among the farmers in this region. Generally, poultry manure contains a large quantity of calcium (Wijewardena 1993; 1994; 1997). Green house experiments conducted by Wijewardena (1994) showed that the drainage water from pots treated with poultry manure had a high calcium content compared to that from untreated pots. Hence, the application of poultry manure and other organic manure could also be a reason for the high content of calcium in well waters in both zones.

Table 6. Calcium content (mg/l) in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ Mean ± SD	UCWZ Mean ± SD
01	7.1 ± 2.2	24.5 ± 6.5
02	10.5 ± 4.5	18.4 ± 9.1
03	6.2 ± 2.1	9.7 ± 6.7
04	12.7 ± 7.4	7.6 ± 5.1
05	6.6 ± 4.1	12.6 ± 12.9
06	7.2 ± 4.6	17.4 ± 13.4
07	8.1 ± 2.0	7.3 ± 3.3
08	8.8 ± 4.3	12.5 ± 5.6
09	6.7 ± 1.8	5.9 ± 2.8
10	11.3 ± 2.9	11.9 ± 6.6
11	10.2 ± 3.5	15.9 ± 10.5
12	10.6 ± 4.6	12.7 ± 10.3
13	16.4 ± 6.7	12.8 ± 6.3
14	13.8 ± 9.6	6.3 ± 4.0
15	9.8 ± 12.3	11.8 ± 4.9
16	8.7 ± 2.4	5.9 ± 3.4
17	10.4 ± 6.6	5.6 ± 4.5
18	16.2 ± 8.8	13.3 ± 5.9
19	8.9 ± 2.7	7.4 ± 5.3
20	7.4 ± 2.4	7.2 ± 3.2
Average	9.9	11.3

The calcium content in drinking water in the UCWZ was higher than in the UCIZ. This could be attributed to higher rates of liming materials used by farmers in the UCWZ than those used by farmers in the UCIZ (Rezania, Yogaratnam, and Wijewardena 1989).

Magnesium

The magnesium content in the UCIZ well waters ranged from 4.7 to 14.9 mg/l while in the UCWZ it ranged from 2.8 to 10.5 mg/l (table 7). The appreciable amount of magnesium in well waters in the upcountry may be attributed to the use of a high rate of organic manure. In addition, this could have been also due to the high leaching of magnesium in acid soils (Mikkelsen, Dreitas, and Muchung 1963). Long-term field experiments conducted by Wijewardena and Amarasiri (1993) and Wijewardena (1996b) in upcountry areas of Sri Lanka also revealed the absence of magnesium accumulation even in plots treated with kieserite. In addition, the use of dolomite for crops grown in this region is a common practice. Generally, dolomite is used in large quantities in this region for plantation crops like tea, which may have been washed down to the well waters in this region.

Table 7. The magnesium content (mg/l) in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ			UCWZ		
	Mean	±	SD	Mean	±	SD
01	4.7	±	0.6	10.5	±	1.0
02	11.6	±	6.1	7.8	±	3.6
03	8.0	±	1.5	4.0	±	1.2
04	7.9	±	3.8	3.5	±	2.9
05	5.0	±	2.3	5.4	±	2.7
06	5.4	±	1.9	7.5	±	4.6
07	8.2	±	2.0	5.0	±	0.9
08	9.5	±	3.9	4.0	±	0.6
09	5.9	±	1.8	3.7	±	2.1
10	14.9	±	1.4	5.4	±	1.6
11	11.1	±	1.0	6.4	±	2.7
12	10.8	±	4.1	4.5	±	1.7
13	11.3	±	1.9	5.0	±	1.6
14	9.3	±	3.0	2.8	±	0.9
15	4.9	±	2.0	10.5	±	2.8
16	9.6	±	1.4	4.0	±	0.7
17	8.3	±	4.1	4.3	±	0.6
18	9.1	±	4.3	7.4	±	0.6
19	6.4	±	2.2	4.2	±	1.0
20	8.4	±	2.1	3.6	±	0.6
Average	8.5			5.5		

The higher magnesium content in the drinking water, especially in the UCIZ compared to UCWZ may be attributed to the application of a high rate of poultry manure in the UCIZ (Wijewardena 1993). In general, the use of poultry manure is much more pronounced in the UCIZ. It is well known that poultry manure has a high content of magnesium (Japenga and Harmsen 1990). This may perhaps be the reason for a higher magnesium content in the well waters in the UCIZ.

Phosphorus

The phosphorus content is extremely low in the well waters of the upcountry. It ranges from 0.172 to 0.844 mg/l and from 0.166 to 0.772 mg/l in the UCIZ and the UCWZ, respectively (table 8). Amarasiri (1965) and Nagarajah et al. (1988) reported a very low level of phosphorous in rice irrigation and Jaffna irrigation waters, respectively. This could be anticipated because the movement of any soluble phosphorous to groundwater is restricted due to the ready phosphorous fixation by soil minerals. The low pH of the Ultisols would have encouraged this fixation. In fact, Vighi et al. (1991) reported that phosphorus losses are independent

Table 8. The pH value of phosphorous content (mg/l) in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ			UCWZ		
	Mean	±	SD	Mean	±	SD
01	0.329	±	0.087	0.472	±	0.065
02	0.844	±	0.129	0.401	±	0.072
03	0.436	±	0.036	0.772	±	0.200
04	0.393	±	0.179	0.348	±	0.196
05	0.343	±	0.129	0.572	±	0.106
06	0.329	±	0.101	0.451	±	0.122
07	0.393	±	0.322	0.522	±	0.451
08	0.365	±	0.036	0.522	±	0.193
09	0.175	±	0.039	0.166	±	0.067
10	0.384	±	0.346	0.593	±	0.064
11	0.457	±	0.379	0.644	±	0.072
12	0.479	±	0.357	0.395	±	0.263
13	0.243	±	0.122	0.472	±	0.123
14	0.464	±	0.393	0.458	±	0.100
15	0.594	±	0.122	0.329	±	0.009
16	0.608	±	0.108	0.200	±	0.126
17	0.472	±	0.092	0.522	±	0.193
18	0.786	±	0.071	0.272	±	0.201
19	0.172	±	0.129	0.548	±	0.342
20	0.505	±	0.159	0.200	±	0.129
Average	0.439			0.443		

of the fertilizer phosphorous application rate even in intensive cropping systems. Many workers previously reported that in the absence of erosion little phosphorous could reach the surface water (Loher 1974; Dillon and Kirchner 1975; Miller et al. 1982; Heise 1984). Wijewardena (1994) reported of extremely low phosphorous leaching even in soils fertilized with organic manure and phosphorus fertilizers.

The phosphorus contents in drinking waters in both zones were almost similar. Though fertilizer practices are rather different in these two zones the similar phosphorous contents in drinking waters indicate that the fertilizer application would contribute to a rather insignificant impact of phosphorous in drinking water due to low phosphorous leaching in soils. Hence, similar phosphorous concentrations in drinking waters in both zones could be seen in this study.

Nitrate

The nitrate content in drinking well waters ranged from 0.34 to 1.30 mg/l NO_3-N and 0.29 to 2.13 mg/l NO_3-N (table 9) in the UCIZ and the UCWZ, respectively. These values were low compared to the WHO recommended level of 11.3 mg/l NO_3 - N (Olsen 1978) and to the USA permissible level of no more than 10 mg/l NO_3 - N (Gervy 1986).

Results of the experiment suggest there is low nitrate pollution of the well waters in the upcountry. In contrast, nitrogen fertilizer use has been shown to strongly affect nitrate concentrations in drainage waters (Baker and Johnson 1981; Wijewardena 1994). Studies conducted in Jaffna by Nagarajah et al. (1988) and in Kalpitiya by Kuruppuarachchi (1995) reported the high concentration of nitrate in groundwater under different soil conditions. However, the low nitrate content in the drinking waters of the upcountry may be attributed to the heavy textural fraction in Ultisols. This may have restricted the leaching of nitrate to the drinking waters. Gamberell, Gilliam, and Weed (1975) reported that the loss of nitrate to groundwater was regulated by the amount of infiltration occurring in the soil, being high for

Table 9. Nitrate (NO_3-N) content (mg/l) in drinking water (mean of the 12 monthly samples).

Well No.	UCIZ Mean ± SD	UCWZ Mean ± SD
01	0.69 ± 0.80	2.13 ± 1.20
02	0.42 ± 0.20	1.47 ± 1.06
03	0.77 ± 0.55	1.11 ± 1.48
04	1.14 ± 1.26	0.29 ± 0.27
05	0.50 ± 0.40	1.29 ± 1.37
06	0.69 ± 0.42	1.86 ± 1.79
07	0.62 ± 0.64	1.08 ± 1.07
08	0.83 ± 0.87	0.55 ± 0.63
09	1.30 ± 1.49	0.59 ± 0.28
10	0.57 ± 0.56	1.57 ± 1.10
11	0.43 ± 0.25	1.65 ± 1.34
12	0.83 ± 0.66	1.86 ± 1.66
13	0.88 ± 0.35	0.68 ± 0.40
14	1.22 ± 1.07	0.51 ± 0.57
15	0.77 ± 0.40	0.57 ± 0.31
16	0.53 ± 0.28	0.62 ± 0.25
17	0.66 ± 0.78	1.13 ± 0.61
18	0.34 ± 0.39	2.12 ± 1.57
19	0.50 ± 0.24	0.82 ± 0.34
20	0.54 ± 0.35	0.83 ± 0.83
Average	0.71	1.14

a moderately well-drained soil and low for a poorly drained soil. In addition, vegetable crops grown in the upcountry have been considered as high nutrient removers (Greenwood et al. 1980; FAO 1984). Therefore, nitrate leaching would have been controlled by the high removal of nitrogen from the cultivated fields by vegetable crops. However, it is also reported that vegetables containing high nitrate ions (NO_3^-) as a result of excessive use of nitrogen fertilizers, could also result in the health problems associated with high nitrate ions in drinking water (White 1975).

Results revealed that a higher nitrate concentration prevails in the well waters in the UCWZ than in the UCIZ. This may be due to the high organic and chemical fertilizer use by farmers in the UCWZ. This position could be further aggravated with the heavy rainfall experienced in the UCWZ when compared to UCIZ. Hence, the tendency to increase leaching effects of nitrates to drinking water may be rather easier in the UCWZ than in the UCIZ.

Water samples analyzed during the 12-month period showed variation in different plant nutrient contents. This may be due to variation in leaching of plant nutrients as a result of fertilizer application, crop removal, and also changes in the pattern of rainfall during the study period

CONCLUSION

Findings of this study demonstrate there is a possibility that excessive plant nutrients contribute to the high concentration of some chemicals in drinking water in wells situated in the upcountry. This indicates that drinking water could get polluted by plant nutrients due to intensive vegetable cultivation. Suitable preventive steps should, therefore, be undertaken to minimize the buildup of such concentrations of plant nutrients. It is, therefore, recommended that the Department of Agriculture take up this matter with the Department of Health, Provincial Councils, and other Local Government Bodies, etc., to introduce suitable and appropriate regulatory measures to eliminate or minimize the contamination of drinking water by plant nutrients and agrochemicals. To achieve this the following recommendations are suggested:

- using recommended quantities of organic and chemical fertilizers
- encouraging the use of substitution levels of chemical fertilizers whenever organic manure is used
- encouraging the use of straight fertilizers rather than mixed fertilizers
- incorporating fertilizer into the soil immediately after application
- avoiding soil nutrient buildup by adopting soil-test-based fertilizer recommendations
- avoiding overirrigation and encouraging the use of drip irrigation

In addition, long-term monitoring of well waters in this region is also considered as a highly preventive step and as a way of collecting information regarding the contamination of drinking water on a long-term basis.

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