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Plant Nutrient Contamination of Shallow-Groundwater in Intensive Vegetable Gardens of Nuwara Eliya

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ABSTRACT. *The up country region of Sri Lanka is considered very important with respect to water resources. Suitable climatic conditions prevailing in the up-country and higher returns lead to year around cultivation of exotic vegetables and potato in a very intensive manner. Deterioration of soils and water resources are inevitable with over and improper application of plant nutrients to the cropping fields in this region. A study was conducted taking Katumanna as a representative location for intensive vegetable and potato cultivation in the region to evaluate plant nutrient contamination of shallow-groundwater, and to correlate shallow-groundwater nutrient contaminations with soil nutrient contents. The catena selected was divided into five slope positions. The upper-most position was a virgin forest while the other four positions were under intensive cultivation. Water samples were collected from 11 wells selected to represent shallow-groundwater, in two weeks intervals for 18 months during July, 2003 to December, 2004. Water samples were analyzed for NO_3^--N, NH_4^+-N, K, Ca, Mg P, pH and EC. Soil samples were also collected from each slope position, during five cropping events (duration for a given crop) and analysed for pH, EC, total N, available P, exchangeable K, Ca and Mg.*

EC, concentration of basic cations and NO_3^--N of the well water showed higher values in the cropped fields, whereas much lower values were recorded in the virgin forest. However, NO_3^--N concentrations of well water in cultivated lands in the lower slopes were higher than the virgin forest and were 2 - 3 times higher than the WHO standards (10 mgL^{-1}). NH_4^+-N showed low values in the forest as well as in the cropping lands. None of the cropping events showed significant differences related to nutrients in water. Cultivated soils of the studied area showed enrichment of N, P, K, Ca and Mg. Positive correlations were observed for Ca, K, Mg, and EC values of soil with shallow-ground water. Plant nutrient increments in the shallow-groundwater could be due to the application of high doses of fertilizers and manure combining with other agronomic practices such as over irrigation and continuous cultivation. Shallow-groundwater of most wells in cropped lands of the Katumanna area has a higher degree of contamination with basic cations, and NO_3^--N making it unsuitable for human consumption. EC and pH values in the water of some wells in the area showed poor irrigation water quality as well.

INTRODUCTION

Cultivation of high priced exotic vegetables and potato is popular in the up country-wet zone (UCWZ) of Sri Lanka because of the suitable climatic conditions such as low

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ambient temperature, adequate solar radiation and higher annual rainfall prevailing in the region (Panabokke, 1996). Being the major producer of exotic vegetables and potato for the country, intensive vegetable and potato cultivation system in the up country earns considerable profit in relation to the input use (Maraikar *et al.*, 1996). On the other hand, cultivable land area is being reduced continuously, mainly because of high population pressure on land and related factors. Hence, the farmers are compelled to intensify their cropping patterns aiming at maximum utilization of available land to earn higher profits.

Continuous growing of crops without having at least a short fallow period is one of the ways of maximizing the utilization of available land. However, at the same time, inherent soil fertility or the soil's ability to help better crop growth by means of supplying nutrients and better soil environment may obviously get reduced, under such exploitation, thereby reducing the crop yield. However, the farmers are not ready to accept this law of nature but try to improve the soil to a condition, which helps better crop growth, by applying more plant nutrients in the form of fertilizers and manure. Rezania *et al.* (1989) and Gunewardena *et al.* (1998) reported that most of farmers in the up country apply inorganic fertilizers in quantities 2-3 times more than the doses recommended by the Department of Agriculture. At the same time, because of higher profit generated in this farming system, farmers apply higher doses of cattle and poultry manure at rates of 10 to 15 tons and 20 to 30 tons/ha/year respectively (Wijewardena, 2001). Application of nutrients in any form in excess, damages the environment by leaching to the ground water or by build up in the soil (Jeevanathan *et al.*, 1995). On the other hand, applied fertilizers without incorporating them to the soil could easily move into surface water bodies. Besides, cultivation on slopes of the region with minimum soil conservation measures is frequently observable, damaging the soil environment mainly by erosion leading to physical pollution of water resource by sediments (Gunewardena, 2000a). Under the above exploitation of soils and water bodies, fertilizer pollution of soils and water has become a primary hazard and only a few studies have been conducted to ascertain the gravity of this problem. Therefore, the objective of this study was to evaluate the quality of shallow ground water at a representative location of intensive vegetable growing system in relation to plant nutrients. An attempt was also made to relate soil data with nutrient concentration in the well water at all slope categories considered.

MATERIALS AND METHODS

This study was conducted in Katumanna of Nuwara Eliya district as a representative site for intensive vegetable and potato cultivation. Katumanna is located in the agro ecological zone of WU3, which lies between 1400 to 2550 m a.m.s.l. and has minimum and maximum temperatures of 8 ^{0}C to 20 ^{0}C respectively. This Agro ecological zone receives >1800 mm of average annual rainfall (Punyawardena, *et al.* 2003). The predominant soil group found in WU3 is Ultisol (Panabokke, 1996). Katumanna village is located nearly 3 km away from the Nuwara Eliya town towards Welimada at about 1850 m a.m.s.l. and has about 20 ha of land extènt. The upper slope of the catena was occupied by undisturbed forest and middle and lower slopes were cultivated intensively with exotic vegetables like carrot, beet, leeks, radish and potato throughout the year. Farmers in this area use shallow dug wells either for irrigation of their croplands and/or for domestic purposes including drinking and cooking. Some wells in the area were identified only for drinking whereas others were used for both irrigation and drinking.

The catena selected was divided into 5 slope categories as upper-most (undisturbed forest), upper, middle, lower and lower-most and 11 wells (water sampling points) were identified traversing along the catena to represent the entire catena (Table 1). Some water sampling points were also prepared using thick gauge PVC tubes wherever necessary.

Natural water sampling points include shallow dug wells and small-stagnated water bodies. There were two sampling points in the forest, served as non-contaminated controls. Shallow ground water samples were obtained in intervals of two weeks from the wells for a period of 18 months from the middle of the water body. Samples were collected in polythene bottles after rinsing well with the same water. Water samples were preserved by adding 1ml of 1% $HgCl_2$ per liter of water, then were transported to the Soil Chemistry Laboratory of the Department of Soil Science, University of Peradeniya and stored in a deep freezer until analysis. pH and electrical conductivity (EC) of the samples were measured in situ using portable meters at the time of sampling.

Table 1. Uses and the nature of the selected wells

Slope category	Well no	Uses	Nature of the well
Upper-most	1	ODU	Un protected open
	2	-	Prepared using PVC tube
Upper	3	-	Prepared using PVC tube
	4	-	Prepared using PVC tube
Middle	5	D/ I /ODU	Unprotected open
	6	D/ I /ODU	Protected open
	7	D/ I /ODU	Protected open
Lower	8	D/ I /ODU	Protected open
	9	D/ I /ODU	Protected open
Lower-most	10	I	Un protected open
	11	*ODU*	Un protected open

ODU = other domestic uses, D = Drinking, I = Irrigation

Determination of Ca^{+2} and K^{+} was done by using a Flame Emission Spectrophotometer (FES) and Mg^{+2} was determined by using an Atomic Absorption Spectrophotometer (AAS). Ammonium-nitrate and phosphorus were determined colorimetrically using the indophenol blue, the sodium salycilate and the ammonium molybdate/ascorbic acid methods respectively.

Soil samples were also collected using a gauge auger from each slope category from surface depth of soil (0-15 cm) and a sub sample was taken for the composit sample. Soil samples were taken in each cropping event (duration of a given crop), air-dried and passed through a 2 mm sieve prior to analysis. Soil analyses were done for pH, EC, available phosphorus (P), exchangeable potassium (K), calcium (Ca) magnesium (Mg) and organic matter (OM). pH was measured in 1:2.5 soils: H_2O suspension using a glass electrode. EC was measured using a conductivity meter. Available P was determined by the Olsen's method (Olsen and Sommers, 1982). Cation exchange capacity (CEC) was measured by adopting the method explained by Hesse (1971), and the leachate produced in this procedure was used to determine exchangeable cations. K and Ca in Soil extract were measured using Flame Photometer technique and Mg was determined using AAS technique.

Organic carbon content was determined by the Walkey and Black method (Nelson and Sommers, 1982). Total nitrogen was determined by distillation of NH_3 after Kjeldahl digestion (Bremner and Mulvaney, 1982). Data in different cropping events were analyzed using statistical procedures for repeated measures. General Linear Model (GLM) was used to analyze data in same cropping event and different slope positions.

RESULTS AND DISCUSSION

Electrical conductivity and pH values of well water

Electrical conductivity and pH values of well water in Katumanna area are shown in Table 2. EC values of the well water ranged from 0.09-1.79 dSm^{-1} over the whole catena. Variation of the EC in the well water in virgin forest (upper-most slope position) was very low and ranged from 0.09-0.10 dSm^{-1}. However, wells within the cultivated lands showed values ranging from 0.35–1.79 dSm^{-1}. Generally, EC of the water interprets the content of soluble salts in the water. Therefore, higher soluble salts present in the well water in cropped lands may be the result of application of higher doses of fertilizers, manure and liming materials in this farming pattern (Gunewardena *et al.*, 1998; Wijewardena and Yapa, 1999). The EC values ranging from 0.1 to 2.0 dSm^{-1} within this catena can be categorized as highly saline irrigation water. Nagarajah *et al.* (1988) classified irrigation water having an EC value from 0.75-2.25 dSm^{-1} as high saline water. Accordingly, wells in the cropped land in middle, lower and lower-most slope positions had highly saline water, and the water of those wells could be categorized as unsuitable for irrigation. However, Wijewardena *et al.* (2001) reported lower EC values for well water in the up country. EC of soil in the different slope positions showed an increasing trend from virgin forest towards the cultivated lower slopes (Table 2). This build up of soluble salt in the soil may have been caused due to application of higher doses of fertilizers and manure for intensive cropping. Water source of the catena originates in the undisturbed natural forest. Contamination with agrochemicals takes place toward lower slope positions due to cultivation.

pH of the well water was near neutral in almost all wells in the whole catena, whereas in the cropped land, it ranged from 4.9 to 7.3. Well water in the forest did not show much variation over the cropping events (Table 2). However, pH of water in the cropped lands was acidic fluctuating around 4.9 in some cropping events in the middle slope. As Jayakody (2002) explained, reduction of pH values of the well water in the cropped land may be due to dealkalization of water by uptake of basic cations by water plants and algae in the water. National Water Supply and Drainage Board of Sri Lanka (1983), recommended pH range for safe drinking water as 6.5 - 9.0. Some wells in the cropped lands especially in the middle slope had acidic water, which may be harmful to the human health. Ayers and Westcot (1985) reported that pH range of 6.5 - 8.5 as acceptable pH for irrigation. Wijewardena *et al.* (2001) have also reported similar pH values for up country well water, but Jayakody (2002) reported higher acidic levels for the well water in Pattipola area in the up country which has intensive vegetable cultivation.

In the Dry zone of Sri Lanka Amarasiri (1973), Nagarajah *et al.* (1988) and Kuruppuarachchi *et al.* (1990) have reported higher pH values in tank and well water respectively as against these results. pH of the soil in the different slope positions (Table 4) were comparable to the average soil pH for up country soils (Dassanayake and Hettiarachchi, 1999; Mapa, 1999). Relationship between EC values of soil and EC values of well water of different slope positions is shown in the Figure 1, which shows a strong positive relationship. However, the relationship between pH in soil and well water was weakly related (Figure 2).

Table 2. Electrical Conductivities (EC) and pH values in well water of different cropping events and different slope positions

Property	Slope position	**Cropping event				
		1	2	3	4	5
pH	Upper-most	6.8[a]	6.9[a]	7.3[a]	6.8[a]	7.1[a]
	Upper	6.9[a]	6.6[ab]	6.8[ab]	6.4[ab]	6.9[ab]
	Middle	6.1[b]	5.3[b]	5.3[b]	4.9[b]	5.3[c]
	Lower	6.8[a]	6.6[ab]	7.0[ab]	6.3[ab]	6.4[abc]
	Lower-most	6.7[ab]	6.1[ab]	5.8[ab]	5.7[ab]	5.8[bc]
EC ($dS.m^{-1}$)	Upper-most	-	0.09[d]	0.09[c]	0.07[c]	0.1[d]
	Upper	-	0.35d[c]	0.39[c]	0.67[c]	0.51[c]
	Middle	-	1.64[a]	1.73[a]	1.79[a]	1.65[a]
	Lower	-	0.91b[c]	1.02[b]	1.19[b]	1.25[b]
	Lower-most	-	1.03[ab]	1.16[ab]	1.26[b]	1.39[ab]

EC= Electrical conductivity
Means in the same column for a given property with same superscript are not significantly different at p=0.05.
** Duration of a given crop

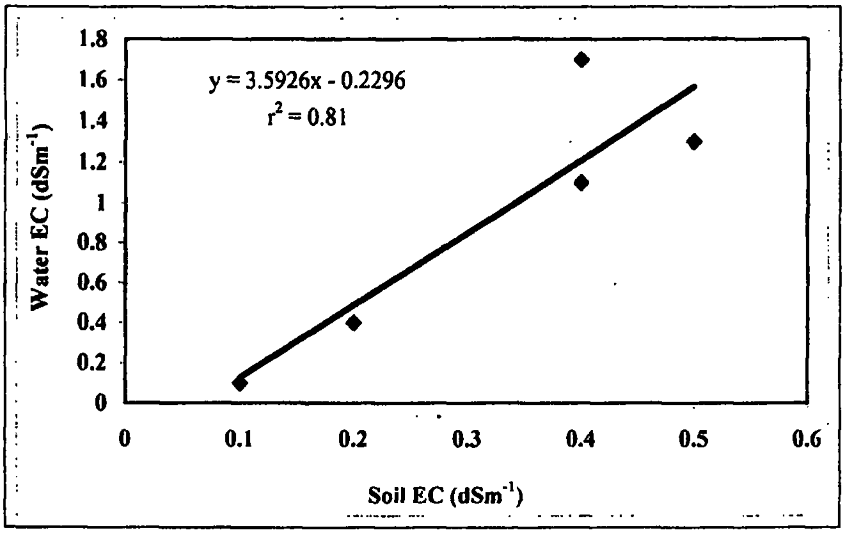

Fig. 1. Relationship between EC (dSm^{-1}) in soil and well water

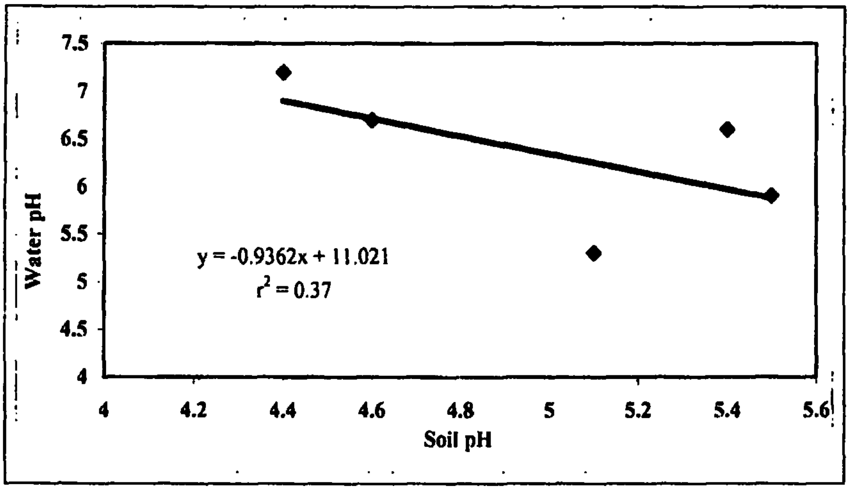

Fig. 2. Relationship between soil pH and well water pH

Basic cations in well water

Average concentrations of Ca^{2+}, Mg^{2+} and K^{+} in well water at each cropping event and each slope position are shown in the Table 3. The sequence of basic cation concentrations showed a similar sequence of $Ca^{+2} > K^{+} > Mg^{+2}$ as reported by Jayakody (2002) for some wells in Pattipola. All cations showed very low concentrations in the well water taken from the forest or upper most slope position, whereas all the basic cations were found to be high in wells situated in the middle slope position. Even though the general trend of basic cations is an increase from the virgin forest to the lower slopes, the middle slope position showed highest concentration of almost all nutrients measured. The reason for this may be the very high density of cropping in the middle slope. Concentrations of all the basic cations in well water were not significantly different at different cropping events. Basic cations are applied to the cropping system directly as plant nutrients as well as indirectly as soil amendments such as lime. In up country, intensive vegetable growing system uses a lot of fertilizers and manure to cater the relatively higher demand of plant nutrients by the short aged vegetables and potato. Rezania *et al.* (1989) and Gunewardena *et al.* (1998) stated that up country vegetable growers apply very high doses of chemical fertilizer to their croplands. These chemical fertilizers may be one of the reasons for elevated concentrations of basic nutrients. Triple Super Phosphate and Muriate of Potash are being added at very high doses as chemical fertilizer. At the same time, improved soil fertility conditions by supply of nutrients in the form of fertilizers and manure as well as of water by irrigation may also have accelerated the weathering of minerals which may supply nutrients specially K to well water. In addition, animal manure such as poultry manure and cattle manure are added in higher doses generally in this cropping system by farmers (Gunewardena, *et al.*, 1998; Wijewardena and Yapa, 1999). Animal manure is a rich source of nutrients supply, especially of Ca (Maraikar and Amarasiri, 1988; Wijewardena and Yapa, 1996; Wijewardena, 2001). On the other hand, liming materials such as burnt lime and dolomite applications are of common use in the up country-wet zone to reduce the acidic level of the soil (Wijewardena, 2001). With these materials a large amount of Ca and Mg are being added to the fields. All these factors could affect on elevation of basic cations in the well water (Jayakody, 2002).

However, Jayakody (2002) and Wijewardena *et al.* (2001) have reported that low concentrations of basic cations for well water of up country. Concentrations of basic cations in the soils of the different slope positions showed a build up of basic nutrients in the soil under the cultivation patterns adopted in the region (Table 5). There could be a greater risk to contaminate well water and surfacing of cation antagonisms in relation to nutrient uptake inducing deficiencies. The relationships between basic cation in soil and in well water showed this potential risk (Figures 2, 3 and 4).

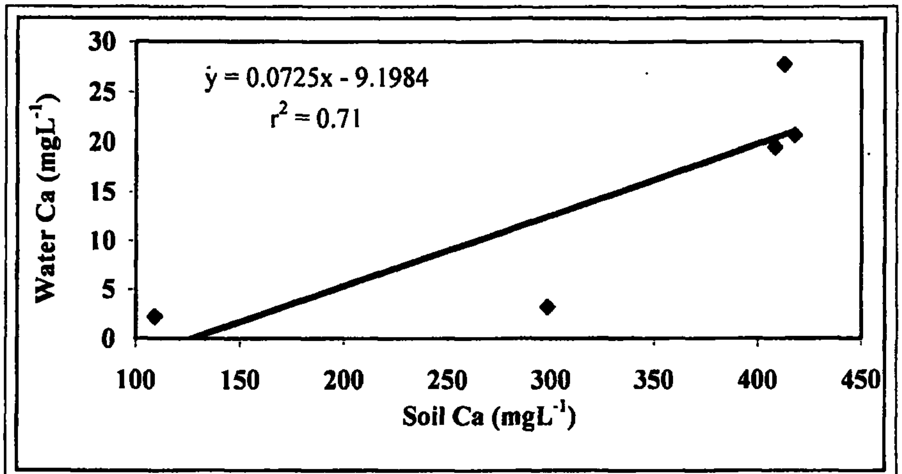

Fig. 3. **Relationship between Ca^{2+} concentration in soil and Ca^{2+} in water**

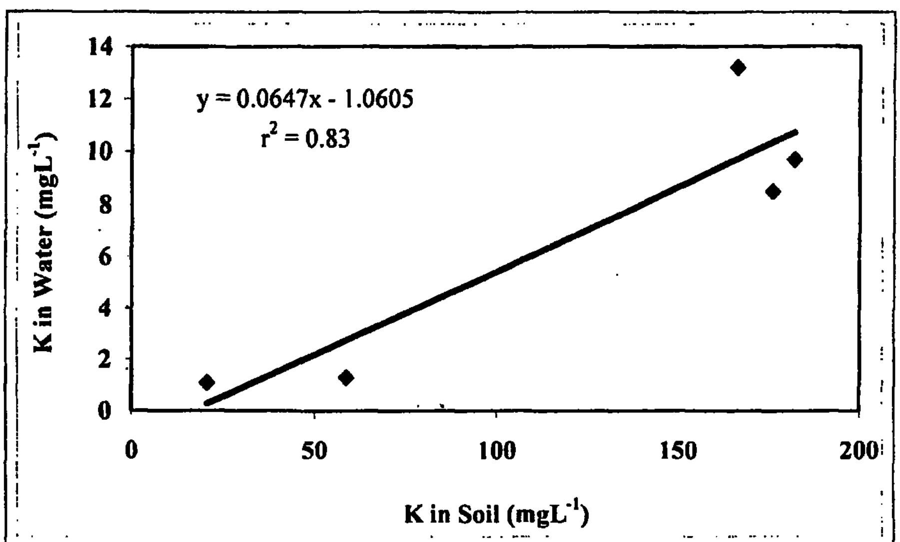

Fig. 4. **Relationship between K^+ concentration in soil and K^+ in water**

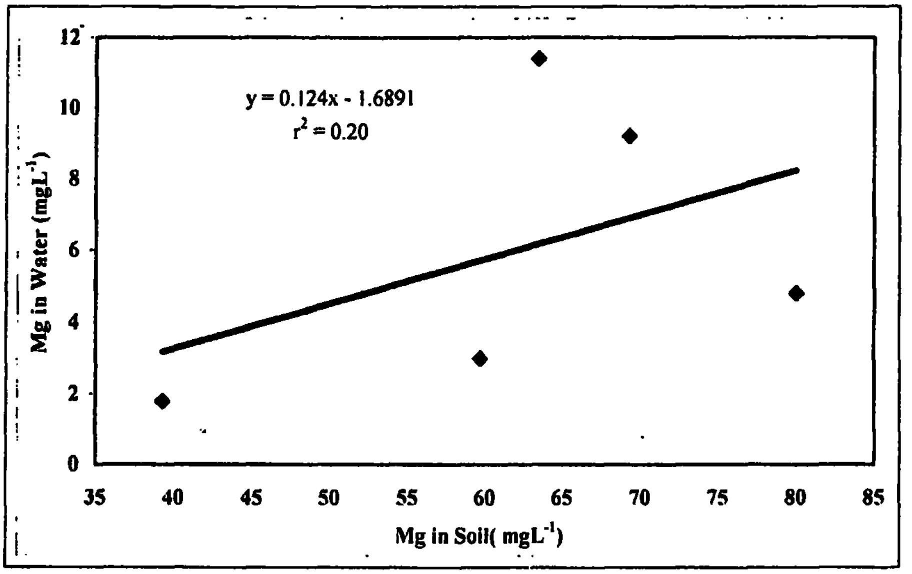

Fig. 5. **Relationship between Mg^{2+} concentration in soil and Mg^{2+} in water**

Nitrogen contamination of well water

Nitrate nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N) and total soluble inorganic nitrogen (NO_3^- - N+ NH_4^+-N) concentrations of well water in different slope positions and different cropping events are shown in the Table 3. The NH_4^+-N concentration of the well water ranged from 0.11-0.62 mgL^{-1} in the whole catena. Significant differences in NH_4^+- N concentrations among slope positions were observed only in cropping events 1 and 5 (Table 3). Over the other cropping events, the differences were not significant. Such an insignificant fluctuation has been established, perhaps because of retention of the ammonium ion by the soil cation exchange complex so that only a little would be reaching the wells. Nitrate nitrogen concentrations of well water collected from the virgin forest were very much lower compared to the other wells in cropped fields and ranged from 0.22 – 0.53 mgL^{-1}. In the cropped land, the NO_3^- - N values ranged from 1.02-32.87 mgL^{-1}. Nitrate nitrogen concentrations of well water showed significant increase from virgin forest to the lower positions of the catena. Similar to the behavior of nutrient cations, NO_3^- - N content showed higher concentrations at the middle slope positions of the catena.

However, lower slopes showed higher nitrate nitrogen concentration compared to the well water in the forest. Jayakody (2002) reported a similar trend from upper parts of a catena towards the lower parts in Pattipola. Even though this study was continued over 18 months, a significant difference was not observable over the cropping events. Reasons for variation between the virgin forest and cultivated lands for nitrate nitrogen concentration in well water may be the application of nitrogen fertilizers and manure at high rates. As Nagarajah *et al.* (1988) explained nitrate in ground water was derived from mineralization of organic matter, symbiotic and asymbiotic nitrogen fixation, rainfall, inorganic fertilizers, green manures, animal wastes, crop residues and sewage effluents. On the other hand, the ionic nature of the nitrate is also responsible for contamination, as it is not adsorbed by soil complex compared to ammonium or other cations.

Table 3. Plant nutrient concentrations in well water at different cropping events and different slope positions

Nutrient (mgL^{-1})	Slope position	Cropping event[1]				
		1	2	3	4	5
Ca^{+2}	Upper-most	1.62^{b}	1.93^{b}	1.79^{b}	2.96^{c}	2.43^{b}
	Upper	2.45^{b}	3.73^{b}	2.48^{b}	3.01^{c}	3.98^{b}
	Middle	22.32^{a}	26.0^{a}	28.98^{a}	31.4^{a}	26.54^{a}
	Lower	13.18^{a}	16.53^{ab}	16.23^{ba}	24.72^{ab}	23.86^{a}
	Lower-most	17.57^{a}	20.89^{a}	18.44^{ab}	21.8^{b}	23.39^{b}
Mg^{+2}	Upper-most	0.82^{c}	0.81^{c}	1.05^{c}	1.49^{c}	0.95^{b}
	Upper	0.76^{c}	0.52^{c}	1.38^{c}	2.13^{c}	1.76^{b}
	Middle	10.37^{a}	13.29^{a}	14.22^{a}	14.15^{a}	12.62^{a}
	Lower	6.7^{ab}	8.87^{b}	7.90^{b}	7.78^{bc}	10.68^{a}
	Lower-most	5.59^{b}	8.70^{b}	9.63^{b}	11.12^{ab}	11.59^{a}
K^{+}	Upper-most	1.88^{b}	1.63^{b}	1.54^{b}	1.96^{b}	2.31^{c}
	Upper	3.81^{b}	3.63^{b}	2.86^{b}	2.01^{b}	2.94^{c}
	Middle	11.18^{a}	11.62^{a}	9.33^{a}	12.92^{a}	13.76^{a}
	Lower	5.02^{b}	5.29^{b}	4.42^{b}	11.43^{ab}	10.88^{ab}
	Lower-most	3.54^{b}	3.36^{b}	3.20^{b}	6.67^{ab}	6.34^{bc}
NH_4^{+}-N	Upper-most	0.11^{b}	0.24^{a}	0.53^{a}	0.46^{a}	0.29^{b}
	Upper	0.17^{b}	0.11^{a}	0.67^{a}	0.61^{a}	0.3^{b}
	Middle	0.16^{b}	0.34^{a}	0.56^{a}	0.60^{a}	0.51^{a}
	Lower	0.41^{a}	0.21^{a}	0.47^{a}	0.43^{a}	0.26^{b}
	Lower-most	0.23^{b}	0.33^{a}	0.62^{a}	0.56^{a}	0.27^{b}
NO_3^{-}-N	Upper-most	0.22^{b}	0.34^{d}	0.34^{b}	0.56^{b}	0.36^{b}
	Upper	1.34^{b}	1.02^{d}	1.15^{b}	1.10^{b}	1.13^{b}
	Middle	32.62^{a}	19.63^{a}	32.08^{a}	32.87^{b}	30.33^{a}
	Lower	9.91^{b}	9.71^{b}	10.1^{ab}	14.11^{b}	17.23^{ab}
	Lower-most	14.61^{ab}	6.39^{c}	17.26^{ab}	15.72^{ab}	16.88^{ab}
TSIN	Upper-most	0.33	0.58	0.87	1.02	0.65
	Upper	1.51	1.13	1.82	1.71	1.43
	Middle	32.87	19.97	32.64	33.47	30.84
	Lower	10.32	9.92	10.57	14.54	17.49
	Lower-most	14.84	6.72	17.88	16.28	17.15

For a given nutrient, mean values in a given column with same superscript values show that they are not significantly different at a probability level of 0.05.

[1] Duration for a given crop

Farmers in the Katumanna area also apply very high doses of inorganic fertilizers as well as poultry and cattle manure. Highest concentrations of nitrate nitrogen were observed in the well water in the middle slope position. The reason for this could be the very high density of cultivation observed in the middle slope position compared to the other slope positions. Nitrate nitrogen concentrations of well water in the middle, lower and lower- most slope positions were very high. All the wells situated in the middle slope showed very high nitrate nitrogen concentrations of 19.63 - 32.87 mgL^{-1}, exceeding 2 to 3 times the acceptable nitrate nitrogen concentrations in potable water allowed by WHO (10 mgL^{-1}). However, water in the wells of this slope category are been used for drinking and other domestic activities. Jayakody (2002) also reported very high NO_3^- - N concentrations for wells in the Pattipola area in up country-wet zone, but Wijewardena *et al.* (2001) reported that very low concentration for wells in intensive vegetable cropping systems of up country.

The total nitrogen percentage of soil in the different slope positions showed increasing trends from the virgin forest to lower slopes. However, correlation between total N in soil and well water was not significant. Even though available phosphorus in the soil is considerable (Table 5), phosphate-phosphorus concentration of the well water was very low ranging from 0.02- 0.2 mgL^{-1} in the catena.

Table 4. Chemical properties of soils collected from different slope positions

Slope position	CEC c mol Kg^{-1} (± SD)	pH 1:2.5H_2O (± SD)	EC dS m^{-1} (± SD)	OM% (± SD)	C: N Ratio (± SD)
Upper-most	31.8 (0.3)	4.4 (0.2)	0.1 (0.0)	4.8 (0.17)	9.0 (1.4)
Upper	17.2 (1.4)	4.6 (0.4)	0.2 (0.0)	4.5 (0.4)	5.0 (2.2)
Middle	19.7 (3.6)	5.1 (0.2)	0.4 (0.0)	4.6 (0.2)	7.0 (1.8)
Lower	15.9 (1.3)	5.4 (0.3)	0.4 (0.0)	4.1 (0.2)	6.0 (1.8)
Lower-most	16.6 (1.7)	5.5 (0.3)	0.5 (0.1)	3.9 (0.3)	4.0 (0.3)

CONCLUSIONS

Plant nutrient contamination of well water in the cropped lands is significantly higher compared to the wells in the virgin forest of the upper-most slope due to intensive vegetable cultivation. Some wells in cropped land bear acidic water, which is not suitable for human consumption. Well water in cropped lands of middle and lower slopes can be categorized as saline irrigation water. Pollution of shallow groundwater (well water) by NO_3^- -N is alarming in lower elevations of the catena. Over the different cropping events, contaminations of plant nutrients of well water in any slope position are not significantly different during the 18 months period.

Table 5. Nutrient status of soils collected from different slope positions

Slope position	Avai.- P ppm (± SD)	Ex.K ppm (± SD)	Ca^{2+} ppm (± SD)	Mg^{2+} ppm (± SD)	N% (± SD)
Upper-most	5.2 (0.3)	20.6 (2.7)	109.1 (5.1)	39.3 (1.8)	0.3 (0.06)
Upper	4.9 (0.7)	58.7 (13.7)	298.3 (108.4)	59.7 (4.8)	0.6 (0.2)
Middle	15.4 (1.1)	166.3 (20.1)	412.9 (149.5)	63.4 (4.7)	0.4 (0.1)
Lower	17.0 (0.9)	176.1 (11.0)	408.4 (102.9)	69.3 (5.3)	0.45 (0.1)
Lower-most	16.0 (1.1)	182.2 (5.2)	418.0 (39.6)	80.0 (3.2)	0.6 (0.1)

Avai.-P = Available phosphorus
Ex- K = Exchangeable potassium

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REFERENCES

Amarasiri, S.L. (1973). Water quality of major irrigation tanks in Sri Lanka. Tropical Agriculturist. 129: 133 - 149.

Ayers, R.S. and Westcot, D.W. (1985). Water quality for agriculture, irrigation and drainage. Paper No. 29 (Rev. 1) FAO, Rome. pp. 174.

Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen-total. In Methods of soil analysis. Agronomy Monograph, 9. (2nd Ed), Madison, USA. pp. 595-615.

Dassanayake, A.R. and Hettiarachchi, L.S.K. (1999). Soils of the up country wet zone. In Soils of the wet zone of Sri Lanka. R. B. Mapa, S. Somasiri and S. Nagarajah (Eds.). Soil Science Society of Sri Lanka. pp. 122-138.

Gunewardena, E.R.N. (2000) Pollution of water resources in Sri Lanka with special reference to agricultural pollution. Silver jubilee commemorative volume (Ed. H. P. M. Gunesena), Post graduate Institute of Agriculture, University of Peradeniya, Peradeniya. 116 - 126.

Gunewardena, E.R.N., Rajapaksha, U., Nandasena, K.A. and Rosier, P.T.W. (1998). Water quality issues in the uplands of Sri Lanka. Proceeding of the final workshop of the University of Peradeniya – Oxford forestry institute link project (Ed. H.P.M. Gunesena) university of Peradeniya, Peradeniya. 37 - 44.

Hesse, P.R. (1971). A text book for soil analysis, Wilson Clover and Sons limited, London. pp. 30 - 33.

Jayakody, A.N. (2002). Soil fertility and nutrient contamination of water in a hilly catena of Sri Lanká under intensive cropping. In: Proceedings, 17th World congress of soil science, Symposium on soil fertility as an ecosystem concept, Thailand. pp. 123-1 - 123-9.

Jeevanathan, B., Seneviratne, R. and Eriyagama, I. (1995). Phosphorus and potassium status of vegetable growing soils in mid country and up country in Sri Lanka. Krushi 15: 17-18.

Kuruppuarachchi, D.S.P., Fernando, W.A.R.N. and Lawrance, A.R. (1990). Impact of agriculture on ground water quality in Kalpitiya peninsula in the north western dry zone of Sri Lanka. In Irrigation and Water resources (Ed. E.R. N. Gunewardena) Post graduate Institute of Agriculture, University of Peradeniya. 199 - 213.

Mapa, R. B. (1999). Fertility evaluation for wet zone soils of Sri Lanka. J. Soil Sci. Soc. Sri Lanka. 11: 1 - 8.

Maraikar, S. and Amarasiri, S.L. (1988). Plant nutrient contents of animal waste. Tropical Agriculturist. 144: 79 - 87.

Maraikar, S. and Nambuge, S.N. (2001). Secondary and micro nutrient contents of animal wastes. Annals of the Sri Lanka Department of Agriculture. 3: 111-119.

Nagarajah, S., Emerson, B.N., Abeykoon, V. and Yogalingum, S. (1988). Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution. Tropical Agriculturist. 144: 61-78.

NWSDB (1983). Analytical report regional laboratory, National Water Supply and Drainage Board, Gatambe, Peradeniya, Sri Lanka.

Nelson, D.W. and Sommers, L.E. (1982). Organic carbon. In Methods of Soil Analysis. Agronomy Monograph 9. (2nd Ed) Madison, USA.

Olson, J.R. and Sommers, L.E. (1982). Phosphorus. In Methods of soil analysis. Agronomy Monograph 9. (2nd Ed) Madison, USA.

Panabokke, C.R. (1996). Soils and agro-ecological environment of Sri Lanka. Natural resources series, Natural resources, Energy and science authority, Colombo, Sri Lanka. p. 220.

Punyawardena, B.V.R., Bandara, T.M.J., Munasinghe, M.A.K., Nimal Jayaratna Banda and Pushpakumara, S.M.V. (2003). Agro-ecological regions of Sri Lanka (Map). Natural Resources Management Center, Department of Agriculture, Peradeniya, Sri Lanka.

Rezania, M., Yogarathnum, V. and Wijewardena, J.D.H. (1989). Fertilizer use on potato in relation to soil productivity in the up country areas of Sri Lanka. FAO, Rome. Field document No. 3. p. 35.

Wijewardena, J.D.H. and Yapa, U.W.S.P. (1996). Effect of animal manure on vegetable cultivation in the up country. Poce. Sri Lanka Ass. Advmt. Sci. 52 (1): 52.

Wijewardena, J.D.H. (2001). Effects of sources and levels of limiting materials on soil acidity in ultisols of the up country, Annals of the Sri Lanka Department of Agriculture. 3: 365 - 372.

Wijewardena, J.D.H. and Yapa, U.W.S.P. (1999). Effect of the combined use of animal manure and chemical fertilizer on potato and vegetable cultivation in the up country of Sri Lanka. Sri Lankan J. Agric. Sci. 36: 70 - 82.

Wijewardena, J.D.H., Yapa, U.W.S.P. and. Yatagama, S.M.K.G. (2001). Drinking water quality of some wells in the intensive vegetable growing lands in the up country wet zone. J. Soil Sci. Soc. Sri Lanka 13: 14 - 21.