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EFFECT OF AGRICULTURAL PRACTICES ON CHEMICAL QUALITY OF WATER IN KALA OYA RIVER BASIN

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ABSTRACT

An assessment of nitrates and phosphates in groundwater and surface water in two heavily agricultural areas (Talawa and Giribawa) within the Kala Oya River Basin was carried out to study the temporal effect on the groundwater upon fertilizer applications. Behaviour of some major cations, pH and conductivity were also studied. The total number of sampling points is 296 and weekly sampling was carried out at 20 locations within the two selected areas. The rate of fertilizer application was monitored during the sampling within three months period.

The results of the study indicate that the pH is more alkaline in agricultural and dug wells whereas it is more acidic in tube wells. The health risk levels of WHO limits for nitrate and phosphate are not exceeded in almost all the water samples studied. However, a strong relation between the fertilizer application and the nutrient increase in water has been observed. Higher nitrate values were recorded from deep groundwater whereas some lake water is enriched with phosphates. The results of surface water analysis show that stream and canal waters are rich in Ca and Mg. In contrast, lake water is characterized by many dissolved ions except Ca and Mg. The highest values of Fe and Mn are found in lake water. The dissolved cations in all groundwater bodies studied are comparatively high. Although Ca and Mg levels are low, Na is high in agricultural wells. The total hardness is very high in some dug wells whereas lower values of Fe and Mn are recorded from groundwater.

It was clearly observed that the intense agricultural practices increase nitrate and phosphate concentrations as well as other dissolved ions in groundwater. The geology of basement rocks and climatic conditions may also enhance the dissolved ion content in water. However, prevailing reducing conditions, overburden soil formation and pH of water act as buffers in reducing the intensity of accumulation of nutrients in water bodies.

Keywords: fertilizer, agricultural practices, nitrate, phosphate, groundwater

INTRODUCTION

Polluted water is not potable and it cannot be used even for washing or irrigation purposes. Sri Lanka is poised to face this threat, especially from groundwater. In the Kala Oya study area, water contamination occurs mainly by increased agricultural practices. Such practices not only introduce nutrients to the water but also contribute a number of cations such as K^+ and Na^+.Nitrate pollution of the groundwater due to agricultural practices has become an environmental issue (Spalding and Exner, 1993) which with time may cause eutrophication and algal blooms in aquifers and even produce potential hazards to human health (Knobeloch *et al.,* 1992: Gulis *et al.*, 2002) though the link is still disputable (Forman, *et al.*, 1998). During the past few decades, many countries have faced the threat of groundwater contamination due to intense fertilizer application. Recent work shows that nitrate and phosphate concentrations of groundwater in agricultural areas of Sri Lanka are high (Rajakaruna *et al.,* 2005; de Silva 2004; Gunatilake, 2005).

Investigations by Ileperuma *et al.,* (2004) have shown that excess fluoride in water can form a complex with aluminum in poor quality kitchen utensils during cooking. This may cause kidney problems in the north central area of Sri Lanka.

Contaminated water due to halogens, mainly chlorine, causes non-Hodgkin's lymphoma, bowel enlargements and cancer in the brain, kidney, bladder or liver. The associated major compounds are trihalomethane (King *et al.,* 1996, RJ; Birnbaum *et al.,* 1995). Manganese and iron in excessive concentrations may prove to be detrimental to health whereas hardness and salinity of water directly affect the taste, odour or colour of water (Dharmagunawardhana, *et al.,* 1989).

Agricultural activities are comparably higher and this covers 38% of the total land area of Kala Oya Basin. The main crop is paddy. Communications with farmers in the area revealed that the fertilizer application was eight to ten times in excess.

The basin has low rainfall (1200 – 1600mm/year) and high evapotranspiration (1706mm/year) (Third interim report of the KOB, 2005). These factors stress the importance of investigating the contamination potential of water resources of Kala Oya area.

There are many other chemical parameters that can cause hazardous conditions making water non-potable. One such parameter is the hardness of water. Temporary hardness of water can often be removed by boiling, but not the permanent hardness. The cations can cause salinity. Due to high ionic concentrations, water can cause many skin and alimentary canal diseases (Dissanayake and Weerasooriya, 1987). Removal of vegetation cover, loosening of soil, regular watering of the cultivated lands and reusing water gathered from runoff of cultivated lands are common practices in these agricultural areas. As water interacts frequently with soils in such areas, mobile ions in soil can easily leach out, and the levels of dissolved ions in water may increase gradually. Further, the climatic conditions such as low rainfall and high evaporation may promote the increase of dissolved ion concentrations in water. The present study focuses on the relationship between water quality and anthropogenic activities in highly agricultural areas of Kala Oya river Basin in the dry zone of north central Sri Lanka.

Study Area

Kala Oya River Basin has a total extent of 2,873 km^2. It is a highly agricultural area. Seventy six percent of land of the Kala Oya basin is situated in the dry zone and the rest (24%) in the intermediate zone. The arable land is utilized for productive farming and the rest is used for settlements, forest, pasture and non-agricultural activities. Most of the land is used for paddy cultivation in the wet season and other crops are grown during the dry season.

Reddish Brown Earth is found in most of the Kala Oya basin area. This soil occupies the crests and the well drained upper and mid slopes of the undulating landscape. Some of the areas comprise of clayey soil.

The area is underlain mainly by charnockites, charnokitic gneiss, thin bands of quartzites and calc-gneiss. Most of these rocks contain high amounts of Fe-Mg minerals. Common clay minerals available in this area are montmorillonite and kaolinite (Herath, 1998).

The lowland Kala Oya area receives water via diversions from Mahaweli basin with unlined canals running on either side. These canals feed almost all the cultivated land. The main groundwater-bearing formations in the area are the fractured crystalline bedrock and its weathered overburden. Alluvial deposits present along the streams also play a vital role in water supply. The water table is high whereas the area above the command depends only on the rainwater harvested in small tank cascades. Depth of the groundwater table varies between 1 and 10m with an average seasonal fluctuation of 4m.

Traditionally, paddy cultivation is carried out twice a year. In addition, there are also vegetable, grain and fruit cultivations in the area. But recently onion, banana and papaya cultivations have become wide spread. Therefore, the regular farming practices have changed. In the present cultivations, the soil is very frequently fertilized, and occurs as loose entities.

METHODOLOGY

The topographical, geological, land use maps and aerial photographs were studied and a detailed survey was carried out to select locations for the investigations. The locations were agricultural wells, dug wells, tube wells and surface water bodies such as lakes, streams and canals. The total number of sampling points is 296 (Figure 1).

The temporal variation of water quality was studied from 20 locations of two selected areas (Figure 2). The rate of fertilizer application was monitored during a period of three months. Sampling was carried out on a weekly basis, except on days with heavy rainfall.

In the field, during the sample collection, pH, conductivity and temperature of water were measured. Nitrate and phosphate contents of samples were measured using the HACH DR 2010 spectrophotometer. The cations such as Na, Ca, Fe, Mn, K and Mg were measured on the Perkin Elmer atomic absorption spectrophotometer at the Department of Geology, University of Peradeniya, Sri Lanka. Standard methods for sampling and analyzing were employed during the study.

RESULTS AND DISCUSSION

The observations (Table 1) show that dug wells have higher Mn (up to 2.51 ppm) than both agricultural (0.02 – 1.43 ppm) and tube wells (up to 0.79ppm). A characteristic variation cannot be observed from concentrations of iron and the values are in a range below detection limits of 1.59ppm. Almost similar values of Ca and the Mg ion concentrations were observed in all types of groundwater bodies (see Table 1). However, extreme values were obtained from some tube wells (up to 624 ppm). The highest mean K ion concentration was found in the dug wells. The tube wells and agricultural wells are characterized by similar concentrations (see Table 1). The Na concentrations are high up to 719.0 ppm in almost all categories. The pH is more alkaline in the tube wells.

High nitrate values were found in almost all the surface waters (Table 2), but the lowest nitrate range is found in the canals (0 – 10.7 ppm). The highest phosphate concentrations were found in the lakes (upto 21.6 ppm). Lower values were found in the canals (0.02 – 2.6 ppm) and the streams (0.02 – 0.66 ppm). However, higher mean values of both were recorded for canal water as compared to lake water (Table 2).

Chemical and Physical Quality of Groundwater

Nolan (1999) has mentioned that almost all natural waters will have nitrate values below 2mg/l. Kite-Powell *et al.,* (2006) showed that if the groundwater has nitrate-N higher than 3mg/l some anthropogenic source of contamination is suspected. When both nitrates and phosphates are present in agricultural water in higher amounts than in the natural waters, the accumulation of nutrients should be due to application of fertilizer since it is the only anthropogenic activity in the area contributing to increase of nutrients.

Within the Kala Oya river basin, some agricultural wells showed values higher than 3mg/l nitrate-N (19%). This may be a result of release of nitrate from agricultural fields to groundwater.

In the temporal study carried out in the Talawa and Giribawa secretarial divisions, it was evident that the nitrate levels were high almost two weeks after fertilizer application (3 – 6.4 ppm; see Figure 3).

The phosphate concentrations however, varied irregularly (0.07 – 1.53 ppm) depending on the soil conditions and did not depend on fertilizer applications (0.07 – 1.53 ppm: Figure 4). Though nitrate and phosphate fluctuation seems to have a direct relationship upon fertilizer application, most of the phosphate seems to be adsorbed onto clay particles or precipitated with Ca in the area.

The Fe-Mg bearing primary minerals and secondary clay minerals such as montmorillonite and kaolinite (Herath, 1998) in the overburden soils formed from the basement rocks could have been responsible for reducing the nutrient levels of groundwater. These iron bearing minerals have a high adsorption capacity for nitrate (Thayalakumaran *et al.*, 2004). They also play a major role in precipitation of phosphate under natural pH conditions (Bohlke, 2002).

According to water quality investigations carried out by Mahaweli Authority and Colombo University, the nitrates range from 0.68 – 1.8 ppm and phosphates 0 – 13.84 ppm in the Kala Oya area. Further, results of a number of studies carried out within the country, suggest that the excess fertilizer applied can move into nearby water bodies (Silva, 2005; Gunatilake and Gunatilake, 2004). In many countries throughout the world, research has revealed that even under different agricultural practices, excess application of fertilizer poses a large threat to the quality of drinking water (Jordan *et al.*, 1997).

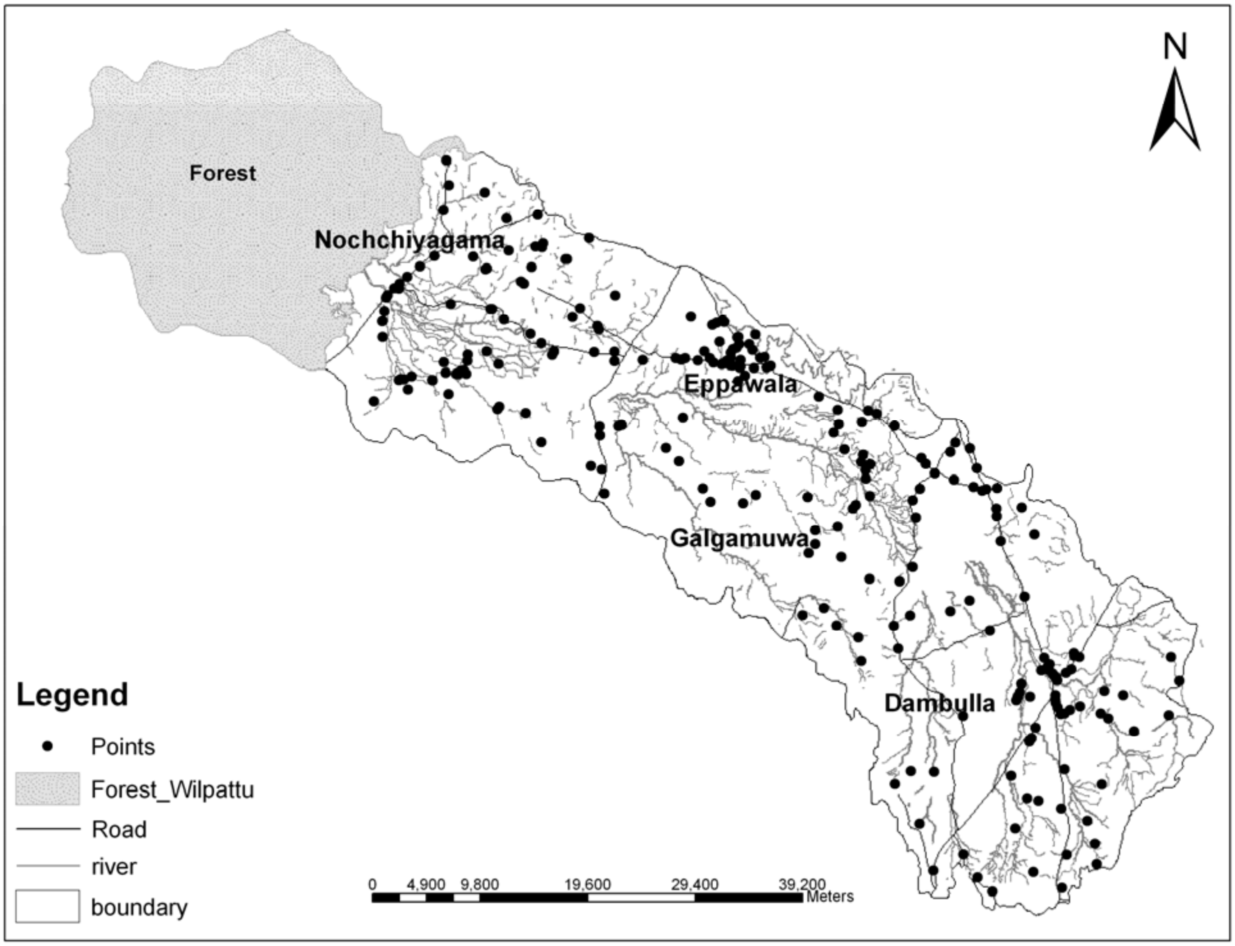

Figure 1: Selected sampling locations in the Kala Oya Basin, Sri Lanka.

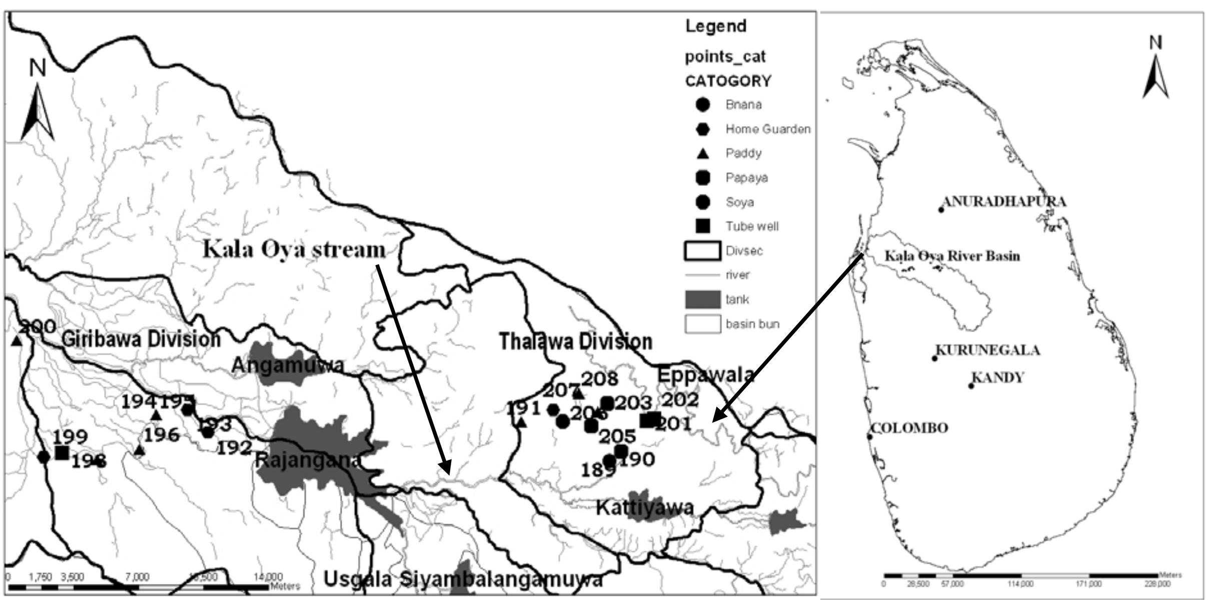

Figure 2: Study area and sampling points of the Talawa and Giribawa secretarial divisions located on left and right banks of the Kala Oya Basin.

Table 1: The minimum and the maximum of the dissolved ions (ppm) and pH of the groundwater of the Kala Oya River Basin

Parameter	**Dug well (ppm)**	**Agricultural well (ppm)**	**Tube well (ppm)**
NO_3^- -N	0- 25.3	0 – 30.8	0 – 12.5
PO_4^{3-}	0.03 – 1.95	0.05 – 1.43	0.02 – 1.19
Mn	0.00 – 2.51	0.02 – 1.43	0.00 – 0.79
Fe	0 – 1.59	0 – 2.11	0 – 1.39
Mg	1.22 - 139	6.84 – 103.6	1.81 - 173
Ca	1.02 - 442	1.79 – 79.4	2.75 – 624
K	0.3 - 80	0.35 – 15.3	0.23 - 12
Na	9.07 - 545	5.77 – 719	12.35 - 575
pH	4.83 – 10.31	6.62 – 8.83	5.86 – 7.52

Table 2: Ranges of dissolved ions (ppm) and pH of surface water - Kala Oya River Basin

Parameter	**Lake (ppm)**	**Canal (ppm)**	**Stream (ppm)**
NO_3^- -N	0 – 29.9	0 – 10.7	0 – 23.4
PO_4^{3-}	0.01 – 21.6	0.02 – 2.6	0.22 – 0.66
Mn	0.03- 3.08	0.00 – 2.04	0.01 – 0.44
Fe	0.12- 21.9	0 – 6.1	0.02 – 3.89
Mg	1.33 – 75.8	1.12 – 93.8	9.7 – 55.1
Ca	0.86 – 93.2	6.06 – 48.9	2.52 – 25
K	1.16 – 32.7	0.21 – 10	0.91 – 9.11
Na	2.4 – 548	7.05 – 100.3	4.73 – 60.7
pH	4.68 – 9.4	5.62 – 8.37	5.93 – 7.92

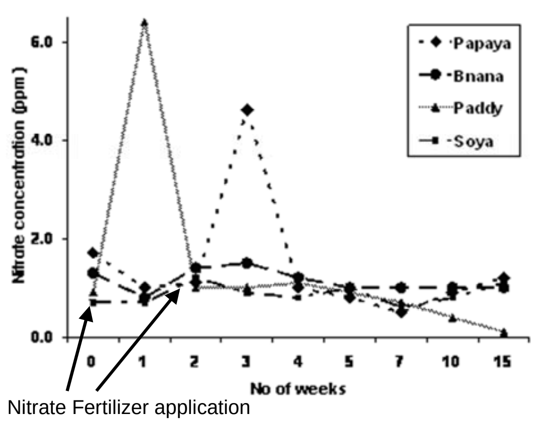

Figure 3: Nitrate variations with time in some selected agro-wells (From 18.05.2006 to 01.09.2006) in the Talawa and Giribawa secretarial divisions (Young *et al.,* 2009). The graph shows that nitrate concentration is high at the initial stage of some fields of cultivation generally up to four weeks, and the values reach the background levels subsequently.

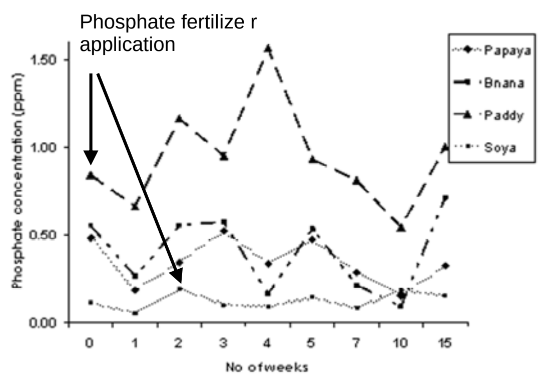

Figure 4: Phosphate variation in selected agro wells in the Talawa and Giribawa secretarial divisions with time (Young *et al*., 2009). The graph shows that the application of phosphorus fertilizer does not show a significant effect on the phosphate concentrations in well water.

Most dissolved cations in ground water are comparably high. However, the concentrations of Fe and Mn are low compared to surface water. Tube wells are more alkaline compared to dug and agricultural wells. However, the deep groundwater has more dissolved ions. The dug wells are markedly characterized by higher K levels and agricultural wells are rich in Na ions.

When excess calcium ions present, phosphate reacts with calcium and tends to precipitate as $CaPO_4$. Therefore, low phosphate concentrations may be due to this precipitation.

Ca and Mg can exchange with Na sorbed on the surface of the clay minerals in aquifers containing fine sediments or clay minerals. The exchange can cause decrease of Ca and Mg and increase of Na in the groundwater from the intermediate zone (Guo and Wang, 2003). On the other hand, water in the agricultural wells show high concentrations of Na. This show evidences for the fact that in addition to ion exchange, the agricultural input of Na^+ could also contribute to the increase of Na^+ in groundwater.

Compared to drinking waters dug wells, agricultural wells have higher dissolved ion concentrations. It may be due to the accumulation of infiltrated water running over the agricultural fields. As these wells are located within the agricultural lands, there are high water-soil interactions due to recycling. Therefore, the dissolved ion concentrations will dramatically increase. In the future with time, due to recycling of the same water, saline condition can develop and increase. In places where high values of nutrients and cations exist, sandy soils which inhibit high pores and seepage properties could be found.

Dug wells are used to extract groundwater, which is seasonally being recharged by the abundant monsoon rainfall. During the monsoon, both rainfall and runoff are plenty. However, during the remaining seven to eight months, water deficits are observed. These conditions control the chemistry of all waters in the area.

Some lakes show high phosphate values (21.7 ppm, when surrounded by shrubs and forest) where there is high eutrophication. This may be due to the accumulation of nutrients gathered from agricultural fields located in catchment areas of such lakes. The lakes fed by canals in contrast, are low in phosphates, indicating clearly that leached ions from agricultural fields are diluted by irrigated water. The nitrate values of surface water indicate a low accumulation of nitrate in the surface waters although there are high application rates of nitrate as urea fertilizer for cultivated lands. The surface waters are flowing in large quantities. Hence such water will have low concentrations of nutrients.

In addition to the factors discussed above, the riverbanks play a major role towards the occurrence of dissolved ions in surface water of the agricultural areas (Meynendonckx *et al.*, 2006,: Jonathan *et al*., 2006). The riparian zones found in the canals of the area have heavy growths of nutrient consuming plants such as Ipomoea spp. When the water flows, the plants in the river banks absorb heavy loads of nitrate and phosphate. Therefore, low values of nitrate and phosphate will be found in the canal water though high values are expected with high application rates of fertilizers.

Lake water in the area is characterized by many dissolved ions except Ca and Mg (Table 02). The most interesting feature is that the high values of Fe and Mn found in lake waters. In lake waters, the high iron concentration gives rise to reducing conditions. The occurrence of high concentrations of other ions is attributed to high evapotranspiration taking place in the area. However, more than the traditional paddy cultivation, intense agricultural practices, mainly vegetable cultivation has heavily influenced on the water quality of the area. The pH is also more alkaline in lakes (4.68 – 9.40) compared to that of the streams (5.93 – 8.02) and canals (5.62 – 8.37).

On the other hand, Na concentration is dramatically high in lake water and the reason is the high agricultural activities and mineral dissolution. The low Ca and Mg values in lakes may be caused by the precipitation of calcite and dolomite. (Guo *et al*., 2003). The results show that stream and canal waters are rich in Ca and Mg, but other ions are considerably low. However, the canal and stream water chemistry is complex and does not have a relationship with the natural conditions.

Overview of chemical quality of water

Most of the drinking waters of the Kala Oya area are within WHO or safe limits. However, certain parameters are high due to various reasons. Nitrates are high in few wells located in areas where fertilizers applied within two weeks of sampling. High phosphate concentrations observed in some of the lakes in the area. The highest K concentrations were also observed in lake water. This implies that the fertilizer applied to the crops has a direct impact on nearby water resources.

The traditional paddy cultivation is carried out only twice a year, and it does not involve much recycling of the same soil and water. Since recent times the farmers have started cultivating vegetables, onions, papaya, banana etc. They are short term crops which involve the use of same recycled water and soil. This condition increases the amount of dissolved ions in the nearby wells. Therefore, the agricultural wells have high Na which is caused by the novel agricultural practices carried out in the area.

In addition, the high Fe and Mn in the surface waters show that they prevail under reducing conditions. In the reducing environment, the nitrate is bound to attenuation. Consequently, the nitrate in the water will be removed. Besides, the riparian zones found in the streams and the canals also reduce the nitrates in water. Therefore, the waters of the Kala Oya area have less concentrations of nitrate in water though high amounts are being supplied to the cultivated land.

Also, the Ca and the Mg concentrations are considerably high in the agricultural wells. Therefore, due to the precipitation of calcium phosphate and sorption of Ca to clay particles the phosphate values in water will be low.

CONCLUSIONS

Present agricultural practices affect the quality of deep groundwater as well as shallow water. However, the contamination rate is not very high compared to the application rate of fertilizer. Pollution rate is controlled by available reducing conditions, overburden soil type, basement geology and drainage networks with riparian zones.

Recently introduced agricultural practices may increase water pollution. The intense agricultural practices specially in the vegetable cultivations have caused high cations and nutrients in water of agricultural wells, dug wells and lakes due to recycling of the same water several times a year. Also, the high cations in the deep groundwater are due to high rock interaction which is a natural process.

The irrigated lake water is less contaminated but some isolated lakes are highly contaminated. It can be assumed that the groundwater recharge from lakes may affect the chemical quality of groundwater.

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