The Impact of Inappropriate Soil Management on River Water Quality: A Case Study in the Kurundu Oya Sub-catchment of the Upper Mahaweli Catchment, Sri Lanka

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Abstract

The results of many studies have revealed that intensive farming on steep slopes, coupled with over application of fertilizers and accumulation of nutrients in downstream water bodies due to soil erosion, have contributed to environmental hazards in the Upper Mahaweli Catchment Area (UMCA) of Sri Lanka. The encroachment of riparian zones for exotic vegetable cultivation has aggravated this situation. In view of this, a study was conducted in the Kurundu Oya catchment, a micro-catchment of the UMCA, to investigate the soil management practices within the farming systems and their impacts on river water quality. Three villages were selected along the Kurundu Oya: Mahakudugala, Kumbalgamuwa and Batagolla. The study consisted of a survey of 150 households in 2007 and 2008, to gather information on the characteristics of householders and on soil management practices. A soil survey was carried out to analyze the soil fertility of farmlands. Water quality parameters were measured periodically in different sections of a selected stream. The results revealed that nearly 50 % of the riparian zones in the upper catchment of the Kurundu Oya stream are encroached to cultivate potato and other exotic vegetables. In addition, it was observed that over application of fertilizers on the vegetable plots was causing nutrient accumulation and the plots also recorded high levels of phosphorous (P) (above 75 ppm). Results of the water quality analysis showed that nitrate and available P levels were within the standard limits, but nitrate nitrogen (NO_3-N) levels were close to the upper level of the standard limit. Therefore, in order to minimize water pollution, it is strongly recommended that fertilizer application is based on soil tests. In addition, encroachment of sensitive lands has to be addressed. Priority should be given to strengthening institutional capacity in order to facilitate the implementation of existing environmental legislation.

Introduction

The Upper Mahaweli Catchment Area (UMCA) is considered very important to the Sri Lankan economy as it provides the water needed to generate 55 % of the electricity requirement of the country and to cultivate large extents of paddy and other field crops. Year around cultivation of exotic vegetables, including potato, which provides higher returns compared to other crops, is possible because of the suitable climatic conditions prevailing in most parts of the UMCA. Since per capita land availability is continually reducing, farmers have tended to cultivate more intensively to increase their production and income. The tendency to encroach forest reserves has also increased due to high population pressure. It can be observed that continuous cultivation with minimum soil conservation measures and without the required fallow period, has contributed significantly to land degradation in the UMCA. Furthermore, it has reduced the capacity of soil to provide the required amount of plant nutrients for crop growth. Farmers attempt to overcome the problem by adding organic manure and inorganic fertilizers in excess of the recommendations made by the Department of Agriculture (Rajakaruna et al. 2005).

It is a well known fact that leaching of excess water soluble nutrients from agricultural systems adversely affects the quality of drainage water and can impact on downstream water quality. In general, market vegetable gardens in the UMCA are highly vulnerable to soil erosion, and most have reported annual erosion rates of over 75 t/ha thus significantly increasing the sediment yield in runoff and stream water (Stocking 1992). .The transportation of sediments caused by soil erosion from UMCA contributes significantly to the siltation of major reservoirs that are used for hydropower generation and delivering water for irrigated agriculture in the downstream areas. For example, according to a technical report the Rantambe Reservoir silted at a rate of 4.3 % in 1991-1992; Polgolla Reservoir at 2.8 % per annum during 1976-1992; and Victoria Reservoir at 0.08 % rate during 1985-1993.

Kurundu Oya adjoins the Uma Oya catchment and they share a similar land use pattern. Since the 1980s, exotic vegetable cultivation has been expanded to a commercial-scale in the Kurundu Oya catchment and now contributes significantly to household incomes and to the well-being of the community. According to Kumarihamy (2008), the total land extent under market vegetable gardens in the Kurundu Oya catchment is 881 ha. However, the actual land extent is likely to be more than this because some farmers use paddy fields for vegetable cultivation during the yala season or both yala and maha seasons. Since 1984 the area under commercial vegetable farming has increased and the extent of home gardens has declined as home gardens have been converted to intensive vegetable farming systems. Field observations revealed that this is the main cause of high soil erosion in these two catchments. Farmers seem unconcerned about soil conservation, which may be attributed to inadequate agricultural extension services being provided by relevant institutions and the unsatisfactory implementation of legislations against the encroachment of sensitive lands.

Despite this, no systematic study has been conducted with respect to soil erosion and nutrient depletion from the catchment. This study was therefore undertaken to investigate the soil management in the farming systems, particularly market vegetable gardens, in the Kurundu Oya catchment, and its effect on stream water quality. An attempt was also made to identify the institutional gaps which adversely affect the implementation of the Soil Conservation Act at the field level.

Materials and Methods

The studied villages are located in the Kurundu Oya catchment (between $7^0$01' and $7^0$13' N and $80^0$48' and $80^0$55' E), which lies mainly in the mid- and up-country intermediate zones where mean annual rainfall is about 1,700 mm. Three locations were selected along the Kurundu Oya stream representing lower, middle and upper parts of the catchment. These are Batagolla, Kumbalgamuwa and Mahakudugala. Land is the most limiting natural resource in the catchment, because most of the lands are on steep slopes and are not suitable for any use other than natural forests. Batagolla is a village situated at the valley bottom where paddy fields are predominant. Kumbalgamuwa is located in the middle catchment, where rotational farming (paddy in the maha season and vegetable in the yala season) is practiced. Mahakudugala in the upper catchment area consists of tea and intensive vegetable cultivation. Apart from that, home gardening and rain-fed farming are practiced in middle and lower catchment areas for subsistence.

The study consisted of a household survey to gather socioeconomic data, soil analysis to describe soil fertility levels, and water sampling and analysis to asses the existing quality of stream water. A pre-tested questionnaire was used to interview 150 household heads. It included household characteristics, type of farming systems and their management, and questions about the existing institutional set-up in the study area.

Soil samples were collected from each farm allotment belonging to the surveyed household heads. A gauge auger was used to draw soil samples from the surface (0-30 cm depth) and two samples were obtained from each allotment. Soil sampling was carried out prior to land preparation and brought to the Soil Science Laboratory at the Faculty of Agriculture of Rajarata University for analysis. All the samples were air dried and passed through a 2 mm sieve prior to analysis. The particles above 2 mm in diameter were separated and weighed to determine the percentage of the gravel in each sample. Soil pH was measured in a soil: water (1:2.5) suspension, which was stirred occasionally over a 20-minute period, using a pH meter. Electrical conductivity (EC), which is a measure of the concentration of soluble salts, was determined using a digital conductivity meter (Hesse 1971). Organic carbon content was determined by the 'Walkey and Black Method' (Nelson and Sommers 1982). The available phosphorous (P) was measured by 'Olsen's Method'. The exchangeable potassium (K) was estimated by flame photometry. The total nitrogen (N) was determined by distillation of ammonia (NH_3) after Kjeldhal digestion (Bremner and Mulvaney 1982).

Water samples were obtained at 2-week intervals from the selected sampling points on the stream from February to March. A sampling point in the natural forest, served as an uncontaminated control. Other sampling points were established at 100 m intervals along a tributary of the Kurundu Oya in the upper catchment, where intensive vegetable farming is practiced. Water samples were transported to the Soil and Water Engineering Laboratory of the Department of Agricultural Engineering, University of Peradeniya, and stored in a deep freezer until analysis.

For the analysis of suspended sediments, water samples were filtered through 'Whatman 'No.01 filter papers. The sediment retained after filtration was dried at 40^{o}C for 24 hours. It was weighed and compared with the weight of another filter paper after the filtration of an equal volume of distilled water as a control. The dried sediment samples and the supernatants were analyzed separately for different parameters.

The EC, total dissolved solids (TDS) and pH of the water samples were measured using a digital conductivity meter (Thermo Orion Model 145) and pH meter (Lonalyzer Model 407 A), respectively. Nitrate nitrogen and available P were determined colorimetrically using the indophenol blue, the sodium salicylate and the ammonium molybdate/ascorbic acid methods, respectively. The same methodology used to analyze soil samples was followed in sediment analysis.

Results and Discussion

A general description of the selected locations of the study area is given in Table 1.

Table 1. General characteristics of the study locations.

Location	Number of households	Monthly household income (Rs.)	Main farming system	Main soil conservation method	Encroached lands (ha)
Batagolla	121	3,000	Paddy	Bench terraces	5
Kumbalgamuwa	147	7,000	Paddy and vegetable	Bench terraces	23
Mahakudugala	202	12,000	Vegetable	Forward terraces	78

Source: Household survey, 2008

Batagolla is a traditional village in which paddy is the main farming system. Since most of the soils of this area are poorly drained, paddy is the only crop which can be cultivated without much difficulty. The paddy fields are mainly located in valleys (lowland) where water is available in both yala and maha seasons. In general, paddy fields are found in the bench terraces, which are highly stable and less vulnerable to soil erosion. Since paddy tracks are well protected by bunds, the rate of soil loss from the system is minimal (Madduma Bandara 1997). The mean monthly household income in Batagolla is lower than the other two locations, mainly due to low paddy yield. The extent of encroached lands reported in Batagolla is also low, which could be due to low demographic pressure and less demand for paddy farming, especially among the younger generation.

A rotational farming system is practiced in the Kumbalgamuwa micro-catchment. Farmers prefer to cultivate paddy during the maha season because of heavy rainfall. Vegetables are grown in paddy tracks during yala, which provides a better income than the maha season. Since the same tracks are used for paddy and vegetables, the rate of soil erosion reported from the farmlands in the Kumbalgamuwa area is moderate to low.

Mahakudugala is located in the upper catchment (above 1,250 m from mean sea level) and the environment is more favorable for exotic vegetables. Therefore, intensive vegetable farming is predominant and the cropping intensity is above 2.5 (this means the land is cultivated more than two seasons per year). High demographic pressure and increasing demand for exotic vegetables puts pressure on limited land resources in this part of the catchment. As a result, the tendency to encroach forest reserves and riparian zones is remarkably high. The findings of the socioeconomic survey revealed that nearly 78 ha of lands have been encroached in the Mahakudugala micro-catchment, most of which are being used for vegetable cultivation. In general, vegetables are grown in forward sloping terraces, which are not very successful in terms of soil conservation. Stocking (1992) reported that annual soil loss from market vegetable plots in the up-country of Sri Lanka is about 75 t/ha. According to the results of the soil analysis, market vegetable plots recorded the highest gravel content of 33 % in the top soil (0-30 cm depth) compared to other farming systems. These factors very clearly indicate that this farming system is more vulnerable to soil erosion than the others.

Soil Properties of Different Farming Systems

Taxonomically, all the soils in the study area belong to the ultisols (Panabokke 1996). However, the soil pH of different land uses ranged from 5.4 to 6.5 (Table 2). In general, mid- and up-country soils are acidic, mainly due to high leaching. Intensive vegetable farming systems showed slightly higher pH values compared to other land uses. The most plausible reason for this is the incorporation of poultry manure and the application of lime to the fields. These fields were also recorded as having the highest organic material content of 3 % compared to other land uses. In general, animal manure such as poultry and cattle manure are added in high doses to vegetable plots by farmers (Wijewardane and Yapa 1999).

Table 2. Soil properties of different land uses.

Land use	Soil pH (1:2.5) soil:H_2O	Soil EC dS m^{-1}	Gravel (%)	OM** (%)	Available P (ppm)	Exchangeable K (ppm)	Nitrate N(ppm)
Paddy	5.4 ^{b}	0.3 ^{b}	18 ^{c}	1.8 ^{c}	61 ^{b}	124 ^{a}	19 ^{c}
Paddy - veg	5.9 ^{b}	0.4 ^{b}	25 ^{b}	2.4 ^{b}	67 ^{b}	137 ^{a}	37 ^{b}
Forest	5.7 ^{b}	0.1 ^{c}	26 ^{b}	2.8 ^{b}	18 ^{c}	48 ^{b}	19 ^{c}
Vegetable	6.5 ^{a}	0.6 ^{a}	33 ^{a}	3.3 ^{a}	103 ^{a}	142 ^{a}	56 ^{a}

Source: Soil survey, 2008

Note: *Means in a single column for a given property with same superscript are not significantly different at $p = 0.05$. ** Organic Matter

The EC of vegetable growing soils showed the highest value, compared to the other samples, of 0.6 dS m^{-1}, indicating a medium salinity level. One reason for this may be the over application of chemical fertilizers to meet the relatively high demand for plant nutrients by exotic vegetables. At the same time, the available P level of the vegetable soils was 103 ppm, which is five times higher than the P content of the forest soils. According to the FAO standards, 30 ppm of P in agricultural soils is considered to be very high, but all the farming systems studied exceeded this amount. Similarly, reported K and NO_3–N levels in vegetable-growing soils were significantly higher than the crop requirements. This could be because, as reported by Rezania et al. (1989) and Gunawardane et al. (1998), up-country farmers apply very high doses of chemical fertilizers to their vegetable plots.

The gravel content (particles > 2 mm in diameter) of the top soil (0-30 cm depth) is one of the soil erosion indicators widely used by researchers (Botschek et al. 1998). The vegetable-growing soils reported the highest gravel content of 33 %, which is significantly higher than all other land uses. Paddy fields, which are well protected, showed the lowest gravel content of 18 % in the top soil. Therefore, it is clear that, intensive vegetable farming systems are more vulnerable to soil erosion than other farming systems practiced in the catchment.

Quality Parameters of the Stream Water

Shallow groundwater contributes to maintaining the base flow of natural streams, especially during dry spells. Jayakody (2002) and Rajakaruna et al. (2005) found that there is a positive relationship between the ion concentration of the soil and the groundwater in up-country dug wells.

The water sample taken from the stream at the natural forest showed the highest pH value of 6.8 and was closest to neutral (Table 3). A reduction in pH was observed along the stream and the lowest value of 5.9 was reported at the 300 m sampling point. Jayakody (2002) stated that well water in the Pattipola area is acidic because basic cations that are dissolved in the water are absorbed by the algae and other aquatic plants. The acceptable range of pH for irrigation water is 6.5 to 8.5 (Ayers and Westcot 1985). According to the recommendation of the National Water Supply and Drainage Board of Sri Lanka, the acceptable pH range for drinking water is 6.5 to 9.0. According to these standards, the acidity of the stream water is slightly higher than the acceptable range for drinking and irrigation.

Table 3. Water quality along a natural stream in the Kurundu Oya catchment.

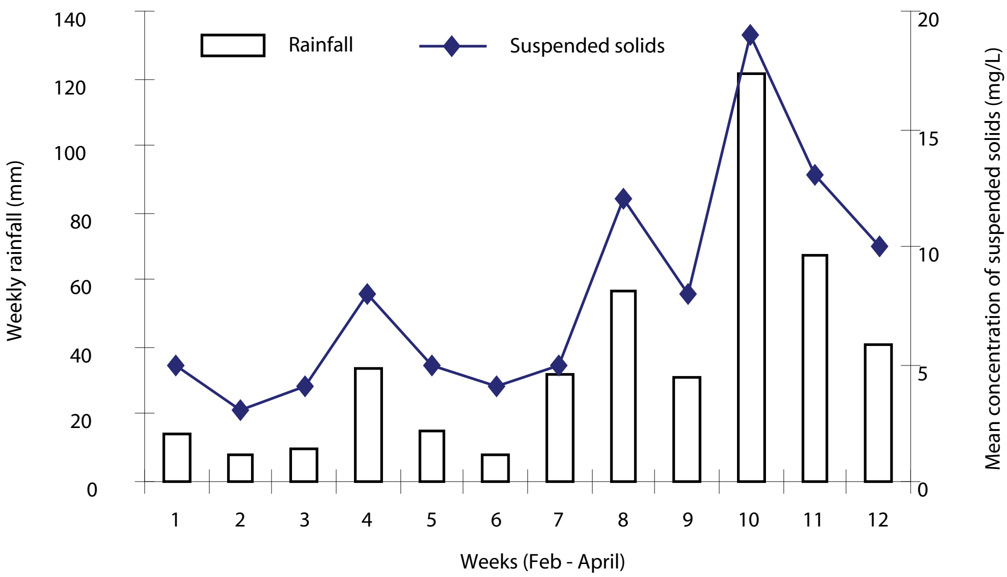
Sampling point	pH	EC dS m^{-1}	TDS (mg^{-1}/L)	Available P (mg^{-1}/L)		Nitrate N (mg^{-1}/L)	
				particulate	dissolved	particulate	dissolved
Forest	6.8	0.01	7	0.2	0.00	0.4	0.00
100 m	6.4	0.02	10	0.79	0.17	2.6	0.52
200 m	6.0	0.11	55	1.8	0.25	5.2	1.2
300 m	5.9	0.13	68	2.9	0.28	9.7	2.4
400 m	6.0	0.13	62	2.6	0.27	9.2	2.3

The EC of the water samples ranged from 0.01 to 0.13 dS m-1. The water samples from the stream at the natural forest showed the lowest EC and TDS values. However, both parameters increase as the stream passes through the vegetable farming area. Gunawardane et al. (1998) and Wijewardane and Yapa (1999) emphasized that the over application of chemical fertilizer may increase the soluble salt content of shallow groundwater in up-country vegetable-growing areas. The influence of vegetable farming on the nutrient level of the stream water is also clearly reflected by the comparison of results given in Table 3. The available P and N levels of the stream water in the natural forest are remarkably low compared to other sampling points. Collins and Jenkins (1996) reported that in the middle hills of the Himalayas in Nepal, agricultural catchments contributed more to the nutrient content of stream water than the forested catchments. They further stated that mineral fertilizers and organic manure applied to the agricultural lands significantly affected the water quality of the streams.

A simple comparison between two fractions of nutrients (particulate and dissolved) in stream water is also given in Table 3. It reveals that more nutrients are transported with the solid fraction than the dissolved fraction. Therefore, higher concentrations of nutrients in streams tend to be associated with higher levels of suspended sediments. Kothyari (2004) observed a strong relationship between rainfall-runoff and nutrient losses in the agricultural lands of Bhetagad watershed in the Central Himalayas in India. Collins and Jenkins (1995) stated that the major dynamics of water chemistry of streams in the Middle Himalayas in Nepal occur during the monsoon due to surface runoff and the return flow from agricultural lands.

The fluctuation of SS in stream water and the weekly rainfall over 12 weeks from February to April is plotted in Figure 1. It is clear that high sediment concentrations coincide with high rainfall events. Most of the vegetable plots in upper Kurundu Oya catchment are located in forward sloping terraces from which soil is easily removed during monsoon periods. In addition, available plant nutrient levels in the soil are extremely high for vegetable cultivation compared to other land uses (Table 2). Therefore, vegetable farming systems can be considered to be the main non-point pollution source with respect to the stream water pollution in the area.

Figure 1. The relationship between rainfall and the average concentration of SS of stream water.



Nutrient Management in Vegetable Farming Systems

It is a common myth among farmers that the higher the rate of fertilizer application, the higher is the crop yield. Therefore, they tend to apply high doses of mineral fertilizers and organic manure in order to artificially build-up soil fertility. However, such an application may actually induce nutrient imbalances in the soil and adversely affect the crop yield. Furthermore, the existing fertilizer recommendations for vegetables in Sri Lanka often consist of one predetermined rate of N, P and K for vast areas of vegetable production. Such recommendations assume that the nutrient requirements of vegetables are constant irrespective of the temporal and spatial variability of plant nutrients in the soil. In reality, supplemental nutrient needs of a crop can vary greatly between fields, seasons and years due to the differences in crop and soil management, and climate (Porch and Hunter 1999). Hence, the management of nutrients for vegetables requires a new approach that involves an adjustment to the application of N, P, and K to accommodate field-specific needs.

Site-specific Nutrient Recommendations

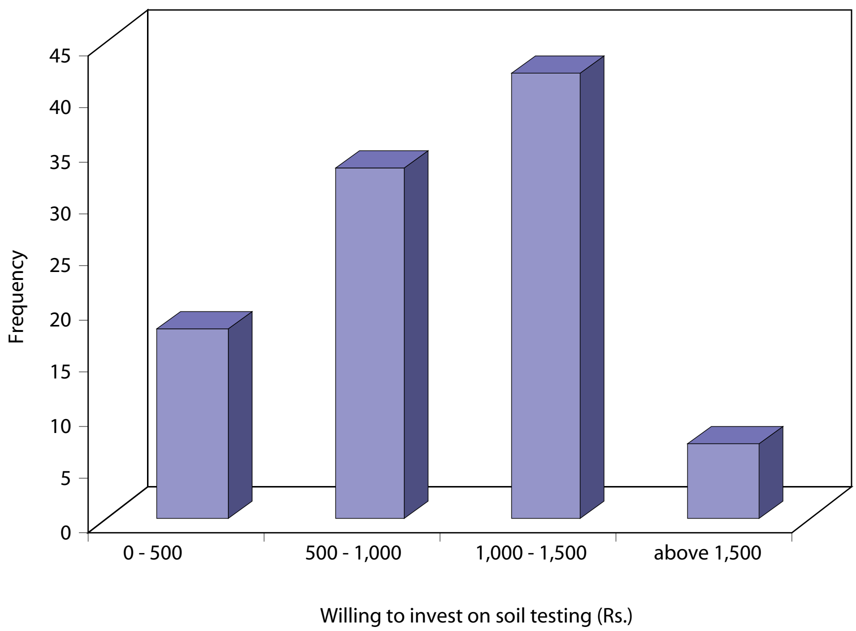
Many European countries use soil fertility maps to make fertilizer recommendations for a vast range of crops, often using sophisticated technologies such as EC mapping to define soil types. These maps are highly accurate and very useful for prescribing site-specific fertilizer recommendations. However, this type of technology is more applicable to farms with thousands of hectares than to the highly fragmented and scattered plots seen in the Kurundu Oya catchment, where the average farm size for vegetable cultivation is about 0.25 ha (Household survey 2008). Since farmers practice different management systems, the spatial and temporal variability of the soil fertility is extremely high. Therefore, soil test-based fertilizer recommendations could be more effective for this kind of situation than any other method.

In this site-specific nutrient management, crops are fed according to the nutrient availability at the site so that the quantity of fertilizer used will fill the deficit between the nutrient needs of the crop and the nutrient supply from naturally-occurring indigenous sources such as soil and organic amendments (Portch and Hunter 1999). Site and crop-specific fertilizer application rates can reduce the accumulation of excess amounts of plant nutrients in the soil, which are very likely to be removed with surface runoff and may enter waterways.

The sample population was asked about their preference for investment in soil-test-based fertilizer recommendations. It was found that nearly 50 % was willing to invest more than Rs.1,000 for soil testing per annum (Figure 2), and that almost all the farmers prefer to practice soil test-based fertilizer recommendations than to add fertilizer according to the existing broad recommendations.

One practical difficulty with soil test-based fertilizer recommendation however, is the cost of soil analysis. The capacity of government research institutes will not be adequate to cater for the whole farming community. Therefore, the private sector should be involved in the process and assistance should be provided to enable them to develop their facilities.

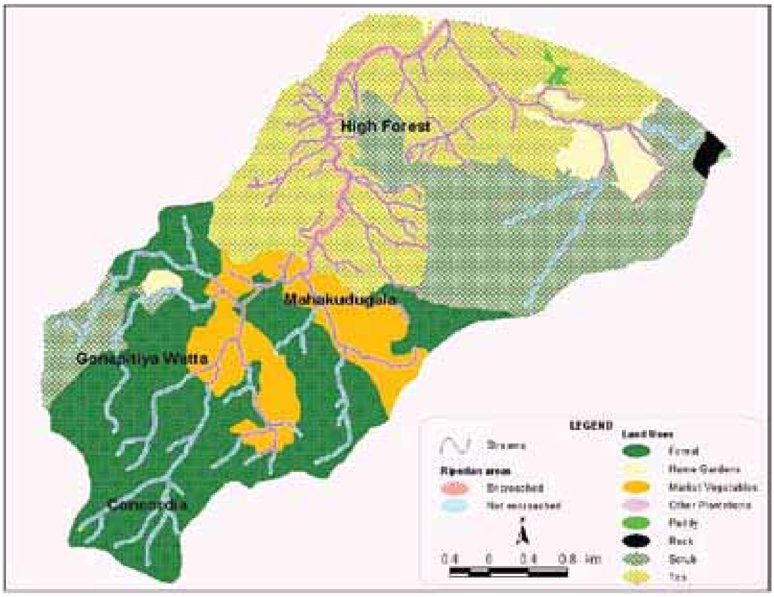
Figure 2. Farmers' willingness to invest on soil testing per annum (n =100).



Institutional and Legal Framework

Over fertilization, inefficient soil conservation and encroachment of sensitive lands such as forest reserves and riparian zones are closely associated with intensive vegetable farming in the Kurundu Oya catchment. Most of the riparian zones in the tea estates have also been encroached by state workers for vegetable farming (Figure 3).

Figure 3. The extent of encroached riparian zones in a part of the Kurundu Oya catchment.



Source: Land use mapping of Kurundu Oya catchment, 2008

There is existing legislation to control some of these illegal practices and reduce environmental damage, including 13 major pieces of legislation to ensure protection and sustainable utilization of land resources, but unfortunately there is no statute that applies to the management of lands in the Kurundu Oya catchment (Amarasekara et al. 2008). Some of the legislation that is in existence includes the Forest Ordinance (1907), the Soil Conservation Act (1951) and the National Environmental Act (1980), which are all closely linked with the mitigation of soil erosion and prevention of land encroachments. However, these documents provide only a legal platform and the institutional set up does not have sufficient capacity to implement such legislation at the field level. In addition, several government authorities have mandates to operate in the area but there is a lack of co-ordination between them and inadequate numbers of grass-root level officers to implement the Acts. These are major factors that hinder proper land management in the study area.

The Soil Conservation Act, which was implemented by the Natural Resources Management Centre (NRMC) of the Department of Agriculture, is the most powerful piece of legislation with respect to soil erosion and soil conservation. It was amended in 1996 to make provision for the establishment of the Soil Conservation Board, with representation from relevant government agencies, and for the establishment of a Soil Conservation Fund. Powers under the Act have also been delegated to Divisional Secretaries but the Soil Conservation Board has not yet been established. At the same time, the lack of field-level officers to implement the Act is a major limitation. The Agricultural Instructors, attached to the Provincial Departments of Agriculture and under the purview of the Provincial Councils, are expected to implement the Act at the field level; but the NRMC is under the Central Government of Sri Lanka. Since these two institutions function in two different administrative frameworks, many controversies have occurred in the implementation of the Act.

In the Kurundu Oya catchment there are only three Agricultural Instructors to cover the whole catchment, which is cultivated by about 4,500 families. The Agricultural Research and Development Assistant (ARDA) is the only field-level officer who can assist Agricultural Instructors to implement the Act. However, ARDAs are attached to the Agrarian Services Department of the Central Government, which has no direct link with the Provincial Councils. Therefore, priority should be given to introduce a grass-roots level category of extension workers under the Department of Agriculture, not only for the implementation of the Soil Conservation Act, but also to assist farming communities to solve their field problems. In addition, the Soil Conservation Board should be established without delay to empower the Divisional Secretaries so that they can in turn implement the Act at the field level.

Conclusions

Intensive vegetable farming is currently a major land use in the upper part of the Kurundu Oya catchment. Due to the high market demand and favorable climate, farmers prefer to grow exotic vegetables than other field crops. However, the increasing population is putting more pressure on limited land resources, which in turn creates a tendency to encroach forest and stream reservations, as these are the only land parcels available in the catchment. Such inappropriate land management practices associated with intensive vegetable farming have caused many problems such as soil erosion and sedimentation of water bodies. It was found that sediment carries more nutrients than the dissolved fraction, and hence, heavy sediment loads coming from vegetable plots with surface runoff may increase the nutrient levels in the stream water. Over application of fertilizers and inefficient soil conservation techniques associated with vegetable farming systems have also aggravated the situation. Therefore, it is proposed that fertilizer recommendations should be made according to soil tests rather than being based on a single predetermined rate, as this would reduce the accumulation of nutrients in both soil and water bodies. In addition, priority should be given to implementation of the Soil Conservation Act at the field level by strengthening the existing institutional set up.

Acknowledgements

The financial support given by the Crossing Boundaries Project of the PGIA, University of Peradeniya, Sri Lanka is greatly appreciated.

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