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# IRRIGATION, HEALTH, AND THE ENVIRONMENT: A LITERATURE REVIEW WITH EXAMPLES FROM SRI LANKA



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# Contents

**Introduction** ... 1

**Background: Irrigation Development in Sri Lanka** ... 1

**Identifying the Health and Environmental Impacts of Irrigation Development** ... 2
- Quantifying health and environmental impacts ... 3

**Description and Quantification of Irrigation, Health, and Environment Linkages in Sri Lanka** ... 5
- Food supply and nutritional aspects ... 5
- Impacts from access to irrigation water for domestic use ... 6
- Pesticide poisoning (acute and chronic impacts) ... 7
- Vector-borne diseases ... 10
- Siltation and sedimentation ... 11
- Water quality impacts ... 13
- Waterlogging ... 16
- Salt-affected soils ... 16
- Weed infestation ... 17
- Effects on biological diversity ... 18
- Social impacts of resettlement ... 19

**Conclusions** ... 19
- General conclusions ... 19

**Acknowledgments** ... 20

**References** ... 21

## Tables


| | | |
|---|---|---|
| Table 1. | Physical and economic quantification of irrigation, health, and environment linkages | 4 |
| Table 2. | Per capita availability of calories, proteins, and fats from vegetable resources (1985-1994) | 6 |
| Table 3. | Main Sri Lankan pesticide suppliers | 9 |
| Table 4. | Sedimentation studies for Mahaweli reservoirs | 12 |
| Table 5. | Fertilizer use in Sri Lanka, 1979-81 and 1989-91 | 15 |

## INTRODUCTION

The world's irrigated agriculture plays a vital role in increasing food production. Over the next 30 years, 80 percent of the additional food supplies required to feed the world is expected to depend on irrigation (FAO 1993). Because there is only limited scope for development of new water resources, increasing the efficiency of irrigated agriculture is vital. To understand ways to improve the efficiency of a system, it is necessary to move beyond the narrow engineering view of a system and perceive the interactions with the local communities served by the system and the natural environment within which it is located.

This paper attempts to present the linkages between irrigated agriculture, human health, and the environment based on a review of data available from Sri Lanka. Section 2, presents the background by reviewing irrigation development in Sri Lanka. Section 3 presents an outline for selecting the key environmental impacts of irrigation development, and suggests physical and economic indicators to quantify these impacts. Section 4 presents the main data with a short explanation of the main irrigation, health, and environment relationships and a review of their current status in Sri Lanka. Section 5 presents the conclusions.

## BACKGROUND: IRRIGATION DEVELOPMENT IN SRI LANKA

The history of irrigation in Sri Lanka dates back to 500 BC with a number of major schemes introduced between 275 A.D. and 1186 A.D. However, after the twelfth century, no large irrigation structures were built until the 1930s, although there was considerable restoration and rehabilitation of the earlier systems. In the last 30 years, there has been a significant expansion in major irrigation schemes with the area irrigated nearly doubling. Now there are 266 major irrigation schemes: 74 schemes in the Southern and Uva provinces and 159 schemes in the North Central, North West, and North Eastern provinces (Ministry of Irrigation, Power and Energy 1995). The recent major schemes include projects along the Mahaweli River, Walawe River (Uda Walawe Reservoir), Kirindi Oya (Lunugamvehera Reservoir), and Gal Oya. Current irrigation development projects, such as the National Irrigation Rehabilitation Project (NIRP), focus on the rehabilitation of tank systems encompassing rehabilitation of 800 minor and 35 major irrigation schemes.

Over the 30 years from 1963 to 1993, the area irrigated by major irrigation schemes in *maha* (the wet season) increased by 110 percent (from 118,000 ha to 247,000 ha) and in *yala* (the dry season) by 86 percent (from 87,000 ha to 162,000 ha). Much of this increase is a result of the Mahaweli Program, which services over 110,000 ha. In addition, medium-sized irrigation schemes cover about 45,000 ha and it is estimated that about 15,000-20,000 operational village tanks and anicuts irrigate about 235,000 ha. This gives a total irrigated area in maha of about 530,000 ha (ADB 1994). Thus about one quarter of the 1.9 million ha of cultivated land in the country is irrigated. There are about 123,000 ha of rain-fed rice in the southwest wet zone, with the remaining area of cultivated land devoted to plantation crops and rain-fed farming (Department of Census and Statistics 1995). Cropping intensity in the irrigated areas is about 140 percent, meaning an average of 1.4 crops per year. Generally, farmers prefer to grow rice in maha when rain is more plentiful (often combined with other food crops on rain-fed land), and other food crops in yala, when rain is less.

In addition to surface irrigation, groundwater is being increasingly used for irrigation, particularly in the Jaffna and the Kalpitiya peninsulas. As groundwells are unregulated and mostly provided by the private sector, no reliable data are available. However, estimates are that over 15,000 tube wells for both irrigation and domestic water supply have been constructed so far (Karunaratne 1991).

## IDENTIFYING THE HEALTH AND ENVIRONMENTAL IMPACTS OF IRRIGATION DEVELOPMENT

To identify the many environmental-irrigation linkages evident in Sri Lanka, it is necessary to have a conceptual model of the different physical causes and effects. At its simplest, this requires an identification of the key environmental issues. One such list has been drawn up by the International Committee on Irrigation and Drainage which divides environmental/natural resource issues of irrigation into the following eight major categories:

- hydrology
- water and air quality
- soil properties and salinity effects
- erosion and sedimentation
- biological and ecological change
- socioeconomic impacts
- human health
- ecological imbalances

Once the environmental issues have been identified, they need to be grouped into causes and effects, which result in a number of conceptual problems. First, it is important to carefully define physical boundaries. This is necessary since all phases of the water cycle are ultimately interlinked and the effect of a change in one part of the system will lead to changes in water quantity and quality in many other parts of the cycle. This makes it difficult not only to clearly demarcate between environmental changes within the system and between upstream and downstream (especially where one irrigation system flows into another system) but also to draw boundaries between surface water and groundwater. A second conceptual problem is to define the direction of the impact: while the natural environment affects the productivity of irrigated agriculture, irrigated agriculture affects the environment. Therefore, upstream deforestation is an environmental change that affects irrigation, while salinization is a change within the irrigation system that affects the broader natural environment outside the system.

These difficulties have been recognized and a model applicable to Sri Lanka is to separate the irrigation/environmental interface into four types of linkages (Kijne 1993):

- environmental impacts which occur within the domain of the irrigation system and affect its productive capacity (e.g., salinization of soil, depletion of aquifer)

- environmental changes outside the irrigation system that affect the productive capacity of the system (e.g., catchment degradation that increases siltation, irrigation water polluted by industry/domestic use)

- actions within the irrigation system that cause environmental changes outside (e.g., agro-chemicals, salinization with downstream effects)

- actions within the irrigation system which do not necessarily affect the productivity of agriculture, but which may still have undesirable environmental/health impacts (e.g., increase in vector-borne diseases)

In this paper all four types of linkages have been described to the extent of available information. An effort has also been made to generate a full list of potential impacts, both negative and positive.

## Quantifying Health and Environmental Impacts

Before turning to the review of environmental and health issues of irrigation development in Sri Lanka, possible indicators of environmental and health impacts were identified and listed. These indicators have been selected for use in quantifying impacts in both physical and economic terms (table 1). Physical quantification is a necessary first step, but economic quantification is useful in prioritizing environmental impacts in terms of cost to farmers, the government, and society. In this paper, the indicators have only been applied where information has permitted a rough estimation.

For an actual irrigation system, the economic quantification of a project's costs and benefits is normally conducted during the project feasibility stage, when the project must be justified economically by valuing the benefits of all possible impacts. Additional physical impacts are normally identified during the Environmental Impact Assessment (EIA) which focuses on mitigating negative environmental and health impacts. There is a growing emphasis on combining these two stages by costing the positive and negative environmental impacts in economic terms, so that their mitigation can be included before the EIA stage.

While it is often suggested that environmental degradation and irrigated agriculture affect each other, the exact extent of these linkages remains under-researched. There is a need to quantify the physical linkages both independently and with respect to the background changes that would occur regardless. For example, what is the level of water-related diseases or salinity with and without the irrigation system, or what is the extent of siltation with and without improved watershed management? Only when we have answered these questions is it possible to separate the issues specific to irrigated agriculture.

Once physical quantification has been achieved, it is possible to estimate the economic cost of the health or environmental changes. The advantage of this approach is that it can be very useful for policy makers to estimate the relative cost of each possible impact, for example, is salinization more damaging to the economy than siltation?

*Table 1. Physical and economic quantification of irrigation, health, and environment linkages.*

| Impact | Physical and economic quantification |
|---|---|
| Food supply and nutritional status | Calorie intake per capita, child growth monitoring<br>Value of changes in health status (cost of medicine and health care, work days lost/gained, etc.) |
| Access to irrigation water for domestic use | Daily use/reallocation ($m^3$) of irrigation water<br>Value of time spent on domestic water collection; value of changes in health status; value of changes in agricultural output |
| Pesticide use | Change in agricultural output pesticide poisoning: acute and chronic (incidence, prevalence, and mortality)<br>Value of changes in health status including loss of income; value of changes in agricultural output |
| Vector-borne disease | Incidence, prevalence, and mortality figures<br>Value of changes in health status, including loss of income |
| Water quality impacts:<br>Agro-chemical use, inflow of urban/industrial effluents into irrigation | Concentration of heavy metals and pesticide residuals; biochemical and chemical oxygen demand (BOD, COD), concentration of pathogens<br>Cost of treatment, decline in productivity; value of changes in health status; value of changes in agricultural output |
| Hydrology:<br>Conjunctive use | Groundwater yields and rate of extraction of groundwater ($m^3$/year);<br>Increased agricultural output; cost of groundwater pumping; cost of reduced water availability for nonagricultural purposes |
| Waterlogging | Area affected (ha)<br>Decline in productivity, cost of drainage, and changes in water management |
| Salt-affected soils | Electrical conductivity<br>Decline in productivity, cost of drainage and changes in water management |
| Siltation and sedimentation | Soil loss (tonnes/$km^2$); reduced dam-storage capacity<br>Decline in productivity, cost of dredging |
| Aquatic weeds | Area affected (ha)<br>Decline in productivity, cost of removal |
| Effects on biological diversity | Fish (per $m^3$ in reservoir), number and composition of birds and other forms of wildlife<br>Changes in current and future output from fisheries and agricultural yield; value of changes in tourism |
| Socioeconomic<br>(e.g., resettlement) | Number of households affected<br>Cost of compensation |

## DESCRIPTION AND QUANTIFICATION OF IRRIGATION, HEALTH, AND ENVIRONMENT LINKAGES IN SRI LANKA

### Food Supply and Nutritional Aspects

Irrigation development, combined with the introduction of high yielding varieties of rice and increased use of fertilizer and pesticides, has helped double rice production in Sri Lanka over the past 30 years. This increase in food production is one of the most obvious health benefits of irrigated agriculture. In general, increased food production not only has a beneficial effect on the farmers involved but also increases food security for the urban population. However, some cases have shown that the nutritional status of the farming community is adversely affected if the system has a very low productivity or its main focus is on cash crops.

Food production from irrigation has increased when Sri Lanka is taken as a whole. The intensively irrigated areas provide a disproportional share of the food and export crops. The Mahaweli area alone, which covers about 12-14 percent of the area sown to rice each year produces about 17-20 percent of the total food production. The main reason for this is that average annual unhusked rice yields per ha in 1993-1994 in the Mahaweli area were about 2,000 kg more at 8,700 kg than the national average of 6,700 kg per year (Department of Census and Statistics 1995). Total rice production has increased (maha and yala combined) over the past 30 years from just under 1 million tonnes in 1963 to 2.57 million tonnes in 1993 (Department of Census and Statistics 1995). The main crop is produced during the maha season of the northeast monsoon, which brings less rain but covers a larger portion of the island than the southwest monsoon of the yala season.

However, the effects of this increase in food production on the nutritional status are not clear. While rice production has been increasing at an average of 5 percent a year for the past 30 years, the population has been growing at about 2.2 percent over the same period. From the data from the Food Balance Sheet (table 2) the per capita availability of calories, proteins, and fats from vegetable and animal sources including both national production and imports is calculated. Data in table 2 for vegetable sources (which include cereals, roots, sugar, pulses, nuts, and vegetables) do not show an increase in per capita nutritional levels (i.e., better calorie intake) in the past 10 years.

Only a few studies have focused on the nutritional status within irrigated areas. However, several nutritional studies have been carried out after the Kirindi Oya Irrigation and Settlement Project (KOISP). A review of these studies is presented in a report of the KOISP Impact Evaluation Study (IIMI 1994). According to this report, the percentage of the population chronically undernourished (stunting) in the KOISP area is almost the same as the national average of 36.4 percent (1994). Furthermore, anthropometric measurements carried out in the KOISP project area in June 1994 showed a very high degree of acute undernourishment (wasting) among the population in the area: 45.5 percent compared with the national average of 18.4 percent. Part of the reason for the nutritional problems in the KOISP area may be the lack of water for irrigation purposes, which reduces household income and results in an inadequate dietary intake by the farmer families.

*Table 2. Per capita availability of calories, proteins, and fats from vegetable resources (1985-1994).*

| Year | Calories per day | Proteins (grams/day) | Fats (grams/day) |
|---|---|---|---|
| 1985 | 2,396.6 | 43.3 | 51.7 |
| 1986 | 2,266.7 | 40.8 | 46.5 |
| 1987 | 2,133.9 | 38.3 | 42.4 |
| 1988 | 2,199.8 | 40.2 | 42.8 |
| 1989 | 2,118.1 | 40 | 44.6 |
| 1990 | 2,159.5 | 41 | 44.4 |
| 1991 | 2,203 | 42.6 | 42.9 |
| 1992 | 2,146 | 41.1 | 44.4 |
| 1993 | 2,158.1 | 41.3 | 44.7 |
| 1994 | 2,345.9 | 46.6 | 49.8 |

*Source:* Department of Census and Statistics 1995.

Studies from some countries have shown that for irrigated agriculture to have the maximum impact on the nutritional status of plot holders, the nutritional requirements of all household members have to be considered. If the introduction of irrigation results in a change from subsistence farming to focusing solely on cash crops, it may have a negative impact upon the nutritional status of the farm families although cash income may increase (Bradley and Narayan 1987).

Fish can also be bred in irrigation systems, which would provide a valuable source of protein. Sri Lanka has few natural freshwater lakes. However, man-made irrigation tanks can be and are used to provide fish. Chinese carp and tilapia were introduced in the 1950s, and the Indian carp introduced later. Following opposition, government support to inland fisheries was terminated in 1989. The private sector, NGOs, and cooperative societies did continue with inland fishing (the fishery stations were leased to the private sector). Their relative lack of technical expertise and the end to the government's large subsidy program for fingerlings and other assistance led to a 75 percent decline in inland fishery production with a loss of Rs 1.2 billion per year in lost production (Jayasekera 1996). The 1989 decision was reversed by the government elected in 1994, and government fisheries field stations (e.g., at the Uda Walawe Reservoir) have now been reopened. An Aquaculture Development Division has been set up in the Ministry of Fisheries with a government subsidy program. The government also proposes to amend the Fisheries Act to restrict reservoir fishing rights to Fisheries Cooperatives. These plans may lead to an expansion in inland fishing as a source of income and nutrition for communities near irrigation systems.

## Impacts from Access to Irrigation Water for Domestic Use

In arid and semiarid parts of the world, irrigation provides an important source of water for purposes other than agricultural production. An increased source of immediately available water for a large part of the year could have a positive effect on the hygienic status of the population involved and can considerably reduce the occurrence of enteric, skin, and eye diseases

(McJunkin 1993). However, the provision of readily accessible water close to settlements will lead to this water being used for washing, bathing, and sometimes even for drinking. This, in turn, may eventually increase the number of cases of enteric diseases and increase such risks as cholera epidemics, since the canal water will inevitably be contaminated with infective microorganisms. It is, therefore, always safe to assume that when developing an irrigation system the water delivered for irrigation purposes will be used for multipurposes, especially where proper water supply facilities have not been developed. In areas where the groundwater is saline or the groundwater table is too low, possibly as an effect of the introduction of tube wells, canal irrigation water may be the only source of water for the community for part of the year.

Irrigation development in Sri Lanka can provide an important source of water for purposes other than agricultural production, especially in the dry zone areas, such as at Gal Oya and Kirindi Oya. Unfortunately, very little is known about the multiple use of irrigation water in Sri Lanka and its possible health impacts. But it is likely that populations living within systems that utilize drainage water from intensively cultivated areas, such as the Rajangana System (which receives drainage water from System H of the Mahaweli Project), run a risk when using canal water for domestic purposes.

The opposite situation seems to arise in the Uda Walawe area and parts of the North Central Province, where there is very high fluoride concentrations in the water due to the deposits of serpentine that contain 100-200 ppm of fluoride. Samples taken from the Uda Walawe River basin during planning of the irrigation scheme showed that surface water can be used for drinking and irrigation without any treatment, but water from dug wells needed to be treated as it showed an electrical conductivity at 300 microS/cm higher than the national standard for irrigation water, and the fluorine and chlorine values exceeded the World Health Organization (WHO) standard for drinking water (CEA 1995a).

The Anuradhapura tanks also provide water known to be less saline and has a lower fluoride level than the groundwater (CEA 1994). Thus in these areas drinking surface irrigation water instead of the high fluoride groundwater has positive health impacts preventing skeletal fluorosis.

### Pesticide Poisoning (Acute and Chronic Impacts)

Agro-chemicals are applied to reduce crop loss. Estimates are that plant pests, if left uncontrolled, would cause losses of between 10 and 15 percent of total yields, depending on the particular crop (Kudagamage, Senarath, and Fernando 1992). Losses are generally highest in horticultural crops: flowers, vegetables, and fruits. Therefore, it is essential that pests be controlled. A variety of methods, including biological, selecting pest-resistant crops, mechanical, and chemical can be used to reduce crop losses. But agro-chemical measures have the advantage that they are convenient to use, give quick control, and are able to reduce pests to extremely low levels.

However, the intensive use of agro-chemicals within irrigation systems can have an impact on human health, not only through the contamination of the water sources but also through acute and chronic pesticide poisoning. Pesticides can also have an impact on the ecosystem and there are growing concerns over pesticide-resistance pests. The use of pesticides is likely to be higher in irrigated than in nonirrigated areas making the study of pesticide-related health problems especially relevant to irrigated communities.

The reason for the high use of pesticides in irrigated areas is linked to the increased intensity of production, following the shift from low- to high-input agriculture. The technological shift during the green revolution introduced high yielding varieties, monocultures, and increased dependency on agricultural inputs. This, in turn, led to a general commercialization of agriculture in irrigated areas where private and public companies encouraged the use of chemicals by improving accessibility, providing credit facilities, and increasing sales promotional work. It could also be argued that the increased soil moisture created through irrigation aggravates the pest problem by providing breeding grounds for weeds and insects. High chemical use was also stimulated by rises in farm wages, which made labor-intensive weeding more expensive. Instead of hand weeding, over two-thirds of rice now cultivated in Sri Lanka has weedicide applied (Department of Census and Statistics 1995).

Rice consumes about 70 percent of the pesticides imported to Sri Lanka, mostly weedicides (NARESA 1991). On a national average, irrigation farmers in maha 1992/93 who cultivated rice spent about Rs 2,600 per ha on pesticides (Department of Agriculture 1994). However, due to the significant price premium for an unblemished appearance of high-value crops such as vegetables, and field crops such as chili, they receive a higher input of pesticides per hectare than on rice production. The key pesticides used in Sri Lanka are organophosphate insecticides, carbomate insecticides (carbofuran, BPMC, and carbaryl), herbicides (paraquat, propanil, 2,4-D, and MCPA), and fungicides (propineb, mancozeb, and thiram).

The market for pesticides is also affected by the industry. The Sri Lankan market is dominated by a few large local firms that import base chemicals (e.g., carbofuran, paraquat) under license from brand name producers (table 3). The imported chemicals are generally mixed with unpatented versions available from Taiwan and elsewhere, and then bottled/packed for sale. The four formulation plants producing approximately 60 percent of the formulated products in the market (de Alwis 1989) are listed in table 3. For marketing purposes, most firms employ former officials of the Department of Agriculture. Industry sales personnel are either not well-trained or not inclined to provide advice for minimizing pesticide use but their advice is taken seriously by farmers. A survey in 1987 in Nuwara Eliya found that 51 percent of farmers obtained their information on pesticides from pesticide traders, 30 percent from other farmers, 7 percent from their own experience, and only 12 percent from the government extension officer, the KVS (Abeysekara 1988). The firms submit samples of new products to the agricultural research stations (e.g., at Mahailuppallama) and some of the results are published by the Department of Agriculture as instructions to field staff and as a handbook, which is regularly updated for recommended pesticide applications.

Acute pesticide poisoning is a major health problem in Sri Lanka with between 10,000 and 13,000 cases per year. In several agricultural districts, pesticide poisoning is the main cause of death (Fernando and Fernando 1995). Approximately 73 percent of these cases are due to intentional poisoning (Jeyaratnam, de Alwis, and Copplestone 1982). There is still not enough information on intoxication due to occupational exposure but a study of hospital records of the Anuradhapura District indicated that 31.9 percent of all hospital admissions were due to occupational exposure (Jayaratnam, Lun, and Phoon 1987). Another study of hospital admissions in Mahaweli System H found 19 percent of the cases due to occupational exposure (van der Hoek et al. 1997). However, most cases may not require admission to a hospital and are therefore not included in routine health statistics. Most acute occupational poisoning occurs during spraying or within 4 hours after spraying. Chronic pesticide poisoning is less well-documented, but studies in other countries show that it can have immunological effects, reproductive effects, and be carcinogenic.

*Table 3. Main Sri Lankan pesticide suppliers.*

| Local Firm | International Supplier | Share of Market (%) |
|---|---|---|
| Hayleys Ltd. | Bayer (German) | 30-40 |
| Harrison and Crossfield Ltd. | Ciba-Geigy (Swiss) | 20 |
| Lankem Ltd. | Shell Co. (UK-Dutch) | 20 |
| Ceylon Petroleum Corporation | FMC Corp. (US) | 20 |

*Source:* R. de Alwis 1989.

There are a limited number of studies documenting the specific health impacts of pesticide use within irrigated areas. A mortality study covering 27 settlements in Mahaweli System C showed that suicide was the leading cause of death during the period 1983-87 with 91 percent of those committing suicide using pesticides (Fernando and Fernando 1995). A survey based on household knowledge, attitudes, and practices relating to pesticides use in Mahaweli System H found that the majority of farmers had suffered from pesticide-related illnesses. The same study found that although the farmers were aware of the danger of pesticides none used protective clothing before engaging in highly hazardous practices (van der Hoek et al. 1997).

The other major impact of pesticides on human health is contamination of food and water. In 1986, a study undertaken by the Ceylon Institute of Scientific and Industrial Research found that pulses such as green gram and cowpea had appreciable levels of malathion residues. Although the use of malathion in agriculture was banned in 1979 it is used extensively in malaria control, and may be used illegally in agriculture (Mubarak 1988). Besides the direct impact on humans as a consequence of the high use of pesticides there could also be a devastating long-term impact on the ecosystem and thereby on the health of humans through the bio-accumulation of toxic substances in the food chain.

Reducing these negative impacts from pesticides could include both changing the demand for pesticides by farmers through integrated pest management, and by working with pesticide producers to improve labeling on bottles, or to provide powders instead of easily digestible liquids.

In terms of the supply side responses, the industry is regulated by the Control of Pesticide Act No. 33 of 1980 which provides for "the licensing of pesticides to regulate their import, packaging, labeling, storage, formulation, transport, sale, and use." Arising from this Act, in 1983 the Pesticide Registry was set up at the Department of Agriculture, Peradeniya. Registration began in 1985. In 1987, there were altogether 405 products; and 94 active ingredients registered 50 insecticides, 17 herbicides, and 27 fungicides. There are a number of banned agro-chemicals, including DDT, endrin, parathion, parathion-methyl, leptophos and 2,2,4-T. In addition, there are a number of restricted chemicals including all pesticides of WHO Class 1A and 1B, all organochlorines, and all pyrethroids. The Pesticide Registrar recommends a gradual phasing out of the most hazardous pesticides, for example monocrotophos, the import of which has been banned since mid-1995.

For labeling, WHO recommendations were initially adopted, requiring that the label be in Sinhala, Tamil, and English and marked "poison." In November 1995, the Sri Lanka Standards Institute published a draft code of practice for packaging pesticides (first revision).

In terms of demand, the Ministry of Agriculture is involved in farmer training in integrated pest management (IPM). IPM extension services are jointly operated in 13 districts by the Department of Agriculture through its plant protection service and the FAO. In recent years, the government, NGOs, and international aid agencies have increased emphasis on IPM. Experience elsewhere in the region suggests that insecticide use, in particular, can be cut significantly with no drop in yields, if combined with IPM. The main problem is overapplication of pesticides by farmers. A survey in Nuwara Eliya in 1987 (Abeysekera 1988) found that 65 percent of vegetable farmers used more than the recommended dose, with 7 percent using four times the recommended dose. However, a very extensive long-term program of training farmers on IPM will have to be launched to significantly reduce the use of pesticides in Sri Lanka.

### Vector-Borne Diseases

Of the more than 30 diseases linked to irrigation development, vector-borne diseases are probably the most pronounced, especially schistosomiasis (also called Bilharzia but not found in Sri Lanka), malaria, and Japanese encephalitis (JE). Disease vectors like mosquitoes and snails find ample breeding opportunities in the water retained within the irrigated system in canals, seepage pools, rice fields, or along the margins of reservoirs. The actual propagation of these vectors following irrigation development, if any, is determined by a variety of interacting factors, among which geographical location, technical design, human migration, choice of crops, operation and maintenance practices, pre-project health, and socioeconomic status are considered primarily important (Goonasekera and Amerasinghe 1987; Birley 1989; Weil et al. 1990).

In Sri Lanka, large water resource development projects such as the Minneriya, Gal Oya, and Mahaweli projects, have increased the malariogenic potential of areas through increased vector propagation, aggregation of labor, and resettlement of people from non-malarious areas who had no immunity (Samarasinghe 1986). The largest number of studies on malaria and irrigation development have been undertaken in Mahaweli System C which, mainly in the early stages of project implementation, showed a very high incidence of malaria. The most thorough study was done in Block 6 of this system as a longitudinal study mainly researching the vector ecology and species composition before, during, and after irrigation development. This study concluded that irrigation development led to reduced breeding by the majority of species; however, most species that did increase in prevalence were potential vectors of human disease (Amerasinghe and Ariyasena 1990: Amerasinghe and Indrajith 1994).

Another study carried out in Mahaweli System C focused on irrigation management and design, and their impact upon vector breeding. This study found that where maintenance of the system is neglected, or inefficient water management is practiced, increased vector breeding sites could be created through waterlogging, seepage from canals, excess water in the drainage system, reduced canal water velocity, and water rotations favoring the propagation of vectors (Speelman and van den Top 1986). Jayawardena (1993) surveyed a resettlement population in Mahaweli System C from 1985 to 1987 and found that malaria had a significant impact on the households and hampered the implementation of the project. One of the reasons for malaria becoming such a big problem in this system could be that a large part of the new settlers came from the wet zone of Sri Lanka and had neither the experience in dealing with the disease nor immunity against the parasite. Another reason was the absence of a clear health policy at the beginning of the settlement program. It is reported that over 100,000 people were brought into the system by 1987 with only one doctor in place. Later, a network of subdivisional health centers was established to serve the population. A study of the direct and indirect cost of malaria to a community living in an area with a small-scale tank-based irrigation was carried out in the Huruluwewa watershed in the Anuradhapura district. The total average annual cost per household for all episodes of malaria experienced over a year made up approximately 10 percent of the net household income (Konradsen et al. 1997a; 1997b).

Japanese encephalitis (JE) has been known to be endemic in Sri Lanka for many decades. However, the disease did not constitute a serious hazard to human health until the 1980s. In 1985 and 1987, major JE epidemics occurred in the low country dry zone rice-growing areas in the North Central and North Western provinces (Peiris et al. 1993). The association between JE and irrigation was briefly reviewed on the basis of survey data collected from selected villages within System C and the Kirindi Oya Irrigation and Settlement Project. It was found that JE transmission in these areas could be linked to vector breeding in the rice fields (Vitarana 1986).

### Siltation and Sedimentation

Siltation and sedimentation lead to a buildup of soil in irrigation channels and reservoirs, which can shorten their useful life considerably, or require costly dredging to remove the silt. As with other environmental issues, the key issue is to establish a natural baseline since all rivers carry sediment. Changes in stream flows due to inappropriate watershed management are controversial and hard to measure. The dose-response relationship linking, for example, deforestation with increased water runoff and flooding, remains unproved because of the lack of thorough research. Work on experimental plots clearly shows that water runoff is greater with bare soil than with vegetative cover. However, demonstrating this at actual sites requires extensive data.

Removal of vegetative cover in the watershed has shown to increase the runoff portion of the rainfall, accompanied by high sediment levels. Observations made in the 1970s show that in the wet zone catchments, rainfall-runoff ratios increased by 1.28 percent while in the dry zone they increased by 0.75 percent. In the Nilwala Ganga catchment, the rate was 2.17 percent (Yatawara 1997). In the Mahaweli basin, similar trends of runoff were observed despite decreases in rainfall.

Sedimentation in dams is itself a "natural" process, but is exacerbated by poor watershed management. It is natural for the velocity of the river to drop as it approaches the reservoir which, in turn, reduces the sediment transportation capacity of the water and hence leads to sedimentation. Once the sediment loads carried by the river are deposited in a reservoir, the water released is generally clear. This can cause problems downstream if the sediment is no longer available for deposition as has happened following the construction of the Lunugamvehera Reservoir at Kirindi Oya which adversely affected about 125 ha in the lower floodplain (IIMI 1994). Evidence shows that, often, the natural rate of sedimentation goes up following construction of a dam as people move into the catchment area as a result of resettlement. This has happened in the Mahaweli areas. This may be one of the reasons why preoperational estimates of dam sedimentation may be much less than the actual post-operation rate of sedimentation.

In Sri Lanka, siltation affects both large-scale irrigation schemes and the small minor irrigation schemes. In the case of the large schemes, the areas of the country most prone to sedimentation are the Mahaweli reservoirs, which are affected by upstream land use change. Research indicated that about 46 percent of the Polgolla Barrage in the upper Mahaweli was silted in 1996 only 20 years after its commissioning. However, Polgolla is a barrage and not a reservoir so water storage is less important, and the latest research suggests that Polgolla has reached a state of equilibrium with the total incoming sediment load being flushed out (Yatawara 1997). The siltation rate of Rantembe Reservoir is estimated at over 5 percent a year (Lawarance and Kuruppuarachchi 1986) and it has now lost 36 percent of its reservoir volume in 7 years (Yatawara 1997) as shown in table 4.

*Table 4. Sedimentation studies for Mahaweli reservoirs.*

| Reservoir name | Date of impoundment | Surveyed capacity* (mcm) | Surveys conducted | Capacity lost/ year (mcm) | Percent lost/ year |
|---|---|---|---|---|---|
| Kotmale | 1985 | 170 to 183 | two (1990, 1995) | 0.62 | 0.3 |
| Polgolla | 1976 | 2.5 | two (199, 1996) | 0.1 | 4 |
| Victoria | 1985 | 713 | one (1993) | 0.5 | 0.07 |
| Randenigala | 1986 | 791 | one (1996) | 7.24 (?) | 0.9 |
| Rantembe | 1988 | 7 to 9.4 | four (1991, 1993, 1994, 1995) | average 0.42 | 5.25 |

* Figures are rounded to one decimal place

*Note:* mcm = million cubic meters.

*Source:* Yatawara 1997.

In the case of siltation in the smaller schemes, the coarse soil particles are deposited first in the tank, while the finer, more loamy soil is deposited in the canals below the tank. In the ancient tank systems, each tank had a *mada sorovva* (silt-sluice), which enabled the farmers to secure the silt that had accumulated in the tank bed and use it as fertilizer (Disanayake 1992). The main reason for siltation in the tanks is the unsustainability of the traditional land use system of rain-fed upland farming in the catchment of the tank and irrigated cultivation downstream of the tank. This system is now under pressure from population growth, fragmentation of land, and other problems which means that the upland chena farming leads to soil erosion, which reduces the water storage capacity in the tanks. The soils in the chena lands are highly fertile, but undergo high erosion once the tree cover is removed. If the land is kept fallow for 8-10 years, the tree cover will return, but this no longer happens (Dharmasena 1994). Studies done in the Nachchaduwa catchment in the North Central Province showed that runoff from chena-cultivated lands was as high as 36-54 percent of rainfall. For the scrub and forest areas, this percentage was lower than 2 percent. Soil losses from the chena land exceeded the sustainable limits by 17 percent, while those from the scrub and forest areas were less than 1.5 percent of the sustainable limits (Sumanaratne and Somasiri 1990).

The economic damage of siltation has been estimated in Sri Lanka in a number of studies. However, the key economic issue is not only the total cost to the economy of poor watershed management but who bears that cost. Basically, in the present situation, poor watershed management is a cost to the upstream farmers and the Irrigation Department and is of some benefit to the downstream farmers. The upstream farmers suffer a loss of topsoil, which can in some cases affect productivity, while the downstream farmers may be hired to desilt downstream canals and then use this rich soil for their own fields. Estimates based on potato farmers in Perawella assume that erosion causes a 1 percent yield decline each year over 20 years. This gives a productivity loss to upstream farmers of Rs 333 per ha in the first year, which rises to Rs 6,074 per ha by the 20th year (Clark 1994). It is the practice in Sri Lanka not to desilt tanks since this is prohibitively expensive. Irrigation canals are however desilted annually. A review of the records for this paper shows that, on average, the Irrigation Department spends over Rs 50,000 per year for desilting minor irrigation channels in each scheme. This works out to about 25-50 percent of the total annual operations and maintenance budget of each minor scheme.

The solution being proposed for improved watershed management is conservation farming, which generally uses vegetative methods to reduce soil runoff. This approach has been tried in a number of areas and the main determinant of success seems to be a strong institutional structure of farmers and other groups, and allowing the farmers to select the combination of vegetative crops which will provide them with the highest economic return. While some studies show that farmers can cover their costs by growing profitable tree crops, other studies suggest that they may need to be subsidized.

## Water Quality Impacts

### *Nonagricultural use of water*

The use of water for nonagricultural purposes can have an effect on both the quantity and quality of water available for irrigated agriculture. The effect on quantity arises as the increased need for water allocations reserved for domestic/urban consumption may reduce the irrigation intensity in existing systems or hamper the possibility for future developments. This competition for water will increase in Sri Lanka as in most other Asian countries where irrigation will come under pressure to reduce its use due to increases in industrialization and urbanization. Actual water quantity conflicts have arisen in the Philippines, where the residential and energy demands of Manila are causing water shortages for irrigation in Central Luzon. The same is occurring in Hyderabad, India, and Jakarta and Surabaya, Indonesia.

The effect on quality arises because the water from domestic or industrial areas provided to irrigated agriculture for reuse is often polluted. The main source of pollution in water from the domestic sector comprises pathogenic microorganisms, including bacteria, viruses, protozoa, and helminths (worms). These can cause enteric diseases in the human body. The three groups that could be affected are populations consuming vegetables irrigated with wastewater, sewage farm workers, and populations residing near wastewater-irrigated fields.

In many cases, these pathogens can be treated cost-effectively by pond stabilization, with the treated water being rich in plant and soil nutrients. In addition, the microorganisms can break down naturally in the water if there is sufficient distance to the irrigated fields. This natural process is often employed to reuse water from urban areas.

The main source of water pollution from the industrial sector is heavy metals. While very low levels of metals are found naturally in water, soils, and plants, at higher levels these metals can accumulate as they move up the food chain until at the top of the food chain (i.e., humans) they can be present in concentrations to cause toxicity. In the past, this problem was not such a priority for irrigated agriculture, but it is now beginning to develop as industrialization takes place. The problem of industrial waste water entering irrigation systems has been reported from a few areas in Sri Lanka, such as Kurunegala, Galle, and Ambalangoda, where urban pollution is entering irrigation channels. In Kurunegala, spent dyes from textile factories and spent oil from bus depots enter the town drainage scheme which then enter the irrigation scheme. An area of about 30 ha of land has been abandoned due to this pollution affecting the soil. Also, the Embilipitya Paper Mill and a large milk factory at Ambewela in the Badulla District are causing industrial pollution.

In Sri Lanka, the conflict between irrigation and hydropower generation is an issue in the Mahaweli areas where the reservoirs are used both for generating hydropower and for providing water to irrigation. The most contentious issue is over the amount of water diverted to Polgolla during the severe drought of 1996. Water released downstream at Polgolla has a much higher generating head in the Victoria-Randenigala-Rantembe cascade of the main Mahaweli than water that is diverted at Polgolla, which serves either System H (generating hydropower only at Ukuwela) or Systems D and G (generating power at both Ukuwela and Bowatanne). Each million cubic meters diverted at Polgolla under normal operating conditions causes an average loss of 0.48 gigawatt hours of energy (Weerakoon 1989). This issue arose during the recent drought (1996), when it was proposed that to maximize water for hydropower, water should not be diverted to Mahaweli H at Polgolla. The farmers who suffer from the reduction in irrigation water have been compensated.

### *Water quality impacts of agrochemical use (fertilizer and pesticides)*

Modern intensive agricultural production requires inputs of both pesticides (as mentioned under *Pesticide poisoning* p.8) and inorganic fertilizer. The use of inorganic fertilizer has increased as a result of increased cropping intensity with high yielding varieties, making it difficult to replenish the soil nutrients by means of traditional organic fertilizers.

Initial reports by TAMS (1981) found that pesticides at low concentration were found in certain samples from irrigation water. For example, water samples collected from the Minneriya Reservoir in 1979 had traceable levels of aldrin, deildren, and BHC (CEA 1995b). An indication of the ecological impacts of pesticide use in Sri Lanka is the finding that chemicals have contributed to the decline of inland fish species living in tanks and rice fields.

Chemical fertilizers act faster and are more concentrated than their organic equivalents. The use of fertilizers is closely correlated with yield growth, with potential yield increases ranging from 50 percent to 80 percent. In 1987, in Sri Lanka, about 102,000 tons of fertilizer were consumed by the rice sector (150 kg/ha) which was about half the total fertilizer consumption in the country. Between 1957 and 1987, fertilizer use in the rice sector increased about 9 times, from 16 kg/ha to 150 kg/ha (IRRI 1991). However, average fertilizer use has been growing slowly compared with other Asian countries (table 5). Thus, unlike pesticides which are generally applied above the recommended dose, fertilizers are still applied below the recommended amount. But in certain areas of intensive commercial vegetable farming, such as the Kalpitiya and Jaffna peninsulas, fertilizer application is well above the national average.

*Table 5. Fertilizer use in Sri Lanka, 1979-81 and 1989-91.*

| Country | Fertilizer use 1979-81 (kg/ha) | Fertilizer use 1989-91 (kg/ha) | Fertilizer use (% annual increase 1979-81 to 1989-91) |
|---|---|---|---|
| Sri Lanka | 81 | 98 | 21 |
| India | 33 | 73 | 121 |
| Bangladesh | 45 | 101 | 124 |
| Malaysia | 89 | 188 | 111 |

*Source:* World Resources Institute 1994.

Fertilizers, like other chemicals, impair the quality of water in streams and rivers through drainage from farms and through deep percolation with irrigation water which can affect the groundwater. Studies carried out in the Jaffna peninsula showed that about 79 percent of the farm wells in the area contained water with nitrate contents above the value recommended by WHO for drinking water. In the islands off the peninsula, 50 percent of the wells contained water above the recommended range. The wells with high nitrate contents were located near farms with high cropping intensity and high fertilizer application. By comparison, in coastal areas where rain-fed rice is grown with low fertilizer application, the nitrate content was low (Nagarajah et al. 1988a).

More intensive irrigation after the introduction of water pumps in the early 1960s is another reason attributed to the high nitrate concentration in Jaffna. It was observed that after the introduction of water pumps, there is a tendency to use more water than necessary. The soils of this area, being well-drained, possess high infiltration rates. As a result, excess nitrates rapidly reach the aquifers containing groundwater (Nagarajah et al. 1988b). The east of Sri Lanka (Mullaitivu and Batticaloa) also exhibits high groundwater use and fertilizer application which could have an impact on groundwater.

Another area of high nitrate use is the Kalpitiya peninsula, where intensive cropping under groundwater irrigation is practiced. High nitrate concentrations (up to 40 mg N/l) have been observed in shallow hand-dug wells in the peninsula. Reports by the Department of Agriculture and the British Geological Survey (Lawarance and Kuruppuarachchi 1986) attribute the high nitrate levels to leaching of inorganic fertilizers. During the 1970s and 1980s the area under groundwater irrigation increased to about 1,000 ha as new crops such as onion, chili, and vegetables were introduced, more wells were dug, and mechanical pumps installed to meet the demand for more water. Onion is now the main crop (up to 3 crops per year), while yala chili and yala and maha tobacco are also important. Nitrogen fertilizers are used extensively, with the recommended doses being 200 kg N/ha for a single crop; phosphate and potassium use is also high. Actual application rates in the Kalpitiya peninsula are often much higher than the recommended level and can be as much as 1,000 kg N/ha/yr. This is applied with a base application at the time of sowing and then followed by 3-4 dressings for the remainder of the cultivation season. Each irrigation well has a command area of between 0.6-1 ha and irrigation is practiced all year-round, mainly by spray irrigation with a hand-held hose. It is estimated that 1,000 mm are applied annually, of which approximately 200 mm are likely to return to groundwater. Such high leaching is a clear economic loss since a leaching loss of 60-120 kg N/ha is equivalent to Rs 2,000-4,000/ha (Lawarance and Kuruppuarachchi 1986).

In addition, increased fertilizer runoff from irrigated areas stimulates the growth of algae and plants in the waterways. The increased decomposing algae and plant material use up oxygen in the water and cause fish and aquatic organisms to die (Moss 1989). Water quality surveys of many irrigation reservoirs and channels were found to contain high nutrient levels (e.g., in Mahaweli System H and irrigation reservoirs in the Anuradhapura and Polonnaruwa districts). There is a risk that phosphate levels in Nuwara Wewa and to a lesser extent in Tissa Wewa (both in Anuradhapura) are reaching levels which may be high enough to cause severe eutrophication (CEA 1994). Similar results for the surface waters in Mahaweli System H found that the high concentrations of nutrients in the water between Kalawewa and Rajangana indicated high agricultural/agrochemical inputs (Azmy, de Alwis, and Dassanayaka 1993). In 1996 there were large algal blooms in Kotmale Reservoir. Such algal blooms would be more widespread but are naturally controlled to some extent by the reduction in water level in the reservoirs and canals during the dry season, which allows grass to grow that is often eaten by cattle. This results in the loss of nutrient from the sediment (Azmy, de Alwis, and Dassanayaka 1993).

## Waterlogging

Continuous growth of groundwater level, owing to excessive leaching of irrigation water and poor drainage, in many cases leads to waterlogging accompanied in some arid areas with salinization of soils. Although carefully designed irrigation water management practices can avoid these conditions in some cases, land lost due to waterlogging is on the increase. Effects of waterlogging on crops include reduced nutrient availability and uptake, reduced oxygen levels, and the development of toxic compounds in the soil, which lead to reduced production. These result from restriction of root development impeding the decomposition of organic matter and obstruction of gas exchange in the soil.

Due to the inadequacy of studies, the actual extent of the problem in Sri Lanka is unknown. However, high water use observed in schemes such as the Uda Walawe and Kirindi Oya projects in the south of the island, indicates that the potential exists for waterlogging.

## Salt-Affected Soils

Primary minerals in the soil are often the main sources of salt constituents. Surface water and groundwater irrigation can convey these salts to agricultural areas from their origin. Especially in dry zone areas, salinization may occur when evaporation of water near the soil surface leads to a steady accumulation of salts.

The increase of osmotic pressure in the soil solution due to the high salt concentration makes it difficult for plants to absorb water through their roots. Another effect is the absorption of toxic ions from the salt-concentrated water. An indirect effect of salinity is interference with the activities of the soil's microbial population leading to the retardation of the soil nutrient transformation process (Abrol, Yadav, and Masood 1988).

The different soil and environmental conditions under which salinity occurs in Sri Lanka are well-understood. In the wet zone, salinity is mainly confined to the coastal low-lying rice lands due to salt water intrusion. Salinity problems in the dry zone are mainly observed in the saline and alkaline soils that occur in the northwest coastal plain of the country. In the dryer southeast, the valley bottoms are usually saline or alkaline (C.R. Pannabokke, personal communication). In most environmental-related literature of relevance to Sri Lanka, salinity is seldom mentioned as a major problem. However, researchers found that after the Kirindi Oya irrigation system came into operation salinity levels in the older downstream irrigation systems increased. A retardation in the growth of rice plants was observed in the affected locations, especially in the poorly drained areas. The highest concentration of salts was recorded in the lowermost outfall to the sea, the Magama outfall, which registered an EC of 1.78 milli mhos per cm by late August 1993 (IIMI 1994).

### Weed Infestation

*Salvinia molesta* and water hyacinth are examples of aquatic weeds that can cause major problems for irrigated agriculture, especially in areas with high inflow of fertilizer nutrients. Salvinia propagates by division and spreads in stagnant water, and under favorable conditions doubles every 2 days.

Salvinia has been observed in Sri Lanka since the early 1940s, and has now spread widely with the water buffalo acting as a carrier. It is estimated that approximately 25 percent of Sri Lanka's 50,000 tanks are affected by salvinia. Fortunately, many small tanks and reservoirs are seasonal and during the dry season the weed dies off. It is estimated that 30,000-50,000 ha of rice land are affected by salvinia (Doeleman 1989).

In the 1950s, the initial attempt to reduce salvinia was to chemically control it (using paraquat). However, this has since been abandoned due to the high cost of application, the need for repeated applications, and the danger of using toxic chemicals. The method currently preferred is mechanical with early physical removal.

Another solution to the problem is to use biological control in the form of a weevil, *Cyrtobagous salviniae* which feeds on the weed. From 1986 to the beginning of 1989, this weevil has been released to 96 places with 16 cases of effective control, 23 cases of near success, and 27 cases more where the weevil population is still present.

The economic costs of salvinia are high and include production losses and fishing losses. The Department of Agriculture has estimated that crop losses in salvinia-affected areas are 2 percent to 3 percent of yield, and that altogether 9,000-25,000 ha are affected in the country. This gives a lower-bound estimate of losses at Rs 9 million, and an upper-bound estimate at Rs 22 million (Doeleman 1989).

### Effects on Biological Diversity

Irrigation can negatively affect biological diversity by leading to land clearing which removes forests and by altering rivers and flood plains which sustain natural habitats. However, irrigation development can positively contribute to biological conservation since more efficient and intensive agriculture can reduce the pressure to expand into marginal land and help preserve certain areas for habitat protection. By providing reservoirs and water sources for animals, irrigation can contribute to biodiversity protection. Downstream irrigation development can also lead to pressure for improved upstream catchment protection, which will in turn reduce deforestation and promote biodiversity conservation.

Available data suggest that among Asian countries, Sri Lanka has the highest biological diversity per unit area (NARESA 1991). However, this status is threatened by the alarming rate of deforestation. According to FAO estimates of 1981, the 3.5 percent annual deforestation rate in Sri Lanka is the highest in Asia. Natural forest cover has been reduced from 70 percent at the turn of the century to 25 percent in the early 1990s (NARESA 1991).

Mechanical jungle clearing in the Gal Oya project area destroyed large areas of jungle that had important medicinal plants (Paranamana and Mendis 1994). The Accelerated Mahaweli Development Project has replaced about 200,000 ha of natural wildlife habitat with irrigation infrastructure (NARESA 1991). It has been pointed out that the habitats of several species including those endemic to Sri Lanka have been affected by the Mahaweli Project. Loss of forest area has also seriously affected the elephant population (TAMS 1981).

However, irrigation development can also be an impetus to the protection of certain habitats if these fall within the catchment area of the scheme. To mitigate these biodiversity losses and to safeguard irrigation catchments, several protected areas have been declared upstream of irrigation schemes, as in the case of Gal Oya and Uda Walawe. The Uda Walawe National Park was set up early in the 1970s to protect the immediate catchment upstream of the Uda Walawe Reservoir, used for irrigation and power generation, and to provide protection for animals displaced by opening of land in lower reaches of the Walawe River (CEA 1995a). As the CEA Report explains: "Concern about life shortening due to sedimentation of large and expensive-to-build reservoirs has been one of the main reasons why the Uda Walawe National Park has been established. Establishing a protected area has, when effectively managed, various advantages. It assists in the catchment and protection of the catchment above dams and reservoirs, increases the production of timber, and improves habitat for wildlife. At least 184 bird species have been sighted in the park, 8 of which are endemic and 12 threatened" (CEA 1995a).

Impacts of irrigation on riverine systems that sustain habitats have been to some extent avoided by careful consideration of possible impacts. The KOISP would have affected the Bundala Bird Sanctuary if it had included sensitive tracts 3 and 4, but these have been dropped (IIMI 1994). Similarly, the Menik Ganga Project, to supplement water at KOISP was recommended against the EIA Report due partly to the downstream impacts on the Yala National Park. As the EIA Report states: "The Menik Ganga must be considered the lifeline of the Yala National Park."

One of the species most affected by irrigation development is fish. Comparing several sources of information, Silva (1993) estimates that the number of indigenous freshwater fish species in Sri Lanka is between 52 and 64. Of these, 18 species are endemic to Sri Lanka. It is estimated that 43 indigenous fish species, 10 of which are endemic, are present in the Mahaweli River basin. When the reservoirs under the Mahaweli Project were built they were anticipated to serve to increase the fish yield. However, it was also noted that the reduction of flow velocity and increase in sediment loads affect some fish species adversely. Further, some indigenous riverine fish species need to move upstream to successfully reproduce and they are likely to be affected negatively by the Mahaweli project (Silva 1993).

### Social Impacts of Resettlement

There has been a significant controversy over the resettlement impacts of large-scale irrigation projects. Many of these large projects combine irrigation with hydropower. Therefore, to attribute all the impacts on to irrigation is incorrect. In addition, much of the controversy was caused owing to resettled communities not receiving compensation in the form of new land, etc., as promised. However, if this is the main problem, the solution to this problem would be to improve implementation of resettlement plans and not to reject large irrigation altogether. The controversy over large schemes has led to pressure to switch from large dam schemes to the use of smaller schemes over a wider area. While this may reduce the need for major relocation from one single area, it does not necessarily reduce the number of people affected by the project. Indeed, many smaller dams are generally less efficient than one large dam due to the increase in the relative size of the dead storage.

In Sri Lanka, the debate over large versus small dams is acute in the southern area as a result of the problems with the Lunugamvehera Reservoir. This reservoir was commissioned under Phase 1 of the ADB-funded Kirindi Oya project in 1986. While the reservoir was intended to provide irrigation to 12,930 ha in 1994, only 9,170 ha were irrigable—a shortfall of approximately 30 percent. The water resources potential of the Kirindi Oya basin has been controversial but it seems that the estimated average inflow has decreased by 25 percent from the ADB's 1976 estimated inflow. The main reason for this is the one-third decline in average rainfall within the basin, and the small number of tanks constructed within the catchment which has obstructed regular flow to the reservoir (IIMI 1994). In addition to water shortages, the project suffered from land use conflicts between settlers and existing farmers, and between rice farmers and cattle owners. The project area has no grazing lands reserved for cattle, resulting in severe damage to crops and irrigation channels. Social conflicts between the re-settled and the native population have also been experienced linked to the Accelerated Mahaweli Development Project. It was especially during the early stages of resettlement that the resettled population experienced severe stress and hardship.

## CONCLUSIONS

### General Conclusions

The expansion of irrigated agriculture has immensely contributed to the increased agricultural output in Sri Lanka. However, the sustainability of this increased output depends on human health and environmental impacts of irrigated agriculture. The conclusions of this survey suggest that there are both positive and negative health and environmental impacts of irrigation development in the country.

The environmental factors, which influence irrigated agriculture such as siltation and aquatic weeds in particular, impose a significant cost to the irrigation authorities responsible for managing the system. In addition, some of the environmental and health side effects of irrigation such as high pesticide and fertilizer use, and vector-borne diseases impose a high cost on communities and may eventually have an impact on the productivity of irrigated agriculture. The lack of understanding and poor data available suggest that further research on these particular linkages should be a major priority for irrigation, health, and environmental authorities. A review of the literature shows that only a few studies have addressed the problems and opportunities linked to the traditional small-scale anicut or tank irrigation systems. The large majority of studies have focused on the impact of the Accelerated Mahaweli Development Project.

One of the main reasons for the lack of priority given to environmental and health-related research linked to irrigation is the institutional structure, which often separates those who cause environmental impacts from those who suffer the costs. Like so many development sectors, the main problem is that control and access to the resource, and responsibility for its health and environmental impacts, are divided among many private and public stakeholders.

This can be illustrated by the problems involved with altering irrigation operation and management to reduce the spread of vector-borne diseases. Responsibility for controlling vector-borne diseases rests with the Ministry of Health, while responsibility for irrigation management rests with the Irrigation Department, farmer organizations, etc. However, the Irrigation Department does not have the data or the motivation to manage the irrigation systems to reduce health impacts, while the Department of Heath does not have the control or knowledge to use irrigation management as a preventative mechanism to reduce diseases. A similar problem arises in the environmental field with the many competing agencies responsible for watershed management and soil conservation. The Irrigation Department spends large sums of money each year clearing desilted canals, while it is the responsibility of other agencies to manage catchment degradation. It is only in the Mahaweli Upper Watershed Division that there is any attempt to combine downstream and upstream users in the same organization. However, to improve coordination, new committees have been established: the Central Coordinating Committee for Irrigation Management, the National Sector Coordination Committee for water supply and sanitation, and the Water Resources Council (ADB 1994). These efforts at greater coordination will hopefully focus on the irrigation, environment, and health linkages, too. These linkages, at the moment, are overlooked due to poor institutional coordination.

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## References


Abeysekera, W. A. T. 1988. *Pesticide use in the food production sector in Sri Lanka, use of pesticides and health hazards in the plantation sector,* pp.12-37. Colombo, Sri Lanka: Fredreich-Ebert-Stiftung.

Abrol, I. P., J. S. P. Yadav, and F. J. Masood. 1988. *Salt affected soils and their management.* Rome: Food and Agriculture Organisation (FAO).

Amarasekera, N. 1992. Environmental consequences of major irrigation development in Sri Lanka: A preliminary assessment. *Water International* 17(2):88-97. IWRA, USA.

Amerasinghe, F. P., and N. G. Indrajith. 1994. Postirrigation breeding patterns of surface water mosquitoes in the Mahaweli Project, Sri Lanka, and comparisons with preceding development phases. *Journal of Medical Entomology* 31(4):516-523.

Amerasinghe, F. P., and T. G. Ariyasena. 1990. Larval survey of surface water breeding mosquitoes during irrigation development in the Mahaweli Project, Sri Lanka. *Journal of Medical Entomology* 27(5):789-802.

Asian Development Bank (ADB). 1994. Comprehensive water resources management in Sri Lanka. Draft strategy framework and action plan. Vol. 2, Annex.

Azmy, S.A.M., P. de Alwis, and N. H. Dassanayaka. 1993. *Water quality in the irrigation network of the Mahaweli H System.* Colombo, Sri Lanka: Annual Scientific Sessions of National Aquatic Resources Agency.

Birley, H. M. 1989. *Forecasting the vector-borne disease implications of water resources development.* PEEM Guidelines Series 2.

Bradley, D., and R. Narayan. 1987. Epidemiological patterns associated with agricultural activities in the tropics with special reference to vector-borne diseases. In *Effects of Agricultural Development on Vector-Borne Diseases,* pp. 35-44. Rome: FAO (Publications AGL/MISC/12/87).

Central Environmental Authority (CEA). 1994. *Anuradhapura tanks.* Wetland Site Report. Colombo, Sri Lanka: Wetland Conservation Project.

CEA. 1995a. *Udawalawe reservoir.* Wetland Site Report. Colombo, Sri Lanka: Wetland Conservation Project.

CEA. 1995b. *Minneriya reservoir.* Wetland Site Report. Colombo, Sri Lanka: Wetland Conservation Project.

Clark R. 1994. *Soil erosion in Perawella.* Forestry Land Use Mapping Project. Sri Lanka: Environment and Forestry Conservation Division, Mahaweli Authority of Sri Lanka.

de Alwis, R. 1989. *An analysis of the nature of the market for agrochemicals in Sri Lanka, pesticides in Sri Lanka,* pp. 27-34, ed. Botterweck, G. Colombo, Sri Lanka: Fredreich-Ebert-Stiftung.

Department of Agriculture. 1994. *Cost of cultivation of agricultural crops maha 1992/1993.* Agricultural Economics Study no. 54. Peradeniya, Sri Lanka: Socio-Economic and Planning Centre.

Department of Census and Statistics. 1995. *Statistical abstract of the Democratic Socialist Republic of Sri Lanka 1994.* Colombo, Sri Lanka.

Dharmasena, P. B. 1994. Conservation farming practices for small reservoir watersheds: A case study from Sri Lanka. *Agroforestry Systems* 28: 203-212.

Disanayaka, J. B. 1992. *Water in culture, the Sri Lankan heritage.* Colombo, Sri Lanka: Ministry of Transport, Environment and Women's Affairs.

Doeleman, J. 1989. *Biological control of Salvinia Molesta in Sri Lanka: An assessment of costs and benefits.* Canberra, Australia: ACIAR.

Fernando, R, and D. Fernando. 1995. *Pesticide poisoning in Sri Lanka. Review of the eighties and the outlook for the nineties.* Colombo, Sri Lanka: National Poisons Information Centre, General Hospital.

Food and Agricultural Organisation (FAO). 1993. *The state of food and agriculture.* Rome: FAO.

Goldsmith, E. and N. Hildyard. 1984. *The social and environmental effects of large dams, Vol. 1, overview.* UK: Wadebridge Ecological Center.

Goonasekera, K. G. A., and F. P. Amerasinghe. 1988. Planning, design and operation of rice irrigation schemes: the impact of schistosomiasis. In *Vector-borne diseases control in humans through rice agroecosystem management*, pp. 51-67. Colombo, Sri Lanka: PEEM/IRRI Publication.

Gunatilake, K. H. S. 1991. The Mahaweli Development Project, an overview. Prof. E. O. E. Pereira Commemoration Lecture 1991. *The Journal of the Institute of Engineers, Sri Lanka* XIX(4).

Hunter. J. M., L. Ray, and D. Scott. 1982. Man-made lakes man-made diseases. Towards a policy resolution. *Social Science and Medicine* 16:1127-1145.

Hunter. J. M., L. Ray, K. Y. Chu, E. O. Adekolu-John, and K. E. Mott. 1993. *Parasitic diseases in water resources development. The need for intersectoral negotiation*. Geneva: World Health Organisation.

International Irrigation Management Institute (IIMI). 1994. *Kirindi Oya Irrigation and Settlement Project impact evaluation study.* Colombo, Sri Lanka: IIMI.

International Rice Research Institute (IRRI). 1991. *World rice statistics 1990.* Philippines: IRRI.

Jayasekera, A. M. 1996. Inland fishery development. Paper presented at the Annual Scientific Session of the Fisheries Society, Colombo, Sri Lanka.

Jeyaratnam, J., R. S. Seneviratne de Alwis, and J. F. Copplestone. 1982. Survey of pesticide poisoning in Sri Lanka. *Bulletin of the World Health Organization* 60:615-619.

Jeyaratnam, J., K. C. Lun, and W. O. Phoon. 1987. Survey of acute pesticide poisoning among agricultural workers in four Asian countries. *Bulletin of the World Health Organization* 65:512-527.

Jayawardena, R. 1993. Illness perception: Social cost and coping-strategies of malaria cases. *Social Science Medicine* 37 (9):1169-1176.

Jayawardena, R. A. 1988. The impact of malaria on new settlers in the Mahaweli Development Project, Sri Lanka. The University of Connecticut. Unpublished thesis.

Karunaratne, N. 1991. Sustainable and environmentally sound development of water resources in Sri Lanka. In *ESCAP, Towards an environmentally sound and sustainable development to water resources in Asia and the Pacific.* Water Resources Series no. 71. New York, NY: USA.

Kijne, J. W. 1993. *Environmentally sound water management: Irrigation and environment.* Proceedings of the International Symposium on Environmental Assessment and Management of Irrigation and Drainage Projects for Sustained Agricultural Growth, pp.14-45. 24-28 October 1993. Lahore, Pakistan.

Konradsen, F., W. van der Hoek, P. H. Amerasinghe, F. P. Amerasinghe, and K. T. Fonseka. 1997a. Household responses to malaria and their costs: A study from rural Sri Lanka. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 91:127-130.

Konradsen, Flemming, Wim van der Hoek, Priyanie H. Amerasinghe, and Felix P. Amerasinghe. 1997b. Measuring the economic cost of malaria to households in Sri Lanka. *American Journal of Tropical Medicine and Hygiene* 56(6):656-666.

Kudagamage, C., H. B. Senarath, and H. J. P. Fernando. 1992. National Integrated Pest Management Programme in Sri Lanka. In *Integrated pest management in the Asia Pacific region,* pp.163-180, ed. P. A. C. Ooi, G. S. Lim, T. H. Ho, P. L. Manalo, and J. Waage. Wallingford, UK: CAB International.

Lawarance L. A., and D. S. P. Kuruppuarachchi. 1986. *Impact of agriculture on groundwater quality in the Kalpitiya Peninsula.* UK: British Geological Surveys.

McJunkin, F. E. 1983. *Water and human health.* Washington D.C.: USAID (AID/DSAN-C00063).

Ministry of Irrigation, Power and Energy, 1996. *Environmental guidelines for irrigation sector projects.* Colombo, Sri Lanka.

Ministry of Power and Energy. 1995. *Annual report.* Colombo, Sri Lanka.

Moss, B. 1989. *Ecology of fresh waters, man and medium.* Oxford, London: Blackwell Scientific Publications.

Nagarajah, S., B. N. Emerson, V. Abeykoon, and S. Yogalingam. 1988a. Water quality of wells in Jaffna and Kilinochchi. *Tropical Agriculturist* 144:89-99.

Nagarajah S., B. N. Emerson, V. Abeykoon, and S. Yogalingam. 1988b. Water quality of some wells in Jaffna and Kilinochchi with special reference to nitrate pollution. *Tropical Agricultralist* 144:61-78.

NARESA. 1991. Natural resources of Sri Lanka. A report prepared for the natural resources, energy and science authority of Sri Lanka. Sri Lanka: Keel Business Systems Ltd.

Paranamana P. A. G, and D. L. O. Mendis. 1994. Environmental *impact assessment study of an ancient soil and water conservation system (irrigation system).* Kandy, Sri Lanka: Institute of Fundamental Studies.

Peiris, J. S. M., F. P. Amerasinghe, P. H. Amerasinghe, C. B. Ratnayake, S. H. P. P. Karunaratne, and T. F. Tsai. 1992. Japanese encephalitis in Sri Lanka: The study of an epidemic vector incrimination, porcine infection and human disease. *Transactions of the Royal Society of Tropical Medicine and Hygiene.*

Samarasinghe, M. U. L. P. 1986. *The present malaria situation in Sri Lanka with particular reference to areas where irrigation has recently been introduced.* Proceedings of the Workshop on irrigation and Vector-Borne Disease Transmission, 15 October, 1986. Colombo, Sri Lanka: IIMI.

Silva, E. I. L. 1993. *Discontinuation of the Mahaweli River and its impact on the distribution and diversity of indigenous riverine fish fauna.* Proceedings of the International and Interdisciplinary Symposium Ecology and Landscape Management in Sri Lanka. Kandy, Sri Lanka: Institute of Fundamental Studies.

Speelman, J. J., and G. M. van den Top. 1986. *Irrigation and vector-borne diseases: A case study in Sri Lanka.* Proceedings of the Workshop on Irrigation and Vector-Borne Disease Transmission, 15 October, 1986. Colombo, Sri Lanka: IIMI.

Sumanaratne, H. D., and S. Somasiri. 1990. Runoff generation and soil erosion under three different land uses in the dry zone of Sri Lanka. *Tropical Agriculturist* 146:1-9.

TAMS. 1981. *Environmental impacts of the Accelerated Mahaweli Programme.* Colombo, Sri Lanka.

van der Hoek, W., F. Konradsen, K. Atukorale, and T. Wanigadeva. 1997. Health hazards of pesticide use in Mahaweli H. *Social Science and Medicine* (in press).

Vitarana, U. T. 1986. *Study of mosquito-borne diseases in some irrigation schemes in Sri Lanka with particular reference to filarisasis and abroviral diseases.* Workshop Proceedings on Irrigation and Vector Borne Disease Transmission. Sri Lanka: IIMI.

Weerekoon L. U. 1989. Water management in the Mahewali Project. *Sri Lanka Economic Journal* 4(2):37-55.

Weil C. D. E, A. P. Alicbusan, J. F. Wilson, M. R. Reich, and D. J. Bradley. 1990. *The impact of development policies on health: A review of the literature.* Geneva: World Health Organization.

World Resources Institute. 1994. *World resources 1994-5.* Washington D. C., USA.

Yatawara, S. 1997. Upper Mahaweli catchment and sedimentation studies. Paper presented at Sri Lanka association for the Advancement of Science Symposium, July 6, 1997, Colombo, Sri Lanka.