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NATIONAL WATER CONFERENCE
Nov. 4-6, 1998
BMICH, Colombo Sri Lanka

RESEARCH PAPERS PRESENTED

Session No.13 5 November 1998 2:00 p.m.

Watershed Management

Paper No.75

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Participatory Watershed Management: A Comparative Analysis Of The Experiences Of North-Western Province Water Resources Development Project And Shared Control Of Natural Resources Project

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PARTICIPATORY WATERSHED MANAGEMENT : PRESENT STATUS AND FUTURE PROSPECTS¹

H. M. Wimalasinghe and C. M. Wijayaratna²

Introduction - Participation and Watershed Management

Participation: Participation of local people or beneficiaries in development planning and participatory implementation of projects and programs have drawn much attention from the planners, policy makers, politicians and donor communities in the recent past. The concept of participation has become rhetorical and considered as a "panacea" for the problems such as the failure of projects to achieve expected benefits. At the same time it has been observed that different interpretations are given by different people for "participation". For example, Borrini considers participation as an inherited human quality and it connotes: taking part, sharing and acting together. People's participation is nothing more than the basic texture of the life. Historically, human beings have participated in shaping their cultures and survival strategies in a variety of ecological environments and their sharing of tasks and responsibilities took place in self regulated small groups- fifty, sixty individuals who interacted face-to face shared the hunting, gathering, leisure and learning of daily life (Borrini, 1993).

In the recent past, development planners "labeled" participation as the involvement of local people in development projects and programs. Umma Lale (1981) identified participation as: sensitizing people, and, thus, to increase the receptivity and ability of rural people and make them respond to development programs, as well as to encourage local initiatives. It has been claimed that participation is considered a voluntary contribution by people to programs that are supposed to contribute to national development, but the people are not expected to take part in shaping the program or to criticize its content (Community Development Journal, Vol.8 no.02). However, in this paper, it is argued that a participatory process should involve resource users at all stages of a given project or program including, project design, planning for watershed resource use, implementation, monitoring and evaluation and sharing benefits. And, it is proposed that participatory watershed management should be a collaborative process, and based on partnerships between stake holders such as the resource users, Government, organized private sector etc.

¹ Paper presented at the National conference on "The status and Future Direction of Water Research in Sri Lanka," Colombo, 4 - 6 November, 1998

² Land Use Planner, Environment and Forestry Conservation Division, Mahaweli Authority of Sri Lanka and Senior Agricultural Economist / Watershed Management Specialist, International Water Management Institute, IWMI, respectively.

The responsibility for the contents of this paper rests with the authors and does not necessarily reflect the views of The Mahaweli Authority of Sri Lanka, The International Water Management Institute or any other organization.

Active participation of both the Government officials and rural communities, or partnerships and collaborative efforts are important to achieve cost effectiveness and success of natural resources management programs. After an in-depth "learning process" and analysis of the Gal Oya farmer organization program in Sri Lanka, Uphoff (1992) concluded that lot of potential exists in both rural communities and in government bureaucracies for promoting "bottom-up" development. Moreover, he argues that "bottom-up" and "top-down" approaches are not mutually excluded: top-down efforts are usually required for bottom-up development.

Watershed: Increasing awareness of world watershed degradation has led to form various definitions on *watershed* highlighting different dimensions, mainly spatial, hydrological, socioeconomic and political. Usually watershed is defined hydrologically as the area of land surface that drains water into a common point in a drainage system. Two of the oldest definitions on watershed has given by the United States Soil and Water Conservation Society (1951). One definition identifies watershed as the total land area, irrespective of the size, above a given point on a water way that contributed run-off water to the flow at that point while the other defines it as a major drainage area subdivision of a drainage basin. These two definitions do not totally agree with each other: the first one says that the size is regardless but, according to the second, watershed is smaller than the drainage basin. Moreover, they both consider only the hydrological aspect and have failed to consider a watershed as a socioeconomic and political unit as well. The FAO watershed management field manual (Sheng, 1990) covers not only the technical aspects but also the sociopolitical aspects more comprehensively. According to this definition watershed is a topographically delineated area that drains in to a point in a stream system or a river. Moreover, Sheng describes watershed not only as a hydrological unit but also as a physical-biological unit. In certain occasions, it has been considered as a socioeconomic-political unit for planning and management of natural resources.

Li Wenhua (1992) too, considered a watershed as to indicate the area of the land that drains into an individual, stream or lake. Thus watershed may only be a few hectares in area or may consist of tens of thousands of square kilometers in area. These definitions relate to the geographical extent, however, the FAO Conservation Guide included a range of natural resources especially, water, soil and the vegetative factors.

For the purposes of this paper the watershed is defined as "the area of land surface that drains water into a common point along a stream or river". Hence the river basin is considered as the highest order watershed. Areas that generate separate streams/tributaries within a larger watershed (or a river basin) can be conveniently defined as "sub-watersheds" and "micro-watersheds". It has been argued that "watershed" be considered as the basic planning, coordinating and implementing unit for natural resources management (or natural resources based development) for the following reasons (Wijayaratna, 1950):

- It is the physical entity geographically defined by the important natural resource, water,

- The ways in which the water is used in upstream affect the ways in which it *can be used* in downstream, and also affect the associated land use,
- Various segments of the watershed are physically and operationally linked,
- It is a logical unit to assess hydrological linkages,
- It is a logical unit to integrate land and water resources management,
- It is a logical unit for a holistic/integrated development approach based on natural resource utilization and conservation,
- Both on-site and off-site erosion effects can be considered,
- It is a logical unit to assess environmental impact,
- It allows to consider socioeconomic and institutional interactions,
- It is a logical unit to integrate the activities of irrigation, forestry, agrarian/support services and agriculture, and
- Sub/micro watersheds can be identified to be managed by local communities/groups and these can be federated upwards to integrate activities, for coordination and to achieve economies of scale.

Watershed Management

United States Soil and Water Conservation Society defines watershed management as the use of watershed lands in accordance with such predetermined objectives as the control of erosion, stream flow, silting floods etc. (US Soil and Water Conservation Society, 1951). This definition considers only the technical aspects. However, later on the definitions have incorporated, production, and socioeconomic, including human factors into the subject area of watershed management. For example, Li-Wenhua had defined (1985) “rational watershed management” as “the management of land and water resource within a watershed to achieve optimum production which can be sustained without causing degradation to the resource base or disturbing the ecological balance (Li-Wenhua, 1992). Even though, this definition has not directly included socioeconomic factors, it considers both production and ecological balance as a requirement of watershed management. The FAO conservation guide and watershed management field manual defined watershed management as the comprehensive development of a basin so as to make productive use of all its natural resources and also to protect them. It is suggested that watershed management is a process of formulating and carrying out a courses of action involving the manipulation of a watershed to provide goods and services without adversely affecting the soil and water base. Further, it advocates that watershed management must consider social economic and industrial factors operating within and outside the watershed area (FAO Watershed Management Field Manual 1990).

Watershed Problems

Severe effects of watershed degradation are challenging the sustainable development efforts of many countries of the world. Watershed erosion had caused serious off-site effects such as the siltation of reservoirs, consequently affecting hydropower generation and downstream irrigation. In addition, on site effects, includes the reduction land productivity and agricultural production. Loss of land productivity may also lead to

extensive and destructive uses of land. For example, slash and burn cultivation without an adequate fallow cycle leads to loss of soil fertility and this in turn result in more and more encroachments by inhabitants. Watersheds are also threatened by the encroachment of farm population, firewood collection, large-scale commercial logging (more often than not illegal), road construction into virgin areas, major civil works such as dams and highways and the conversion of forest to plantation.

FAO report on Natural Resource for Food and Agriculture in the Asia and Pacific Regions has emphasized the severity of region's watershed degradation problem and commented that the Asia and Pacific regions support over the half the world's population, and nearly 50% of them live in mountain areas experiencing serious environmental degradation. Population pressure in uplands is leading to degradation of watersheds. As a result, the other half of the population living in the plains suffers from floods and droughts and the waterways, harbors, reservoirs and water development schemes are affected by sedimentation. The entire economy of these droughts-prone areas is subjected to periods of emergency as mountain watersheds loose their capability to hold water and regulate river flows (FAO 1986-7). Further more, off site effects, including water shortages for downstream irrigation as well as hazardous floods, due to watershed degradation are common in many areas.

Participatory Watershed Management Experiences in India and China

India: National government, state governments, international funding agencies and NGOs are working in several areas with local people in improving watershed resource use. Some of these are participatory watershed management projects. Salient features of these projects are:

- Usually the watershed projects consider water conservation as a priority area;
- Conservation activities have been coupled with income generation activities, day to day life style and with the local social structure;
- In many of the participatory watershed management projects, agriculture and forestry are taken as key areas of people's participation;
- Application of biological conservation measures and simple low-cost mechanical measures are being considered as important elements;
- In many of the successful projects, success is largely attributed to the leadership quality and dedication of some key people attached to the Government, an NGO or local communities.

Watershed development in India is a recent phenomenon. And, the severely degraded watersheds require well planned long-term interventions which would be extremely difficult to implement by the Government alone. Hence, especially in a country like India participatory programs need to be given priority. Also, because of the difficulties in funding and because most of the watersheds are inhabited by a large number of small farmers who are at subsistence levels, India may have to continue to rely much on low cost technologies.

China: It is reported that the Chinese people have a history of forced participation of soil conservation, with the influence of king or under communist system, until the recent past. Nevertheless, it is accepted that in China, although watershed management is continuing to progress through stages of refinement, it is not a new concept. The early Chinese recognized the importance whitewashed management and, in particular, the importance of maintaining forest cover. For example, as early as 1600 BC, Chinese Emperor Yu implemented a major forestry program to "control erosion and floods" under the slogan "to protect the river, protect the forest" (Brown and Beschta, 1985 quoted by UNDP/FAO, 1986). The country's population is about 1250 million people and the average per-capita land availability is about 0.1 ha. Further, 43% land area is mountainous and hilly. Watershed degradation is severe; for example, the average annual sediment discharge of *Yellow River* along is 1887 million tons. However, China has made a remarkable progress in the field of watershed management using various strategies including participatory approaches. According to Wu-Deyi (1996), China has made an accelerated progress in the area of watershed management in the last ten years. Some of the significant supporting policies include: a) a household based management system in which land management has been carried out by the individual household through a contract system, b) a conservation system in which number of watersheds were comprehensibly managed to get multiple benefits and c) the integration of short , medium and long term benefit generating from conservation measures. The land productivity and per-capita income of farmers have increased by 100-200% with the implementation of comprehensive management system of small watersheds.

Economic and social policy changes under the new concepts adopted by Chinese have led to a rapid progress in the field of Participatory Watershed Management. Despite the fact the ownership of land is vested with the Government, participation of the resources is encouraged by different types of land management contract systems, which could be agreed by the farming community according to their desires. Farmer's contribution to participatory watershed projects has risen up to 60-70%. The strategies that contributed to these achievements include: family level watershed land development contract system, collective or group contract system, professional family contract system and responsible participation of the government officers (Wu-Deyi, 1996).

Watershed Management in Sri Lanka

Agriculture accounts for nearly 25 - 30% of the Gross National Product and remains to be the main employment provider of the Sri Lankan economy. With the restoration of the ancient irrigation systems, Mahaweli Scheme and the construction of other new irrigation systems, Sri Lanka has exhausted the most promising and cheapest sources of irrigation supplies. At the same time degradation of the catchments of many of these reservoirs, some of which also serve as power generators, is continuing at an alarming rate. Hence there is a growing emphasis on the need for watershed management in the central hills and the other watersheds in the intermediate and dry zones.

The Upper Mahaweli Catchment (UMC), in the central high lands of the country which covers an extent of about 3125 km² is the source of the country's largest river the Mahaweli Ganga and the watersheds of Kotmale, Victoriya, Randenigala, Rantembe and Polgolla reservoirs. Because of the severe catchment erosion, Pollgolla has sedimented 44% of its volume after 25 years and sedimentation of Rantembe is 4-6% per annum (Manthreethalaka and White, 1995). The magnitude of the problem should be viewed in the context of the expected services of Mahaweli reservoirs: it is expected to provide water for about 125000 farm families in the settlement areas and also provides 52 % of the country's electricity supply to the national grid.

Furthermore, except Mahaweli reservoir, there are about 200 major irrigation schemes and 13000 minor tank schemes functioning all over the country. Many of these schemes, too, are seriously affected by siltation. The feasibility report of the Asian Development Bank funded NorthWestern Water Resources Development Project (ADB-NWP/WRDP) highlighted the siltation of the tanks is one of the major problems faced by the many irrigation schemes (ADB-NWP/WRDP, 1990).

Managing these watersheds including the adoption of soil and water conservation measures is important in order to protect the reservoirs and to increase the long-term agricultural productivity. Attention has been drawn by the Food and Agriculture Organization, FAO, to the higher rates of erosion rates and their impact on productivity of the land and the sustainability of the farming systems and development projects (Stocking, 1996). Non protective land use and agricultural practices including chena cultivation, tobacco cultivation as well as such events as overgrazing, illicit felling of trees for timber and fuel wood, poorly managed tea states etc., are among the major causes of watershed degradation. Few selected attempts of watershed management are examined below.

Hapuwela Micro Watershed Management Program (HMWMP)

Hapuwela micro watershed is situated about 40 km east to Kandy in the mid - country intermediate zone, with an average rainfall of 1500 mm falling mainly in the North-East monsoon period. The geographical extent of the area is 264 ha and elevation vary from 1400 to 1500 meters, with rolling and undulating terrain. Land use comprised of tobacco, vegetable and marginal type Kandian forest gardens, in the uplands and irrigable paddy in the valley bottom. There are 477 households in the area with an average size of 5 members per family and an average family farm is less than 0.5 ha for both upland and low land. Agriculture, animal husbandry (with free grazing), off-farm activities are the main economic activities. It should be noted that 87% of the families are food aid receivers. Community organizations include village development society, funeral society and young farmers clubs etc. However, these are not strong and nothing much has been done on natural resources conservation.

Watershed Problems: About 80% of the people have experienced soil loss on their fields and consequently crop yield reduction. Land degradation has influenced their agricultural

decisions, notably the selection of crops and farming practices. For example, most of them farmers cultivate vegetable and tobacco on lands with slopes over 30%, with least or no conservation measures. People have experienced water shortages in their wells during long dry spells. Agencies working in the area have not emphasized much on soil and water conservation.

Approach and Implementation: Initial area selection was done by considering physical factors like slope of the terrain, erosion rates, land use and socioeconomic factors such as poverty, income distribution as well as the availability of rural infrastructure. Farmer participation has been observed during the planning workshops organized by the UMWP. Further, they participated lively at meetings and made their comments on the activities.

Implementation activities initiated with the environmental awareness program followed by the introduction of various soil and water conservation measures such as Sloping Agricultural Land Technique (SALT), mulching, stone terracing and gully control measures. Field level activities were carried with the help of the government line agencies, non-governmental organizations, watershed level farmer groups and the field staff of the UMWP and extension officers. Moreover, one field officer of the UMWP permanently resided in the catchment area with the purpose of improving the coordination and contact between farmers and the management. Incentives were given for agreed conservation activities and UMWP contributed for infrastructure development activities.

Progress: Initial planning workshop was a good starting point to get the views of the people on watershed degradation, but most of them are not priority watershed degradation issues. Their main concerns were road development, pipe borne water, school building and so on. Beneficiary participation in terms of free labor through *sramadana* was high during the project period, but this was drastically reduced towards the end of the program. This implied that they have not understood the reality or the core problem of the watershed degradation and consequences. Farmers were not much serious in doing soil conservation to avoid siltation in the Victoria reservoir.

Towards the end of the program there was a tendency for people to depend much on incentives for conservation works, and many farmers expected every thing free of charge, an attitude which has existed for a long time (Decurtins, 1995). Further, poor relations between institutions, conflicts among villagers due to political differences, implementation problems through line agencies and problem of law enforcement on various watershed management issues were among the main obstacles during the implementation period.

Watuliyadda Watershed Management Program

Watuliyadda village is situated about 45km. East to Kandy, on the immediate left bank of the Victoria dam. The area belongs to the intermediate zone and therefore climatic pattern is as same as Hapuwela watershed. The geographical extent of the area is about 120 ha.

and elevation varies from 1100 to 1450 meters. There were 134 households in the village with an average of five members per family and household land ownership was less than one ha. for both upland and lowland. Agriculture was the main livelihood with less off-farm activities. Land use comprised of Kandian home gardens, vegetable, tobacco, and paddy. Several village organizations have been observed including village development society, school development society, and funeral society. It has been observed that these organizations are comparatively better than in Hapuwela.

Watershed Problems: Like in Hapuwela, watershed degradation was observed to be severe and due to population pressure people have encroached more land in the surrounding government forests.

Implementation of Watershed Management Interventions: The objective of the program was to initiate action to restore the ecosystem. The strategies used were: awareness building, training, mobilizing human and other local resources for action with maximum farmer participation and minimum external inputs. The project promoted farmer-farmer dialogue and interactions, attempted to cultivate self-reliance, facilitated ecosystem restoration planning through animators and tried to obtain support from other programs. A detailed PRA mapping exercise was conducted.

Progress: Even though most of the planned inputs of the project had been provided during the project period, due to factors such as: shortcomings in the line agency activities, inadequate services of the animators etc., project could not achieve the expected benefits. Encroachment in to forest, forest fires etc., continued. However, farmer participation in project activities has been successful to certain extent.

The Asian Development Bank - North Western Province Water Resources Development Project, ADB-NWP WRDP, -- Watershed Management program

The ADB assisted North Western Province Water Resources Project commenced in 1992. In the past five year period the project was provided with financial and other resources to rehabilitate and improve about 630 minor tanks and 33 major/medium tanks. Under the environmental management component of the project, two pilot watershed management mini projects have been implemented in Wilgamuwa and Patapola. These two are micro watersheds and Wilgamuwa is selected for a brief analysis. Wilgamuwa is located nearly 27 km. Southwest of Kurunegala in the Alawwa Divisional Secretariat area. The area is in the wet zone and the annual rainfall is about 2500 mm.

The land area is 88 ha. With sloppy terrain and the elevation ranges from 47 meters to 170 meters (above sea level). Degraded forest, poorly managed coconut home garden is the major land use patterns. There were 49 households in the micro watershed and the total population was about 260 people. Upland cultivation and off-farm employment were the main livelihood of the inhabitants. Several of village organizations were present but conflicts, mainly due to political factors, were common.

Watershed Problems: Wilgamuwa micro watershed has been degraded and it was clearly evident from rill and gully formation, loss of top soil and resulting problems associated with cultivation and siltation of the tank, downstream. Nearly 60 % of the tank capacity has lost due to siltation. Forest fire has been recognized as another problem and it removes ground cover, which in turn result in enhanced sheet erosion. Over grazing, poor land and road management etc., were also identified as causal factors for environmental degradation.

Watershed Interventions: When the ADB-NWP WRDP started investigating for the development / rehabilitation of the Wilgamuwa small tank and the distribution system, it discovered the status of catchment degradation and associated siltation problem. The project initiated discussions with water users (in this case the farmers) and the users were willing to collaborate. The planning process has been participatory and much similar to that of Watuliyadda. However, farmer participation at Wilgamuwa has been better: they agreed to form and strengthen the farmer organization, contribute labor for most of the items included in the development process and to work closely with the relevant government organizations.

Participatory Rural Appraisal procedures have been used for diagnostic analysis and to enhance farmer collaboration. Implementation of the plan was begun in 1995 and despite the drought situation prevailed in 1996; the project recorded a considerable progress by 1997. Improvements effected by the resources included: installation of mechanical barriers in gullies, tree planting, establishment of biological soil and water conservation measures (such as Sloping Agricultural land Technologies, SALT, hedges, live fences and brushwood work for water conservation etc.).

The degree of participation and collaboration of different government organizations had been different; certain institutions did not pay much attention to the program while few others actively played a partnership role. Encroachment of state land and political disputes can be quoted as major problems confronted. However, a significant progress had been observed in such areas as: farmer collaboration in conservation based production, participatory monitoring using simple indicators of soil erosion, home garden development and use of appropriate technologies (especially biological methods) in conservation etc.

Shared Control of Natural Resources, SCOR, Project

Shared Control of Natural Resources, SCOR, funded by the United States Agency for International Development (USAID) has been implemented by the International Irrigation Management Institute (IIMI) in collaboration with the Government of Sri Lanka, resource users and Non-Governmental Organizations. SCOR) aimed at developing and testing a holistic approach to integrate production goals with environmental and conservation concerns. The underlying theme of SCOR action research was to “learn from action”. The project considered watershed management as the process of (participatory) planning/formulating implementing and monitoring/adjusting and evaluating a course of

action involving natural, human and other resources. Therefore, the project believed that an integrated/holistic watershed management approach should consider those physical, socioeconomic and institutional linkages that exist between upstream and downstream of a river basin/watershed, and between systems within watershed.

SCOR Approach: With watersheds as basic units, SCOR operated at multiple levels with different organizational/institutional arrangements. At the lowest level, the sub- or micro-watershed, which typically includes a couple of villages, the local officials, the resource user groups/organizations, and SCOR catalysts/change agents, interacted to understand the present resource use pattern, combined indigenous and external knowledge, developed a vision for the future and translated it into action plans. At the divisional and watershed levels, the officials, representatives of farmers and SCOR professionals discussed plans emerging from grass roots levels.

The project has selected about 25 sub-watersheds ranging from 75 ha to 600 ha. for interventions. In the sub-watershed, a participatory appraisal of the characteristics of resource uses and users as well as mapping of current resource use were done by groups comprising of resource users, NGO, Government agencies and SCOR project team. Subsequently, a participatory resource management "mini project" was formulated. The "mini-project" aimed at changing the present land and water use pattern to a more profitable yet environmentally sound resource use.

Progress: Analysis of progress in the first four years of project implementation revealed that the project has achieved significant outputs in farm production, enhanced farmer incomes and profits, policy impacts and to some extent, outputs related to natural resources conservation. Farmers were exposed to new knowledge on conservation farming. Farmers have adopted selected conservation measures -- notably, organic bunds followed by earth bunds on contours and produce cash crops such as soybean and maize for identified markets through forward contracts. In addition, valuable timber trees have been planted to provide security for the future. Many farmers tried out mulch farming using straw in rice fields raising a crop in the dry season for the first time in their village.

Problems and Prospects: However, in both watersheds, achievements in regard to the adoption of conservation practices have been below the expectations. For example, farmers could not cover the entire landscape with conservation measures during the 5-year project period. There exist significant variation across farms in regard to the quality of conservation measures such as the contour bunds. Nevertheless, it is too early to evaluate the sustainability of conservation measures. Moreover, as farmers are increasingly producing for identified markets through forward contracting mechanisms and as they get a better price, they may invest more on technologies that would enhance the sustainability of production. Therefore, such an approach may be considered as a "market oriented conservation" strategy that may have the potential of replacing "subsidized conservation." (Wijayaratna, 1998).

In a process of participatory and market-oriented natural resources management, resources users grouped and united for various purposes, ranging from groups for fish

farming through small hydropower plants (coupled with conservation of the corresponding hydro catchment) to production companies. Four farmer companies have been formed during the project period they are responsible for organizing conservation-based production processes for special markets, capturing economies of scale in input and output markets, collection, storage, quality control and value-added production. Companies have already established new partnerships between farmers and state and between farmers and the private sector.

The significant policy changes initiated by SCOR includes: grant of usufructuary rights for using state lands; Government's acceptance (as a declared policy) of small farmer companies and follow up action; decision to establish a "legal" agricultural settlement incorporating "illegal encroachers" of Government land in the upstream of Huruluwewa watershed; recognition of watershed-based farmer organizations by the government, even though they are not coterminous with administrative boundaries; extending the mandate of the Irrigation Management Division of the Ministry of Irrigation, Power and Energy, to manage watersheds; decision by the Cabinet to offer contracts for supplying maize and soy bean (for the requirement of a Government program) to farmer companies etc.

Lessons for the Future

The rationale for using the watershed as the basic unit for integrated planning of (land and water) resources utilization is clear. The watershed is a physical entity geographically defined by an important natural resource, water; the way in which the water in the upper parts of the watershed are used affect the ways in which it can be used downstream, and they affect the associated land resource.

The experience of Hapuwela, Watuliyadda, ADB-NWP/WRDP and SCOR as well as the experience elsewhere suggest that a participatory watershed management approach is more effective when the watershed is occupied by people, especially small farmers and when their day-to-day activities are largely responsible for watershed degradation. It has been pointed out that the most glaring gap in watershed management is, that most professionals and trainers do not know the process to make them farmer programs (Sharma, 1997). Collaboration or partnership between actors, mainly the resource users, government officials and project implementers, is important at all stages of watershed management including the design process, implementation, monitoring and evaluation and the identification of constraints and their removal.

The basic concept, direction and goals may be the same for all participatory watershed management programs. However, the strategies, activities and action may differ from one watershed to another, depending on the technical (including biological), socioeconomic and political differences. This implies two important propositions: every participatory watershed management program is a "novel learning process" and it is essential that socioeconomic, technical and political characteristics should be studied prior to the formulation of action plans. Hence, a pure top down or a blue print approach should be

avoided. Instead, planning should be based on a learning process³ starting with a participatory assessment of present resource use pattern, a participatory diagnosis of reasons for watershed degradation and participatory evaluation for alternative intervention strategies followed by carefully designed action plans. In the process of diagnostic appraisal, the conventional PRA/RRA and associated mapping processes can be modified and advanced techniques could be used in countries like Sri Lanka, because secondary information and maps drawn to scale are available and also because the literacy level of users is high.

Another important lesson learned is that, simple but effective progress monitoring indicators can be used. Such indicators on watershed degradation including soil erosion, reservoir sedimentation, reduction of soil fertility and crop yields, changes in the type of vegetation etc., can be submitted/developed by both the intervention team and resource users agreed upon at the participatory appraisal and planning stages. In designing production and conservation interventions and in formulating monitoring and evaluation indicators, it should be recognized that both indigenous as well as external knowledge are important and should be respected.

It is recommended that crops/enterprises with economic value should be included in a program of changing land use aimed at conservation. This need to be linked with the adoption of simple soil and water conservation measures and conservation farming techniques. Participatory monitoring, using simple indicators to identify and understand such processes as: tank bed siltation, soil erosion, magnitude of rill and gully formation, changes in weed composition (due to changes in micro environment), decline in upland productivity etc., should be an integral component of such a program.

Inadequate coordination among the relevant institutions was seen as a major threat to watershed management programs. Watershed resources belong to various ministries, departments and statutory bodies. This has been further complicated due to the lack of clearly demarcated responsibilities between the central Government and Provincial Councils. This situation affects watershed management decisions and need to be resolved.

³ Learning and building awareness are important for both parties – resource users and “implementing agencies” or intervention teams.

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**Planning of Watershed Development Projects
Using Non-project Focused Participatory Methods
Lessons from Mee Oya**

Jinapala K, Senaka Arachchi R.B., Somaratna P.G., Jayasinghe G, Makin I.W¹

Abstract

Participatory Rural Appraisal (PRA) is firmly established as an effective methodology for planning, monitoring and evaluating projects and has made undoubted contributions to increasing the involvement of local communities in development. However, due to project focused operational procedures, PRA may on occasion have failed to correctly identify the real development needs of some rural communities. This may have been due to the community members tending to respond positively to the objectives and priorities set by donors and project sponsors. Consequently, project focused PRA can become a tool to extract people's acceptance of pre-determined development objectives rather than a means to find the real needs.

This paper examines potential shortcomings of project focused PRA and proposes non-project based PRA for project identification when planning watershed developments. The application of the non-project focussed methodology is illustrated by a case study at two locations in the Mee-Oya basin. Even when PRA is conducted to identify the local requirements for pre-determined project components, the field work should focus on identifying the real needs of the rural communities. PRA and opinion survey techniques are proposed as a methodological improvement for design of rural development projects.

Introduction

This paper presents methodological innovations adopted in the preparation of a sub-watershed development plan for the Mee-Oya basin in Sri Lanka. The proposed innovations arose from the authors' experiences in a number of rural and irrigation development projects in Sri Lanka and elsewhere where diverse problems were encountered in obtaining user participation in implementation. Similar problems were encountered during the Shared Control of Natural Resources (SCOR) project completed in September 1998.

Available evidence suggests that if a too narrow, project focussed, approach is taken during planning interventions then participation by the local communities in project activities is lower than expected. This is thought to be due to the unintentional disregard of the real felt needs of the community and adversely affecting community participation in project activities (Jinapala and Somaratne 1996,1997).

Project Preparation Methods

Until relatively recently the approach to project preparation and the design of development programs for rural communities was dominated by top-down strategies. Interventions were conceived and developed by central agencies and then transferred to the field. Such projects were often inflexible and offered little or no choice to the community intended to benefit from the intervention. Results of such approaches were frequently disappointing due to a lack of enthusiasm for participation in project activities.

¹ International Irrigation Management Institute

Recognising the poor results of top-down design methods increasing '*beneficiary participation*' in project design has become popular. However, frequently such participation that does occur is limited to consultations with beneficiaries when subject matter specialists collect field level data required for project design. Analysis and design of interventions is often done in isolation from the communities expected to implement the project. Farmers and other members of the community are given limited opportunities to be actively involved in the development of the project design and even less in formulation of development policies. The rhetoric is participation, however, the reality frequently remains top-down.

Techniques to obtain full participation of communities in problem diagnosis and design of locally relevant solutions to problems are available. Participatory Rural Appraisal (PRA) is bottom-up and has been demonstrated to have specific application in preparation of rural development interventions. The growing body of literature on PRA methodologies has arrived at a general agreement on the importance of participation by project beneficiaries in preparation of projects and programs. PRA methods and tools have evolved and have been tested in a wide range of countries, including Sri Lanka. Specialists in project design have applied PRA with rural communities to collect and analyse information on ecological, socio-economic and political conditions. Information obtained by PRA has also contributed to national and provincial level planning of projects and in policy formulation.

The new participatory approaches require changes in practices, including:

- single sector project designs replaced by multi-sector and multi-disciplinary designs;
- less delivery of perceived wisdom and increased listening and learning from local communities;
- less data collection, analysis and planning in isolation by professionals and more data presentation, analysis and planning by local communities farmers with technical specialists as advisors and facilitators;
- fewer questionnaire surveys to obtain information from communities and more application of arrays of participatory methods of learning from, with and by farmers; and
- less identification of development priorities by external agents and more identification and selection of priorities local residents.

Appropriately applied, participatory methods have been demonstrated to be popular, powerful and cost-effective techniques for project design in rural communities. These techniques can lead to better identification of appropriate and sustainable development options for local implementation. However, PRA techniques can result in inappropriate intervention designs in some circumstances. The experiment in two communities in Mee-Oya basin described in this paper examines a refinement to PRA. The use of '*opinion-survey*' techniques is intended to minimise the occurrence of inaccurate problem diagnosis due to inadvertent bias in the selection of the PRA group or due to application of the techniques by inexperienced users.

A Project Focused Approach

Donor funded rural development projects are largely designed to implement sector specific activities. Although components can often be included to address immediate requirements of beneficiary communities, many rural development projects in Sri Lanka have not given local priorities sufficient attention. For example a water resource development project implemented in the dry zone to rehabilitate small tank systems paid insufficient attention to interactions of small tanks in each cascade when designing engineering interventions (Jinapala et al. 1996). When a project has a focus limited to preconceived objectives, planners tend to neglect the real needs of the community and tend to 'receive' requests for activities within the purview of the defined project. Consequently, active participation by the community is often difficult to obtain when the projects fail to address the pressing needs of the community.

Adoption of an exclusive project focus in planing rural development projects (especially water resources development) may lead to two major problems:

1. Agencies may promote activities that are not attractive to the community but which are impressive to donor agencies and therefore obtain approval for funding.
2. Communities may tend to indicate approval for some activities in anticipation of attracting other benefits resulting from implementation of any project in their locality, although the project components are inappropriate or of low priority in the local context.

Failure of planners to adequately recognise these problems is responsible for negative impacts of some water resource development projects. Firstly, active participation of the community in implementation of project activities may be difficult to obtain, even though the project may be making valuable contributions to land and water resource management. Secondly, the lack of perceived ownership of the interventions may make it necessary to provide additional incentives to community members to stimulate implementation of the project. These factors can create serious sustainability problems after the project once incentive payments cease. In this case activities that do not fit the existing socio-economic environment tend to fail.

An Alternative Approach

The proposed refinement of project design using PRA techniques involves two factors. Firstly the PRA process is predicated on the assumption that members of a community will tend to express their real and immediate development needs when consulted during planning phase provided the consultation is not artificially constrained. Secondly, opinion-poll survey techniques are a valid mechanism for confirmation of a consensus that the PRA has correctly identified the development issues.

To test the proposed methodology two locations were selected in the Mee-Oya watershed. Local administration officers identified members of the communities to participate in PRA sessions designed to identify real and immediate development needs of the communities. No attempt was made during the sessions to focus on land and water resource issues, however considerable effort was directed towards ensuring that each participant was able to express their own concerns freely. To verify whether the issues identified in these sessions were the concern of the general community a rapid survey was implemented in each community.

The relative priority of each issue was determined during the PRA sessions and also in the course of follow-up interviews. Local Administration officers working in each location were also consulted to verify the community responses.

The process followed in these locations clearly indicates that non-project focused methods do enable capture of the communities felt needs. Follow-up surveys enable disaggregation of responses to identify variations in priority issues in different segments of the community.

Application of the Alternative Approach in Mee-Oya Watershed

Trial applications of the proposed project design approach were carried out in two locations in the Mee-Oya Watershed during June 1998. The objectives of the field exercise were two-fold, firstly to evaluate the validity of the proposed techniques; and secondly to gather information to identify key issues with relevance to proposals for participatory watershed development.

Sample locations were selected to reflect two different socio-economic and environmental conditions. The first location (Palukadawela) is within the command area of a major irrigation system and therefore the community were relatively better off. The second location (Gurugoda) is outside of the command area and largely dependent of rain fed agriculture.

Fieldwork in the sample areas involved two stages:

- Village level PRA with small groups
- Questionnaire survey with large sample size

Village Level Participatory Rural Appraisal

Separate PRA consultations were organised with participants selected as representative of the general community of each location. During the preparation for the PRA sessions, including selection of participants, the objective of the project design was not revealed to the community. Rather each was requested to consider the local development issues that concerned them. During the sessions each participant was given full opportunity to express their opinion on the immediate and long-term development problems in the area.

The role of the project design team during the PRA sessions was to facilitate the discussions and to ensure each participant was able to contribute as freely as possible. By not focusing discussions on the narrower objectives of designing a watershed development project the team was able to gain considerable insight to the concerns of the community. In addition to the expected issues regarding access to land and water resources the participants also identified problems related to livelihood activities, health, education, and infrastructure.

Community members identified the problems of concern and developed a consensus on the relative importance of each issue for the general community. With the assistance of the design team the participants explored potential solutions to the key issues and discussed the resources required to implement solutions.

Separate discussion were held with officials of the local administration and line-agencies working in each area to gain their perceptions on the problems identified and the priorities assigned by the communities. The officials were also given the opportunity to identify their ranking of the problems in the areas and their proposed solutions.

Development issues identified by selected communities

During PRA sessions in the two villages (Gurugoda and Palukadawala) the participants identified a number of problems considered to be constraining development in the area.

In separate interviews the issues identified through PRA (Tables 1&2) were fully endorsed by line agency officials. In addition, officers of the Agricultural Department stressed the need to implement measures to conserve highland areas and homesteads in Gurugodalla area to address problems of moisture stress. As for marketing they suggested that farmers needed to organize them selves to bargain in the market instead of waiting for Government interventions to provide better prices.

Confirming the validity of PRA results- follow-up survey

During the PRA interviews in Mee-Oya, the project design team had the benefit of facilitators with extensive PRA experience able to help the process without obscuring the real concerns of the group. The issues identified during the sessions received broad support from the participants and line-agency staff interviewed subsequently. However, many PRAs are carried out by persons with less skill and experience and may not correctly identify the communities real concerns.

A follow-up survey is proposed as an objective method of verifying the PRA results with a wider participation. This second stage survey also overcomes, to some extent, an inherent weakness of PRA the inclusion of only a sample of community members where there is a slight danger that the selected group may put forward problems of personal concern, disregarding the common interest.

However, traditional benchmark or agro-economic surveys tend to involve detailed questions covering a wide range of topics. Such surveys take considerable time to design, administer, check, code and analyse. Many benchmark surveys do not become available until late in the project cycle and very rarely are available at project design time.

To understand the significance and magnitude of the development needs identified during PRA, a market research or opinion poll form of survey was designed and implemented.

Development issues identified by follow-up survey

The questionnaire presented the respondents with a series of issues, with opportunity to identify others. Each respondent was asked to rank the issues identified as problem areas in the PRA exercise. The sample sizes were 76 in Gurugoda and 222 in Palukadawala.

The questionnaire originally designed could be completed quickly; the intention being that a respondent would spend less than fifteen minutes with the enumerator. This enables rapid survey of the community. In practice this questionnaire was expanded such that a typical interview took about 20 minutes. Careful design of the questionnaire format and selection of key characteristics of the respondents, such as age, gender, educational status, and principal occupation allows useful disaggregation of responses. Particular care must be taken to avoid the addition of redundant questions.

Of the issues presented, only those identified as problems faced by the respondent were ranked. The rank frequencies for the two samples are given in Tables 3 and 4. In each set of data additional issues identified the respondents are classified as 'Other'. The responses identifying the main

problem areas were analyzed first so as to identify those that are popularly most critical. In doing so, socio-economic subgroups, or the stakeholder groups, were given equal weight.

The given ranks were first transformed into $1/\sqrt{rank}$. The transformed rankings were summed to give an overall ranking for each issue, for each subgroup. This meant that the larger the number of people identifying an issue, the higher the contribution to the sum. The transformation ($1/\sqrt{rank}$) means that, in this case, rank one (1) makes the highest contribution and 13 lowest, in a non-linear fashion. Within each subgroup the issues were ranked, according to the magnitude of the sum, to represent the ranks collectively given by that subgroup.

Tables 5 & 7 present the transformed ranking data for the entire sample and each subgroup at the Palukadawala and Gurugoda respectively. Tables 6 and 8 are the reduction of Tables 3 and 4 to frequencies. For example, the top left cell of table 6 shows the number of subgroups in Palukadawala that ranked irrigation water as the first priority. This frequency table was interpreted directly to determine the overall priority of issues. This form of data exploration was repeated with the mean of the transformed ranks, instead of the sum, to investigate whether the results changed when subgroups of different size are given equal weight. For both Palukadawala and Gurugoda the overall priority of issues did not change with either form of analysis.

Conclusion and recommendations

The results indicate that, in these cases, the issues identified by a small group in PRA sessions did not deviate substantially from those identified by the larger group in survey. Both groups identified diverse development needs in the areas, some of which would not be addressed by the proposed watershed development activity. Had the PRA been narrowly focussed on water resources development, or if the facilitators been less skilled, the diversity of concerns may not have been identified. The rapid survey techniques used here enabled confirmation of PRA findings in a timeframe that enabled input to the design process.

The methodology presented here indicates that the approach adopted in Mee-Oya is more appropriate for identification of felt needs in rural communities than project focused approaches. The generalised approach enables project designers and planners to identify development priorities which would otherwise have been missed as they do not fit within the proposed project. Better knowledge of the other needs of the community enables appropriate parallel actions to be implemented, either as a supporting component of the project or be mobilisation of other resources through the local or national administration.

By ensuring that the priorities are properly identified limited development funds can be better targeted towards the real needs of rural communities. Increased participation by the community can only be expected when the actual development issues of the community are addressed directly.

To adequately identify local development issues the methodology presented here is recommended. However when applying the techniques users must consider:

- Participants in PRA sessions must be selected to properly represent the range of socio-economic conditions of the area and also be drawn from locations that represent the range of physical features in the target area;

- Community members and representatives of line agencies and local administration must have a clear definition of their roles and responsibilities;
- Findings of PRA and surveys should be validated against the development priorities for the area; and
- Established methods are required to address community needs outside project focused activities following problem identification.

A significant issue that emerges is how can non-project focused needs identified by the community be addressed by specific projects. Our argument here is that co-ordinators of area development strategies must integrate the immediate needs of the community with the longer-term development objectives. If the felt needs of the community are neglected because of they outside the focus of specific projects then genuine and active commitment of the communities to implement projects will be unsuccessful.

The SCOR project proposed watersheds as the logical planning unit for rural development in Sri Lanka. The state is the main owner of land and water resources. However, the de-facto managers of many of these resources are the local communities. In the absence of appropriate strategic management of these resources, unsustainable practices are common. To improve the management of the land and water resource uses watershed management must be considered as a component of area development programs.

In the Sri Lanka context, Divisional Secretaries are the appropriate focal point for management of local development. Mobilisation of financial and other assistance to address community needs that fall out of the scope of particular development projects is dependent on the correct identification of needs. The methods proposed here appear to be appropriate methods to, firstly identify broad development concerns, and secondly enable regular updates of community concerns.

References.

Jinapala, K., P.G. Somaratna, 1995. Periodic reports on Shared Control of Natural Resources Project (SCOR), IIMI Unpublished Reports.

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Table No.1, Development Priorities and Proposed Solutions in Gurugodalla.

Issue	Nature of Problem	Solutions proposed
Water	<ol style="list-style-type: none"> 1. Drinking water problems – Poor availability of drinking water in the settlement area. have to go to distant places to fetch water. Even the limited number of wells in the village run dry during dry periods. 2. Shortage of water for agriculture – Farmers are highland cultivators depending on rain for cultivation. They face crop failures due to shortage of rains. 	<ol style="list-style-type: none"> 1. Providing tube wells 1. Providing lift irrigation 2. Construction of agro-wells in highlands and chena lands
Health	<ol style="list-style-type: none"> 1. Long distance to hospitals and health clinics 2. Non availability of latrines 3. Service of community health workers not available to the community 4. Lack of knowledge on community health care 	<ol style="list-style-type: none"> 1. Establishment of a community health center (dispensary in the village) 2. Awareness creation in the community on community health care
Lands	<ol style="list-style-type: none"> 1. Productivity of lands is very low 2. No ownership rights to land 3. Most of the land in the area have been encroached by outsiders 	<ol style="list-style-type: none"> 1. Introducing more profitable crop varieties 2. Providing better marketing arrangement guaranteeing reasonable prices 3. Issue of permits and deeds for encroached lands 4. Putting up trees along the boundary of lands
Education	<ol style="list-style-type: none"> 1. Shortage of essential equipment, furniture and class rooms 2. Shortage of teachers 3. Lack of knowledge in the part of parents of the value of education and increase of dropouts 	<ol style="list-style-type: none"> 1. Supply of essential equipment , furniture and infra structural facilities 2. Holding classes in the village school up to Grade 10 3. Filling the vacancies of teachers in the school 4. Opening up of a primary school
Roads	<ol style="list-style-type: none"> 1. Bridge on the main road is on dilapidated condition 2. Roads are narrow. 3. Dilapidated condition of the roads leading to paddy field 	<ol style="list-style-type: none"> 1. Widening of roads 2. Installation of culverts 3. Gravelling of roads
Livestock	<ol style="list-style-type: none"> 1. Non availability of cows of improved breed 2. Marketing problems 	<ol style="list-style-type: none"> 1. Providing animals of improved breed 2. Establishment of marketing center for the farmers to sell their milk produce
Social relations	<ol style="list-style-type: none"> 1. Conflicts in the village community 	<ol style="list-style-type: none"> 1. Implementing a social mobilization program

Table No.2, Development Priorities and Proposed Solutions in Palukadawal

Issue	Nature of Problem	Solutions proposed
Irrigation water	1. Scarcity of water for cultivation	<ol style="list-style-type: none"> 1. Increasing the capacity of small tanks connected to the main irrigation canal 2. Repairs to irrigation structure 3. Stopping the use of irrigation water by encroachers 4. Construction of a new irrigation supply canal from Mahakannoruwa tank to Mahagalgamuwa and
Wild Elephants	Damages to crops and houses by wild elephants	<ol style="list-style-type: none"> 1. Action by the Dept. Of Wild Life to send the wild elephants to game centuries 2. Issue of fire arms to farmers by authorities
Electricity	<ol style="list-style-type: none"> 1. Inconvenience encountered by villagers due to non-availability of electricity for day to day needs 2. Inability to start some small scale industries due to non-availability of electricity in the village 	<ol style="list-style-type: none"> 1. Organizing community to influence authorities to provide electricity (through politicians and other means)
Homesteads	<ol style="list-style-type: none"> 1. Water scarcity for crops 2. Plants die due to water scarcity 3. Gravel in the ground below one feet 4. Plants are not provided by authorities at appropriate time 5. Damages to crop and house by wild elephants 6. Gravel on the surface of land 	<ol style="list-style-type: none"> 1. Providing lift irrigation using agro wells 2. Selection of suitable crops. Awareness to farmers on soil conservation 3. Providing plants at appropriate time 4. Awareness creation on soil and water conservation 5. Providing protection from wild elephants through Wild Life Department
Main Irrigation Canal	1. Water shortages due blocks and barriers in main canal	<ol style="list-style-type: none"> 1. Use of pipe lines in areas where blocking occurs in the canal due to garbage and waste materials from towns
Capital for investment	<ol style="list-style-type: none"> 1. Inability to start self employment without access to capital 2. Lack of knowledge on government programs to provide loans. to start small-scale industries etc. 	<ol style="list-style-type: none"> 1. Awareness on government programs providing credit facilities for self-employment, industries etc.
Marketing	<ol style="list-style-type: none"> 1. Exploitation by middlemen 2. Difficulty to get a reasonable price for crops 3. Lack of storage facilities to store crops till prices go up 	<ol style="list-style-type: none"> 1. Organizing farmers for marketing 2. Maintaining quality standard of crops to get a better price 3. Intervention by the government or other marketing institute for purchasing agricultural produce
Reservations	<ol style="list-style-type: none"> 1. Construction of houses in reservations 2. Digging of gravel pits in reservations 3. Use of reservation for crop cultivation 	<ol style="list-style-type: none"> 1. Demarcation of reservation
Health	<ol style="list-style-type: none"> 1. Illnesses due to lack of latrines (diarrhea) 2. Malnutrition 3. Addiction to alcohol 	<ol style="list-style-type: none"> 1. Program to provide latrines 2. Awareness of community health care 3. Awareness on malnutrition to parents 4. Implementing government thriposha program 5. Committees to fight against alcoholism 6. Awareness to school children on the impact of drugs and alcohol
Roads	1. Dilapidated condition of the roads in the area	<ol style="list-style-type: none"> 1. Installing culverts in places where they have been damaged 2. Raising the level of roads by earth filling 3. Graveling

Issue	Nature of Problem	Solutions proposed
Animal husbandry	<ol style="list-style-type: none"> 1. No sufficient grazing grounds 2. Water scarcity for animal husbandry 3. Lack of capital 4. Lack of veterinary services in the area 	<ol style="list-style-type: none"> 1. Demarcation of Warayaya area as a grazing ground 2. Awareness creation on animal husbandry as an alternative income generating activity 3. Providing lift irrigation facilities for animal husbandry 1. Credit arrangement for animal husbandry
Education	<ol style="list-style-type: none"> 1. Shortage of teachers 2. Lack of equipment 3. Shortage of buildings 4. Non-availability of play ground 5. Increase in dropout rates 6. Lack of care for education 7. Poverty of parents 	<ol style="list-style-type: none"> 1. Appointment of some more teachers to the school 2. Awareness to the parents on the importance of education 3. Government initiative provide equipment etc. To the school

Table 3. Palukadawala. Frequencies of ranks given.

Rank	1 Irrigation water	2 Wild Elephants	3 Electricity	4 Water for Home gardens	5 Capital	6 Marketing	7 Protected Areas	8 Border Disputes	9 Health issues	10 Roads	11 Livestock	12 Drinking Water	13 Other
1	102	42	7	11	10		1	3	1		61	2	
2	55	25	27	30	26	2	3	2	7	8	3	33	3
3	14	47	29	26	30	3	1	4	10	9	11	32	5
4	8	47	29	33	35	11	2	4	20	9	13	14	
5	3	18	34	39	23	23	9	2	23	18	10	11	8
6	5	12	18	19	30	26	12	16	37	13	19	7	3
7	1	15	16	19	16	34	10	10	30	28	23	10	3
8	5	5	10	7	20	30	16	12	27	29	33	12	1
9	1	4	12	16	11	30	17	16	17	39	20	5	4
10			11	4	9	20	31	28	25	20	11	5	2
11		2	5	4	2	8	24	41	14	11	19	7	5
12		1	15	4	2	4	46	18	1	7	12	8	1
13								1		1	1		2
Total	194	218	213	212	214	191	171	155	214	193	175	205	39

Table 4. Gurugoda. Frequencies of ranks given.

Rank	1 Drinking Water	2 Irrigation water	3 Land ownership	4 Land Productivity	5 Livestock	6 Health Facilities	7 Schools & Education	8 Roads	9 Community Organization
1	52	14	2	1		1	3	3	
2	13	37	2	3	2	11	3	4	
3	3	8	5	11	10	18	8	12	
4	2	4	13	18	7	10	11	10	1
5	2	3	6	11	12	17	15	10	1
6	3	8	17	6	14	10	7	7	3
7			18	13	11	4	14	11	4
8		1	11	13	17	3	11	16	2
9			2		2	2	2	2	43
Total	75	75	76	76	75	76	74	75	54

Table 5. Palukadawala. Ranks by subgroup.

Subgroup rank is calculated by ranking the sum of the individual transformed ranks for each issue.

	01 Irrigation Water	02 Wild Elephants	03 Electricity	04 Water for Home Garden	05 Capital	06 Marketing	07 Protected Areas	08 Border Disputes	09 Health Issues	10 Roads	11 Livestock	12 Drinking Water	13 Other
Total Sample	1	3	6	4	5	9	11	12	7	8	10	2	13
Gender													
Female	1	3	6	5	4	8	11	12	7	9	10	2	13
Male	1	2	6	4	5	10	12	11	7	8	9	3	13
Age Group													
18-35	2	3	4	6	5	10	12	11	7	9	8	1	13
36-55	1	3	6	5	4	8	11	12	7	9	10	2	13
55>	1	2	5	4	6	9	10	12	7	8	11	3	13
Source of Main Household Income													
Cultivator	1	2	6	4	5	8	11	12	7	9	10	3	13
labourer, farmer													
Household chores	1	2	5	7	4	8	11	12	6	9	10	3	13
Professional	2	4	5	3	6	9	12	11	7	8	10	1	13
Salaried Employed													
Retired	1	2	4	5	6	10	11	12	8	7	9	3	13
Residency Status													
1st Gen	1	2	5	4	6	9	10	12	7	8	11	3	13
2nd Gen	1	3	6	5	4	8	11	12	7	9	10	2	13
3rd Gen	1	4	6	5	3	12	11	9	7	10	8	2	13
Other	1	4	3	6	5	9	11	10	8	7	12	2	13
Education Status													
No education	1	2	7	4	6	9	10	11	5	8	12	3	13
Primary/secondary	1	2	6	5	4	9	11	12	7	8	10	3	13
GCE O/A	1	3	5	4	6	8	11	12	7	9	10	2	13
Undergrad													
Main Farm Type													
Farming	1	3	6	4	5	8	12	11	7	9	10	2	13
Non-farming	1	2	6	4	5	9	11	12	7	8	10	3	13
Chena	1	4	5	2	7	10	13	11	6	8	9	3	12
Water Source													
Small tank	11	2	7	1	5	10	9	12	8	4	6	3	13
Main tank	1	3	6	4	5	8	12	11	7	9	10	2	13
N/A	3	1	5	6	4	9	11	12	7	8	10	2	13

Table 6. Palukadawala. Frequencies of group ranks.

E.g. 18 groups ranked irrigation water as priority 1.

Overall Priority	1	3	6	4	5	9	11	12	7	8	10	2	13
	01 Irrigation Water	02 Wild Elephants	03 Electricity	04 Water for Home gardens	05 Capital	06 Marketing	07 Protected Areas	08 Border Disputes	09 Health	10 Roads	11 Livestock	12 Drinking Water	13 Other
Rank													
1	18	1		1								2	
2	2	10		1								9	
3	1	7	1	1	1							11	
4		4	2	9	6								
5			7	6	8				1	1			
6			10	3	6				2		1		
7			2	1	1				16	2			
8						8			3	9	2		
9						8	1	1		9	3		
10						5	3	1		1	12		
11	1						12	7			2		
12						1	5	13			2		1
13							1						21

Table 7. Gurugoda. Ranks by subgroup

Subgroup rank is calculated by ranking the sum of the individual transformed ranks for each issue.

	01 Drinking Water	02 Irrigation Water	03 Land Ownership	04 Land Productivity	05 Quality Livestock	06 Health Facilities	07 Educational Facilities	08 Proper Roads	09 Community Organisation
Total Sample	1	2	7	5	8	3	6	4	9
Gender									
Female	1	2	8	6	7	3	5	4	9
Male	1	2	5	4	8	3	7	6	9
Age Group									
18-35	1	2	7	6	8	3	4	5	9
36-55	1	2	6	5	8	3	7	4	9
55>	1	2	6	4	7	3	8	5	9
Source of Main Household Income									
Cultivator+labourer+farmer	1	2	6	4	8	3	7	5	9
Household chores	1	2	8	6	7	3	4	5	9
Professional Salaried Employed	2	1	3	4	9	7	5	8	6
Retired	1	2	7	5	8	4	6	3	9
Residency Status									
1st Gen	6	1	5	3	7	2	8	4	9
2nd Gen	1	2	8	4	6	3	7	5	9
3rd Gen	1	2	5	8	7	4	3	6	9
Other	1	2	4	5	8	3	7	6	9
Education Status									
No education	1	2	8	4	6	3	7	5	9
Primary/secondary	1	2	5	4	8	3	6	7	9
GCE O/A Undergrad	1	2	7	6	8	5	4	3	9
Main Farm Type									
Farming	1	2	7	6	8	3	4	5	9
Non-farming	1	2	7	4	6	3	8	5	9
Chena	1	2	6	7	8	3	5	4	9
Water Source									
Small tank	1	2	8	5	6	4	3	7	9
Main tank	1	2	7	4	5	3	8	6	9
N/A	2	1	6	3	7	4	8	5	9

Table 8. Gurugoda. Frequencies of group ranks.

E.g. 19 groups ranked drinking water as priority 1.

Overall Priority	1	2	7	4	8	3	6	5	9
	01 Drinking Water	02 Irrigation Water	03 Land Ownership	04 Land Productivity	05 Quality Livestock	06 Health Facilities	07 Educational Facilities	08 Proper Roads	09 community Organisation
Rank									
1	19	3							
2	2	19				1			
3			1	2		15	2	2	
4			1	9		4	4	4	
5			4	4	1	1	3	9	
6	1		5	5	4		2	4	1
7			6	1	6	1	6	2	
8			5	1	10		5	1	
9					1				21

Social and environmental aspects of watershed vulnerability in the Sri Lankan hill country

Ralf Starkloff, Sabaragamuwa University

Abstract

The impact of selected human land use practices on the behaviour of water in the land phase of the hydrological cycle of watersheds in the Sri Lankan hill country is analysed. The study is based on the author's ethnographic research and consultancy work in Sri Lanka since 1991. Eco-hydrological and socio-ecological models of the co-dependency of water and socio-economic development are presented. Tree plantations, vegetable cultivation, tea estates and smallholdings, rural settlement and road construction, as well as the use of forests and grasslands are discussed. Social constraints on implementing hydrologically sound land use, as well as the social actors and organisations involved are identified. Fundamental knowledge deficits among land users, selectivity of competing economic interests and the lack of an integrated water centred approach to land use are observed. Land users are oriented towards narrow and relatively short-term economic returns and high productivity land use. Watershed vulnerability is the composite effect of the ecological consequences of such social constraints. The need for scientifically up to date education of government organisations and the public on eco-hydrology, and for regulatory measures implemented by an adequately empowered 'watershed management authority' are stressed as policy recommendations.

Introduction

Water is an indispensable resource for both the maintenance of viable ecological systems and the sustainability of economic production. The expansion of economic activity and of human populations causes an ever-increasing demand on water resources, while at the same time adversely affecting the environmental conditions of water availability. Water scarcity as a result of land degradation and resource competition in montane watersheds, prevails in innumerable communities in tropical and sub-tropical countries. The use of polluting technologies in both agricultural and industrial production, as well as unsanitary hygienic practices, undermine the quality of drinking water. As a result the production of livelihoods, the physical health of human beings, and the integrity of environmental resource bases may be jeopardised.

Water is therefore not merely an engineering problem, but a social issue. However, scientific understanding, as well as public knowledge, of the relationship between water and society are as yet insufficiently developed. The failure to adequately consider social and environmental aspects of water in development projects may significantly contribute to unanticipated social, economic and environmental costs, and thereby lead to project failures. These in turn could result in social conflicts, the containment of which can be both costly and difficult.

In this paper, I will provide an overview of some of the more significant current land use practices, which adversely affect water availability and quality in the hill country of Sri Lanka. First, I will provide two theoretical models, which situate human land use in the context of social and ecological systems in general, and of the land phase of the hydrological cycle in particular. Then I will discuss the impact on water of the following selected land use forms: Tree plantations, vegetable cultivation, tea estates and smallholdings, rural settlement and road construction.¹ The hydrological significance of forests and grasslands will be pointed out. For each impact I will identify the social causes of hydrological vulnerability, specifically the cognitive and economic constraints experienced by involved social actors and organisations. In this context, I will point out some policy implications to address the problems indicated.

¹ Some other hydrologically adverse land use forms not studied by the author, such as gem mining or urban built-up and waste are not included in this discussion. This in no way is meant to underestimate their importance.

This study is based on ethnographic field research and consultancy work carried out in the Sri Lankan hill country since 1991. Participant observation, open-ended structured interviews, life histories, survey research, participatory rural appraisal, collaborative mapping and the evaluation of demographic data available from government sources were among the research methods employed. I studied the knowledge and land use practices of farmers, foresters, planters and development consultants, as well as engineers involved in water development, road construction and housing development projects. Research was carried out in the upper Mahaweli watershed, including the Uma Oya catchment in the Uva Basin and the Nuwara Eliya region, as well as the upper Walawe watershed, and the Knuckles Range.

The Sri Lankan hill country comprises the island's central mountain massif, the Dumbara massif and the Rakwana massif, ranging from 500 to 2524 metres altitude and extending roughly over 10,000 km². The hill country falls into both the Intermediate and Wet Zones with annual rainfall ranging from 900 mm to 5000 mm (Vitanage 1997; de Silva 1997; Pannabokke 1997). The annual and inter-annual distribution of rainfall is highly variable, and, depending on location, altitude and aspect, distinct micro-climatic conditions need to be considered in land use planning. The major river basins originating in the hill country include the Mahaweli Ganga, Maha Oya, Kelani Ganga, Kalu Ganga, Gin Ganga, Walawe Ganga, Kirindi Oya, Menik Ganga and Kumbukkan Oya. These nine carry about 41.2 percent of the total discharge volume of all of Sri Lanka's 103 river basins². Their innumerable micro-catchments generate essential water resources for agricultural, household, industrial and electric power production.

Theoretical models

The cognitive framework within which we conceptualise socio-economic activity and development efforts and their relationship to ecological systems and their hydrological components is very important. This will determine whether we perceive or ignore the impact of human land use practices on water resources and the effects of water availability on our capacity for sustainable socio-economic production. In this section I am proposing two theoretical models which emphasise the co-dependency of social and ecological systems in general, and of water and human land use in particular.

Figure 1 demonstrates the need to analyse social and ecological systems as co-dependent (O'Connor 1989) networks. Human beings are powerful participants of ecological systems, who depend on the viability of other participating life forms (biomass) and geo-climatic phenomena (water) in order to produce their livelihoods. Human beings participate in water and biomass flows as members of social systems and their conduct in ecological systems is decisively shaped by social factors. The entire gamut of social relations - power, stratification, conflict, the market, the state, development - and systems of knowledge shaping their activities impinge on human resource use and the relations of co-dependency within ecological systems (Starkloff 1998a, 1995b). At the same time the state of natural resources decisively shapes the capabilities of social production systems and thus knowledge and social relations.

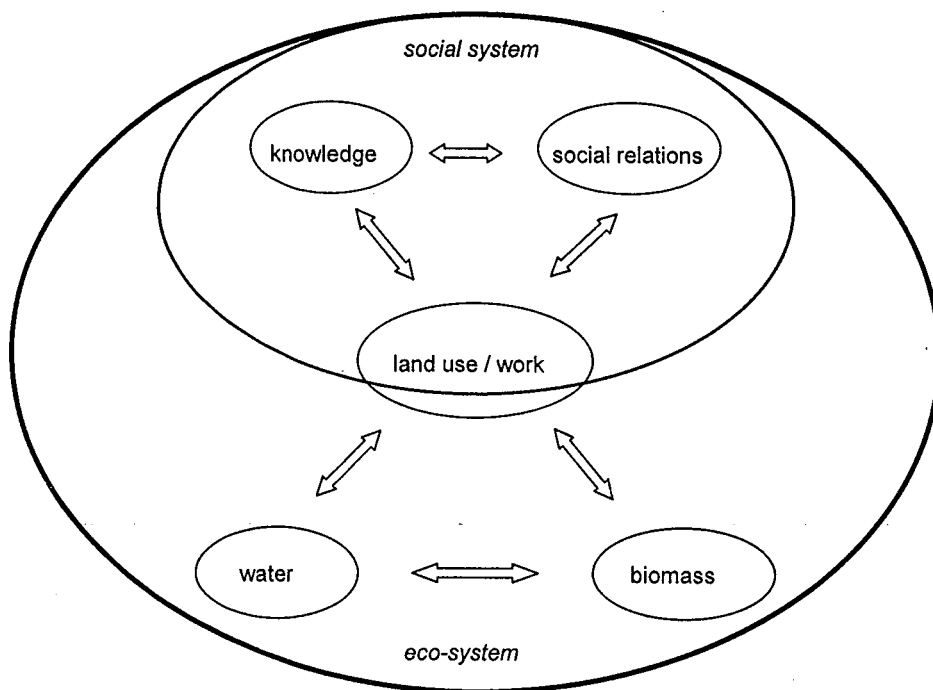
Land use and work constitute the interface between social and ecological systems. Therefore, mediated by human productive activity, pathways between the production of water and biomass are linked to social relations and knowledge systems in a reciprocal manner. Both degrading and sustaining systemic effects are transmitted along these pathways. The type of knowledge we apply to production is influenced by and influences reciprocally the social relations, in the context of which land use is organised. These then affect the production of biomass and water availability. Between biomass and water resources reciprocal co-dependency relations exist as well, where a certain type of biomass structure determines hydrological conditions and is at the same time affected by water availability itself. Water availability and the structure of biomass and soils in turn shape human land use and therefore social relations and our knowledge. Thus, the experience of water scarcity in many parts of the tropics and sub-

² Calculated from the data on discharge volume provided by the Survey Department of Sri Lanka (1988).

tropics has motivated us to rethink our current production systems and to seek to reorganise these in a sustainable manner.

Consequently, it is paramount that we do not perceive fragments of eco-systems as isolated resource bases of human land use, but view ourselves as embedded within eco-systems and the mutually structuring relationships in which we are forced to participate. If we fail to anticipate the potential consequences of our land use activities, we may be confronted with unanticipated consequences, which can adversely affect our ability to produce sustainable livelihoods and economic growth.

Figure 1: Socio-ecological model of production



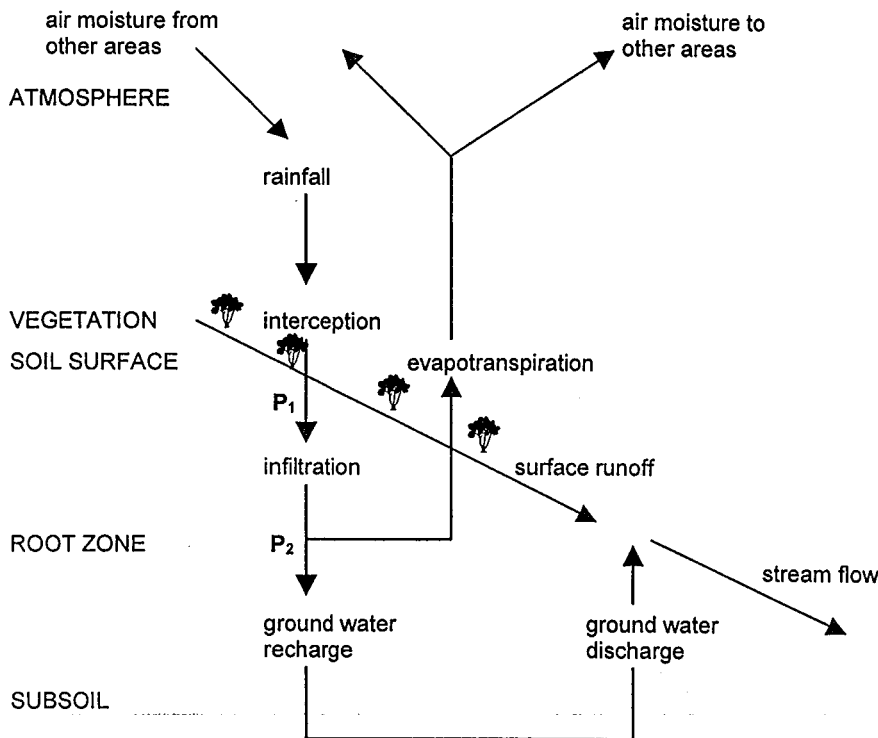
All components are co-dependent, interactive and mutually structuring. Social actors are participants in nature.

↔ Indicates pathways, links or flows of energy, matter and information, transmitting both sustaining and degrading systemic effects. A given state of geo-climatic conditions is assumed.

The 'eco-hydrological' model depicted in Figure 2 further analyses the co-dependency between the behaviour of water, the production of biomass and human land use practices (Falkenmark and Lundqvist 1992; Falkenmark and Chapman 1989; ECE 1989, 1992; Bandyopadhyay 1988; Jayal 1985; Hamilton 1983; Bruijnzeel 1986). The relative quantitative distribution of rain water among three pathways in the land phase of the hydrological cycle - surface runoff, evapotranspiration and ground water recharge, partitioned at the soil surface P_1 and in the root zone P_2 - is determined by the structure of the vegetation and soil. Structures conducive to percolation and infiltration of rain water, such as forests and wet grasslands, minimise surface runoff, and ensure both plant growth and reliable dry season stream flow, on which irrigated agricultural crops, as well as households, industry and electricity production depend. Surface impermeability due to soil erosion and compaction, and/or excessive water uptake by vegetation, such as fast growing tree species, lead to landscape desiccation and

water scarcity. Human land use practices therefore decisively affect the maintenance or degradation of the conditions of production of water, which in turn affect the viability of the production of human livelihoods (Starkloff 1998a).

Figure 2: Rainfall Partitioning 'P'



(Adapted from Falkenmark and Lundqvist 1992)

These models indicate the hydrological pathways along which polluting substances and effects are transmitted. Water necessarily flows through all components of ecological and embedded social systems and thus transports anything from human waste, through silt to industrial pollutants, which then may impair the viability of these systems.

Vulnerability of watersheds can thus be defined as the prevalence of land use forms which promote excessive surface runoff of rainfall at the expense of evapotranspiration and ground water recharge, as well as excessive evapotranspiration of infiltrated rainwater at the expense of ground water recharge. It is noteworthy that there is a necessary proportion of evapotranspiration, which sustains a biomass structure and permits the necessary catchment effect, i.e. infiltration and ground water recharge. In other words, each ecosystem component must be 'paid' for its services in order to function as a co-dependent participant. A sustainable ecosystem then would be one in which all participating components, including human beings and other biomass or life forms, as well as water and soils, are sustained in their existence without undermining the production conditions of others.

The eco-hydrological framework is not only an important conceptual device but provides us with a scientific explanation of unmeasured hydrological processes. For example, in the case of pine plantations, no representative longitudinal data was produced on evapotranspiration, soil moisture, stream flow patterns and silt load, before, during and after plantation establishment. Research in the 1980s neglected the geo-climatic conditions in the Uva and Sabaraga-

muwa Provinces, while the USAID funded Forest Department research station in Weweltalawa observed the behaviour of pines under the wettest rainfall conditions in the country (~5000mm) on closely guarded and fire protected plantations (Perera A. 1988; Gunawardena 1989). This procedure must be judged scientifically unsound.

The adoption of these theoretical premises provides us with a complex cognitive framework, from which guidelines for regulating human land use may be derived. It is, however, clear that mere technical insight into social and ecological necessities is insufficient to promote sustainable land use practices. These depend on human motivation and interest, which are shaped by socio-cultural perceptions and practices as much as social and economic constraints. For example, stratified property and power relations may provide large land users, such as the state or private corporations, with access to seemingly abundant resources and thus result in careless and wasteful use. This in turn would marginalise groups of smaller land users dependent on the same eco-system. These may thus be forced to overexploit the remaining scarce resources. Either group may make decisions based on fragmented knowledge, in which various land use activities occurring in the same watershed are perceived as independent of each other and of a social context. The resulting overall effect of such socio-ecological relations may be the wearing down of an eco-system. Therefore, sustainability requires an appropriate socio-cultural knowledge base and conducive social relations. The practical meaning of these concepts would need to be negotiated and regulated under consideration of existing power relations and environmental necessities. This is a difficult, but in my mind, indispensable task.

Land use and watershed vulnerability

In what follows I indicate the practical relevance of these theoretical considerations. I will deal with the hydrological impact of tree plantations, vegetable cultivation, tea estates and small-holdings, rural settlement and road construction, as well as with the involved actors' social constraints. Various policy recommendations are considered.

Tree plantations

Despite considerable controversy during the late 1980s and early 1990s, pine plantations have remained a dominant feature of the Sri Lankan Forest Department's current planting strategy (Starkloff 1998b). Between the 1960s and 1990, the Sri Lankan Forest Department had grown 18,614 hectares of pine and 18,570 hectares of eucalyptus in its Up-Country Division, making these the most frequently planted genera in the island's watersheds (Bharati 1990). Despite their relatively limited extent, the eco-hydrological impact of tree plantations is considerable as they are invariably planted in the upper and mid-slopes of the hill country's micro-catchments. The decisive factors in the choice of these genera are the relative ease and speed of establishment, which reduces the cost of labour and other material inputs, and their fast growth, which provides for the earliest possible return on investments and the greatest volume of timber, fibre and/or resin per unit of time.

Globally, pine and eucalyptus are widely used as well to replace clear-felled forests and grasslands with monocrop plantations. They are an integral component of the Tropical Forestry Action Plan designed by the United Nations in conjunction with the World Bank and the World Resources Institute, 'to conserve and develop tropical forest resources on a long-term sustainable basis' (FAO 1987; World Resources Institute 1985; Environmental Defence Fund 1987; Shiva 1987; Wood 1988; Hamilton 1983).

In Sri Lanka during the 1960s research and forestry policy emphasised high productivity and thus concentrated on 'the building up of new industries and creating an economic base for the good of society' (Forest Department of Ceylon 1961). To make 'more, better and cheaper goods', 'ecological research' was carried out to find the most suitable species which would withstand the impact of 'severe environments', i.e. the grasslands of the hill country. The potential impact of the trees on such environments was never considered. Results of the trials

persuaded local foresters and their advisors that pine and eucalyptus establish with relative ease and outgrow any indigenous forest species, which appear to be unable to survive seasonal moisture stress in the Uva grasslands. *Beeriya* was shown to be the only desirable indigenous timber species able to succeed under a canopy of eucalyptus. With the help of the Oxford Forestry Institute's data bank 'suitable' species and provenance were searched. *Pinus caribaea* from Belize (former British Honduras) and various species of eucalyptus from Australia were selected. Government financial resources supported planting at this point (De Rosayro 1945/46; Wood 1988; Bandaratilake 1988; Vivekanandan 1988).

As environmental discourse entered international development debates, 'production forestry' was coupled with 'conservation forestry'. In the context of Upper Mahaweli Watershed Management, the development of a new Forestry Master Plan and various IRDPs, the Forest Department received funds (US\$ 16.5 million in loans and grants) and international development expertise from USAid, the World Bank, Finnida, ODA, UNDP and the Dutch government, to carry out the Reforestation and Watershed Management Project (RWMP). In the Upper Mahaweli watershed 9713 hectares of tree plantations were planted, consisting predominantly of pine and eucalyptus species. The rationale behind this strategy was the assumption that 'more trees' would cause 'watershed protection and soil conservation' (Bandaratilake 1988; Jaakko Poeyry 1986). The interest in bringing large expanses of the hill country watersheds under pine and eucalyptus could be legitimised by the circumstance that indiscriminate tree planting has become a popular ritual in environmental symbolics. The main sites of afforestation remained grasslands and abandoned degraded tea estates, which were summarily labelled 'denuded and degraded' (Perera W.R.H. 1988; Bharatie 1990; Bandaratilake 1988).

According to the 20 year evaluation of plantation resources carried out by ODA consultants at the Forest Department in 1991 (Forest Department of Sri Lanka 1991 a and b), and the then DFO Badulla, plantations established reasonably successfully, but were not adequately maintained, as thinning operations failed to be carried out. Foresters argued that the cost of harvesting pine from steep slope sites was above the current market price for private sources of fuelwood mainly from tea estates. Therefore thinning was unprofitable from the Timber Corporations perspective. Rather, the pine plantations are now leased out to local enterprises for tapping of oleoresin, thus making high planting densities desirable.

The controversy between farmers, foresters and environmentalists drew in politicians and members of Sri Lanka's academic community, and 'pinus' became a negative icon in the press and in general public discourse. The Forest Department was confronted with phasing out pines and started to exploit existing resources through successive tapping, thinning and eventual clear cutting. In response to public grievances about the experience of water scarcity in hill country villages, especially in the Intermediate Zone, some inter-planting trials were undertaken. Rows of trees within a few pine lots were cut, felled trees were placed as erosion barriers along the contour and various indigenous species were inter-planted. Once again 'more trees' were perceived as an environmentally sound measure. In the Kandyan Wet Zone Peradeniya University botanists experimented with inter-planting indigenous species under thinned pines. These established successfully due to higher rainfall. The impact on water resources remained unmeasured in these trials.

Desiccation of micro-watersheds afforested with pine and eucalyptus results from increased runoff generation at P1 and increased evapotranspiration at P2 of the rainfall partitioning in the land phase of the hydrological cycle. Pine and eucalyptus plantations present therefore, a worst case scenario for decreased ground water recharge.

In areas with regular seasonal dry periods, as in climatically exposed grasslands (*patana* and *talawa*), water demand of fast growing trees increases moisture stress in the soil surface and upper root zone. The canopy density of the ill-maintained plantations prevents the survival of the climatically adapted sun-tolerant grassland species which survive dry seasons through root dormancy. Shade-tolerant undergrowth, ecologically adapted to forest ecosystems, cannot establish. Litter matting from pine and eucalyptus adversely affects the capacity for seed-

ing accidental species, promotes runoff and changes the chemical structure of the soil. The paucity of resources required by fauna reduces seed import and bio-diversity.

With the impact of inter-monsoon thundershowers and monsoon rains the plantation floor is eroded and the upper soil layers are washed away. In the plantations rocks are exposed, roots destabilised, and the soil structure is compacted due to the lack of moisture, micro-organisms and soil fauna.

These changes in the biomass structure effect increased runoff and evapotranspiration, thus unbalancing seasonal stream flow. In affected micro-watersheds, farmers and the author observed increased runoff, stream flow, earth slips and landslides during rainy periods. Erosive runoff causes silting of water courses, reservoirs and fields. During dry seasons, irrigation and household water resources decline or subside earlier in the agricultural cycle, than before plantation establishment.

If possible, farmers and villagers seek to cope by adopting pump irrigation from remaining water sources and by participating in household water supply projects. If these resources are not available, fields are abandoned or revert to rainfed cultivation, and household water is fetched from more distant sources, predominantly by women. All of these degradation phenomena and coping mechanisms impair the livelihood strategies of local households. They induce resource competition and potential conflict between farm uses and household uses, as well as between the Forest Department and the villagers.

Regular seasonal burning of pine plantations by villagers aggravates degradation effects. Burning is primarily a consequence of widespread anger among farmers. In addition, they burn the plantations to flush out wild boar as a pest control measure. Boars feed on pine roots, inoculated with mycorrhiza fungi to stimulate nitrogen fixation (Perera, A. 1988), and have increased in numbers. They raid the farmers' crops during the night.

Roaming cattle used to graze in the grasslands during daytime in rainy seasons and in the fallow paddy fields during the dry season. These were displaced after the planting of pine and eucalyptus, due to the loss of the cattle's habitat. Thereby, a crucial source of biomass processing and fertility was removed from local ecosystems.

The effects on water users of the hydrological impact of tree plantations vary depending on precipitation levels, which range between 1400 mm in the Uva Basin and 5000 mm in Weweltalawa. The longer the period of normal seasonal drought, the higher is the desiccation effect. In the Horton Plains (~ 3000 mm annual rainfall), one of the crucial catchments of the hill country, the dying back of cloud intercepting old-growth forests has been observed. The hypothesis that this is a consequence of the lowering of the water table of the plains by extensive planting of eucalyptus and pine 'buffer zones' around the lower slopes of the catchment (Paliawadana 1998), should be investigated. This would extend seasonal root zone desiccation beyond the critical tolerance threshold of the montane cloud forests. From Keppetipola in the Uva Basin to Aratenna in the Knuckles Range, farmers have complained bitterly about increased water scarcity. As the first upstream water consumers the plantation trees absorb considerable amounts of water resources and unbalance seasonal stream flow patterns on which local communities had depended for centuries.

By contrast, forests and grasslands had comprised environments high in bio-diversity (de Rosayro 1945/46), which provide an optimum catchment effect for locally specific geo-climatic conditions. The longer the typical dry season, the more forests and wet grasslands occurred only in sheltered gullies and hollows of micro-watersheds, while dry grasslands (*patana*) expanded over the larger climatically more exposed sites. In areas with less moisture constraints, forests cover larger areas and grasslands contain a higher concentration of sun-tolerant tree species (*talawa*). These dynamic constellations are conducive to less evapotranspiration in grasslands, while their runoff infiltrates into humus rich wet grasslands and forests located in gullies. In forests canopy interception and percolation further serve to slow down runoff and promote infiltration and soil moisture storage, which is slowly released into local water courses. The disturbance of these critical hydrological functions by the introduction of

new land use forms interacts with the increasing water demands of a growing population to reduce the carrying capacity of micro-watersheds of the hill country. Pine and eucalyptus plantations, established on crown lands above most other water users, must be considered as a prime adverse impact.

The knowledge base of the foresters involved in plantation establishment was severely constrained by their lack of understanding of site-specific ecological and social conditions, and of the consequences of their activities. Forestry is not river basin centred and is not carried out with an eco-hydrological framework in mind. Rather, it is undertaken as a selective, fragmented activity, single-mindedly focussed on the production of a single commodity, wood for pulp and paper, timber, oleo resin and firewood.

The notions that indigenous tree species have a superior conservation effect than exotics, and that 'more trees are better' are generally accepted fallacies. These ignore climatically specific conditions and therefore the hydrological value of grasslands. The issue is not whether or not trees are indigenous, but their suitability in specific environments regardless of their geographic origin. Global movement of genetic resources during centuries has provided many of Sri Lanka's eco-systems with well adapted species, such as avocado, papaya, rambutan, cypress, bread fruit, and the like. The manner of plantation establishment, i.e. monocrops, under inappropriate geo-climatic conditions, the density of plantations and fast growth are the decisive issues.

Fast growing tree species in monocrop plantations were utilised because they promised the highest economic return on investments and made 'results' visible in a comparatively short period of time, a concern of any development project. The ignored or unintended adverse consequences of tree plantation establishment are treated as externalities, the costs of which are borne by land users other than the Forest Department.

The property rights of the state and the authority of the Forest Department legally sanctioned the industrialisation of forestry in the crownlands of watersheds. Farmers and villagers were excluded from access rights to resources from significant components of their former livelihood systems. They were never consulted about the land use conversion undertaken in their catchments. Even as they complained to the authorities about the effects of tree plantations, their knowledge was invalidated as unscientific, their grievances were evaded and inaction prevailed. Social distancing and exclusion decisively impair communication among the social actors involved in the pine conflict and continue to marginalise farmers. The only positive impact of the pine and eucalyptus plantations is the vastly increased opportunity for fuelwood cutting. This is, however, illegal and punishable, although it alleviates the often-acute shortages of firewood and thereby the pressure on gully forests in the Intermediate Zone.

Lack of plantation management betrays both cognitive and economic constraints, as well as a prevalent attitudinal problem among many governmental land users towards rational and reliable maintenance operations. The impact of not thinning overly dense canopy for 20 years was not considered. The lack of economic viability of thinned out pine timber served to rationalise the foresters' failure to follow prescribed procedures.

Foresters and all concerned land users need to acquire eco-hydrological knowledge and raise their awareness of the interdependence of various human user groups, other fauna and flora, and geo-climatic conditions. Water security and social equity need to be primary considerations of forestry projects, in order to avoid desiccation and resource conflict. Foresters need to revise their exclusive preoccupation with trees and consider grassland conservation and utilisation as one of their concerns.

Forestry requires organisational restructuring. Along with other governmental land use activities it needs to be integrated into river basin centred agencies, regulating and co-ordinating local land use activities. These institutions would bring various land users together at river basin, watershed and micro-watershed levels. These would undertake education among foresters, farmers, engineers, politicians and the interested public, and co-ordinate research and debates on land use planning, decision making and implementation, based on an ethic of eq-

uity and fairness. Property and access rights to crownlands of (micro-)watershed users need to be reorganised to ensure participation in land use planning and conservation measures among all pertinent actors.

Status rituals and attitudes serving to distance social groups from each other need to be unlearned to facilitate effective communication. Farmers need recognition as competent and interested land planners and users, capable of relevant contributions just as foresters, hydrologists or sociologists.

The pine and eucalyptus plantations need to be transformed through a range of conservation measures serving the interest of local land users in stabilising water resources and their livelihood needs. Conservation land use may include staggered felling of portions of the tree plantations in question; biological erosion control measures, such as sloping agricultural land technology (SALT); mixed forest gardens; low-extraction forests and wetlands in immediate catchments; improved grasslands for closely managed herding of cattle; and planned community based fuelwood production.

Specific measures would in the end need to be jointly developed by all land users and experts involved in a pine conversion project, under consideration of local conditions and carrying capacities.

Vegetable cultivation

The cultivation of exotic vegetables in the hill country dates back to the early colonial period. It turned into a widespread and successful production sector from the Second World War and expanded during the "Grow More Food" drive of the Sri Lankan government during the mid-1970s (Weitzel 1971; Abeysekera and Senanayake 1974). By now a productive and lucrative vegetable trade links hill country farmers with urban and rural consumers, mediated by the marketing services of traders and transport entrepreneurs³. Farmers employ green revolution technologies, involving improved seed varieties, agrochemical fertilisers, pesticides and weedicides, sprayers, kerosene pumps, and monocrop planting techniques. Corporate producers and wholesalers, private local traders, and the government's co-operative organisations provide these inputs. Input prices are high compared to farm gate earnings, particularly since the reduction of fertiliser subsidies (ARTI 1993). Vegetable fields are established in rotation with paddy fields, or by converting chena swidden cultivation into permanent hill fields, or by clearing forests and wet grassland, especially in or near gullies close to water sources (Starkloff 1998a, 1995a).

Vegetable cultivation contributes to landscape desiccation, water scarcity and seasonal imbalance of stream flow. The removal of forest and grassland flora and their replacement with clear-weeded high-productivity monocrops increases soil exposure to rainfall impact. Erosive runoff contributes to the silting of watercourses, reservoirs and fields. Agrochemical inputs reduce organic matter in the soil and destroy micro organisms and soil fauna. Soil water evaporation and soil erosion, and runoff increase at the expense of ground water recharge. These effects are aggravated by splash erosion where water pumping with 2-inch irrigation hoses is carried out.

The rotation of paddy and vegetable crops in valley fields involves the cyclical shift from banded paddy fields to well-drained raised vegetable beds. This practice disturbs the structure of the soil and contributes to increased erosion and runoff. The disappearance of the fallow deprives the soil of fertility inputs (dung and green manure) and water retaining organic matter.

Agrochemical residues are leached into the pathways of water and expose downstream water users to pollution. Priyantha's research carried out in the Badulla district found that 76 percent of farmers applied more than the recommended dosage of pesticides, some at concentrations as high as 200 percent (1990). He indicates that as a result pests, which cannot be controlled by pesticides, have increased, as beneficial predators were eliminated.

³ No reliable data on the extent of vegetable cultivation are available, as the Department of Census and Statistics classifies cultivated lands in which vegetables may be grown as paddy, highland and homegardens.

Although many farmers worry about input prices, lack of organic matter in the soil, water pollution and scarcity, they fail to fully understand and acknowledge the adverse hydrological consequences of their own production practices. While many aspects of eco-hydrological knowledge are observable among farmers, most understand only unsystematic fragments and rarely apply these in their land use planning and practices.

Sustainable cultivation practices are constrained by farmers' interest in cash, needed in a modern competitive cash economy. Since producer incomes are relatively marginal and vulnerable to adverse weather conditions and market fluctuations, farmers lack the capacity to invest in conservation measures, and aim for short-term returns on their investments. High-productivity crops serve their interests and lock them into dependency relations with input traders, transport agents and retailers.

Furthermore, vegetable cultivation is an individualised form of cultivation and imposes less labour mobilisation constraints than paddy cultivation. High caste goigama farmers who are frequently under obligation to extensive reciprocal attam (exchange labour) relations therefore prefer it. Lower caste and estate labour vegetable cultivators, who are anyhow excluded from these labour mobilisation relations and frequently from paddy field ownership in the fertile valley bottoms, prefer vegetable cultivation as well.

Water scarcity motivates hill country farmers to reduce or abandon paddy cultivation. Diminishing returns lead them to intensify vegetable cultivation, and to expand further into forests and grasslands to increase their acreage. This effect interacts with population increase which has caused increasing subdivision of family plots and the opening up of new agricultural land where possible. By now very steep slopes, which experience degradation very quickly, have been brought under cultivation in the Uva Basin.

Farmers need to be reoriented towards an eco-hydrological conceptual framework, which requires education of extension officers as well. Small and mid-sized farmers' cultivation would have to be integrated into a river basin centred approach to land use planning and practice. Farmer participation in institutional land use planning discourses, decision making and implementation, needs to be ensured. Both research with farmers and representation of farmers in regulatory and implementing organisations can provide essential inputs.

Cost and pricing structures need to be influenced to ensure more equitable and higher returns on investments while freeing capital for farmer driven conservation measures. Diversification into perennial, value-added crops for export and local sale, needs to be encouraged. This may be done through subsidies, grants, loans and taxation. Farming practices that have less adverse hydrological impact would be rewarded with financial and institutional support, while high levels of externalities need to be punished. None of this can, however, work without ensuring that markets for ecologically sound products create sufficient demand to sustain conservation farming.

Conservation measures with the dual goal of increasing watershed capacity and economic returns should be tailored to the needs of cultivators with different levels of resources and incomes. These measures may include SALT using both tree and grass species; increase of organic matter and fertility (dung, compost, mulch), in combination with reduced application of agrochemical fertilisers (to ensure economically sustainable yields among low-income farmers); biological pest control and companion planting, in combination with reduced use of agrochemical pesticides (to ensure economic sustainability); as well as long-term investment in mixed perennial crops to diversify production among middle farmers and associations of small farmers. In all of these instances sound marketing is essential.

Increased use of cows for the production of milk (direct sale and value added processing) and manure requires careful management. Grassland feeding is feasible only if stocking densities are kept below specific thresholds to avoid erosion and overgrazing. Supervision by full-time herders, tethering and fencing may be needed to avoid crop damage from straying cattle. During nights cattle need to be locked in stalls. Stall-feeding may lead to over-cutting of

grasslands, especially in gullies, and requires the planned production of fodder resources by farmers on allocated plots.

This complex set of requirements remains constrained by the limited acreage available to most farmers, a matter to be considered in watershed land use planning on decision-making levels higher than individual households. It remains furthermore constrained by desiccating land use practices of upstream users, such as the Forest Department. Successful conservation implemented by farmers is only feasible if sufficient water resources are available. The need for integrated planning and action, which overcomes the current state of fragmentation in knowledge and practices, appears self-evident.

Tea estates and small holdings

Tea estates cover an extensive land area in the hill country's watersheds and are a significant source of foreign income earnings in Sri Lanka. In Nuwara Eliya District 51,906 hectares, in Badulla District 30,406 hectares and in Kandy District 23,391 hectares were under tea in 1994 (Department of Census and Statistics 1997). The tea estates are currently in a process of transformation to increasing private ownership by corporate investors, although the state remains an important producer. In addition, small to midsize planters and farming households maintain 23,685 hectares of smaller tea gardens in Nuwara Eliya, Badulla and Kandy Districts (Sri Lanka Tea Board 1996). Larger estates in particular occupy the upper catchment areas of innumerable hill country watersheds and tend to be located above village land, thus impacting resource availability of downstream land users.

Tea cultivation has been thoroughly affected by green revolution high productivity technologies with the aim to maximise returns on investment. It involves the use of improved plant material, and agrochemical fertilisers, pesticides and weedicides. Biomass production on most tea estates is highly dependent on external nutrient inputs of agrochemical fertilisers. The sector consumes the greatest amount of inorganic fertiliser per hectare in the country. Between 1979 and 1987 overall applications increased from 425 kg/ha to 625 kg/ha (NARESA 1991). Amounts are likely to be lower in small private estates, where cash flow tends to be limited and access to credit is constrained, by comparison to large state owned or privatised plantations. The reduction of fertiliser subsidies would have further reduced fertiliser use.

Tea plantations are generally rainfed monocrops established on cleared forest and grassland. Various other perennial crops may to some extent be inter-planted. In well-maintained estates pruned tea trees form a dense low canopy which covers the ground almost entirely. High and low shade trees provide an intermittent barrier to direct sunlight. In degraded tea estates the groundcover is frequently interrupted, shade trees are often lacking, plant growth is inferior and the soil is eroded. This occurs particularly in old plantations requiring replanting, and on steep slopes.

Estates and smallholdings are based on an industrial labour mobilisation regime with a predominantly Tamil estate labour force. Vegetable cultivation and cattle rearing are important production components of hill country tea estates and a source of income for planters as well as estate labourers. The settlement of the estate labour force and of managerial staff involves considerable resource claims and impacts as well.

Historical research into the impact of tea plantations (Meyer 1983) suggests that farmers experienced reduction of stream flow and silting of paddy fields in addition to the loss of free biomass resources from crownland. Plantation establishment in the 19th and early 20th centuries met with frequent complaints and litigation. Typical degradation effects in tea estates are soil exposure due to clear weeding, reduction of organic matter in and compaction of the soil, and leaching of agrochemicals into pathways of water. As tea estates are frequently located on steep slopes, vulnerability to rainfall impact is evident. Conventional soil conservation measures such as terracing are often lacking. Recycling of biomass produced inside the estates is minimal. There is little build-up of leaf litter, and emerging ground cover of herbaceous plants is weeded frequently and removed, leaving the soil exposed. Even on very steep slopes where no tea can be grown ferns and grasses are often removed with hoes, causing minor

earth slips. The tea plants are pruned before the onset of the rainy season, thus increasing the exposure of the soil to rainfall. Continuous treading of the slopes by estate workers compacts the soil or causes its dislocation. In Nuwara Eliya District 28,903 hectares (above 50 percent) of land under tea are considered poorly managed and account for 55.3 percent of total erosion in the district (Widanapathirana 1991).

The hydrological effects of tea plantations are similar to those in tree plantations. The dense planting of deep-rooted monocrops increases evapotranspiration compared with forest and grassland flora, and the degradation of the soil reduces infiltration and groundwater recharge. Hamilton reviewed studies of conversions of forested land to tea and other food or extractive tree monocrops and concluded that steep slopes, clear weeding and the lack of soil conservation measures were associated with increased surface runoff and erosion (Hamilton 1983).

Forests in proximity to tea estates, particularly in gullies and in the upper catchments, but also in areas distant from the estates, experience resource demand for fuelwood by both tea factories and the estate population. Pruned and lopped fuelwood from tea and shade trees can only partially and seasonally cover workers' demand for fuelwood. Homegardens are usually not a part of estate workers livelihood systems for lack of land, time and custom, and no self-produced sources are available. In the lower sections of estates gully forests are usually non-existent. They have been cleared and converted to tea, vegetable cultivation or fodder grass. In the upper sections closer to forest resources estate workers extract fuelwood from natural forests. Both dead and life trees (lopped branches as well as whole trees) are harvested. If extraction exceeds the forest's capacity for regeneration, forest cover in the upper catchments of tea estates is gradually reduced.

Fodder production for cattle maintained by estate workers and by estates themselves poses another threat to forests and grasslands. Particularly in gullies, persistent fodder cutting causes the exposure of soil to rainfall impact and thus erosion, and the regeneration of forestland is prevented. In so-called bio-tea estates in the Haldummulla Division, Badulla District, demand for fodder and green manure has increased tremendously to facilitate composting, the only source of fertiliser permitted. As a consequence, estate workers, who sell compost to the estates and milk to local processing facilities, are persistently clear-cutting fodder grass resources in micro-catchments and stream gullies, as well as on steep hills not utilised for tea. One of the estates involved operates three lorries with crews of up to 12 workers who regularly scavenge fodder grass in an area with a radius of 100km from Haldummulla town. In this case, a project seeking environmental sustainability actually increases demand for organic sources of fertiliser production and thus generates new externalities not accounted for in the internal production process.

Settlement conditions of the estate population pose various hydrological hazards as well. The staggering lack of toilets and the prevalent reluctance to use available communal facilities, cause widespread defecation into watercourses, and thus pollution of downstream water sources for drinking, bathing and washing. Housing facilities are ecologically unsound as well. The cutting of level platforms on steep slopes and the lack of proper drainage systems promote erosive runoff. These effects are further discussed in the section on rural settlement below.

Vegetable production in the estates is subject to the same impacts and constraints indicated in the section on vegetable cultivation. As many estates are located upstream of village cultivation their water demands and erosive effects directly impact the state of resources in the villages. Here resource conflict bears the potential for ethnic friction. In the Walawe Ganga catchment near Haldummulla downstream paddy farmers mobilised the local Grama Niladari to march into the vegetable fields of estate labourers located upstream, and destroyed their irrigation channels, claiming that these significantly reduced water availability during the yala cropping cycle.

Just as pine and eucalyptus plantations, tea plantations are responsible for the reduction of water availability, unbalanced seasonal stream flow and the silting of watercourses, reservoirs and fields. The application of agrochemicals severely alters the chemical composition of water

resources, and human waste pollutes downstream water sources, all of which pose hazards to the health of human and other life. Their historical and continuing impact on forest and grassland resources is severe and has significantly altered the hydrological regime of the hill country. This impact is today perceived as more or less normal, since degradation in tea estates had been initiated already about 130 years ago. By contrast the additional impact of tree plantations and vegetable cultivation has been fairly recent. It must, however, be noted that each of the land use transformation undertaken since human settlement of the central hill country from approximately the 11th century adds to a cumulative degrading effect. The recent interventions have simply pushed the conditions of production of water beyond the threshold of viability, given the simultaneous increase in water demand.

The main social constraints involve again cognitive limitations, as the owners, operators and labourers of tea estates are generally ignorant of eco-hydrological dynamics and their production techniques are not oriented by such knowledge. Their training focuses on high productivity monocrops and thus fragments the tea sector from its environment. Moreover, the socio-economic purpose of estates the generation of profit from an export commodity, as well as the structure of production relations in estates favours single-minded productivism and the externalisation of environmental costs.

The relatively high cost of production based on agrochemicals, causes reluctance to invest in conservation measures. Especially in smallholdings, due to the relatively small scale of production, operators lack the necessary financial means to invest in replanting of degraded sectors and in soil conservation. Social constraints interact here with cognitive ones. Planters for example assume that weed competition would lower productivity, while it is not considered whether the costs of erosion losses and of fertilisers and weedicides outweigh the benefits of clear weeding. The bio-tea alternative may successfully address these issues, but generates new resource demands and externalities. In either case, profitable production is only maintained by externalising environmental cost factors and destabilising local eco-hydrological conditions.

The Upper Mahaweli Watershed Management Project (UMWP) was able to reform production practices among participating privatised tea estates to some extent with the introduction of biological erosion control measures. Large estates are comparatively easy targets for such programmes, since their top-down command structure permits the imposition of new production techniques on large expanses of land. The level of environmental knowledge among the management of these estates was observed as being comparatively high, due to extensive training and expert support from the UMWP. As long as plantations remain profitable, self-sufficient and sustainable biological erosion control may be expected to continue. The question remains how non-participating estates in the private and state sectors, as well as small holders can be motivated to implement the same measures.

In addition to biological erosion control, it will be necessary to introduce composting and mulching of weeds to increase organic matter content of the soil. Rehabilitation, protection and sustainable use of forests and grasslands in hydrologically sensitive areas will be needed. The early colonial practice of keeping gully and catchment forests within tea estates uncultivated to ensure water supplies to down stream users on and outside tea estates needs to be revived.

The current Estate Forestry / Buffer Zone Management Programme among private tea estates growing eucalyptus plantations for fuelwood and value-added timber processing needs to be carefully controlled to avoid further watershed degradation. The production of fuelwood and timber resources by estates themselves is desirable in order to address shortages and depletion of forest resources. Planting in hydrologically sensitive locations needs to be prevented.

Access rights to natural resources by estate workers need restructuring to avoid indiscriminate and degrading resource use. Without user rights which provide a personal stake in resource maintenance this impoverished social group will hardly be motivated to practice responsible land use.

Comprehensive education regarding eco-hydrological dynamics and improved land use practices will be required as well. Institutional structures integrating the tea sector into river basin land use planning as much as regulatory measures, need to be implemented with sufficient means for positive and negative sanctions. Tea producers need to be persuaded that they are not simply producing a single crop but are the managers and users of entire micro-watersheds responsible for either the degradation or maintenance of water and biomass resources on which they themselves, as well as other down stream users depend.

Rural settlement

The number and density of homesteads in the village and estate sectors have increased due to population growth⁴. Scarcity of housing motivates three strategies, the expansion of settlements by squatting and eventually acquiring titles in forest and grassland areas, or by subdivision of existing family homesteads, or by participation in rural village and estate sector housing projects. The latter allocate state land for dense settlement to rural households. In the hill country this invariably requires homestead establishment on hill slopes, some of which may be extremely steep. House construction is generally undertaken without environmentally sound design and water or soil conservation measures, and thus constitutes a considerable adverse impact on water resources.

Customarily level platforms (*gepola*) are cut into a slope to provide a construction site. The soil is thrown down the slope, smothers vegetation and topsoil of home gardens, forests and fields, and is left to erode with the rains. The increase of platforms, roofs, roads, paths and drains create impermeable surfaces which promote increased runoff and erosion (Kovacs, Zuidema and Marsalek 1989).

Increased settlement density simultaneously contributes to the reduction of ground water recharge and increases demand on water resources thereby lowering local water tables. The recent widespread rural water supply and sanitation projects failed in general to consider and carry out source protection. Insufficient upstream sources motivate groundwater extraction with open and tube wells. This practice has induced resource competition between up- and downstream users, especially between household and cultivation needs (Starkloff 1996). As a result of a NGO project in a village near Hali-Ela, Uva Basin, villagers had deprived themselves of water sources for their downstream paddy and vegetable fields by installing a water supply scheme. They eventually decided to dismantle their household water supply scheme, returned to their customary *pihila* (spouts) and cultivated their fields.

Water waste among household users is widespread but unmeasured. Local observation confirmed that many supply systems are ill maintained and leak perpetually, and that users fail to shut-off public and private taps, thus treating pipe borne water as if it was a stream. Water on tap in homesteads is far more wasteful if not used conservatively, in contrast to carrying pots from spouts and wells. While this is admittedly a burden for women, water users are motivated to conserve every drop of their heavy load.

Human garbage, faeces, agrochemical residues, and silt adversely affect the quality of household water supplies. Insufficient and polluted water lowers personal hygiene and impairs human health, especially among small children.

Home gardens have traditionally surrounded rural village homesteads and used to act as a sink for runoff from house sites, as well as a self-sufficient source of food and fuelwood. Current practice fails to maintain or establish homegardens with perennial trees. Extensive felling and establishment of vegetable cultivation have been observed in many old homegardens. At best tall trees are maintained at the peripheries of these gardens. New homesteads generally lack a canopy altogether and favour vegetable cultivation. Fast growing timber species, especially eucalyptus, have become a desired home garden cash crop. Again, the hydrological effect is increased runoff and evapotranspiration at the expense of ground water recharge.

⁴ Except for Nuwara Eliya District, which experienced a 12.3 percent population decline, all hill country districts estimated population increases from 8.4 percent in Kegalla to 17.9 percent in Kandy between 1981 and 1990 (Department of Census and Statistics 1991).

The transformation of home gardens towards annual cash crops and fast growing timber tree species is, of course, a response to both the need for cash and the prevalence of land scarcity among villagers.

Ecological impact of human settlement in rural areas is among the least researched environmental problems and neither individual homesteaders, nor public housing projects undertaken by the state or NGO sector welfare organisations, consider eco-hydrological dynamics. Besides ignorance, the cost of housing prevents poorer households from investing in water conservation and erosion control measures. Furthermore, the lack of a long-term personal stake in a homestead of their own, undermines estate workers' interest in conservation.

Comprehensive and detailed research into prevalent housing practices and their ecological impact is needed. On the basis of research, an education project on eco-hydrological dynamics and the impact of current housing practices needs to be organised for the general public and state actors involved in housing. Currently, no regulatory framework promoting ecologically appropriate rural housing, which covers both individualised and state organised house construction, exists. Guidelines for improved design and construction of housing need to be developed. Regulatory agencies need to be able to positively and negatively sanction settlement practices. Housing and concerned government bodies need to be integrated into a river basin centred institutional structure of land use planning and implementation.

Among desirable improved techniques would be the introduction of houses on stilts to avoid cutting of *gepola* on steep slopes; proper rainwater collection and channelling from roofs to rainwater harvesting tanks, silt sinks and check dams for run-off; source protection of household water supply systems; the improvement of building materials to ensure durability as well as reduction of resource demand, for example for fuelwood in firing bricks; and the promotion of full-canopy homegardens around houses to trap run off and provide an immediate source of food and fuelwood.

Property and access rights to housing, particularly in housing projects, need to provide occupants with a clear stake in their homesteads and may be used as an incentive for environmentally improved techniques of design and construction.

Road construction and maintenance

In the hill country roads are built along the slopes of often-steep hills and mountains, thus posing potential erosive hazards which affect the surrounding land and water resources. Current road construction and maintenance practices are unsatisfactory from an eco-hydrological point of view. They promote erosive runoff, landslides, and silting of watercourses, reservoirs and agricultural lands. Road construction technology fails to adequately consider these impacts as much as the geo-climatic conditions under which it operates.

At the beginning of the 1997 April rainy season in the highland Uva, the Road Development Authority (RDA) of the Badulla district commenced road-widening activities along the road from Welimada to Bandarawela, Haputale, Beragala and Marangahawela. Along the upper side of the road, large earth removal vehicles scraped off earth and rocks. The debris was then dumped downhill into adjacent lands and along the road. In the process road drains and culverts were clogged with earth and rocks as well⁵. As the rainy period intensified the roads and the debris produced huge amounts of muddy runoff draining indiscriminately into gullies, streams and agricultural fields⁶. Meanwhile, road construction stopped in the second half of 1997 after the completion of road-widening activities, due to the lack of funds.

⁵ The same effects result from improper maintenance of road drainage channels. Once overgrown and silted drains and culverts are clogged, roads are destabilised due to seepage of stagnant water.

⁶ Another example of this widespread condition was observed in the immediate catchment of the Samanalawewa reservoir: A paddy farmer reported flooding of erosive runoff into his homegarden from earth removal sites of the Samanalawewa wet-blanketing project and from eroding drains and culverts along the project's steep access road constructed in 1998. He feared that severe rains during the coming monsoon would carry water and silt into his house and paddy fields.

Ever since, erosive runoff from road-widening as well as from uphill land use is conducted along the road during rainfall events. Water is collected in stagnant pools above ill-maintained portions of the road, from where it slowly seeps under the road surface to cause its movement and breaking, and eventually land slides, due to soil saturation. In this instance, uphill land degradation and road construction interact to destabilise the landscape.

The 1997/98 landslides between Halpe in Sabaragamuwa Province and Koslanda in Uva Province along the main trunk road occurred predominantly below tea or pine plantations along portions of the road with ill-maintained drains. Curiously public blame was accorded to high levels of rainfall. However, high levels of intense rainfall are normal in tropical environments and land users need to consider such phenomena as routine conditions. The blame lies with people, not weather, since the hydrological conditions created by the land use practices of planters, foresters and the RDA have resulted in the destabilisation of the road.

Road engineers and workers are cognitively constrained by fragmented, single-issue oriented knowledge, which fails to take eco-hydrological implications into account. The lack of timely road maintenance indicates lack of proper planning and of a work ethic promoting responsible, reliable and environmentally sensitive work. These deficits are compounded by the lack of adequate funds and their cost-effective allocation. As in other land use impacts discussed above, carelessness, ignorance and the externalisation of environmental costs, can conspire to produce disastrous consequences.

The viability of a new highway system that directly connects hill country towns to additional trunk roads crossing the lowlands should be investigated. This would ease the volume of traffic on unstable hill country roads.

Improved road construction techniques would require proper geological surveys and reasonable siting decisions; proper fit of work schedules within climatic patterns (commence work at the end of rainy periods); removal and reuse or careful disposal of excavated earth and rocks; persistent maintenance of drains at all times; and the introduction of biological erosion control measures along roadsides.

These measures would of course increase the cost of road construction, but current externalities would be avoided and the true price of road construction would be at least to some degree borne by the responsible land user. Yet, upstream responsibility for increased silted runoff would still be evaded if road building was reorganised without changes in its socio-ecological context. The fact that road degradation results from interactive effects of various land use forms, affirms the need for integrated watershed and land use management which can target tea estates and the Forest Department alongside the RDA, and for a watershed management authority capable of supporting and enforcing compliance.

A final example illustrates this point from the perspective of the Uma Oya watershed. Along Welimada road dumping of debris from road widening by RDA, during several days of rainfall caused immediate silting of the Mahatotila Oya, a tributary of the Uma Oya. Uma Oya's heavy silt load is derived from erosive runoff in pine and eucalyptus plantations, tea estates, vegetable cultivation, urban and rural settlement, in addition to road construction. This silt load is eventually deposited in the Rantembe reservoir and adversely affects the project's power generation capacity.

Conclusion

Watershed vulnerability in the Sri Lankan hill country is the composite effect of the ecological consequences of a range of social constraints on human land use practices. Land use practices, which increase runoff and evapotranspiration of rainwater in the land phase of the hydrological cycle, at the expense of ground water recharge, impair the productive capacity of watersheds and consequently human livelihood activities. In my discussion I identified fundamental knowledge deficits among all land users, the selectivity of competing economic inter-

ests and the lack of an integrated water centred approach to land use as typical social constraints.

- The knowledge of land users tends to be fragmented and selectively oriented towards isolated interests. It lacks insight into eco-hydrological dynamics and the socio-ecological conditions and consequences of human land use practices. Land users therefore fail to adequately understand and acknowledge adverse hydrological consequences.
- In land use planning, interdisciplinary scientific research into social and environmental aspects of water remains an exception and public education on water and land use is inadequate.
- Land use practices are fragmented and selective as well, as they are focussed on the production of isolated goods or services. In a commoditised and competitive economic context, land users seek the highest economic return on investments within the shortest possible period of time. They therefore favour high productivity land use technologies and seek to externalise environmental costs.
- Low-income land users are particularly affected by scarcity of cash. However, the relatively high cost of agricultural production based on green revolution technologies constrains the financial capacity and/or willingness to invest in conservation measures among all land users. Similarly, the considerable cost of housing constrains the ability of low-income groups to invest in water conservation and erosion control measures.
- The lack of more equitable access rights to resources and the legally sanctioned capacity of state and corporate actors to dominate resources, disempower less affluent land users, who therefore fail to perceive long-term personal stakes in resources which would motivate their conservation.
- Communication among land users is frequently ineffective because of status rituals and social distancing. Experts and government officials tend to de-legitimise the knowledge of lower status groups.
- Inadequate planning, ignorance, carelessness and the lack of a satisfactory work ethic often prevent reliable and environmentally sensitive maintenance operations in land use activities.
- The lack of an institutional context capable of initiating, co-ordinating and regulating integrated watershed management within the context of river basins is a significant social cause of watershed vulnerability. Current governmental, non-governmental and private organisations involved in water and land use management are fragmented and lack shared communication and planning.

The following summary of policy recommendations, made in greater detail throughout my analysis of selected land use forms, indicates how the constraints outlined above may be approached. These are no more than general pointers intended to stimulate debates. I perceive the need for both an improved knowledge base shared among land users of a watershed and the institutional regulation and co-ordination of their interests and activities as the central tasks.

- All concerned land users need to acquire eco-hydrological knowledge. A comprehensive education project to familiarise people with eco-hydrological concepts, to inform them about adverse consequences of their land use practices and to promote alternative production strategies, needs to be implemented in schools, communities, governmental, non-governmental and private organisations, and the media.
- Interdisciplinary research on all social, environmental and technical aspects of watershed management will be an indispensable input into both education and project design and implementation.

- Currently fragmented groups and organisations, involved in land and water use, need to be integrated by watershed management authorities, which regulate and co-ordinate all land use activities occurring within a river basin. Site-specific local activities could be under the jurisdiction of micro-watershed management projects, and island-wide co-ordination could be carried out by an apex organisation within the national government.
- Among the functions of watershed management authorities would be research, education, public debate, the development of guidelines for ecologically sound and socially equitable water and land use, as well as the overall planning and supervision of the implementation of resource development projects in a river basin.
- To enforce such guidelines, the authorities would need to be empowered with sufficient means of positive and negative sanctions. Subsidies, grants, loans and taxation can be used to reward hydrologically sound land use or to punish high levels of environmental externalities. An effective legal framework needs to be established within which offenders who violate watershed integrity can be sanctioned.
- Participation of affected land users in debates, decision making and in project implementation, needs to be built into these authorities, to motivate interest in co-ordinated land use. These structures of communication need to overcome social distancing between different status groups.
- The authorities need the capacity to influence cost and pricing structures in order to ensure sufficient returns on land users' investments to free capital for conservation measures. They should also seek to support markets for environmentally sound products.
- Finally, watershed management authorities need to function as a forum to negotiate and regulate access rights to resources, in order to mediate potential resource conflicts among land users.

Well managed sustainable land use requires de-fragmentation of knowledge, authority and land use practices, and the establishment of information and biomass flows promoting a co-dependent existence of life forms and phenomena suitable for a watershed. Suitability is of course a matter of definition, of human judgement. The proposed watershed management authorities thus need to be sufficiently democratic and transparent to allow a free and scientifically sound debate about what kind of watersheds human beings can and want to live in.

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NATIONAL WATER CONFERENCE

Nov. 4-6, 1998

BMICH, Colombo Sri Lanka

RESEARCH PAPERS PRESENTED

Session No.14 5 November 1998 2:00 p.m.

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SOURCE PROTECTION FOR COST EFFECTIVE AND SUSTAINABLE RURAL WATER SUPPLY

BY
K S K Ranasinghe
Senior Engineer (Rural Water Supply)
National Water Supply and Drainage Board

1.0 Introduction

Sustainability of water supplies of adequate quality to satisfy basic human needs towards social and economic development has consistently been recognised over the past two decades as a major concern. This concern has been increasingly expressed at various forums. In June, 1997 general assembly of United Nations noted that water would become a major limiting factor in Socio-economic development in view of the growing demand, unless early action was taken. It called for highest priority to be given to the serious fresh water problems facing many countries.

In number of countries, the improvements in some aspects of fresh water development, protection and management have been achieved since the adoption of Agenda 21 principles in 1992. However, the overall progress in the implementation of objectives of Agenda 21 with regard to the application of integrated approaches to the development, management and use of water resources has not been adequate to reverse the trend of increasing shortages and deteriorating water quality.

Degradation of capacity, deterioration of water quality etc. of sources of rural water supply schemes are observed as obstacles for smooth functioning of such water schemes. Various recommendations are suggested so far by the experts to overcome this situation. These are mostly found as technically bias costly measures, such as rehabilitation of the whole scheme, replacing of mechanical components such as pumps and motors or even the augmentation of the schemes. Eventhough, they are important suggestions, implementing such proposals are found to be difficult due to lack of funds and suitable skills. Therefore, alternative appropriate and cost effective measures have to be identified with regard to depletion of the recommended yields of rural water sources irrespective of the type of source.

2.0 Rural Water Sources

Any type of water source can be utilised as a rural water resource. A rural water supply scheme is generally designed to cover a population of 500 – 6000 inhabitants. This covers the villages and the rural centres or small towns as well within an administrative area of a Pradeshiya Sabha as per the newly drafted rural water supply policy. Under village schemes, most of sources are found to be the traditionally used streams, medium scale rivers, springs and protected dug wells. In the dry zone the hand pump tube wells also contribute to this situation. These sources are often easy to manage and the reliability of supply is high and can be categorised as environment friendly.

However, the condition of water sources of small towns is not that fascinating. Small towns are defined in the draft rural water policy as rapidly growing rural centres where pipe borne water is a condition for it's economic development. Selecting a water source for a Small Town Water Supply Scheme is an important activity in which attention has to be focused to number of important factors. Population growth rate of rural centre is much greater and is also subjected to gradual development. It has a more exposure to increasing commercial and domestic mobility hence the demand for drinking water and the improvement of level of service are essential requirements of that society. Therefore, selecting a suitable water source for a Small Town has a severe bearing on such implications and it should also be accountable to the increasing demand in the future.

The tropical climate of Sri Lanka does not allow constant saturation conditions in water availability. Prolong hot weather periods dry off most of surface water sources and reduced the ground water table. Heavy rain increases the flood situations and erodes the earth surface, increasing soil erosion and reducing fertility. Therefore, careful consideration should be given when selecting rural water sources irrespective of the type of the source. Further, demand of the users, required water quality and quantity and uncertain environmental conditions should be given much thought when selecting the source.

2.1 Surface Water Sources

Adequate flow measurements to be done if a surface water source is to be selected as a source for a rural water supply scheme. Flow measurements have to be carried out during the dry period for sufficient duration to ensure the quantity of water that can be abstracted from the source. Obtaining a sufficient quantity of water, continuously with an acceptable quality would be the first step towards the sustainability of scheme. Selecting a suitable point of abstraction may have a bearing on cost of transmission and type of structures to be built to receive the water. Designer should be mindful on the budgetary limitations for

the scheme when selecting the point of abstraction as it could influence the cost effectiveness as well.

2.2 Ground Water Sources

If a ground water source is selected as a water source, different type of measures have to be undertaken to guarantee the reliability. Addition to the quality measurements taken through the sample bottles or containers, adequate measurements of pumping test data to be collected to estimate the quantity that can be extracted. Possible environmental impacts have to be studied before recommending the suitable yield. When ground water is the available option as a source, it would be either shallow or deep water depending on the requirement and the existing conditions. Whatever the type of ground water extraction method used, how the mobility of water to the source from soil strata, availability of different type of soil strata, how saturated they are, how reliable the supply etc. have to be studied in detail before finalising a well or another suitable method as the point source for a scheme. Fracture patterns of rock and dynamics of ground water hydrogeology and rock dipping behaviour also to be studied in detail with regard to deep tube wells.

3.0 Source Protection

The objective of the source protection is to implement measures to assure priority usage of water resources to drinking water and to protect quality and sustainability of ground water resources.

Following activities have been identified to achieve the above objective.

- ◆ Define appropriate remedial measures to address water quality problems.
- ◆ Design a strategy for developing water supply schemes in areas with water quality problems to meet safe drinking water requirement and acceptability (preference) of users.
- ◆ Develop technology and other innovative options for solving water quality problems (Fluoride, iron and arsenic) both at village and household level as well as for piped schemes.
- ◆ Develop ground water legislation and regulations and develop regulators' capabilities to manage and protect ground water resources.

- ◆ Develop institutional capabilities for multi-sectoral water allocation, Planning and Management, including water pricing mechanism and features to prioritise allocation for drinking water and protection/mitigation against pollution.

Drinking water for rural households is facing increasing competition. Most of rural populations of Sri Lanka rely on shallow or deep ground water aquifers for drinking water. The recent expansion and development of industry and agricultural sectors have swelled the demand for ground water based industry and irrigation. The rapid development of industry and irrigation is depleting ground water resources, resulting in dried up sources of drinking water. This clearly has serious social, financial and institutional implications for the rural drinking water supply, especially where alternative suppliers require more complex and expensive technology.

With regard to the rural water supply schemes, source protection would achieve very favourable results. It may drastically reduce the cost of treatment and improve the quality of water which intern guarantee the improved health conditions of the end users and increase their efficiency and productivity. Unlike in major schemes, in rural sub sector, it is very convenient to carryout source protection programmes, as the capacity and cost are very low. Once the source is adequately protected, maintenance of the other components of a water treatment plant also can be reduced. Therefore, it is understood that source protection is an unavoidable component in the rural water supply sub sector if cost effective and sustainable rural water supply schemes are to be developed.

3.1 Management of the Source and Policy Development

The overall economic achievements of recent decades, together with the rapid growth in population, have put increasing pressure on limited fresh water supplies and increased the complexity of development and management of fresh water resources in the region. Moreover, several countries are already facing a water crisis, with serious seasonal water shortages and heavily contaminated and depleted surface water and ground water resources. There is therefore an obvious and urgent need for more efficient management of water resources to avert problems caused by diminishing water availability and the increasing scarcity and growing depletion of water resources.

In many parts of the world, misuse of water resources and poor water resource management practices have already resulted in the depletion of aquifers, falling water tables, shrinking inland lakes and stream flows diminished to ecologically unsafe levels.

Therefore, it is imperative to focus the attention to keep a provision for source protection of rural water supply schemes in the policy development processes.

In the draft National Rural Water Supply Policy this issue is addressed with an outstanding importance and responsibility under the main philosophies governing the Policy. The policy spells out that "RWSS systems should be in harmony with environment without causing negative effects on water resources, over abstraction of water etc." It also quotes the important statements issued under "Agenda 21" as goal of the government of Sri Lanka in the area of water and sanitation as noted below;

- ◆ Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- ◆ Water has an economic value in its entire competing users and should be recognised as an economic good.

Recent developments related to the water sector of Sri Lanka emerged the development of several policies such as ground water policy, water resources management policy, policy on water rights etc. It is fascinating to notice that all the said policies address the source protection measures with a greater emphasis.

4.0 Community Participation in Rural Water Source Protection

From a national perspective, community participation in public RWSS services has been negligible until recently. The totally government provided water supply scheme systems have created a culture of dependence in which the water supply system is not mainly perceived as common property. The Jathika Sarvodaya Movement, Estate Sector institutions and the World Bank Assisted "Community Water Supply & Sanitation Project (CWSSP)" have offered programmes on water supply with the active community participation since 1980. Community participation has been more successful when it occurs throughout the project cycle and it is noticed that participation is not effective when agencies retain control over the details of implementation or when issues concerning physical infrastructure and technology are addressed more effectively than issues of social organisation necessary for managing the project works. The forms of user participation vary substantially, ranging from representational committees of users to committees dominated by the rural elite and from direct involvement in construction to supervision of contract.

Under the CWSSP, several Small Town Water Supply Schemes emphasis on source protection with a special consideration due to the nature of the source as well as emphasising more on cost effectiveness and sustainability of scheme. Three Catchment Preservation Programme are being carried out by user communities so far in the districts of Matara, Badulla and Ratnapura as source protection measures.

Eventhough, Catchment Preservation of rural water sources seems very straight forward method leading to source protection of rural water source, there are other activities also which could be adopted as water source protection measures depending on the state of the source. In Koslanda Small Town Water Supply Scheme, the catchment leading to the water source is very well maintained but various human activities carried out within the catchment area add polluting elements to the source. User communities identified the prevention of pollutants from reaching the water source should be the appropriate source protection measure other than the extensive catchment preservation programme.

User involvement in source protection activities elaborated very significant results. Some of them are identified as follows.

The Government is still not in a position to implement any source protection programmes alone. Eventhough existing environmental law has provision to prevent occurrence of such polluting activities, there is no suitable observer to watch such incidences. In response, more appropriate observing agents would be those who use the water from such sources for their consumption.

On the other hand, the extent or the capacity of the source also have an important role to play. In major water supply schemes chatchments are spread covering a larger extent. Organising preservation activities in such a large extent is an impossible task with community participation. However, in rural water supply schemes, it seems very feasible and easy to implement. Difficulties or obstacles which can be surfaced during the implementation process under centrally managed system also could be overcome by undergoing community participation for source protection or through the bottom up approach.

5.0 A Case Study

Extensive catchment preservation programme leading to water source protection was carried out in the community managed rural water supply scheme, Kirinda/Puhulwella. Quality improvement in fresh water, reducing the quality fluctuations and reliability of supply are the achievements in Kirinda/Puhulwella RWSS implemented through the active user involvement. Reducing the treatment cost could be reflected in the tariff once house connections are given though the scheme, illustrating the valuable achievement in-terms of cost effectiveness.

5.1 Details of the Kirinda/Puhulwella Source Protection Programme

Location - Kirinda/Puhulwella is a Small town situated in Matara District in Southern Province of Sri Lanka. It is located about 15 km from Matara on Matara – Hakmana Main Road. The town area falls within the administrative division of Kamburupitiya Pradeshiya Sabha and Kamuburupitiya Divisional Secretary Area.

Background - People of Kirinda/Puhulwella are adversely suffered due to lack of water for a long time. Most of the dug wells within and around the vicinity turn dry during the dry period. Sharing of water available in wells by groups of families could be frequently seen in Kirinda/Puhulwella during dry periods.

This situation gives rise to;

- ◆ Uncertainty on the reliability of well water
- ◆ Water Quality Fluctuations
- ◆ Insufficient Quantity of Well Water

With the inception of small town water supply programme under CWSSP, the main beneficiary request was to guarantee the reliability of source, provide continuous supply and improve the quality of water at a reduced cost as the income levels of the recipients are not adequate to bear high tariffs.

Influence of the NGO (Partner Organisations)

- ◆ Community mobilisation for Kirinda/Puhulwella was done by an Environmentally based NGO called “Youth Greenlogists”. In addition it was responsible to create an environment to develop a Community Based Organisation with in the community.
- ◆ As a NGO, their main concern was on environmental protection in addition to water supply.
- ◆ In the Community mobilisation activities, “Youth Greenlogists” always paid more attention on protection of water resources, as it was the problem of the area with regard to drinking water. Beneficiaries were inspired by their approach and rallied around the protection of Kirinda/Puhulwella water source.

Catchment Preservation

- ◆ Kirinda/Puhulwella small town has to be provided with water by two deep boreholes.
- ◆ Preservation of the catchment leading to the Kirinda/Puhulwella borehole sources were identified as the most possible and applicable source protection technique.
- ◆ First step towards the source protection is recommending a suitable yield to be abstracted, from the boreholes without adverse effects to the environmental conditions.
- ◆ It is clearly indicated that severe environmental and social impacts could be generated if the extraction from bore holes are not done carefully. Therefore, controlling of water abstraction should be done scientifically as well as by implementing adequate catchment preservation methods leading to the improvement of bore hole water.
- ◆ Secondly, demarcating the boundary of the catchment which could lead to nourishment of the borehole recharge capacity.

Demarcation of Boundaries - Boundaries of the catchments leading to the BHs have been identified using the possible fracture patterns of the rock.

Activities proposed by the beneficiary community for preserving this catchment is indicted below.

- ◆ Controlling the soil erosion in the slopy areas by planting appropriate trees which encourage the rain water seepage in to the ground.
- ◆ Controlling the surface runoff by constructing barriers in the hilly areas.
- ◆ Educating the people not to uproot or cut down the trees meaninglessly within the vicinity.
- ◆ Find the water hating trees growing in the area and replacing with water loving trees.

Participatory Activities - Under the catchment preservation, following activities were identified to carryout;

- ◆ Educate the people in the area
Display the name boards (Awareness), in order to indicate the catchment area.
- ◆ Controlling soil erosion in sloppy areas
By constructing barriers
By digging trenches to control and to carry the run off
Improve percolation
Prevention of massive excavation of earth
- ◆ Planting the appropriate trees in a scientific manner

Advantages of Participatory Process Practised at Kirinda/Puhulwella

- ◆ User communities and local NGO's have easy access to the individuals. Therefore, land problems could be settled very easily.

At Kirinda/Puhulwella, even though a borehole is situated in a private land, community was able to receive it for the project free of charge. To compensate it, a free house connection is to be provided to the owner of the land. It can also be considered as his contribution towards the project. Under centrally managed system, this could be very time consuming, painstaking and a tedious effort.

- ◆ Construction of masonry barriers across the slopes and digging trenches also to be carried out in private properties. Consent of landowners are obtained due to participatory approach to execute preservation activities in the respective properties.
- ◆ Dealing with Forest Department directly by the affected community avoids lot of correspondences and meaningless delays. In Kirinda/Puhulwella, CBO/NGO directly channel the Matara District Forest Department and incorporate some of catchment preservation activities in to the Community Forestry programme of Forest Department.
- ◆ Maintaining and control the depletion of ground water tables.
- ◆ Avoid artificial recharge for aquifers.

5.2 Catchment Preservation Under Centrally Managed Systems

- ◆ Under the centrally managed systems, it is very difficult or impossible to carryout preservation activities, as procedures are tedious and complex as well as the extents of catchments are so large or undefined.
- ◆ In centrally managed provider systems, catchment preservation could not be a priority as it mostly controlled by demand and supply.

6.0 Conclusion

Experience obtained in the source protection exercise so far elaborate to emerge more meaning-full strategies with regard to cost effectiveness and sustainability of rural water supply schemes. Kirinda/Puhulwella example only provides one model which illustrate how catchment preservation is adopted with beneficiary participation as an effective source protection measure. There can be various other scenarios that can be developed leading to this objectives such as adopting waste water disposal measures in micro catchments, prevention of flowing human excreta leachate in to water bodies etc. It is very clear that community awareness and participation has a vital importance to carryout such activities.

On the other hand, it is also important to build up policy framework keeping the provision for water source protection as an essential phenomenon with regard to cost effectiveness and sustainability of rural water supply schemes. Participatory approach in planning and implementing the source protection activities also need to be addressed.

It is indeed essential to carryout research studies to develop various models on source protection. It is noticed that the model developed to Kirinda/Puhulwella rural scheme could not be effectively implement in Kaltota, Koslanda or Haliela rural water schemes due to prevailing constraints in location, extent of catchment and type of source etc. of those schemes. Therefore, more research to be done in this area to develop effective models on source protection, leading to the sustainable and cost effective rural water supply schemes.

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**Irrigation Water Quality in the Southeastern Dry Zone of Sri Lanka: A
Case of the Kirindi Oya Scheme**

By

Y. Matsuno, W. K. B. Elkaduwa, and Y. Shinogi

**International Water Management Institute
P.O. Box 2075 Colombo, Sri Lanka**

HO 23529

ABSTRACT

The objectives of this study were: a) to characterize the water quality of different sources in the Kirindi Oya Irrigation and Settlement Project (KOISP) area; b) and to assess potential uses of shallow groundwater and drainage return flow for irrigation, with the aim of increasing the irrigation intensity.

The major quality parameter of irrigation water, Electrical Conductivity (EC) level, was monitored in currently used irrigation water, drainage water and shallow groundwater for a one year period. The results showed that the lowest average in EC was in irrigation water throughout the period followed by drainage and shallow groundwater. Spatial and temporal variations were also observed in drainage and shallow groundwater, probably due to irrigation issue, landform, and drainage condition.

There is potential to increase irrigation intensity by using drainage and ground water conjunctively with reservoir water. However, the existing climatic, soil, and hydrological conditions are favorable for salinization and water logging, especially in the downstream flat alluvial plain. Therefore, irrigation management should include the practice to avoid any secondary salinization of previously productive cultivated soil as a result of discharge of lower quality water and inappropriate drainage management.

INTRODUCTION

As a result of increasing sectorial competition and overall demand for freshwater due to growing population and industries, efforts have been made to sustain agricultural production with less water input. In Sri Lanka, a large portion of water is used by the agricultural sector and it accounts for about 96 % of usable fresh water (IIDE, 1992). However, because of seasonal, annual, and regional variations of rainfall, water availability varies in time and space especially in the dry zone of the country which has often faced water shortage for irrigation and even for domestic needs. For this reason, there has been a growing interest to utilize alternate water sources for irrigation. Water quality has been an increasingly important issue because such water is often recycled that it may pass through pollution sources, used for human activities, etc., and thus contains more pollutants.

Salinity problems have been reported in a number of irrigated areas in the dry zone of Sri Lanka. It occurs in a relatively small scale under different topography and hydrological condition when compared with other countries. Despite of a less attention at regional and higher levels, farmers have often faced a significant reduction in their crop production owing to salinity problems.

The Kirindi Oya Irrigation and Settlement Project (KIOSP) located in the southeastern dry zone of Sri Lanka (Figure 1) is known to have a salinity problem (IIMI, 1995; Roonage, 1995). Following the construction of the Lunuganwehera Reservoir commissioned under the KIOSP in the 1980s, irrigation water in the reservoirs located in

the downstream was affected by the salt-enriched drainage from the newly developed area (IIMI, 1995).

This area presently achieves irrigation intensities of 110 % in 5,500 ha of the newly developed area and 180% in 4,100 ha of the already existing old area, the Ellegala Irrigation System (EIS). There is potential to bring additional fields under irrigation. To achieve this, improving performance both at reservoirs and field level, and supplementing supply of irrigation water are considered. In supplementing irrigation supply, use of drainage water and groundwater are available alternative sources in the absence of diversion of water from any other basin. Such an approach would require a pre-requisite knowledge of irrigation suitability of water from available alternate sources.

This study attempts to characterize the water quality of different sources for irrigation use in the Kirindi Oya scheme and to assess potential to improve land productivity for using drainage and groundwater supplementary to increase the irrigation intensity.

BACKGROUND

The Kirindi Oya Irrigation Scheme covers the Kirindi Oya River basin on both banks between the Lunugamvehera Dam in the north and the coastal lagoons in the south. The project area lies within the agro-ecological region demarcated as DL₅, i.e. a part of the dry zone low country, which represents a semi-arid tropical environment. At 75% probability level, the 100-year mean annual rainfall of the project area is 970 mm and, of this amount, 67% occurs in the maha (wet) season from October to February and 29% in the yala (dry) season from March to August. Temperature is nearly constant and remains within 26° C to 28° C. The 20-year mean annual evaporation of Class A open pan is 2000 mm and evaporation exceeds precipitation in all months except in November and December. As the annual potential evaporation is about twice the rainfall and strong dry westerly winds during June to September period bring in cyclic atmospheric salts, there is potential for significant accretion of salts in this region.

The major reservoir Lunugamvehera, with a 198 million cubic meter (MCM) capacity was commissioned in 1986. The reservoirs in the EIS (viz. Pannagamuwa, Weerawila, Debara Wewa, Tissa Wewa and Yoda Wewa) receives water from the Lunugamvehera Reservoir through the main Left Bank (LB) canal. In addition, considerable drainage water is received from the newly irrigated areas and a limited inflow of catchment runoff from rainfall. Part of the drainage water of the LB reaches the Debara Wewa, Tissa Wewa, and Yoda Wewa through the command of the new area. Drainage discharge from the Tissa Wewa irrigation command area also reaches the Yoda Wewa. Part of the drainage water from the Right Bank (RB) reaches the Pannagamuwa and Weerawila tanks. Drainage water from the RB is also discharged into the Embilikala lagoon located in the Bundala National Park.

The land forms of the KOISP are characterized by a flat alluvial plain and an undulating mantled plain. The EIS is exclusively within the flat plain of the Kirindi Oya, with a slope of a 0-3% gradient. Although natural levees, particularly Kirindi Oya River banks (extensively used as homesteads), occupy a slightly elevated position than the rest of the flat plain, there is only a slight difference in elevation between the extensive rice fields and interspersed coconut lands of the EIS. The slightly higher aspects of the micro-relief consists of imperfectly drained brown alluvial soils and the lower aspects consist of poorly drained grey alluvial soils. On the contrary, the new area of the KOISP is located exclusively in the mantled plain, which is characterized as moderately sloped at 2- 8 % gradient.

The major reservoirs of the EIS are located in the transitional landscape between the undulating residual plain and the flat alluvial plain. The soils in about 75% of the undulating residual mantled plain are Reddish Brown Earth (Chromic Luvisols Lvx) and the soils in the rest of the area are Solodized Solonets (Gley Solonetz Sng), which is a sodic soil with an exchangeable sodium content of more than 15% of the exchange complex.

Compared with the flat alluvial plain of the EIS, the new area has better drainage conditions facilitated by the undulating terrain, well to moderately well drained soils, higher drainage density, and satisfactory gradients of drainage canals. Through the center of the flat alluvial plain, the Kirindi Oya River cuts through with a distinct incised drainage path providing the main drainage, and with variations in the drainage within the flat alluvial plain.

The Weerawila irrigation command area (i.e. old area Right Bank) is situated in a slightly uplifted and dissected alluvial plain which grades into the main Kirindi Oya in a convex - concave transverse profile with a slope of 1.5 - 2.5%. In the flat alluvial plain, the highest drainage density is evident in this type of landscape and together with gradient of drainage ways to the Kirindi Oya incised main drain it provides a steady outflow from the irrigation command area. In contrast, the Tissa Wewa and Yoda Wewa irrigation command areas (old area Left Bank) are located in the flat alluvial plain with an average slope of 0.5% and a relatively less drainage density and therefore, have a comparatively sluggish natural drainage. The natural drainage in the Tissa Wewa and Yoda Wewa irrigation command areas are governed by the gradient to the bed level of the incised Kirindi Oya which is about 5 m below the land surface in lower reaches of Kirindi Oya. However, the irrigated lands of the Yoda Wewa are a distant away from the Kirindi Oya and drainage is mainly through a drainage canal with an outlet located just above the sea level, which is impeded by the formation of a sand dune ridge. As a result, drainage conditions in the Yoda Wewa irrigation command area are inferior to that of Tissa Wewa.

MATERIALS AND METHOD

Irrigation water quality was monitored in the reservoirs of Lunuganwehera and the EIS for a one-year period from the January to December 1997. Water samples were taken

monthly from all the major reservoirs of the KOISP and analyzed for the content of Ca, Mg, and Na. PH, Electrical Conductivity (EC) was also measured using portable field equipment. The water quality was analyzed by the procedure recommended by the National Water Supply and Drainage Board (NWSDB) of Sri Lanka. After the analysis, the Sodium Absorption Ratio (SAR) was calculated.

Additionally, the EC of surface water and shallow groundwater of main drainage canals including three locations at the Kirindi Oya river, and selected shallow wells was measured during the same period but more frequently in all the major reservoirs of the KOISP. EC levels were monitored at weekly intervals during the first five months followed by two week intervals for the rest of the period. 83 wells were selected in the project area. Wells are not equally distributed in the project area, though every effort was made to select wells at random. In 30 wells, EC levels at different depths of water (i.e. at 25 cm, 50 cm, and 75 cm from the surface water level, and at the bottom of the well) and also salinity of a water sample drawn from the well were measured. In all of these wells, there was no significant variation in salinity at different depths or in the water sample drawn at a given time. The magnitude of variation observed was only to the second decimal point of salinity measured in decisiemens per meter (dS/m) in few of the wells. Therefore, in each well, EC was consistently monitored only at one depth, about 30 cm below the water surface.

Information such as rainfall, reservoir inflow and outflow, tank water levels, irrigation water issues, etc., were obtained from the records maintained at the Irrigation Department KOISP Office and from personal communications with officials attached to this office. Drainage ways in and out of different irrigation command areas of the KOISP were identified using the available maps and field observations. The information gathered through field observations and discussion with local people was used as a guide to identify the possible cause-effect relationship.

RESULTS AND DISCUSSION

Irrigation water

Table 1 shows the statistics of irrigation water quality parameters measured in the KOISP. According to the irrigation water quality guidelines by Ayers and Westcot (1985), the measured range of EC and SAR falls within the slightly to moderate effect on infiltration problem.

EC is considered the main criteria for determining quality of water for crop irrigation and probably one of the most widely monitored water quality indicators. It is also a good estimate for other quality parameters such as salinity, total dissolved solid (TDS), nutrient level, dissolved oxygen demand (DO), and inorganic ions (Wang and Yin. 1997). Figure 2 shows the comparison of average EC in different sources over the study period. EC in the reservoir including the Lunuganwehera are clearly lower than that of drainage (including the Kirindi Oya river) and shallow groundwater. A lower standard deviation of reservoir EC is an indication of relatively stable EC relating to seasons and locations.

The lowest level of salinity was found in the Lunugamvehera Reservoir throughout the study period (Figure 3). Compared to EC levels reported in the 1990- 1993 period (Roonage 1995), no appreciable change in the EC level of Lunugamvehera Reservoir has taken place during 1997 and water remains of good quality for irrigation use for most parts of the year. The drainage discharge should be responsible for higher EC levels in the EIS reservoirs, and the difference in EC among the tanks of EIS could be related to the proportion of drainage water received by them compared with water from other sources such as the Lunugamvehera Reservoir and catchment rainfall-runoff.

Drainage water

When compared with EC in the reservoirs, a higher level of EC was observed in drainage water (Figure 2). The high variation in EC measurements could be caused by both spatial and temporal variations. Figure 4 shows an increasing of EC in the Kirindi Oya river as the distance from the Lunugamvehera increases. The EC of the reservoirs also shows similar trends as it increases at the downstream locations (Figure 3). Salt content of drainage water also changed greatly during the season and probably relates to the irrigation water issue to the command area. Figure 5 shows a trend of higher EC in the RB main drainage when less irrigation water was issued to the RB main canal. The highest EC was monitored in the RB drainage among all drainage locations. A similar relationship was also observed between Yoda Wewa irrigation issue and EC of the Yoda Wewa main drainage. It is supposed that drainage flow depends on irrigation supply and rainfall. But rainfall during the period did not correspond to the fluctuation of the drainage EC, and therefore irrigation water was a dominant factor to determine the EC fluctuation during the period.

Besides the incised Kirindi Oya river, which serves as the main drainage, the EIS used to have a good drainage network leading out to several out falls into the sea. However, they were disrupted during the 1969 flood and they have not been restored to previous conditions. The present maintenance of the drainage network is unsatisfactory and water stagnates in many drainage canals due to farmer interference to re-use these drainage flows etc. This impeded drainage, particularly due to siltation in the final 2-km stretch of narrow canal leading to the sea and the sand barrier formed at the sea out fall. These conditions have resulted in stagnant water in the Yoda Wewa drainage canal most of the time without adequate flushing. A recent survey (unpublished) conducted by the Irrigation Department reported that the soils are affected in this area and soil saturation extracts of EC and SAR were as high as 32 dS/m and 31 respectively. In fact, water logging due to poor drainage has caused severe problems of salinity in the lower reaches of the Yoda Wewa irrigation command area, resulting in about 80 ha of paddy being totally abandoned for the past ten years.

The present level of irrigation water has a potential to cause yield reduction under the least drainage facilities prevailing in the Yoda Wewa irrigation command area. Considering the present drainage conditions, the RB of EIS (i.e. Pannagamuwa and Weerawila irrigation command areas) could tolerate more saline irrigation water compared to that in the LB (i.e. Debara Wewa, Tissa Wewa and Yoda Wewa irrigation

command areas). Irrigated lands in the new area could tolerate higher salinity in irrigation water compared to that of the EIS because of a better drainage condition.

The shallow groundwater EC was the highest among the three sources with a high variation. Groundwater quality generally depends on soils, amount and source of the groundwater. Major sources of the shallow groundwater are rainfall and irrigation water including seepage from the canals and reservoirs, both sources having much less salinity than that observed in groundwater. Therefore, a higher proportion of dissolved constituents found in groundwater could be the result of greater exposure to soluble material in geologic strata and environmental factors, such as accumulation of salts in the wells from shallow aquifers due to poor subsurface drainage conditions.

Groundwater

Figure 6 shows the EC of monitored shallow wells plotted as a box-plot. EC in the majority of wells observed did not vary during the period, while there were more variations between wells. This implies that the spatial variation of the groundwater EC was relatively higher than its temporal variation. It seems that wells having a relatively higher range of EC also have a high temporal variation. Further analysis is being carried out to relate these variations to locations of wells.

Using the average values of salinity observed in each well, the wells were ranked from lowest to the highest EC levels and then divided into groups of different water quality categories in accordance with the irrigation water salinity classification by the US Salinity Laboratory (Agricultural Compendium, 1981). The result (Figure 7) shows that wells with the class 2 quality (EC: 0.25 - 0.75 dS/m) shallow groundwater are mostly in the newly irrigated and its surrounding areas, which are located in the undulating residual mantled plain. The class 3 quality (EC: 0.75 - 2.25 dS/m) groundwater is common within the EIS in the flat alluvial plain of the Kirindi Oya basin. The class 3 shallow groundwater is also found in some parts of the undulating residual plain. The classes 4 (EC: 2.25 - 4.00 dS/m) and 5 (EC: 4.00 - 6.00 dS/m) quality groundwater is found both in the undulating residual and alluvial plains. However, the number of wells with the classes 4 and 5 quality is less compared to that of the class 2 and 3 quality and wells with such poor quality categories of water is less in the mantled plain than in the flat alluvial plain. Therefore, it is reasonable to conclude that the spatial distribution of salinity levels of shallow groundwater is governed mainly by the drainage conditions determined by landscape hydrology and other drainage characteristics such as drainage density and gradient of drainage ways.

Although there are a few locations with temporal variations, the dependence of spatial distribution of shallow groundwater EC on the overall drainage condition is an indication that high EC results mainly from net inflow of ground and surface water in poorly drained parts of the landscape, micro depressions, areas with drainage congestion in adjacent drainage ways. Therefore, relatively high saline groundwater areas are in low lying poorly drained lands as a result of the mobilization of large quantities of salts by leaching of irrigation water, and the subsequent accumulation of the salt in localized areas with restricted drainage in the landscape where the water table is near the soil

surface. This is further exacerbated by the accumulation of salt in the soil due to an evaporation-driven processes. Restricted drainage is mainly due to the presence of shallow groundwater related to topographic position and poor permeability of soils due to high content of alluvial clay, which impedes downward movement of water. As a result, wells show less salinity when leaching out of salt occur through near surface soil profile with rain (particularly in maha season) and irrigation water as revealed by the temporal variation in salinity.

Relatively better drainage conditions and better quality of groundwater in the new area compared with the EIS area provides a potential for use of groundwater in conjunction with presently used irrigation water from the Lunugamvehera reservoir. Even now shallow groundwater is used for irrigation of non-rice field crops during the yala season on a very limited scale in areas located outside the irrigation command of the LB. However, while attempting to increase the irrigation intensity in the new area, care must be taken not to disturb the present salt balance that maintains water at Ellegala tanks at the optimum EC range for crop production.

CONCLUSIONS

Considering the prevailing hydrological situation and salinity level, approaches should include the following combination of practices to increase irrigation intensity while preventing reduction of production.

- a) Implementation of more efficient irrigation water management practices with presently used class 1 quality water available from the Lunugamvehera major reservoir and class 2 water from all other reservoirs of the EIS.
- b) Conjunctive use of shallow groundwater and drainage water together with presently used irrigation water (i.e. water in Lunugamvehera reservoir and tanks of the Ellegala system) to achieve this higher irrigation intensity. This would also aid in lowering water table elevations. Introduction of other suitable field crops at least in the new area, particularly during the yala season should be considered, as they would demand less water.
- c) Improvements in the existing drainage conditions in both project and on-farm levels to achieve a good drainage network to intercept and quickly remove drainage water, particularly in the EIS to minimize salinization of soils and groundwater, the other alternate sources of water. Drainage water from the KOISP system is ultimately discharged into the sea and downstream lagoons.

It is very important to preclude any secondary salinization of previously productive cultivated soil as a result of discharge of low quality water into good quality water and inappropriate drainage management. The existing climatic, physiological and hydrological conditions are favorable for salinization and water logging, particularly in the flat alluvial plain if quality of irrigation water and management become poor the

water table is almost at the surface during irrigation periods. Periodical measurements of water quality are important to ensure that salinity is being kept below the acceptable levels.

Similar salinity problems have observed in the other irrigation schemes in the dry zone of Sri Lanka. The problems likely occur when 1) irrigation water supply was not sufficient to leach out the excessive salts, or/and 2) drainage facility are not adequate or not properly maintained. The former can be seen at tail end farms and in the irrigation schemes of which often face water scarce situation. This was also reported in the KIOSP (Roonage, 1995), while the latter has discussed in this study and the other (Gangodawila, 1994). The situation can be improved if the government authorities take an appropriate action as well as farmers to gain adequate knowledge on dealing with the salinity.

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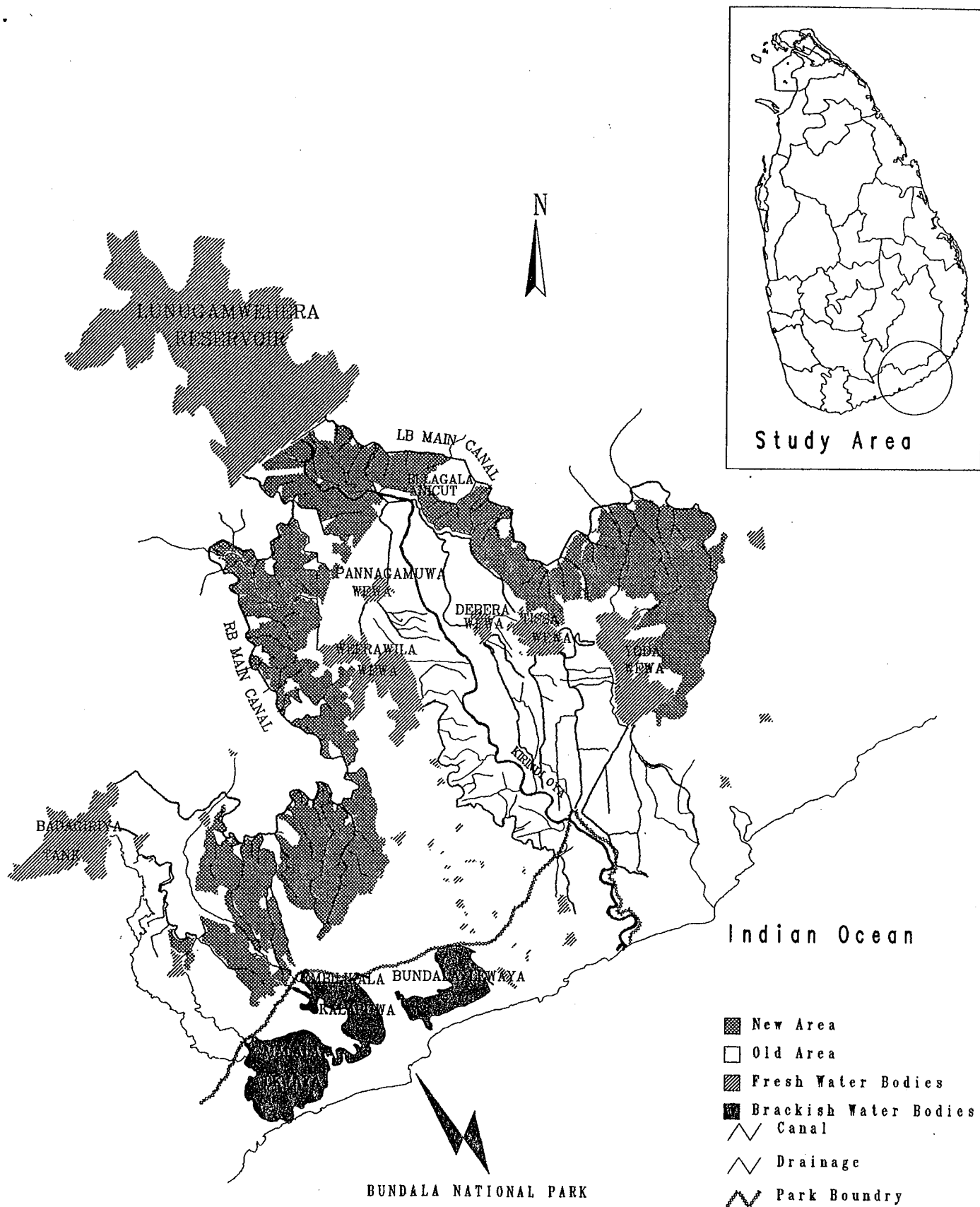


Figure 1

Map of the study area

Table 1. Irrigation water quality in KIOSP

Parameter	Unit	Average	Standard deviation	Maximum	Minimum
Temp (water)	°C	28.97	1.71	33.00	25.20
pH		7.22	0.60	8.25	6.07
EC	dS/m	0.44	0.13	0.79	0.20
SAR		0.21	0.30	1.02	0.02

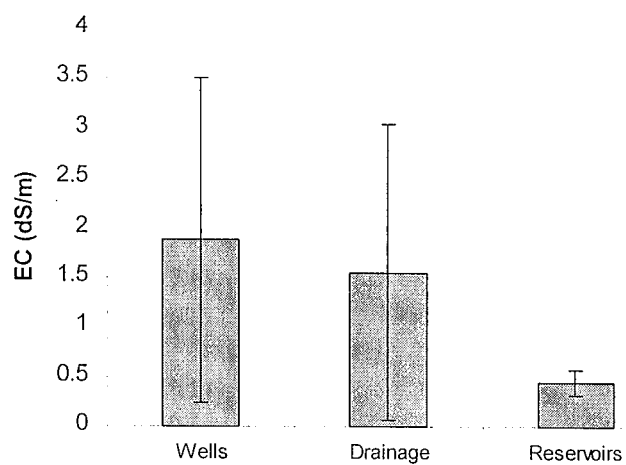


Figure 2 Comparison of average EC values in different sources. Vertical bars indicate the standard deviation

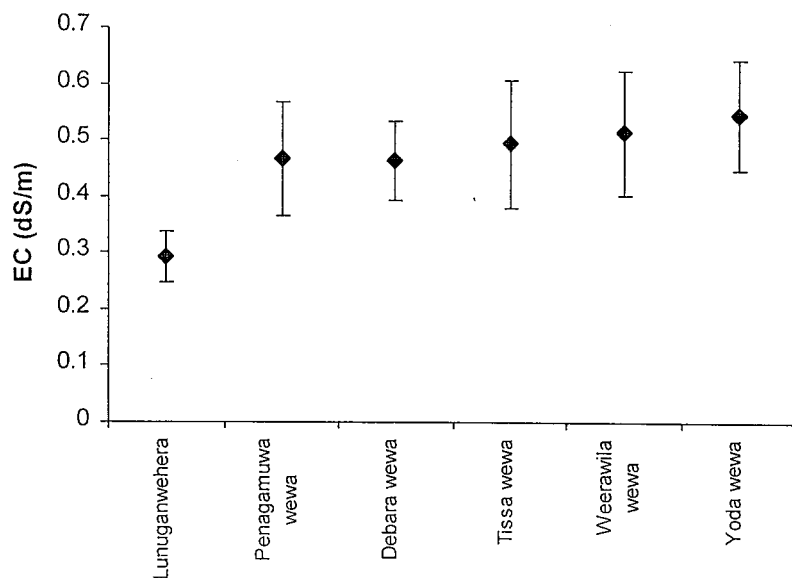


Figure 3 Average and standard deviation of EC in the reservoirs of KOISP

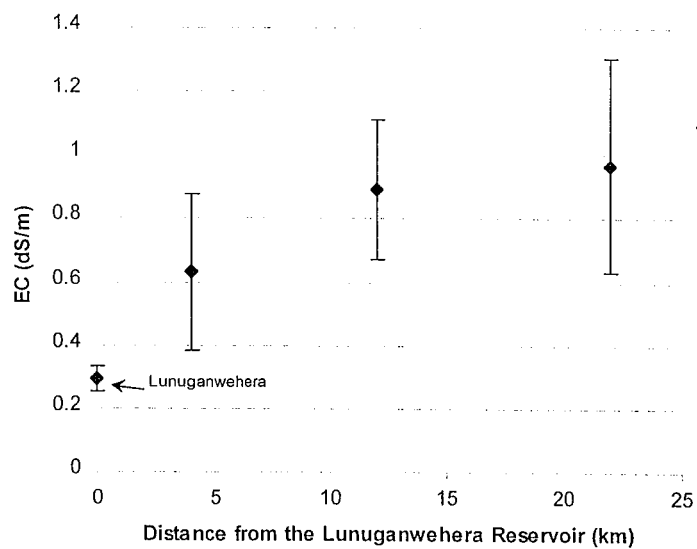


Figure 4 Change in EC along the course of Kirindi Oya river. Vertical bars indicate the standard deviation

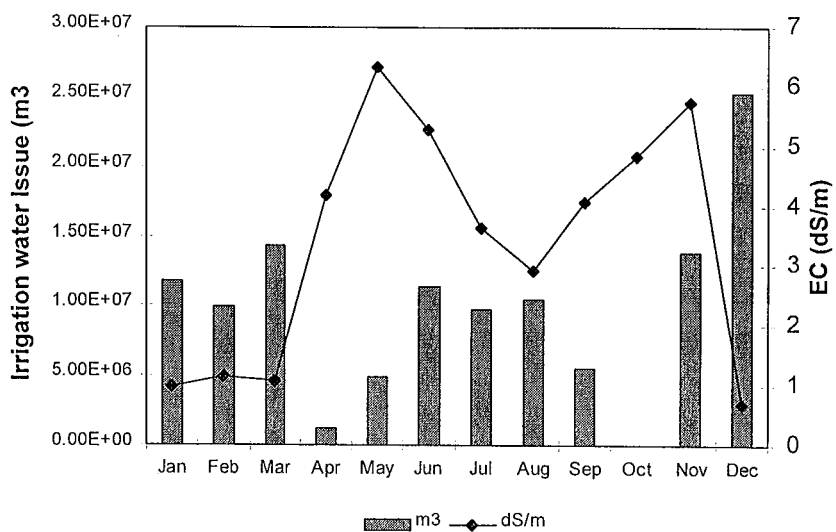


Figure 5 Monthly irrigation issues to the Right Bank and EC values in the Right Bank main drainage

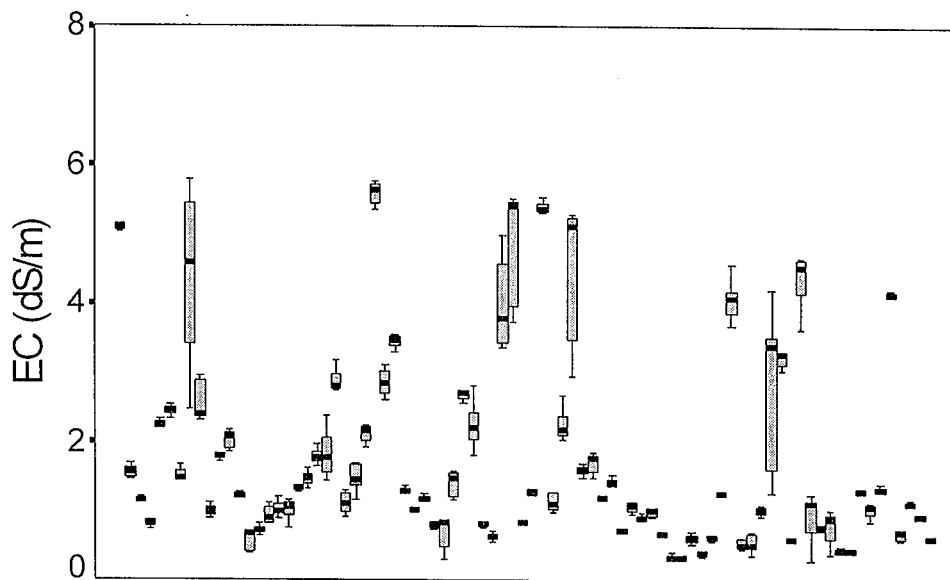


Figure 6 Box-plot of EC values in 83 shallow wells, indicating maximum, minimum, median, 25% and 75% percentiles

WATER QUALITY OF BRACKISH WATER ECOSYSTEM FROM DEDERU OYA TO MUNDEL LAKE: AREA OF EXTENSIVE SHRIMP FARMING

T.N. Ariyananda¹ and E.I.I. Silva²

1. *Intermediate Technology Development Group, No.5, Lionel Edirisinghe Mawatha, Kirulapone Colombo 5*
2. *Institute of Fundamental Studies, Hantana Road, Kandy*

Introduction

Shrimp farming has been expanding lucrative business operating on the north-west coast of Sri Lanka since 1985. There are over 500 farms operating in the area surrounding the Dutch Canal from Deduru Oya to Mundel Lake. For these farms Dutch Canal and the Mundel Lake is the main source of water and also the main water body receiving farm effluent. The effluent containing high organic load, nutrients, chemicals and disease (white spot) has lead to many economic and environmental losses. This study looks at the change in water quality in the Dutch Canal over one year period November 1995 to October 1996 and Mundel Lake from February 1997 to January 1998. Following water quality parameters were determined in situ at each site: Temperature, Salinity, pH, and alkalinity and in the laboratory: dissolved oxygen, suspended solids, nitrates, nitrite, phosphorous, COD (Chemical Oxygen Demand) ,BOD₅ (Biological Oxygen Demand) and Chlorophyll-a.

Study Area

Mundel Lake and the Dutch Canal, is situated in the Puttalam District of the North Western Province between the sea and the Colombo-Puttalama road/railway (Figure 1).

The Lake is (12 x 3-4 km, 3,600 ha) and shallow (< 1m), brackish lagoon fringed by mud flats, salt water marshes and remnants of mangrove strands. It is separated from the sea by a narrow sandy dune ridge. At the north is connected to the Puttalama lagoon and eventually to the sea by a narrow corridor channel. In the south, through the Dutch Canal to Deduru Oya estuary. Close to Udappuwa village as it connects to the Dutch Canal the it is separated from the sea by a sandy dune ridge, that narrow to a causeway. Dutch Canal connecting the Deduru oya estuary and the Mundel Lake is approximately 15 km long and also linked to the Muthupantiya lagoon. The Canal is 2-40 m in width and 2-3 m in depth and fringed with mangrove strands, marsh land and shrimp farms.

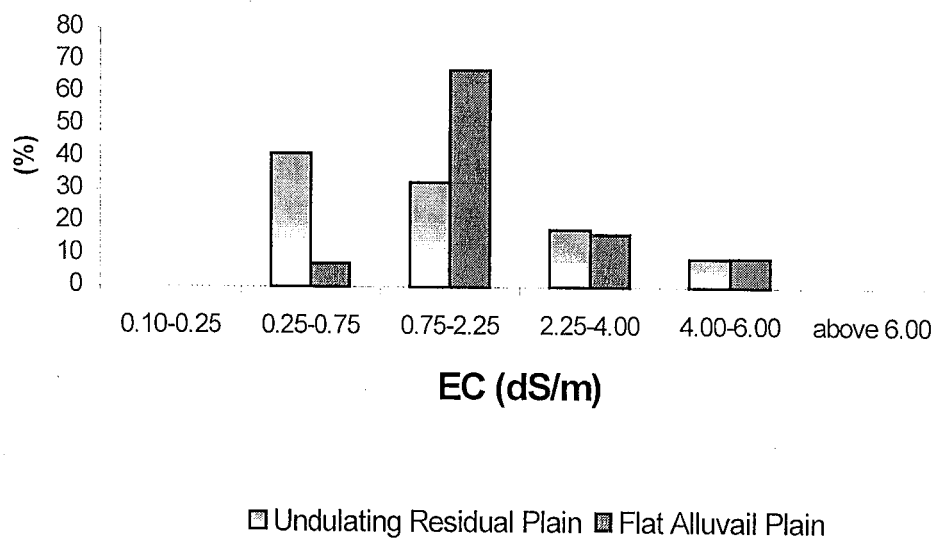


Figure 7 Percentage of average EC values in wells categorized by the irrigation salinity class

Shrimp Farming system in Sri Lanka

The Dutch Canal and the Mundel Lake is the main source of water for approximately 70% of the total area under shrimp cultivation. Majority of the farms are unauthorised, unplanned hazardous construction with poor operation practises.

Contemporary prawn farming methods are usually described as extensive, semi-intensive and intensive, depending on the stocking density and the amount of inputs used. Most shrimp farms in Sri Lanka now operate semi-intensive level with stocking densities between 6-20 post larvae (PL) per m² with artificial aeration of the pond water. The average production from one ha varies between 1500 mt –1200 mt per crop.

During the growth phase of the industry (19985-1989) most of the farms operated under intensive condition with stocking densities up to 70-90 post larval per m2.

Water quality impact of shrimp Farming

1. Water pollution

Contaminated waste water from the ponds are discharged into the same Canal Lake from which other farms draw water to their ponds. The aquatic pond effluents are: residual of fertilisers and supplementary feed, acidic discharge's from new pond constructed on potential acid sulphate soil, and chemical used for water treatment, insect control, predator fish control and fish health control. Toxic chemicals such as teaseed cake used to kill predatory fish species and Malchte green currently banned in USA used to control bacterial and fungal infection are used in the ponds. These chemicals when out of the ponds produce a serious chemical threat to aquatic life.

High Concentration of nutrients, suspended solids and toxic metabolites are recorded from effluent discharged from ponds (Jayasinghe, et al., 1994). Comparing to earlier studies by NARA (Table 1), present survey indicates a change in the pH, salinity, nutrients and suspended solids in of the Dutch Canal. High organic loading were indicated at sites of high shrimp farming intensity in the Dutch Canal. Temperature, BOD₅, Suspended solids and Salinity recorded during this survey was below the acceptable range for *Panaeus monodon* culture (Jayasinghe, et al., 1994)

2. Eutrophication

High nutrient loading into the Canal and Lake can result in eutrophication or even hypertropication of the water body result in algal bloom (some of which are toxic), severe oxygen depletion and fish or shrimp mortality. Relative high concentration of nitrites and sulphide recorded by previous surveys (Jayasinghe, et al., 1994) as well as this survey (Table 1) indicate high nutrient loading to the Dutch Canal and Mundel Lake.

The concentration of chlorophyll-a in the water is often taken as an index of biomass of algae present. Highest chlorophyll a values were recorded from sites of high shrimp farm intensity.

Certain algae species of genus *Ceratophora* and *Enteromorpha* which are indicative of eutrophication was observed from the Dutch Canal and Mundel Lake.

3. Salt water intrusion

Abstraction of ground water for fresh water supply to pond culture will result in salinization of the fresh water aquifers through the sub-surface sea water intrusion. Some farms abstracted fresh water from boreholes to avoid spread of white spot disease and some growth deficiencies in hatcheries. Salinization of ground water can result in degradation of domestic and agricultural water supplies, which can cause serious conflicts with local and resident community. Extent of salt water intrusion has been assessed yet for this area and will be a part of this study.

Conclusion

Evidence of eutrophication of the Dutch Canal and Mundel Lake is indicated due to high nutrient input from farm effluent in areas of high intensity of shrimp farms. Inadequate exchange rate and poor water management in ponds has resulted in poor water quality in Dutch Canal and Mundel Lake. As a result outbreak of White spot disease in shrimp ponds occurred in this area causing severe environmental and economic losses to the area. More recently an epizootic disease has been reported from the areas which is thought to be the Yellow head disease in shrimp. Eutrophication and increased sediment loading to these water bodies likely to have more severe long term effect on the natural fauna and flora of this water body.

Mundel Lake and the Dutch Canal have a narrow fringe of mangroves. A significant proportion of these mangroves has been eliminated due to construction of shrimp farms. Since mangrove areas are vital breeding and nursing areas for many commercially important coastal fish, shrimp and crab species, their removal has a most serious negative impact on marine and coastal fisheries.

Inadequate exchange rate and poor management practices resulted in outbreak of white spot disease in most farms in 1995. Many of these farms were shut down for long periods causing serious economic losses to the industry and to the area. Release of the disease to the wild was not assessed, but the consequences can be serious and long term.

Many other environmental and social cost of shrimp farming industry has not been adequately assessed for this district. Salinization of the ground water, decline in wild fish and other sea life, flooding, deforestation, loss of agriculture land and production are

some of the many problems encountered in other countries like Taiwan, India, Bangladesh due to shrimp farming. Despite the bitter experiences of many farmers in the far east, prawn farming is being still been promoted other areas without adequate precautions.

Recommendations

1. Strengthening of legal framework particularly enforcement measures and institutional capacity to follow up conditions laid on permits, rules and regulations introduced by the government monitoring system.
2. An effluent treatment system should be installed in every farm to treat effluent before discharge. The quality of the discharged effluent monitored for compliance with the standards.
3. Rehabilitation of the water bodies, removal of sediment, clearing of sandbars to improve tidal exchange.
4. Built in a condition in the licensing of shrimp farms, to replant and maintain a buffering mangrove belt.
5. Establish a technical and environmental advisory service to agree detailed sustainable guidelines for production for each site specifically for small scale developers.
6. Research and development effects should be directed towards building on traditional, integrated and polycultural production system which are suitable for small farmers and sustainable.
7. Develop strategies to stop the deterioration of the ecosystem identified.

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Table 1: Comparison of Water Quality Range Recorded in the Dutch Canal and Mundel Lake with previous data

Parameters	Recorded Water Quality Range					
	Dutch Canal			Mundel Lake		Acceptable range for <i>Paneus Monodon</i>
	1983 (NARA)	1993-94 (NARA)	1995-1996 (This study)	1987 (NARA)	1997-1998 (This study)	
Temperature (C°)	23-32	25-30.5	21-33.8	25.5-37.5	28-33	28-31
DO (mg/l)	NA	8.4-13.2	4.1-17.2	4.3-9.8	1.8-7.4	
pH	4.8-6	7.2-8.0	7.01-8.77	7	7.73-9.06	7-8.7
Salinity (ppt)	0-26	0-28	0-42	19-50	10-109	10-35
Phosphate (mg/l)	0.02-0.05	0.0005-0.46	0-254	0.04-0.30	2-44	
Nitrate (mg/l)	0.01-1.6	0-0.052	0.05-30.3	0.02-0.4	1.2-141	up to 200
Nitrite (mg/l)	NA	0.005-0.042	0-39.3	0.1-8	0-28	<0.25
BOD ₅	NA	8.6-42.4	0.5-29.25	NA	1-4.2	<10
Suspended solids (mg/l)	10-22	50-225	13-330	NA	31-306	110-150

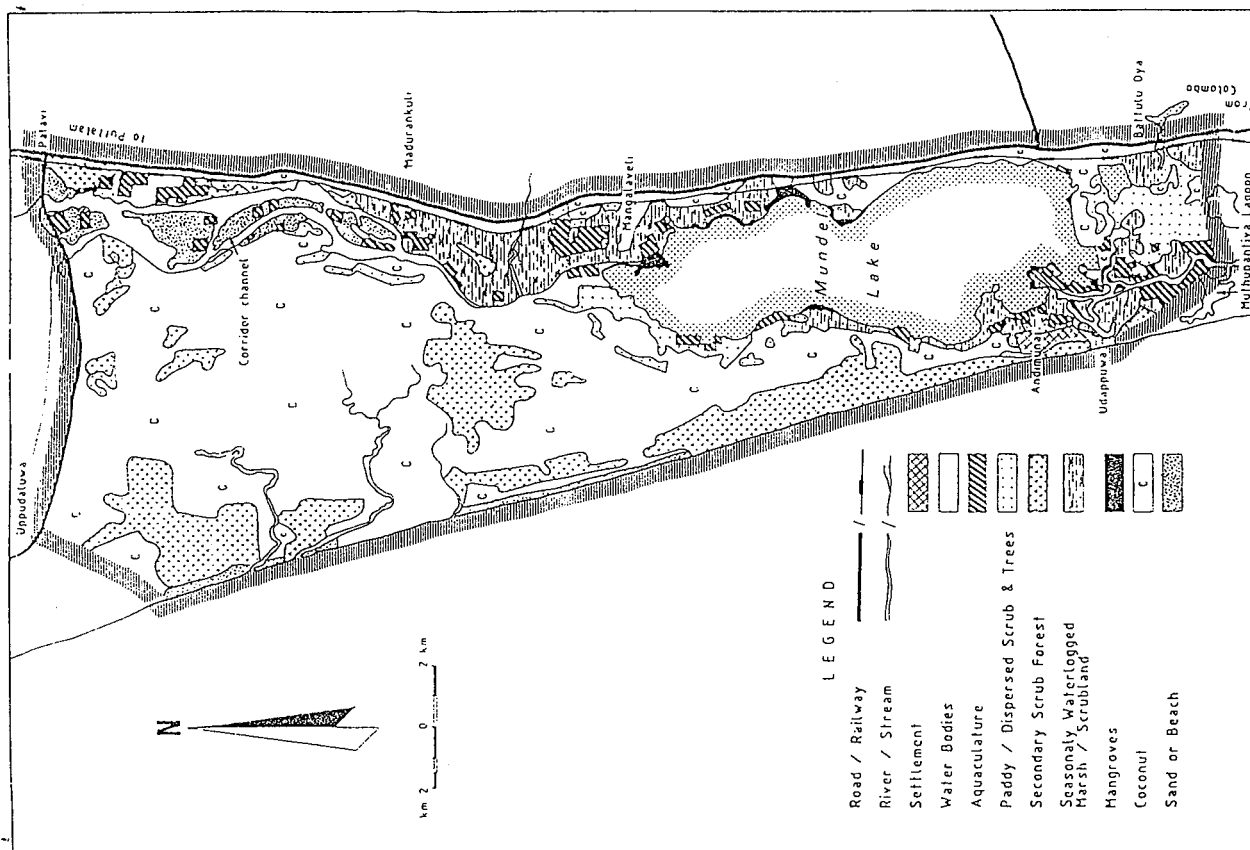
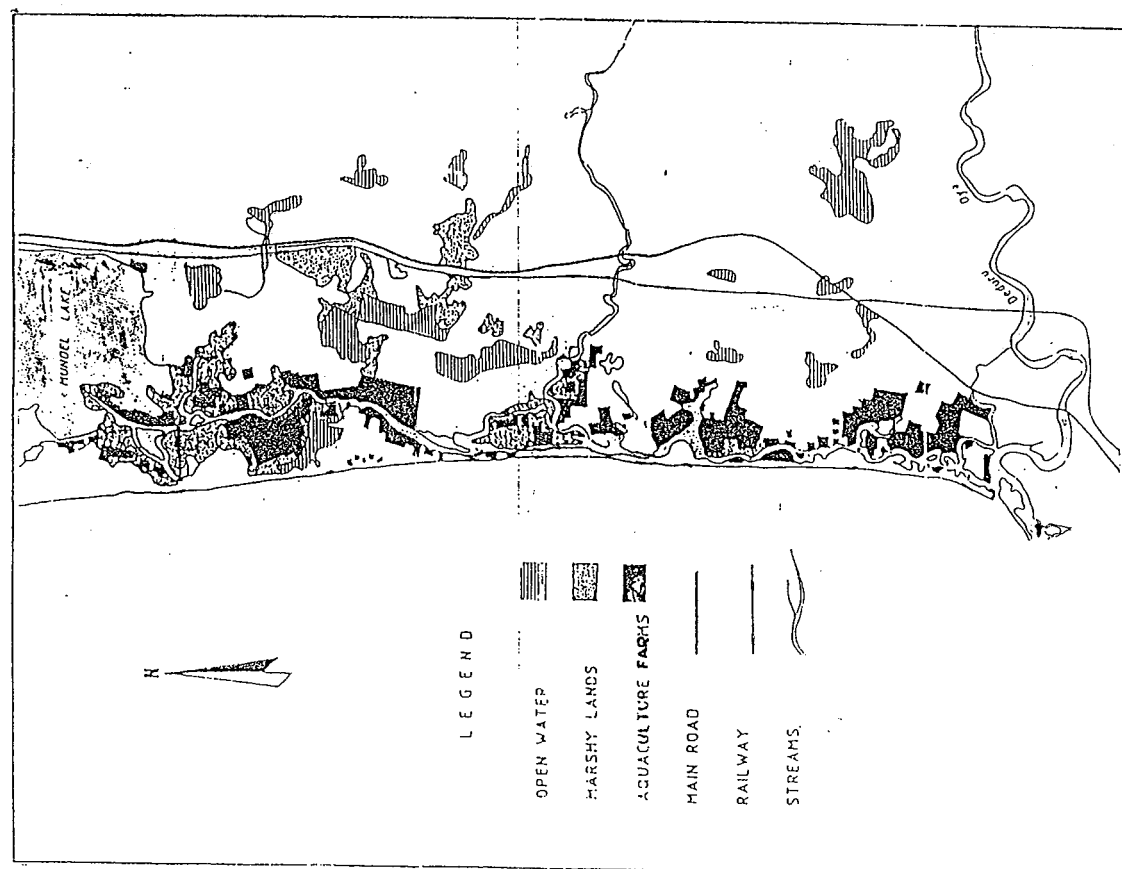


Figure 1 Study area and environs

A. N. Navaratne * and A.P.Aluthge

Department of Chemistry
Faculty of Science
University of Peradeniya
Peradeniya.

**Evaluation of Agriculturally important water quality parameters
of "Ketawala Anicut" located in Gampaha District.**

* To whom the correspondence should be addressed.

Abstract

This project was carried out to evaluate agriculturally important water quality parameters of Ketawala anicut located in Gampaha district over a period of four-months. The analysis was carried out to evaluate mainly Sodium Adsorption Ratio (SAR), salinity and ammonical nitrogen. Furthermore, total hardness of water, Phosphate and nitrate contents and chemical oxygen demand (COD) were also evaluated. The data gathered in this project, specially SAR and salinity provide an indication that the quality of irrigation water can be affected by poor water supply and evapotranspiration. This type of base line data are useful in monitoring the quality of irrigation water of this reservoir.

Introduction

It is reported that the percapita availability of water in Asia declined by 40-60% between 1965-1990. Under these circumstances it is very likely that Asia will have to face a water crisis by the year 2025 A.D (1). There are two adverse effects in this regard. If the surface water becomes unsuitable for irrigation and the ground water becomes unsuitable for drinking purposes, we really facing a water crisis. In order to prevent this, it is very important to prevent pollution of water regardless of the purpose. During the flow of irrigation water, before it reaches to the field of crop, soluble salts can be dissolved in it and resulting in salinity. Salinity can be increased with deforestation. Evapotranspiration of water in the field accumulates dissolved salts. Which has an impact on soil properties and crop growth. It has been reported that irrigated areas have to be abundant due to the increase in salinity, specially when the rain fall is low (2-5).

It is necessary to have an idea about chemical composition of irrigation water to check salt-build up during irrigation. Irrigation with bad quality water under poor drainage conditions lead to increase salinity. Diverted water for irrigation is lost through evapotranspiration in the field (evaporation and transpiration). This is due to the changes from liquid to gaseous state by energy of sunlight. When the water is lost due to evapotranspiration, any dissolved solids present in the water are left behind. The major constituents of irrigation waters are sodium, copper, Magnesium, chloride, sulphate and bicarbonate ions. In some cases it is possible to find potassium, nitrate, copper, cobalt and phosphate are present as minor quantities. They usually do not affect irrigation water. Boron is also found in low concentration in irrigation waters, but it is harmful to crop growth above a concentration of a few ppm. The harmful effects of metal ions sometimes depend on the speciation.

Suitability of irrigation waters depend on several factors such as total salt concentration, cation and anion composition, physico chemical properties of the soil profile, salt tolerance characteristics of the crop plant. Drainage conditions and climatic parameters etc. The degree of adverse effect on soil properties and crop growth is mainly related to the chemical composition of irrigated water. The quality of irrigation water is generally judged by total salt concentration, sodium adsorption ratio (SAR), boron concentration and bicarbonate content. High value of total salt concentration of irrigation water will increase the salinity of water. The relative proportion of sodium to other cations is determined by SAR. It has been observed that plant growth is affected with increase of total concentration of salt, SAR or both. Irrigation waters rich in bicarbonates tend to precipitate soluble calcium and magnesium their carbonates. This increases the sodium content in proportion to Calcium and magnesium there by increasing the SAR.

This project was carried out to evaluate agriculturally important water quality parameters of Ketawala Anicut located in Gampaha district. Gampaha is a suburb of Colombo. Ketawala anicut was build in 1943 by utilizing the water of Attanagalla oya and provide irrigation water for a vast area of paddy fields. It is also used for bathing purposes by the people in the vicinity. The project was carried out for a period of four months to monitor sodium adsorption ratio (SAR), salinity, ammonical nitrogen, total hardness, phosphate and nitrate contents, and chemical oxygen demand (COD). Preliminary water quality parameters of this field was carried out previously(6).

Experimental

Materials

All the chemicals used were analytical grade and distilled deionized water was used for the experiments. Water samples were collected from the Ketawala anicut once a month for the duration of four months. Water samples were collected in bottles which are cleaned with 10% HNO_3 followed by tap water and deionized water. In the case of measurements of dissolved O_2 , the dissolved oxygen was fixed at the site by adding MnSO_4 and alkali with azide. After collection, the samples were kept at 4°C until used for analysis. The measurement of pH and temperature are done at the site.

Methods

Chemical oxygen demand (COD) was determined using dichromate reflux method. Determination of ammonical nitrogen was carried out with Nessler's reagent (Colorimetric method). Phosphate concentration of the water samples were evaluated with vandomolybdophosphoric acid colorimetric method. The determination of total hardness (Ca^{2+} and Mg^{2+} content) was accomplished by EDTA complexometric titration and determination of Ca^{2+} by it self was done by patton and Reedere's (HHSNNA) titrimetric method. Determination of sodium content was accomplished with flame photometry. From the values of calcium, magnesium and sodium, SAR values were calculated. Salinity was determined with Argentometric titration procedure and finally nitrate (NO_3^-) content was determined using nitrate ion selective electrode.

Results and discussion

Evaluation of water quality parameters of the field located at the Ketwala anicut (locations as indicated in the figure 1) was done from ploughing to harvesting for a duration of four months (02.10.1996 - 13.01.1997). During this period considerable variation of temperature and pH was not observed. However the conductivity measurement were fluctuated between 40.0 uScm^{-1} and 58.0 uScm^{-1} (Table 1,2,3).

It is noted that nitrate concentration in the water samples was reduced toward the last dates of sampling (Table 4). Significant variation of chemical oxygen demand (COD) was observed at the 2nd and 3rd sampling dates (Table 5). Ketawala anicut uses water of the Attanagalla oya which is not situated close to any industrial zone and therefore this water body has low COD values. Phosphate ion concentration was not varied significantly during this sampling period. Usually natural water contains less amount of phosphates. According to the WHO standards, average concentration of phosphate in surface water is 0.054 ppm. Calcium and magnesium contents also were not varied significantly during the sampling period (Table 6). However significant increase of ammonical nitrogen content was observed at the third sampling date as evident in the table 7. That is probably due to the fact that the use of urea fertilizer around this date in the field. Significant variation of salinity was not observed (table 8) during the period of sampling. The average value of salinity of this analysis is 0.155gkg^{-1} . This is very low compared the harmful levels of salinity for crop growth . Finally a considerable increase of SAR was reported at the 4th sampling date. This could be probably be attributed to evapotranspiration. Around this date supply of water to the field was stopped and field contained less water resulting in high evapotranspiration .

Conclusions and future directions

Evaluation of water quality parameters of irrigation water of Ketawala anicut was carried out through four months period. Considerable variation of water quality even under application of agrochemicals could not be observed during four months sampling period. At any rate, to arrive at a conclusion it is necessary to carry out this analysis for a longer time period.

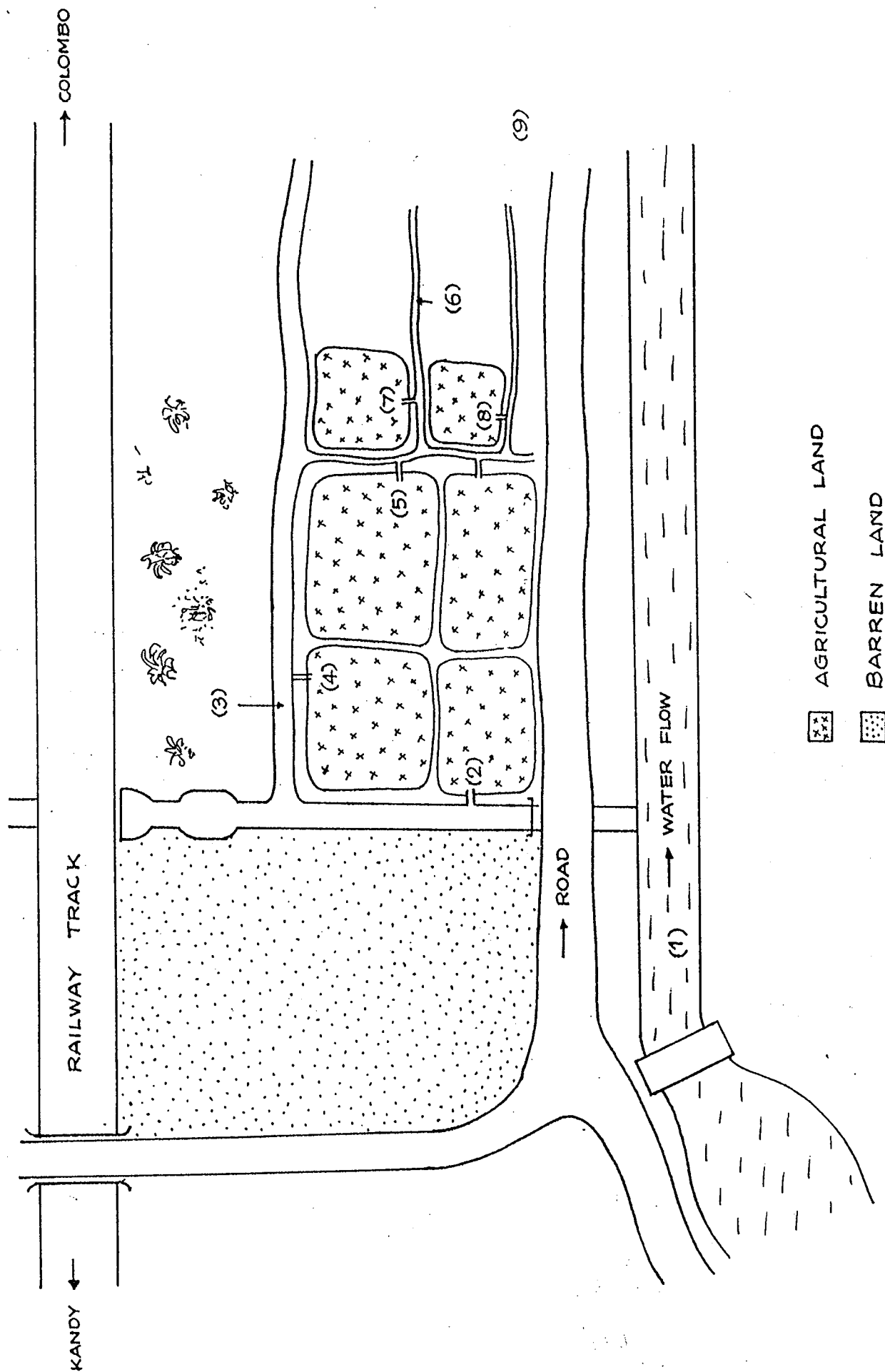
The data gathered in this project specially SAR and salinity provide and an indication how the quality of irrigation water can be affected by poor water supply and evapotranspiration. Also it has been observed beyond a certain value of SAR and salinity that particular irrigation water becomes unsuitable for agricultural purposes. Therefore monitoring of the water quality with respect to these parameters are very important when the successful agricultural production is expected. Furthermore, this type of base line data are very important to this particular water resource as such data are not currently available. In addition the data of this type could be very useful in environment research.

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ROUGH SKETCH OF THE AGRICULTURAL LAND (STUDY SITE)

FIG. (1)



Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	29.0	29.0	28.0	29.0
2	29.0	29.0	28.0	29.0
3	29.0	29.0	28.0	29.0
4	28.0	33.0	29.0	30.0
5	31.0	33.0	29.0	---
6	31.0	32.0	29.0	---
7	31.0	32.0	29.0	30.0
8	31.0	31.0	29.0	---
9	30.0	33.0	29.0	---

Table 1. Variation of temperature (C°).

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	5.67	6.00	6.71	6.81
2	6.84	6.00	6.80	6.70
3	5.95	6.01	6.97	6.75
4	6.09	7.03	6.96	7.19
5	6.08	7.00	6.90	-----
6	7.18	6.92	6.95	-----
7	6.24	7.20	7.12	7.41
8	6.53	6.37	6.95	-----
9	6.62	6.77	6.90	-----

Table 2. Variation of pH determined by pH electrode.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	43.0	54.0	37.0	56.0
2	42.0	54.0	38.0	55.0
3	43.0	54.0	40.0	55.0
4	48.0	47.0	39.0	57.0
5	46.0	47.0	36.0	-----
6	40.0	50.0	37.0	-----
7	50.0	43.0	36.0	58.0
8	43.0	55.0	38.0	-----
9	43.0	50.0	37.0	-----

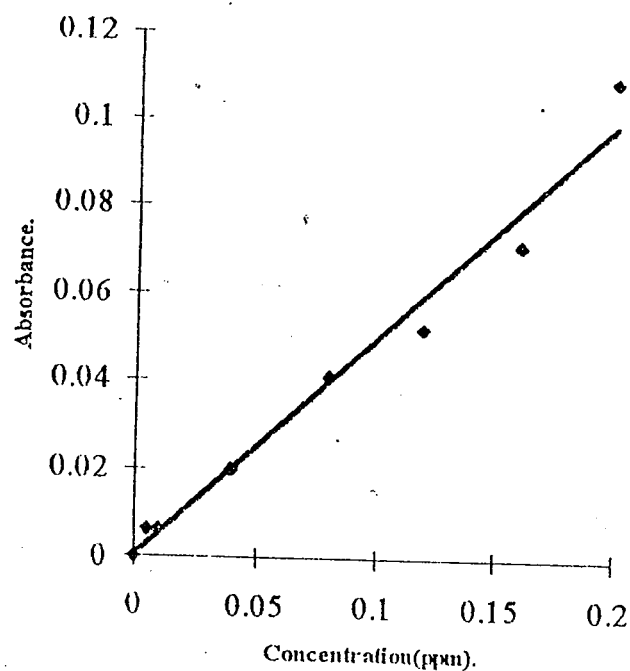
Table 3. Variation of conductivity determined by conductivity meter/ $\mu\text{S cm}^{-1}$.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.550	0.358	0.202	0.211
2	0.552	0.360	0.344	0.188
3	0.557	0.325	0.212	0.177
4	0.368	0.190	0.169	0.159
5	0.381	0.170	0.131	-----
6	0.240	0.178	0.296	-----
7	0.582	0.120	0.314	0.147
8	0.332	0.213	0.352	-----
9	0.346	0.163	0.286	-----

Table 4. Variation of N-NO_3^- concentration determined by the ion selective electrode/ppm.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	15.80	4.80	1.70	8.70
2	17.00	5.60	1.50	7.00
3	14.60	3.80	1.50	7.20
4	8.00	5.80	3.10	12.40
5	11.00	5.60	4.70	-----
6	14.60	4.20	2.90	-----
7	14.60	4.60	4.50	11.10
8	10.00	3.80	5.10	-----
9	8.60	7.80	4.70	-----

Table 5. Variation of Chemical Oxygen Demand (COD) determined by dichromate titrimetric method/ ppm.



Calibration curve for the determination of PO_4^{3-} .

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.082	0.012	0.070	0.041
2	0.064	0.014	0.067	0.045
3	0.072	0.018	0.074	0.057
4	0.063	0.018	0.077	0.044
5	0.070	0.015	0.056	-----
6	0.162	0.013	0.068	-----
7	0.063	0.013	0.081	0.057
8	0.063	0.014	0.063	-----
9	0.069	0.015	0.079	-----

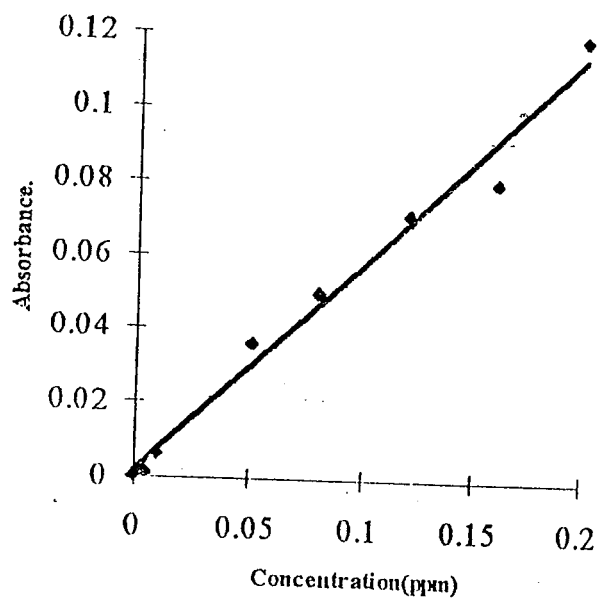
Table 6. Variation of PO_4^{3-} ion concentration determined by the vanomolybdophosphoric acid colourimetric method/ ppm.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	1.650	3.170	1.876	2.560
2	3.200	3.184	2.345	2.171
3	1.600	3.175	2.188	2.41
4	3.200	2.381	2.657	2.710
5	3.200	2.375	2.345	-----
6	1.600	2.381	2.188	-----
7	1.600	3.174	1.876	3.135
8	0.200	2.460	2.345	-----
9	0.100	3.174	2.423	-----

Table 7. Variation of Ca^{2+} ion concentration determined by the EDTA titrimetric method/ppm.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.980	0.963	0.854	0.973
2	-----	0.963	1.138	1.101
3	0.973	0.971	1.043	0.816
4	0.978	0.479	0.854	1.215
5	1.958	0.482	0.854	-----
6	1.946	0.482	0.614	-----
7	0.973	-----	0.854	1.117
8	-----	1.446	0.617	-----
9	1.946	-----	0.522	-----

Table 8. Variation of Mg^{2+} ion concentration determined by EDTA titrimetric method / ppm.



Calibration curve for the determination of NH_3 .

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.488	0.225	0.960	0.235
2	0.378	0.233	1.155	0.227
3	0.401	0.462	1.230	0.237
4	0.553	0.528	1.332	0.213
5	0.767	0.408	1.407	-----
6	0.823	0.373	1.398	-----
7	0.267	0.377	1.444	0.219
8	0.214	0.377	1.277	-----
9	0.112	0.318	1.277	-----

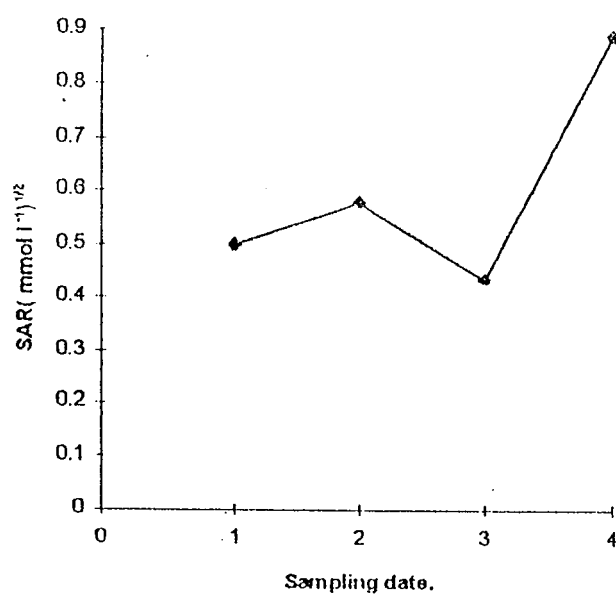
Table 9. Variation of NH_3 ion concentration determined by Nesslerization method/ ppm.

Location	Sampling date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.096	0.129	0.131	0.210
2	0.083	0.129	0.135	0.207
3	0.105	0.157	0.144	0.194
4	0.105	0.135	0.153	0.211
5	0.118	0.129	0.180	-----
6	0.118	0.192	0.165	-----
7	0.118	0.284	0.126	0.207
8	0.096	0.183	0.153	-----
9	0.097	0.277	0.156	-----

Table 10. Variation of Salinity determined by the argentometric method gkg^{-1} .

Location	Sampling . date			
	02/10/96	13/11/96	07/12/96	13/01/97
1	0.594	0.545	0.477	0.913
2	0.594	0.545	0.413	0.990
3	0.573	0.540	0.427	0.987
4	0.491	0.494	0.421	0.831
5	0.426	0.434	0.413	-----
6	0.459	0.661	0.460	-----
7	0.569	0.444	0.468	0.947
8	0.580	0.545	0.423	-----
9	0.468	0.537	0.423	-----

Table 11. Variation of Sodium Adsorption Ratio (SAR) / (mmol l⁻¹)^{1/2}



. Variation of average SAR of the field.

NATIONAL WATER CONFERENCE

Nov. 4-6, 1998

BMICH, Colombo Sri Lanka

RESEARCH PAPERS PRESENTED

Session No.15 5 November 1998 2:00 p.m.

Precipitation and Evapotranspiration

Paper No.1

de Costa, R.S.G. Shahane

A Study on the Interception Process and its Hydrological Impact

Paper No.17

Kadupitiya, H.K.

Nayakekorala, H.B.

Chithranayana, R.D.

Characterization Of Rainfall In The Low Country Wet Zone In Terms Of Crop Water Requirements Of Annual Field Crops

Paper No.5

Seneviratne, L.W.

Storm Transposition In Sri Lanka

Paper No.133

Bandara, Palitha

Land Surface Evapotranspiration for Water Balance in the Kirindi Oya Watershed. A Remote Sensing Approach

A STUDY ON THE INTERCEPTION PROCESS AND ITS HYDROLOGICAL IMPACT

Dr. SHAHANE DE COSTA

Dept of Civil Engineering, Open University of Sri Lanka.

Nawala, Nugegoda, Sri Lanka

Costas@Civil.ou.ac.Lk

ABSTRACT

The catchment has been modelled in the laboratory and artificial rainfall is induced using a pipe net work system. A series of experiments have been carried out using tropical vegetation (Rubber and Mango) of varying densities and thereby an attempt has been made to understand the interception process. It has been found that Rubber retards the rainfall runoff transformation more than Mango and it also has a greater storage capacity. It has also been found that the interception process could be separated into two segments. One, when the vegetation actively retards the rainfall runoff transformation process and stores water resulting in loss of rain water, and the other is when the vegetation has absolutely no effect on the rainfall runoff transformation process.

Key Words : Interception, Effect of vegetation, Plant storage, Canopy flow

1. INTRODUCTION

The basic hydrological aspects of a catchment in relation to rainfall runoff transformation are its interception due to vegetation, infiltration and its conducting capabilities. Nevertheless generally these aspects (the process of input of water into the streams due to rainfall) are lumped into runoff coefficients and the subject of runoff routing is concentrated on routing of stream network systems [1]. However it has been found that, even though the use of runoff coefficients for long term analysis yields satisfactory results, when considering short term analysis this tends to give rise to appreciable deviations for the rising limb, recession period and the peak discharge [2],[3]. Therefore, for detail rainfall runoff transformation calculations with appreciable degree of accuracy, the interception characteristics, the infiltration characteristics and the conducting capabilities must be taken into consideration.

Vegetation intercepts the rainfall, and initially accumulates a certain proportion of it at the canopy and thereafter accumulates a good part of it both in the canopy and the stem. This not only brings about a loss of water but also retards the rainfall runoff transformation process. Taking this into consideration there is a conceptual framework [4] which attempts to quantify the effect of interception on the rainfall runoff

transformation. Nevertheless since there has been no studies on the practical aspect of the effect on interception / vegetation [5], this study endeavours to understand the effect of interception on the rainfall runoff transformation process specially for Sri Lankan conditions.

Here, the catchment has been modelled in the laboratory and a series of experiments have been conducted using tropical vegetation. Artificial rainfall has been induced and thereafter analysing the temporal variation of the discharge, the effect of vegetation (tropical) on the rainfall runoff transformation process has been obtained.

2. THEORETICAL VIEW

Interception of rainfall could be assumed as a function of the growth (largeness of trees) and density (closeness of trees) of vegetation and thereby expressed as canopy flow and stem flow. It is physically observable that, larger trees intercept and store more water than smaller trees and as the density of trees increase interception increases. Therefore this could be expressed as follows.

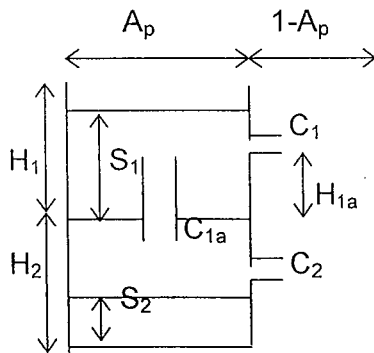
$$\begin{array}{lcl} I & \propto & G \\ I & \propto & C \end{array}$$

I : Interception

G : Growth of trees

C : Density of trees

Taking these two factors into consideration a conceptual model has been developed as follows.



A_p : Influence ratio

H : Characteristic heights of tanks

S : Storage heights of tanks

C : Coefficients of tanks

Subscript 1 indicates canopy while 2 the stem.

Fig.1 Interception model

Here $1-A_p$ is the proportion of rainfall that falls on the catchment without being intercepted by rainfall. A_p is the proportion that is being intercepted. A_p is the ratio of the sum area of canopy of all the vegetation to the total catchment area. Here it could be seen that the intercepted water would be initially stored in the canopy (S_1) and once it passes its characteristic storage (H_{1a}) the water will flow to the catchment surface through C_1 . The intercepted water will also flow to the stem through C_{1a} . Once the stem storage (S_2) is also full (H_2) the water will flow to the catchment surface through C_2 . C_1 ,

C_2 , C_{1a} , S_1 , S_2 etc., are characteristics of the catchment and vary according to the growth and density of vegetation. H_1 , H_2 , S_1 and S_2 are parameters related to canopy and stem storage while C_1 , C_2 and C_{1a} are parameters related to the ability of the vegetation to release water to the catchment surface. Therefore if C_1 , C_2 , C_{1a} , H_1 , H_2 , S_1 and S_2 are known it is possible to quantify the interception process. Nevertheless this necessitates a prior in-depth experimental study of the catchment.

It could be noticed that once S_1 and S_2 are full vegetation will have no affect on the rainfall runoff transformation process. Since these conceptual characteristics needs an experimental study for its validation and also for further investigation for the interception process the following experiments have been performed.

3. EXPERIMENTAL APPARATUS AND DATA

In order to model a real catchment in the laboratory a scale down version of a catchment has been constructed and artificial rainfall has been induced by a series of pipe net works connected to a water tank. The model catchment is of 1.5m in length and 1.33m in width giving a total catchment area of 2 m². Small plants of commonly found vegetation in Sri Lanka namely, Rubber and Mango have been used to simulate the vegetation of the catchment.

Since the whole catchment has been scaled down it is assumed that a plant of the real tree will represent the true catchment condition. However, since the average plant height is of 0.6m to 0.8m it could be said that there has been a scaling affect of 1 : 10. The pipe network used for the artificial rainfall also has been connected with due consideration to rain drop distances and to simulate the above scaling down affect. Since in total 1500 ml of water fell as rain fall over this catchment of 2 m² considering scaling affects it could be said that this simulates a 7.5mm rainfall ($1500 \times 10 \times 10^{-6} / 2 = 7.5$ mm) falling over a catchment. Fig. 2 indicates the model catchment with the pipe network for artificial rainfall.

The discharge occurring on this catchment due to the rainfall has been measured. Numerous experiments have been conducted for each type of plant with varying densities. The density has been increased by increasing the number of plants in the model catchment. Fig. 3 indicates the discharge occurring over the catchment.

A series of experiments with 2 Mango plants, 4 Mango plants, 2 Rubber plants, 4 Rubber plants and mixed plants (2 Rubber and 2 Mango) have been performed. In order to keep the initial conditions uniform experiments were conducted on a 4 hourly basis. First rainfall was induced on the catchment without the vegetation and the temporal variation of discharge was measured. Thereafter the vegetation was introduced, rainfall induced and the temporal variation of discharge was measured. Using these values it is possible to obtain the actual effect of interception on the rainfall runoff transformation phenomena. A series of experiments have been carried out for each category. The following table indicates the average values obtained. It must be noted that after 1200ml it took a longer time to collect the balance and the maximum collected was below 1,300ml. This meant that there was a average loss of 250ml, 1/6th of the total supplied. In rainfall terms, 1.25mm of the 7.5mm rainfall was lost due to interception.



Fig. 2 Model catchment & artificial rainfall



Fig. 3 Catchment discharge & measurement

Table -1 Effect of vegetation

Discharge (ml)	Time in seconds for 100 ml to collect					
	No Vegetation	Mango 2 plants	Mango 4 plants	Rubber 2 plants	Rubber 4 plants	Man. & Rub. 2 plants each
100	49	56 (7)	63 (14)	60 (11)	67 (18)	65 (16)
200	66	77 (11)	87 (21)	82 (16)	94 (24)	90 (24)
300	76	88 (12)	99 (23)	94 (18)	109 (33)	104 (28)
400	83	97 (14)	109 (26)	103 (20)	121 (38)	115 (32)
500	88	103 (15)	117 (29)	110 (22)	131 (43)	124 (36)
600	92	108 (16)	124 (32)	116 (24)	139 (47)	131 (39)
700	96	112 (16)	130 (34)	121 (25)	145 (49)	137 (41)
800	100	116 (16)	135 (35)	125 (25)	150 (50)	142 (42)
900	104	120 (16)	139 (35)	129 (25)	154 (50)	146 (42)
1,000	108	124 (16)	143 (35)	133 (25)	158 (50)	150 (42)
1,100	112	128 (16)	147 (35)	137 (25)	162 (50)	154 (42)
1,200	116	132 (16)	151 (35)	141 (25)	166 (50)	158 (42)

Figures in parenthesis indicate actual effect of vegetation.

4. DATA ANALYSIS

It could be seen from Table - 1 that for 100ml and 200ml to collect in the case of no vegetation it has taken 49 and 66 seconds respectively. This is due to the model catchment characteristics such as gradient etc. However when Mango (2 plants) are introduced for 100ml to collect it has taken 56 seconds while for 200 ml to collect it has taken 77 seconds. This means the effect of Mango (2 plants) for the first 100ml is a delay of 7 seconds ($56 - 49 = 7$). Like wise for 200 ml it is a delay of 11 seconds ($77 - 66 = 11$). It could be seen that for 500 ml to collect it has caused a delay of 15 seconds

(103 - 88 = 15). Similarly for 600 ml to collect the delay is 16 seconds, however thereafter the delay remains constant which means that the vegetation has no effect on the rainfall runoff transformation process. Therefore it could be said that the impact of interception on the rainfall runoff transformation process decreases with time. Similar results could be seen for the other categories too. Fig. 4 indicates the effect of vegetation in the rainfall runoff transformation process.

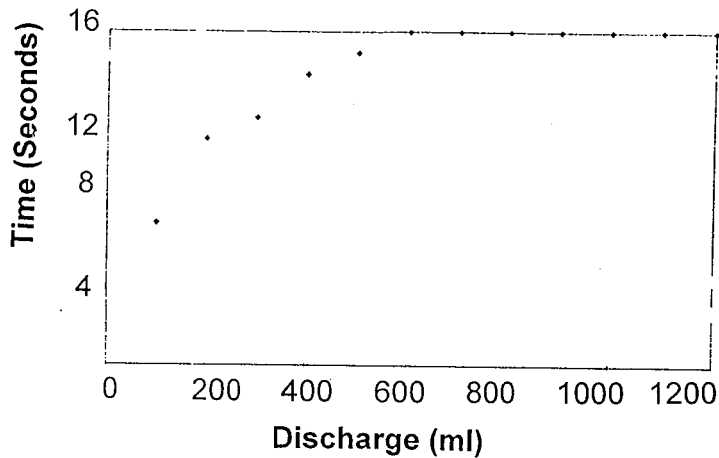


Fig. 4 Effect of Mango (2 plants)

From the above it could be seen that the interception process (effect of vegetation on rainfall runoff transformation) could be basically divided into two segments. One the initial stage, the stage in which the vegetation absorbs or begins to collect (stores) the water. This results in retardation of the rainfall runoff transformation as well as brings about a loss of rain water volume. The second stage commences after a time threshold. Beyond this threshold the vegetation has absolutely no effect on the rainfall runoff transformation phenomena. It could be seen from the above experiments that once 600ml for Mango (2 plants), 800ml for Mango (4 plants), 700ml for Rubber (2 plants) and 800ml for Rubber (4 plants) were collected they all reached a uniform state. Probably as it has reached maximum storage capacity. During this stage the transformation process would be identical to the condition of no vegetation. The results obtained here are in perfect agreement with the previously mentioned conceptual framework.

Therefore it could be said that vegetal growth effects rainfall only during the initial stages of rainfall. This means that for longer duration high intensity rainfall vegetation does not appreciably effect the rainfall runoff transformation. However for the low intensity short duration case vegetation has an appreciable influence on rainfall runoff transformation.

The time threshold the vegetal growth influences the rain fall runoff transformation is characteristic to the type of vegetation, the growth of vegetation and the density of vegetation. As either growth or density, or both increases the time threshold extends. The type of vegetation also impacts the interception process. It was found that Rubber has a higher time threshold than Mango as it took 700 ml to pass for the case of Rubber

(2 plants) while for Mango (2 plants) it took only 600 ml to pass before no effect condition was reached. It was also found that Rubber retards the rainfall runoff transformation more than Mango as for 100 ml to collect Rubber (2 plants) took 121 seconds while Mango (2 plants) it took only 108 seconds. Therefore it could be said that for catchments with typical shorter duration rainfalls the rainfall - runoff transformation process could be controlled by the type, growth and density of vegetation, but not for catchments with typical long duration high intensity rainfalls. Nevertheless if it is required to retard the rainfall runoff transformation of a catchment prone to floods (for example to reduce flood damage (reduce flood peak) or to delay the occurrence of flood peak in order to enhance the flood warning time) it is better to grow Rubber trees on such catchments than Mango.

5. CONCLUSION

From the above experimental analysis the following conclusions could be made.

1. The results of the experimental analysis agrees well with the conceptual framework.
2. The interception process basically consists of two area. The first is when it actively retards the rainfall runoff process and brings about a loss of rain water. During this stage interception has a decreasing impact on the rainfall runoff transformation process. The second is the stage beyond a characteristic time threshold, where the vegetation has absolutely no effect on the rainfall runoff transformation. This time threshold could be varied as it is characteristic to the type of vegetation, growth and density of vegetation.
3. For longer duration high intensity rainfalls vegetation has no significant effect on the rainfall runoff transformation, however for short time duration low intensity rainfalls vegetation has an appreciable effect on the rainfall runoff transformation process.
4. Rubber retards the rainfall runoff transformation more than Mango. Rubber also possesses a greater storage capacity comparative to Mango. Therefore for catchments that are subject to flooding even for short duration rainfalls Rubber would be more suited than Mango and could be used to retard the peak occurrence as well as reduce the peak flow.

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NATIONAL CONFERENCE ON " THE STATUS AND FUTURE
DIRECTION OF WATER RESOURCES IN SRI LANKA" 1998

STORM TRANSPOSITION IN SRI LANKA

Eng L. W. SENEVIRATNE, BScEng, PGDip., MEng (Hydrology), MEng(Env. Mgt), FIE (Sri Lanka), Deputy Director of Irrigation, Irrigation Department, Sri Lanka

H023534

Title

STORM TRANSPOSITION IN SRI LANKA

Author

Eng. L. W. Seneviratne, BSc Eng, MEng (Hydrology), MEng (Environmental Engineering and Management), Deputy Director of Irrigation, P. O. Box 1138, Irrigation Department, Colombo, Sri Lanka

Abstract

Storm transposition formula $K = ABC$ is directly giving the modified coefficient to the required location for any designs requiring intensity of rainfall with reference to a capital town in the area. One hour rainfall intensity map is prepared for Sri Lanka. This result is for the use in designing play grounds, drains, culverts, rooves etc. The maximum one hour rainfall intensity recorded is 110 mm at Puttalam.

1.0 Introduction

Maximum rainfall intensities are collected and plotted on a map to derive isohyets for one hour precipitation. Figure one gives this map. The map also possesses elevations, locations, streams etc.

1.1 Development of intensity distribution maps for Sri Lanka

Resources

Sri Lanka has recorded the rainfall data for naval use during Dutch period. In 1830 Trincomalee has recorded 762 mm one day rainfall. In May 17, 1940 Balangoda has recorded 751 mm one day rain fall. Data is available at many institutions.

Traditional acceptance

The isohyetal map of Sri Lanka shows the wet zone dry zone demarcations with annual rainfall. Seasonal rain fall is given for yala and maha. This method of expressions are helpful for agriculture. The intensity of rainfall is useful for design of spills drains gutters rooves of urban areas. People use a type of roofing material to stand for high intensity. Cadjan asbestoes tiles are selected for roofing in wet zone. Hilly areas with less warming and rainfall can select iron sheets as roofing material.

Short term effective precipitation maps are not available and hence it is necessary to prepare a map to show the intensity of rainfall for the last 20 years.

It is also necessary to derive a suitable formula to relate an occurrence at one place for the expected storm at another place.

1.2 Storm transposition

When a known storm is recorded at one station it is transformed at another location. Any deviation more than 30 km from the wind direction is not reliable. Same way a 10 deg deviation is also not reliable. However the coastal towns are recording intensities at meteorological stations. Any provincial town has to transform data recorded at main stations.

Method of analysis

The storm pattern in Sri Lanka is studied for this project. The zones are divided as wet zone, dry zone, central mountains, arid zones, rain shadows etc.

However these zones are receiving storms with seasons, such individual patterns are important to consider reasons for high intensity.

Wet zone receives SW monsoons and coastal rains

Dry zone receive NE monsoons and coastal rains

Puttalam and Hambantota receive NE monsoon and coastal rains

These areas receive inter monsoon rains developed due to motion of the sun.

Monsoonal action brings the change of wind direction due to position of the sun which creates upwind due to heating. Surface wind generates due to filling of vacuum created by up wind. This wind is again deflects due to coriolis force depending on the location of the land from the equator.

Sri Lanka is with in 6 -10 deg Latitude. So it begins in September and March as the sun crosses vernal equinoxes. This is the doldrums where wind is low and pressure is high with low rains. High winds develop in May, June in wet zone and November, December in dry zone. A flood in August is rare but occurred in 1947. Usually main wind stream enters Sri Lanka in May and pass into India in June. High wind developing results in continuous rainfall if the force is big enough to develop high as 3000 meters. December SW upwind and NE down wind can bring heavy rainfall. June SW down wind and NE upwind can bring heavy rainfall.

Bay of Bengal is a small water surface when compared with Indian Ocean. Hence the effect of Indian Ocean brings major supply into island in both seasons to the SW zone. The central hills catch rains from both directions.

Only 8% of Ocean evaporated water reaches the land. Ocean evaporation utilizes 25% of SOLAR RADIATION. This shows that only 2% of insolation is converted to create rain fall over the land areas. This energy is converted into wind motion and with dynamic cooling releases latent heat onto the land. This is increasing the air temperature. However wind is reducing the air temperature. The land surface needs more warming to attract the wind from cooler ocean surface. Unusual warming of ocean surface reduces the potential of wind leaving the ocean.

Ocean surface and land surface have different albedo and cooling rates. This creates the coastal wind patterns. Coastal belt receives part of this wind with rainfall. These coastal rains reach a distance of 30 km. Monsoonal rain has a periodic interference with day and night winds.

Anticlones and cyclones form a series of events with a combination of pressure, temperature and wind velocity. High pressure zones are calm and quiet. Low pressure zones are creating winds and precipitation. The depression moves from point to point. Any location can receive heavy downpours due to depressions. The frontal type cold mass hot mass mixing also creates high rainfall with thunder storms.

Cloud patterns

The cumulonimbus type of clouds deliver 90 % of the rainfall where as balance 10% is delivered by stratus clouds. Ciriform clouds do not deliver rainfall. Sri Lanka receives hail falling other than water occasionally. Hail is a combination of glaze and rime. Rime is opaque while glaze is transparant. Snow falling was recorded in Nuwara Eliya.

Probable Maximum Storm

PMS is likely to occur due to high winds passing over the land. This wind creates dynamic cooling when travels uphill and drops more rainfall. Same wind passes the summit and moves downhill with dynamic heating and gives no rainfall. Series of mountain ranges can have windward side and the summit getting heavy rains with leeward side getting no rains.

PMS has distance from the sea as a parameter. It has little sea effect beyond 30 km. Direct influence of rainfall is more on the western coast. The SW area has more rains and the effective centre lies around Kalutara. In 1940-50 period more rainfall reached Benthota.

The high intensity records are plotted on a map to identify high intensity areas. One hour period is considered for analysis. The zones are grouped into seven sectors. There are three high intensity build up namely Puttalam, Attanagalla- Kitulgala- Eheliyagoda, and Moneragala areas. Western coast has high intensity which gradually reduces landward but eastern coast has low intensity which gradually increases towards the land.

Rain shadow areas in central hills has low intensity. North has low intensity. Three recorded storm data are annexed.

1.3 Storm Transposition Formula.

The map gives a fixed locational response to the problem. But in practice the available rain fall data is available at capital towns and transposition can be done with a formula. This formula linearly reduces the parameters to the required location from the reference location. Hence the storm either get reduced or enlarged into the new location.

Transposited formula for the SW monsoons.

$$K = A.B.C$$

K is the modified coefficient for the new location

A is the distance coefficient for the distance in km from sea to the new location

B is the distance coefficient for the distance in km from SW line drawn through the reference point. North is the positive direction

C is the locational quality factor where it is facing leeward or windward to the reference wind direction.

The following tables give the coefficients for the above formula.

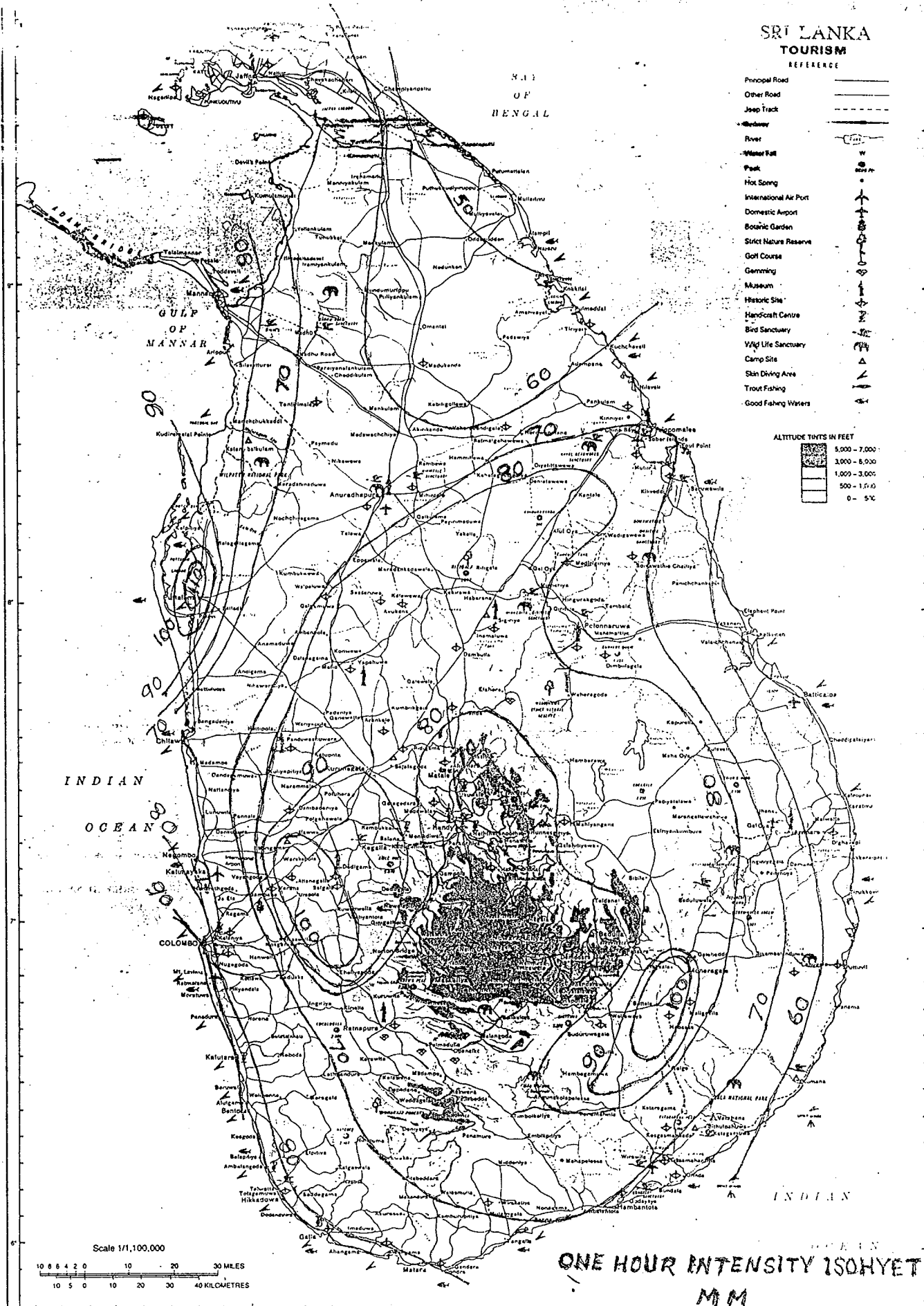
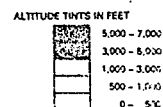
Intensity are given as Puttalam 110 mm, Colombo 90 mm, Kalutara 90 mm, Galle 80 mm, Hambanthota 70 mm.

Sea distance km	0	6	12	18	24	30
Coefficient A	1	0.96	0.92	0.89	0.84	0.80

TABLE 1

SRI LANKA TOURISM REFERENCE

- Principal Road
- Other Road
- Jeep Track
- Railway
- River
- Water Fall
- Park
- Hot Spring
- International Air Port
- Domestic Airport
- Botanic Garden
- Strict Nature Reserve
- Golf Course
- Gemming
- Museum
- Historic Site
- Handicraft Centre
- Bird Sanctuary
- Wild Life Sanctuary
- Camp Site
- Snorkelling Area
- Trout Fishing
- Good Fishing Waters



Scale 1/1,100,000



ONE HOUR INTENSITY ISOHYET
MM

Based upon the map of the Sri Lanka Survey Department with sanction of the Surveyor General

Eng. L.W. SENEVIRATNE
1998

Distance (km)	30	20	10	0	-10	-20	-30
Coefficient B							
Puttalam	1.2	1.1	1.0	1	0.9	0.8	0.7
Colombo	1.0	0.95	0.9	1	1.0	0.9	0.85
Kalutara	1.15	1.1	1.05	1	0.85	0.80	0.75
Galle	1.0	1.0	1.0	1	0.9	0.8	0.7
Hambanthota	1.35	1.25	1.1	1	0.9	-	-

TABLE 2

Dry zone C = 1.0

Arid zone C = 1.0

Wet zone leeward elevated shadow C = 0.8

Wet zone windward elevated face C = 1.2

Sri Lanka map is used for evaluation.

TABLE 3

1.4 Conclusion

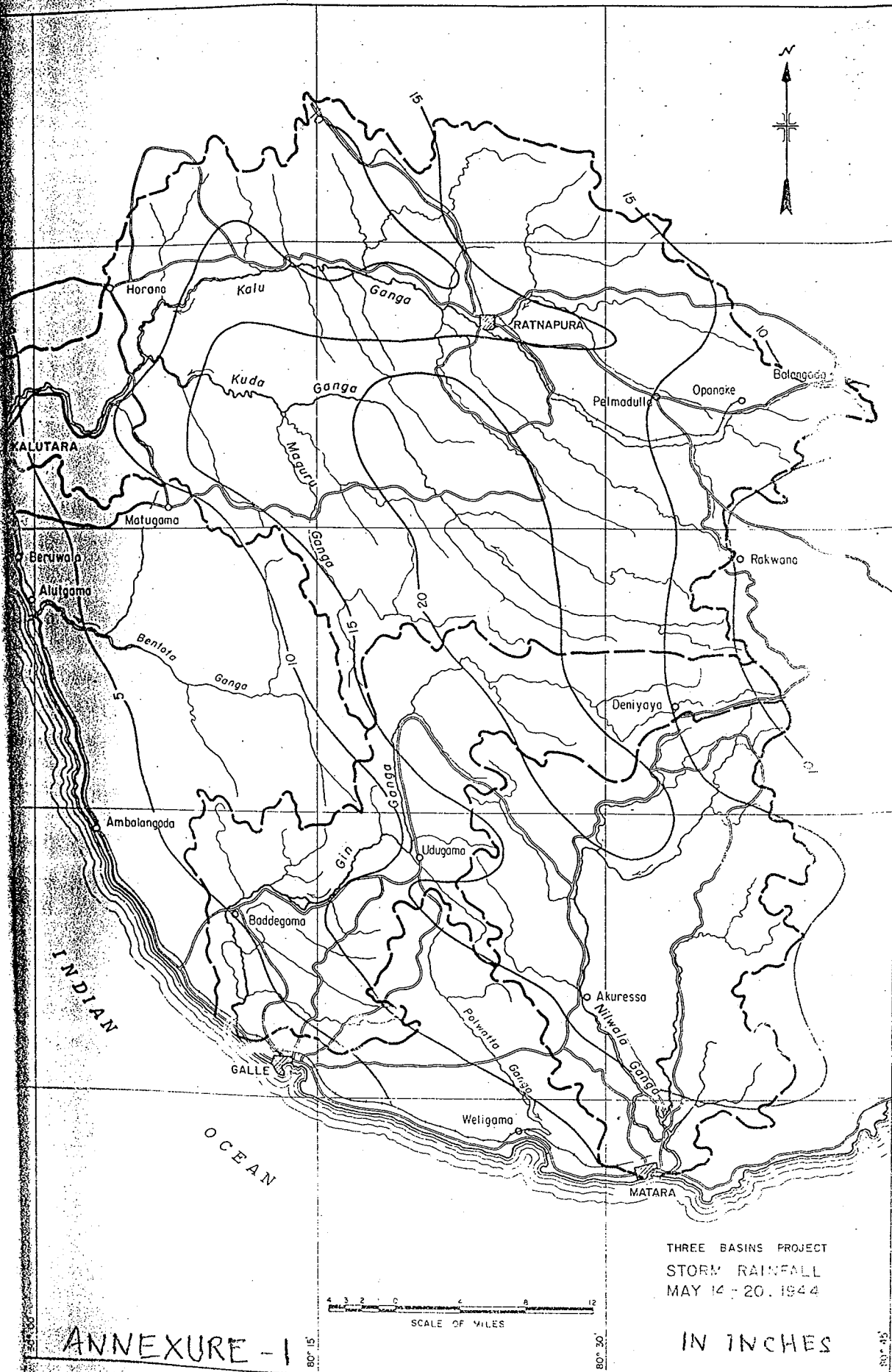
Sri Lanka has fairly stable pattern of rainfall. The trends are mainly due to land use patterns. Losing vegetal cover can cause low friction to wind. It can also reduce evapotranspiration. It can increase run off. Ground relief is unchanged. A heavy storm is likely after a drought. Also a drought is likely after a heavy storm. Urban planner shall use the above derivations for his designs.

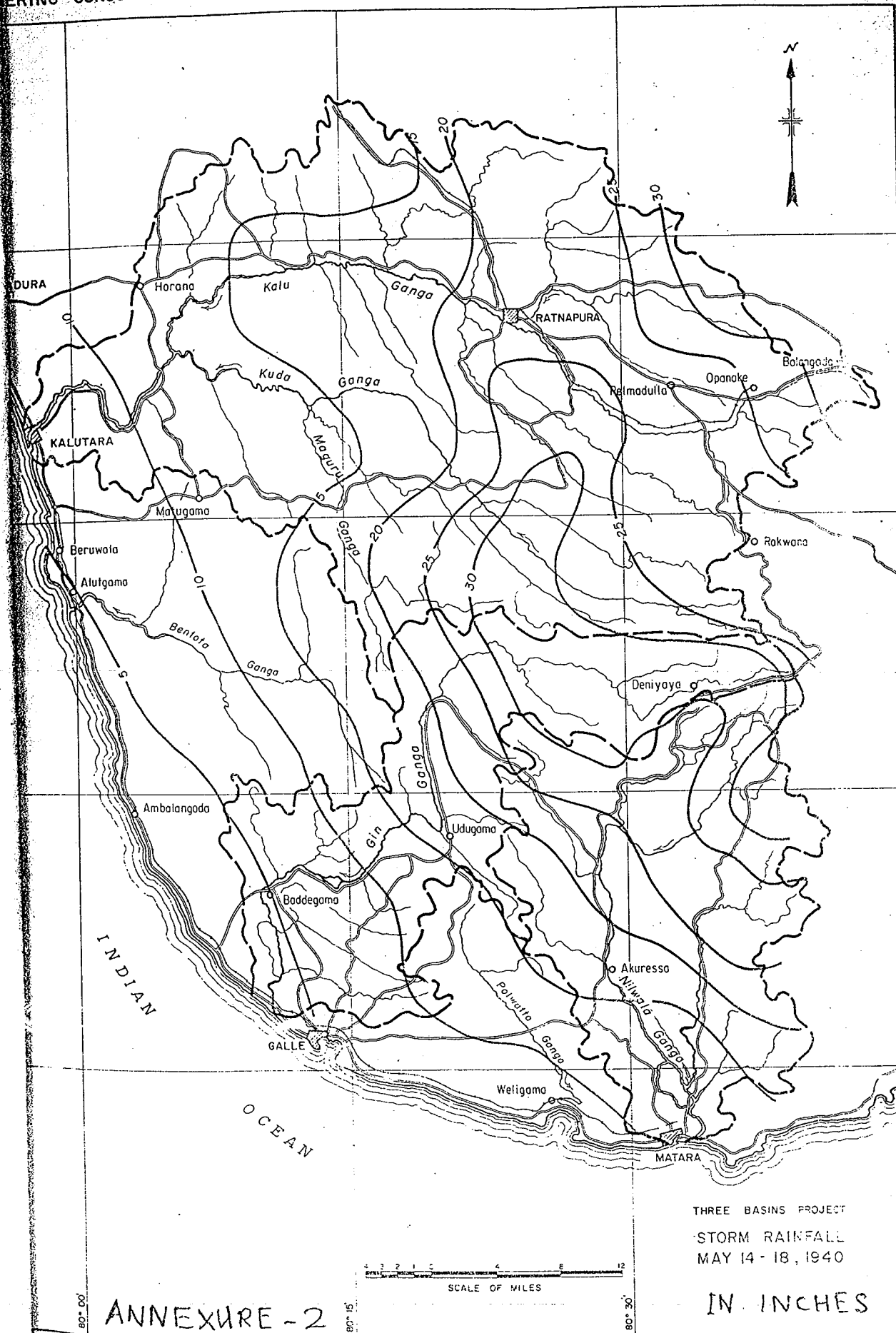
1.5 References

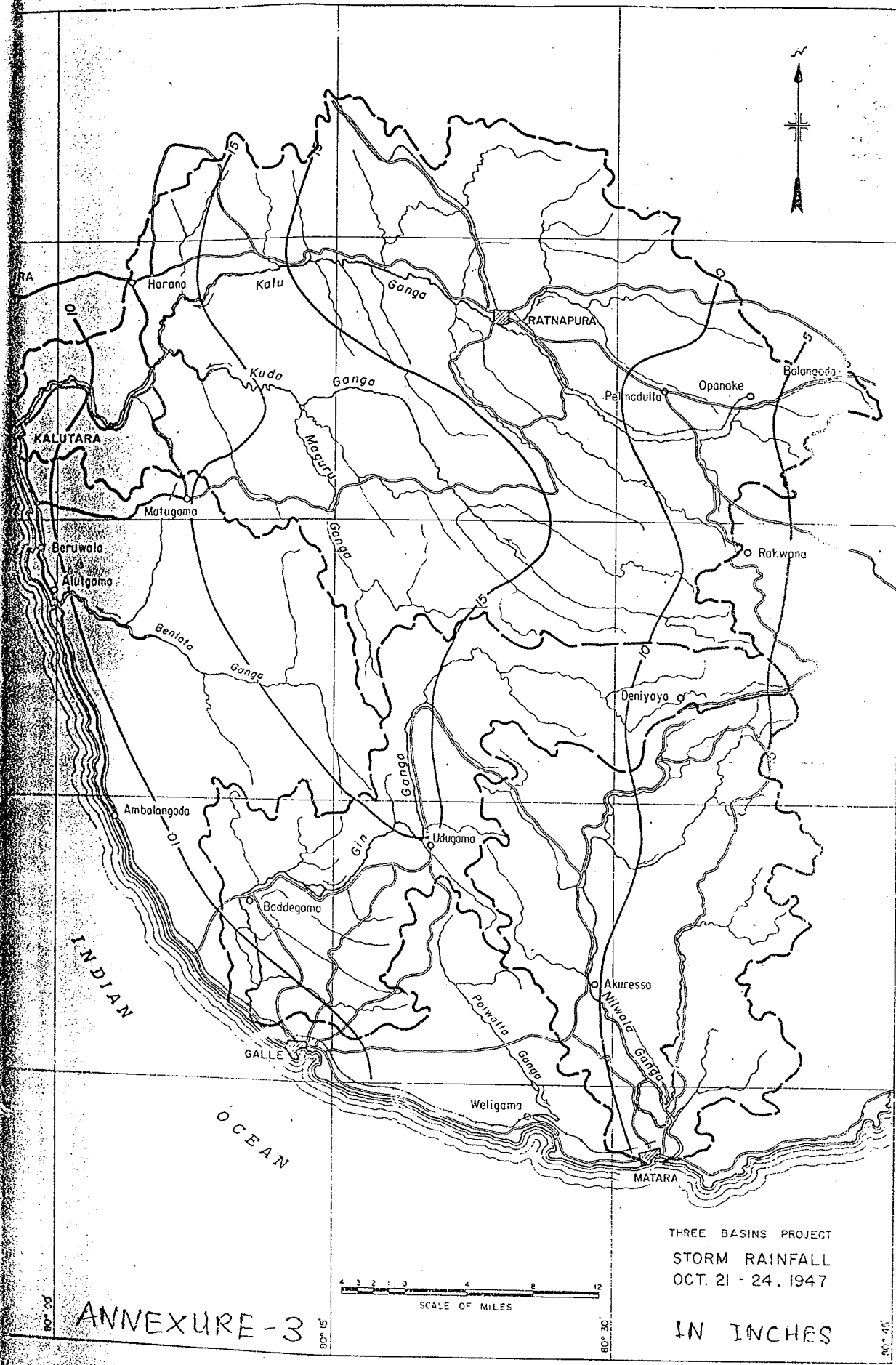
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1.6 Acknowledgements

Author wishes to thank Dr.Sohan Wijesekare and Ms M. D. M. S. Gunetilleka







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Characterization of Rainfall in the Low Country Wet Zone in Terms of Crop Water Requirements of Annual Field Crops

*H.K.Kadupitiya,
H.B. Nayakekorala,
R.D. Chithranayana*

1998

*Natural Resources Management Centre
Department of Agriculture
Peradeniya*

H 023533

Characterization of Rainfall in the Low Country Wet Zone in Terms of Crop Water Requirements of Annual Field Crops

H.K.Kadupitiya, H.B. Nayakekorala, R.D. Chithranayana

ABSTRACT

It is observed that many lowland paddy fields are left for fallow during the Yala season in the low country wet zone of Sri Lanka. One of the main reasons for this fallowing is the lack of water for irrigation. Since streams, which supply irrigation water to these paddy fields, dry up soon after rainstorms, the risk of water shortage for irrigation is high. The high risk has compelled farmers to give up Yala season rice cultivation. However, as the water requirements of the field crops are generally low, great potential remains for diversification of these paddy fields with other field crops (OFC) during Yala season. Characterization of rainfall of the area in terms of possibility of meeting the crop water requirements is a pre-requisite for development of a suitable cropping pattern for the area. Such an exercise will help identify the periods of water shortage and water excess compared to water requirements of crops. This exercise will also help development of water resources at farm level for agricultural use. Water resource development at farm level should look into irrigation and field drainage problems. This paper presents results of analysis of weekly rainfall of Ratnapura and Bombuwela in order to find out possibility of meeting potential evapotranspiration (PET) of some annual crops in the low country wet zone. Attempts were made to identify the periods where rainfall exceeds the PET and periods when rainfall falls below PET. The analysis showed that excess water is a limitation for growing OFC in area represented by Ratnapura. In the area represented by Bombuwela rainfall characteristics during period from mid February to end of August can be considered suitable for growing OFC. However, supplementary irrigation and drainage facilities become two essential requirements for such an exercise.

INTRODUCTION

The percapita land availability in Sri Lanka continues to decline with the population growth. The present percapita land availability is about 0.36 ha. The percapita land availability with regard to arable lands is half of this. Under this situation improving the productivity of available land is one of the most important task ahead of us. FAO has alarmed that there going to be a famine in the near future. Food security has been a slogan of FAO at present. Under this context it is very important to identify the lands where the productivity is low, find out the reason for problems and develop ways and means by which productivity can be improved. Paddy fields in low country wet zone has been identified as having low cropping intensity. The statistics on cultivated extents of paddy showed that in Yala 1995 only 54% of the paddy lands of low country wet zone districts namely Colombo, Gampaha, Kalutara, Galle, Matara, Kegalle and Ratnapura was cultivated. Insufficient water availability for growing paddy in Yala season and low profitability of paddy cultivation are the reasons attributed to fallowing of lands in this region. Introduction of alternate crops and cropping systems to improve the land productivity may help to put the paddy lands back to cultivation. A pre-requisite for such an exercise is the assessment of the water resource to determine the potential for various crops and cropping patterns. The objective of this paper is to assess the rainfall characteristics of the low country wet zone in relation to water requirements of annual field crops.

METHODOLOGY

This study was aimed at paddy fields in the low country wet zone region. The climatic data available for estimation of evapotranspiration of crops is very much limited in this area. Data were available only in two meteorological stations namely Ratnapura (6°40'N 80°25'E) and Bombuwela (6°32'N 80°E). Therefore data of these two stations were used for the analysis. Weekly mean data for 20 years (1977 - 1997) from meteorological station at Bombuwela and 21 years (1976-1997) from the meteorological station at Ratnapura were used. Weekly rainfall data were used for rainfall probability calculations. As normal distribution of rainfall of standard weeks was not associated with rainfall data, quintile method was used in estimation procedures (Doorenbos and Pruitt, 1984).

Potential Evapotranspiration (PET) was calculated using modified Penman equation (Doorenbos, 1997). Weekly averages of maximum and minimum temperature, day and night relative humidity, sunshine hours and wind velocity were used in this calculation. Weekly PET calculated for the respective periods were used to estimate probability. Quintile method was used. Ratio of rainfall at 75 % probability level to PET at 75 % probability level was used in determining water adequacy /inadequacy for meeting water requirements of various crops.

RESULTS

Climate: Rainfall temperature and solar radiation are the main variables of crop growth. Humidity is a factor, which has greater relationship on disease incidence of the crops. The data of these variables of that two stations indicate that there are no major limitations of temperature, radiation and RH for growth of the crops in the area. However, the rainfall seems to be highly variable and this seems to be the most important variables, which could limit the crop production through its effect on meeting the water requirements of the crops.

Rainfall: Weekly rainfall distribution at 75% probability level for the two stations are given in figure 01. For agricultural planning 75% probability of rainfall has been suggested (Pannabokke and Walgama 1974) From 75% probability rainfall distribution prominent period with very low rainfall could be identified at both stations. The duration of these periods at two stations were different. At Ratnapura it was about 9 weeks long starting from 1st week of the year. At Bombuwela it was 13 weeks long starting from 1st week of the year. Another similar very low rainfall period of 2 weeks could be identified around 32 and 33 week at Bombuwela but this period is not prominent in Ratnapura. These low rainfall periods could be considered as dry periods in the area

Two prominent rainy periods are also identified at both stations. The lengths of them were different at the two stations. These two rainy periods are in Yala and Maha seasons. The length of the 1st rainy period is about 22 weeks long from 9th week to 31st week at Ratnapura and about 19 weeks from 13th week to 32nd week at Bombuwela. The second rainy period begins soon after the 1st period without leaving a prominent dry period at Ratnapura. The length of second rainy period is from 31st week to about 49th week at both stations. During both rainy periods the weekly rainfall at Ratnapura exceed than that at Bombuwela.

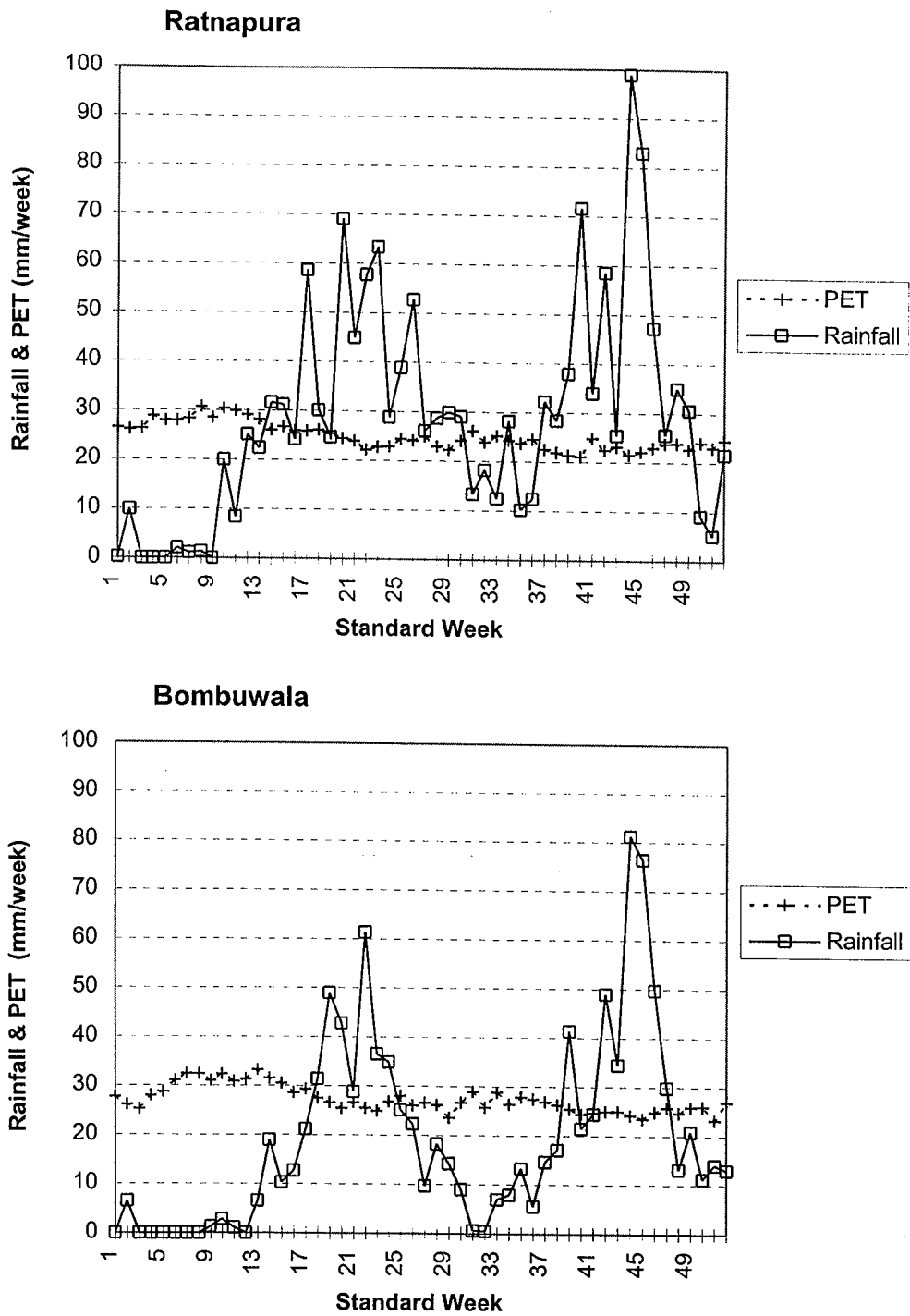


Figure 01: Rainfall and Potential Evapotranspiration at 75% Probability at Ratnapura and Bombuwela

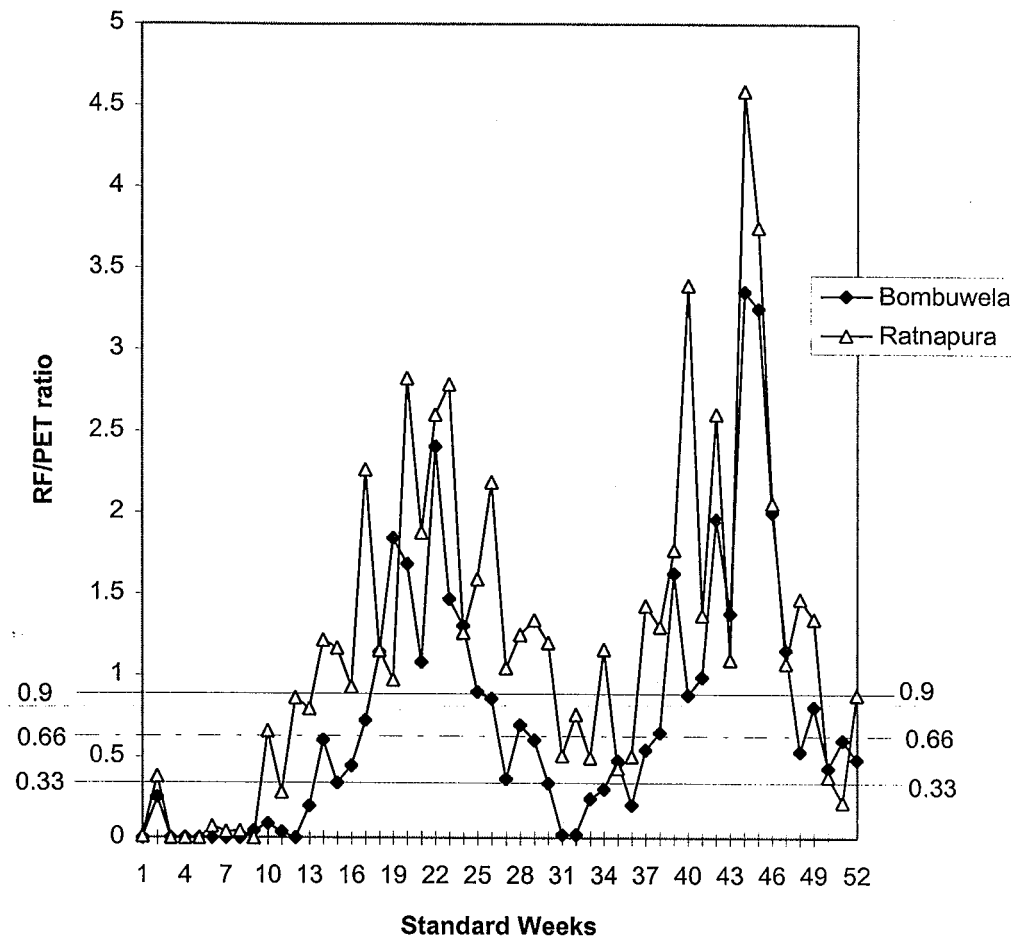


Figure 02. Variation of RF/PET Ratio over the Year at Ratnapura and Bombuwela

Potential Evapotranspiration: The change of potential ET of 75% probability level over the year at the two stations is given in figure 01. The pattern of change is more or less the same. However, the rates at Bombuwela seems to be higher than that at Ratnapura in some months. The mean annual PET at Ratnapura was 24 mm/week while it was 27 mm/week at Bombuwela. The PET at Ratnapura and Bombuwela ranged between 21-31 mm/week and 24-32 mm/week respectively. Two periods where rainfall (RF) below PET and two periods where RF is above PET could be identified at both stations. The length of these periods at the two stations are different. The 1st period where $RF < PET$ at Bombuwela is from 48th week to 18th week; a period of 5 months. The 2nd period is from 26th week till 39th week; a period of 3 months. At Ratnapura the comparable periods are; the 1st period is from 48th week till 13th week; a period of about 4 months. The second period is from 29th week till 36th week; a period of about 2 months. Unlike the rainfall, the PET remains more or less same over the year.

Hargreaves (1974, quoted by Kannangara, R.P.K., Rainfall climatology of selected locations in the dry zone of Sri Lanka, Unpublished) used RF/PET ratio ($RF =$ rainfall at 75% probability) for determining adequacy of rainfall for growing rainfed crops. If the ratio is above 0.99, the period is considered very wet and suitable for low land crops and paddy. The period when the ratio is 0.66-0.99 maize can be grown with improved drainage. If the ratio is 0.33-0.66 there is adequate moisture to grow maize, sorghum and pulses. The periods with the ratio below 0.33, moisture is deficit for growing under rainfed conditions. This criteria could be applied to identify period suitable for growing different crops in the low country wet zone. The variation of RF/PET ratio during the year is given in figure 02. The periods where the ratio > 0.99 is given below for different stations.

Period	Station	Standard week No.	Duration Weeks (Months)
1	Ratnapura	13-31	18 (4.5)
	Bombuwela	18-26	8 (2)
2	Ratnapura	30-50	12 (3)
	Bombuwela	38-47	9 (2.25)

The length of the period seems to be not adequate at Bombuwela for growing paddy as rainfed crop in both seasons. However, as there is water for supplementary irrigation for about two months following Maha rains paddy could be grown in Maha season in this area. During Yala season (Period 1) however, as the Yala rainfall is not high as in Maha season there is no adequate water for irrigation following rain period and the duration with $RF > PET$ is not sufficient to grow rice crop of even 3 months age class without adequate irrigation. There is no problem of growing rice in Ratnapura in both seasons. The period where RF/PET ratio < 0.33 is about 6 weeks long at both station extending through 3rd - 9th weeks. According to the figure 02, there is no period with sufficient length (at least 3 months) where $RF/PET = .33 - .99$ to grow other field crops. Therefore growing period of these crops have to be considered to be extended in to moisture deficit periods (with irrigation) and moisture excess periods (with adequate drainage). According to the data given in figure 02 there is no much scope for growing field crops in areas represented by Ratnapura station because of wet conditions. In the case of areas represented by Bombuwela, there is no much scope for Yala season Paddy cultivation. Therefore periods from mid February (6th

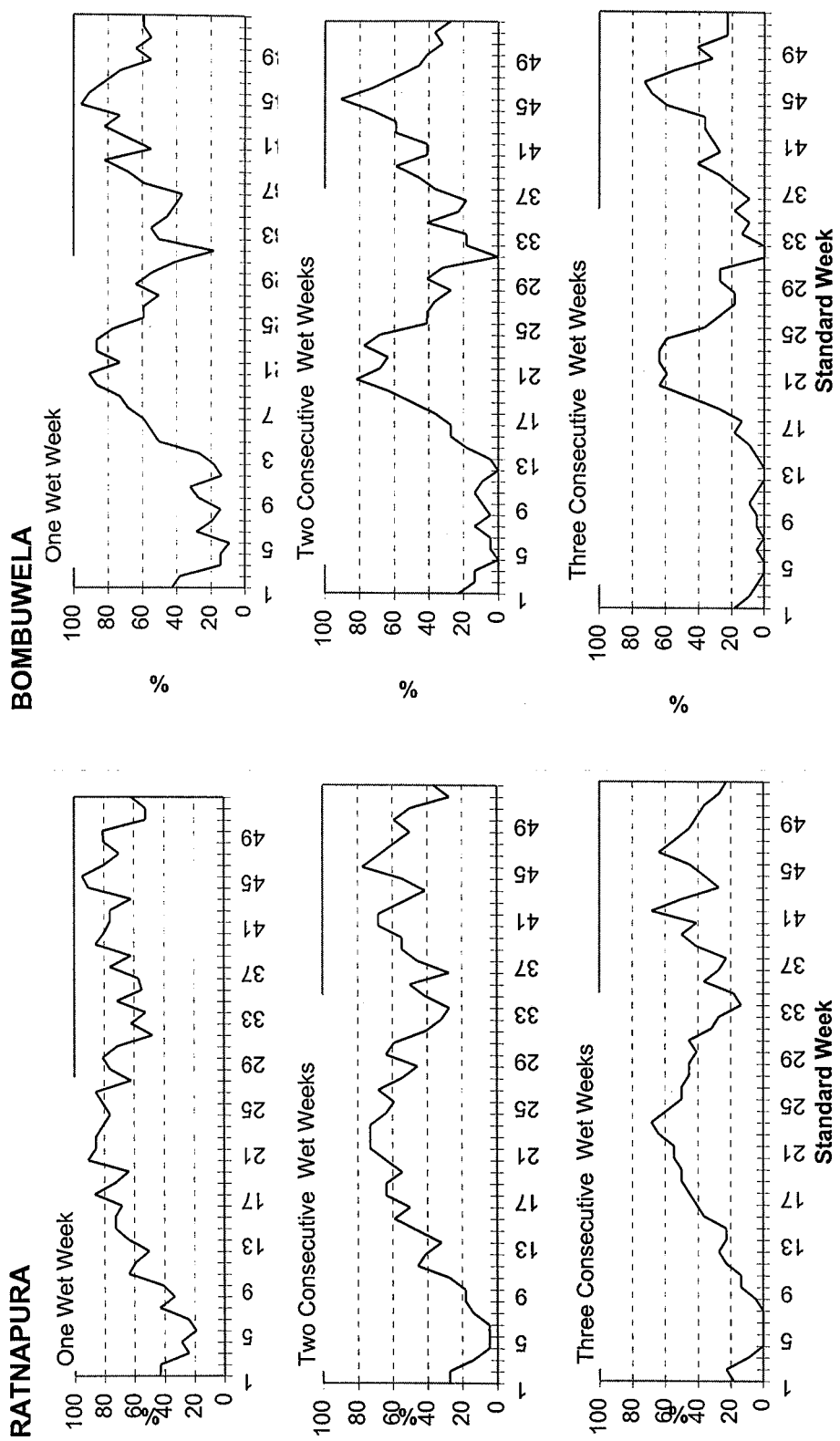


Figure 03 :Probability of Occuring Wet Periods¹ at Ratnapura and Bombuwela

¹ Wet : rainfall > potential evapotranspiration (RF > PET)

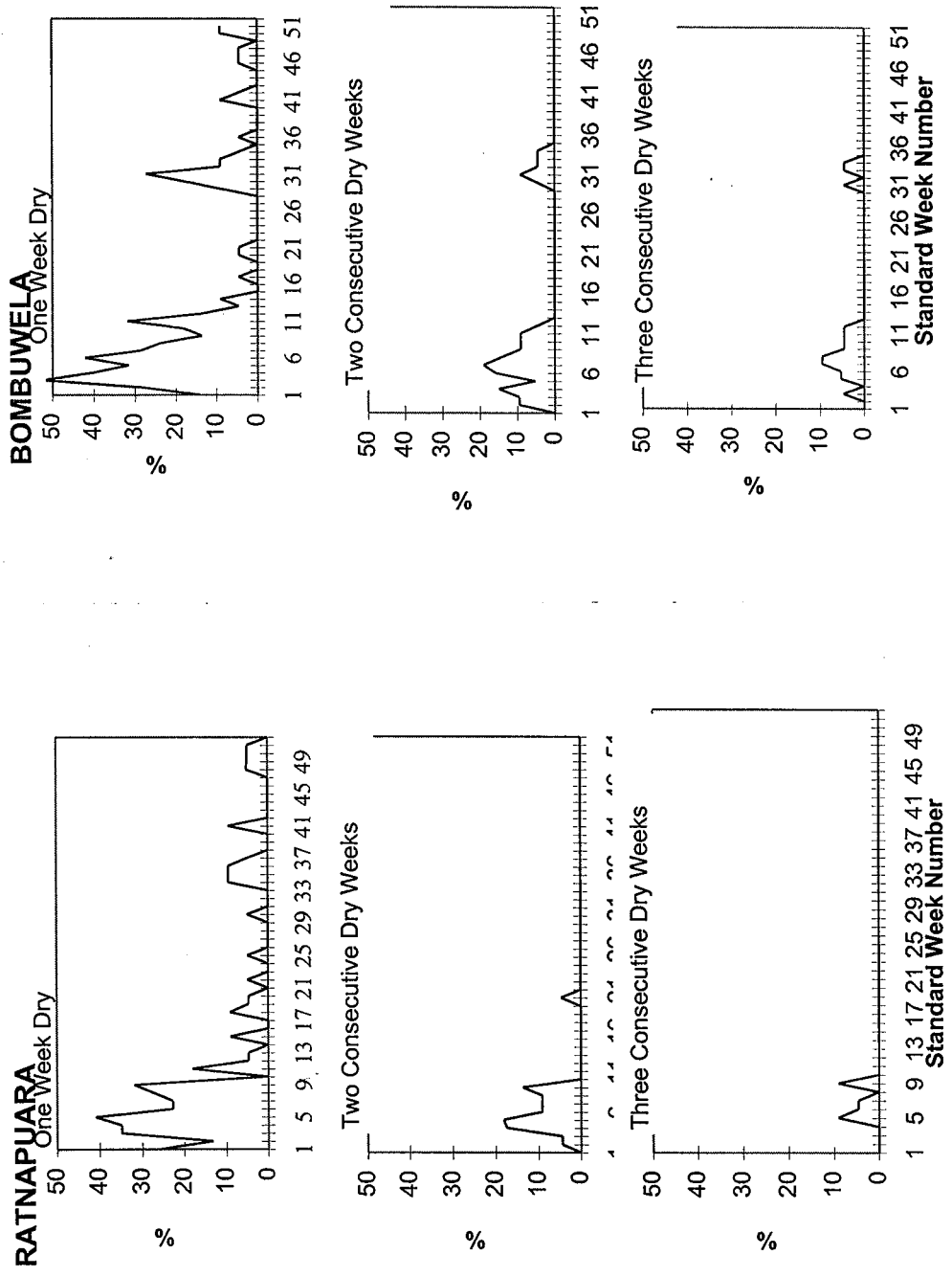


Figure 04 : Probability of Occuring Dry Periods² - Ratnapura & Bombuwela

² Dry = periods with zero rainfall

week) to mid September (36th week) can be considered for growing field crops with provision of irrigation and drainage facilities.

Probability of occurrence of wet periods: Wet periods are defined for the discussion here as periods where $RF > PET$. The probability of occurrence of 1 week, 2 consecutive weeks, and 3 consecutive wet weeks at Ratnapura and Bombuwela are given in figure 03. The probability of occurrence of wet periods is high at Ratnapura than at Bombuwela. At Bombuwela there is over 60% probability of having such wet weeks during both rainy periods. However, period of 2 and 3 consecutive wet weeks become shorter. The period from 20th - 25th week in Yala season and 45th - 48th weeks in Maha season seem to be critical at Bombuwela. When planning field crops, these periods could be avoided for crops which are very sensitive for wet conditions. For crops, which can tolerate excessive soil water conditions, surface drainage have to be improved by proper land preparation.

Probability of Occurrence of Dry Periods: Dry periods are also very important in crop production. They are needed for crop maturity. The dry weeks are defined as weeks having no rainfall for this discussion. Figure 04 shows the probability of one week, 2 consecutive weeks and 3 consecutive weeks being dry at Ratnapura and Bombuwela. The highest probability was shown during the 1st dry period of the year. The highest probability of single week being dry is about 50% at Bombuwela. This is in 2nd week of the year. The probability of 2 or 3 consecutive weeks being dry is very low at any time of the year at both stations. Crops which need 2-3 weeks of continuous dry period for maturity may not be suitable for this region.

CONCLUSIONS

The analysis show that areas represented by agro-climatic station at Ratnapura (WL1) have no limitations for growing rice in Yala and Maha season. The amount and distribution of rainfall is sufficient to meet the water requirement of the crop. In the areas represented by Bombuwela agro-climatic station (WL3 & WL4) length of rainy periods is not sufficient to meet the ET requirement by rainfall alone. Therefore, irrigation water has to be made available. Periods with sufficient length having ideal conditions for growing other field crops under rainfed conditions are not found in areas represented by both stations. However, in areas represented by Bombuwela, suitable periods could be identified with supplementary irrigation and improved drainage. Period from mid February to end of August can be considered for this purpose. Analysis of rainfall in many more stations are required before generalization could be made.

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Land surface evapo-transpiration for water balance in the Kirindi Oya watershed. A remote sensing approach.

Eng. Palitha Bandara*, Dr. Wim Bastiaanssen**/***, Dr. Lucas Janssen**

* Irrigation Department, P.O. Box 1138, Colombo, Sri Lanka.

** International Institute for Aerospace Survey and Earth science (ITC), P.O.Box 6, 7500 AA, Enschede, The Netherlands.

*** International Irrigation Management Institute, P.O.Box 2075, Colombo, Sri Lanka.

Abstract

The world has entered a new era of water management that requires large increases in the productivity of water use, in addition to water development programs. The management of irrigated areas is becoming more critical by increasing demands for food and water. The Kirindi Oya watershed in Southeast Sri Lanka needs improvements for the utilisation of land and water resources.

The Kirindi Oya watershed exhibits many different small-scale agro-ecosystems. The water consumption of these systems is difficult to measure. Water "wasted" or "discharged" on one part of the watershed is often recaptured and re-used in another part. Hence, improvements in water use efficiency would generate large amounts of additional water supply. The wide diversity in vegetation and hydrology can be surveyed with remote sensing. Satellite images acquired from the Landsat Thematic Mapper have been used for this research.

An evapo-transpiration algorithm based on the surface energy balance (SEBAL) has been applied to determine the actual evapo-transpiration during the different moments of the year. SEBAL computes the actual evapo-transpiration on pixel by pixel basis, independent from the type of the land cover / land use.

SEBAL computes the *actual evapo-transpiration* of different land use /land cover classes. Conventional methods compute the *potential evapo-transpiration* of selected agricultural crop types with respect to a reference crop.

Actual evapo-transpiration of different land use/ land cover samples of the Kirindi Oya watershed has been computed on pixel basis. The results are shown in graphical form.

It is concluded that advance remote sensing techniques can provide basic data for proper land use planning for the water management at the watershed level.

Key words: Atmospheric correction, Evapo-transpiration, Heat flux, Radiation, Spectral range, Surface albedo, Surface energy, Surface temperature, Vegetation index.

1. Introduction

1.1 Water use of the Kirindi Oya watershed

The water, which inflows to the Kirindi oya watershed, re-cycles among its land cover classes. At present there is no precisely developed system for the computation of optimum utilisation of water used in different land cover classes. Since wastewater from one land cover class within the watershed area is re-used by another land cover class, optimal water utilisation systems cannot be planned, focusing on one particular issue.

With the land development programs and increase of population, water availability becomes a primary and scare resource. In order to manage such a scare resource, water development strategies are needed. Hence, planning for optimal water utilisation systems with effective and efficient water management strategy is necessary. Water consumption varies on land cover class, land use type, and the seasonal changes. Hence, *it is required to know the water consumption of different land cover classes and land use types for water use planning*. Integrated water management system for the whole watershed area is therefore needed.

1.2 Actual water consumption and Evapo-transpiration [ET]

Actual water consumption for a particular land cover class can be described in terms of actual plant water requirement and the surface water evaporation, of that class subject to seasonal changes. This is related to the term evapo-transpiration (ET), which is one of the key parameters of the water balance. Evapo-transpiration can be defined as the net water loss from the earth surface characterised by a combination of evaporation and transpiration. Evaporation

represents a significant mass and energy transfer from the ground to the atmosphere. Transpiration refers to water loss from plants into the atmosphere through stomata opening. Computation of actual evapo-transpiration for a particular land cover class during a time period relates the actual water consumption of that land cover class for that specific time period. This information is required for the planning of integrated water management strategy at the watershed level.

1.3 A remote sensing approach

Methods have been developed for the computation of actual evapo-transpiration values for land cover class by using space borne remotely sensed data. It has to be investigated how these methods could be applied for the Kirindi Oya watershed. Remote sensing measurements of land surface radiative properties offer a means to indirectly measure land surface state conditions on a range scale. A Surface Energy Balance Algorithm for Land (SEBAL) has been developed to convert these state conditions into surface flux densities. Although the concept has a physical basis, the parameters are estimated by empirical relationships (Bastiaanssen, 1995).

It is impossible to measure the water balance terms with remote sensing techniques. But, remote sensing techniques could be used to compute actual evapo-transpiration, which is one of the terms of water balance. The actual, potential and relative evapo-transpiration is linked to the terms of the surface energy balance, which can be detected with remote sensing techniques. This is the basic relationship between the SEBAL and the water balance. SEBAL has been developed to solve the equation for surface energy balance on pixel by pixel basis. The main advantage of this method is that it does not need land use data for ET calculation.

2. Material and the SEBAL model

2.1 Space borne remotely sensed data

Space borne remotely sensed data, the data about spectral radiance, is required for the land cover classification and for the SEBAL. The SEBAL process requires spectral data of thermal infrared range. Landsat Thematic Mapper (Landsat TM) records seven spectral bands with longest wavelength in band 6, the thermal infrared band. Other bands represent the visible and infrared ranges. A Landsat TM data set acquired on 19th June 1995 is used for the sample study.

2.2 Topographic, land use and meteorological data

- i. The topo-maps for co-ordinate transferring (georeferencing)
- ii. Up to date land use maps are required to identify the present land cover / land use of the area concern.
- iii. Air temperature data – Maximum and minimum Temperature data, for the date of satellite data captured. These data are required for the atmospheric correction of the spectral thermal radiation.
- iv. Relative humidity – The data is required to calculate the moist air density in the SEBAL.

2.3 SEBAL model

Application of the Surface energy balance algorithm for land (SEBAL) for the computation of the actual evapo-transpiration of the study area is the next part. The SEBAL model is based on the surface energy balance of the land surface, which can be described as follows (Bastiaanssen, 1995);

$$Q^* = G_0 + H + \lambda E \quad [W m^{-2}] \quad (1)$$

Where

Q^* = net radiation absorbed at the land surface	$[Wm^{-2}]$
G_0 = soil heat flux to warm or cool the soil	$[Wm^{-2}]$
H = sensible heat flux to warm the atmosphere	$[Wm^{-2}]$
λE = latent heat flux associated to the actual evaporation of water	$[Wm^{-2}]$

Using the TM data sets, latent heat flux (λE) density of the surface energy balance, can be computed on pixel-by-pixel basis through the SEBAL. Evaporative fraction (Λ) can also be calculated from the SEBAL. Using additional input parameters with the SEBAL outputs, actual evapo-transpiration map can be computed on pixel-by-pixel basis. The model for SEBAL is shown in the Fig.1.

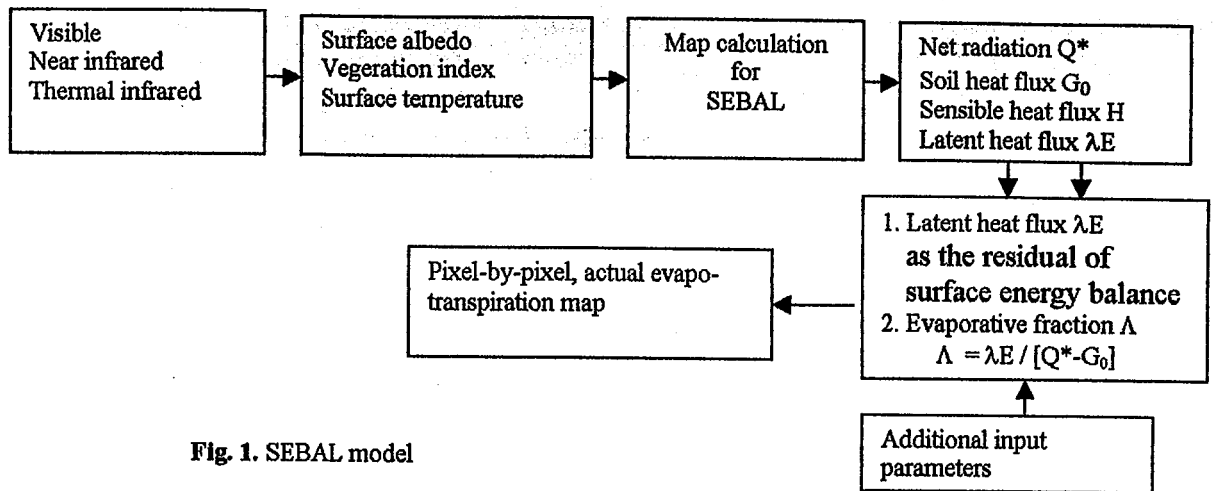


Fig. 1. SEBAL model

3. General physics of SEBAL

3.1 Surface energy balance

The surface of the earth is continually reflecting, absorbing, and emitting energy. The principle source of energy at the earth's surface is radiant energy from the sun. At any time, the balance achieved between energy received, energy stored, and energy lost from a given portion of the earth's surface represents an energy budget for that portion of the earth. The particular energy budget achieved depends upon the energy supply, characteristics of the surface, and influence of the hydrologic cycle. The land cover, i.e. soil, water, and vegetation, influences operation of hydrologic cycle (Reeves, 1975).

3.2 Net radiation flux density (Q^*)

Emissivity (ϵ_0) indicates the ratio of the radiant energy of a certain wavelength at a certain temperature and the radiant energy of a black body of the same wavelength and at the same. The sun emits radiation as a black body ($\epsilon_0 = 1$). The emission of solar energy is exclusively dependent on the temperature of the body and its surface emissivity (Reeves, 1975).

The principal energy source that drives the land surface flux densities G_0 , H , and λE , is delivered by net radiation flux density Q^* . For a flat horizontal and homogeneous surface, the integrated wavelength electromagnetic balance in terms of the up (\uparrow) and downwelling (\downarrow) radiative propagation is related to Q^* as follows (Basteaanssen, 1995);

$$Q^* = K^\downarrow - K^\uparrow + L^\downarrow - L^\uparrow \quad [\text{Wm}^{-2}] \quad (2)$$

Where K represents the shortwave (0.3 – 3 μm) and L the longwave (3 to 100 μm) radiation components. When electromagnetic radiation strikes an object, different interactions such as transmission, absorption, scattering and emission between radiation and objects arise. The spectrally emitted radiances, which are related to temperature, are calculated through Plank's law for emission, which is valid for black bodies (Reeves, 1975). On contrary, grey body radiators reflect a small fraction of long wave radiation ($\epsilon_0 \neq 1$). Natural land surfaces behave usually as grey bodies and consequently a correction is required to interpret spectral radiance measurements into temperature.

The net radiation is converted at earth's surface into the sum of land surface flux densities and which is called the surface energy balance (Eq. 1).

3.3 Soil heat flux density (G_0) and sensible heat flux density (H)

The signs of the energy balance components are dependent on time of day and climatic conditions. During the day, the soil and the crop absorb the radiation from the sun. Thus, the soil and canopy surfaces are warmer than the air so that sensible heat flux, H , is away from the crop volume. During the day, the soil surface is warmer than the soil at greater depths so that soil heat flux, G_0 , is downwelling (\downarrow) from the crop volume. At night, soil and canopy surfaces lose heat through the emission of longwave radiation because longwave radiation emitted from the crop volume is nearly always greater than atmospheric counter radiation. Since heat deficit cannot be made up by radiation from the sun, soil heat flux

and sensible heat flux are toward the crop volume to counteract the radiation loss. But, conditions may exist where the air is cooler than the canopy and soil surfaces during the night. In such a case, sensible heat flux will be away from the crop volume during the night (Reeves, 1975).

3.4 Latent heat flux density (λE)

During the day latent heat flux is away from the crop volume. At night latent heat flux may be away or toward the crop volume depending on the respective temperatures of the air and crop and soil surfaces. In dry climatic conditions, latent heat flux will continue to be away from the crop volume both day and night, and dew formation will not occur. Horizontal divergence terms will normally be greater than the day due to the higher wind speed. Divergence may be influence at night if movement of frontal system occurs. Over large macro-climatic land areas, horizontal divergence of latent heat must be included because of the large amount of water vapour present in the air (Reeves, 1975).

3.5 Difference between net radiation and soil heat flux density ($Q^* - G_0$)

The difference between net radiation and soil heat flux ($Q^* - G_0$) determines the available energy to be portioned between the surrounding environment and the heat required for evaporation. When water is available for evapo-transpiration and if atmospheric water pressure is low, then most of the energy will be used to evaporate water (latent heat flux). Conversely, if moisture is limited, then the available energy, which could have been used for evapo-transpiration, is now made available for sensible heat flux (Reeves, 1975).

3.6 Sensible heat flux density and assignment of dry pixels

Typical polynomial regression reality between the surface temperature and the surface albedo (r_0) is shown in the Fig 2.

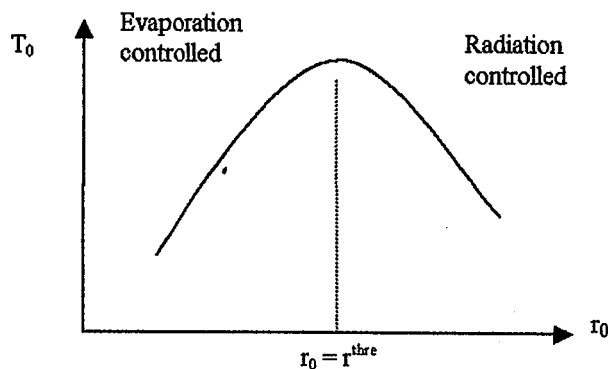


Fig. 2 Typical relationship between Surface temperature (T_0) and the Surface albedo (r_0)

The positive slope of this regression curve suggests an increase in temperature with increasing albedo until moisture is depleted and a critical metric pressure is reached. This indicates that as the surface dries up, more sensible heat becomes available to the surrounding and also reduced soil moisture increases the albedo. The lower region portion of this positive trend is supposed to be well-watered or open water bodies where potential evapo-transpiration takes place ($H \approx 0$). This portion is therefore evaporation controlled up to the peak of the curve where evaporation ceased due to depleted soil moisture. This rising part of the curve therefore means that evapo-transpiration is governing energy balance as most of the energy is used for evapo-transpiration.

At the peak of the curve where evapo-transpiration becomes zero ($\lambda E = 0$), all energy available is used for increasing the surface temperature (Daka, 1997). The value of the surface albedo (r_0), at the turning point of the curve is called the threshold value (r_0^{thr}). This negative trend ($r_0 > r_0^{thr}$) is indicative of more radiation being reflected leaving less energy for heating the surrounding in resulting decreasing temperature as the albedo increases. This portion is yielded a radiation-controlled region of the area. In SEBAL, the pixels of the surface albedo map under the region where $r_0 > r_0^{thr}$ are called dry pixels where as the pixel $r_0 < 0$ are called wet pixels.

3.7 Evapo-transpiration as a residual of energy balance

Actual evapo-transpiration, ET_a (mm day^{-1}), is defined as the quantity of water that evaporates from a land surface per unit area, per unit time, given the present hydro-meteorological situation. The land surface can be cropped, bare or

partially covered. The potential evapo-transpiration, ET_p (mm day^{-1}), is defined as the quantity of water that can evaporate from a land surface per unit area, per unit time, under the condition of optimum water supply. (Bastiaanssen, Roerink et al., 1997)

SEBAL calculates the latent heat flux density, λE (W m^{-2}), as the residue of the surface energy balance equation, i.e. $\lambda E = Q^* - G_0 - H$.

The actual evapo-transpiration (mm day^{-1}) can be calculated from the daily-integrated latent heat flux according to (Bastiaanssen, Roerink et al., 1997):

$$ET_a = 10^3 \int_0^{24} [\lambda E(t) / \lambda \rho_w] dt \quad [\text{mm day}^{-1}] \quad (3)$$

Where

λ = latent heat vaporisation $[\text{J kg}^{-1}]$
 ρ_w = density of water $[\text{kg m}^{-3}]$

In the situation without water stress (potential evapo-transpiration, $H=0$) the surface will use all available energy ($Q^* - G_0$) for evapo-transpiration. Then potential evapo-transpiration becomes:

$$ET_p = 10^3 \int_0^{24} [(Q^*(t) - G_0(t)) / \lambda \rho_w] dt \quad [\text{mm day}^{-1}] \quad (4)$$

The relative evapo-transpiration can be expressed as:

$$ET_{rel} = ET_a / ET_p \quad [-] \quad (5)$$

The instantaneous version of this term is called the evaporative fraction:

$$\Lambda = \lambda E / [Q^* - G_0] \quad [-] \quad (6)$$

Shuttleworth *et al.* (1989) showed that the mid day Λ - value is almost similar to the daily value of Λ . Then the actual, potential and relative evapo-transpiration can be obtained from the instantaneous SEBAL output as:

$$ET_{rel} = \Lambda \quad [-] \quad (7)$$

$$ET_a = \Lambda ET_p \quad [\text{mm day}^{-1}] \quad (8)$$

To calculate the potentials value of the evapo-transpiration (ET_p), the values of G_0 and Q^* on a daily basis have to be known. In 24 hours G_0 often equals zero, so only the daily Q^* has to be calculated from instantaneous values computed. The latter can be realised by relating instantaneous to daily radiation values (Kustas *et al.*, 1994);

$$Q^*_{24} = (1 - \epsilon_0) K^{\downarrow}_{24} - \epsilon_0 \sigma T_{0,24}^4 + \epsilon' \sigma T_{a,24}^4 \quad [\text{J s}^{-1} \text{m}^{-1}] \quad (9)$$

Where,

Q^*_{24} = average daily net radiation $[\text{J s}^{-1} \text{m}^{-1}]$
 K^{\downarrow}_{24} = average daily incoming shortwave solar radiation $[\text{J s}^{-1} \text{m}^{-1}]$
 σ = Stefan Boltzman constant (5.67×10^{-8}) $[\text{J s}^{-1} \text{m}^{-1} \text{K}^{-1}]$
 $T_{0,24}$ = Average daily surface temperature $[\text{K}]$
 $T_{a,24}$ = Average daily atmospheric temperature $[\text{K}]$

4. Multi-spectral data and input needs

4.1 Multi-spectral data in SEBAL

Land surface fluxes vary spatially as a result of spatial heterogeneity of soil physical properties, fractional soil cover, land use, rainfall and hydrological processes. SEBAL is associated with energy balance modelling on the basis of thermal infrared measurements and all heat fluxes derived from surface radiation parameters. The SEBAL algorithm applied to this research study has been developed to solve the energy balance equation on a pixel by pixel basis (Bastiaanssen, 1995). Multi spectral images, which cover the spectral range within visible, near infrared and thermal infrared, can be used to compute the components of surface energy balance. The Landsat TM images provide this

requirement since it covers the spectral range between 0.45 μm and 12.5 μm with seven spectral windows (i.e. seven bands).

4.2 Remote sensing input needed for SEBAL operations

The physically based multi-step SEBAL needs three basic input parameters namely hemispherical surface reflectance r_0 , vegetation index NDVI, and surface temperature T_0 . The hemispherical surface reflectance is commonly referred as surface albedo (r_0). By inter relating these three input parameters, SEBAL computes other land surface parameters being required for estimating the components of surface energy balance.

4.3 Surface albedo (r_0)

All Landsat TM bands, except band 6, acquire shortwave radiances receiving from the atmosphere within each spectral range (spectral window). These bands acquire the reflectance properties of solar radiation of different land cover classes (when corrected for atmosphere). This can be simplified as short wave range TM bands acquire the spectral properties at top of the atmosphere.

4.4 Vegetation Index (NDVI)

Because chlorophyll (green vegetation) has a strong absorption in the TM band 3 (red) and strong reflection in the TM band 4 (near infrared), land surface spectral reflectances (r) provide information on surface vegetation conditions. Hence, Normalised Difference Vegetation Index (NDVI) is defined as below;

$$\text{NDVI} = [r(\text{infrared}) - r(\text{red})] / [r(\text{infrared}) + r(\text{red})] \quad [-] \quad (10)$$

Spectral values of TM band 4 and 3 are needed as inputs for the determination of vegetation index.

4.5 Surface Temperature (T_0)

Band 6 of the Landsat TM data provides the spectral variations of longwave radiation receiving from the atmosphere. Since the spectral range of the TM band 6 is within the thermal infrared region, spectral values of the TM band 6 are related with the temperature variations of the different land cover classes (when corrected for atmosphere). The spectral value of TM band 6 is needed as input for the computation of surface temperature.

5. Atmospheric corrections for SEBAL inputs

5.1 Surface albedo

The amount of shortwave solar radiation reaching the land surface, K^\downarrow , depends on atmospheric absorption and scattering of short wave radiation. An explicit description of aerosol scattering can be avoided by recognising a macroscopic atmospheric perturbation on radiation transfer by means of an effective transmission coefficient, τ_{sw} in the shortwave range:

$$\tau_{sw} = K^\downarrow / K^\downarrow_{\text{TOA}} \quad [-] \quad (11)$$

where $K^\downarrow_{\text{TOA}}$ is the radiation entering the top of the atmosphere at a horizontal plane between 0.3 and 3.0 μm (i.e. shortwave radiation). A portion of the direct solar beam $K^\downarrow_{\text{TOA}}$ is due to Rayleigh scattering converted into the path radiance in the upper part of the atmosphere, K^\uparrow_a . Radiance observed by satellite sensors relate to a small field of view at the top of atmosphere and which are directional (Bastiaanssen, 1995).

A simple semi-empirical radiation transfer model proposed by Arino et al.(1992) is used for computation of r_0 .

$$r_0 = (r_p - r_a) [\tau_{sw} + r_d (r_p - r_a)]^{-1} \quad [-] \quad (12)$$

Where r_a is the atmospheric reflectance ($K^\uparrow_a / K^\downarrow_{\text{TOA}}$), and r_d is the atmospheric reflectance of diffuse radiation and τ_{sw} is the two-way atmospheric shortwave transmittance. The hemispherical surface reflectance r_0 (referred as surface albedo,) is defined as the fraction of incoming shortwave radiation at the land surface, at one particular moment, and which is reflected from land surface elements ($K^\uparrow / K^\downarrow$).

In absence of sky diffuse radiance and specularly reflected sunlight, i.e. $r_d = 0$, Eq. 12 can also be shaped in a linear form (Ahern et al., 1977);

$$r_0 = (r_p - r_a) / \tau_{sw} \quad [-] \quad (13)$$

The relation between r_0 and r_p can be established by plotting measured surface albedo's against corresponding planetary albedo's, and fitting the data by linear regression;

$$r_0 = (1/\tau_{sw}) r_p + (-r_a/\tau_{sw}) \quad [-] \quad (14)$$

Since no field measurements for r_0 are available, by using the standard values of r_0 for identified areas such as water ($r_0 \approx 0.05$), green vegetation ($r_0 \approx 0.15$), and bare soil ($r_0 \approx 0.25$), r_0 can be computed. The value of τ_{sw} was calibrated from Eq. 14 using latter standard values.

5.2 Normalised difference vegetation index (NDVI)

For the NDVI, comparison has to be made between field measurements and standard calculations, in order to get an atmospheric correction. The NDVI at the top of the atmosphere can be obtained from the Eq. 10. Negative NDVI values (for water bodies) shall be set at zero. Since no field measurements for NDVI are available, atmospheric correction was not established.

5.3 Surface temperature (T_0)

Surface temperature is one of the principal parameters required for the SEBAL model. It is one of the key factors in determining the exchange of energy and matter between the earth's surface and the atmosphere. The surface temperature is being calculated with the aid of TM band 6, which lies in the thermal infrared region (10.4–12.5 μm) of the electromagnetic spectrum. The radiance of the band 6, which the satellite measures at the top of the atmosphere, has to be found with the standard calibration for Landsat TM band 6 (Roerink, 1995).

Atmospheric disturbances may have a significant effect on the outgoing narrow band longwave radiation (band 6 of Landsat TM data) which is measured at the top of the atmosphere (L_6^{TOA}). In order to convert L_6^{TOA} into the radiation emitted and reflected at the land surface ($L_6(T_0^R)$), measurements of at least two ground points must be available. Temperature values at Kirindi oya meteorological station and sea surface were available for the study.

$$L_6^{\text{TOA}\uparrow} = \{\epsilon_0 L_6^{\uparrow} + (1-\epsilon_0) \epsilon_6' L_6^{\text{atm}\downarrow}\} \tau_{lw} + L_6^{\text{atm}\uparrow} \quad [\text{Wm}^{-2} \mu\text{m}^{-1}] \quad (15)$$

Where $L_6^{\text{atm}\uparrow}$ is the up welling spectral radiance from atmospheric emission and scattering that reaches the sensor. $L_6^{\text{atm}\downarrow}$ is the down welling spectral radiance from atmospheric emission incident upon the land surface. Since the temperature value at surface incoming longwave radiation is assumed as uniform all over the image, $L_6^{\text{atm}\downarrow}$ also become a constant all over the image. τ_{lw} is the spectral atmospheric transmission. Eq. 15 can be simplified as;

$$L_6^{\text{TOA}\uparrow} = (\tau_{lw}) L_6^{\text{sur}} + L_6^{\text{atm}\uparrow} \quad [\text{Wm}^{-2} \mu\text{m}^{-1}] \quad (16)$$

Where;

$$L_6^{\text{sur}} = [\epsilon_0 L_6^{\uparrow} + (1-\epsilon_0) \epsilon_6' L_6^{\text{atm}\downarrow}] \quad [\text{Wm}^{-2} \mu\text{m}^{-1}] \quad (17)$$

Then an atmospheric correction procedure can be established by plotting the, $L_6^{\text{TOA}\uparrow}$ obtained from the images, and L_6^{sur} calculated from the field measurements.

By inter relating the basic parameters r_0 , NDVI, and T_0 , SEBAL process can be operated to solve the energy balance equation;

$$\lambda E = Q^* - G_0 - H \quad [\text{Wm}^{-2}] \quad (18)$$

The latent heat flux, λE is then obtained as the residue of the Eq 18.

6. Results

At the end of the SEBAL process, it provides the out put image of actual evapo-transpiration on pixel by pixel basis with mm day^{-1} . Samples of different land use / land cover types have been considered for the computation of ET_{act} . Graphical representations of actual evapo-transpiration (Et_{act}) for different land use / land cover samples are shown in

Fig.3. Et_act values (mm per day) are given, against the cumulative percentage of the number of pixels within the sample area.

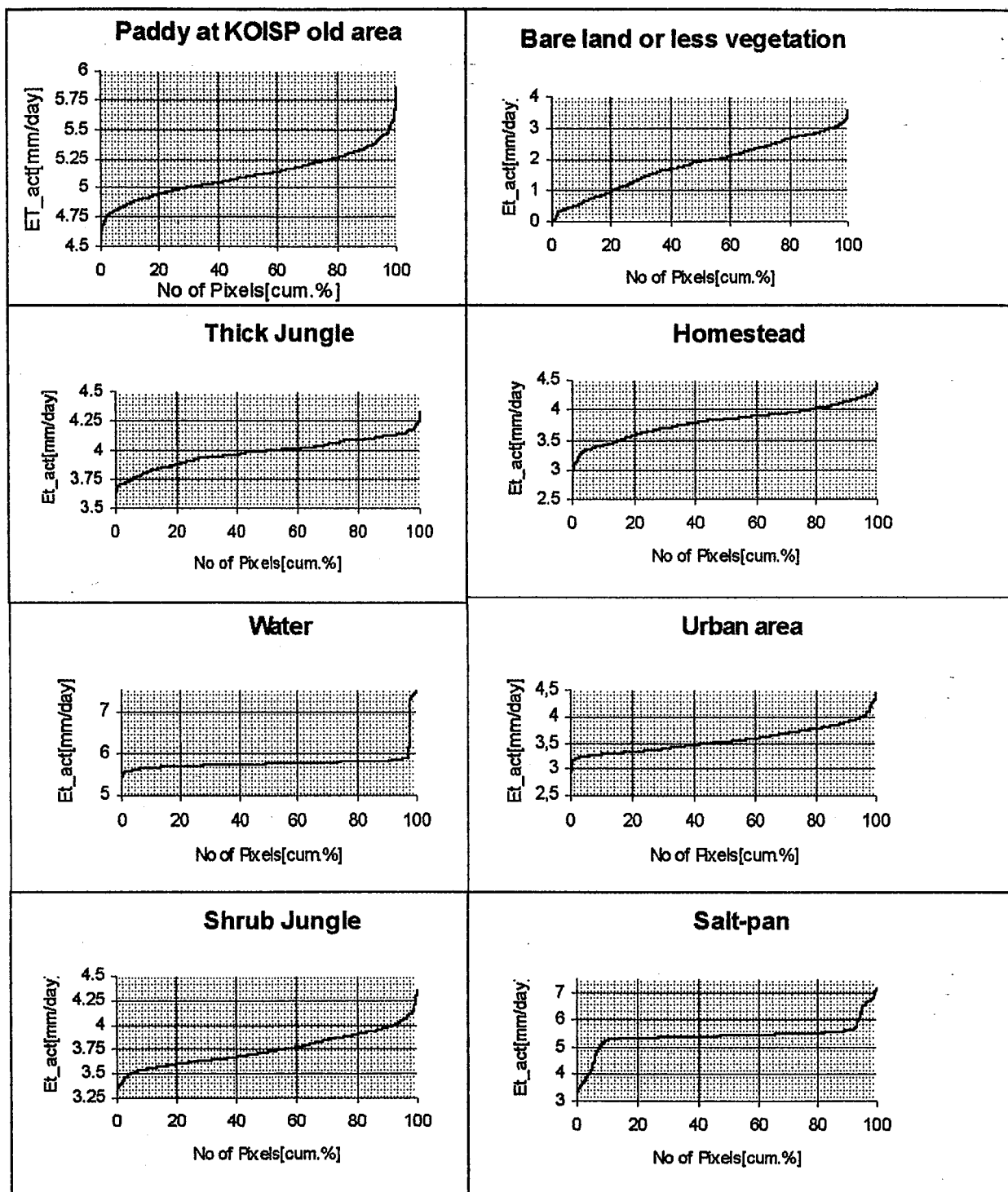


Fig.3 Actual ET values different land surface samples against cumulative percentage of pixels for the date 19th June 1995.

The values are varying within a certain range. At macro level, land use/ land cover can be categorised into different classes such as forest, grass, paddy, bare soil, water, urban, etc. and can be treated as homogeneous. Landsat TM provides the satellite images with the resolution of 30 m* 30 m pixels. At the pixel level, such land classes cannot be treated as homogeneous because of mixed vegetation, and other spatial differences. For instant, in a large reservoir, spectral properties of the water surface closer to the upstream peripheral may differ from the deeper areas due to the quality of water. In paddy fields, spectral properties may differ from area to area due to the different growing stages of paddy. Therefore any specific value of ET_{act} cannot be assigned for a certain land use / land cover type even though the results are on daily basis.

7. Concluding remarks

7.1 Conclusion

The results achieved in this study confirm the competence of using remote sensing data for mapping actual evapo-transpiration on different land cover / land use of the Kirindi Oya watershed. SEBAL computes the latent heat flux as the residual of the surface energy balance and thereby the evaporative fraction, which computes the actual evapo-transpiration in millimetres per day. Traditional methods compute potential ET instead of actual ET. And also such methods derive ET values for specified single crop types related to a reference crop and no facilities are available for land surfaces with mixed vegetation.

SEBAL outputs are independent from the land cover / land use. The user gets the advantage of estimating the actual water consumption using more precise values of evapo-transpiration on pixel basis (with co-ordinates). This is a challenge for the classical methods in which calculating only crop evapo-transpiration (agricultural crops) based on an identified reference crop.

7.2 Recommendations

Following recommendations can be made in order to improve the results in SEBAL level.

- Instead of taking the sea surface temperature, another point on the land surface, within the study area, shall be obtained.
- Field measurements obtained from the radiometers can be used to improve the semi-empirical relationships used to determine the SEBAL parameters.
- A relationship for NDVI at top of the atmosphere and the land surface is one example.
- Validation should be carried out at least at the regional level for the verification of the results. This will become a new project.

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