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Volume 1
Irrigation for Food Security

P. Weligamage, G. G. A. Godaliyadda and K. Jinapala, editors

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Irrigation Department

Department of Agriculture

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INTERNATIONAL WATER MANAGEMENT INSTITUTE

The editors: P. Weligamage, PhD Candidate; G. G. A. Godaliyadda, Director of Irrigation, Irrigation Department, Colombo, Sri Lanka; K. Jinapala, Researcher/Institutions Specialist, International Water Management Institute (IWMI), Colombo, Sri Lanka.

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Please direct inquires and comments to: *iwmi-research-news@cgiar.org*

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Professor M. S. Swaminathan from India delivered the key-note speech and the Hon. Prime Minister of the Democratic Socialist Republic of Sri Lanka, Rathnasiri Wickremanayaka attended as the chief guest. Both provided us with some very enlightening information and interesting observations, and we are extremely grateful to them for sharing their opinions with us and enriching the conference.

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Partners

This workshop is a collaboration of the following organizations:

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Overview: The Volume on Irrigation for Food Security

K. Jinapala
International Water Management Institute (IWMI), Colombo, Sri Lanka

Background of the Conference

This is the first volume on the proceedings of the national conference on 'Water for Food and Environment', which was held from June 9–11, 2009 at the Bandaranaike Memorial International Conference Hall (BMICH). The volumes two and three have been produced as separate documents of this report series. In response to a call for abstracts, 81 abstracts were received from government institutes dealing with water resources and agriculture development, also from universities, other freelance researchers and researchers from the International Water Management Institute (IWMI). Forty Seven of the eighty-one abstracts that were submitted were accepted for compiling full papers. Further details of the conference have been described in paper one of volume three (see introductory section of volume three of this publication series).

Emerging Issues in the Irrigation and Agriculture Sectors

Thirteen papers were presented at the conference on the theme – 'Irrigation and Food Security'. The issues, which emerged from the papers that were presented and the subsequent discussions that took place, are summarized below.

Revitalizing Irrigation for Food Security

Food security has become a significant issue globally and it is equally applicable to Sri Lanka. It is imperative to consider food security from a household level to a national level. It has been observed that national food security issues are quite often discussed but household security is not a subject that gets much attention in the food sector discourses. Hence, different strategies are required to address national as well as household food security issues and to ensure that due attention is given to both at the relevant food sector programs.

Food security does not mean ensuring self-sufficiency in rice only – it must entail a balanced and nutritional diet for everybody. This is an important and critical issue among the poverty groups in the country. In most rural families although they have sufficient rice to eat, their regular diet does not include the necessary nutritional food items. This aspect, however, is not a subject that comes under the purview of the Ministry of Irrigation or the Ministry of Agriculture; it comes under the Ministry of Health.

Factors such as access, affordability, socioeconomic conditions, and health (to absorb nutrients) are other food security issues-related considerations. None of these factors come under the areas managed by either irrigation or agriculture ministries; they come under the purview of other ministries such as finance and planning, trade, and Ministry of Health.

Do We Know Enough About Food Security in Sri Lanka?

This is an important issue in the field of food security. There is no adequate and frequently available information on food security with its multidimensional aspects as described above. This may require further studies and a national data set. The national data set needs to be updated frequently to provide a comprehensive time series picture, and also the situation of a particular year or time for policymakers to develop appropriate policies, other institutional mechanisms and strategies to address the issues of food security.

Major Challenges for Food Security

The prevailing constraints in land and water resources due to population increase are the two major challenges faced by this sector. Although the average annual population growth of the country is significantly less than 1.5 %, the increasing population, nevertheless, is a problem for sharing limited natural resources such as land and water. Less land and less water per person is becoming a significant issue. Land fragmentations in many cases create problems related to scale of economy and the practices of some farmers in small pieces of lands, and also lead to low land productivity. A similar problem is emerging with regards to water resources. The per capita water for agriculture is becoming less and less, creating the need for alternative ways of water management.

The constraints for land and water are due to the fact that they are required for other uses besides agriculture, such as industrial, domestic and so on. One emerging trend that has been observed is that there is a growing number of urban centers that absorb migratory population from /the rural agricultural sector. The urban growth has lead to an increase in water use in other sectors, e.g., industries. It has also increased the use of water for various domestic purposes. The need for land for bio-fuels production is another challenge that is becoming significant in the world. However, in Sri Lanka it has not yet become a significant issue.

Changes in the climate and natural disasters (flood, drought, cyclones and epidemics) have aggravated the constraints on natural resources such as land and water, which have already been strained by population increases. Although flooding is not a frequently occurring problem in the agricultural areas of the country, droughts that occur from time to time in these areas do create serious problems. In some years, farming systems such as agriculture under small irrigation are confined to one season only due to the drought. Farming communities try to overcome these challenges by tapping groundwater for their agricultural requirements. However, the frequency of droughts experienced in certain periods of time has lead to problems even with regards to the availability of groundwater for agriculture. Cyclones and other pest-related epidemics too occur periodically and create problems. However, these are neither frequent nor impactful enough to create serious problems in the field of agriculture in Sri Lanka.

Options for Addressing Food Security

When facing the challenges of food security, increasing the extent of land cultivated is the option that is often suggested by many experts. However, many irrigation systems including major, medium and minor, lack additional land to develop for agriculture. In most of the irrigation schemes, farmers have already developed more than the area that was originally designed in the command. The reservations for irrigation canals and also for other purposes have been captured already for cultivation by the communities. Therefore, additional land development under the existing irrigation schemes is an option that has serious limitations. Development of new irrigation schemes also has significant limitations, as most of the natural water resources that are economically, socially and technically feasible have been already captured for irrigation development. There may be some limited possibilities for new water resources development. However, such possibilities require careful investigation by multidisciplinary researchers to evaluate their feasibility status. Improving cropping intensity by augmentation (water transfer to major and minor systems) and management interventions will be the best option available for wider application. The government, however, does make interventions in some systems for the augmentation of water to improve the cropping intensities in irrigation schemes where productivity is low due to lack of water for cultivation in the two seasons. Improved water management for crop diversification will be the other strategy worth employing when addressing the problem of low productivity in agriculture. There should be a balance between paddy and other field crops where farmers can improve their cash flows and also improve household food security.

There is an emerging need to seek new technologies for water management in irrigation systems. The conjunctive use of surface and groundwater for irrigated agriculture is a common practice in countries like India. Sri Lanka too can explore this option. Other technologies such as sprinkler irrigation are useful methods for improving water use efficiency.

The efficient and sustainable use of natural resources is a recommended precaution for natural resources management. In Sri Lanka, many people discuss managing water that is developed for use but rarely talk about managing natural water resources that are flowing in rivers and moving under the ground. These are factors to be considered for the long-term sustainability of land and water resources. Watershed management strategies are also recommended to enrich the water in the soil.

What are the Challenges for Irrigated Agriculture and Options?

As mentioned above, exploring possibilities for using groundwater as a conjunctive resource in irrigation schemes is a useful option. Tapping groundwater for agriculture cannot be a solution that can be prescribed to every region or every location. There are specific locations that are feasible for the application of this option. Extracting groundwater can be a high-cost intervention in some locations and in some other locations it will not be feasible due to environmental issues. Likewise, options for micro-irrigation (drip and sprinkler) must also be explored. Similar to groundwater, this option can be applied in areas where high-value crops are cultivated. Growing high-value crops with intensive water management technologies may be one solution for improving the productivity of small-land parcels.

The system of rice intensification (SRI) has been identified by some groups such as Oxfam Australia (an NGO working in Sri Lanka) as a suitable option for managing the problem of water scarcity in relation to rice cultivation. Different people have different opinions on the SRI system and its suitability for wider application. However, further studies are needed to draw firm conclusions on this issue.

Water availability is becoming a critical issue and, therefore, all possibilities are to be explored to make water available from all potential sources. Rainwater and runoff harvesting are two such potentials discussed by many persons doing research in this field. Rainwater harvesting is being practiced by communities in some areas of the country for domestic use. This potential source can be further improved to use even for home gardening at a small-scale level. Runoff harvesting needs to be carefully investigated so that it can be implemented in the kind of locations that won't create water scarcity in the runoff harvesting schemes, which have already been developed in the same water sheds.

Small-tank-cascade-systems play a significant role in the rural economy of the country. Water for agriculture in the dry zone is provided by the small-tank-cascade-systems. Some tanks in the cascades require rehabilitation and modernization. The rehabilitation programs should consider cascades as a single unit when improving the individual tanks in the cascades. There may be possibilities for the augmentation of new water sources to some tank-cascade-systems in the dry zone. These potentials need to be planned carefully through studies, taking into consideration hydrological and socioeconomic factors.

It is observed that the cropping intensity of some major irrigation schemes is lower than the expected rates. Furthermore, infrastructure and management improvements in major irrigation schemes need to be carried out to improve the cropping intensities. In addition, specific interventions for different tanks are required for improving their performance in agriculture.

The Challenge Goes Beyond Irrigated Agriculture – Livelihoods Security

The agriculture sector needs innovative approaches to establish sustainable economies for communities depending on such systems. A variety of options will have to be available depending on local conditions and needs. To ensure food security, the solution needs a livelihood-focused approach. Every possibility should be explored to enhance all livelihood capitals. The livelihood capitals include social relations, economic diversities, cash flows, physical infrastructure, health, education and other environmental considerations. This means planning by multiple organizations is a critical need for irrigation systems to establish sustainable livelihood systems for the people. Coordination is a key requirement for these multidimensional development programs. Combining production of grains with fruit and vegetables, fisheries and livestock are potential economic diversifications in irrigation systems in the country. The production systems, whatever that are introduced and practiced, need to consider environmental sustainability in the irrigation systems as whole.

Agriculture versus Environment

There are evidences that current agricultural practices have impacted negatively on the environment, including water, soil etc. Excessive use of synthetic fertilizer and other agrochemicals have created this problem.

In some irrigation schemes concrete-lined canals have created negative impacts on the groundwater in the areas that are close to these lined irrigation canals. However, research is required to justify these assumptions. Changes are needed (reduce the use of chemical inputs) and are taking place, e.g., canals are no longer lined.

The challenge is how to balance these aspects to ensure irrigation efficiency while protecting the environment for long-term sustainability and food security.

Some Suggested Needs

* More scientific research on new methods and techniques.
* Specific options for specific locations or situations.
* Better data on food security.
* Appropriate management — collaboration between sectors and community involvement.
* Balancing agricultural production with environment.
* Taking account of wider livelihoods needs.
* Ensuring food and nutritional security, at various levels.

Key Issues Determined from the Papers Presented at the Conference on the theme – Irrigation and Food Security

1. We must consider and learn from the ancient irrigation systems when planning new systems.
2. We need to improve water productivity at several levels – from the basin, scheme, to the household level.
3. We should manage rural irrigation systems as a total production system (environment, agroforestry, fisheries and livestock).
4. Maintenance of wet zone irrigation systems to ensure sustainability.

5. Management of aquatic plants – to benefit irrigation schemes and for sustainable utilization.

6. Need to consider, test and where appropriate, promote new technologies such as SRI and zero-tillage.

7. Verification of agro-ecological zones (climate change).

8. Simplified and up-to-date monitoring of irrigation systems – pro-active management.

Water Shortage in the Lower Deduru Oya Basin

K. N. J. Katupotha
Department of Geography, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka

Abstract

Acute water shortage for agricultural, domestic, industrial and other activities is evident in the Lower Deduru Oya Basin (LDOB) due to changes in land use, abandonment of irrigation structures, extensive use of tubewells and lowering of groundwater levels. This situation has lead to a slowdown in the rate of agricultural development, weakening the socioeconomic activities and social milieu and also in controlling the improvement of living standards in the area.

In the early 1990s, farmers had agro-wells dug in their own farmlands. Subsequently, farmers obtained water from shallow tubewells and then shifted to deep tubewells due to the lowering of the groundwater levels following micro-morphology. Many farmers have reported that turbidity, pollution and salt water intrusion are the major issues in tubewells. In some instances, high salt concentration in tubewell water has made extracting water for irrigation a problem.

In order to evaluate the quality of water of the LDOB, the present study team examined the electrical conductivity, salinity and pH values of the water of 32 water samples from different locations. In some locations, for example, where the electrical conductivity is below 2000 and the salinity is also below 5.85, the water cannot be used for bathing and even for washing purposes. Laboratory analysis reveals that the salinity exists even in water samples obtained from tubewells that are 10-15m deep.

The Deduru Oya Basin and its surroundings receive heavy rains during the 1st inter monsoon and 2nd inter monsoon and northeast monsoon periods giving surplus water. The trend lines of the average annual rainfall of the Deduru Oya Basin indicate decreasing trends, and are insufficient to maintain mega irrigation works such as the proposed Deduru Oya Reservoir as well as proposed hydropower projects, which will be expected to be completed by 2010. Nevertheless, even after the completion of the Deduru Oya Reservoir by 2010, the Ridibendi Ela, Magalla Wewa and LDOB will face water shortage. Consequently, the problem will be arisen seriously than at present, and that is not a relevant response to the water shortage in the LDOB area.

Introduction

The Lower Deduru Oya Basin (LDOB) is a unique example that highlights the water shortage problem, and the way such a shortage obstructs and imposes negative impacts for socioeconomic development. During the recent past, supporters of politicians, law enforcement officers and other law-implementing government personnel disregarded and ignored the existing rules and regulations, to help their clients to expedite unscrupulous activities. The backing of the politicians and law-implementers have encouraged, especially among the sand miners, the removal of sand from the river bed and river banks, thus disturbing the natural cycle of interconnections between surface and groundwater levels. As a result, water deficits (shortage) even in short dry periods and water pollution have emerged as significant problems in the surrounding areas of the LDOB.

The acute water shortage for agricultural, domestic, industrial and other activities is evident in LDOB due to changes in land use, abandonment of irrigation structures, extensive use of tubewells, lowering of groundwater levels and water pollution. All these are linked to the insufficiency of water (water shortage) for the people, and this situation has been instrumental in slowing down the agricultural development, weakening of socioeconomic activities and social milieu and also in controlling the improvement of living standards in the area.

A properly designed management action plan is needed to minimize water shortage even during short dry periods and water pollution problems, which are caused by unwarranted land utilization practices. The development of a management action plan, for the LDOB in this particular case, requires a sound understanding of interactions between the physical characteristics (mainly topography, surface geology and climate) of the river basin and its human activities. The availability of detailed information pertaining to the above enables us to assess options such as allocating land for forest reservations, development of appropriate farming systems for certain areas, development of location-specific appropriate farming systems, increasing the groundwater table to the maximum possible levels etc. in terms of the relationship between physical and human resources.

The middle part of the Deduru Oya Basin (MDOB) extends from Pallama to Kalatuwakele (Ibbagamuwa Divisional Secretary [DS] Area). Within this area, the number of diversion structures have been built across the Deduru Oya, for example, Ridibendi Ela anicut and Deduru Oya anicut at Batalagoda use the water mainly for irrigation purposes. Besides, small and medium size tanks gather water from streams connected to Kimbulwana Oya and Hakwatuna Oya. Likewise, people around the streams of Maguru Oya and Deduru Oya also use a considerable volume of water for their daily use. Although, this is an outstanding feature for controlling severe floods during the heavy rainy periods in the Lower Deduru Oya Basin, a severe drought when it hits, will endure in the same area for nearly 7 to 9 months creating an acute water shortage. Furthermore, this situation is likely to aggravate in the future after the construction of the proposed Deduru Oya Reservoir.

The population increase and enhanced economic activities in the recent past have seriously affected the topography, existing drainage system and land cover in the LDOB. Hence, a detailed analysis of the existing situation is a prerequisite for any integrated development effort. This paper will provide a basis for the development of a management action plan for the LDOB, which is a typical river basin system with all the characteristics required for a comprehensive study on water shortage. This paper is based on the study "Vulnerability of Land Use to Environmental Impacts: Evidence from the Lower Deduru Oya (river) Basin (LDOB), Sri Lanka", The main objective of the Research Project was to identify and document the topography, land use activities and land cover of the LDOB. More specifically, its other objectives can be divided into two, as, a) to analyze more particularly the physical processes and b) to analyze the links among topography, land use activities and environmental impacts. This paper attempts to reveal the reasons and consequences for the water shortage in the study area. This study can be used as a framework for developing environmental action plans for similar river basins in the country.

Methodology

A review of relevant literature and existing material pertaining to the environmental impacts that are caused by water shortage was conducted to gather evidence from the LDOB on a comparative footing. Water samples for laboratory analysis and deep-well locations were geo-referenced using a GPS device (SporTank MAGELLAN). Pre-testing of the questionnaire to collect socioeconomic data was done prior to the commencement of field work. Group discussions similar to Participatory Rapid Assessment (PRA) for the selected user groups such as Farmer Organizations (FOs), sand miners and transporters, small entrepreneurs, school teachers, senior citizens, Association of the Chilaw Tax Payers, public officers (government officers and police officers) were conducted with a focus to identify the water shortage problem in the study area.

An Overview of the Deduru Oya Basin

The LDOB lies within the intermediate climatic zone in the western part of Sri Lanka. It consists of lowland terrain (flat and flat to slightly undulating terrain) which extends from the river mouth (between Mahaduwa and Muttuwa) to Podidelpotha in Pallama DS Area (Figure 1). The area is located within the 91000E - 107000E and 265000N - 270000N National Grid System (1:50000 Chilaw Metric Map).

The whole Deduru Oya Basin is located in the Intermediate Agro-climatic Zone and its upper tributaries originate in the western part of the Central Highlands. This basin can be divided into two broad categories namely (a) Uplands, and (b) Lowlands. Within these two categories, six Geomorphic Surfaces (terrains) in the Deduru Oya Basin have been identified by Katupotha (1992) on the basis of absolute altitude, slope and other characteristics. The relationships of these phenomena are shown in Table 1. The drainage density and patterns as well as land use systems on each geomorphic surface depend on the geological structure, characteristics of each terrain, soil conditions and present climate.

Basic data of the Deduru Oya Basin are shown in Table 2. When compared, this basin with selected wet zone basins such as Kelani, Kalu and dry zone basins and Kubukkan Oya, Kirindi Oya, it represents that specific characteristics, mainly extended area of the basin, average amount of rainfalls and bifurcation ratio. They are accountable for the gross amount of contribution of rainfall to groundwater recharge and sub-surface run-off. Such a comparison is essential to understand water sufficiency and insufficiency in any area. Parameters such as the catchment area, gross contribution of rainfall to groundwater recharge, evapotranspiration, and sub-surface run-off losses, net groundwater recharge are also shown in the same table, while a categorization of streams by drainage orders is presented in Table 3.

The water shortage or deficit of the LDOB is controlled by the middle part of the Deduru Oya Basin (MDOB) and the upper reaches. The MDOB is more significant than the upper Deduru Oya Basin (UDOB), because the water flow of the main river is diverted to large irrigation reservoirs situated away from the river course. Examples are Magalla Wewa, and Batalagoda Wewa. In addition, the Hakwatuna Oya Reservoir located on a major tributary, catches an extensive volume of water. This pattern will be expanded after the construction of the proposed Deduru Oya New Reservoir. The MDOB area appears as mainly undulating terrain extending 30 m – 150 m AMSL, which is significant as a water storage area.

Figure 1. Study area, the Lower Deduru Oya Basin (from Deudru Oya mouth to Podidelpota).

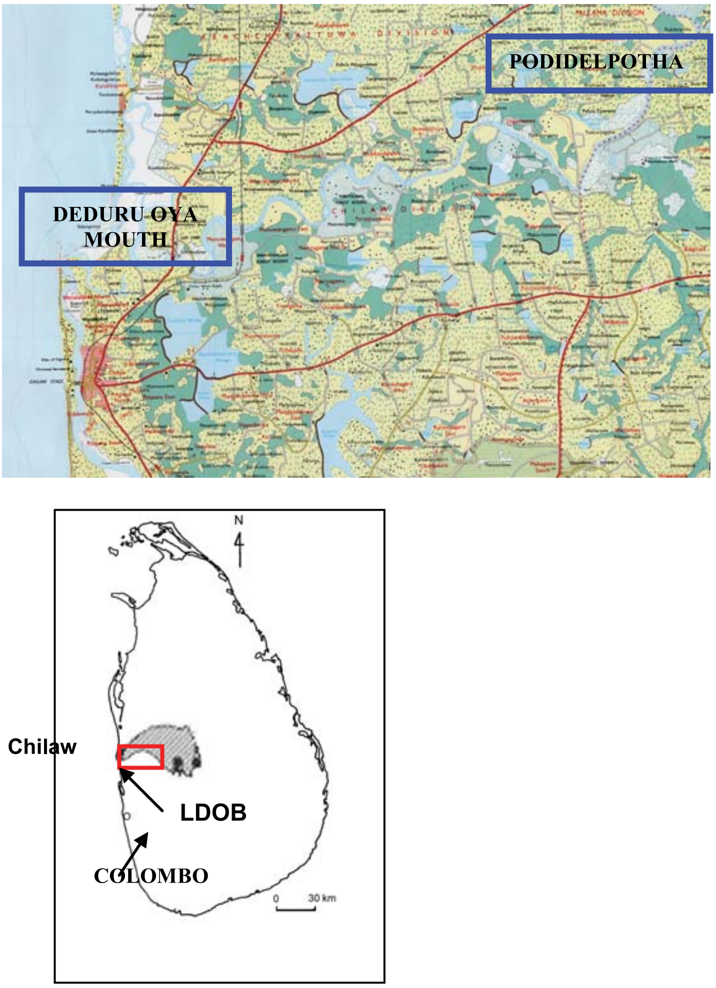


Table 1. Characteristics of terrains in the Deduru Oya Basin.

Class (Terrain)	Absolute altitudes (meters)	Landforms	Vegetation	Soil
Almost flat (A I)	< 30	Sand spit, barrier beach, beach ridges, brackish-water marshes, swamps, peat bogs, meanders, point bars, ox-bow lake	Creeping vegetation mangroves, grasslands riverine forest	Unconsolidated sand, silt and clay; peaty clay.
Flat to slightly undulating (A II)	< 30	Low hills and rises; natural level, flood plain, marshes	Riverine forest, dry evergreen forest, swamp vegetation	Red or yellow with brown earths; alluvial soil, bog soil

Undulating (B)	30-150	Hills and rises, low rock knobs, valley bottoms	Dry evergreen forest, swamp vegetation	Reddish-brown earths; Non-calcic brown soils and low humid glay soils; red-yellow podzolic soils; strongly mottled sub-soils and low humid glay soils
Rolling and hilly (C)	150-460	Hills and ridges, rock knobs and erosional remnants, valley bottoms.	Dry evergreen to semi-evergreen	Reddish-brown earths and immature brown loams, red-yellow podzolic soils
Dissected rolling and hilly (D)	460-915	Dissected hills and ridges, deep slopes, moderately deep valleys, erosional remnants, rock-lands and lithosols.	Semi-evergreen forest	Immature brown loams,erosional remnants with shallow soils
Steeply dissected rolling and hilly (E)	Over 915	Steeply dissected hills and ridges, steep slopes, deep valleys, rock-lands and lithosols	Semi-evergreen forest	Reddish-brown latazolic soils; erosional remnants with shallow soils

Source: Katupotha 1992

Table 2. Basic data of the Deduru Oya Basin.

Attribute	Value
Catchment area (sq. km)	2,616.32
Perimeter (km)	306
Axial length (km)	86
Basin width (km)	308
Form factor	0.36
Circulatory ratio	0.36
Elongation ratio	0.68
Stream frequency	0.57
Average rainfall in the Deduru Oya Basin (mm)	1,728
Gross amount of rainfall of the basin (MCM)	4,522
Evapotranspiration and sub-surface runoff losses (Cu. Mt.)	3,648.41
Net groundwater recharge CM	5,472.33
Discharge to the sea (MCM)	1,608
Discharge density	0.747
Bifurcation ratio	4.23
Discharge to the sea (percentage of rainfall amount)	36 %
Average net groundwater recharge for catchment per km CM	13.77

Source: Arumugam 1969; Irrigation Department 1974; Piyasiri, 2007

Table 3. Drainage orders of the Deduru Oya Basin.

Stream Order	Number of Streams	
	Strahler[b]	Horton[a]
1 st order	701	1,146
2 nd order	172	294
3 rd order	38	55
4 th order	8	12
5 th order	2	3
6 th order	1	1

Notes: [a]Based on Horton (National Atlas of Sri Lanka),
[b]Based on Strahler (Drainage Orders by Katupotha [personal observation])

Identify the Long-term Climatic Conditions and Trends

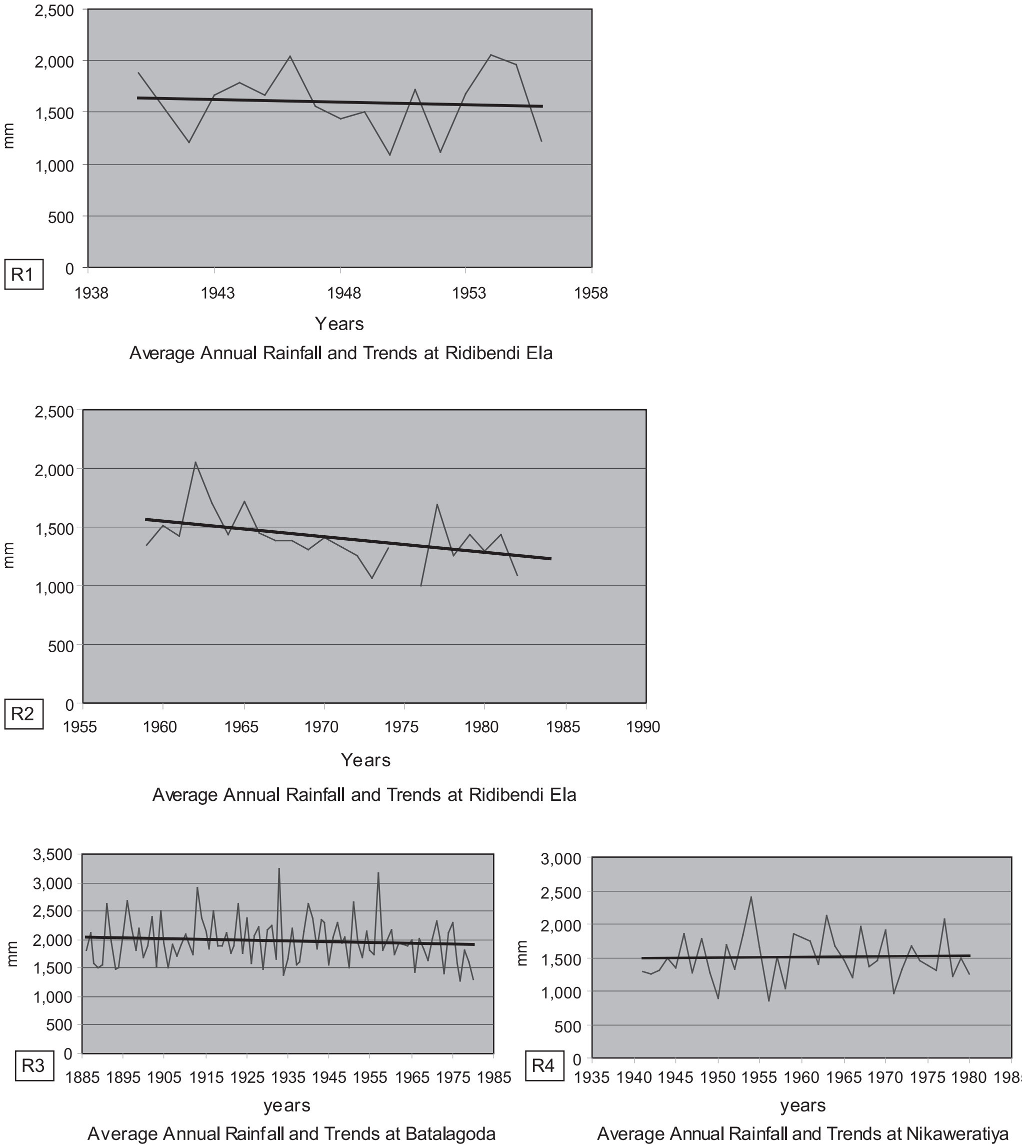
The global average of near surface air temperature over land, and sea surface has increased since 1861. Over the twentieth century this increase has been 0.6° ± 0.2° C. This value is about 0.15°C larger than the estimate by the Second Assessment Report (SAR) for the period up to 1994. These numbers take into account various adjustments, including urban heat and island effects. The records show a great deal of variability. For example, most of the warming occurred during the twentieth century, during two periods, from 1910 to 1945 and from 1976 to 2000. Globally, it is very likely that the 1990s were the warmest decade and 1998 was the warmest year in the instrumental record, since 1861.

The trend lines of the average annual rainfall of the Deduru Oya Basin indicate decreasing trends in the two periods at Ridibendi Ela Rainfall Station (Figure 2 - R1, R2 and R3). Figure 2 (R2) shows a high decreasing trend. At the Batalagoda Rainfall Station (RS), the rainfall has been decreasing at a lower rate than at Ridibendi Ela RS.

However, the trend lines of rainfall at Nikaweratiya and Kurunegala show an almost equal distribution (Figure 2 R4 and Figure 3 R5). The trend lines at Maradawila Estate, about 1.5 km away from the Deduru Oya (left bank) shows that the average annual rainfall has been decreasing, but with fluctuations (Figure 3 R7). Twenty-year records of this station revealed that 1991, 2001 and 2003 were minimum rainfall years. Although the Ratabalagara Estate represented an increasing trend line, the years such as 1991/1992, 2001 and 2003 reported minimum rainfalls (Figure 3 R7). This estate is located on the same river bank and is about 10 km away from Deduru Oya. When compared with rainfall data (years) at Maradawila Estate and Ratabalagara Estate with Batalagoda, Kurunegala, Chilaw and Nikaweratiya RSs, these have more data (years) to examine long-term trends.

The annual average temperature (AAT) at the Kurunegala Meteorlogical Station (MS) shows an increasing trend between 1870 and 1990. Puttalam and Katunayaka MSs are located to the north and south of the Deduru Oya estuary, respectively. The trend line at Puttalam MS reveals that the AAT is increasing as rapidly as in the Kurunegala MS. At the Puttalam MS, higher temperatures were recorded around 1869, 1881, 1906, and 1914, 1945 – 1950 and 1980 – 1990. These periods are coinciding with the high temperature values at Kurunegala

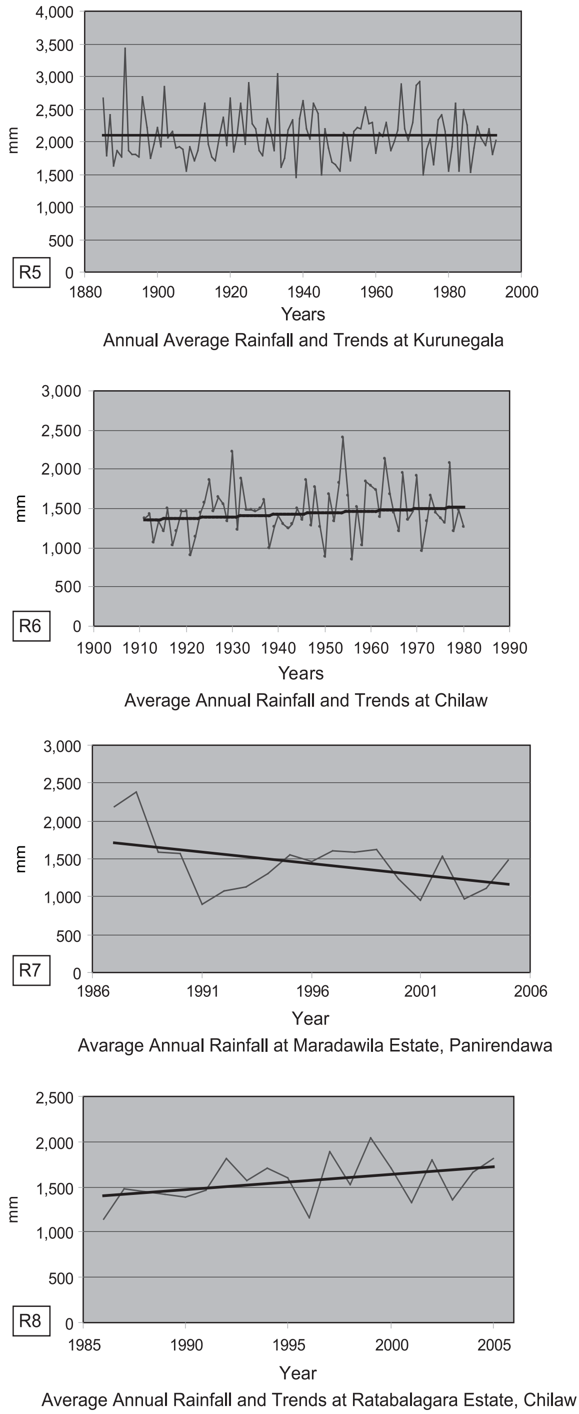
Figure 2. Decreasing trends of rainfall at selected stations of the MDOB.



MS and also with global warming periods. The low rate of increase at Puttalam MS is related to its location, close to the Puttalam Lagoon and the sea. The Katunayaka MS is also located close to the Negombo Lagoon and the sea. The second episode of global warming (1976 – 2000) is reflected in the Katunayaka MS data. The trend line indicates that the AAT has risen at a higher rate than at the Puttalam MS.

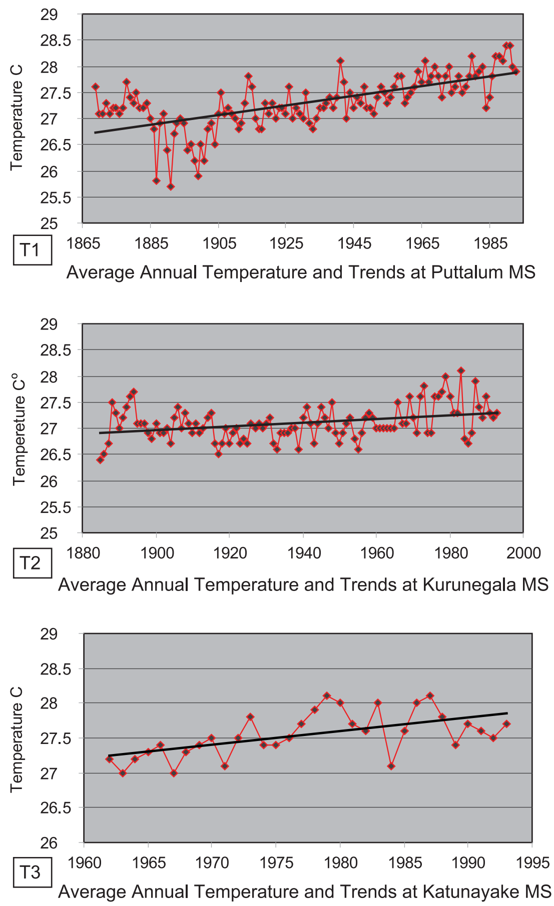
It is noteworthy that the fluctuations of AAR and AAT within the Deduru Oya Basin can be correlated with the changes of the land use pattern in the area. Man-made causes such as urban development, resettlement schemes, and deforestation in and around the basin,

Figure 3. Trends of rainfall at selected stations of the MDOB and LDOB.



have been responsible for the vulnerability of land use. The two global warming periods that have been identified from 1910 to 1945 and from 1976 to 2000 are reflected in these data of the rainfall stations of the Deudru Oya LDOB and MDOB and Puttalam, Kurunegala and Katunayaka Meteorological Stations (Figure 4 – T1, T2 and T3).

Figure 4. Trends of temperature at selected stations of the MDOB and LDOB: NagasawT1T2.



Source: Nagasawa et al.1995

It is very difficult to find continuous rainfall and temperature data relating to the Deduru Oya Basin. However, the limited data that is available provide sufficient clues to identify sequential drought and flood periods. Likewise, these data reflect the results of deforestation, encroachment of forest reservations, chena cultivation etc. The lapse of time, increase of population by settlement rather than by natural growth, improper land use practices, legal and illegal forest felling in forest reservations and other forests were instrumental in reducing surface water storages and groundwater levels.

Water Shortage

Recent changes in land use activities and land cover, which took place during the last few decades, are easily observable, while inadequate water for agriculture and domestic use account for a large part of this change. Forest felling in the bank reservations and surrounding areas, sand and clay mining and encroachment of forest lands have been instrumental in fluctuating the water level and in eroding the banks of the Deduru Oya. These activities have been responsible for widening and deepening the river in the study area. As a result, annual frequency and intensity of floods decreased, and the continuous flow of the stream has been hampered.

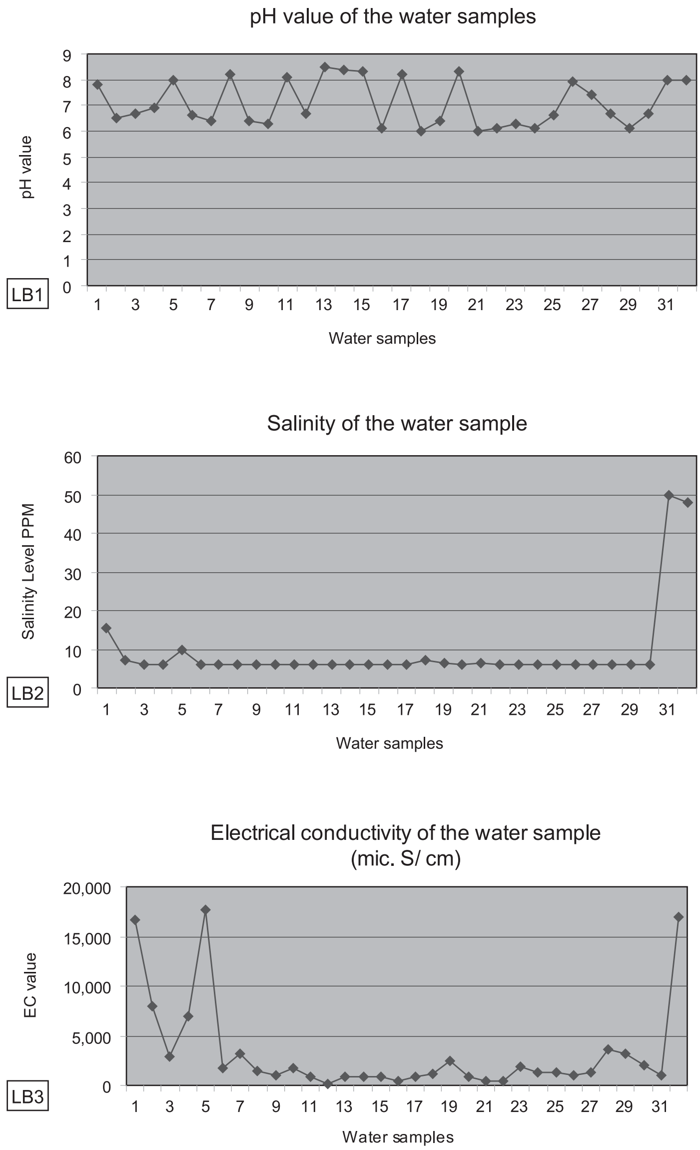
The traditional water source for surface irrigation was water collected in depressions (locally known as *ebas*). Once *ebas* have no water, farmers used to dig open ponds (agro-wells, named as *Gala Linda*) within their farmlands to provide water for cultivation. Using these open ponds, farmers cultivated coconuts, paddy as well as leafy vegetables. The open water ponds dried up gradually due to the reduction in the volume of water flow in the Deduru Oya, and lowering the water table because of excessive sand mining in the river bed and at the banks. Consequently, farmers who faced water scarcities for their cultivations were compelled to use tubewells. At the beginning these wells were 8-12 meters deep. Hundreds of tubewells are found in the four DS Areas in the LBOB. Water is pumped from these tubewells for the cultivation of coconut, paddy and leafy vegetables, as well as for animal husbandry and domestic uses.

During recent years banana and leafy vegetables have become the predominant crops in the study area. There is no longer any paddy cultivation, and coconut lands have been reduced to the minimum due to gradual lowering of the water table. The response of the farmers to this situation is manifested by the construction of tubewells, which sometimes are as deep as 20 – 30 meters or more from the surface level. Suspended and dissolved impurities present in the water of these tubewells make it unsuitable for many purposes, mainly for growing crops and using for drinking purposes. This is an acute problem experienced in many locations close to the Deduru Oya.

One of the major contributory factors for this is the extraction of water without any limitation from both public and private tubewells for agriculture as well as for domestic uses. Simultaneously, the water level of the river also shows a sharp drop owing to the deepening of the river bed by sand mining. This has resulted in further environmental problems. Lateral seepage of water from the ground into the river and the flow of tidal water upstream have been more significant among them. The inflow of tidal water flow is of such an extent as to cause salt water intrusions into the tubewells. This inflow is at its maximum during the pronounced dry periods occurring in February to March and July to mid-September.

Once water supplies are classified, water quality standards may be set up for different purposes such as drinking, other domestic uses and cultivation. To evaluate the water quality of the LDOB, the present study examined 31 water samples from different locations. The result of these water samples are shown in Figure 5. The SLS (SLS Drinking Water Standards 614; 1983 Part 1) drinking water standards show that the pH value should range between the preferred values of 7.0 to 8.5. But the maximum pH values of WHO range from 6.5 – 9.2 and SLS values range from 6.5 – 9.0. According to SLS, Electrical Conductivity Value (ECV) for drinking water should be 750. But the maximum value is represented to be at 3,500. The laboratory test data show that ECV in Sample Nos. 12, 16, 21 and 22 are below the preferred values and Samples 1, 2, 4 and 5 exceed the maximum values.

Figure 5. Water quality of the surveyed area from different locations.



Salinity is the saltiness or dissolved salt content of a body of water. It measure as 35 g dissolved salt / kg sea water = 35 ppt = 35 o/oo = 3.5 % = 35,000 ppm (The Engineering Tool Box 2005). The salinity of different waters is as follows:

drinking water - 100 ppm

restriction on drinking water - 500 ppm

limit drinking water – 1,000 ppm

limit agriculture irrigation – 2,000 ppm brackish water - 500 - 30,000 ppm

sea water - 30,000 - 50,000 ppm

brine > 50.000 ppm,

The field investigations revealed that the salinity levels of samples varied from below 5,850 to exceeding 48,000. No. 1 is 15,500 ppm. It is possible to assume that values exceeded 2,000 ppm due to sea water (tidal water) flow reaching up to about 8 km inland from the Deduru Oya Estuary. However, the sodium content of the drinking water has not been specified. It was revealed that due to salinity and electrical conductivity the water is not suitable in many locations for drinking.

The following is a list of water sample locations: 1. Deduru Oya Bridge (Left Bank), 2. Siripura Saw Mill (to east), 3. Gajanayaka Stores (Back Side, 4. Sirirpura, 5. Old Bridge (Deduru Oya), 6. Temple (Well), 7. Rathmal Canal, 8. Daduru Oya, 9. Manuangama (East), 10. Manuangama (East), 11. Weherakale, 12. Weherakale Close to Deduru Oya, 13. Wilatthawa Mankada (Deduru Oya), 14. Isurugama Dematapitiya, 15. Diganwewa Mankada, 16. Weherakale, 17. Weherakale In front of China Pump House (Southern Band), 18. Weherakele, 19. P.V.A Ariyarathna (Praja Sala Road), 20. Waragodella Mankada, 21. Ariyagama North, 22. Ariyagama (Just to Mr Ariyarathna's Land), 23. Rambepitiya, 24. Rambepitiya, 25. Ariyagama (Jalashakthi Water Tank – not purified. 26. Ariyagama (Jalashakthi Water Tank) – purified, 27. Ariyagama (Jalashakthi Water Tank) – Purification Center. 28. Ariyagama South. 29. Manuwangama East, 30. Manuwangama East, 31. New Bridge, 32, Chilaw Fishery Harbor.

Even in some sample locations for example, electrical conductivity is below 2,000 and the salinity is also below 5,850, which indicates that such water supplies cannot be used even for bathing and washing purposes. Inability to use soaps and similar material and coloring of white cloths are the major problems in many locations (Katupotha 2006). If this water, supplied with sodium, iron and carbonate concentrations is used for leafy vegetables, they will be easily exposed to sun-burning. Nevertheless, many farmers in the LDOB continue their agricultural activities using low quality water, resulting from the depletion of surface water and lowering of the groundwater table. Further, laboratory analysis reveals that salinity exists even in water samples, obtained from tubewells 10-15 m deep. This is a result of tidal water flow up to Ariyagama, Rambepitiya (left bank) and Dematapitiya (right bank), about 8–10 km inland from the Deduru Oya mouth.

Findings of the Study

Many prevailing environmental issues in the LDOB can be identified. Some of these are related to physical processes and others are related to anthropogenic activities. Table 4 shows environmental issues in the LDOB (by DS Area), which are definite causes for acute water shortage in the LDOB.

Changes in Land Use

During the early 1950s to 1990s, adequate water was available in the Ebas, and other surface water bodies in the LDOB. Irrigated paddy cultivation was the major type of crop cultivated by

Table 4. Environmental issues in the LDOB (by DS Area).

GSDs and GNDs	Deforestation	Encroached forest reserves	Flash floods	Soil erosion (river bank)	Water deficit	Groundwater pollution	Lowering of groundwater level
Pallama							
Pallama	H	H	H	H	M	L	H
Wathupola	H	H	H	H	M	L	H
Puliyankulama	H	H	H	H	H	L	H
Tammana	H	H	H	H		L	H
Arachchikattuwa							
Elivitiya	H	H	H	H	H	M	H
Dematapitiya	H	H	H	H	H	H	H
Diganwewa	H	H	H	H	H	H	H
Mukkandaluwa	H	H	H	H	H		H
Bingiriya							
Molaeliya	H	H	H	H	H	H	H
Getulawa	H	H	H	H	H	H	H
Pahala Thalampola	H	H	H	H	H	H	H
Ihala Galwewa	H	H	H	H	H	H	H
Pahala Galwewa	H	H	H	H	H	H	H
Bingiriya	H	H	H	H	H	H	H
Chilaw							
Weerapandiyana	H	H	H	H	H	H	H
Manuwangama West	H	H	H	H	H	H	H
Manuwangama East	H	H	H	H	H	H	H
Nariyagama North	H	H	H	H	H	H	H
Nariyagama South	H	H	H	H	H	H	H
Parappanmulla	H	H	H	H	H	H	H
Thissogama	H	H	M	H	H	H	H
Deduru Oya	H	H	H	H	H	H	H

L = Low, M = Medium, and H = High

Source: Field observations 2006

farmers. Paddy is a lowland crop which needs relatively more water than other crops. Due to the unavailability of water, farmers gradually shifted to cultivate upland crops such as pumpkin, maize, and leafy vegetables etc. (Annex 1, E and F), which consume a lesser amount of water. In the meantime, farmers also started to cultivate perennial crops such as coconut, mangoes etc. At present irrigated paddy cultivation is only a minor agricultural activity. Due to insufficiency of water, only a few farmers cultivate paddy using rainwater and water from tubewells.

Abandoned Surface Irrigation

The survey revealed that almost all surface water bodies such as Ebas, Kaliyas, Gala Lin, tanks, anicuts and irrigation canals were abandoned. In many places, these appear as ruins of waterways and water bodies which are now filled with soil and other debris. In many cases, shrubs and small trees have covered these irrigation structures. The encroachment of reservations for settlement, for cultivation practices and for sand and clay mining continued in or around such structures. The banks of the canals and water bodies have been destroyed. These water bodies were neglected for a long time without proper maintenance and management, and no steps have been taken to rehabilitate them for a long time.

Extensive Use of Tubewells

Extracting water from tubewells for surface irrigation has been a common practice in the LDOB. The information gathered indicated a gradual shift of water sources by farmers from, surface water bodies in the early period to large diameter agro-wells and finally to shallow tubewells. The drying up of large diameter agro-wells compelled the farmers to shift to the practice of tubewells. At present farmers use tubewells with depths of 20 – 30 m (or more) to extract groundwater (Annex 1, G – J). Hundreds of tubewells exist in both banks of the study area and almost all the surveyed households have tubewells to extract water.

Lowering Groundwater in the Deduru Oya

The groundwater level in the area was around 8–12m historically. This was increased up to 30 m. The amount of water flow in the Deduru Oya also has reduced. Moreover, in some places, water is not flowing due to a lesser amount of water and due to the deepening of the river. About 20 years ago, the river bed was about 6–8 m from the surface level and today the depth of the river bed is 12–15 m below the river bank. This has resulted in groundwater flowing into Deduru Oya through lateral seepage (Annex 1, D).

Soil Erosion

Soil erosion in the Lower Deduru Oya Basin (LDOB) has a close relationship with slope units on a geomorphic surface. Hence, undulating terrains with gentle to moderate slope (3^{o}– 8^{o}) with 1 in 20 to 1 in 5 and 3 gradients experience sheet erosion or sheet wash. The sheet erosion removes surface debris at relatively slow speeds and over long periods occurring concurrently with rains. During heavy rainfall, sheet erosion becomes flash flood in which case soil erosion becomes extremely severe. As a result, well-drained, cultivated and built-up crests of the undulating terrain becomes barren land with the formation of rills and gullies, and the surface debris that is transported along the slopes gradually fill or silt up wide valley bottoms, flood plains, marshes, and downstream resulting in severe floods and water pollution in flat and undulating landscapes (Annex 1, A and B). The human activities such as illegal forest felling, inefficient agricultural practices and overexploitation of sand from the banks and the river bed of the river have accelerated the above physical processes.

Occurrence of Flash-floods

About 30 - 40 years ago, the frequency of floods that resulted in the submergence of the area was one to three annually. But no severe damages were caused due to the existence of a forest cover. Frequent flooding had reduced since 1998. However, flash floods have attacked the banks, dams and other man-made structures occasionally. For example, during late October and early November in 2006, flash floods caused damage to river banks, dams, cultivated lands and other man-made structures (Annex 1, A and B). The absence of surface vegetation due to deforestation, reduction of infiltration of water into the soil, absence of proper draining systems, filling and siltation of reservoirs, canals and open water holes have aggravated flash floods. As mentioned by Chandrajith et al. (2008), the water from flash floods cannot be used for drinking and domestic use because of pollution from organic matter, phyllosilicates, and heavy minerals in the sediments.

Deterioration of Water Quality

Many farmers reported that turbidity, pollution and salt water intrusion are the major issues in tubewells. Using for irrigation the water from tubewells that are situated closer to banks and the river mouth has become a problem due to the high salt concentration in the water. This observation was confirmed by a laboratory analysis of water samples.

Thus, the absence of adequate water for agricultural, domestic, industrial and other activities was evident. Changes in land use, abandoned irrigation structures, extensive use of tubewells, and lowering of groundwater levels were recorded. All these are considered responsible for weakening socioeconomic activities and social milieu. This situation has been instrumental to slow down the development as well as to arrest the improvement of living standards of the people in the LDOB.

New Reservoirs in Middle Deduru Oya Basin (MDOB) Area

More than 50 years ago, mega irrigation projects were proposed to cross the Deduru Oya at Thunmodara in Wariyapola and Demodara, where the Hakwatuna Oya and Kimbulwana Oya met to irrigate the Kurunegala District, Puttalam District and the Rajanganaya. Despite several efforts, this project never materialized due to the protests of affected parties.

The proposals for the Deduru Oya scheme include plans to construct a dam across the Deduru Oya. The capacity of the reservoir will be about 75 MCM while it incepts catchments of about 1,400 km^2. The left bank canal will provide water for several small tanks. The Right bank canal will be a trans-basin diversion to the Mi Oya catchment, to feed the Inginimitiya tank. In addition, a power plant of 8 GWh is to be installed and is expected to provide drinking water for the two cities of Wariyapola and Nikaweratiya.

As mentioned above, the Deduru Oya flows through Intermediate and Wet Zones. The expected outcome of comparing parameters such as stream frequency, drainage density and numbers of stream orders etc. of the Deduru Oya, when compared with the same of the Kelani, Kalu, Walawe, Mundeni Aru, Maduru Oya and Mahaweli Ganga, are a daydream. This is because, the Deduru Oya Basin and its surroundings receive heavy rains during the 1st inter-monsoon and 2nd inter-monsoon and northeast monsoon periods, thereby ensuring a surplus of water. The trend lines of the average annual rainfall of the Deduru Oya Basin indicate decreasing trends in rainfall, and that the rainfall is insufficient to maintain mega irrigation works as well as proposed hydropower projects, which will be expected to be completed by 2010. Nevertheless, even after the completion of the Deduru Oya Reservoir by 2010, the Ridibendi Ela, Magalla Wewa and LDOB will face more severe water shortages than at present.

Recommendations

The formulation of recommendations under this study was done after an extensive analysis and evaluation of findings and consultations with relevant stakeholders in considering the magnitudes of the issues related to water shortage and deterioration of living standards.

The banning of sand mining in the Deduru Oya until the sand deposits at the river bed improve again, is one recommendation given that at present, there is no balance between the natural deposition of sand and human excavation and transportation. Around 1997 or 1998, the deposition of sand was greater than the transportation, and continued to be greater until the river had an adequate compilation of sand in the banks and river bed. But, since then and up to the present, more than 80 % of the braided sand deposits of the LDOB have been exploited by sand miners and transporters. Therefore, the following recommendations are needed to overcome the difficulties faced by the LDOB.

Strict Law Enforcement

Strict law enforcement by relevant institutions on sand mining and transportation is required immediately as regards the LDOB. At present, enough legal documents exist to protect and conserve the land, soil, air, water as well as fauna and flora. It is necessary to pursue law enforcement from the bottom and upwards. Therefore, the *Grama Niladhari* should be considered as the key officer at the village level. According to the Diary of the *Grama Niladhari*, (Section 4.14) he should "take actions in (the) conservation of reservation lands and rivers, streams and river banks". Based on this power, if all *Grama Niladhari* Divisions of any DSD conserve the reservation lands and rivers, streams and river banks, invariably the natural resources will be protected. Therefore, it is necessary to organize the officers at this level to negate the interference of politicians, their followers and power groups and law enforcement officials of the relevant authorities.

Concerning the Deduru Oya sand robbery or sand terrorism, the agencies or officers such as GSMB, CEA, PEA (NWP), District Secretary, DS and GN are expected to implement rules and regulations through police officers. This has been a very difficult task because some police officers have close connections with sand miners and transporters. The DIG of the Northwestern (west) Division or SSP Chilaw Division is not willing to handle this responsibility (as evident during the Project period in 2007). Therefore, the Inspector General of the Police should take the power to control the environmental destruction of the LDOB.

All officials relevant to Deduru Oya sand mining and transportation, are familiar with the Supreme Court case (SC FR, Application No. 226/2006), proceedings of which are still continuing. Some letters of GNs and NGOs addressed to the DS, question as to how illegal sand miners and transporters could continue with their business against the wishes of institutions such as of GSMB, CEA, PEA (NWP) and the police when a Supreme Court case is ongoing. If some sand transporters are taken into custody by the police, the links established by the offenders enable them to escape easily. Sometimes, these alleged offenders would pay large amounts of money as bribes.

Protection of River Bank Reservations

The demarcation of river bank reservations by the Irrigation Department, DS and other provincial authorities, with the help of the Survey Department, should be pursued to protect the river banks. These reservations should be controlled by the GN, and it should be monitored by the DS and the Irrigation Department.

Rehabilitation and Restoration of Irrigation Structures

It is recommended that a barrage (dam) across the Deduru Oya (Manuwangama west is the most appropriate place) is built to divert water to irrigation canals. The location of this barrier should satisfy engineering suitability criteria on one hand, and people's wishes on the other. This will enable to recharge the groundwater table, facilitate the gravity flow of irrigation water, reduce the input cost for irrigation through tubewells, discontinue the tidal water flow upstream and allow the rebuilding of sand deposits. Because of heavy damages already caused in many places of the LDOB, it is necessary to prohibit sand mining initially for a period of at least 5 to 8 years, and selective mining for a longer period of about 15 to 25 years or more under the supervision of the GN and DS.

If suitable sand deposits for mining exist, the locations for mining and quantities that could be taken out should be decided by GN and Community Organizations such as Farmers Organizations, Environmental Conservation Organizations at village level. Such sand should essentially be used to satisfy local requirements. Issuance of issuing licenses for such mining activities, the DS, and if necessary with the consultation of the Irrigation Department, should oversee such mining.

Delegation of Permit Issuing Authority to the Divisional Secretariat

The GN and DS are the most appropriate officers who have a wide knowledge on sand deposit and the balance of nature. The present license issuing system is not effective and efficient; it has created negative impacts to the environment creating acute water shortage, soil and bank erosion of the river, and break down of social coherence and social milieu. Past experience relating to LDOB sand mining, indicates that the GSMB issues licenses without proper consultation with local level authorities - GN and DS - and from the Irrigation Department. As the needed procedure is not in place, mining has caused heavy losses to the river bed and banks of the study area. Therefore, the license issuing authority for sand mining from river beds and banks should be taken away from the GSMB, and transferred to the Irrigation Department owing to the fact that the GSMB is preoccupied with earning incomes through issuing licenses, forgetting its responsibility as a service rendering institution.

Encourage Social Organization and Improve Coordination among Stakeholders, Public Organizations and Public Agencies

Although, many social organizations have mushroomed in the villages of the present day, they are not actively engaged in taking positive actions to mitigate the ill-effects of excessive sand mining. These community agencies should establish effective links with relevant public agencies in order to attain the desired objective of discontinuing the ‘sand robbery’ or ‘sand terrorism’ in LDOB.

Rehabilitation of Village Tank Network

Within the LDOB and MDOB area, there are a large number of small and medium sized tanks, but the water of these is not sufficient for paddy fields and other crops as well as domestic purposes. Although, the Deduru Oya Reservoir will be completed by 2010, the water shortage will arise in the right bank canal, of the proposed hydro power and drinking water supply projects. The project is carried out at a cost of Rs. 6,500 million. It is worth that this massive village tank network is rehabilitated by using this money of the proposed mega work. By this, it is possible to reduce flash floods and soil erosion, and in addition to, increase the groundwater table, which are helpful to minimize the water shortage in the LDOB.

Conducting a Community-based Awareness Program

Since a significant number of people are engaged in sand mining transportation, a large number of affected people are trying to keep the control of sand mining to a sustainable level. Before sand mining assumed hazardous proportions and provided an income source for politicians, power groups and some officials, it was a way of livelihood for some rural people. They used carts, tractors and small vehicles (like tippers) to transport sand on a small scale. With the beginning of commercial mining, the livelihoods of the people had been threatened. Due to the loss of their incomes, they are facing many socioeconomic problems. Therefore, it is necessary to introduce effective awareness programmes at different levels, especially for the victims as well as the beneficiaries in the LDOB. School level programs will also be very fruitful to induce long term results. All these will help to minimize the water shortage in the LDOB.

Conclusions

Many farmers have reported that turbidity, pollution and salt water intrusion are the major issues in tubewells. In some instances, due to a high salt concentration in the water of tubewells closer to the Deduru Oya and river mouth, extracting water for irrigation have become a problem. In order to evaluate the quality of water of the LDOB, the present study team examined the electrical conductivity, salinity and pH values of the water of 33 water samples from different locations. The result of these samples revealed that the quality of water is not suitable for drinking. In some locations, for example, where the electrical conductivity is below 2000 and the salinity is also below 5.85, water cannot be used for bathing and even for washing purposes. The inability to use soap and similar material and discoloring of white cloths are the major problems in many locations. If this water is used for leafy vegetables, the vegetables will be easily exposed to sun-burning. Further, laboratory analysis reveal that salinity is found even in water samples obtained from tubewells 10-15 m deep, where the tidal water flows up to Ariyagama, Rambepitiya (left bank) and Dematapitiya (right bank), about 8–10 km inland from the Deduru Oya mouth.

It has been revealed that the village society in the past has had a well linked social coherence. Accordingly, construction, maintenance and rehabilitation of rural tanks, roads, community work and other infrastructure improvements have continued with the participation of all. This has been changed due to the introduction of market based economic activities, especially the plantation of commercial crops. This process was aggravated due to excessive sand mining during the last decade, and damaged self-sustaining economic activities. The social milieu was also destroyed, creating several social issues, for example, the increased use of alcohol, hashish and similar things.

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Annex 1

Damages caused by flood water at the Deduru Oya dam close to Puliyankulama.

Example of a damaged river bank.

Sand transportation routes at the river.

Bank erosion threatening coconut trees and surface water flow towards the river bed.

Watering for leafy vegetables.

Leafy vegetables in paddy field at Manuwangama.

Silt and muddy water create water pollution by flash floods, bank erosion and sand transportation routes at the river (Photos A, B, and C). Photo [D] shows the lateral seep of water from the ground into the river due to deepening the river bed. Likewise, unavailability of water, farmers gradually shifted to cultivate leafy and other vegetables in paddy fields in the LDOB.

The farmers drop the instruments to the bottom of a former used well to obtain deep water.

Aspect of the dropped tubewell instruments (same well).

Lowering of water level of surface wells due to excessive sand mining in the area.

Aspect of the dried well and dropped tubewell instrument to the bottom.

Water of this well cannot be used due to the low salinity and other impurities.

Community water supply scheme at Ariyagama, The tubewell at this place is 30 m deep from the surface level.

Farmers put tubewell instrument at the bottom of wells to obtain deep water for cultivation and other purposes [Photos: G, H, I and J]. The tubewells and normal wells [Photo L] waters with suspended and dissolved impurities in are not suitable for irrigating crops and using for domestic purposes.

Utilization of Aquatic Plants: A Method to Enhance the Productivity of Water in Seasonal Tanks in the Anuradhapura District

J. U. Munasinghe [1], M. A. A. B. Dilhan [2] and T. V. Sundarabarathy [1]
[1]Department of Biological Sciences, Faculty of Applied Sciences, Rajarata University of Sri Lanka, Mihintale.[2] The Open University of Sri Lanka

Abstract

Heavy infestations of aquatic plants in a water body cause considerable economic and ecological losses. Many seasonal tanks in the Anuradhapura District suffer from this problem and cannot be neglected in water resource development and management schemes. This study was focused on the uses of aquatic plants and the problems caused by huge manifestations of aquatic plants in the selected seasonal tanks in the Anuradhapura District.

The study was conducted in four seasonal tanks viz., Galkulama, Thirappane Maradankadawala and Thibbatuwewa in the Anuradhapura District. Information on the utilization of aquatic plants, exploitation level and harmful effects were gathered by using a structured questionnaire to interview people who were residing close to the study sites. The attitudes of the public towards the aquatic plants i.e., conservation of aquatic plants, the potential uses of native plants and harmful effects of invasive aquatic plants were collected.

Twelve species were identified as economically important aquatic plants through the questionnaire survey. Among the 50 respondents, 92 % utilized aquatic plants for food, 58 % utilized flowers for offerings and decorations, 52 % utilized aquatic plants for medicinal purposes, 42 % utilized them as ornamental plants, 30 % used them as bio-fertilizers and 28 % utilized them for weaving.

The edible aquatic plants consumed by the rural community in the Anuradhapura District are Ipomoea aquatica (72 %), Alternanthera sessilis (66 %), Nelumbo nucifera (64 %), Nymphaea pubescens (60 %) and Aponogeton spp. (52 %). Some edible aquatic plants, namely Neptunia oleracea, Ottelia alismoides and Ceratopteris thalictriodes, which are present in the Anuradhapura District, are not consumed, although these are consumed in many other countries. N. nucifera is the most commonly used flower for offerings in the temples and for decorations. In addition, N. pubescens, Nymphaea nouchali are also used for flowers. Bacopa monnieri, N. nucifera, Acanthus illicifolia, N. nouchali and Aponogeton spp. have been recorded as medicinally important plants. Though there are many ornamentally important

aquatic plants, only N. pubescens, N. nouchali, B. monnieri, Nymphoides hydrophylla are used. Salvinia molesta and Eichhornia crassipes are the two aquatic plants commonly used as bio fertilizers.

With reference to the questionnaire survey, there were seven major problems that were discovered to exist due to heavy infestations of aquatic weeds in the water bodies viz., sedimentation and unsuitability for domestic use, interference with navigation, effects on fisheries, blocking irrigation canals and evapotranspiration. The most problematic plants in the Anuradhapura District include E. crassipes, N. nucifera, S. molesta, Pistia stratiotes and Ceratophyllum demersum.

Economically important aquatic plants available in the shallow water bodies of the Anuradhapura District, are marginally utilized, when compared with the utilization of aquatic plants in the global scenario. There appears to be a lack of a well organized action plan to cope with this situation. The public suffer a lot from the problems created by the heavy mass of aquatic plants, which covered the village tanks. The public are, however, willing to get organized and to engage in a participatory approach to restore their water bodies. There is a need for research and development of management strategies for the sustainable utilization of these valuable resources. Awareness programs should be conducted to promote sustainable utilization of aquatic plants. Creating awareness among the people about the nutritional and economic benefits of these natural resources will be useful for Sri Lanka, as a developing nation.

Introduction

The inland aquatic resources of Sri Lanka create a diversity of natural habitats for various aquatic flora and fauna (Jayasinghe 2000). Consequently, a rich aquatic flora is present in the areas of irrigation i.e., reservoirs, natural depressions, swamps, rivers and streams. The aquatic flora of Sri Lanka consists of 11 endemics, 90 peninsular species, and 7 non-peninsular species (Abeywickrama 1955).

An appropriate population of aquatic macrophytes contributes to the general fitness and diversity of a healthy aquatic ecosystem (Flint and Madsen 1995). They would be a direct food source for aquatic animals as well as a source of detritus for saprotrophic organisms (Sastroutomo 1985). In addition, they provide habitats for insects, fish and other aquatic or semi-aquatic organisms (Madsen et al. 1996). Submersed and emergent macrophytes also aid in the anchoring of soft bottom sediments and removing suspended particles and nutrients from the water column (Madsen et al. 1996). Many aquatic plants have played fascinating roles in the life of man since primitive times (Gupta 1987), deriving economic benefits such as sources of food, fiber, paper pulp and green manure (Boyd 1968, 1970 and 1972; Gujral et al. 1986).

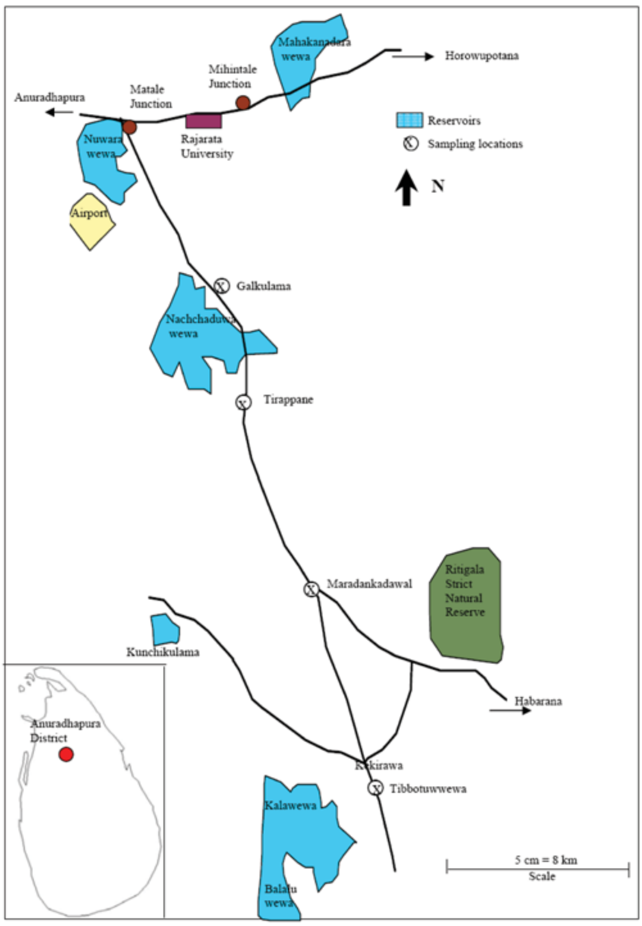
Although there are many benefits in aquatic plants, the excessive growth of water plants is a source for many common water quality problems throughout the world (Chapman et al. 1974; Shireman et al. 1982). Related in particular to the use and management of water resources, these problems include, loss of water storage due to transpiration, effects on fisheries, provision of habitats for vectors of diseases, interference with navigation, slow decomposition leading to decrease in water clarity and increased siltation (Sastroutomo 1985). In some aquatic ecosystems, alien species have grown to such an unprecedented level that they have even resulted in the drying up of water bodies (e. g., Eichhornia spp., Salvinia spp. and Pistia spp).

The vast potential of water plants is only marginally utilized and no scientific approach has been developed for deriving greater economic and ecological benefits (Mohan Ram 1991). The present study focuses on documenting the potential for the utilization of, and problems created by, aquatic plants.

Methodology

The study was conducted in four selected seasonal tanks viz., Galkulama, Thirappane Maradankadawala and Thibbatuwewa in the Anuradhapura District in the dry zone of Sri Lanka. The location of study tanks are shown in Figure 1. Information on the patterns of utilization of aquatic plants, levels of exploitation and opinions on the harmful effects of aquatic plants were gathered using a structured survey schedule. Fifty people residing close to the study sites were interviewed.

Figure 1. Map showing the locations of selected tanks in the Anuradhapura District.



Results and Discussion

Reduction of Productivity of Water in Seasonal Tanks by Aquatic Plants

According to the information gathered from the survey, there are seven major problems that arise due to heavy infestations of aquatic weeds in seasonal tanks. They are: a) increased sedimentation; b) unsuitability of water for domestic use; c) interference with navigation; d) effects on fisheries; e) blocking irrigation canals; f) evapotranspiration leading to increased water loss; and g) damages to the environment. Heavy infestations of aquatic weeds have had impacts on agriculture, fisheries, transportation, health, living conditions as well as the social fabric and the economy of some communities in the Anuradhapura District.

According to views held by the public, sedimentation (caused by heavy infestation of aquatic plants) is the most serious problem prevailing in the Anuradhapura District. The tanks with heavy aquatic plant infestation get silted easily as the dead materials of the plant biomass get deposited on the tank bottom. Sediments lead to a decrease in the depth of tanks, which in turn reduces the water retention capacity of the tanks. This situation has direct influence on the livelihoods of the surrounding communities, who depend on the tank water for their day-to-day water requirements. The shortage of water in the dry period has caused problems for paddy and other cultivations.

Utilization Pattern of Aquatic Plants

Respondents mentioned six current uses for aquatic plants. These uses are: 1) food; 2) flowers for religious offerings and decorations; 3) medicinal use; 4) ornamental plants; 5) bio-fertilizer; and 6) weaving of baskets. Ninety-two percent of respondents used aquatic plants for food, while 58 % used the flowers of water plants. The percentage of respondents reported as using aquatic plants for medicinal purposes and ornamental plants were respectively, 52 % and 42 %.

Comparatively lesser percentage of respondents (30 % and 28 %) reported the use of aquatic plants for bio-fertilizer and for basket weaving, respectively. The present survey revealed that the consumption of aquatic plants was low compared to the available resources in the study area.

As a Source of Food

Table 1 presents the common names, scientific names and percentages of respondents reported using at least one species of aquatic plant for identified uses. According to Table 1, Ipomoea aquatica is the plant used by the highest percentage of respondents.

Leaves and young shoots of both Ipomoea aquatica and Alternanthera sessilis are consumed. Some people consume these plants by harvesting them from the water body, while others buy them from the market. The selling of these plants has become a source of income for some people in the rural community. The price for a stack of plants varies from Rs. 10.00 to Rs. 20.00.

Nelumbo nucifera (lotus) roots are a fiber-rich food for villagers and people elsewhere. The lack of water in water bodies during the dry season facilitates the extraction of lotus roots. As a result, they are mainly consumed in the dry season. Extracting lotus roots and supplying

Table 1. Aquatic plants and their uses.

Common Name	Scientific Name	% reported as using for				
		(1)	(2)	(3)	(4)	(5)
Lotus (Nelum)	Nelumbo nucifera	64	36	54	0	0
Water lily (Olu)	Nymphaea pubescens	60	0	36	42	0
Blue lotus (Nil Manel)	Nymphaea nouchali	0	18	32	28	0
Water hyssop (Lunu-wila)	Bacopa monnieri	0	44	0	18	0
Swamp morning-glory (Kankun)	Ipomoea aquatica	72	0	0	0	0
Joyweed (Mugunuwenna)	Alternanthera sessilis	66	0	0	0	0
Kekatiya	Aponogeton spp	52	38	0	0	0
Ikiliya	Acanthus ilicifolius	0	34	0	0	0
Salvinia	Salvinia molesta	0	0	0	0	12
Water hyacinth (Japan-jabara)	Eichhornia crassipes	0	0	0	0	22
Crested Floating heart (Kumudu)	Nymphoides hydrophylla	0	0	0	12	0
Cattail (Hambu-pan)	Typha angustifolia[a]	0	0	0	0	0
Water mimosa (Diya-nidikumba)	Neptunia oleracea[b]	0	0	0	0	0
Duck-lettuce	Ottelia alismoides[b]	0	0	0	0	0

Notes: Use categories are, (1) Food, (2) Medicine, (3) Flowers, (4) Ornamental Plants, and (5) Bio-fertilizer

[a] These plants are used as material for basket/bag/mat weaving

[b] These plants are, as reported by other researchers, commonly used for the purposes listed. Although such uses were observed by the researchers, respondents to the survey did not indicate any significant uses for these plants

them to the market provides a substantial employment opportunity for villagers. The price per one kg of lotus roots varied from Rs. 60.00 to Rs. 80.00.

Consumption of other parts of Nelumbo nucifera, in either raw or cooked form, is reported in other regions of the world. For example, young leaves, petioles, fruiting torus and flowers are eaten in some regions in India (Pandey 2003; Kio and Ola-Adams (1987). Flowering stalks are eaten as vegetables by the community in the study area. This plant is not exploited to a marketable level. In addition, seeds of Nymphaea pubescens are also eaten as rice, and is said to be beneficial for diabetic patients. In the Aponogeton, flowers, flower stalks and tubers are consumed by the people in the Anuradhapura District. Although Aponogeton is commonly found in many water bodies in the study area (Munasinnghe et al. 2008), its consumption is not popular.

Some edible aquatic plants, namely Neptunia oleracea, Ottelia alismoides and Ceratopteris thalictriodes, which are present in the Anuradhapura District (Munasinnghe et al. 2008), are not consumed by these rural communities, although these are popular and consumed in many other countries (Gupta 2001; Mazid 1983).

Source of Flowers

Nelumbo nucifera is the most commonly used flower for offerings in the temples and for decorations. Flowers of Nymphaea pubescens are also commonly used in temple offerings.

However, the occurrence of Nymphaea nouchali is less when compared to the other two species, and as a consequence are less harvested for offerings. The demand for flowers increases during religious seasons like *Poson* and during wedding seasons because of the increased need for flower offerings and flower arrangements, respectively, during such times. The price of a single flower ranges from Rs. 2.00 to Rs. 5.00 at the place of harvesting and Rs. 5.00 to Rs. 10.00 at flower stalls.

For Medicinal Value

A variety of aquatic plants are used in curative therapy in traditional communities. For instance, Bacopa monnieri is used for stomach disorders and coughs suffered by small children, and is also used for some skin diseases, and to purify the blood stream. Aponogeton has a therapeutic value for diabetes and ailments due to gas. The findings of this study on uses of aquatic plants for curative therapy are consistent with those of Jayaweera (1982).

For the Ornamental Aquatic Plant Industry

Aquatic plants have drawn attention worldwide for their importance in the ornamental plant industry. Although many ornamentally important aquatic plants are abundant in the Anuradhapura District, only four species are used by the fringe community (Table 1).

As Bio Fertilizers

Salvinia molesta and Eichhornia crassipes were reported as used for bio fertilizers by respondents to the survey (Table 1). These are mainly used in their raw form in coconut cultivations, and are sometimes used to make compost. Generally, the average N, P and K contents of aquatic weeds are accepted as 1.5 - 4.0 %, 0.2 - 2.0 %, and 0.15 - 4.9 %, respectively (Mazid 1983). In some regions outside the study area there was evidence of using Azolla as a bio fertilizer. Azolla is an important aquatic plant because of its nitrogen fixing capacity. It can be grown in fish culture ponds to serve as feed and also in rice paddies to add nutrients to the soil.

Use for Weaving

The use of many Cyperus spp. to weave mats, hats, bags, spoon holders and other utensils for their own usage has been a common practice since ancient times. The people collect the requisite weaving materials directly from the marshes and limnetic water bodies. Respondents to the survey pointed out that, there is a drastic decline in Cyperus spp. due to their overexploitation in the weaving industry. However, respondents reported the use of Typha species as the material for weaving. The price of mats weaved using Typha spp. range from Rs. 200.00 to Rs. 500.00 depending on the size of the mat.

Potential to Derive Benefits from Aquatic Plants While Mitigating the Problems Caused by Heavy Infestations

In view of the huge biomass production potential of aquatic weeds, there could be many suggestions for their commercial utility (Gupta 1987). When compared with the utilization of aquatic plants on a global scenario, the usage of aquatic macrophytes in the Anuradhapura District is not at a satisfactory level. Since there are lots of crop cultivations taking place in the Anuradhapura District, the concept of using these aquatic weeds as bio-fertilizers would be an ideal solution to the pollution caused to the water bodies by the use of chemical fertilizers. Making farmers aware of these eco-friendly farming practices will result in a better balance between the economy and the environment. Boyd (1968) says that "utilization of water weeds as food could probably alleviate protein shortages in local populations of many developing nations, but it is doubtful that these plants could contribute greatly to the total food supply of any nation." Moreover, he stated that exploratory research should be initiated to assess the food value of the native aquatic flora. Such utilization of edible aquatic plants and making people aware of the nutritional benefits and economic benefits of these natural resources will be useful to Sri Lanka, as a developing nation.

The ornamental aquatic plant industry, which is a blooming industry worldwide, is neglected in the Anuradhapura District. This should be given more attention as a potential income source. Many ornamentally important aquatic plants are present in a large scale in the natural environment in the study area. The sustainable exploitation of such plants will be a good source of income for the surrounding community and a method of controlling the overpopulation of aquatic macrophytes. In addition, the culture of economically important plants will also provide a good employment opportunity for the villagers residing close to shallow water bodies in the study area in particular, and in other areas, in general. Though this is a novel concept for Sri Lankans, such aqua -culturing of economically significant fresh water aquatic plants is common in many Southeast Asian countries as well as countries like USA, China and Germany. In several developed countries, culturing of aquatic plants is mainly targeted on ornamentally important plants, while the target in Southeast Asian countries is more for food plants.

The use of aquatic plants to derive biogas is another good option to control problematic aquatic weeds. The potential of Eichhornia crassipes should be exploited. According to Casfbow (1967), each kilogram of water hyacinth produces 370 liters biogas containing 70 % of methane. However, this is not practiced in the study area. Appropriate programs should be initiated to harness this potential and to contribute arresting the excessive growth of weeds. Other aspects of use of Eichhornia crassipes include food for animals, raw materials for industry and a source of gases, proteins and other chemicals. In addition, some species can be used for making paper pulp, fish food and other live stock food.

Heavy infestations of Nelumbo can be controlled by a greater consumption of Nelumbo roots. Popularizing the use of Nelumbo leaves as food wrappers will reduce the leaf surface area in the water bodies, which in turn would block light penetration for the submersed plants. Pistia is another commonly problematic plant and mechanical harvesting is done by the surrounding community to control the overgrowth of the plant. Regular production of bio-fertilizer from this weed will mitigate the severe problems caused by this plant.

The public suffer a lot from the problems created by heavy aquatic plant covers present in their village tanks and they are interested in knowing how to overcome these problems. They are willing to get organized and engage in a participatory approach to restore their water bodies. In some villages, people organize themselves and practice mechanical harvesting using ropes, baskets etc. After harvesting, some use Salvinia molesta, Eichhornia crassipes as biofertilizers, while others pile up the harvested plants close to the tank, which lead to the spread of those plants again. Some people burn and remove aquatic weeds. These people are not aware of the benefits they can derive from Eichhornia. These weedy plants can be turned into useful industrial crops and people can earn from these weeds, while cleaning their water bodies. However, most people do not have the requisite knowledge to resolve their problems in this way. Local communities in this area are unaware of such industries. The provision of government incentives and helping with the necessary facilities for the relevant industries, such as energy production and paper industry, will promote the surrounding community to engage in the exploitation of heavily infested aquatic plants in the water bodies. Meanwhile, people must be aware of the importance of not exceeding the limits of sustainable utilization of these fresh water aquatic resources.

At present, using village tanks for day to day water requirements have been reduced as a result of supplying pipe-borne water. This undisturbed situation has also favored the growth of aquatic macrophytes in seasonal tanks. Promoting people to use the aquatic resources in the village tanks will be beneficial to the village community as well as for the sustenance of the tank itself.

Conclusions and Recommendations

Heavily infested aquatic plants create problems in water usage in many seasonal tanks in the Anuradhapura District. The magnitude of sedimentation is getting worse and people are willing to take measures to control this situation in order to conserve water bodies and to increase the water-holding capacity of these tanks. However, they are not aware that they can control this situation through the sustainable utilization of aquatic weeds.

Although there are lots of economically important aquatic plants available, those are marginally utilized. There is a high potential to develop industries related to aquatic plants in this area. The provision of government incentives to develop and to practice novel methods in the utilization of aquatic weeds will be greatly helpful in controlling aquatic weeds in a nonpolluting way, and restoring water bodies to their intended uses.

Many employment opportunities can be provided by industries related to the use of aquatic plants in these remote areas, which can in turn resolve the prevailing unemployment problems in the rural villages. Research should be directed to find new methods of harvesting and processing aquatic weeds for better exploitation of these resources. It is recommended that the public be made aware of the potential industries that can be used to improve the livelihood of those using aquatic macrophytes, while conserving their village tanks.

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Instability of Paddy Production and Regional Food Insecurity in Sri Lanka

A. P. S. Fernando[1], A. M. S. Perera[2] and K. Karunagoda[3]
[1] Lecturer, Department of Agricultural System, Faculty of Agriculture, Rajarata University, Sri Lanka
[2] Program Assistant, Socio Economics and Planning Centre, Department of Agriculture, Sri Lanka
[3] Senior Agricultural Economist, Socio Economics and Planning Centre, Department of Agriculture, Sri Lanka.

Abstract

Addressing food insecurity has become an important policy issue due to a host of factors such as climate change, export restraints, alternative uses of food, e.g., as bio-fuels and income-induced demand changes. The world has to find avenues to provide sufficient food to cater for the new developments in the food sector taking into consideration the risks of the changes these may effect on the environment. Paddy, the staple food crop of Sri Lankans, plays a significant role in stabilizing food security in the country. The production levels of paddy have been accompanied with wide regional variations due to irregularities in the rainfall patterns and cyclical effects of the production fluctuations. More thrust has been placed on irrigated paddy production in the areas of the dry zone, while traditional areas of the wet zone have been subjected to immense population pressure amidst various institutional arrangements. At present, more than half of the paddy output comes from the major irrigation schemes. The wide fluctuations in paddy production levels in these areas indicate the potential for regional vulnerability for food insecurity. This paper examines the growth of paddy production and evaluates the instability of paddy production in terms of the areas cultivated, productions and yields for the dry zone (DZ), intermediate zone (IZ) and wet zone (WZ) and districts in these climatic zones. The growth rates for different zones were estimated using a log linear function. The instability of area, production and yield was measured using a coefficient of the variation (CV). The CV of production, area and the yield for three major climatic zones and seasons are estimated. In addition, the indices for the risk of cultivation and amount of green vegetation on the island were used as indicators of instability. Paddy production has increased at the rate of around 2 % and 1 % per annum in the DZ and IZ, respectively; and has decreased in the WZ at the rate of 9 % per annum. The CVs for paddy production in the DZ, IZ and WZ in the *maha* and *yala* seasons are 18.15, 18.36, and 9.2 and 30.33, 25.38 and 19.22, respectively. The results indicate that instability of paddy production in the WZ is much lower than those

of the other two zones. The lowest levels of instability with respect to production (Matara), yield (Kegalle) and harvested extent (Ratnapura) were observed in the wet zone districts. The highest level of instability with respect to area, yield, production and harvested extent was observed in the Anuradhapura District. In the *maha* season, the IZ shows the lowest variation in the sown extent and highest variation in the harvested extent, and it indicates the higher risk of production at the later stage of the crop. The IZ shows the general risk in paddy production in the *yala* season, indicated by the highest instability in both sown and harvested extents. Similar observations for the IZ were observed in the sown to harvest and CV of vegetation index. The negative growth rate observed in the WZ was brought about by the reduction of the cultivated area. The higher stability in production could be utilized to augment regional food security as well as the supply of seed paddy for other regions. Thus the results highlight the importance of maintaining WZ as a buffer zone of production and investments in irrigation in the IZ to secure the availability of paddy.

Introduction

Food security exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. It is often directly or indirectly dependent on agricultural and forest ecosystem services. Addressing food insecurity has become an important policy issue due to a number of factors such as climate change, export restraints, alternative uses of food such as bio-fuels, income-induced demand changes among many others. Impacts on the production of food will affect food supply at both global and local levels. Thus the world has to find avenues to provide sufficient amounts of food to cater to new developments in the food sector and at the same time be aware of the consequences that these changes in production may have on the environment. Today, countries in the world envisage increasing food production either by increasing the cultivatable extent or by increasing productivity through technology and the efficient use of resources. Paddy, the staple food crop of Sri Lankan, plays a significant role in food security in the country. There has been a steady increase in paddy production through time, leading to near self-sufficiency in feeding the population of 20 million. The paddy production in the *yala* season in 2008 showed a 51 % growth yielding 1.75 million metric tonnes, thus recording the second highest growth rate in any season after obtaining National Independence in 1948 (Central Bank Report 2009). This rise has been attributed to the following: a) increased area under cultivation; b) mass investment in irrigation development; c) improved seed varieties; d) increased fertilizer application; and e) favorable prices for rice.

However, the growth of the paddy sector with stability has been a matter of concern in the strategy of ensuring food security. The production levels of paddy have been accompanied with wide regional variations due to irregularities in the rainfall pattern and cyclical effects of production fluctuations. In Sri Lanka paddy is cultivated in all the agro-ecological zones under three different water regimes namely, major irrigation, minor irrigation and rain-fed. The island has been divided into three principal agro–climatic zones, which have been demarcated based on hydrology, meteorology, soils and vegetation. The wet zone (WZ) receives an annual rainfall of more than 2,500 mm. The intermediate zone (IZ) receives between 1,750 and 2,500 mm of rainfall and the dry zone (DZ) receives less than 1,750 mm of rainfall annually. Thus, there is a considerable variation in production, yield and the area cultivated from region to region, mainly because of low rainfall, water scarcity and drought-prone districts. At present, more than half of the paddy output comes from major irrigation schemes. In 2008, the contributions to the island- wide paddy production from DZ, IZ and WZ were 64 %, 23 % and 13 %, respectively (Department of Census and Statistics 2009).

More trust has been placed on irrigated paddy production in the areas of the dry zone, while traditional areas of the wet zone have been subjected to immense population pressure amidst various institutional arrangements. The 'asweddumized' extent of paddy in WZ has decreased by around 21 %, while the 'asweddumized' extent of paddy in DZ and IZ has increased by around 11 % and 23 %, respectively, during the period of 1979 to 2006 (Department of Census and Statistics 2009). In the past two decades, more investment has gone into irrigation development, various subsidy schemes and to research and development, especially to increase the level of production in DZ and IZ. Hence, the variability in crop production increased by region to region, after the development of irrigation and implementation of many other promotional programs. However, this higher potential of production in DZ and IZ compared to WZ is alleged to be accompanied by considerable year to year fluctuation, thereby giving rise to increasing instability in the production of paddy. The wide fluctuations in paddy production levels in these areas indicate the potentials of regional vulnerability for food insecurity, but even though the potential of paddy production in WZ is stagnated due to urbanization and many other various institutional arrangements, fluctuations in production are not significant. It is, therefore, important to understand the causes of fluctuations in production, yield and extent cultivated within different agro-ecological zones. This study analyzes fluctuation in paddy production, yield and area to understand the nature of food security at the regional level.

In the light of the problem discussed above, this paper attempts to analyze interregional variation in the extent cultivated, yield and production of paddy using time series data for the period of 1979 to 2008. The study is specifically focused on the following objectives: a) present the overview of the extent cultivated, yield and production of paddy to identify the fluctuations around the trend line; b) estimate the instability in the extent cultivated, yield and production of paddy in different agro-climatic zones and districts; and c) estimate the growth rate of the extent cultivated, yield and production of paddy by season and its association with rainfall.

The paper is divided into five sections. The next section (Data and Method) presents the method and data used. In section three (Results and Discussion) the district and regional level analysis of the trend of paddy extent cultivated, yield, and production is presented. Next, the estimates of instability in yield, area and production, with respect to DZ, IZ and WZ and district level under the three different water regimes of major irrigation, minor irrigation and rain-fed are presented. Section four (Production Growth Rate) discusses the growth rate of production and area with respect to time, season and rainfall. The final section (Conclusion) presents conclusions and policy implications.

Data and Method

An analysis of fluctuations in major food crops is important for understanding the nature of food security and income stability at the regional level. Trend analysis using time series data of extent and yield and production of paddy in the major irrigation regime for the period of

1979 to 2008 is conducted in this study. Graphical methods are used to differentiate trends among agro-climatic zones and administrative districts.

The coefficient of variation (CV) can be used as a measure of instability of crop production. In general, the coefficient of variation measures the amount of variation of the response variable. This statistic is useful for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. Studies in instability related to the food crop sector in Sri Lanka are very rare. However, some studies carried out in India have used CV as a measure of the instability in food grains. A study of growth and instability of agricultural production in Maharashtra (Mitra 1990) used CV as a measure of the instability in crop production in different regions. Mahendradev (1987) reviewed the trends in instability using a moving period approach with Standard Deviation (SD) as the measure of instability. Dhawan (1987) assessed and compared the instability of irrigated farming with the corresponding instability in rain-fed farming of the 11 states of India by using the CV.

Equation (1) represents the ratio of the standard deviation of a variable to its mean, and it

(1) $$CV = \frac{\sigma_{\hat{Y}}}{\hat{Y}}$$

Where, CV is the coefficient of variation, its mean and is the standard deviation of the variable concerned.

In addition, an index for risk of cultivation was derived as an indicator of instability in the area cultivated i.e., ratio of sown area to harvested area (Equation 2).

(2) $$\text{Production risk of cultivation} = \frac{\textit{harvested extent (ha)}}{\textit{sown extent (ha)}}$$

This index can be utilized to assess and compare the production risk in different regions and thereby the instability in the area cultivated. Value of this index varies from zero to unity. An index value closer to unity indicates higher stability.

The growth rate of production and area was carried out for the overall period of 29 years (1979 – 2008) with respect to the three different agro-ecological zones. The rates of growth for this period are estimated by using a log linear function of the time series data on paddy production and area of the DZ, IZ, and WZ as well as the island as a whole. The two estimated equations are as follows:

(3) $$In\ Q_t = \beta_0 \pm \beta_1 T + \varepsilon$$

(4) $$In\ Q_t = \beta_0 \pm \beta_1 T \pm \beta_2 S \pm \beta_3 W + \varepsilon$$

Where; Qt = Production (mt or /Area cultivated (ha), T = Time in years, S = Season dummy, W = Weather factor (rainfall) expressed in, and ε is the stochastic error term.

The coefficient b1 in equation (3) gives the unadjusted trend growth rate, while β_1 in equation (4) gives the growth rate adjusted for weather and seasonal effects. The coefficient β_2 represents the seasonal effect while b_3 provides the elasticity of production or area cultivated with respect to rainfall.

Zonal and district-wise time series data for 29 years i.e., 1979 to 2008, pertaining to area, yield and production under major irrigation, minor irrigation and rain-fed conditions were used in the study. Data used in the study were compiled publications from the Department of Census and Statistics, the Socio Economics and Planning Centre of Department of Agriculture, Natural Resource Management Centre of Department of Agriculture and Central Bank of Sri Lanka. Time series data on rainfall were collected from available weather stations in a way to represent selected districts for the analysis. Administrative districts in the country were categorized into three agro-climatic zones namely, the Dry Zone (DZ), the Wet Zone (WZ) and the Intermediate Zone (IZ). Districts included in the DZ category are, Puttalam, Anuradhapura, Ampara, Hambantota, Udawalawe and Mahaweli 'H'. Kurunegala, Matale, Badulla and Monaragala represent the IZ while Colombo, Kalutara, Gampaha, Galle, Matara, Rathnapura, Kegalle, Kandy and Nuwara Eliya represent the WZ. All districts in the Northern and Eastern provinces except Ampara were excluded due to unavailability of data for a part of the study period.

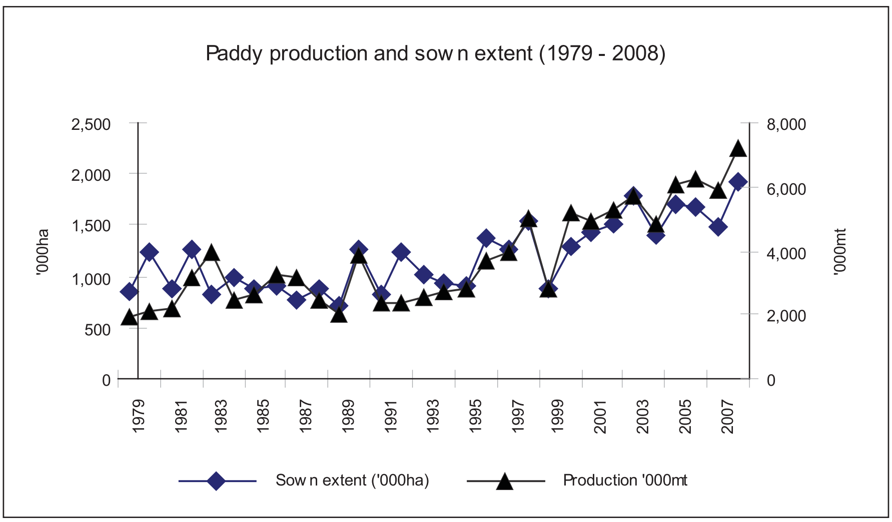
Results and Discussion

Long-term Trend in Production, Extent and Yield

Trends in paddy production and sown extent are shown in Figures 1 to 3. These trends indicate that the performance of the paddy sector has improved. This increment was mainly brought about by the increase in the area of cultivation and partly by yield improvement.

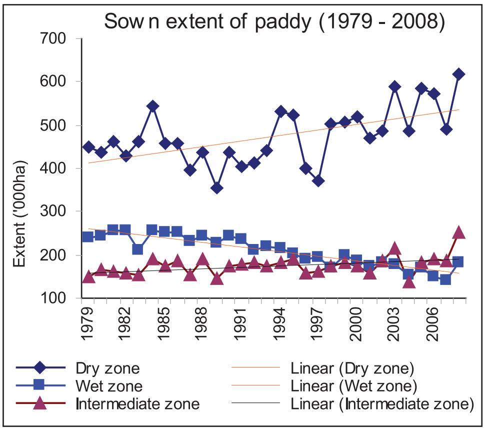
Both sown extent and paddy production have increased in DZ (Figure 2). This increase could be due to rapid irrigation developments whereas, a decreasing trend was observed in WZ. The general neglect of paddy land, changes in cropping system and utilizing paddy lands for other uses would be the main attributable factors in this regard. Production and extent is

Figure 1. Island paddy production ('000 mt) and sown extent ('000 ha).



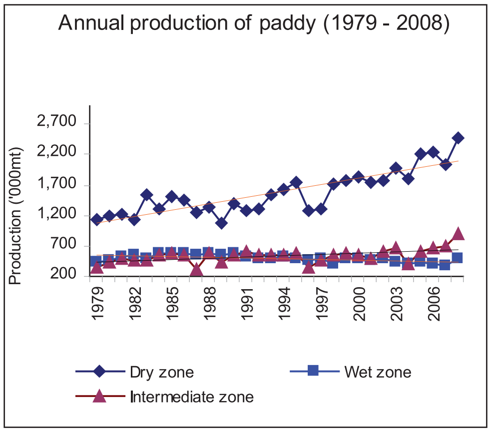
Source: Paddy Statistics, Department of Census and Statistics 2009

Figure 2. Sown extent of paddy ('000 ha) in three major agro-climatic zones.



Source: Paddy Statistics, Department of Census and Statistics 2009

Figure 3. Production of paddy ('000 mt) in three major agro-climatic zones.

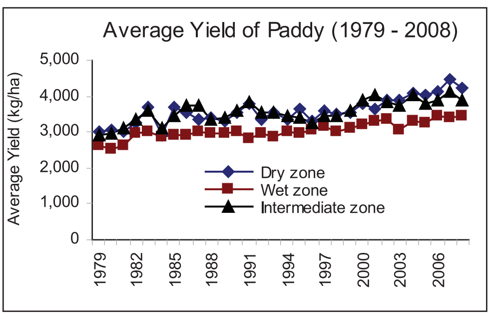


Source: Paddy Statistics, Department of Census and Statistics 2009

being stagnated in IZ because paddy is mainly cultivated under rain-fed and traditional seasonal tanks, and there were no significant irrigation infrastructure development programs that were implemented.

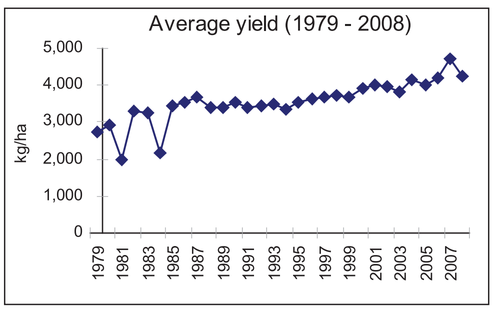
Average yield of paddy also shows an increasing trend but at a lower rate in all three zones as well as in the island as a whole (Figures 4 and 5). This highlights the improvement of technology and this increment also contributed to the increase in production.

Figure 4. Average yield of paddy (kg/ha) in three major agro-climatic zones.



Source: Paddy Statistics, Department of Census and Statistics 2009

Figure 5. Island average yield of paddy (kg/ha).



Source: Paddy Statistics, Department of Census and Statistics 2009

Instability in Paddy Production

Two methods, coefficient of variation (CV) and index of production risk of cultivation were used in measuring instability. The results of CV analysis show that the range of differences in the magnitude of instability of production within agro-climatic zones varied from 18.15 % in the DZ to 9.2 % in the WZ for *maha* season. Relatively higher instability in production can be shown in *yala* for all three zones (Table 1). On average in *yala*, instability in production is 63 % higher than *in maha*. This would be a result of water scarcity and low abandoned rainfall during *yala*.

Compared to the DZ and IZ, the instability of production and yield are lower in the WZ both in the *maha* and *yala* seasons (50 % lower in production instability and 25 % lower in yield instability) — (Tables 1 and 2). The IZ shows the highest instability in average yield under all three major irrigation schemes and the CV of yield in DZ comparable with WZ showing stable productivity of paddy in the *maha* season (Table 2).

Table 1. Zone–wise coefficient of variation of net harvested extent and production for *maha* and *yala* seasons.

Agro-climatic zone	Net harvested extent		Production	
	Maha	*Yala*	*Maha*	*Yala*
Dry	12.65	23.78	18.15	30.33
Intermediate	16.30	32.01	18.36	25.38
Wet	12.75	24.83	9.20	19.22

Note: This is based on the author's estimation of CV

Table 2. Zone–wise coefficient of variation of net harvested extent and production in different agro-climatic zones by season and by water regime.

Agro-climatic Zone	Water Regime							
	Major Irrigation		Minor Irrigation		Rain-fed		All Regimes	
	Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
Dry	9.41	39	12.03	56.08	12.94	42.22	10.14	23.45
Intermediate	51.03	39.49	48.19	24.47	47.50	62.73	49.19	30.86
Wet	9.05	8.85	8.35	19.19	8.53	31.18	7.52	24.66

As regards the extent cultivated, DZ indicated the highest value of CV for the area sown compared to the other two zones. However, under the major irrigation and rain-fed condition, IZ shows the highest variation in the *yala* season and comparably the lowest value of CV for the area sown could be observed in WZ (Table 3).

Inter-zonal differences in CV of harvested extent also show a similar pattern (Table 4). In the *yala* season under the major irrigation and rain-fed conditions, the highest instability was recorded in IZ and the stability of harvested area could be observed in WZ. With respect to the sown extent, the lowest instability was recorded from the IZ, conversely it receives the highest instability in harvested extent in the *maha* season. In the *yala* season, the highest instability was recorded in both sown and harvested extents for the IZ. It reveals that during the *maha* season, IZ also receives a fairly large amount of rainfall, giving farmers an incentive

Table 3. Agro-climatic zone-wise CV of sown extent in the *maha* and *yala* seasons.

Agro-climatic Zone	Water Regime							
	Major Irrigation		Minor Irrigation		Rain-fed		All Regimes	
	Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
Dry	11.27	24.39	30.44	56.08	35.46	42.22	11.25	23.45
Intermediate	11.35	39.49	12.16	24.47	7.13	62.73	8.90	30.86
Wet	4.00	8.85	10.18	19.19	15.60	31.18	12.43	24.66

Table 4. Agro-climatic zone-wise CV of sown extent in the *maha* and *yala* seasons.

Agro-climatic Zone	Major Irrigation		Minor Irrigation		Rain-fed		Total	
	Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
Dry	12.07	24.57	34.54	58.81	37.44	48.90	12.87	23.89
Intermediate	12.04	38.44	18.95	28.67	21.52	70.73	15.80	38.07
Wet	3.94	9.39	10.59	19.85	15.68	31.29	12.60	24.84

Note: This is based on the author's estimation of CV

to put their land under cultivation, but in the *yala* season, the highest instability due to water scarcity was brought about by the uncertainty of rainfall.

According to the district-wise analysis presented in Table 5, the highest CV has recorded from Colombo District both in the *yala* and *maha* seasons, indicating the highest instability in the area cultivated as well as production. On the other hand, districts representing WZ show the minimum value of CV of the area cultivated and production, where the Matale District shows the minimum value of CV in sown extent for the *maha* season and Kalutara shows the minimum value for sown and gross harvested extent and production, indicating the stability in paddy cultivation in the *yala* season. The Kurunegala District is the most vulnerable to food insecurity in terms of paddy cultivation in *yala*. Next to Colombo, the Anuradhapura District shows a higher magnitude of instability in both seasons for paddy cultivation.

Table 5. District-wise CV in *maha* and *yala* seasons.

District	SE		GHE		AY		NHE		PRO	
	M	Y	M	Y	M	Y	M	Y	M	Y
Puttalam	19.9	58.5	23.7	63.4	18.4	20.7	23.7	63.4	28.8	73.9
Anuradhapura	35.0	70.9	38.7	71.7	12.5	15.2	38.7	71.7	42.0	81.0
Polonnaruwa	18.6	29.2	18.8	29.2	11.8	13.5	18.8	29.2	25.0	38.8
Ampara	11.7	22.7	14.9	23.6	13.3	11.3	14.9	25.5	25.0	31.1
Hambantota	13.8	25.0	14.6	25.8	10.0	10.5	14.6	24.9	18.0	30.0
Udawalawe	21.8	21.4	21.8	21.4	9.1	12.3	21.6	20.3	25.0	25.7

Mahaweli 'H'	10.1	62.8	12.5	64.1	9.7	22.3	14.3	64.9	19.3	81.0
Kurunegala	11.7	75.9	23.8	96.6	7.9	99.3	23.8	69.4	25.6	41.8
Matale	8.6	30.7	11.9	32.2	10.2	13.0	11.9	32.2	16.4	39.0
Badulla	10.8	22.9	12.2	23.1	12.1	17.8	12.2	23.1	21.0	33.8
Monaragala	27.9	55.1	32.5	57.8	11.0	15.3	32.5	57.8	41.6	71.9
Colombo	46.0	59.0	45.6	59.2	10.1	16.5	45.6	59.2	44.8	64.0
Kalutara	13.5	21.5	13.5	20.6	12.7	14.5	13.5	20.6	13.6	15.4
Gampaha	22.1	64.9	21.8	65.2	9.6	12.6	21.8	65.2	20.5	66.4
Galle	13.2	38.6	13.3	38.5	18.7	21.4	13.3	38.5	12.9	34.4
Matara	11.6	27.8	11.6	27.9	16.1	22.7	11.6	27.9	11.4	32.3
Ratnapura	9.5	26.6	9.5	26.6	10.7	20.7	9.5	25.3	12.3	27.1
Kegalle	10.5	31.7	14.0	31.7	7.2	19.0	14.0	27.9	14.3	27.8
Kandy	16.0	30.4	16.3	30.4	9.9	18.8	16.3	27.4	16.1	26.8
Nuwara Eliya	12.0	46.1	11.4	46.1	9.7	19.1	11.4	46.9	16.9	44.9

Source: This is based on the author's estimation of CV

Note: SE – sown extent, GHE – gross harvested extent, AY- average yield, NHE – net harvested extent, PRO – production, M (*maha*) and Y (*yala*)

To further analyze the instability in paddy cultivation, this paper developed an index—the production risk of the cultivation index—to analyze the variation in area cultivated within the zones and districts. The deviation of this index (between 0 and 1) clearly shows that WZ receives the minimum risk of paddy cultivation (index is more close to one) under all three irrigation regimes, whereas the index of the other two zones is frequently furthest from 1, thus indicating comparatively a higher risk of production (Figures 6, 7 and 8).

According to this analysis the Anuradhapura and Puttalam districts indicated the highest risk of cultivation under the major irrigation regime; the Mahawelli area showed the lowest risk of cultivation because water is secured throughout the year from diverted Mahaweli waters

Figure 6. Fluctuations in the production risk of cultivation under major irrigation regime in *maha* and *yala* seasons.

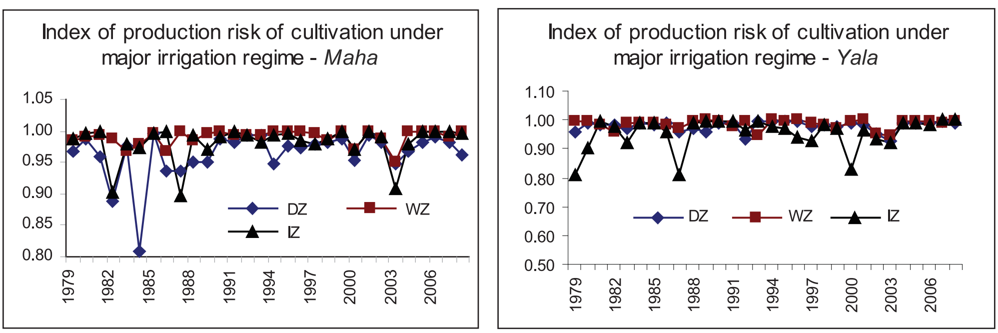


Figure 7. Fluctuations in the production risk of cultivation under minor irrigation regime in *maha* and *yala* seasons.

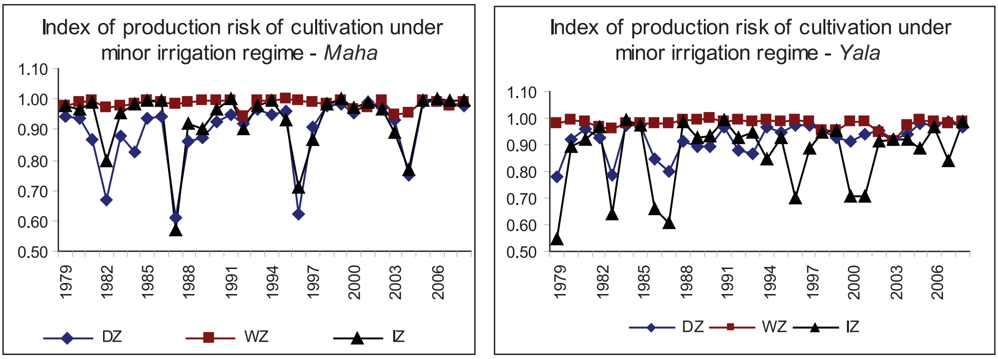
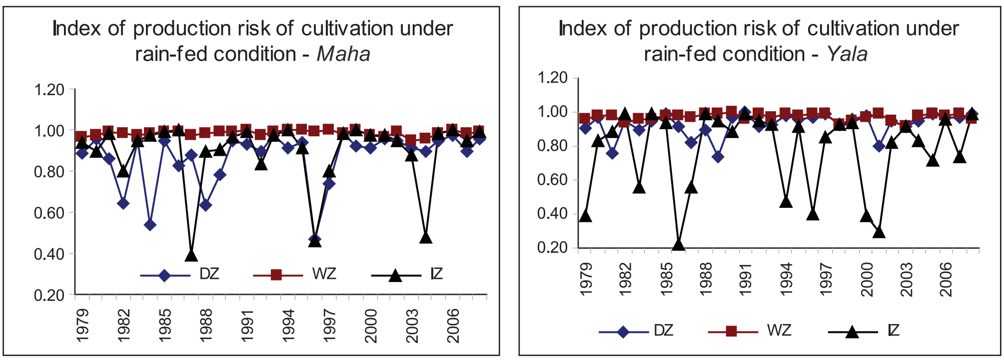


Figure 8. Fluctuations in the production risk of cultivation under rain-fed condition in *maha* and *yala* seasons.



Note: This analysis is based on the authors' estimation of the index (Production risk of cultivation)

(Table 6). Under rain-fed conditions, the Galle, Ratnapura, and Colombo districts also show a minimum risk of cultivation, because these districts are secured from the amount as well as the distribution of rainfall (Table 6).

Table 6. District-wise production risk of cultivation index under three major irrigation regimes in the *maha* and *yala* seasons.

	Major Irrigation		Minor Irrigation		Rain-fed		Total	
District	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
Puttalam	0.95	0.94	0.90	0.88	0.85	0.83	0.91	0.89
Anuradhdpura	0.97	0.97	0.89	0.89	0.79	0.79	0.93	0.93
Polonnaruwa	0.99	0.99	0.94	0.94	0.92	0.92	0.99	0.99
Ampara	0.96	0.96	0.94	0.94	0.91	0.91	0.96	0.96
Hambantota	0.99	0.99	0.97	0.97	0.96	0.96	0.98	0.98

Udawalawe	1.00	1.00	na	na	na	na	1.00	1.00
Mahaweli 'h'	0.99	0.99	na	na	na	na	0.99	0.99
Kurunegala	0.98	0.98	0.90	0.90	0.88	0.88	0.91	0.91
Matale	0.98	0.98	0.96	0.96	0.94	0.94	0.96	0.96
Badulla	0.99	0.99	0.99	0.99	0.92	0.92	0.98	0.98
Moneragala	0.98	0.98	0.94	0.94	0.88	0.88	0.93	0.93
Colombo	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Gampaha	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Kalutara	0.97	0.97	0.99	0.99	0.98	0.98	0.98	0.98
Galle	na	na	0.99	0.99	0.99	0.99	0.99	0.99
Matara	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98
Ratnapura	0.99	0.99	0.99	0.99	0.98	0.98	0.99	0.99
Kegalle	na	na	0.98	0.98	0.97	0.97	0.97	0.97
Kandy	1.00	1.00	0.98	0.98	0.98	0.98	0.99	0.99
Nuwara Eliya	0.99	0.99	0.98	0.98	0.96	0.96	0.98	0.98

Note: This analysis is based on the authers estimation of the index of production risk of cultivation, figures highlighted are indicated the minimum value of the index na- data not available.

Production Growth Rate

Paddy production has increased at a rate of around 2 % and 1 % per annum in the DZ and IZ, respectively, during the period of 1979 – 2008. The higher growth rate can be observed in the *maha* crop compared to the *yala* crop. Paddy production in the WZ has decreased at a rate of 0.8 % per annum. However, the decreasing rate is lower in *yala* (Table 7).

Comparisons of unadjusted growth rates for weather and seasons reveal that the weather and seasonal fluctuations do not affect the rate of growth in paddy production. A negative elasticity of production with respect to rainfall can be observed in the DZ (- 1.3). IZ and WZ show a positive elasticity of production with respect to rainfall i.e., 0.27 and 0.17, respectively

Table 7. Unadjusted growth rate of production by agro-climatic zone.

Zone	Annual		*Maha*		*Yala*	
	R2 %	Growth Rate Percent	R2 %	Growth Rate Percent	R2 %	Growth Rate Percent
DZ	69.5	2 (0.002)	51.1	1.5 (0.002)	73.1	0.031 (0.003)
IZ	20.1	1 (0.004)	14.9	0.8 (0.004)	18.3	0.016 (0.006)
WZ	40.6	-0.8 (0.002)	25.9	-0.5 (0.001)	35.4	-0.013 (0.003)

Note: Figures in parentheses are standard errors
The determinants are significant at 1 % level

(determinants are not significant). Table 8 shows that the inclusion of rainfall index and seasonal dummy improved the value of R2 for all three zones. It indicates that variation in rainfall and season partly explains the variation in paddy production within the zones. IZ reports the highest value with respect to the seasonal elasticities. Furthermore, it indicates that the growth rate in the *maha* season is higher in DZ and IZ whereas it is lower in WZ.

Table 8. Zonal-wise growth rate of paddy production (adjusted).

Zone	R2		GR %		ER	ES
	unadjusted	adjusted	unadjusted	adjusted		
Dry	69.5	83.9	2* (0.002)	2 (0.002)	-0.13** (0.09)	0.59* (0.04)
Intermediate	20.1	76.7	1* (0.004)	1 (0.003)	0.09** (0.16)	0.8* (0.066)
Wet	40.6	78.9	-0.8* (0.002)	-0.9 (0.002)	0.18** (0.10)	0.44* (0.03)

Note: figures in parentheses indicated the standard error
* Coefficients are significant at 1 % level
** Coefficients are not significant
GR – growth rate, ER – elasticity of production with respect to rainfall, ES – elasticity of production with respect to season

Area Growth Rate

The highest adjusted and non-adjusted area of growth rate has been recorded in the DZ (Table 9). It has increased at a rate of 0.8 and 1 % per annum, respectively. Mass irrigation infrastructure programs have been implemented during the period concerned, weather adjusted R2 has increased from 28.2 to 84 in DZ and from 18 to 83 in IZ, explaining the importance of the weather factor, even where developed irrigation infrastructure is available.

Table 9. Zonal-wise growth rate of paddy area cultivated.

Zone	Unadjusted	Adjusted			ER	ES
	GR %	R2	GR %	R2		
Dry	0.8* (0.002)	28.2	1* (0.002)	84	-0.11*** (0.1)	0.71* (0.04)
Intermediate	0.5** (0.002)	18	0.4** (0.002)	83	-0.005*** (0.1)	0.66* (0.039)
Wet	-1.8** (0.001)	82	-1.9* (0.001)	80.4	0.03*** (0.09)	0.33* (0.03)

Note: figures in parentheses indicated the standard error
* Coefficients are significant at 1 % level
** Coefficients are significant at 10 % level
*** Coefficients are not significant
GR – growth rate, ER – elasticity of area cultivated with respect to rainfall, ES – elasticity of area cultivated with respect to seasonal effect

On the other hand, the WZ area growth rate decreases at a rate of 1.8 % per annum. A similar set of observations were made in the case of trend analysis. The higher stability in production could be utilized to augment regional food security as well as the supply of seed paddy for other regions. Thus the results highlight the importance of maintaining WZ as a buffer zone of production and investments in irrigation in the IZ to secure the availability of paddy.

Conclusion

The production levels of paddy have been accompanied with wide regional variations due to irregularities in the rainfall patterns and cyclical effects of the production fluctuations.

More thrust has been placed on irrigated paddy production in the areas of the dry zone, while traditional areas of the wet zone have been subjected to immense population pressure amidst various institutional arrangements. However, according to the derived results, the highest production stability was recorded in the WZ. This could be utilized to augment regional food security as well as the supply of seed paddy for other regions. Thus the results highlight the importance of maintaining WZ as a buffer zone of production, and investments in irrigation in the IZ to secure the availability of paddy. In the *maha* season, the IZ shows the lowest variation in the sown extent and highest variation in the harvested extent. It indicates the higher risk of production at the later stage of the crop. The IZ shows the general risk in paddy production in the *yala* season, indicated by the highest instability in both sown and harvested extents. This reiterates the importance of directing investments into irrigation developments for the IZ.

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Agriculture, Environment and Food Security in the Context of Rice

P. B. Dharmasena
Consultant (Soil and Water Management)

Abstract

Agriculture requires inputs, which can be found within the system or need to be supplied from outside. The latter, referred to as the 'Green Revolution' in the 1950s and developed as the high external input agriculture, has spread over the world as a solution to the food crisis that arose due to World War II. The drive embraced a special package including high- yielding crop varieties, inorganic fertilizer, agro-chemicals and farm machineries. As a result, farmers in many developing countries began to practice mono-cropping with high external inputs. This has turned traditional ecological agriculture into environmentally destructive food production systems, which provided huge amounts of produce causing serious environmental damage. During the 'Green Revolution' traditional crop varieties were replaced by high-yielding new improved varieties, which had higher yield potential. However, natural pest resistance of these high-yielding varieties was generally poor, while nutritive requirements were high. Increased use of pesticides and chemical fertilizer is a matter of concern. Some of the issues and problems due to indiscriminate use of pesticides are: a) pest resistance; b) pest resurgence; c) health hazards; d) environmental pollution; and e) lower profits to farmers. Extensive use of chemical fertilizer has created environment issues such as nitrate leaching, release of greenhouse gases and eutrophication of inland water bodies.

Millennium development goals earmark the eradication of extreme poverty and hunger, while ensuring environmental sustainability. This dispels the concept of achieving food security in any country through the adoption of high external input agriculture.

Sri Lanka remains vulnerable to natural disasters such as floods, droughts, cyclones, landslides, epidemics etc., causing substantial threats to the food security situation of the country. Challenges posed by external factors due to globalization and open-economic policies have directed the country's agriculture to move away from self- reliance. This situation demands a firm and perfect policy for the country's agriculture. Furthermore, present agriculture does not show any indication of sustainability as it has ignored the centuries-old wisdom of traditional agriculture. Farmers' dependency mentality evolved due to modern agriculture and government policies, which dealt with agriculture from time to time. This should be gradually replaced by developing farmers' self-confidence, self-motivation and empowerment.

There is a great potential to increase productivity in Sri Lanka as only 40 % of the average potential for grain yield was achieved in different ecological and hydrological regimes. By narrowing this gap between actual and potential yield, Sri Lanka will not only increase productivity but also increase the competitive advantage for rice with other countries in the region. The experiences of the present productivity improvement program of the Department of Agriculture (DOA) have clearly shown that the average yield could be increased.

In achieving food security in the country, a major set back in the development process is that institutional linkage among agencies responsible for water, land, agriculture and environment is very weak, and they work in isolation, setting their own targets. The need is felt for the immediate formulation of a firm policy to implement a sustainable agricultural production program in the country in order to ensure the food security in Sri Lanka.

Introduction

Any kind of agriculture practiced in the world requires various inputs such as water, seeds, nutrients etc. These can be found within its environment or need to be brought from outside. Depending on the manner in which the inputs are supplied, the dependence and sustainability of agriculture can vary widely. World agriculture has moved from internal low input agriculture to external high input agriculture as greater food production is demanded by a rapidly increasing world human population.

Sri Lanka had been self-sufficient before it came under the British rule. The population up to independence was relatively small and, hence, food requirements remained at a low level. Agriculture was practiced with low external inputs. Mixed cropping, except in paddy fields, was more popular under rain-fed conditions. Under such a diverse system of cultivation, there is a low possibility for the multiplication of pests and for disease to spread. Nevertheless, traditionally grown crop varieties were well adapted to the environment, hence pest attacks did not occur at significant levels.

Traditional Farming

Farming methods in the past also incorporated traditional crop protection methods such as '*kem krama*', rituals etc., and relied on cosmic influence to protect the crop from pests and diseases. The fertility of the land was ensured through fallowing and by incorporating organic matter such as straws, lopping from hedges and fences, dung and other animal waste to the soil. Once the paddy crop was harvested, cattle were allowed to feed on the stubble. This helped not only in destroying weeds but also enriching the soil by adding a considerable amount of cow dung and urine to the field.

Biodiversity

Despite its small size, Sri Lanka has a varied climate, topography and soil, which have resulted in rich biodiversity, and was distributed within a wide range of ecosystems. In terms of species, genes and ecosystems, Sri Lanka has a very high biodiversity, and it is one of the 18 hot spots in the world declared by Conservation International. Also it is one of the 250 sites of prime importance identified for the conservation of the world's floristic diversity. Sri Lanka has the highest biodiversity per unit area of land among Asian countries in terms of flowering plants and all vertebrate groups except birds. The vegetation of Sri Lanka supports over 3,350 species of flowering plants and 314 species of ferns and fern allies. It is also noted for its high proportion of endemic species among its fauna. There is also considerable invertebrate faunal diversity. The provisional list of 'threatened' faunal species of Sri Lanka includes over 550 species, of which over 50 % are endemic.

In addition to the crop diversity seen in coarse grains, legumes, vegetables, roots and tubers and spice crops, there are over 170 species of ornamental plants. Among domesticated animals of economic value are some indigenous species of buffalo, cattle, fowl and fish.

Forest Cover

The forest cover in Sri Lanka shows a steady decline from 44 % in 1956 to 23.9 % in 1992 and dropping further to 22.4 % in 1999. The total forest cover in 1999 was 2.02 million hectares. The reduction of forest cover is strongly related to the increase in population of Sri Lanka. Colonization in major irrigation schemes, clearing of lands for rain-fed cultivation and the removal of natural vegetation for plantation crops such as coffee, tea and rubber collectively diminished the forest cover in Sri Lanka. Furthermore, inappropriate land use trends, unsuitable forestry practices and the high market price of timber are some other causes for deforestation. The destruction of the forest-related ecosystem threatens the survival of many species of fauna and flora.

Irrigated Agriculture

Once the '*Rajakariya'* system' was abolished in 1832, nobody was found responsible for maintaining irrigation systems. Subsequently the British rulers realized the necessity of introducing regulations for the management of the irrigation system and passed the first Irrigation Ordinance in 1856.

During the latter part of British rule, the importance of and need for irrigated agriculture to feed the increasing population was realized. The British repaired abandoned tanks and constructed new irrigation schemes. Since independence in 1948, the government embarked on a massive irrigation project and brought large new areas under paddy cultivation. The Accelerated Mahaweli Development Project that was implemented in the 1980s is the best example. However, opening up a new area for agriculture and other development projects has resulted in reducing the forest area in the island.

Green Revolution

Annual cereal production in the world has more than doubled within 25 years since 1961. Annual rice production in Asia too has shown the same pattern. This growth is often attributed to the increase in irrigated area complemented by Green Revolution technology that is considered as a package including high-yielding varieties and inorganic fertilizer. The concurrent application of agro-chemicals and increased use of farm machinery were also contributed to the transformation of traditional agriculture to a high external input regime.

In Sri Lanka, the sources of growth in rice production are identified: a) as a greater area planted with rice (32 %); b) as an increased irrigated area (25 %); c) as an increased application of fertilizers (22 %); and d) from the inherent high-yielding quality of modern rice varieties (21 %).

Traditional farming systems were characterized by a mixture of rice tracts intermingling with other natural habitats of varying types. Major irrigation systems also lead to the expansion of contiguous areas of large paddy tracts leading to a reduction of natural biodiversity. Additionally, intensive paddy monoculture systems, popularized by the green revolution, created an environment that is conducive to pest growth. The increased cropping intensity also contributed with the same magnitude to biodiversity loss as species adapted to the fallow phase of paddy fields were forced out both spatially and temporally.

It has been realized by many that bringing the agricultural technology developed in western countries to many of the peripheral countries has been a factor in jeopardizing their century-old and ingenious agricultural systems and the wisdom that is associated with them, which had been instrumental in maintaining sustainability and environmental harmony. The introduction of new agricultural technology has resulted in many disastrous situations such as bio-degradation, soil fertility depletion, pest and disease invasion, food poisoning, collapse of food sovereignty etc. At present, attempts are being made to study this burying knowledge by a few international organizations and to restore under the prevailing environmental, economic and sociological conditions.

Use of Pesticides

Pesticides guarantee against crop failure, and were considered as a necessary input in modern rice production. The use of chemical insecticides as primary agents of pest control is a widely adopted cultivation practice. The use of pesticides has contributed to improved productivity in rice.

The introduction of a limited number of rice varieties on a very large scale to replace a diverse array of plant races grown previously has been the major factor responsible for the rapid multiplication of rice pests and diseases. The widespread promotion and indiscriminate use of insecticides has aggravated the situation further.

Although rice insect outbreaks have been recorded over the last 1,300 years, they are more frequent and damaging today than before. Also, insect pest complexes have undergone rapid changes during the last three decades. Although insecticides are known to have rapid curative action in preventing economic damage, the indiscriminate use of insecticides has led to the destruction of natural enemies, causing the resurgence of several primary and secondary pest species and the development of insecticide-resistant pest populations. Other detrimental effects of pesticide misuse include human health impairment due to direct or indirect exposure to hazardous chemicals, contamination of ground and surface waters through runoff and seepage, and the transmission of pesticide residues through the food chains.

Pesticides used in rice cultivation can have a devastating effect on living organisms other than those targeted for shorter or longer periods of time. The impact of biocides used in rice cultivation on vertebrates inhabiting rice fields and surrounding aquatic habitats has been investigated by researchers in the Philippines and South America. In Sri Lanka, the use of pesticides continue to be the most popular method of pest control despite the known harmful effects of such usage on human health, the ecosystem, and the environment. The misuse of pesticides is very common in Sri Lanka. Farmers often ignore technical recommendations, and use their own experience leading to the indiscriminate use of pesticides. Although alternatives such as varietals resistance and Integrated Pest Management (IPM) are well known, the relative importance of exclusive chemical pest control methods has increased.

High-yielding Varieties

Traditional seeds that were used in the past have been replaced over the years. The ‘Green Revolution’ made most of our farmers to move away from traditional rice varieties to modern improved varieties. However, high-yielding varieties could not continue to give better yields without the additional supply of nutrients. Because bumper harvests removed most of the nutrients as yield and caused faster depletion of soil fertility, the application of chemical fertilizers became a convenient way to meet crop nutrient requirement. Long-term application of chemical fertilizers led to the fast disappearance of organic matter content of the soil, thereby affecting the physical fertility of the soil.

‘Germ-plasm’ of traditional rice varieties has been preserved locally but most of them are also available in international ‘germ-plasm’ depositories. It is unlikely that Sri Lanka’s prior consent will be obtained or that it will share any benefit if its traditional ‘germ-plasm’ in these depositories is used in the development of new commercial seeds.

Millennium Development Goals

Sri Lanka remains vulnerable to natural disasters such as floods, droughts, cyclones, landslides, epidemics etc. This situation causes a substantial threat to the food security of the country. Challenges posed by external factors due to globalization and open economic policies have directed the country’s agriculture to move away from self- reliance. This situation demands a firm and perfect policy for the country’s agriculture. Furthermore, present agriculture does not show any indication of sustainability as it has ignored the centuries-old wisdom of traditional agriculture. The farmers’ dependency mentality evolved due to modern agriculture and government policies, which dealt with agriculture from time to time. This should be gradually replaced by developing self- confidence, self-motivation and empowerment.

Though considered not very profitable, the production of rice is not necessarily highly capital-intensive. Increased productivity would provide rice with a comparative advantage over other crops and it would be able to compete with imports. Paddy irrigation contributes to generate other benefits including, flood prevention, groundwater recharge, prevention of soil erosion and land slides, water and air purification, enhanced eco-systems, cultural heritage, aesthetic value and cooling effect.

Therefore, it appears that there is a better potential for continuing with irrigated agriculture in Sri Lanka, compared to other countries. The U.N Millennium Development Goals (MDGs) also subscribed to by Sri Lanka in 2000, have relevance to water sector strategies and goals. Target 10 of goal seven (on environmental sustainability) deals with water supply. The global target is to have by 2025 the problem of people without sustainable access to safe-drinking water halved with around 75 % of the country population having access to safe-drinking water.

Population growth, requirements of the economic policy and food security considerations need an increase of food production without damaging ecosystems. The production increases have to be attained in a situation where resources for irrigated agriculture such as land and water are limited.

Cropping intensity and yield need to be increased while lowering the damage to ecosystems and preserving biodiversity. In order for government efforts to be effective, complementary investment by farmers in irrigated agriculture is necessary. This can be achieved by increasing their income from agriculture, if the efforts are concentrated in areas with high cropping intensity.

Challenges Ahead

The current population of 20 million in Sri Lanka is expected to increase to around 23 million and stabilize by the year 2025. Based on the past experience of increase in per capita rice consumption, demand for rice in the future will continue to grow. The demand for rice- based food products are on the rise and demand for rice is intensifying. According to the Department of Census and Statistics (2009), of the 10.5 million ha of rice cultivated in 2007/2008 cultivation year, 55 % was grown during the *maha* season. Major, minor and rain-fed areas, respectively, accounted for 53 %, 25 % and 22 % of the annual rice area.

Issues

The annual cropping intensities of major irrigation schemes vary. Low cropping intensities generate lower annual incomes for farmers.   When annual returns are low, returns from investments are also low. Water scarcity is one of the major reasons for low cropping intensities in major irrigation systems. The productivity of minor irrigation is less than that of major irrigation. However, minor tanks generate other social benefits from uses such as bathing, washing, and livestock watering and cleaning, fishing and also serve as an easily accessible source of water in the rural villages. Unfavorable weather conditions, inadequate availability and use of resources and technology, low productivity, high cost of production, lack of infrastructure and inconsistent government policies are some of the factors that hinder the sustainability of food production. The full potential of irrigation systems with respect to both minor and major systems has not been reached. It has been shown that rice farming would be profitable when the grain yield is at or above 6 tonnes/ha. This target could be easily achieved from the dry zone. The profit margin can be further increased or unprofitable areas can be made profitable, if special rice is produced for specialized markets.

Management of Water Resource

By the year 2025, the country's population is estimated to reach 23 million. If current consumption/production patterns are to remain constant, annual consumption requirement of rice would increase up to 4.5 million kg. According to production patterns in 2007 and 2008 cropping intensity of major irrigation is 1.96 and 79 % of the annual rice production, respectively. Assuming production from other regimes remain constant, production from major irrigation should be increased to 3.3 million tonnes. If current yield remains unchanged it would be required to increase the area under irrigated rice to 0.69 million ha. As the current cropping intensity is close to 2.00 (200 %) the only way of achieving this target is via expansion of the irrigated area, which is a difficult task as almost all potential areas are already developed for irrigation. Table 1 indicates the requirement of expanding irrigated area and development of storage capacities, both of which are difficult targets to achieve and very expensive. A scenario could be suggested that if the irrigation effectiveness could be increased from the present level of 32 % to 41 %, the need for spending money for irrigation structures and for additional land development would not arise. This clearly shows the importance of efficient water management in a country's agricultural practices. Therefore, our future vision should be to make the most efficient use of our reservoirs, canals and other water management structures to obtain maximum effectiveness, and promote farmers for efficient management of the water resource in agriculture.

Table 1. Scenario analysis on production requirement of rice in 2025.

	2007/08	2025	
		Projected	Proposed
Population (million)	17.2	23.0	23.0
Total rice demand (mil. mt)	3.87	4.5	4.5
From other regimes			
Rice production (mil. mt)	1.20	1.20	1.20
From major irrigation			
Share of production	0.69	0.73	0.73
Rice production (mil. mt)	2.67	3.30	3.30
Irrigated rice area (mil. ha)	0.55	0.69	0.55
Yield (kg/ha)	4,775	4,775	6,000
Cropping intensity[1]	1.96	2.42	1.96
Irrigation water requirement (m ha.m) [2]	0.86	1.02	0.86
Crop ET[3]	4,775	4,775	6,000
Irrigation effectiveness	32 %	32 %	41 %

Notes: Production and yield figures are from the Department of Census and Statistics (2009)
[1] Assuming all major irrigation areas that are suitable for rice are cultivated in the *maha* season
[2] Based on current irrigation water use presented in Dharmasena (2004)
[3] Based on 1,000 liters per kg of rice yield

Some of the strategies to increase irrigation effectiveness to attain the above-mentioned level during a period of 5 years are given below.

- Increase productivity of unit of water through improved cropping and irrigation techniques in existing as well as new schemes. Water productivity to be increased at least by 20 % in major schemes and by 10 % in minor schemes during the period of 5 years.
- Improve the management of existing major schemes, by successfully implementing participatory management systems in these schemes.
- Improve the existing systems of operation and maintenance (O&M), through participatory approaches and establish viable funding mechanisms.

- Improve the watersheds of small, medium and large systems through participatory approaches.
- Implement watershed management programs, soil water conservation programs and biodiversity conservation programs.

Management of Soil Fertility

There is a great potential to increase productivity in Sri Lanka since only 40 % of the average grain yield of its potential was achieved in different ecological and hydrological regimes. By narrowing this yield gap, Sri Lanka will not only increase productivity but also increase the competitive advantage for rice with the other countries in the region. The experiences of the present productivity improvement program of the Department of Agriculture (DOA) have clearly shown that the average yield could be increased.

The Granary Area Program (GAP) of 2003 was initiated by the Government of Sri Lanka with the objective of achieving a sustainable irrigated agricultural system that would contribute to greater food security, and generate enhanced incomes and improve living standards with the commercialization of small farm agriculture (concentrating on high potential rice areas). The program included: a) provision of agriculture extension and support services; b) improvement of water management through effective water management practices; c) credit facilitation and input supply; d) farm mechanization at field level; and e) promoting marketing, product improvement, processing and storage. The program has emphasized the addition of organic matter, use of quality seeds and integrated pest management. Outcomes expected from this program are: 1) an increase of rice yield from 4.5 t/ha to 6 t/ha; 2) a 20 % increase in cropping intensity; and 3) an increase of production from high potential areas to meet 70 % of the national requirement (52 % in 2003). Data shown in Table 1 indicates some success of this program.

Food Security

The formal definition for food security for many years was "the availability of food to balance unequal food distribution regionally and nationally." Subsequently, it was admitted that availability, though a necessary element, is not sufficient for food security, because food may be physically existent, but inaccessible for those who are in need. The World Bank (1986) suggested a new definition of food security as "the access by all people at all times to the food needed for an active and healthy life." The FAO/WHO (1992) came up with a more specific definition, which is an extension of the World Bank definition as "food should be sufficient in terms of energy, but also in protein, fat and micronutrient. It should be adequate with regard to quantity, quality, safety and it should be culturally accepted." Rather it is dependant on what is meant by food security when applying this term. Various development projects highlight their activities to improve food security, but many of them are limited to aspects of food availability and access, but do not include any interventions to improve the use and utilization of food.

In 2003, the Sri Lanka Country Office of the United Nations World Food Program conducted a mapping exercise on vulnerability to food insecurity in Sri Lanka. This study covered all (323) Divisional Secretary Areas of the country and defined food insecurity as "limited or uncertain availability of nutritionally adequate and safe food or limited or uncertain ability to acquire acceptable foods in socially acceptable ways." Findings indicated Jaffna, Mullaithivu, Killinochchi, Mannar and parts of Vavunia, Moneragala, Batticaloa, Trincomalee and Ampara districts as the most vulnerable districts for food insecurity. This indicates the need for close attention to ensure food security to the whole nation.

In achieving food security in the country, a major set back of the development process is poor institutional linkage among agencies responsible for water, land, agriculture and environment. These agencies often work in isolation and set their own targets and as a result, various programs and projects often stand apart without synergy. There is diffused jurisdiction of functions and uncoordinated actions by different implementing agencies. For example, as suggested by National Council for Economic Development (NCED), many programs involved in poverty alleviation ensuring food security can be mainstreamed through the implementation of the new NPRGS (National Poverty Reduction and Growth Strategy). The proposed structure will comprise a reformed Samurdhi Program, which will be the main and largest poverty alleviation program, and all other sub-programs organized in a well-planned and coordinated manner. The need is also felt for urgent attention to formulate a firm policy to implement a sustainable agricultural production program in the country in order to ensure food security in Sri Lanka.

Conclusions

As a result of the 'Green Revolution', traditional crop varieties have been replaced by the high-yielding new and improved varieties, which despite of their high-yield potential are low in natural pest resistance and require a high level of nutrients.

- Extensive use of pesticides has developed the resistance of pests to pesticides, pest resurgence, health hazards, environmental pollution and lower profits to farmers. It has created environment issues such as nitrate leaching, release of greenhouse gases and eutrophication of inland water bodies.

- Sri Lanka remains vulnerable to natural disasters such as floods, droughts, cyclones, landslides, epidemics etc., aggravated due to human activities causing substantial threats to the food security situation of the country.

- Challenges posed by external factors due to globalization and open-economic policies have weakened the self-reliance of the country's economy. This has to be corrected by a firm and sound policy for the country's agriculture.

- It is possible to increase productivity further in Sri Lanka as only 40 % of the average potential of grain yield has yet been achieved in different ecological and hydrological regimes. By narrowing this yield gap, Sri Lanka will not only increase productivity but also increase the competitive advantage for rice with the other countries in the region.

- In achieving food security in the country, a major set back of the development process is that institutional linkage among agencies responsible for water, land, agriculture and environment is very weak. A collective effort is very much needed through the formulation of a firm policy to implement a sustainable agricultural production program in the country in order to ensure food security in Sri Lanka.

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Impact of Water Saving Irrigation Systems on Water Use, Growth and Yield of Irrigated Lowland Rice

W. M. W. Weerakoon, T. N. N. Priyadarshani, C. H. Piyasiri and L. S. Silva
Rice Research and Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka

Abstract

To meet the growing demand for food and other needs from an increasing population, the rice production in Sri Lanka, which was 3.87 million tonnes in 2008, has to be increased to 4.2 million tonnes by the year 2020. This requirement could be achieved by increasing productivity and/or by increasing the cultivated extent. In 2008, about 77 % and 68 % of the total paddy land extent was cultivated with either partial or full irrigation during the *maha* and *yala* seasons, respectively. A considerable extent of paddy land was either not cultivated or cultivated for other crops due to the scarcity of water in the dry and intermediate zones. Furthermore, with increased competition for water for domestic and industrial needs and climate change, there will be further reductions in the availability of water for rice cultivation. Conserving irrigation water would increase the cultivated extent of land while reducing the probability of late season water-stress in the cultivated rice crop. We studied the impact of different soil water regimes on water use, nutrient uptake, growth and grain yield of 3 – 3½ age lowland rice at the Rice Research and Development Institute, Batalagoda, Ibbagamuwa. There was no significant difference in the grain yield in rice when grown under either saturated or flooded conditions, but the yield decreased significantly with alternate wetting and drying. However, under saturated conditions, the irrigation water requirement was significantly lower than the flooded condition. The lowest irrigation water requirement was recorded with saturated to dry conditions. The irrigation water requirement under flooded conditions, when compared with the saturated condition, increased by 39 % during the *yala* season. During the *maha* season, even though the total irrigation requirement was lower, when compared to saturated conditions, four times more irrigation water was required under flooded conditions. There was a significant increase in plant dry matter production and leaf N (nitrogen) under saturated conditions, when compared with conventional flooded conditions. These findings suggest that when soil water is maintained at a saturated level in lowland rice, a considerable amount of irrigation water could be saved without sacrificing grain yield.

Introduction

Rice is the staple food for over 20 million Sri Lankans and is the livelihood of more than 1.8 million farmers. Sri Lanka produced about 3.9 million tonnes of paddy in 2008 with a national average paddy yield of 4.2 t/ha. With the present population growth rate of 1.1 %, increasing per capita consumption, requirements for seed, and post-harvested wastage in handling, Sri Lanka will need about 20 % more rice in the year 2020. This target could be achieved by increasing the area under rice cultivation and/or increasing productivity per unit area. Out of the island's total rice land extent of 0.71 million ha, about 0.43 million ha was cultivated under irrigated conditions in the year 2007/2008 *maha* season. However, due to the scarcity of water, the extent of rice cultivation under irrigated conditions during the *yala* season decreased to 0.38 million ha. Furthermore, due to the scarcity of water, about 12 % of the area cultivated with rice was also not harvested in 2007. Growing alternate crops in these land classes are difficult due to the presence of excess water during the initial stages. Therefore, most of these lands must be cultivated with rice at the risk of facing moisture stress during the late vegetative and reproductive stage.

It is expected that the future demand for water extracted from major rivers for domestic and industrial needs will increase significantly. With diminishing inputs for thermal power generation, the demand for hydro-power will also increase, thereby diverting less water from the Mahaweli River towards the dry zone. These measures would lead to a decrease in the quantity of water supplied for irrigated agriculture, especially for rice cultivation in the dry zone.

Rice is a major user of the global water supply. About 40-46 % of Asia's total irrigated agricultural lands are utilized for rice cultivation. Studies conducted on irrigation water use suggest that much of the water is being lost due to inefficient water allocation and distribution in the irrigation systems. About 400 – 5,000 liters of water are needed to produce one kg of paddy (Tabbal et al. 1992).

It is reported that over the last 20 years the vulnerability of the northeast monsoon has increased along with an increase in the consecutive dry days in the dry zone. Even though the reduction in annual total rainfall over the island is negligible, increased dry days and less reliability on the monsoon would increase demand for irrigation water, especially in the dry and intermediate zones. With the change in climate, the demand for water from sectors other than agriculture also would increase resulting in a reduction in the availability of water for irrigation. Furthermore, the adverse impacts of climate change on rice will be aggravated with the reduction in the quality and quantity of irrigation water. Hence, there is an urgent need to increase irrigation water use efficiency.

Water is lost through evaporation from free water surface, transpiration from the crop, seepage and percolation of the soil, bund leakages and runoff from the field. Seepage and percolation vary with the soil environment, which could be partially controlled through proper management. In the dry zone of Sri Lanka, seepage and percolation losses vary between 7-10 mm per day in the 'reddish brown earth (RBE)' soils, while it is lower in the 'low humic gley (LHG)' soils. The total irrigation water requirement for the rice crop grown in RBE and LHG soils are around 1,057 mm and 948 mm, respectively. This suggests that with the conventional system of water management, a significant quantity of water is required for a lowland rice crop. Percolation of water is increased with a large depth of water (Sanchez 1973; Wickham and Singh 1978).

Other than the traditional flood irrigation system, many methods of irrigation have been proposed to conserve irrigation water in lowland rice cultivation. Systems such as alternate wetting and drying, maintaining soil water below saturation and maintaining saturated conditions are some such methods. This study was designed to compare different irrigation systems used in Sri Lanka based on water use, water productivity and grain yield of rice.

Materials and Methods

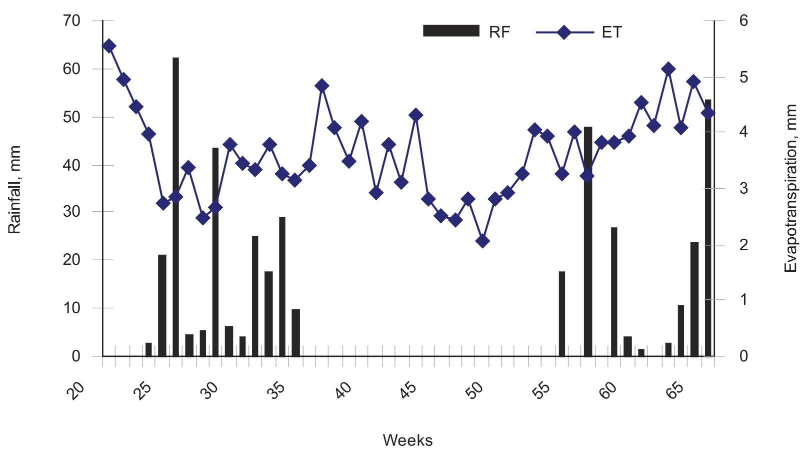
Experiments were conducted at the lowland rice fields at the Rice Research and Development Institute (RRDI), Batalagoda, Ibbagamuwa (07^0 31' N and 80^0 26' E) during the *yala* season of 2003 and *maha* seasons of 2003/2004. The experimental site was located in the middle portion of the rice track in the well-drained lowland soil category, and the experiment plots were prepared under lowland conditions. Fields were ploughed twice to a depth of about 15-20 cm and leveled to maintain uniformity within the field. Four separate fields were considered as four separate blocks. Within each block, six 9 m x 9 m plots with a 40 cm wide bund around the plot were prepared. At the time of leveling of each plot, a basal fertilizer mixture containing 5 kg/ha of N (nitrogen), 35 kg/ha of P_2O_5, 15 kg/ha of K_2O and 2 kg/ha of $ZnSO_4$ were applied to rice varieties, Bg 352 with a 3 ½–month maturity age, Bg 305 with 3-month maturity age, and Bg 358 with 3 ½–month maturity age were used during the *yala* 2003, *maha* 2003/2004 and *yala* 2004 cultivation seasons, respectively. Rice seeds were soaked in water for 24 hrs and incubated for 48 hrs and then were sown onto these well-prepared seed-beds. One week after germination, treatments were employed on to rice plants grown in these plots. Even though the treatments were randomly allocated to each plot, to minimize lateral seepage, similar treatments of water management were grouped together. To control weeds at 12 days after sowing, Nominee (Bispyribac Sodium, 100g/1SC) was applied and water to all plots was impounded to a depth of about 10 cm at 3 days after the application of weedicides. Thereafter, the treatments were employed again and continued until either panicle initiation (PI) or the late booting (LB) stage. Treatment combinations were: maintaining 10 cm water layer (standing water) throughout the cropping period; irrigate to a water depth of 10 cm when soil moisture reaches saturation level and continued until the late booting (LB) stage (flood to saturate^{-1}); irrigate to soil saturation level when soil started to form cracks and continued until the LB stage (saturate to dry^1); irrigate to a water depth of 10 cm when soil moisture reached saturation level and continued until PI stage (flood to saturate^{-2}); irrigate to soil saturation level when soil starts forming cracks and continued until the PI stage (saturate to dry^2); maintain soil at saturated level until LB (saturate throughout). At the end of the respective treatment period, plots were filled with water to a depth of 10 cm and continued until physiological maturity. Nitrogen fertilizer in the form of urea was applied to the treatment at 21, 35, 49 and at the late booting stage at the rate of 20, 30, 30 and 15 kg/ha, respectively. Thirty kg of K_2O in the form of 'muriate of potash' was applied at 49 days. Insecticides recommended by the Department of Agriculture (DOA) were applied to control leaf folder and the paddy bug. There was no disease incidence during the experimental period.

The amount of water applied to each plot in each block was measured using a calibrated partial flume. The partial flume water height was then converted to the amount of water applied using the calibration curve. Weekly rainfall and average pan evaporation data were collected from the meteorology station located about 100 m from the experimental site. Plant samples were collected from all plots using a 50 cm x 50 cm quadrant at physiological maturity. Plants were separated into component plant parts and weighed after oven drying for 72 hrs at 80^{o}C. At maturity, plants from the rest of the field were harvested, leaving a 50 cm border around the plot. The final harvest was cleaned and filled and grains were sun-dried, and the final yield was adjusted to 12 % seed moisture content. Data were analyzed using the normal ANOVA procedure for an experiment arranged in the randomized complete block design using SAS statistical package.

Results and Discussion

Figure 1 suggests that average daily pan evapotranspiration in the experimental site was about 3.5 mm and 4.0 mm during *yala* 2003 and *maha* 2003/2004 seasons, respectively. In general, there was sufficient water received during the latter part of the *yala* crop, and the total number of irrigations given for different stages of treatments was greater during the *yala* season than the *maha* season (Table 1). In general, 10 irrigations were made during the *yala* crop to maintain standing water to a depth of 10 cm, while only 5 irrigations were needed during the *maha* season. The average number of irrigations and the amount of water applied were lowest, with the treatment, where water was applied in small quantities to maintain the field between soil saturation and crack formation until late booting (Table 1). Furthermore, the difference in the amount of water applied between saturated soil culture and saturate to dry was not statistically significant.

Figure 1. Weekly total rainfall and average weekly evapotranspiration at the experimental-site during the experimental period.



In the saturated soil culture, soil was kept close to saturation throughout, thereby reducing the hydraulic head and keeping seepage and percolation at a very lower level. Therefore, the amount applied per water issue was relatively lower. However, the number of water issues did not decrease significantly when compared with the flooded system of irrigation. It was reported that with saturated soil culture, water input decreased by an average of 23 % from the

Table 1. The number of irrigation issues and the amount of irrigation water applied (m^3/ha) to each treatment from seedling establishment during 2003 *yala* and 2003/2004 *maha* seasons.

Treatment	Number of irrigations		Amount of water applied (m^3/ha)	
	Yala	*Maha*	*Yala*	*Maha*
Standing water throughout	10	5	4,426 ^{b}	2,047 ^{a}
Flood to saturate $^{-1}$	11	4	5,427 ^{a}	1,610 ^{a}
Saturate to dry $^{-1}$	5	3	2,872 ^{c}	523 ^{ac}
Flood to saturate[2]	9	4	5,551 ^{a}	1,738 ^{a}
Saturate to dry[2]	10	3	5,042 ^{ab}	829 ^{b}
Saturate throughout	9	3	3,363 ^{c}	558 ^{bc}

Note: [1] – treatment employed up to LB, [2] – treatment employed only up to PI

continuous flooded condition (Bouman and Tuong 2001). In the saturate to dry treatment, it was expected that a much lower amount of water is necessary, but the heavy percolation through the cracks formed have increased the amount of water applied. This was particularly true when treatment was employed only up to the PI stage and, thereafter flooded the field. However, the lowest amount of water applied was recorded with the ‘saturate to dry’ treatment employed up to the late booting stage. This suggests that alternate wetting and drying could save a considerable amount of irrigation water. The amount of water applied, and the number of water issues, is significantly lower during the *maha* season than that of the *yala* season. This was due to higher rainfall coupled with the 3-month maturity aged rice variety used in this study during the *maha* season. The results of many field experiments suggest that the total water input could decrease by 15 – 30 % without any significant impact on the grain yield (Cabangon et al. 2004; Belder et al. 2004). This experiment shows that about 24 – 35 % and 70 % irrigation water could be saved during the *yala* and *maha* seasons, respectively, if the field is either maintained at saturated condition or saturate to dry situation. Even though the total amount of water applied is greater during the *yala* season, the difference between water saving irrigation treatment remained the same, suggesting that a significant amount of irrigation water could be saved irrespective of the season, if the field is maintained at saturated or saturated to dry condition.

However, the dry condition in treatments of flooded to dry or saturate to dry could create a hidden water stress, which could affect both growth and yield of rice. It was indeed true that there was a reduction in all growth parameters when the field was subjected to a dry situation (Table 2).

There was a significant increase of the total biomass in treatments where there is no moisture stress to the rice plant. Maintaining rice plants at a saturated condition throughout the growing period has resulted in a significant increase of the total biomass (Table 2). In all treatments where flood water was maintained to a certain depth, there was a significant reduction in the plant growth when compared with the saturated soil culture. Furthermore, it was observed that the leaf greenness or SPAD value (measured during the late booting stage using SPAD 502, Minolta Co. of Japan) was 42.1 in the saturated treatment, while it was 41.6 in the flooded treatment. SPAD values in all other treatments ranged between 36.9 and 40.4.

Table 2. Total plant dry weight, root dry weight and number of panicles per square meter, spikelet number and filled grain number per panicle, 1,000 grain weight and Harvest Index (HI) of rice plants at physiological maturity stage during 2003/2004 *maha* season.

Treatment	Total dry weight, kg/m^2	Root weight g/m^2	Panicle number $/m^2$	Spiklets /panicle	Grains /panicle	1,000 grain weight, g	HI
Standing water throughout	1,340 b	109.0 b	493 b	68 a	57 a	22.5 a	0.50 a
Flood to saturate $^{-1}$	1,397 b	124.5 a	538 a	64 a	54 a	21.9 a	0.49 a
Saturate to dry $^{-1}$	1,322 b	118.0ab	533 a	59 ab	50 b	22.6 a	0.48 a
Flood to saturate^2	1,291 b	114.9ab	467 b	65 a	56 a	22.2 a	0.50 a
Saturate to dry^2	1,229 c	105.3 b	527 a	58 b	51 b	21.5 a	0.49 a
Saturate throughout	1,418 a	124.6 a	515 a	67 a	57 a	22.5 a	0.49 a

Even though there was no leaf N stress when the SPAD reading was around 40, increase in total biomass and leaf N status suggest that there was an increased uptake of N in the saturated soil condition than the flooded and flooded to dry systems, which could be due to reduced leaching losses. Nitrate leaching losses increase with heavy irrigation regimes in coarse textures soils (Aulakh and Singh 1997; Singh and Sekhon 1976). Furthermore, increased root dry weight also suggests that the ability of the rice plant to take up nutrients had increased with saturated soil culture. With the increase in nutrient uptake, there could be an increase in tillering as there are enough photosynthates produced for developing tiller. However, standing water could suppress tillering. Better canopy status during both vegetative and reproductive stages have contributed to increase the spikelet number and filled grain number per panicle in the non-stressed treatments (Table 2). There was no change in seed weight as that is controlled mostly by the genetic potential of the variety.

Grain yield did not differ among treatments without soil drying in *yala* 2003 and *maha* 2003/04 and *yala* 2004 (Table 3). However, there was a significant decrease in grain yield with soil drying treatments when compared with the flooded or saturated treatments. Furthermore, it did not differ among treatments where the stress was relieved at PI or at LB. This suggests that there will be a significant impact on grain yield with alternate wetting and drying of soil. In contrast many researchers have observed no differences or increases in grain yield with alternate wetting and drying (Wei Zhang and Song 1989). However, Bouman and Tuong (2001) suggest that there is a reduction in the grain yield in alternate wetting and drying when compared with rice grown with standing water. With the reduction in the amount of water used and the increased grain yield in the saturated soil culture treatment, the irrigation water productivity has significantly increased with saturated soil culture than with that of flooded rice culture. Even though the irrigation water productivity in the saturate to dry treatment was not different to that of saturated treatment, the average grain yield was significantly lower in the saturate to dry system. Irrigation water productivity was significantly greater in the *maha* season when compared with the dry *yala* season. This is because the grain yield increased while the amount of irrigation water applied, decreased. This was possible as there was sufficient rainwater to keep the soil under saturation.

Table 3. Grain yield (t/ha) and irrigation water productivity (g grain kg^{-1} water) of rice grown under different soil water regimes during 2003 *yala*, 2003/2004 *maha* and 2004 *yala** seasons.

Treatment	Grain yield, t / ha			Irrigation water productivity, g grain kg^{-1} water	
	2003 *Yala*	2003/4 *Maha*	2004* *Yala*	2003 *Yala*	2003/4 *Maha*
Standing water throughout	4.74 a	5.77 a	5.29 a	1.077 abc	2.829 b
Flood to saturate $^{-1}$	4.90 a	5.75 a	4.95 ab	0.933 bc	3.577 b
Saturate to dry $^{-1}$	4.19 b	5.08 b	4.65 b	1.507 a	10.590 a
Flood to saturate^{2}	4.89 a	5.25 ab	5.03 ab	0.895 bc	3.090 b
Saturate to dry^{2}	4.04 b	4.28 c	4.56 b	0.806 c	5.459 b
Saturate throughout	4.54 a	5.46 ab	5.46 a	1.455 a	12.650 a

Note: * Water productivity not measured

In general, maintaining saturated soil culture in lowland rice paddies could save irrigation water requirement while maintaining the same or even a greater level of grain yield when compared to the flooded system. The water saving, especially during the *yala* season, could be used for the cultivation of an additional area under rice in the dry and intermediate zone of Sri Lanka. These results also suggest that a successful *maha* rice crop could be raised with over 50 % less irrigation water than what is used at present, if saturated soil culture is maintained. However, the irrigation infrastructure has to be modified to meet these requirements.

Conclusions

There is a considerable scope to reduce the irrigation water applied to lowland rice culture during both *yala* and *maha* seasons in the intermediate zone of Sri Lanka. Saturated soil culture significantly decreased irrigation water use while maintaining the same level of yield. Irrigation water productivity was highest with both saturated soil culture and saturate to dry soil culture. ISn the direct seeded rice culture in Sri Lanka, even though maintaining saturated soil culture is difficult with the present irrigation schedule, maintaining saturated soil conditions in the seed bed without imposing a water stress to the plant could save a significant quantity of irrigation water, which could be used to increase the cultivated extent of rice land in Sri Lanka.

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Potential for Zero-Tillage Technique in Rice and Other Field Crop Cultivation in Rice-Based Cropping Systems in the Dry and Intermediate Zones of Sri Lanka

S. N. Jayawardena, S. W. Abeysekera, N. Gunathilaka and H. M. J. K. Herath
Rice Research and Development Institute, Batalagoda, Ibbagamuwa, Sri Lanka

Abstract

The high production cost and scarcity of water for crop cultivation are some of the major problems faced by farmers in many rice-based cropping systems in the country. In many crop production systems, around 15-20 % of the total cost of production accounts for tillage/land preparation, such activities also consume around 15 % of the total water requirement. Hence, it is important to adopt technologies that would save water and reduce the cost of cultivation without sacrificing the yield. This paper discusses the adoption of zero-tillage crop establishments in rice and other field crop cultivation in paddy fields in the dry and intermediate zones. Zero-tillage conditions were created by applying the total weed killer, 'Glyphosate' after the fields were drained and subsequently establishing crops without tillage.

Results of six seasons on rice cultivation show that the rice crop could be established under zero-tillage conditions (without tillage) without significantly affecting the yield. This practice helps to cut down the total cost of cultivation by around 15 %, and save water at least for a period of 1-2 weeks, and shorten considerably, the time taken for land preparation. Similarly, many crops such as green gram, cowpea, black gram and maize could be cultivated under zero-tillage conditions. Experiences show that zero-tillage technology has many advantages over conventional tillage. Hence, more attention needs to be given to develop the appropriate machinery to suit zero-tillage conditions and at the same time, to fine-tune technologies to suit the different cropping systems as well.

Introduction

Tillage is one of the most important field operations in the production of rice and other field crops. The primary objective of tillage is to control the weeds and have a good 'seed bed' for the establishmenmt of a better crop. In addition, it helps to reduce soil compaction. Zero-tillage or no-till farming systems have been developed and applied around the world over several decades. The benefits of zero-tillage in economic, production and the environmental aspects of farming have been recognized. The high cost of production is one of the major constraints in the cultivation of rice and the production of other field crops (OFC) in Sri Lanka. Tillage and other field preparations required to prepare the fields for planting various types of irrigated OFC and rice cultivation, account for around 20 % of the total cost on average (DOA 2008). Therefore, finding ways and means to cut down the tillage cost is important to further reduce the cost of production. In addition to the cost factor, farmers also face other problems in preparing the land, such as the difficulty of finding tractors on time, labor scarcity during the land preparation and establishment period and inadequate time for land preparation. The inadequacy of tractors for land preparation has particularly, resulted in delays in rice crop cultivation in Sri Lanka (Tilakaratne and Tilakeratne 2003).

Crop establishment with zero-tillage is used widely for many crops around the world. It has the potential to save time, energy, water and labor during crop establishment (Piggin et al. 2001). However, little research has been conducted on zero-tillage establishments in rice cultivation (Hood 1961; Boevema 1965; Castin and Moody 1985; Smith 1992; Diop and Moody 1989). Russell and Keen (1941) concluded that the primary function of ploughing is to control weeds, because the omission of ploughing in a weed-free situation did not result in any reductions in the yield. In Sri Lanka, attempts have been made to explore the potential for adopting the zero-tillage technique in rice and other crop cultivation (Abeyratne 1956; Fernando 1981; Jayawardena et al. 2006). However, no priority has been given to this area of research due to various reasons. Research on this issue is important to Sri Lanka now more than ever before, given that lack of labor, the high cost of tractors for tillage and water shortages are known as major constraints in rice and OFC cultivation. This paper reports the results of the experiments conducted during 1995-2008 at the Field Crops Research and Development Institute (FCRDI) and the Rice Research and Development Institute (RRDI), relating to zero-tillage cultivation in other field crop (OFC) and rice.

Zero-tillage Rice Cultivation

Field experiments using the two methods of land preparation, those being conventional tillage and zero-tillage, were carried out in a replicated trial for six seasons from *yala* 2006 to *maha* 2008, in imperfectly drained soils at the Rice Research and Development Institute, Batalagoda, Ibbagamuwa, in the IL1a agro-climatic zone of the low country intermediate zone of Sri Lanka. Initial weed and rice stubble and voluntary seedlings counts in the plots were recorded before the tillage operation using two random 1.0m x 1.0m quadrants per plot and their relative abundance was calculated as a percentage. Soil at the study site was sandy clay loam, with pH 4.9, EC 27.6 (ms/cm) with nutrient contents of, 23.50 mg/kg of K, and 4.50 mg/kg (olsen) of P. The organic matter content was 2.87 % and the bulk density was 1.4 mg m^{-3}. Conventional tillage plots were prepared by ploughing to a depth of 15-20 cm using a mold board plough, followed by harrowing and leveling before crop establishment. Zero-tillage plots were sprayed with Glyphoshate (N-[phosphonomethyl] glycine) at the rate of 4 liters ha-1 3 weeks before the crop establishment. Five to seven days after the spraying and after the weeds turned in to yellow, the field plots were inundated for about one week. Before the crop establishment, rice stubbles and the dead weeds debris in zero-tillage plots were flattened to the ground by pulling a banana log over the field after the field was drained. Pre-germinated seeds of Bg 403 (4-month age) were broadcasted at the rate of 100 kg/ha. Fertilizer was applied at the rate of 150 kg ha-1 of N, 75 kg ha-1 of P2O5, 40 kg ha-1of K2O and 5 kg ha-1 of Zn. Nitrogen fertilizer was split-applied at 0, 2, 5 and 8 weeks after crop establishment at the rate of 5, 25, 30 and 30 kg ha-1, respectively. Phosphorous fertilizer was applied in a single application during the crop establishment, while K was applied at two equal splits at 0 and 8 weeks after the crop establishment. Post emergence weedicide, Nomine (Bispyribac sodium) was sprayed at the rate of 250ml ha-1 week after the establishment of the crop to control weeds. Rice crop establishment counts at 3 WAE (weeks after establishment) were taken using in two random quadrants (0.5m x 0.5m) per plot. Weed biomass was recorded at panicle initiation (PI) stage. Biomass production, yield and yield components were recorded at the harvest. Grain yield was determined from a sample area of 20 m^2 per plot. Yield components were determined from 10 hills selected at random per plot. SAS package was used to analyze the data. Partial budgeting was used to compare the economic advantage of the system.

Crop Establishment

In all six seasons the crop establishment in zero-tillage was comparatively lower than that of conventional tillage plots. The average numbers of seedlings were 321 and 297 m^{-2}, respectively, for conventional and zero-tillage plots. Retaining broadcasted rice seeds on rice stubbles and weed debris without touching the field is the major reason for low establishment in zero-tillage plots. Increasing the seed rate could be the solution for this problem (Table 1).

Table 1. Effect of method of land preparation on the rice crop establishment, grain yield and weed dry weight at RRDI.

Season	Rice crop establishment seedlings m-2 at 3 WAS		Grain Yield t ha-1		Weed dry weight (gm-2) at 5 WAE	
	Conventional tillage	Zero-tillage	Conventional tillage	Zero-tillage	Conventional tillage	Zero-tillage
Yala 2006	310 a	278 b	5.27 a	4.94 b	50.4 a	34.4 b
Maha 2006/07	314 a	276 b	5.46 a	5.15 b	53.6 a	41.6 b
Yala 2007	356 a	333 a	4.43 b	5.30 a	33.6 b	46.0 a
Maha 2007/08	338 b	311 a	5.38 a	5.51 a	41.2 a	48.4 a
Yala 2008	298 a	264 b	4.99 a	4.62 a	39.2 b	59.6 a
Maha 2008/09	311 a	298 a	4.87 a	4.34 b	48.4 b	69.2 a
Mean	321	297	5.06	4.97	44.4	49.8

Source: Batalagoda (2006-2008)

Weed Dry Weight and Composition

Murdannia nudiflora, Cyperus iria, Ludwigia octavalvis, Echinachloa spp.and Isachne globosa were identified as weeds that were in abundance at the beginning. However, in the latter stages of crop growth this composition has changed. The populations of Murdannia nudiflora Isachne globosa, Leftocloa chinensis and Echinochloa colona have increased gradually over time. Piggin et al. (2001) found that it is difficult to control Murdannia nudiflora and Isachne globosa in zero-tillage plots completely with' Glyphosate, Echinochloa colona and Ludwigia octavalvis in wet-seeded paddy and Fimbristylis dichotma in zero-tillage plots. The dry weight of weed in different seasons varied a lot in the two treatments. Perhaps this could be due to the weather conditions and the variation in the management conditions prevailing at the time. Weed dry weight in zero-tillage plots was significantly lower in the first two seasons and thereafter, showed an increasing trend. This is mainly due to the increase in the population of Murdannia nudiflora, Leftocloa chinensis, and Ludwigia octavalvis in the last few seasons (Table 1).

Effects on Grain Yield

Rice yield ranged from 4.34- 5.51 t ha-1 and varied across the seasons. The results were not consistent over the seasons. This inconsistency could be due to the seasonal variation in weather conditions. The overall yield difference between conventional tillage and zero-tillage plots was (0.09 t ha-1) more or less similar. Out of the six seasons that were tested, three seasons (*yala* 2006 and *maha* 2006/07 and *maha* 2008/09) have produced a comparable yield to that of conventional tillage plots. Poor crop establishment due to heavy rains prevailing at the establishment time in *yala* 2006 and *maha* 2007/07 seasons, was the major reason for the low yield (Table 1).

Water Saving

Water requirement for a 3.5 month rice crop is around 1,300 mm and, of which, 300 mm (23 %) accounts for land preparation (IRRI 2005). In the conventional cultivation system, the paddy field is irrigated for about 3 weeks before the establishment of the crop, where at least six irrigations are needed be given. However, in zero-tillage practice the field is inundated only for one week and only two irrigations are required. Hence, at least four irrigations or 60 % of the water required for land preparation could be saved.

Economic Advantages

A partial budget was performed to compare the economic advantages of the systems. The total cost of tillage (first, second ploughing and the final leveling) with a tractor was Rs.10,600 ha-1 while it was only Rs. 4,125 ha-1 for zero-tillage (Table 2). The yield obtained under zero-tillage and conventional tillage was more or less the same. However, net benefit has been increased in zero-tillage plots by Rs.695 ha-1 due to the omitting of the tillage operation. In this calculation, labor cost for pre-weedicide spraying, weedicide cost and labor cost for irrigation until broadcasting has not been accounted. If accounted, the benefit would be much higher than the Rs.695 ha-1. Other than the economic benefits, zero-tillage requires less labor units for the cultivation of a unit of land and also helps to cut down the water requirement for land preparation. Michel et al. (2001) reported that other than the economic advantage, zero-tillage helps to minimize the delivery of soils, nutrients and pesticide pollutants from place to place.

These results suggest that it is possible to establish a good rice crop and obtain a satisfactory yield in a lowland paddy field under zero-tillage conditions. Initial weeds in the zero-tillage plots should be killed and controlled completely and the field should be drained completely before the application of Glyposhate'. The rice crop should be broadcasted as soon as the weeds are killed to avoid germination of weed seeds before the establishment of the crop.

Table 2. Partial budget per hectare for the conventional and zero-tillage establishment methods (1997-2008).

Descriptions	Method of land preparation	
	Conventional tillage	Zero-tillage
Variable cost		
Cost of ploughing (first and second ploughing+leveling) at	10,600	
Rs. 10,600		
ha-1		
Cost of Glyphosate for 4 l h at Rs. 900/liter		3,100
Application cost for Glyphosate 1 man-day at Rs. 525/day		525
Total variable cost	10,600	4,125
Income		
Average yield (t ha-1)	5.06	4.93
Gross benefit(at Rs. 30/kg)	151,880	146,100
Net benefit	141,280	141,975
Net benefit from zero-tillage	695	

Other Field Crop Cultivation under Zero-tillage Conditions

The low economic return due to the high cost of production is one of the constraints to increasing production in rice and many other field crops. Therefore, it is important to introduce technology to lower the cost of production. As an average, around 15-20 % of the total cost of cultivation in other field crops accounts for land preparation, weeding and irrigation.

Effect of Tillage and Mulching on the Growth and Yield of Chilies and Weed

Results from this experiment can be compared with the results from experiments conducted at the Field Crops Research and Development Institute (FCRDI) and by Maha Illuppallama during the late 1990s. The latter mentioned experiments were conducted using field crops other than rice usually referred to as OFCs. Results of an experiment conducted by the principal author of this paper in 1997 to evaluate the effect of tillage methods and mulching on the growth and yield performances of chilli grown in paddy fields (after the *maha* rice harvest) under irrigated conditions, is informative. Four treatments including a combination of mulching (rice straw at 8 t ha-1 on dry basis applied immediately after transplanting of chilli) and ploughing as: a) ploughing with mulching; b) ploughing only; c) no ploughing with mulch; and d) no ploughing and no mulching, were tested in a replicated trial. Soils of the ploughing plots were turned up to 20 cm with a mammoty. Four-week old seedlings of chili (cv. MI-2) were transplanted at 60 x 45 cm spacing with two plants per hill. The recommended dosage of fertilizer was applied. Mammoty-weeedng was done at each weeding and the dry weight of weeds was recorded. Soil moisture at 5, 15 and 30 cm depth was determined gravimetrically. Plant height and canopy cover for five plants selected randomly, were recorded at regular intervals. The harvest yield components for 10 randomly selected plants were recorded. The yield also was recorded separately.

The study revealed that the pod number, 100 pod weight of chilli, dry weights of chilli, and weeds, plant height and final plant stand were not affected significantly by ploughing. Also, 5 days after irrigation the total soil moisture and total root length density were not affected significantly. This shows that chilli could be established in paddy fields after the rice crop without ploughing, thereby eliminating the cost of ploughing. In contrast, mulching had a significant effect on yield components and the dry chilli yield except for 100 pod weight, plant height and final plant stand at harvest. The highest dry chilli yield (1,478 kgha-1) and the highest pod number per plant were recorded from the treatment with ploughing and mulching. The increases in yield and pod number were 13 % and 17 %, respectively, over the conventional ploughing treatment. The lowest weed dry weight (124 gm-2) was observed from the same treatment (Table 3).

Table 3. Yield, yield component of chilli and weed dry weight as affected by tillage and mulching at FCRDI, Maha Illuppallama - *yala* 1997.

Treatment	Pods plant-1	100 pod weight (g)	Dry chill yield Kg ha-1	Weed dry weight g m-1	Plant height at harvest (cm)	Plant stand at harvest (cm)
Ploughing						
+tillage	52	200	1,303	170	29.4	20
-tillage	50	194	1,238	193	27.6	21
LSD (0.05)	4.4	21.8	336.8	63.6	1.7	1.2
Mulch						
+mulch	61	208	1,478	124	30.6	20
-mulch	41	186	1,064	239	25.6	21
LSD (0.05)	8.3	28.4	225.9	42.3	2.1	1.3

Source: Annual reports—FCRDI, Maha Illuppallama

Sandwich Crop Cultivation After *Maha* Rice Crop

Due to the high cost of production and comparatively low returns, farmers are not interested in cultivating legumes in paddy fields under irrigation during the *yala* season. Instead, they prefer to cultivate high-value crops in paddy fields. Therefore, two simple and cost-effective crop establishment techniques were introduced i.e., black gram and green gram, two of the most commonly grown legumes in the country. In the first system, legume seeds are broadcasted into the standing rice crop about 5-7 days before harvesting the rice crop. Here, land preparation or weeding is not practiced. However, in case there is a possibility of poor growth of crops, a few kilograms of urea is applied while broadcasting the seeds. In the second system, seeds of legumes are row-planted using a mammoty or wooden stick on the rice stubble immediately after the *maha* rice is harvested. These zero-tillage applications require adequate levels of soil moisture to facilitate the germination of seeds. Immediately after seeding, Paraguat or Glyphosate is sprayed to kill the existing weed flora. Ploughing is not necessary, while weeding is done whenever necessary. Crops can be irrigated if water is available, otherwise the crop growth is dependent on incidental rains and residual soil moisture. In these systems the land perpetration could be omitted and the considerable amount of money spent on labor for planting could also be saved. Results show that around 300-500 kg of seed yield could be obtained with little inputs (Table 4).

Table 4. Effect of establishment methods on the yield of legumes 1985-1999 at FCRDI, Maha Illuppallama.

Year	Crop	Yield kg ha-1		
		Broadcasted into standing rice crop	Row-planted under conventional tillage	Row-planted under zero-tillage conditions
1985	Black gram	354	551	432
	Green gram	400	521	661
1997	Green gram	520	835	854
1999	Green gram	305	489	503
Mean legume yield		394	599	612

Source: Annual Reports, FCRDI, Maha Illuppallama

The cost and return analysis showed that any of the methods of crop establishment could be adopted to cultivate legumes in paddy fields. As far as income is concerned, among the three methods, row-planting under zero-tillage conditions and row-planting under the conventional tillage system have performed equally in comparison to each other, and better than the income generated when broadcasting seeds into standing rice crop. However, as far as the concern of curtailing the cost of cultivation, broadcasting seeds into standing rice crop is also a good method (Table 5).

Table 5. Estimated cost and returns (Rs. ha-1) of legumes under different establishment methods.

Operation	Broadcasted into standing rice crop	Row-planted under conventional tillage	Row-planted under zero-tillage conditions
Seeds	2,700	2,250	2,250
Land preparation	-	5,477	-
Weeding/weedcide	-	6,623	6,233
Insecticide	3,045	3,045	3,045
Harvesting and processing	6,480	6,480	6,480
Total cost	12,225	23,875	18,008
Yield	394	599	612
Gross return	29,250	46,722	47,736
Income	17,025	22,847	30,728

Source: Annual Reports, FCRDI, Mahailluppallama

Effect of Weed Management and Nitrogen Fertilizer Application on the Weed Growth and Yield of Green Gram Grown under Zero-tillage Conditions in Fallow Paddy Lands

Around 50 % of the paddy lands (0.3 million ha) of the country are not cultivated during the *yala* season due to the inadequacy of water. It has been found recently that the there is a possibility of cultivating green gram under zero-tillage conditions successfully in these uncultivated paddy lands, utilizing the limited *yala* rains. However, weeds are a major problem in green gram cultivation. This study was conducted to find cost-effective weed control methods and to determine whether nitrogen fertilizer application is necessary for green gram grown in these lands. In this study, the effect of five weed control treatments — 1) Paraguat only (4l ha-1 at sowing; 2) Paraguat (4l ha-1) followed by Alachlor (2.5l ha-1); 3) mammoty weeding at 3 weeks after seeding (WAS); 4) mammoty weeding at 3 and 5 WAS; and 5) no weeding and two nitrogen levels (0 and 30 N kg ha-1) were tested on the yield of green gram grown in these lands.

The major weeds at the establishment were rice ratoon, rice seedlings and many spices of grass, sedges and broad leaves. The degree of control ranged from 63-76 % over the control of weeds. The effects of different weed control methods on broad leaves were similar. All weeding treatments have controlled grass weeds significantly (Table 6). However, a higher degree of control was observed from both treatments of Paraguat (>70%) over the mammoty weeding treatment (>40%). Both mammoty weeding treatments have effectively controlled the grass (>53%) over both weedicide treatments (>36%). There was no significant effect from the application of Lasso in controlling weeds. Mammoty weeding at 2 and 5 WAS gave the highest yields of 677 kg ha-1, which is an increase compared to the 73-82 % increase of the other three treatments (Table 7). The application of nitrogen fertilizer increased the yield of green gram significantly and no interaction was observed between weeding methods and fertilizer levels. The overall yield that was increased due to nitrogen fertilizer application was 24 %.

Table 6. Effect of different weed control methods on weeds, rice stubbles and rice seedlings at 4 WAS of green gram grown in fallow paddy lands, at FCRDI, Maha Illuppallama, during *yala* 1998.

Treatment	Weed count/m^2					
	Broad leaves	Grass	Sedges	Rice seedlings	Rice ratoon	Total weeds
Paraguat only	61	21	120	22	187	431
Paraquat followed by Lasso	45	18	132	23	169	377
Mammoty weeding (2 WAS [a])	65	35	94	32	68	294
Mammoty weeding (2 and 5 WAS)	53	38	89	35	67	122
Control (No weeding)	115	62	190	93	192	652
LSD (0.05%)	27.8	12.1	34.9	20.2	24.4	102
CV (%)	26.3	23.3	18.5	31.9	11.6	18.7

Note: [a] WAS refers to weeks after sowing

Table 7. Effect of different weed control methods and nitrogen fertilizer application on the yield of green gram grown under zero-tillage conditions in fallow paddy lands, at FCRDI, Mahailluppallama, during *yala* 1998.

Treatment	Yield (Kg ha -1)
Weeding Methods	
Paraguat only	483
Paraguat fb Lasso	463
Mammoty weeding (2 WAS [a])	459
Mammoty weeding (2 and 5 WAS[a])	677
Control (no weeding)	266
LSD (0.05)	78.8
CV (%)	11.2
Nitrogen levels (Kg ha-1)	
0 N Kg ha-1	419
30 N Kg ha-1	520
LSD (0.05)	
CV (%)	11.2

Note: [a] WAS refers to weeks after sowing

It can be concluded from the results that any of the weed control methods used in these experiments can be adopted to control weeds in green gram grown under zero-tillage conditions in fallow paddy lands. Considering the investment, time, possibility of soil moisture stress due to weeding and risk factors, it is appropriate to control weeds by Paraguat application alone. Application of nitrogen fertilizer at the rate of 30 kg ha-1 is economical.

Conclusions

These results suggest that the potential to establish rice and other field crops to obtain a satisfactory yield and income is there. The zero-tillage technique would help to lower the labor requirement and water requirement for land preparation while saving the time taken for land preparation. There are many aspects, such as development of suitable seeders, better pre-weed control methods, fertilizer and crop management, long-term impact on environment etc., that need to be adopted to support the zero-tillage technique.

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The Importance of Seasonal Planning for Irrigation Water Productivity: Inginimitiya Experience

W. G. Gnanadasa
Irrigation Engineer Irrigation Department, Project Director's Office of PEACE Project, Anuradhapura, Sri Lanka

Abstract

The principal tool in water management in a major scheme is the seasonal planning for water balance. Therefore, the respective officers of such schemes must have this knowledge. Cultivation failures frequently take place in schemes where this method is not adopted. In most of the cases, proper seasonal planning is not done due to lack of interest, knowledge or data. As a result, there are delays in cultivation and decreases in yield, which in turn have a negative impact on farmers' income and their living conditions.

Problems

At the moment, global-wise water usage for agriculture is 85 %. But in the near future it is expected to decrease to 75 % due to the increase in population. On the one hand, food production needs to be increased to meet the food requirements of the increased population but, on the other hand, the availability of fresh water for this purpose is decreasing day by day due to water pollution. Under these two contradictory circumstances, increasing the productivity of irrigation water is an essential requirement. This would be one of the biggest challenges the future world will have to face.

Seasonal Planning

In Sri Lanka, there are two cultivation seasons per year. The period from October to February is called the *maha* season, while the period from April to August is called the *yala* season. Seasonal planning involves the planning of all activities related to cultivation during any one of the aforementioned seasons. Such planning includes the calculation of water balance, determination of cultivation dates, arrangements for operation and maintenance (O&M) activities, arranging cultivation loan facilities, deciding what crops are to be cultivated and the pattern of cropping etc. But the major activity for seasonal planning is the calculation of the water balance equation for the whole season, and it is this aspect that this paper intends to cover and refers to when using the words 'seasonal planning'.

Calculations Pertaining to Seasonal Planning

The following data are required for traditional seasonal planning or operation study:

1. Yield curves
2. Stream flow-data
3. Evaporation data close to the reservoir
4. Reservoir seepage and percolation data
5. Cultivation data
6. Evaporation data at cultivation area
7. Canal-flow data

Inflow to the reservoirs can be calculated using yield curves and rainfall data (Ponrajah 1984). More accurate results than those generated using this basis of calculation, can be obtained if daily stream flow data are available. When weekly or monthly pan evaporation data close to the reservoir is known, reservoir surface evaporation can be calculated using the following formulae.

(1) Evaporation loss = Evaporation factor x Water surface area of the reservoir

If permeability data for the reservoir bed and the dam are known, the percolation and seepage losses can be calculated. If soil permeability is not available, then seepage and evaporation loss is assumed to be 0.5 % of the monthly average storage. (Ponrajah 1984).

(2) Seepage and percolation loss = 0.5 % x Average monthly storage

Crop water requirements (ET_C) can be calculated using the pan evaporation data of the cultivation area (ET_0) and crop factors (k_c), while conveyance losses and canal efficiencies (E_a) can be calculated using canal flow data. Subsequently, daily, weekly or monthly irrigation requirements can be calculated using:

(3) Crop water requirement = $ET_C = ET_0 \times k_c$

(4) Field irrigation requirement = FIR = ET_C / E_a

(5) Irrigation requirement = IR = FIR / E_c

The water balance equation for the period of interest can be derived using:

(6) Storage at the end of previous day + inflow = Storage at the end of day + Irrigation requirement + Reservoir surface evaporation + Seepage and percolation loss

More accurate results can be obtained if calculations are done on a daily basis, which would however, require rather long calculations to be made, which make the work boring and difficult. If a monthly basis is considered, then calculations are easy but results are less accurate, given that the duration between data is long and as such, there may not be a sense of uniformity in the abovementioned components. This leaves the weekly calculations as the best method.

Seasonal Planning in Inginimitiya

Inginimitiya is a major irrigation system in the Mi Oya River basin. The reservoir is located in the Galgamuwa electorate in the Kurunegala District. The irrigation command area is situated in the Anamaduwa and Nawagattegama electorates in the Puttalam District. The total cultivation area is 2,650 ha. The average rainfall is 800 mm – 900 mm annually. Inginimitiya is considered to be a system that faces very serious levels of water scarcity. The average cropping intensity for the system before was 1.0 indicating that cultivation was done every other season. The author understood the need for improvement in the system and decided to change the method used in the seasonal planning that was practiced. This paper presents the author's experiences as the Irrigation Engineer for this system since the beginning of year 2000.

By the year 2000, rainfall and cultivation data for 15 years and inflow data for 7 years were available. I (the author of this paper) analyzed this data in a simple way. Abnormal cases were removed and afterwards, the average inflow for each month of the year was obtained using the balance data. I also understood that precipitation from convectional and inter-monsoon rains during March to May are higher than the north-east monsoon. Therefore, I took a risk without any doubt to analyze the database available for periods mentioned above.

Standard practice of the Irrigation Department is to consider 7 ft. (2.13 m) as the water duty in the *yala* season cultivation planning (Ponrajah 1988). But considering past duties and in a rational analysis, it was assumed that 5.5 ft. (1.68 m) is the overall duty for the whole season. Here, crop water requirements, field irrigation requirements or irrigation requirements were not calculated; instead the assumed total seasonal duty was divided based on the growth stages of the crop so as to calculate the irrigation requirement for the total cultivation area.

Pan evaporation data for either the area close to the reservoir or in the cultivation area was not available in the office. As such, water surface evaporation was calculated based on the evaporation factors of the Tabbowa evaporation station in the same river basin. Based on Ponrajah (1988), monthly seepage and percolation loss was assumed to be at 0.5 % of the monthly average storage. The above water balance equation was thereafter, applied using an 'Excel' worksheet. For storages at the end of each week, the respective water levels were decided using the area-capacity curve. The relevant data was plotted against respective weeks on an A4 size paper. This was used as the tool for the main reservoir water level operation for the whole season.

I (the author of this paper) submitted this plan to the Kanne meeting, which was chaired by the District Secretary, Puttalam. He was very pleased with the plan. I explained the plan at the Kanne meeting in very simple terms, so that farmers could understand. Farmers were encouraged to use rainwater as much as possible. The ancient farmers' water saving techniques were introduced in a new approach.

Implementation and Monitoring

After commencing the water issues for the season, the reservoir water level was measured everyday using the installed gauge and the actual water levels were plotted in the same sheet. To know the problems in the field, I (the author of this paper) introduced field log books to each farmer organization. Departmental irrigators referred these books daily and reported to my office on the same day, which helped to make the necessary flow adjustments expediently. I visited the field with relevant field staff fortnightly. The problems in the field were solved in the field itself. The runoff water, which flowed through the cultivation area, was diverted to the left bank and right bank main canals in two places. This practice reduced water discharges from the main reservoir (sluice discharges) to a great extent and the water level could be monitored easily.

Results

By using this method I (the author of this paper) obtained the following results:

1. 2002 *yala* duty was 4.2 ft. (1.28 m).
2. In 2002 and 2003 the cropping intensity was 2.0 (200 %).
3. I could persuade farmers that my calculations and analyses were correct, which in turn helped me to win the trust and confidence of the farmers, and thereby minimizing the incidence of troubles and unnecessary problems.
4. Farmers' income was increased as the cropping intensity increased.
5. The department was given recognition and considered to be credible.
6. I was commended by farmers and the District Secretary Puttalam.
7. The next season could be started even with a small storage in the reservoir, but expecting a prospective inflow.

Discussion

The forecast I (the author of this paper) made was more than 90 % accurate, even though very advanced theories and complex analyses were not used. The main reasons for this success were,

1. Accurate forecast of components in the water balance equation.
2. Establishing trust among farmers.
3. Integrated approach to water management, taken by Irrigation Engineer's office, Project Manager's office and Farmer Organizations

4. My keen interest on water management.

5. My close monitoring.

I applied the same method for the Kaudulla scheme in Medirigiriya from 2004 to 2006, there again I was able to generate very good results.

Conclusion

It is the author's belief that this method is not specific to the Inginimitiya and Kaudulla schemes; rather it can be applied for all other major schemes as well. This method can even be applied for small schemes as well. If however, it is applied for small schemes, a greater effort will have to be expended to account for the fact that farmers in small schemes are relatively poorer than those who are in major schemes. However, very good water productivity can be obtained even in the small schemes if this method is effectively applied.

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The System of Rice Intensification (SRI) and Food Security among the Poor: Opportunities and Constraints

W. G. Somaratne
Advocacy and Program Policy Manager, Oxfam Australia, Sri Lanka Office, Colombo, Sri Lanka

Abstract

The Global Triple 'F' Crises (Fuel, Food and Financial) caused the escalation in food prices during last 2 years in the global food market. The crises created detrimental effects in developing countries, including Sri Lanka and her food market, in general, and her food security, in particular.

The objective of this paper is to examine the opportunities and constraints in promoting System of Rice Intensification (SRI) to maintain food security among the poor at the household level in Sri Lanka.

The economics of SRI, and its entailing opportunities and constraints in maintaining food security among the poor in Sri Lanka, were analyzed. The upward productivity shift and eco-friendliness of SRI and the attending saving of scarce water resources and reduction of cost of production, created opportunities for farmers to maintain food security among the poor. The constraints in promoting food security through SRI too, were analyzed. Furthermore, the strategic policy and operational options to promote SRI and maintain food security among the poor in Sri Lanka were proposed.

It is absolutely necessary to promote SRI to enhance a sustainable and eco-friendly food production system and to maintain food security among the poor. It will be a new paradigm shift in the right direction to maintain increased food production and food security in the country.

Introduction

The Global Triple 'F' Crises (Fuel, Food and Financial) struck during the years of 2007 and 2008. They have mainly affected the global economy but have also posed a range of complex challenges and threats for the Sri Lankan economy. One such threat that is of particular relevance, is the threat to Sri Lanka's achievement of the Millennium Development Goals (MDGs) of halving extreme poverty and hunger, which are directly threatening people's right to food. Despite the crises, many other actors in the food industry in developed and other countries managed to increase their speculative benefits, generated through increased prices of food (Oxfam International 2009).

During 2008, we witnessed an unprecedented escalation in global food prices and a reduction in the availability of food and feed stocks. The mounting trend in international food prices accelerated in 2008. U.S. wheat export prices increased from US$375/tonne in January to US$440/tonne in March 2008, and Thai white rice export prices (FOB) increased from US$385/ tonne in January 2008 to US$764.25/tonne in September 2008. Such rises came on top of a 181 % increase in global wheat prices over the 36 months leading up to February 2008, and an 83 % increase in overall global food prices over the same period (World Bank 2008). Oxfam International predicted that the hike in global food prices would propel an additional 119 million people into hunger in 2008, resulting in a total of around 967 million people in hunger worldwide (Oxfam International 2009).

The recent increase in food prices can be attributed to the sharp rise in the demand for food (through consumerism from rapid economic growth in many developing countries, particularly in China and India), which has collided with a decline in supply. The supply decrease has been fuelled by reduced yields owing to climate change and the diversion of farm produce to biofuel production as a substitute for fossil fuels in many developing countries. The resultant food price increase from these forces will directly impact on the food industry and food security of the poor even in Sri Lanka on either side of the threshold of subsistence.

Rice is the staple food product in Sri Lanka. Concerns on availability, accessibility and affordability of rice, at national, regional and household levels are central to any discussion on food security in Sri Lanka. Traditionally, there has been strong government intervention in the rice sector with the majority of Sri Lankan farmers maintaining their livelihood through rice production, processing and marketing (including distribution). Accordingly, growth in the Sri Lankan agricultural sector can be attributed to: investment in technology transfer; research and development (R&D); human capital improvement; maintenance of government extension services; and the development of irrigation infrastructure and road networks to improve access to markets. As a result of this investment, the rice sector has maintained a 96-99 % level of self-sufficiency during the last two decades.

Government institutions (e.g., the Government Agent and its regional administrative system including the Department of Agrarian Development) mainly operate in the delivery of production subsidies (i.e., fertilizer, agricultural credit, irrigated water, extension etc.). In addition, the Paddy Marketing Board, Lak-Sathosa outlets, and island-wide co-operative networks are involved in purchasing paddy at the farm gate, milling/processing, and distributing rice throughout the island, and compete with the private sector to deliver rice stocks to consumers.

In this context, the government has devised and operationalized a range of trade policy-tools (e.g., low tariff, export controls, controlled retail price mechanisms etc.,) and micro-level policy options to safeguard the interest of both farmers and consumers and has managed to maintain food security in the country (Somaratne 2009). Regardless of these interventions, it is likely that for the next few seasons further sharp price hikes and continued volatility will be experienced as a result of unforeseen events inflicted by the global financial crises in the economic environment. Domestically, most private sector paddy millers controlled the supply of rice to the market during the food crisis and maintained their speculative profit-seeking behavior. At the same time it was clear that at the advent of the crisis, government intervention was very weak resulting in diminished stocks of rice and ineffective government food distribution mechanisms. During the crisis in 2007-2008, there were no buffer paddy stocks in government stores island-wide and there were no opportunities to purchase paddy stocks from farmers at the farm gate (Somaratne 2009). Consequently, drastic price increases in various rice varieties at the market were observed during 2007 and 2008 (Table 1).

Table 1. Average annual retail prices (Rs/Kg) of various rice varieties (2006-2008).

Product	2006	2007	% Change (Compared with 2006)	2008	% Change (Compared with 2007)
Varieties of Rice					
Samba – Grade 1	41.90	49.64	18.5	82.33	65.9
Samba – Grade 2	38.66	45.48	17.6	77.77	71.0
Samba – Grade 3	35.78	42.62	19.1	72.60	70.3
Nadu – Grade 1	33.04	42.48	28.6	68.36	60.9
Nadu – Grade 2	30.14	39.34	30.5	65.01	65.3
Raw – Red	31.11	43.35	39.3	66.64	53.7
Raw – White	29.69	38.26	28.9	63.97	66.9

In this respect, Sri Lanka adopted a strategic policy mix and operational options to reduce the price impact and improve food production through initiating supply side interventions to maintain food security in the country. System of Rice Intensification (SRI)[1] is practiced in various parts of Sri Lanka since 2000. In 2002. Oxfam Australia began to promote and open up opportunities among the poor farmers in various districts in Sri Lanka with the objective of facilitating them to maintain their household food security. The SRI network (SRIN) was established in 2007 in collaboration with other INGOs, NGOs, CBOs and other government organizations, which promote environmental- friendly (i.e., free of agro-chemicals, and moving away from using chemical fertilizer), low-cost, high-productive paddy/rice production in the country.

[1] System of Rice Intensification (SRI) emerged in the 1980s as a synthesis of locally advantageous rice production practices encountered in Madagascar by Rev. Father Henri de Laulanie, a Jesuit Priest who had been working there since 1961. But, it is Professor Norman Uphoff from Cornell International Institute for Food and Agriculture, Ithaca, USA, who had brought this method to the notice of outside world in the late 1990s. Today SRI is being adopted in many countries in Asia, Africa and Central America as well as South American countries, and the response from farmers has been overwhelming seeing the benefits of the method, notwithstanding the constraints.

The objective of this paper is to examine the relationship between System of Rice Intensification (SRI)[2] and food security, and to identify opportunities and constraints in promoting SRI paddy production to maintain food security among the poor.

This paper is organized as follows: Section 1 (Introduction) presents a brief introduction of global food crisis and its challenges faced in the Sri Lankan economy. Section 2 (System of Rice Intensification (SRI) and Food Security) explains the relationship between SRI and the food security. Section 3 (Economics of SRI Vs Non-SRI (or Conventional Transplanting) Practices of Growing Paddy) describes the economics of SRI Vs Non-SRI practices of growing paddy. Section 4 (Opportunities in SRI Rice Production) explains the opportunities available in SRI rice production. Section 5 (Constraints in SRI Rice Production and Promotion) discusses the constraints in promoting SRI to maintain food security among the poor in the country. Concluding remarks are included in Section 6 (Concluding Remarks).

System of Rice Intensification (SRI) and Food Security

Rice is the staple food item in more than half the world's population. The demand for rice increases with population increase in the world, and is expected to rise by a further 38 % increase in relation to the demand for rice within the next 30 years, according to the United Nations. Conventional paddy cultivation requires large volumes of water i.e., using the method of flooding. Due to growing scarcity of water in many parts of the globe, farmers are shifting to cultivation of less water-demanding methods and crops. In general, it is obvious that reduction in profitability owing to high input costs, low productivity and low prices of rice are also influencing the seasoned farmers and the younger generation of farmers to withdraw from paddy cultivation process in most parts of Sri Lanka. In this respect, strategic policy and operational options are required to make paddy cultivation more efficient in terms of: a) returns on farmer investments; b) lesser use of water resources; and c) possibility to maintain food security at the household level.

Paddy yield increased by more than 70 % between 1966 and 1999 with the introduction of modern high-yielding varieties, which were accompanied by new management practices such as farm mechanization and the replacement of biological fertilizers by chemical fertilizers along with

[2] SRI includes only six basic and new ideas (or practices) to grow paddy. It is not a technology to use in growing paddy**.** Under SRI, farmers have to follow the six new ideas, such as:

1**.** *Use young seedlings to preserve growth potential (however, DIRECT SEEDING is becoming an option); 2. Avoid trauma to the roots-transplant quickly, shallow, no inversion of root tips that will halt growth;*

3. Give plants wider spacing – one plant per hill and in square pattern to achieve 'edge effect';

4. Keep paddy soil moist but unfolded – mostly Aerobic, not continuously saturated;

5. Actively aerate the soil as much as possible; and

6. Enhance soil organic matter as much as possible.

Practices 1-3 stimulate plant growth; while practices 4-6 enhance the growth and health of roots and soil biota.

the ‘Green Revolution’ (Frei and Becker 2005). The existing system of paddy production, particularly the ‘Green Revolution’ technology, is input-intensive and favors capital and technology-rich farmers. Increasing prices of agricultural inputs (e.g., improved seed, chemical fertilizer, agro-chemicals and mechanized farm power) prevent poor farmers from completely adopting modern production technologies. It is clear that the excessive use of chemical fertilizers and agrochemicals (e.g., pesticides, insecticides and herbicides) damages soil biota and contaminates underground water resources, which in turn creates negative environmental and social externalities. In this respect, the system of rice intensification (with its low environmental cost and high yield), will be a sustainable alternative to conventional paddy production to protect the soil biota and safeguard the interest of the society (Uphoff 2002 and Uphoff 2004). Field experiences from some Asian, South American and African countries report that the average rice yield with SRI to be double the current average yield of the conventional practice. Uprety (2004) reports the average rice yield with (phenotype) SRI is 8 tonnes ha^{-1}, whereas the yield is 3 tonnes ha^{-1} under (geno-type) conventional paddy. The evaluation of 167 on-farm trials in Andhra Pradesh, India reports average yield obtained using SRI practices to be 8.1 tonnes ha^{-1}, compared with5.67 tonnes ha^{-1} using conventional practices (Sinha and Talati 2007).

In Sri Lanka, per capita rice consumption was around 100 kg per year. On this basis, if a family includes five members, they need 500 kg per year to maintain their household food security.[3] Accordingly, to be food secure at the household level, the conditions that farmers need to maintain are: availability; affordability (i.e., with income or purchasing power); and accessibility of food.

Economics of SRI versus Non-SRI (or Conventional Transplanting) Practices of Growing Paddy

Results presented in the next section are based on a farm household survey conducted in five districts, namely, Hambantota, Matara, Ampara, Kegalle and Anuradhapura. Data were collected from farmers who have grown irrigated paddy under both SRI and conventional transplanting. Data for the *maha* season 2007/08 were collected from 31 farmers who cultivated paddy with assistance given by Oxfam Australia, Sri Lanka Office. Partial budgeting analysis was considered appropriate to estimate the economic impact because only small relative changes on farm inputs (seed, fertilizer, water) had to be assessed, while all other variables remained the same. Gross margin per hectare of rice cultivated was calculated by subtracting variable costs from gross returns. To assess also the return to labor, the gross margin per man-day was calculated by dividing the gross-margin per hectare by the number of man-days used i.e., of family plus hired labor. Details on household members’ participation in rice farming were directly obtained during the farm-based questionnaire survey.

As shown in Table 2, the cost of production of growing paddy under SRI , based on gross margin analysis, was Rs. 91,148 per hectare (Rs. 36,902 per acre), compared to the cost of production (Rs. 101,685 per hectare or Rs 41,168) of paddy grown under conventional

[3] Food security exists when all people, at all times, have physical and economic access to enough safe and nutritious food to meet their dietary needs and food preferences for an active and healthy lifestyle.

transplanting (i.e., non-SRI), which was 12 % lower than the non-SRI paddy cultivation. Among the farmers interviewed, the cost of production of SRI paddy was lower due to lower seed rate, non use of agrochemicals, and the low cost of fertilizer. The unit cost of production under SRI was lower by 27%, compared to non-SRI paddy production.

Table 2. Cost of production and the level of land, labor and capital productivity in SRI and non-SRI paddy production in *maha* season 2007/2008.

Components	Unit	SRI	Non-SRI	Difference	% Share
1. Cost of Production:					
Cost of Production(including family labor)	Rs/ha	91,148	101,685	10,537	11.6
Cost of Production (excluding family labor)	Rs/ha	60,026	77,973	17,947	29.9
Cost of Production (including family labor)	Rs/ha	20.00	25.35	-5.35	-26.8
Cost of Production (excluding family labor)	Rs/ha	13.16	19.44	-6.28	-47.7
2. Seed Rate Used	Rs/ha	10	306	-296	-2997.2
3. Land Productivity	Rs/ha	4,560	4,011	549	13.7
4. Farm Income					
Farm gate price (average)	Rs/kg	36	34	2	5.5
Gross farm income	Rs/ha	165,104	137,667	27,437	19.9
Net farm income (level of profit)	Rs/ha	73,956	35,982	37,974	105.5
Gross farm income per unit	Rs/ha	36.21	34.32	1.88	5.5
Net farm income per unit	Rs/kg	16.22	8.97	7.25	80.8
5. Capital Productivity					
Rate of returns on Investment	%	81.1	35.4	45.8	
6. Labor Productivity					
Number of man-days used:					
Including family labor	Md/ha	132	111	21	15.9
Excluding family labor	Md/ha	54	52	2	3.7
Labor productivity	Kgs/md	34.5	36.1	-2	-4.6
Value of labor productivity (Gross)	Rs/md	1,251	1,240	11	0.8
Value of labor productivity (net)	Rs/md	560	273	288	51.3
7. Rate of Availability of Rice –(rate of food security)[a]	[a]No of Persons	34	27	7	20.2
Value of increased net productivity under SRI	Rs/ha	19,879[b]			

Source: SRI On-Farm Survey, Oxfam Australia (2009)

Notes: [a] The mill out turn considered as 75 % for SRI rice and 68 % for non-SRI rice
[b] The value of increased productivity per acre is Rs. 8,048

The land productivity in the SRI was higher than that of the conventional method by 549 kg ha^{-1} (13.7 %). However, this is lower when compared with the potential for land productivity of around 8,000 kgha^{-1} reported in India. The gross and net farm income was estimated by using gross margin analysis under both SRI and non-SRI methods. In particular, farm gate price was higher for SRI paddy by about 6 % owing to the high outturn of paddy with less chalkiness and less rate of broken rice (Table 2). The gross farm income and net farm income (or profitability) was higher in SRI by about 20 and 106 %, respectively, with higher productivity and farm gate prices. Considering all, the rate of return on investment in SRI rice production was about 81 % when compared to the same (35 %) in non-SRI rice production. This indicates the favorable position of SRI farmers to improve capital productivity to invest in the process further.

SRI production process is a labor-intensive production system. The labor productivity was lower by 4.8 % in SRI process than the non-SRI process (Table 2). However, the value of labor productivity was higher in SRI process both in terms of gross and net value of labor productivity, owing to the higher farm gate prices of SRI paddy.

The level of household food security that can be reached was estimated based on the national level per capita rice consumption of 100 kg per year. Accordingly, the number of people who can use the amount of per capita availability of rice at the farm level under both SRI and non-SRI methods were estimated. In that respect, if farmers use the SRI methods, they are in a position to improve their household level food security at a level that is 20.2 % higher compared to non-SRI farmers. The value of increased net productivity (kg/ha) with the SRI method was estimated as Rs 19,879 per hectare (or Rs. 8,048 per acre), which assists either way to maintain food security at the farm level (Table 2).

As shown in Table 3, considering the benefits of SRI paddy production (including the value of straw production used as organic fertilizer) and cost of production, the benefit cost ratio was estimated. The benefit cost ratio on SRI practices was higher than non-SRI practices. The benefit cost ratio for the *maha* season 2007/2008 was lower than the benefit cost ratio for the *yala* 2008 season due to the higher level of land productivity. Evidence from the SRI farms in districts surveyed suggests that SRI is economically attractive and that the productivity of land, capital and labor, increases significantly relative to conventional paddy farming. Furthermore, the net gains on SRI practices in terms of income from paddy, gross returns, net returns and less cost of production were higher for SRI than for non-SRI.

Table 3. Economics of cultivation of paddy under SRI and conventional methods and net gains on SRI.

Component	Unit	Non-SRI Practices	SRI Practices	Net Gains	% Share of Net Games
Income from paddy	Rs/hec	137,677	165,104	27,427	19.9
Income from straw [a]	Rs/hec	1,525	1,112	-413	-27.1
Gross return	Rs/hec	139,202	166,216	27,014	19.4
Cost of cultivation	Rs/hec	101,685	91,148	-10,537	-10.4
Net return	Rs/hec	37,517	75,068	37,551	100.1
B:C Ratio (*maha* 2007/08)		1.4	1.8	0.5	33.2
B:C Ratio (*yala* 2008)[b]		1.5	2.6	1.1	73.3

Source: On-Farm Survey, *Maha* 2007/2008, Oxfam Australia (2009)

Notes: [a] It is assumed that based on nutrient analysis, 30 % of fertilizer requirement per hectare is obtained from straw
[b] Based on provisional data, compiled and analyzed by Oxfam Australia (2009)

Opportunities in SRI Rice Production

In Sri Lanka, the practice of SRI among farmers began in the year 2000 in the Kurunegala District (Namara et al. 2003). Various government organizations, INGOs, NGOs, and CBOs promoted opportunities for farmers to adopt SRI practices/methods to improve productivity and reduce cost and thereby improve food security at the farm level. The SRI network (SRIN) was formed in 2008 as an umbrella organization to facilitate the promotion of SRI.

Technological and Production Aspects

In the Hambantota, Ampara, Matara, Kegalle and Anuradhapura districts, there has been only a partial adoption of standard practices of SRI, and this too mostly among small farmers. All farmers are following the requirement of early transplantation, single seedling per hill and wide spacing of seedlings. Most farmers have followed practices in the management of water, fertilizer, and weeding. The farmers concentrated on preparing drainage channels for water management on SRI, which is crucial to facilitate alternate wetting and drying. Most farmers weeded three times during the season to practice soil aeration to improve soil biota. None of the farmers identified or encountered pest damages during the season. Most farmers managed to reduce cost of production by applying zero level of agro-chemicals and reduced seed rate of about 7.5- 10 kg per acre when compared to the rate of 40-100 kg/ha in conventional practice. The farms where the SRI package was followed in a better manner produced higher yield or output, especially those farms on which weeding was practiced more than twice seasonally, indicating that possibilities exist for many farmers to increase average yield further, and with sustainability. In SRI practices, farmers have the opportunity to select either traditional or high-yielding varieties to grow in order to increase production and thereby improve food security.

It has clearly been shown therefore, that opportunities were opened for farmers to adopt the high productive SRI method of growing paddy, followed by environmental-friendly methods (with zero agro-chemicals use) to maintain sustainable farming systems and generate economic and environmental benefits to maintain long-term food security and sustainability of the system.

Quality Improvement and Food Security

Within the system of SRI, there is an opportunity to harvest 10-14 days early, when farmers use young seedlings. From the farmers' point of view, early harvesting is an additional advantage to obtain higher farm-gate prices. In addition, farmers are able to obtain 100 % filled grain, which gives the highest milling out turn compared to half-filled or three-fourths filled rice produced through the conventional system of growing paddy. Though the volume is the same, the SRI paddy gives the highest weight when compared to conventional paddy, and this factor attracts farmers to move from growing conventional paddy to SRI paddy by improving the quality of rice in order to obtain higher market prices.

Once the 100 % filled grain (paddy) is processed, the keeping quality of rice and the shelf-life of SRI rice can be maintained better than those of the conventional rice. This type of paddy, therefore, gives more opportunities for consumers to maintain the taste and the shelf-life of rice and thereby improve food security. Ultimately, the SRI system will further help us to promote SRI rice among other consumer groups as a niche product to attract them.

There is an opportunity to shift from chemical fertilizer to organic fertilizer through the introduction of SRI methods. In view of existing chemical fertilizer use, SLR 40 billion has been spent on fertilizer subsidies for paddy production in 2008. There is a need therefore, to reduce the cost of fertilizer subsidy. Hence, there is a potential to promote alternative methods like SRI to maintain food security sustainably among the poor in the country. In this respect, the promotion of SRI is one of the strategic options in the right direction in creating opportunities for farmers.

Constraints in SRI Rice Production and Promotion

Thirty-two countries in the world, including India, have already implemented programs to promote SRI practices/methods with the support of government departments of agriculture and the other government organizations. Government organizations in Sri Lanka, however, are still showing a lukewarm attitude to SRI. However, the community-based interventions were initiated by INGOs, NGOs and CBOs. These efforts were later integrated through the SRI network to gain the full potential for promoting SRI methods to improve productivity and maintain food security at the farm level with quality, especially in the southern and eastern regions.

As SRI is a labor-intensive system of paddy production, it is important to develop new methods and technology to minimize or save labor, in particular for weeding through investing in R&D on developing a motorized weeder or through improvement of the mechanized weeder. For these purposes, government patronage is essential to find resources and capacities for conducting research programs. Even in India, now they are at the experimental stage of producing a mechanized weeder, which would be utilized to reduce labor time and cost. Government could collaborate with other organizations and develop initiatives for developing a motorized weeder.

The issues in water management in major irrigated areas can be resolved through the introduction of cultivation plans and using water wisely by introducing paddy with SRI methods in whole *'yaya'* area programs (contagious tracts of rice) to promote SRI. SRI needs less water than conventional paddy cultivation. In India, they have managed to save 40 % of water that is usually required in conventional paddy cultivation through the introduction of SRI methods. At present, they are in the process of shifting from conventional paddy cultivation to SRI to be better prepared to face the challenges in future water use in the light of global warming and climate change.

Concluding Remarks

SRI is not a technology. It is a multi-component 'package' including six basic ideas/practices and methods that can be easily followed to improve productivity, and tonne-produce rice of a higher quality at a lower cost as a pesticide-free product. Farmers tend to focus initially on just one or two of the components, rather than adopting the entire recommended package with the six basic ideas/ practices. There is a considerable diversity in how the individual farmer can adopt and implement the proposed package of SRI. This study shows that SRI adoption has enabled farmers to reduce the cost of production consistently (with low seed rate and no agro-chemicals), enhance the level of productivity, and increase the rate of returns. SRI appears to be a significant alternative with an opportunity for raising paddy yields and managing paddy-based farming generally in resource-scarce regions, and particularly in water-scarce regions. With SRI, the total cost is less while productivity is high, thus it is likely to find acceptance among poor farmers and open up opportunities for them to improve their food security at the household level. Once the productivity is higher, farmers can gain an opportunity to improve food security either through utilizing the increased production or earning additional income by selling the products based on an increased quantity of rice. In this direction, farmers tend to improve food security at the household level either way.

One of the major constraints to the adoption of SRI is the lack of interest shown by the government and its institutions in the promotion of SRI as an alternative method for livelihood development, and to maintain food security. Active involvement of the Department of Agriculture (DOA) is a must to promote SRI as a national level program. Furthermore, the government needs to invest in a R&D program to develop labor-saving devices like motorized weeders to minimize the cost of production.

SRI is still evolving and more experiments are being done in different districts through various INGOs, NGOs and CBOs. These initiatives reveal important issues for research, particularly the lack of scientific basis and data on actual water savings with SRI. It is necessary to develop a study to measure how far SRI methods can be used for water savings to create an efficient and sustainable production process. SRI involves less water application in the process through alternate wetting and drying without flooding, as in conventional paddy farming. Areas for further research include scientific investigation in the use of water under the SRI method, and understanding the opportunities for promotion of SRI as a sustainable process for improving food security in the country, in general, and at the farm level, in particular.

Considering the potential of improving productivity, lowering the cost of production, enhancing environmental friendliness and improving quality of rice, paddy/rice production is approaching a new era to maintain food security through SRI. It is a paradigm shift in the right direction in the agricultural production process in Sri Lanka to increase production, in general, and maintain food security and increased production and farm income at the farm level and to develop a sustainable production process, in particular.

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Integrating Agroforestry Characteristics into Agro-well-based Agriculture

Muditha Perera
Lecturer, Department of Geography, University of Peradeniya, Sri Lanka

Abstract

The major challenge for the dry-zone farmers in non-irrigated areas in Sri Lanka is water scarcity. This situation is a major barrier to the sustainable use of resources and maintaining income generation activities throughout the year. In this context, these farmers realized the need for another source of water. The strategy was the construction of large diameter wells (agro-wells) to tap the shallow groundwater in low-lying areas, either near the small tanks or the small streams. Since 1982, the rate of construction of agro-wells has accelerated with the interventions of the Agricultural Development Authority and the Provincial Council. Generally, cultivation of perennial crops using agro-wells is not common. Only seasonal crops are cultivated and income was obtained only during a particular period. As a new trend, some farmers in the dry zone of Sri Lanka used this shallow groundwater opportunity to cultivate perennial crops as well as seasonal crops throughout the year. Furthermore, farmers aimed to grow woody tree species for their timber requirements and economic purposes in their own agricultural land. A lot of farmers have realized that these woody trees such as teak and halmilla may be disturbing their crops. Therefore, they moved these trees to the marginal areas or tail end of the lands. In addition, some farmers attempted to maintain animal husbandry such as rearing cows under the perennial crops, using the shade and grass under the trees. This context provided a unique opportunity to explore this new land use pattern revealed in the dry zone of Sri Lanka, recently. Field research for this study was conducted covering 20 agro-well-based agricultural lands out of the total of 68 in the ‘Aluth Divulwewa sub-watershed’ in ‘Yan Oya watershed’, in the dry zone of Sri Lanka. The collected data was analyzed using qualitative and quantitative methods. The land equivalent ratio (LER) has revealed that 90 % of the lands represent more productivity, and canopy cover has increased up to 41.5 % from 7.9 %. Further, evolution, composition, characteristics, layers, and spatial arrangements of these land use patterns, represent 100 % of agroforestry characteristics according to Nair’s classifications. Thus, this context has successfully proven that these agro-well-based agricultural lands have been converted into ‘more productive and diversified agricultural systems’ with agroforestry characteristics.

Introduction

The major challenge for farmers in non-irrigated areas in the dry zone of Sri Lanka is water scarcity. This situation is a major barrier to the efficient use of resources and to maintain income generation activities throughout the year. The use of a supplementary source of water is essential. The construction of large diameter wells (agro-wells) to tap shallow groundwater was identified as a potential solution. Agro-wells were constructed in low lying areas, either near small tanks or small streams. The rate of construction of agro-wells has accelerated with the interventions of the Agricultural Development Authority that began in 1982, and later by the interventions of the Provincial Councils.

Seasonal crops are cultivated using agro-wells. The use of water from agro-wells to irrigate perennial crops is not common. Therefore, regular income is received only during a particular period. A new trend is emerging of utilizing the shallow groundwater opportunity to cultivate perennial crops in addition to seasonal crops. Farmers include woody tree species for timber requirements and economic purposes. As farmers recognized that woody trees, such as teak and *halmilla*, disturb other crops, they moved trees to the peripheral areas of their lands or to tail ends of surface irrigation ditches. Some farmers attempted to incorporate animal husbandry such as rearing cows under the perennial crops, using the shade and grass under the trees. This study explores this emerging land use pattern in the dry zone of Sri Lanka.

Methodology

The objective of this study was to understand the holistic background of the agro-well based agriculture, such as a) the nature of shallow groundwater utilization, b) the nature of the agro-wells, c) historical changes in land use pattern and current land use d) characteristics of farms including, canopy cover and structures and species composition and e) documented agronomic practices.

Field research for this study was conducted in the Aluth Divulwewa sub watershed in the Yan Oya watershed in the dry zone of Sri Lanka. Twenty agro-well based farms, out of the total of 68, were selected using the purposive sampling method. A structured survey schedule was used to gather respondents' perceptions as well as historical and current information. This was supplemented by a field survey, field mapping, aerial photograph analysis, interviews and field observations. Land equivalent ratio (LER value) was used as the measure of land productivity. This is calculated as the sum of ratios of yields of an intercrop and the potential yield of the same crop if planted as a single crop in the same land area. LER for land with intercrops is obtained by using the following equation by Nair (1990).

(1) Land equivalent ratio $LER = Ry_{1} + Ry_{2} + \ldots + Ry_{n}$

Where, Ryi is the intercrop yield for i^{th} crop/sole crop yield of the i^{th} crop

Results and Discussions

There are two main factors that determine the distribution of the agro-well based agriculture in the Aluth Divul Wewa sub watershed area. They are a) the availability of comparatively low lying lands, and b) availability of roads / accessibility. Aluth Divul Wewa sub watershed is naturally rich with groundwater because of the two mountain ranges situated in its eastern and western boundaries. Chena lands situated in low lying land areas were the most popular lands for excavating agro-wells. Farmers have constructed agro-wells in the vicinity of small tanks or near seasonal streams. According to Dharmasena (1998) there should be a minimum distance of 100 m between two wells due to the shallow groundwater situation in the dry zone of Sri Lanka. This scientific guideline is naturally followed in the study area due to large land extents. All the farmers have 2-5 acres of lands.

There are two major trends in land utilization patterns, a) the decrease in chena (shifting) cultivation, and b) increase in the use of agro-wells. The percentage of lands allocated to chena of all cultivated highlands has declined from 30 % in 1994 to 22 % in 2004. Land under agro-wells has increased from a mere 0.3% to 6% during the same period.

A large majority of farmers (80 %) cultivate crops using agro-wells as the sole source of irrigation. Twenty percent of farmers irrigate their fields using both agro-wells and minor tanks. Farmers usually cultivate chilies, brinjals, soybean, pumpkin, ma-beans, green-gram, bitter-gourd, bottle-gourds, *thibbatu*, okra, and manioc as seasonal crops, during either or both *maha* and *yala* seasons. However, farmers in general do not get enough returns to meet all their annual household needs. Income from seasonal crops is usually spent on debts and day-to-day requirements. Farmers usually do not accumulate any savings.

In this context some farmers incorporate perennial crops such as coconut, jack, lime, tangerine, orange, mango, guava, breadfruits, cashew, drumsticks, betel-leaves, and banana, to increase productivity and to ensure that the flow of income from their lands is smooth. These farmers invest in perennial crops as a mixed system with seasonal crops. (Figures 1 and 2). In such a system, irrigation has to fulfill the water needs of both seasonal and perennial crops simultaneously.

Figure 1. A large diameter agro-well with coconut trees in the background.

Figure 2. Agro-well farming unit with seasonal ground layer crops and perennial crops in the periphery.

A considerable fraction of farmers reserve a part of their land for timber trees such as teak. Timber trees are usually grown in the periphery of the farm and at the tail ends of irrigation ditches. Farmers also plant live fences using Glidsiria sepium, teak, and kohomba (margossa) with the expectation of meeting firewood and timber needs. In addition, lots of farmers grow many timber trees in their lands for economic purposes. This was an easy income-generation activity using degraded areas of their agro-well based lands.

Other than crops, farmers practice animal husbandry as a part of the cropping system. They especially like rearing cows because of the low cost. Fifteen percent of the farmers in the study area practice rearing cows in their agro-well based farmland using tree shade and ground layer grasses in the proximity of the agro-wells. They supplement the household requirements of milk and get extra income by transporting and selling the cow milk to the internal or external market, daily or weekly.

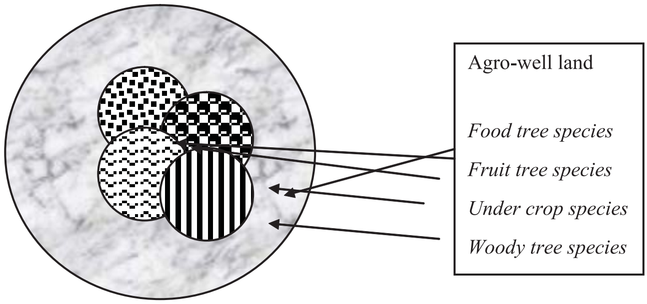
These agro-well based lands convert to 'seasonal and perennial cultivation system with woody trees' or 'seasonal and perennial cultivation system with woody trees and animal husbandry' within 5- 6 years. With this background, cropping pattern under these agro-wells, are being converted to 'agroforestry systems'.

Interventions

All the farmers have integrated trees into these systems and all farmers develop their lands every year. This situation tends to increase the number of trees in their lands. Farmers have introduced various 'food trees', 'fruit trees', 'under crops', as well as 'woody trees' to this area, in addition to the seasonal crops (Figure 3).

Farmers cultivate these trees around the agro-well or around the hut (dwelling within the farmland) according to the water requirment or labor requirement. Crops requiring more water such as tempering leaves, ginger and sugercane are placed around the well. More labour required crops such as friut trees are placed around the hut. The result was the emergence of many diverse crop lands.

Figure 3. Various tree types based on utility.

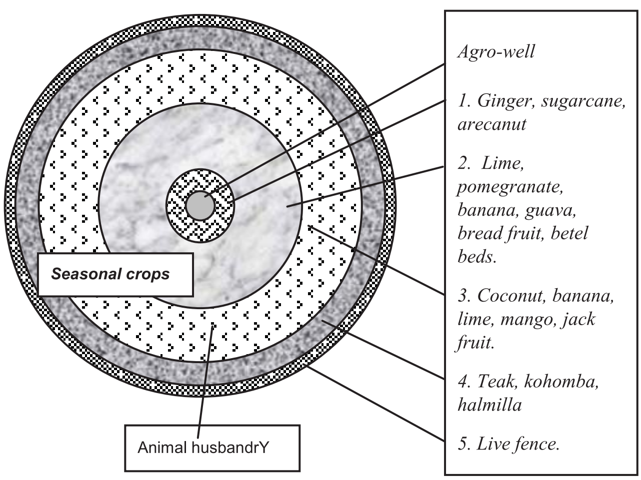


A general spatial pattern of the location of different trees in this cropping system can be identified. The trees with greater water needs and that require a high level of maintenance are grown around the well. Farmers especially use short crops or trees for this zone due to damages from leaves and roots to the well. Eighty-five percent of agro-wells showed this pattern. The composition of several zones that are arranged in concentric rings around the agro-well can be identified. The species composition of these zones with increasing distance from the agro-well are:

1. Ginger, sugarcane, arecanut;
2. Lime, pomegranate, banana, guava, bread fruit, betel beds, with seasonal crops;
3. Coconut, banana, lime, mango, jack fruit with seasonal crops and / or animal husbandry;
4. Teak, *kohomba*, *halmilla* with or without seasonal crops and;
5. Live fence.

This generalized pattern of all agro-well lands, is illustrated using the sketch diagram in Figure 4.

Figure 4. Generalized spatial distribution of these systems*.



* *Source*: - Field survey

Tree Stratification

Further, there is an obvious pattern of tree stratification in this farming system. Different strata mimic the morphology and the function a forest. There are five identifiable components in a well developed land:

1. Seasonal crops/paddy
2. Beetle beds, thibbatu
3. banana, lime
4. mango, jack
5. coconut teak

One hundred percent of well-developed lands represent successful tree stratification. At least three layers can be identified in all lands. The most common components are, 'seasonal crops/paddy', 'banana/lime', and 'coconut/teak'.

Conservation Farming

Motivated by water scarcity and the need to avoid further land degradation, farmers in the area use various conservation farming practices. They also need strong boundary fences for the protection of their crops from wild animals. Inexpensive methods of fencing using trees including Gliricidia sepium are practiced. In addition farmers are also using the leaves of Gliricidia and dry grass to enrich the soil of the lands further, and for animal husbandry. One hundred percent of the farmers use live fences and dry field systems. The dry field system helps to control soil erosion and conserve limited water resources. Forty-five percent of farmers use the mulching system, using dry grass and paddy straw to improve their lands. In addition 20 % of farmers have practiced contour earth bunds for controlling soil erosion. (Table 1).

Table 1. Use of conservation strategies.

Conservation strategy	Number of lands on which method is practiced	Lands on which method is practiced as a % in total well-developed lands
Live fences	20	100
Earth bunds	4	20
Drains	4	20
Mulching	9	45
Dry field system	20	100

Source: Field survey

Canopy Covert Development

The development of canopy cover helps to conserve soil moisture, reduce soil erosion, and maintain bio-diversity. The area under the perennial canopy has been increasing in every agro-well based land. Seventy percent of the lands have more than 30% of land area covered by perennial crops; while 25 % of the lands have more than 50 % of the land area covered by canopy.

Land Productivity and Income

The land equivalent ratio (LER) shows that that 90 % of farms reports higher land productivity than the moncocultured system. Twenty-five percent of the lands indicate LER values of more than 1.5. The highest land equivalent ratio (more than 1.75) is represented in 15 % of the lands. This background gives evidence to prove that the agro –well-based agricultural lands are more productive and effective land use systems when compared to the conventional systems.

Operators of all studied farms obtain year-round incomes. Fifteen percent of farmers obtain more than Rs. 100,000.00 annually and 60 % of farmers obtain more than Rs. 50,000.00 annually, using perennial and seasonal crops. In addition, 15 % of farmers earn annual incomes of around Rs. 50,000.00 from animal husbandry. In addition, these systems contribute vegetables, fruits, spices, firewood, timber, medicines, milk, shade, organic matter, fodder, soil moisture, wind breaks, and aesthetic value, as unquantified and unvalued benefits to the farm household.

Conclusion

This study will help to focus attention on issues and solutions on the need for a comprehensive approach to agro forestry cropping systems with water scarcity. The evolution, composition, characteristics, layers, and spatial arrangements of these land use patterns, represent 100 % of agroforestry characteristics according to Nair's classifications (Nair, 1990). Thus, this context has successfully proven that these agro-well-based lands have converted into 'more productive and diversified agricultural systems' with agroforestry characteristics.

According to our professionals (Panabokke, 2002), (Dharmasena 1994), there is a sufficient groundwater situation, in the dry zone of Sri Lanka during the north-east monsoon period, and a sufficient groundwater level in the vicinity of small tanks, throughout the year. Similarly there is an adequate groundwater level in the low lands and near the temporary dry streams. So, similar lands throughout the dry zone are suitable for constructing agro-wells using appropriate groundwater technology. Then the existing agro-well lands can be converted into more productive lands, with two or three cultivation periods, combining conservation farming, perennial trees, woody trees, and livestock.

This proves that, the attractive 'agro-well-based agroforestry systems' could be stabilized under these available agro-wells and potential lands in due course. Furthermore, it would be timely and very useful to adopt this trend for 'other degraded watersheds' in the dry and dry and intermediate zones of Sri Lanka.

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A Holistic Approach to Ensure Food Security through Cascade System Development in the Dry Zone of Sri Lanka – A Practice from Plan Sri Lanka

K. H. J. K. Harischandra
Presently works in 'Plan Sri Lanka' as the Project Leader in the Cascade System Development Project in Anuradhapura, Sri Lanka

Abstract

The lack of food security is caused by the disruption of agrarian systems, land fragmentation, lack of irrigable land, indebtedness and poor post harvest technology. The additional factors that are shown in secondary data are variable and erratic precipitation of farmer communities, poor development of hydraulic infrastructure and lack of access to water for domestic and productive uses, all of which further exacerbate poverty levels.

The economy of dry zone Sri Lanka is principally dependent on agriculture, on which over 85% of its population depend. As the rainfall distribution is largely unpredictable and uneven, communities have to rely, in addition to rainfall, on a system of complex cascade systems consisting of interdependent reservoirs (called 'tanks'). This ancient system strikes a delicate balance between water management and the physical and social environment. The condition of the cascades is vital for improving the availability of water in the community throughout the year. Tanks support the irrigation needs of farming households, and a variety of other uses – drinking, bathing and other domestic uses.

It is a deep rooted idea that irrigation infrastructure development is vital to address water related development issues. But, it is only a part of a broader range of necessary actions that need to be taken. In addition to physical improvement or physical capital improvements, the provision, retention and management of water in a water scarce environment depends on social, financial, natural and human capital that requires equal priority in development and protection.

Having realized the integrated nature of the systems of survival, 'Plan Sri Lanka' has designed and is implementing a holistic community development approach to cascade rehabilitation in the Anuradhapura District. The program involves restoration activities in five cascades covering 29 irrigation tanks that were selected based on hydrological viability .Farmer organizations that carry out tank restoration activities were provided technical support to ensure continuing follow-up operation and maintenance. They were also given training on appropriate farm technology and watershed management. Cascade management committees composed of

stakeholder representatives were also organized to coordinate development activities and resolve conflicts. Integrated agriculture schemes that incorporate suitable farming systems and improved cropping practices were introduced.

The approach identified the challenges that needed to be addressed and learning that was required by conventional approaches to water and food scarcity. These aspects could be addressed through comprehensive strategies that address a more holistic spectrum of issues. The paper discusses Plan Sri Lanka's experiences and lessons learned in implementing social, financial, physical and natural capital interventions that put the cascade as the operational unit for development. It will examine practical constraints and limitations that are faced in the implementation stage and the institutional and operational requirements which are to be discussed for further improvement in this kind of approach.

Introduction

The overall objectives of this paper are to discuss the reasons for the implementation and the realized results of a participatory project for the village irrigation communities in the Anuradhapura District in Sri Lanka. The project is designed and implemented by Plan Sri Lanka, a nongovernmental organization with over 27 years of work experience. The content of this paper is organized into four sections. This introduction is followed by the second section titled 'Project and Project Activities' that describes the project and its activities. The third section titled 'Immediate Results of the Project' presents the immediate outcome of the project while the fourth section titled 'Lessons Learnt and Recommendations for Future Interventions' discusses recommendations based on the lessons learned.

Project and Project Activities

The Project

For operational purposes the program areas of 'Plan Sri Lanka' are grouped into four main geographical zones out of which the north-western program area comprising the Polpithigama DS area in the Kurunegala District and Mahawilachiya, Anuradhapura Central and Medawachiya DS areas in the Anuradhapura District. Through a technical feasibility study, Plan identified 40 minor irrigation tanks that are hydrologically feasible within 12 hydrological feasible cascades in Mahawilachiya, Anuradhapura Central, Kahatagasdigiliya and Medawachiya DS areas. At present, Plan Sri Lanka is in the process of developing five cascades in Anuradhapura Central, Medawachiya and Mahawilachiya Divisional Secretary areas in an approach that encompasses the conservation and improvement of watershed areas of the tanks within the respective cascades, emphasizing the multiple usage of water for optimal productivity. The objective of the project is to increase household disposable income and to ensure food security of farm families in the dry zone cascades in the Anuradhapura District.

Community Mobilization

Sri Lanka has a long history of community-based organizations. However, prior to Plan initiated interventions, Farmer organizations (FOs) in the project location were dysfunctional, isolated and sometimes characterized by factional conflicts based on political patronage and sharing of resources. Although there is wide sweeping policy and legislative support for farmer organizations, there was a lack of effective mechanisms for service delivery in the project location, as the main plan for a service delivery mechanism sought to address the issues that affect the functionality of the FOs. Some of the key interventions that were conducted include a series of capacity building trainings for the farmer organizations on different aspects such as minor tanks development, operation and maintenance, integrated watershed management and multiple uses of cascade systems in Sri Lanka. Once the functionality of the FOs was established, a cascade management committee was established for each cascade to ensure that FOs worked together and were committed to managing resources efficiently and effectively. The lack of a strong single institution to manage the cascade is an issue in the process of embracing cascade principles into the planning process.

Partnering with Related Stakeholders

Minor tanks (cascades) development requires a multifaceted approach that needs effective involvement of all relevant line agencies such as the District Secretariat, Department of Agrarian Development , Divisional Secretariats , Department of Agriculture (inter-provincial) , Provincial Department of Agriculture, Provincial Department of Animal Production and Health, Forest Department, Department of Wildlife Conservation, Survey General's Department, Land Use Planning Unit, Coconut Cultivation Board, Sri Lanka Cashew Corporation ,Provincial Engineering Department (PID) and the National Aquaculture Development Authority (NAQDA). So at the beginning of the project, a Project Steering Committee (PSC) was formed with the chairmanship of the Government Agent of Anuradhapura District. The presence of all the relevant government agencies at the PSC meeting played a vital role in acting as a coordinating body at the district level to develop multiple uses of irrigation systems. All project plans are sent for approval to the District and Divisional Agricultural and the Coordination Committees. This avoids duplication of activities with other development agencies. Each partner organization has to present a status of their interventions at the PSC in relation to the original plan of action. This helps to verify that the project is in line with, and to identify barriers that hamper, the achievement of project objectives.

Physical Improvement and Catchments Area Development in Minor Tanks

After community mobilization the physical improvement of the tanks was initiated and Tank rehabilitation was done through the participation of farmer organizations and by assigning them to carryout rehabilitation activities (Figures 1 and 2)). Farmer consultation meetings were conducted to identify rehabilitation priorities and construction estimates were prepared in accordance with those priorities. The forest reservations in some tanks were demarcated and some reservations were reforested to provide favorable conditions for tank systems (Figure 3). The reforestation activities were carried out by the children's club with the technical support of the Department of Forest Conservation.

Figures 1 and 2. The bund is being repaired in Ethdathkalla.

(1)

(2)

Figure 3. Contour lining for soil water conservation bunds.

Partner Capacity Building

In consultation with the project steering committee and after a needs assessment, several partner training series were conducted in order to develop capacities of field level extension workers. The lack of knowledge on integrated watershed management was a challenging problem right from the beginning. The knowledge on the concept of cascades and integrated watershed management was improved through training, and technical skills on soil and water conservation were improved through training given by the Natural Resources Management Center of the Department of Agriculture. Training skills in turn were improved by providing training programs for the trainers themselves.

Inland Fishery with Selected Tanks

Traditionally, inland fisheries partly fulfilled the nutrition needs of these communities and it was imperative to re-introduce these sources of food intake to address poverty and food insecurity. In order to provide additional income generation activities and also to meet the protein requirement of villages, the project, in consultation with PSC decided to implement an inland fishery program with the technical support of the National Aquaculture Development Authority.

Out of the 19 rehabilitated irrigation schemes, 12 systems were identified as suitable for inland fisheries by the National Aquaculture Development Authority. In 2006 fingerlings were stocked in two tanks. The value of the harvested fish amounted to Rs.181, 400.00 against the cost incurred Rs.68, 500.00. In 2007, investment for fingerlings in five minor irrigation tanks was Rs.144, 900.00 and the value of harvested fish was Rs.700, 008.00. Rohu, Big-head carp, Catla and Common carp were the varieties introduced to the tanks that have no competition and predation on local/indigenous varieties.

Consequently, inland fishery committees were formed as a subcommittee in farmer organization to implement activities related to fisheries. A set of guidelines in line with the Agrarian Services Act was formulated and included in the constitutions of the farmer organizations, thus ensuring harmony between water users in downstream and upstream and avoiding conflict on water issues between committees of inland fisheries and farmers. (See Figure 4).

Figure 4. Fisheries activities.

Agro-based Entrepreneurship Skill Development

With the recommendation of the project mid term review, an agro-based entrepreneurship skills development program was initiated to build the capacities of potential entrepreneurs. It was noted that mere capacity building was insufficient to enhance the businesses of entrepreneurs and therefore, a value chain development and market networking program were also started in consultation with stakeholders. But due to budgetary constraints and lack of capacity, few interventions on reed sector and diary sector development were carried out in the Medawachiya divisional secretariat area. (See Figure 5).

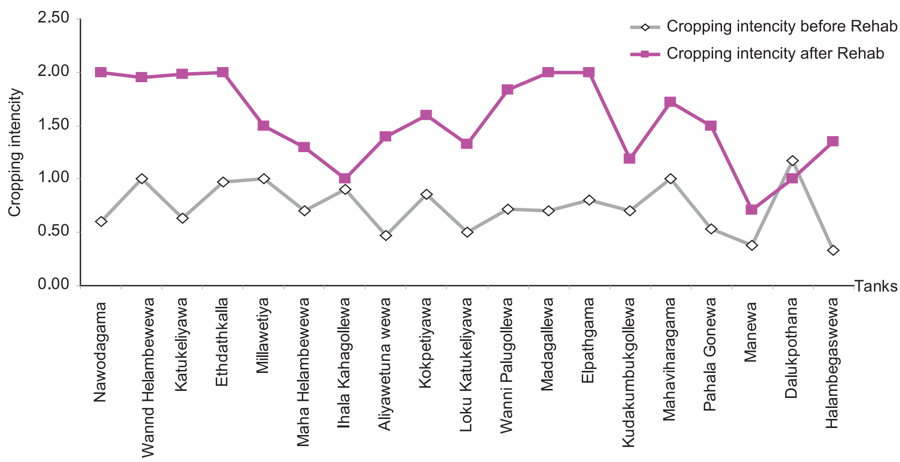
Figure 5. A training session on reed basket making.

Immediate Results of the Project

Capacity improvement and renovation of canal systems have led to the reduction in water losses in the tanks and has ensured the availability of water throughout the year. The availability of water in the dead storage (volume of water retained in the tank below the sluice outlet and which cannot be taken from the sluice) of the tank during dry periods has ensured the survival of aquatic species. Increased groundwater enabled the survival of trees in home-gardens located below tank bed elevations during the dry periods. This is evident in the Ethdathkalla tank where 5 acres are being irrigated by agro-wells.

A production comparison before and after rehabilitation was carried out with rehabilitated tanks and it was found that the yield in the *maha* cultivation has increased from 1.6 t /ac to 2.1 t/ac with a 30 % increment of production. Cropping intensity has increased from 0.8 % to 1.08 % (Figure 6).

Figure 6. Cropping intensity comparisons before and after rehabilitation.



A value was added to water spread area of tanks by introducing inland fish into the tanks. The balance water that was available during the dry period's cultivation of other field crops such as maize, chili, and *mung* bean etc., in paddy lands assured food security in the dry season.

Inland fish production provides significant contributions to animal protein supplies in many rural areas. In the regions that are far away from sea, inland fish represent an essential, often irreplaceable source of high quality and cheap animal protein that is crucial to the balance of diets in marginally food secure communities. The fish harvest that could be obtained from tanks meets the protein requirement of the immediate beneficiaries of tanks while providing rice as the staple food. Much of the inland fish that is produced in tanks is being consumed locally and sells at a half rate which is affordable to the other communities.

Capacity-building of farmers and partner organizations on cascade system development have brought behavioral changes over the participation and protection of their own tanks and cascade systems. But continuous efforts and follow-up is needed to sensitize them and to institutionalize those practices in relevant community organizations especially farmer organizations.

Lessons Learnt and Recommendations for Future Interventions

The multiplicity of services from tanks such as cultivation throughout the year, availability of fish and beneficiary's knowledge on integrated watershed management, and the integrated nature of minor tanks systems ensure the sustainability of tanks systems. The lack of a strong single institution to manage the cascade is an issue in the process of embarrassing cascade principles into the planning process. The role of farmer organizations should not be limited to operation and maintenance and they should have a strong network among upstream settlers and other communities living in the cascade geography.

In order to strengthen the institutional basis of Cascade Management Committees (CMC) a clear distinction has to be drawn between its functions and that of the FOs. The powers and responsibilities of the CMCs should devolve on: (a) resolving conflicts in the use of inter tank resources; (b) developing approaches to resolve common problems that affect cascade communities; (c) developing the bargaining strength of cascade communities vis-à-vis the bureaucracy of local authorities; and (d) creating an awareness among CMCs of the importance of an integrated approach to cascade development. The project effort was not sufficient enough to ensure the stability to some extent of CMCs due to the absence of the above factors.

Despite the Sinhala Buddhist identity, villages in the cascades are not homogenous. This heterogeneity must be taken into consideration in all realistic planning exercises. In particular, developing new institutions such as cascade management committees may have to take note of such differences. Ex. The established cascade management committee in Parana Halmillewa cascade. Stakeholders in Agriculture and irrigation alone cannot address the food security challenges in most cases, particularly since many of the problems are generated outside the agriculture sector. Therefore, approaches such as integrated watershed development and integrated resources management are especially relevant. The key elements for the success of a project are the coordinated and collaborative efforts of all agrarian and agriculture-related organizations and the early participation in planning for development and management.

Understanding a cross sector relationship, especially health and nutrition and livelihood development is vital for ensuring the food security of rural communities. Water resources (development minor tanks rehabilitation) in the dry zones in Sri Lanka are the entry points for broader social development. Health – malnutrition, water sanitation – watershed management /water quality improvement. Different user groups such as fishery society and paddy land holders in the same irrigation systems may create conflicts which need timely planning and implementation activities and unbiased mediation from authorities to minimize the conflicts.

Unlike in the past, the extent of paddy lands at present under each tank has increased due to increased populations. That means, in addition to the 'purana' wells some 'akkara' wells also have become operational. As the 'akkara' well is located at relatively higher elevation areas than the 'purana' well, the 'akkara' well receives less water during the *yala* and even in the *maha* (with drought condition). The farmer conflicts are prominent where this issue exists and as such, there is a need for strong rules and regulation for the management of water in an efficient and effective manner. The encroachment by paddy lands is an issue that needs special and immediate attention from the relevant authorities, and the demarcation of down stream and up stream reservations has now become compulsory to minimize further encroachment.

'Plan Sri Lanka' has made efforts to involve children in environmental projects in the upper watersheds, but this is not implemented consistently in all communities. The involvement of children not only creates an awareness of the importance of watershed management but also facilitates future action for environmental protection and sustained development.

Cascades have limited heterogeneity in land use pattern, land capability, soils, vegetation, micro-climate and the economic patterns of people, cultural perspectives and practices etc. Cascades also make it easier to identify upstream downstream linkages. Getting farmer contribution for reforestation and watershed-related improvement activities is difficult. Assigning construction activities to respective farmer organizations could develop a sense of ownership but the following problems were experienced during the project: a) difficulty in obtaining anticipated farmer contribution; b) gradual loss of interest; c) lack of construction experience; d) non-availability of experienced skilled labor; and e) high reduction of labor availability.

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ජ්‍යෙෂ්ඨ කථිකාචාර්ය, පුරාවිද්‍යා හා උරුම කළමනාකරණය,
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1. ප්‍රවේශය

ශ්‍රී ලංකාවේ මුල් ජනාවාස පිහිටුවා ගැනීමට වඩාත් යෝග්‍ය භූමිය ලෙස ආර්යයන් තෝරාගනු ලැබුයේ වියළි කලාපීය ප්‍රදේශයය. තම කෘෂි කාර්මික කටයුතු සඳහා සුදුසු පරිසරයක් (භෞතික හා ස්වභාවික සම්පත්) මෙම ප්‍රදේශයෙහි පිහිටා තිබීම ඊට බලපෑ ප්‍රධානතම සාධකය විය. වියළි කලාපයේ පවතින විශේෂත්වය වන්නේ වසරේ වැඩි කාලයක් වැසි නොලැබීම ය. මේ නිසා වියළි කාලයේදී මෙම ප්‍රදේශ ඔස්සේ ගලායන ගංගා, ඇළ දොළ ඔස්සේ වැඩි ජලයක් ගලා නොයයි. මේ හේතුවෙන් වියළි කලාපීය ප්‍රදේශවල වාසය කරන ජනතාවට කෘෂිකාර්මික හා අනෙකුත් කටයුතු සඳහා අවශ්‍යකරන ජලය රුස්කර තබාගැනීම ඉතාමත් වැදගත් විය. මේ සඳහා මුලින්ම ගම් වැව් හෙවත් කුඩා වැව් ඉදිකෙරුණු අතර, පසුව ජනගහනය ක්‍රමයෙන් අධිකවත්ම වඩාත් දියුණු වාරි තාක්‍ෂණ ක්‍රම කෙරෙහි අවධානය යොමුවිය. එහෙයින් ගංගාවල් හා ඔයවල් හරස්කර අමුණු තනා ජලය හැරවීම, එම ජලය ඇළ මාර්ග ඔස්සේ විශාල වැව් කරා රුගෙනයාම වැනි විවිධ තාක්‍ෂණික ක්‍රමයන් ආරම්භ විය.

වියළි කලාපයේ එක් ප්‍රධාන සීමාවක් ලෙසින් ද, පුරාණ දක්ඛිණ දේශය ඔස්සේ ගලාගිය ප්‍රධාන ජල මාර්ගයක් ලෙසින් ද දැදුරු ඔයට වැදගත් ස්ථානයක් හිමිවේ. දැදුරු ඔයේ පවතින වැදගත්කම වටහාගත් පුරාණ පාලකයෝ ඒ ආශ්‍රිත වාරි මාර්ග ක්‍රම ඉදිකිරීමෙහිලා උත්සුක වූහ. මේ පිළිබඳව අවධානය යොමුකළ මුල්ම පාලකයා වූයේ මහසෙන් රජු ය. දැදුරු ඔය ආශ්‍රිත වාරි කර්මාන්ත දියුණු කිරීමෙහිලා වැදගත්ම දායකත්වය සපයන ලද්දේ දක්ඛිණ දේශයේ පාලකයාව සිටි පළමුවන පරාක්‍රමබාහු රජු විසිනි.

අතීතයේ සිටම ප්‍රදේශයේ පැවති ජල හිඟය දැදුරු ඔය ආශ්‍රිතව වාරි කර්මාන්තයන් ඉදිවීම කෙරෙහි බලපෑ ප්‍රධානතම හේතුව විය. නිරන්තර වැසි නොලැබීමත්, භූගත ජල මට්ටම වඩාත් ගැඹුරින් පිහිටා තිබීමත් හේතුවෙන් කෘෂිකාර්මික කටයුතුවලට මෙන්ම අනෙකුත් අවශ්‍යතාවයන් සඳහා ද මෙම කලාපයේ ජලය සීමිත විය. දැදුරු ඔය ද්‍රෝණියේ වාරි කර්මාන්තය නගා සිටවීමේ අදහස පළමුවෙනි පැරකුම් රජුට පහළ වන කාලය වන විට මෙම ප්‍රදේශයේ කෙත්බිම් වලින් වැඩි කොටසකට ජලය සැපයෙන්නට ඇත්තේ ගම්වල කුඩා වැව්වලට වර්ෂාවෙන් රුස්කරගත් ජලය මගිනි. බොහෝ කෙත්බිම් වියළි කාලයේ දී වගා නොකරන්නට ඇත. වඩාත් සමතලා නොවූ මෙම භූමි ප්‍රදේශයේ පවතින අභියෝගය ජයගැනීම සඳහා මනාවූ පරිපාලනයක් සහිත වාරි මාර්ග පද්ධතියක අවශ්‍යතාවය වටහාගත් පළමුවන පරාක්‍රමබාහු රජු දැදුරු ඔය ආශ්‍රිතව දියුණු වාරි පද්ධතියක් බිහිකරලීය.

මෙම පර්යේෂණය මගින් අවධානය යොමුකර ඇත්තේ දැදුරු ඔය හා එහි පෝෂක ප්‍රදේශයේ තිබෙන පුරාණ වාරි කර්මාන්ත කෙරෙහිය. විශේෂයෙන් ම දැදුරු ඔය නිම්නයේ මධ්‍ය ප්‍රදේශය තුළ වාරි මාර්ග සම්බන්ධයෙන් වන පුරාවිද්‍යාත්මක සාක්ෂි රාශියක් හඳුනාගැනීමට ඇත. මෙම නිර්මාණ සම්බන්ධයෙන් ක්‍රමවත් පුරා විද්‍යාත්මක ක්ෂේත්‍ර අධ්‍යයනයක් මේ දක්වා සිදුකොට නැත. එසේම විවිධ ස්වභාවික හා මානව ක්‍රියාකාරකම් හේතුවෙන් මෙම සාක්ෂි ඉතා වේගයෙන් විනාශවෙමින් පවතින බව පැහැදිලිය. මෙම සාක්ෂි උපයෝගීත්වයෙන් දැදුරු ඔය ආශ්‍රිත පුරාණ වාරි කර්මාන්තයන්ගේ ක්‍රියාකාරීත්වයද නිර්මාණාත්මක ව්‍යුහය සහ තාක්ෂණික ක්‍රමෝපායන් පිළිබඳව හඳුනාගැනීම මෙන් ම ඉන් වර්තමාන සමාජයට ලබාගතහැකි ආදර්ශයන් පිළිබඳව පරීක්ෂා කිරීම ද මෙම කෙටි නිබන්ධනයෙන් අපේක්ෂා කරනු ලැබේ.

2. භෞතික ස්වභාවය

වර්තමාන භූගෝලීය බෙදීම් අනුව වියළි කලාපය හා තෙත් කලාපය උතුරු දෙසින් වෙන් කෙරෙන මායිම වශයෙන් දැදුරු ඔය සළකනු ලැබේ. මාතලේ කඳුවැටියේ පාකඳු ආශ්‍රයෙන් ඇරඹෙන දැදුරු ඔය කුරුණෑගල හා පුත්තලම දිස්ත්‍රික්ක හරහා සැතපුම් 87 ක් (කිලෝමීටර් 142) ගලා යමින් හලාවතට උතුරින් මුහුදට එක්වේ (Arumugam. 1969. 365). කිඹුල්වානා ඔය, හක්වටුනා ඔය, කොස්පොතු ඔය, මහුරු ඔය හා කොළමුණු ඔය මෙහි ප්‍රධාන පෝෂණ ජල මාර්ග වෙති (දැදුරු ඔයේ ප්‍රධාන ශාඛා).

උතුරින් මී ඔය නිම්නයෙන් හා රත්තම්බල ඔය නිම්නයෙන් ද, නැගෙනහිරින් මහවැලි නිම්නයෙන් ද, ඊසාන දෙසින් කලා ඔය නිම්නයෙන් ද, දකුණින් මා ඔය නිම්නයෙන් හා කඩුපිටි ඔය නිම්නයෙන් ද, බටහිරින් සාගරයෙන් ද සීමාවුණු වර්ග සැතපුම් 1,022 ක (වර්ග කිලෝමීටර් 2,161) ප්‍රමාණයකින් දැදුරු ඔය නිම්නය සමන්විතවේ. මෙහි ඉහළ කොටසෙහි වර්ග සැතපුම් 576 කි. පහළ කොටසේ වර්ග සැතපුම් 446 කි. (rumugam. 1969. 365). පෝෂක ප්‍රදේශයේ වාර්ෂික වර්ෂාපතනය පාරිසරික කලාප අනුව වෙනස්වේ. ඉහළ ප්‍රදේශය තුළ මි.මි. 1,250-1,500 ක සාමාන්‍ය වාර්ෂික වර්ෂාපතනයක් ලැබේ. ප්‍රදේශය පුරාම පවතින මධ්‍ය වාර්ෂික වර්ෂාපතනය මි.මි. 1,850 ක් පමණ ය. මෙම ප්‍රදේශයට ජලය ලැබෙන්නේ පූර්ණ වශයෙන්ම වර්ෂාව මගිනි. දැදුරු ඔය මගින් අක්කර අඩි 12,222,000 ක ජල ප්‍රමාණයක් වාර්ෂිකව මුහුදට එකතුකරන අතර මින් අක්කර අඩි 968,000 ක් ඊසානදිග මෝසමේ දී හා අක්කර අඩි 254,000 ක් නිරිතදිග මෝසමේ දී මුහුදට එක් කෙරේ (rumugam. 1969. 365).

3. ඓතිහාසික ජනාවාසවීම

වී ගොවිතැන ප්‍රධාන කෘෂි කර්මාන්තය කරගත් ලංකාවේ පුරාණ ජනතාව එම කටයුතු වඩාත් පහසුවෙන් කරගැනීම පිණිස තම ජනාවාස ගංගාශ්‍රිතව පිහිටුවා ගනු ලැබූහ (මව.7. 43-44). අතීතයේ දී ජජ්ජර නදිය (මව.68. 16) ලෙසින් හැඳින්වුනු දැදුරු ඔය ආශ්‍රිතව ද මෙලෙස පැරණි ජනාවාස පැවති බවට සාධක සොයාගෙන තිබේ. විශේෂයෙන්ම ජනාවාස පැතිරීයාම සම්බන්ධයෙන් තොරතුරු ලබාගත හැකි ක්‍රි.පූ. 2 සිට ක්‍රි.ව. 2 අතර කාලයට අයත් ශිලා ලේඛන දැදුරු ඔය නිම්නයේ ස්ථාන ගණනාවකින් හමුවී ඇත (IC. 1970. 75 අංක 954 හා 962). මෙම ලිපිවලින් අනුරාධපුර මුල් යුගයේ මෙම ප්‍රදේශයේ පැවති සමාජ තත්ත්වය පිළිබඳ තොරතුරු ලබාගත හැකිය.

ප්‍රදේශයේ පෞරාණික ශිලා ලේඛන කිහිපයක අඹතගරද අඹතොට, මුකළුගම හා තෙලගම යන ස්ථාන නාම සඳහන්වේ (IC. 1970). මෙවැනි ග්‍රාම නාමවලින් පැහැදිලි වන්නේ ඒ වන විට මෙම නිම්නයේ ස්ථාවර ජනාවාස බිහිවී තිබුණු බවය. ක්‍රි.පූ. අවසාන භාගය වන විට දැදුරු ඔය ආශ්‍රිතව බිහිවුණු අම්බට්ඨකෝල නම් ජනපදයක් පිළිබඳව තොරතුරු සඳහන් වේ.

ක්‍රි.පූ. 2 වැනි සියවසේ සිට ක්‍රි.ව. 8 වැනි සියවස තෙක් කාලයට අයත් සෙල්ලිපි ගණනාවක්ම වර්තමාන රිදී විහාරය ආශ්‍රිතවත් අවට ප්‍රදේශයෙත් තිබීමෙන් පැහැදිලි වන්නේ අනුරාධපුර මුල් යුගයේ සිටම මෙහි ජනාවාස ව්‍යාප්තව පැවති බවයි. රෙලගම, හරගම, වටනගම හා පටගලේ යන ප්‍රදේශ නාමයන් මෙම ලේඛනවල සඳහන් වේ (නිකොලස්. 1979. 125).

දැදුරු ඔයට සමීප නුවරකන්ද ආශ්‍රිතව පුරාණ ජනාවාස පැවති බවට සාධක ඇත. ක්‍රි.පූ. 1 වැනි සියවසේ සිට ක්‍රි.ව. 6 වැනි සියවස දක්වා කාලයට අයත් ශිලා ලේඛන රාශියක් නුවරකන්ද හා අවට ස්ථාන කිහිපයක තිබේ (IC. 1970. 71-2 අංක 913-931). මේ ප්‍රදේශයේ තිබෙන ශිලා ලේඛනවලින් පැරණි සමාජ තත්ත්වය පිළිබඳව තොරතුරු ලබාගත හැකිය. ගම් පාලනය කළ ගමිකයින්, ප්‍රධානීන් වූ පරුමකවරුන්, භාණ්ඩාගාරිකවරුන් වූ බඩකරිකයන් වැනි නිලධාරීන් පිළිබඳවත් පෙහෙකරුවන්, අසරුවැන්, ආචාරීන් වැනි වෘත්තිකයන් පිළිබඳවත් තොරතුරු හෙළිවේ (IC. 1970. අංක 913-931).

ක්‍රි.ව. 1 වැනි සියවසෙන් පසු 10 වැනි සියවස දක්වා වූ කාලයට අයත් සෙල්ලිපි ගණනාවක් ද දැදුරු ඔය නිම්නයේ ඇතැම් ස්ථානවලින් හමුවේ. සංගමුව විහාරයේ තිබෙන 6 වැනි සියවසට අයත් ලිපියක ගෝණගිරි හා මහවලගම යන ස්ථාන පිළිබඳව සඳහන් වේ (නිකොලස්. 1979. 119). වැල්ලැගල ඇති පළමුවැනි සියවසට අයත් ලිපියක එම ප්‍රදේශය කඳු පතහේ දිසාව ම යනුවෙන් හඳුන්වා ඇත (නිකොලස් 1979. 122) මේවන විට රජරට දිසා අනුව කොටස් හතරකට බෙදා තිබුණු අතර දැදුරු ඔයෙන් සීමාවුණු දක්ඛිණ දේශය හෙවත් දක්ඛිණ පස්ස එක් දිසාවක් විය. 6 වැනි සියවසේ සිට එය යුවරජුගේ රාජධානිය වී තිබිණ මෙම තත්ත්වය 12 වැනි සියවස තෙක් පැවතුණු අතර එම සියවස අවසානයේ දී දක්ඛිණ දේශය හා මලය දේශය එකතුකොට මායා රට්ඨ (මායාරට) ඇතිකරන ලදි (නිකොලස් 1979. 19). දැදුරු ඔය ආශ්‍රිත ප්‍රදේශය පොළොන්නරු සමයේ දී වැදගත් දේශපාලනික කේන්ද්‍රස්ථානයක් විය.

දැදුරු ඔය පෝෂණ ප්‍රදේශයේ පිහිටි හස්ථිශෛලපුර හෙවත් වර්තමාන කුරුණෑගල ප්‍රදේශය දඹදෙණිය යුගයේ දේශපාලනික වශයෙන් වැදගත් කේන්ද්‍රස්ථානයක් විය. දඹදෙණියේ රජ කළ සිව්වැනි විජයබාහු රජු (ක්‍රි.ව. 1270-1272) මේ පුරය වටා ප්‍රාකාරයක් හා දිය අගලක් කරවා ඇත (මව.88. 53-60). රටේ අගනුවර බවට කුරුණෑගල පත්වූයේ දෙවැනි බුවනෙකබාහු (ක්‍රි.ව. 1292-1932) රජුගේ කාලයේදී ය (මව.90. 60). හතරවැනි පරාක්‍රමබාහු (ක්‍රි.ව. 1302-1326) රජු ද තම රාජධානිය බවට පත්කරගන්නා ලද්දේ කුරුණෑගලයි (මව.90. 60).

පළමුවන පරාක්‍රමබාහුගේ දේශපාලන කාර්යයේ පළමු පියවර වූයේ සිය මළනුවන් වූ කීර්ති ශ්‍රී මේඝ රජුගෙන් පසු ක්‍රි.ව. 1140 දී පමණ දක්ඛිණ දේශයේ පාලකයා බවට පත්වීමයි (ල.වි.වි.ල.ඉ. 1972 පි. 420). හෙතෙම දැදුරු ඔය නිම්නයේ පිහිටි වර්තමාන පඬුවස්නුවර ආශ්‍රිතව පරාක්කමපුර නමින් නගරයක් ඉදිකර එහි සිට දක්ඛිණ දේශයේ පාලන කටයුතු මෙහෙයවූ බව පුරාවිද්‍යාත්මක සාධකවලින් පැහැදිලි වේ. දිවයිනේ අගරජු වීමේ අභිප්‍රායේ මූලික පදනම දක්ඛිණ දේශයේ දී සකස්වූ බව කිවහැකිය. රජු ප්‍රථමයෙන් ප්‍රදේශයේ ආර්ථික සංවර්ධනයක් ඇතිකිරීම කෙරෙහි යොමුවිය (මව. පරි. 68 පෙළ 7-15). දක්ඛිණ දේශයේ කෘෂි කාර්මික කටයුතු දියුණු කිරීමට අදහස් කළ පරාක්‍රමබාහු රජු තම නිලධාරීන්ට උපදෙස් දී උනන්දු කරවා ඇත (මව. පරි. 68 පෙළ 7). විශේෂයෙන්ම ප්‍රදේශයේ පැවති වියළි දේශගුණික තත්ත්වය කෙරෙහි අවධානය යොමුකළ රජු දක්ඛිණ දේශයේ ප්‍රධාන ජල මාර්ගය වූ ජජ්ජර නදිය (දැදුරු ඔය) ආශ්‍රිතව වාරි මාර්ග තැනීම කෙරෙහි යොමුවිය (මව. පරි. 68 පෙළ 16). දැදුරු ඔය ස්ථාන තුනකින් හරස්කර අමුණු බැඳ ගොවිතැනට අවශ්‍ය ජලය සපයාදීමට හෙතෙම පියවර ගෙන ඇත.

> " අහසින් වැටෙන එකඳු දිය බිඳක් පවා මනුෂ්‍ය ප්‍රයෝජනයට නොගෙන මුහුදට ගලා නොයායුතුය "

යන ප්‍රකාශය පරාක්‍රමබාහු රජු විසින් කරන ලද්දේ දැදුරු ඔය ආශ්‍රිතව වාරි කර්මාන්ත ආරම්භ කරන අවස්ථාවේ දීය (මව. පරි. 11-2).

4. අන්තර්ගතය

දැදුරු ඔය හා එහි නිම්න බඳ ප්‍රදේශයේ තිබෙන පැරණි වාරි කර්මාන්ත ප්‍රධාන වශයෙන් ජල සම්පාදන ක්‍රම දෙකක් මත පදනම්ව සකස්වී තිබෙන බව පැහැදිලිය.

1. අමුණු ආශ්‍රිත ජල සම්පාදනය.
2. වැව් ආශ්‍රිත ජල සම්පාදනය.

වශයෙන් හඳුනාගත හැකි මෙම ජල සම්පාදන ක්‍රම අතර අන්‍යොන්‍ය සම්බන්ධතාවක් පැවතුන බව හඳුනාගැනීමට පුළුවන.

4.1. අමුණු ආශ්‍රිත ජල සම්පාදනය

කිසියම් ජල මාර්ගයක ගලායන ජලය වෙනතකට හරවා යැවීම සඳහා පටු හෝ වඩාත් යෝග්‍ය ස්ථානයේ ඉදිකරනු ලැබූ බැම්ම "අමුණ" ලෙසින් හැඳින්වේ. සංස්කෘත හා පාලියෙහි සඳහන් වන "ආවරණ" යන පදයෙන් ආරම්භවී ආවරණ > අවුණ > අමුණ වශයෙන් එය සකස්වූ බව පරණවිතානයන් පෙන්වා දී තිබේ (IC. 1970. 103). ශිලා ලේඛන හා වංසකථා මූලාශ්‍රවල අමුණු ඉදිකිරීම පිළිබඳ තොරතුරු රැසක් සඳහන්වන බැවින් පුරාණ ශ්‍රී ලංකාවේ වාරි කර්මාන්තයේ ප්‍රධාන කොටසක් ලෙස අමුණු නිර්මාණය පැවති බව තහවුරු වේ.

දැදුරු ඔය ආශ්‍රිතව පළමුවන පරාක්‍රමබාහු රාජ්‍ය සමයේ ඉදිකරන ලද අමුණු තුනක් පිළිබඳව චූලවංශයේ සඳහන් වේ (මව. පරි. 68 හා 78). මින් කොට්ඨබද්ධ, සූකර නිජ්ජර හා දෝරදත්තික යන අමුණු හෙතෙම දක්ඛිණ දේශයේ පාලකයාව සිටි සමයේදී ද ජජ්ජර නිජ්ජර නම් වූ අමුණ දිවයිනේ අගරජු ලෙස පොළොන්නරුවේ රාජ ප්‍රාප්ත වූ පසුව ද ඉදිකර තිබේ.

4.1.1. කොට්ඨබද්ධ අමුණ

ලංකාවෙන් මෙතෙක් හමුවී තිබෙන දැව අමුණක් පිළිබඳව වූ වැදගත් සාක්ෂි රැසක් බිංගිරිය ප්‍රාදේශීය ලේකම් කොට්ඨාශයේ මොළළිය මංකඩ ග්‍රාමයට සීමාවූ දැදුරු ඔයෙන් අනාවරණය කර ගැනීමට හැකිවිය.

මෙම දැවමය අමුණ, පළමුවන පරාක්‍රමබාහු රජු දක්ඛිණ දේශයේ පාලකයාව සිටි කාලයේ දැදුරුඔය හරස් කොට ඉදිකරන ලද ප්‍රධාන අමුණක් ලෙස සැලකෙන කොට්ඨබද්ධ අමුණ බවට විශ්වාස කළ හැකි තොරතුරු මගින් අනාවරණය කරගත හැකිය. චූලවංශයේ සඳහන්වන්නේ කොට්ඨබද්ධ අමුණ ශක්තිමත් හා ස්ථිර අමුණක අවශ්‍යතාව පිරිමැසූ බවත් එයින් සාගරය දක්වා ජලය ගෙනගිය බවත් ය (මව. 68. 16-31). ඒ අනුව කොට්ඨබද්ධ අමුණ ඉදිකිරීමේ පරමාර්ථය වී ඇත්තේ සාගරය දක්වා වූ ප්‍රදේශයේ කෘෂි කර්මාන්තයට අවශ්‍ය ජලය සැපයීම වන බවයි. මොළළිය මංකඩ දැව අමුණින් ආරම්භවන ඇළ මාර්ගය එහි දකුණු ඉවුරට යොමුවී තිබෙන අතර ක්‍රමයෙන් එය ස්වභාවික ඔයක් බවට පත්වී මුහුද දක්වාම ගමන්කරන බව හඳුනාගැනීමට පුළුවන. වර්තමානයේ මෙම ජල මාර්ගය සෙංගල් ඔය ලෙස හඳුන්වනු ලබයි. ඒ අනුව කොට්ඨබද්ධ අමුණ සම්බන්ධයෙන් දැක්වෙන සාගරය තෙක් ජලය ගෙනගිය පුවත මෙම දැව අමුණ හා සම්බන්ධ ඇළ මාර්ගය සමග මැනවින් සම්බන්ධ වේ. එම තොරතුරු අනුව නිගමනය කළ හැකිවන්නේ මෙම දැව අමුණ පුරාණ කොට්ඨබද්ධ අමුණ විය හැකිබවයි.

4.1.2. සූකර නිජ්ජර අමුණ

දැදුරු ඔය හරස් කර ඉදිකරන ලද විශාල ප්‍රමාණයේ අමුණක් ලෙස පුරාණ රිදීබැදි ඇල්ල අමුණ හැඳින්විය හැකිය. මෙම අමුණ පාදෙනිය-අනුරාධපුර මාර්ගයේ දැදුරුඔය පාලමේ සිට පහළ දෙසට කි.මී. 1 ක් පමණ දුරකින් ඉදිකර තිබේ.

සූකර නිජ්ජර අමුණ දැදුරු ඔය

මහසෙන් (274-301) රජු විසින් ඉදිකරන ලදුව පළමුවන පරාක්‍රමබාහු (1153-1186) රජු විසින් ප්‍රතිසංස්කරණය කරන ලද නිකවැරටිය ප්‍රදේශයේ පිහිටි මාගල්ලේ වැව ට ජලය සැපයීම පිණිස මෙම අමුණ ඉදිකර තිබේ (මව 37. 49 : 68. 33-5). වංශකථාවේ මෙය හඳුන්වා ඇත්තේ සූකර නිජ්ජර යනුවෙනි (ම.ව 68. 33). පළමුවන පරාක්‍රමබාහු රජු විසින් සංවර්ධනය කරන ලද මෙම අමුණ ඉදිකිරීමේ පරමාර්ථය ලෙස එහි දක්වා ඇත්තේ මාගල් වැවට ජලය සැපයීම හා ඒ දක්වා වූ ප්‍රදේශයේ කෘෂි කර්මාන්තය නගා සිටුවීමත් ය.

චූලවංසයේ සඳහන්වන්නේ කිඹුල්වානා ඔය හා හක්වටුනා ඔය හමුවන ස්ථානයේ රජු විසින් සූකර නිජ්ජර අමුණ කරවූ බවයි (මව 68. 32-3). වංශකථාකරු අනුව යමින් පාකර් සඳහන් කරන්නේ මෙම අමුණ කිඹුල්වානා ඔය ආශ්‍රිතව තිබුණු බවකි (Parker 1889. 8). එකී ස්ථානය ආශ්‍රිතව පුරාණ අමුණක් සම්බන්ධයෙන් සාක්ෂි ලැබුණ ද එය ඉදිකිරීමේ පරමාර්ථය මාගල්ලේ වැවට ජලය සැපයීම නොවන බව ඉතාමත් පැහැදිලිය. එයින් තහවුරු වන්නේ වංශකථාකරුට කිසියම් අතපසුවීමක් සිදුවී තිබෙන බවයි. ඒ අනුව වංශකථාවේ සඳහන් සූකර නිජ්ජර අමුණ ලෙස පිළිගත හැක්කේ දැදුරුඔය හරස්කොට ඉදිකර තිබෙන වර්තමානයේ රිදීබැඳි ඇල්ල නමින් ව්‍යවහාර වන නටබුන් වූ පුරාණ අමුණ බව පැහැදිලිය.

4.1.3. දෝරදත්තික අමුණ

කිඹුල්වානා ඔය හා මගුරු ඔයඅු දැදුරු ඔයට එකතුවන ස්ථානයේ පුරාණ අමුණක් තිබුණ බවට සාක්ෂි හමුවේ. මෙම ස්ථානය දැදුරු ඔයේ දකුණු ඉවුරේ පහළයාය හා වම් ඉවුරේ වල්පාලුව යන ගම්මාන දෙකට මැදිව පිහිටා තිබේ.

පළමුවන පරාක්‍රමබාහු රජු විසින් කරවන ලද දෝරදත්තික නම් වූ අමුණ සම්බන්ධයෙන් විස්තර කරන චූලවංසය

> "දැදුරු ඔය මැද දෝරදත්තික නම් තැන දිය බස්නාවක් ද, මහ ඇළක් ද, කරවා එතැන් සිට ඌරු දොළ දක්වා කෙත් කරවා............"

යනුවෙන් සඳහන් කර තිබේ. මෙහි ඌරු දොළ ලෙස දක්වා ඇත්තේ සූකර නිජ්ජර අමුණ යි. ඒ අනුව දෝරදත්තික අමුණේ මූලික පරමාර්ථය වී ඇත්තේ සූකර නිජ්ජර අමුණ දක්වා වූ ප්‍රදේශය සාරවත් කිරීම බව පැහැදිලිය. නටබුන්ව පවතින ඉහත කී අමුණේ දකුණු ඉවුරෙන් ඇරඹෙන

පුරාණ ඇළ මාර්ගය මගින් ජලය සපයා ඇත්තේ අමුණට පහළින් වූ සීමිත ප්‍රදේශයකට බව පැහැදිලිය. ගංගා ද්වාරයන් එකට හමුවන ස්ථානය යන අර්ථය ගෙන දෙන දෝරදත්තික යන නාමය දෙමෝදර යන්නට ද සමාන වේ. ඒ අනුව දෙමෝදරට පහළින් වූ ගල් රැන නම් ස්ථානයේ පිහිටි නටඹුන් වූ අමුණ වංශකථාවේ සඳහන් වන පුරාණ දෝරදත්තික අමුණ බව නිගමනය කිරීමට පුළුවන.

4.1.4. ජජ්ජර තිජ්ජර අමුණ

වැල්ලව නගරයට ආසන්නව බඹරගොඩ ජනවසම වතු යාය සීමාවේ දැදුරු ඔයේ වම් ඉවුරේ පුරාණ අමුණක නටබුන් ඇත. වර්තමානයේ මෙම ස්ථානය රජ බැම්ම නමින් හඳුන්වයි. පළමුවන පරාක්‍රමබාහු රජු දිවයිනේ අගරජු ලෙසින් පොළොන්නරුවේ රාජප්‍රාප්ත වූ පසුව ද දැදුරු ඔය ආශ්‍රිත සංවර්ධන කටයුතු සිදුකර තිබේ. චූලවංසයේ සඳහන් වන ජජ්ජර තිජ්ජර අමුණ (මව 79. 67-8) ඉදිවී ඇත්තේ එහි ප්‍රතිඵලයක් ලෙසින් යැයි සැලකීමට පිළිවන. ජජ්ජර තිජ්ජර යන නාමය අනුව පැහැදිලි වන්නේ එම අමුණ සෘජුවම දැදුරු ඔය හරස්කර තිබෙන බවකි. ඒ අනුව වෙනත් ජල මාර්ගයක් සම්බන්ධයෙන් නොමැති වූ දැදුරු ඔයේම ඉදිකරන ලද ජජ්ජර තිජ්ජර අමුණ වර්තමානයේ රජ බැම්ම නමින් හඳුන්වන නටබුන් වූ පුරාණ අමුණ ලෙස විශ්වාස කළ හැකිය.

4.1.5. මහ මංකඩ අමුණ

දැදුරු ඔයේ පිහිටා තිබුණු අවසාන අමුණ යැයි සිතිය හැකි තවත් පුරාණ දැව අමුණක සාක්ෂි හලාවත ප්‍රාදේශීය ලේකම් කොට්ඨාශයට අයත් රඹේපිටිය හා තරියාගම යන ගම්වලට මායිම්ව පිහිටා තිබේ. මෙම ස්ථානය ව්‍යවහාරයේ ගොඩැල්ල යායේ මහමංකඩ ලෙස හඳුන්වනු ලැබේ. මෙම ස්ථානයෙන් ලබා ගත් ජලය මුන්නේස්වරම් වැවට හා කරවිට වැවට යොමුකර තිබෙන බවට සාක්ෂි වේ. ඔයෙහි වම් ඉවුරට යොදන ලද ඇළ මාර්ගය ඉතාමත්ම පැහැදිලිව වර්තමානයේ දී දක්නට ලැබේ.

4.1.6. පොළොන්තලාව-විලගම අමුණ

නිකවැරටියේ සිට සැතපුම් 10 ක් පමණ දුරින් දැදුරු ඔයේ පහළ ප්‍රදේශයේ දකුණු ඉවුරේ පොළොන්තලාව හා වම් ඉවුරේ විලගම යන ගම්මාන දෙක මැදිවන ආකාරයෙන් ගොඩබිම දෙසට කපන ලද ඇළ මාර්ග දෙකක සාක්ෂි දක්නට ලැබේ. ඔයේ රැස්වන ජලය පිටතට ගමන් කිරීමට හැකිවන පරිද්දෙන් මෙම ඇළ මාර්ග නිර්මාණය කර තිබෙන බව හඳුනාගැනීමට පිළිවන. මෙවැනි ස්ථානයක ජලය රැස්කළ හැකිවන්නේ ඔය හරස් කිරීමකින් පමණි. මේ අනුව ජලය රැස්කිරීම පිණිස මෙම ඇළ මාර්ගවලට පහළින් අමුණක් ඉදිකර තිබෙන්නට ඇත. පොළොන්තලාව හා විලගම යන ගම්මාන දෙකට මැදිව ඉහත සඳහන් ඇළ මාර්ගවලට පහළින් මෙම පුරාණ අමුණ පිහිටා තිබුණේ යැයි අනුමාන කළ හැකිය.

4.1.7. අලවල අමුණ

දැදුරු ඔයේ ප්‍රධාන අතු ගංගාවක් වන කොස්පොතු ඔය අලවල නම් ප්‍රදේශයේ දී හරස්කොට බ්‍රිතාන්‍ය පාලකයින් විසින් 1887 දී ඉදිකරන ලද ගල් අමුණට පහළින් වන ස්වාභාවික ගල් තලාවේ ඊට පෙර පැවති පුරාණ අමුණක් පිළිබඳව සාක්ෂි හඳුනාගත හැකිය. කුරුණෑගල දිස්ත්‍රික්කයේ රිදීගම ප්‍රාදේශීය ලේකම් කොට්ඨාශයේ අලවල ග්‍රාමයේ මෙම ස්ථානය පිහිටා ඇත.

4.1.8. වැලිමළුව අමුණ

දැදුරු ඔයේ වම් ඉවුරෙහි අමුණුගම ග්‍රාමයට ද දකුණු ඉවුරෙහි පන්නව ග්‍රාමයට ද මායිම්ව වැලිමළුව නමින් හඳුන්වන ඔයේ ඉතාමත් ම පටු ස්ථානයක ඔය හරහා සම්පූර්ණයෙන්ම විහිදී යන බෙහෙවින්ම බාදනය වූ විශාල ගල් රැනක් වේ. විශාල වශයෙන් වැලි එකතු වන ස්ථානයක් වන බැවින් මෙම ස්ථානය වැලිමළුව නමින් ව්‍යවහාර වේ. මෙම ස්වාභාවික ගල් රැන උපයෝගී කරගෙන පුරාණයේ අමුණක් ඉදිකර තිබුණ බවට සාක්ෂි හඳුනාගත හැකිය. වාරියපොල ගනේවත්ත මාර්ගයේ අමුණුගම හන්දියෙන් වමට හැරී කිලෝමීටරය ක් පමණ ගියවිට මෙම ස්ථානයට පිවිසිය හැකි වේ.

4.1.9. කිඹුල්වානා ඔය අමුණ

කිඹුල්වාන ඔයට හක්වටුනා ඔය එකතු වන දෙමෝදරට **මීටර් 750** ක් පමණ පහලින් කිඹුල්වානා ඔයේ ඉදිකරණ ලද පුරාණ අමුණක නටබුන් හමුවේ. මෙම අමුණ සම්බන්ධයෙන් වංශකථාවන් හී තොරතුරු කිසිවක් සඳහන් නොවේ. එහෙත් ජනප්‍රවාදගත තොරතුරු අනුව යමින් බ්‍රෝහියර් සඳහන් කරන්නේ, මෙම අමුණ කරවීමේ අරමුණ වී ඇත්තේ යාපහුව සමිපයේ පිහිටි තලගල්ල නම් වූ වැවට අතිරේක ජල සම්පාදනය කිරීමට වන බවයි (Brohier 1934. P III. 5). පාකර් කිඹුල්වානා ඔය හරහා දිවෙන දුම්රිය පාලමට ඉහලින් පිහිටා තිබෙන අමුණක නටබුන් පිළිබඳව සඳහන් කරයි (Parker 1889). පාකර් සඳහන් කරන ප්‍රදේශය ආශ්‍රිතව පුරාණ අමුණක් සම්බන්ධ සාක්ෂි හමු නොවේ. එම තොරතුරු සමාන වන්නේ දුම්රිය පාලමට සැතපුමක් පමණ පහලින් පිහිටි මෙම අමුණේ නටබුන් සමග වන බැවින් පාකර් ට එහි පිහිටීම සම්බන්ධයෙන් කිසියම් අවුල් සහගත බවක් ඇතිවී තිබෙන බව පැහැදිලිය.

කිඹුල්වානා ඔය අමුණ

4.1.10. හක්වටුනා ඔය අමුණ

කුරුණෑගල දිස්ත්‍රික්කයේ පොල්පිතිගම ප්‍රදේශීය ලේකම් කොට්ටාශයේ අංක **363** ගල්කැටියාගම ග්‍රාමනිලධාරී වසමේ වඳුරුස්ස ග්‍රාමයේ රජයේ රක්ෂිත සීමාව තුළ මෙම පුරාණ අමුණ

හක්වටුනා ඔය අමුණ

පිහිටා තිබේ. කුඩා ප්‍රමාණයේ අමුණක් වන මෙය ප්‍රාථමික නිමැවුම් ලක්‍ෂණවලින් යුක්ත වේ. එසේ වුවද අමුණක බාහිර ස්වරූපය මැනවින් හඳුනාගැනීමට කදිම නිදර්ශණයක් ලෙස මෙය දැක්විය හැකිය. වර්තමානයේ දී මෙම ස්ථානයෙන් හක්වටුනා ඔය ගමන් නොකරන බැවින් මෙය හුදකලා වූ ස්වරූපයක් පෙන්නුම් කරයි. එහෙත් මිට කලකට පෙර මෙම ස්ථානය ඔස්සේ හක්වටුනා ඔය ගලා ගිය බවට පැහැදිලි සාක්‍ෂි හඳුනාගැනීමේ හැකියාව පවතී. කෙසේ නමුත් මේවන විට හක්වටුනා ඔය මෙම පුරාණ අමුණට මීටර් 400 ක් පමණ ඉහළින් අංශක 24 ක් පමණ නිරිතදිග දෙසට හැරී වෙනත් මගක් ඔස්සේ ගලායන ආකාරය දක්නට ලැබේ. අමුණු බැම්ම සැහෙන පමණ ආරක්‍ෂාවීම සඳහා හක්වටුනා ඔයේ ගමන් මගේ වෙනස්වීම බලපා තිබෙන බවද හඳුනාගැනීමට පිළිවන.

4.1.11. අමුණු ආශ්‍රිත ඇළ මාර්ග

අමුණු ආශ්‍රිත ඇළ මාර්ගවල ක්‍රියාකාරීත්වය පිළිබඳව විමර්ශනය කිරීමේ දී එක් එක් ස්ථානවල අමුණු ඉදිකිරීමේ පරමාර්ථ පිළිබඳව තොරතුරු රැසක් අනාවරණය කරගැනීමේ හැකියාව පවතී. වර්තමානයේ ප්‍රතිසංස්කරණය කර තිබෙන ඇතැම් පුරාණ අමුණු ආශ්‍රිත ඇළ මාර්ග පුරාණ පිහිටීම ආරක්‍ෂාවන පරිදි යළි ප්‍රතිසංස්කරණය කර ඇති මුත් වර්තමානයේ වැඩි වශයෙන් දක්නට ලැබෙන නව ඉංජිනේරු ක්‍රමවේදයන් අනුව යෙදූ ඇළ මාර්ග බැවින් පුරාණ ඇළ මං බොහෝ සෙයින් විනාශවී ගොස් තිබෙන ආකාරය හඳුනාගත හැකිය. පුරාණ කොට්ඨබද්ධ අමුණ යැයි විශ්වාස කළහැකි මොලඑලිය මංකඩ දැව අමුණින් ආරම්භ වන ඇළ මාර්ගය එහි දකුණු ඉවුර ඔස්සේ භූමියේ පිහිටීම අනුව සකසා තිබෙන බව හඳුනාගත හැකිය. චූලවංශයේ සඳහන් තොරතුරුවලට අනුව අමුණේ ජලය ගෙන ගොස් ඇත්තේ රත්තකාර ජනපදයට ය. ඒ සඳහා පළල් වූ මොචි ඇළක් කැප්පවූ බව එහි සඳහන් වේ (මව. 68. 23). මෙම ඇළ මාර්ගය පසුකාලීනව සෙංගල් ඔය නමින් ව්‍යවහාර වූ බව හඳුනාගත හැකිය. නිකලස් ද සෙංගල් ඔය යනු කොට්ඨබද්ධ අමුණෙන් ලබාගත් ජලය ගලා ආ ඇළ මාර්ගය වීමට ඉඩ ඇති බව පෙන්වා දී තිබේ (නිකොලස්. 1979. 107). චූලවංශයේ මෙම අමුණෙන් ලබාගත් ජලය සාගරය දක්වා ගෙනගිය බව සඳහන් වීමෙන් නිකොලස්ගේ අදහස නිවැරදි බව පෙනේ (මව. 68. 30-1). මෙම අමුණට තරමක් ඉහළින් මහමංකඩ නම් වූ ස්ථානයේ ඉදිකර තිබුණු තවත් දැව අමුණකින් දැදුරු ඔයේ වම් ඉවුර ප්‍රදේශයට ජලය ලබාගත් ඇළ මාර්ගයක සාක්‍ෂි දැකගත හැකිය. එමගින් මුන්නේස්වරම වැව ට හා කරවිට වැව ට ජලය ලබාගත් බවට විශ්වාසයක් පවතී.

දැදුරු ඔය ආශ්‍රිතව ඉදිකරන ලද ප්‍රධාන අමුණක් වන සූකර නිජ්ජර හෙවත් පුරාණ රිදී බැඳි ඇල්ල අමුණ ඉදිකිරීමේ ප්‍රධාන පරමාර්ථය වී ඇත්තේ මහසෙන් රජු විසින් කරවන ලදුව පළමුවන පරාක්‍රමබාහු රජු විසින් යළි ප්‍රතිසංස්කරණය කරනු ලැබූ මාගල්ලේ වැවට ජලය සැපයීමයි. එහෙත් ඒ සඳහා වන ඇළ මාර්ගය සෘජුවම දැදුරු ඔයෙ අමුණ අසලින් ආරම්භ නොවේ. එයට හේතුව වන්නේ අමුණ ඉදිකළ ස්ථානය ඇළ මාර්ගයක් කැපීමට යෝග්‍ය නොවීමයි. එබැවින් අමුණේ ජලය පිටතට ගෙනයාමට උපයෝගී කරගෙන ඇත්තේ අමුණට මීටර් 80 ක් පමණ ඉහළින් දකුණු ඉවුරෙන් දැදුරු ඔයට එකතුවන තලගල්ල ඇළ නම් වූ ස්වභාවික ඇළ මාර්ගයයි. එම ඇළ මාර්ගයේ මීටර් 856 ක් පමණ ඉහළ ප්‍රදේශයෙන් ආරම්භ වන කෘතිම ඇළ මාර්ගයකට අමුණේ ජලය යොමුකිරීම මගින් මාගල්ලේ වැවට ජලය සැපයීමේ කාර්යය සිදුකර ඇත. තලගල්ල ඇළෙන් ඇරඹෙන එම ඇළ මාර්ගය වර්තමානයේ හැඳින්වෙන්නේ **හීන් ඇළ** නමිනි.

පුරාණ දෝරදත්තික අමුණේ ජලය ලබාගත් ඇළ මාර්ගය ආරම්භ වන්නේ අමුණේ සිට මීටර් 80 ක් පමණ ඉහළින් එහි දකුණු ඉවුර ආශ්‍රිතව ය. මෙය වර්තමානයේ දී **කැප් ඇළ** නමින් හැඳින්වේ. මෙම ඇළට එම නම යෙදී ඇත්තේ කැප්ප වූ හෙවත් කපාපු ඇළ යන අදහසින් බව ප්‍රදේශ වාසී මතයයි. දකුණු ඉවුරෙන් උතුරු දිශානුගතව ඇරඹෙන මෙම ඇළ මාර්ගය ඔයේ මීටර් 300 ක් පමණ ගිය විට තරමක් වයඹ දෙසට හැරී ගමන් කරයි. මෙම ඇළේ ආරම්භක ඉවුරු දෙපස බෙහෙවින් සෝදාපාළුවට ලක්වී ඇත.

පළමුවන පරාක්‍රමබාහු රජු විසින් ඉදිකරන ලද තිලගුල්ලක වාපි හෙවත් තිලගුල් වැවට මෙම අමුණෙන් ජලය ලබාගන්නට ඇතැයි නිකොලස් විශ්වාස කරයි (නිකොලස්. 1959. 6). අභාවිතව ඇති මෙම වැව වර්තමානයේ තලගල්ලේ වැව නමින් හඳුන්වයි. මෙම අමුණින් එම වැවට ජලය ලබාගත් කෘතිම ඇළ මාර්ගයක සාධක වර්තමානයේදී හඳුනාගත නොහැකිය. භූමියේ පිහිටීම අනුව ද තලගල්ලේ වැවට මෙම අමුණින් ජලය ලබාගැනීම අසීරුය. එහෙත් චූලවංසයේ ඉතා පැහැදිලිව දක්වා තිබෙනුයේ මෙම අමුණින් ලද ජලය සූකර නිජ්ජර අමුණ තෙක් කෘෂි කර්මාන්ත කටයුතු කළ බවයි (මව. 68. 38). මේ අනුව මෙම අමුණ ඉදිකිරීමේ මූලික පරමාර්ථය වී ඇත්තේ ඒ අවට ප්‍රදේශයේ කෘෂි කාර්මික කටයුතු දියුණු කිරීමට අවශ්‍ය ජලය සපයා ගැනීමට බව පැහැදිලිය. වර්තමානයේ දී **කැප් ඇළ** නමින් හැඳින්වෙන මෙම අමුණෙන් ඇරඹෙන ඇළ මාර්ගයේ ගමන් මග අනුව දෝරදත්තික අමුණේ පහළ ප්‍රදේශයට මෙමගින් ජලය සපයා තිබෙන බව සනාථ වේ. මේ අනුව දෝරදත්තික අමුණ ආසන්නයේ සිට පුරාණ සූකර නිජ්ජර අමුණට ඉහළින් වූ වර්ග සැතපුම් 9 ක පමණ භූමි ප්‍රදේශයක් මේ නිසා වගා කරන්නට හැකිවූ බව අනුමාන කළ හැකිය.

දැදුරු ඔයේ ඉහළ ප්‍රදේශයේ පිහිටි ජජ්ජර නිජ්ජර නම් වූ අමුණෙන් ඇරඹෙන ඇළ මාර්ගය ඔයේ වම් ඉවුරු ප්‍රදේශයට යොමුකර තිබේ. අමුණේ සිට මීටර් 40 ක් පමණ ඉහළින් ආරම්භ වන මෙම ඇළ මාර්ගයේ සාධක දැනට බඹරගොඩ ජනවසම වතුයායෙන් හඳුනාගත හැකිය. අතීතයේ දී මෙම ඇළ මාර්ගය මගින් වැල්ලව, රංගම, බඹරගොඩ ආදී ප්‍රදේශවල පහත් බිම් හී පිහිටි කෙත් බිම් සඳහා අවශ්‍ය ජලය සපයන්නට ඇත. වර්තමානයේ හඳුනාගත නොහැකි තරමට මෙම ඇළ මාර්ගය විනාශ වී ගොස් තිබේ.

නිකවැරටියට කි.මී. 10 ක් පමණ ඈතින් දැදුරු ඔයේ දකුණු ඉවුරේ පොළොන්තලාව හා වම් ඉවුරේ විලගම ආශ්‍රිතව පිහිටා තිබුණේ යැයි විශ්වාස කරන අමුණක් ඇසුරින් දැදුරු ඔයේ නිම්න දෙකටම ජලය ලබාගත් බවට සාක්ෂි වේ. එම අමුණ ඉදිකර තිබුණේ යැයි අනුමාන කෙරෙන ස්ථානයේ සිට මීටර් 800 ක් පමණ ඉහළින් දකුණු ඉවුරෙන් ආරම්භ වන මෙය වර්තමානයේ **යෝධ ඇළ** නමින් හැඳින්වේ.

මෙම ඇළ මාර්ගය ආරම්භක ස්ථානයේ සිට සැතපුම් 5 ක් පමණ දුරින් පිහිටි **පන්කුලිය** නම් ස්ථානයේ දී නැවත ඔයට සම්බන්ධ වේ. මෙම සම්බන්ධවීම පශ්චාත් කාලයේදී සිදුවූවක් බව ඉතා පැහැදිලිය. දැදුරු ඔයේ ස්වාභාවික වෙනස්වීමක් මෙම ස්ථානයේ සිදුවී ඇති අතර දැදුරු ඔය යෝධ ඇළ තෙක් බාදනය වෙමින් ගමන්කර ඇත. ඒ සමගම නැවත යෝධ ඇළ ඔයේ පිටතට

ගමන් කරන ආකාරය දක්නට ලැබේ. එතැන් සිට සැතපුම් දෙකක් පමණ පහළින් තවත් මෙවැනිම ස්ථානයක් හමුවේ. එම ප්‍රදේශය තෝරවටවන නමින් හැඳින්වේ. එතැන් සිට ක්‍රමයෙන් දැදුරු ඔයෙන් ඈත්වන යෝධ ඇළ පල්ලම ප්‍රදේශයට ගමන් කරනු ලබයි.

වම් ඉවුරේ ඇළ මාර්ගය වර්තමානයේ තම්මැන්නා ඇළ නමින් හඳුන්වයි. මෙම ඇළ මාර්ගයේ ආරම්භක ස්ථානය කැලෑවෙන් වැසී ඇතිමුත් එතැන් සිට ඇරඹෙන ඇළ මාර්ගය විලගම වැව දක්වා ඉතාමත් පැහැදිලිව හඳුනාගැනීමට පිළිවන. ඇළ මග දෙපස ඉවුරු හොඳින් තිබෙන අතරම ඇළ පතුල සමතලා ස්වරූපයකින් යුක්ත වේ. ඇළෙහි ස්වභාවය අනුව මෙය කෘත්‍රිම ඉදිකිරීමක් බව පැහැදිලිය. ඇළ මගෙහි ප්‍රමාණය හා ස්වභාවය අනුව මෙම ඇළෙන් ලබාගන්නා ලද ජලය අඩු ධාරිතාවයකින් යුක්ත වන්නට ඇත. මෙහි ජලය ප්‍රථමයෙන් විලගම වැවට ගෙනගොස් අනතුරුව ඊට පහළින් පිහිටි වැව් කිහිපයකට යොමුකර තිබේ. මෙම ඇළ මාර්ගයෙන් උපෙකැලේ වැවඅ ගීකියනගෙදර වැවඅ තලන්පොල මහවැව හා ගැටුලාව වැව යන වැව්වලට ජලය ලබාගත් බවට සාක්ෂි හඳුනාගත හැකිය.

දැදුරු ඔය හා ඒ ආශ්‍රිත පෝෂණ ජල මාර්ගවල ඉදිකර තිබෙන අමුණුවලින් ආරම්භ වන ඇළ මාර්ග රාශියක් පිළිබඳව තොරතුරු අනාවරණය කරගත හැකිවේ. දැදුරු ඔය ආශ්‍රිතව බිහිවූයේ එම නිම්නයට ම කේන්ද්‍රගත වූ ස්වාධීන වාරි පද්ධතියකි. කලාපයේ ජල හිඟතාව පාලනය කර ගැනීම පිණිස අමුණු ආශ්‍රිතව ඉදිකරන ලද ඇළ මාර්ග උපයෝගී කරගෙන තිබෙන බව හඳුනාගැනීමට පුළුවන.

දැදුරු ඔයේ ප්‍රධාන පෝෂණ ජල මාර්ගයක් වූ කොස්පොතු ඔය හරස්කොට ඉදිකරන ලද අලවල පුරාණ අමුණ මගින් ජලය ලබාගෙන ඇත්තේ කොස්පොතු ඔයේ දකුණු ඉවුරු ප්‍රදේශයට ය. අමුණට සැතපුම් කිහිපයක් පහළින් වූ කෝන්ගොඩ ප්‍රදේශයේ පැවති පුරාණ ජනාවාසය ආශ්‍රිත ප්‍රදේශයට එම ඇළ මග ඔස්සේ ජලය රැගෙන ගොස් තිබෙන බව සිතිය හැකිවේ.

දැදුරු ඔයේ වැලිමළුව අමුණින් ඇරඹෙන ඇළ මාර්ගයෙන් ජලය ලබාගෙන ඇත්තේ දකුණු ඉවුරු බඳ ප්‍රදේශයේ වූ වැව් කිහිපයකට ය. මෙම ඇළ මාර්ගයේ සාක්ෂි එහි ආරම්භක අවස්ථාවේ හඳුනාගැනීමේ හැකියාව පවතී. එම ඇළ ඒ ආසන්නයේ ම පිහිටි මධ්‍යම ප්‍රමාණයේ වැවක් වෙත යොමුකර තිබෙන බව පැහැදිලි ය. පුරාණ කිඹුල්වාන අමුණෙන් හරවා යැවෙන ජලය දකුණු සහ වම් ඉවුරු දෙක සඳහා ම නිකුත් කළ බවට සාක්ෂි හඳුනාගත හැකිය. වම් ඉවුරේ ඇළ මාර්ගය අමුණේ සිට මීටර් 250 ක් පමණ ඉහළින් වන්නට පිහිටා තිබෙන අතර ඉන් ලබාගන්නා ජලය එතැන් සිට කි.මී. 2 ක් පමණ ඈතින් පිහිටි ගල් වැව නමින් හැඳින් වූ පුරාණයේ පැවති විශාල වැවකට යොමුකොට ඇති බව හඳුනාගත හැකිය. පුරාණයේ දී ජලය ලබාගත් ගල් වැව නමින් හැඳින්වූ වැවෙහි ද වර්තමානයේ දක්නට ලැබෙන්නේ විශාල වැව් බැම්ම පමණි. ගල් පර්වත දෙකක් අතර බැඳ තිබූ සොරොව්ව පසුකාලීනව විනාශකර දැමීමෙන් මෙම වැව විනාශයට පත්වී ඇත.

හක්වටුනා ඔයේ පුරාණ අමුණ මගින් ජලය ලබාගෙන ඇත්තේ එහි දකුණු ඉවුර ප්‍රදේශයට ය. අමුණු බැම්මට මීටර් 6 ක් පමණ ඉහළින් ඇළ මාර්ගය ආරම්භ වූ බවට සාක්ෂි වේ. ඇළට වතුර හැරීයාමේ දී ඉවුර සේදීයාම වැළැක්වීමට යෙදූ ආරක්ෂිත ගල් වර්තමානයේ ද ශේෂව පවතී. මෙම ඇළේ බැම්ම යෝධයා පිටල නමින් හැඳින්වූ බව ප්‍රදේශවාසීන් ප්‍රකාශ කරයි. එම බැම්මේ විශේෂත්වය වන්නේ ඇළේ බැම්ම එක් පසක පමණක් ඉදිකර තිබීමයි. භූමියේ උස් ස්ථානවලින් ඇළ මග ගැඹුරට කපමින් එය ඉදිරියට ගෙනගොස් ඇති බවට සාක්ෂි වේ. මැදගම වෙල නමින් හඳුන්වන ලද පුරාණ වෙල්යායට එමගින් ජලය ලබාගත් බවට ද තොරතුරු හමුවේ. ඒ අතරතුර මෙම ඇළ මාර්ගයෙන් අතර මග පිහිටි වැව්වලට ජලය ලබාදී ඇත. වඳුරුස්ස, ගල්කැටියාව, තම්මැන්නාගම ඔස්සේ ගමන් ගන්නා මෙම ඇළ මාගම වෙල්යායෙන් පසු බල්ලා ඇළ නම් ස්වභාවික ජල මාර්ගයට නැවත එක්කොට තිබේ.

4.2. වැව් ආශ්‍රිත ජල සම්පාදනය

කෘෂි කර්මාන්තය වඩාත් සංවිධානාත්මක ලෙස කිරීමට අවශ්‍ය ජලය ලබාගැනීම වැවක් නිර්මාණය කිරීමේ මූලික පරමාර්ථය විය. වියළි කලාපීය කෘෂි කර්මාන්තයේ පදනම ලෙස වැව සැලකීමට පුළුවන. ගම්වැසියා හා වැව අතර පැවතියේ එකිනෙක වෙන්කළ නොහැකි දැඩි සම්බන්ධතාවයකි. විශේෂයෙන්ම වියළි කලාපීය ජනාවාස ව්‍යාප්තවී යාම, කෙත්බිම් ඇතිවීම හා වැව් නිර්මාණය වීම යන අංශ තුන එකිනෙකට බද්ධවූ ක්‍රියාවලියක් ලෙස හඳුනාගත හැකිය.

"ගමට වැවක්" යන සංකල්පය වියළි කලාපීය ප්‍රදේශවලට බෙහෙවින් සාධාරණ අදහසකි. ලොකු හෝ කුඩා වැව් නොමැති ගමක් මෙම ප්‍රදේශයෙන් සොයාගැනීම අසීරුය. වර්තමානයට වඩා පුරාණයේ දී වියළි කලාපීය ජනාවාසකරණය වැව් ආශ්‍රිතව වැඩියෙන් සිදුවී ඇත. මේ නිසා ඔවුන්ට වැව සම්පත් දායකයකු ලෙස කටයුතු කරන බව පැහැදිලිය. කිසියම් ප්‍රදේශයක වැවක් ඉදිකිරීම ප්‍රධාන වශයෙන් කෘෂි කාර්මික අරමුණු කෙරෙහි කේන්ද්‍රගත වුවද, තවත් ක්ෂේත්‍ර ගණනාවක් ඔස්සේ වැව තම සේවය ජනතාවට ලබාදීම සිදුකරලයි. දෛනික ජීවිතයට අදාළ ජල අවශ්‍යතා සපුරාගැනීම, ධීවර කටයුතු, භූගත ජලය ආරක්ෂා කරලීම සහ පරිසරය සිහිල්ව තබාගැනීම ඉන් කිහිපයකි.

දැදුරු ඔය නිම්නය ජනාවාසවීමත් සමග ප්‍රදේශයේ කෘෂි කාර්මික කටයුතු සාර්ථකව පවත්වාගෙන යාම සඳහා විධිමත් ජල සම්පාදන ක්‍රමයක් අවශ්‍යය විය. මෙම අවශ්‍යතාවය සපුරා ගැනීම පිණිස ප්‍රදේශයේ විශාල වශයෙන් වැව් ඉදිකර ඇති බවට සාක්ෂි හඳුනාගත හැකිය. මෙයින් වැඩි ප්‍රමාණයක් කුඩා වැව් ගණයට අයත් වේ. ලංකාවේ ශේෂව තිබෙන ලොකු කුඩා වැව්වල වැඩි ව්‍යාප්තියක් දක්නට ලැබෙන්නේ දැදුරු ඔය ආශ්‍රිත නිම්නබද ප්‍රදේශයේ වීම මෙහිලා සැලකිය යුත්තකි.

පහසුවෙන් ගංගාශ්‍රිත ජලය ප්‍රයෝජනයට ගත නොහැකි ප්‍රදේශවල වගා කටයුතු සඳහා අවශ්‍ය ජලය රැස්කර ගැනීම පිණිස කෘතිම ක්‍රම උපයෝගී කරගෙන තිබේ. දැදුරු ඔය කලාපයේ ජනතාව සෑම ගමකම කුඩා ග්‍රාමීය වැවක් ඉදිකරගෙන ඇත. දැදුරු ඔය මධ්‍ය ප්‍රදේශය නිරන්තර වැසි සහිත භූමියක් නොවූ හෙයින් හා මුල් කාලීනව දැදුරු ඔයේ ජලය ඍජුවම වගා කටයුතු සඳහා යොදා ගැනීමට දැනුමක් හෝ අවශ්‍යතාවයක් නොතිබුණු හෙයින් ඒ සඳහා විකල්ප ක්‍රියා මාර්ග අනුගමනය කර තිබේ. ඒ අනුව වැසි ජලය රැස්කර ගැනීමේ අභිලාපයෙන් හා ප්‍රදේශයේ කුඩා ජල මාර්ගවල ජලය රැස්කර ගැනීමේ අරමුණු ඇතිව කුඩා ග්‍රාමීය වැව් ප්‍රථමයෙන් ඉදිකරන්නට ඇත.

දැදුරු ඔය පෝෂක ප්‍රදේශයේ කෘෂි කර්මාන්තයට ඉවහල් වන වැව් ආශ්‍රිත ජල සම්පාදන ක්‍රම ක්‍රි.පූ. සමයේ සිටම බිහිවූ බවට ඓතිහාසික සාධක තිබේ. රිදී විහාරයේ ක්‍රි.පූ. අවසාන භාගයට අයත් ලිපියක "පගමක" නම් වූ වැවක් පිළිබඳව සඳහන් වේ (නිකලස්. 1979 පි. 125). ප්‍රදේශයේ වාරි නිර්මාණයක් සම්බන්ධයෙන් තොරතුරු දැක්වෙන පැරණිම අවස්ථාව මෙය ලෙස සැලකිය හැකිය.

කුරුණෑගල - නාරම්මල මාර්ගයේ ගලඋඩ විහාරයේ තිබෙන වසභ (ක්‍රි.ව. 67-111) රජුගේ ලිපියක "අමරගලක" නම් වූ වැවක් පිළිබඳව සඳහන් වේ (නිකලස්. 1979 පි. 121). වාරියපොල - හලාවත මාර්ගයේ ගල්වල විහාරයේ ක්‍රි.ව. දෙවන සියවසට අයත් ලිපියක "බමරහගම හා මඩගම" නම් වූ වැව් දෙකක් පිළිබඳව දක්වා ඇත (නිකලස්. 1979 පි. 121). මෙම වැව් ත්‍රිත්වය නිර්මාණය වී ඇත්තේ දැදුරු ඔයට නිරිත දෙසින් ගලා බසින කොළමුණු ඔය ආශ්‍රිතවය. මෙම ඔය පුරාණයේ හඳුන්වා ඇත්තේ **කොළඹින්න නදී** ලෙසිනි (මව. පරි. 90 පෙළ 9-11). පඬුවස්නුවර ආසන්නයේ තිබෙන පුරණ පඩා වැව කරවා ඇත්තේ ද මෙම ඔය ආශ්‍රිතවයම ය. පාණ්ඩවාපිය, පාණ්ඩ වැව ලෙසින් හැඳින්වුණු මෙම වැව පළමුවෙනි විජයබාහු (ක්‍රි.ව. 1055-1110) රජු විසින් ප්‍රතිසංස්කරණය කරන ලදි (මව. පරි. 90 පෙළ 49). දක්ඛිණ දේශය සංවර්ධන කාර්යයේදී පළමුවන පරාක්‍රමබාහු (ක්‍රි.ව. 1153-1186) රජු විසින් මෙම වැව වඩාත් විශාල කර ගොඩනගන ලද අතර, අනතුරුව එය **බැණ සමුද්‍ර** නමින් හඳුන්වනු ලැබිණ (මව. පරි. 90 පෙළ 39-42).

දැදුරු ඔයේ ඉහළ ප්‍රදේශයේ වැඋඩ ආසන්නයේ යටිවිල තිබෙන ක්‍රි.ව. දෙවන සියවසට අයත් ලිපියක "වකොර" නම් වූ වැවක් ද (නිකලස්. 1979 පි. 126), ඔයට ඊසාන දෙසින් වූ නැලව පිහිටි ලිපියක "විහරවලිය" නම් වූ වැවක් ද සඳහන් වේ (නිකලස්. 1979 පි. 119).

දැදුරු ඔය හා ඒ ආශ්‍රිත ජල මාර්ග පාදක කරගෙන වාරි කර්මාන්ත ඉදිකිරීම ආරම්භ කර තිබෙන්නේ මහසෙන් රජු විසිනි. දැදුරු ඔයේ පෝෂණ ජල මාර්ගයක් වන කුම්භීල නදී හෙවත් කිඹුල්වානා ඔය හරස්කර කරවන ලද කුම්භීලවාපි හෙවත් කුම්බාලක වැව මේ රජුගේ වැදගත් වාරි කර්මාන්තයකි (මව. පරි. 38 පෙළ 48). පස්වන කාශ්‍යප, පළමුවන විජයබාහු හා පළමුවන පරාක්‍රමබාහු යන රජවරුන් විසින් නැවත ප්‍රතිසංස්කරණය කරන ලද කුම්බිලසොබ්බක වාපි හෙවත් කිඹුල්වානා වැව ලෙස මෙය හඳුනාගෙන තිබේ. දැදුරු ඔය ආශ්‍රිතව මහසෙන් රජු විසින් මහාගල්ලක වාපි නම් වූ විශාල වැවක් කරවා ඇත (මව. පරි. 37 පෙළ 48). නිකවැරටිය ආසන්නයේ පිහිටි මාගල් වැව මෙම පුරාණ වැව ලෙස හඳුනාගෙන තිබේ. මාගල් වැව පළමුවන පරාක්‍රමබාහු රජු විසින් නැවත ප්‍රකෘතිමත් කර තිබේ (මව. පරි. 68 පෙළ 43). දැදුරු ඔයට ඊසාන දෙසින් පිහිටි හුළුගල්ල නම් වැව මහසෙන් රජු විසින් කරවන ලද සුළුගුලු හෙවත් සුගුළුව වැව ලෙස හඳුනාගෙන ඇත (නිකලස්. 1979 පි. 113). වංසකතාවේ සීරුවැව ලෙස හඳුන්වා ඇත්තේ මෙම වැව විය හැකිය (මව. පරි. 37 පෙළ 49).

ධාතුසේන (ක්‍රි.ව. 455-473) රජු දැදුරු ඔයේ පෝෂණ ශාඛාවක් වූ හක්වටුනා ඔය (සංඛවඩ්ඪමානක නදී) ආශ්‍රිතව මාළිය වැව කරවා තිබේ (නිකලස්. 1979 පි. 118). පළමුවෙනි විජයබාහු රජු මෙම වැව ප්‍රතිසංස්කරණය කළ බව චූලවංසයේ දැක්වේ (මව. පරි. 60 පෙළ 48-53). ධාතුසේන රජු විසින් දැදුරු ඔයට නැගෙනහිර දෙසින් වූ දැනට මැද්දකැටිය වැව ලෙස හැඳින්වෙන පුරාණ සංගමු වැව කරවීය (නිකලස්. 1979 පි. 119). පළමුවන අග්ගබෝධි (ක්‍රි.ව. 571-604) රජු හිරිවඩ්ඪමාන වැව තැනවීය (මව. පරි. 42 පෙළ 8). දැදුරු ඔයට ආසන්න වැල්ලව පිහිටි හිරිවඩුන්න වැව ලෙස හඳුනාගෙන තිබේ.

පළමුවන පරාක්‍රමබාහු රජු දක්ඛිණ දේශයේ පාලකයාව සිටි සමයේ දී හා මහ රජු ලෙස කටයුතු කරන සමයේ දී ප්‍රතිසංස්කරණය කරන ලද වැව් ගණනාවක් පිළිබඳව තොරතුරු අනාවරණය කරගත හැකිය (නිකලස්. 1959 පි. 77-80).

1. සෙට්ඨිවාපි - හෙට්ටිපොල පිහිටා ඇත.
2. අම්බවාසාවාපි - කොඩ්රින්ටන් විසින් නිකවැරටිය අසල වාසියාව වැව ලෙස හඳුනාගෙන ඇත.
3. සාදිග්ගාමවාපි - හාගිතමුව මහ වැව ලෙස නිකොලස් විශ්වාස කරන අතර නිකවැරටිය කඩිගාව ප්‍රදේශයේ පිහිටි හාතිගම්මන වැව ලෙස මා විසින් විශ්වාස කරනු ලැබේ. පැරණි වැව් බැම්ම හා රළ පනාවේ අවශේෂ හඳුනාගත හැකිය.
4. මාලවල්ලිවාපි - හලාවත අසල මාලවල්ලය වැව.
5. කණ්නිකාරගල්ලකවාපි - වෙලන්ගොල්ල වැව.
6. සූකරග්ගාමවාපි - කොඩ්රින්ටන් විසින් දැදුරු ඔය වම් ඉවුරේ පිහිටි ඌරාපොත්ත වැව ලෙස හඳුනාගෙන ඇත.
7. මහකිරාලවාපි - නිකවැරටියට උතුරින් පිහිටි මහගිරිල්ල වැව.
8. කිරාවාපි - හලාවත ප්‍රදේශයේ පිහිටි කිරාවැව ලෙස කොඩ්රින්ටන් හඳුනාගෙන ඇත.
9. කරවිටිය - විලක්තවාපි බිංගිරිය ප්‍රදේශයේ පිහිටි කරවිට හා විලක්තාව වැව.
10. උදුම්බරාගමවාපි - දිවුල් වැව නමින් දැදුරු ඔය නිම්නයේ වැව් ගණනාවක්ම වේ.
11. මුනරුවාපි - හෙට්ටිපොල ආසන්නයේ මලගනේ මුහුන්නරු වැව.

12. කලලහල්ලිකවාපි - මඩහපොල වැව.

13. පොලොත්තරුතලවාපි - නිකවැරටියට තරමක් දුරින් පිහිටි පොලොන්තලාව වැව විය හැකිය.

14. මහාගල්ලකවාපි - නිකවැරටිය මාගල්ලේ වැව" පැරණි වාරි නිර්මිතවල කොටස් හඳුනාගත හැකිය.

15. කුම්බිලසොබ්බවාපි - මහසෙන් රජු විසින් කරවන ලදඅ පළමුවන විජයබාහු රජු විසින් ප්‍රතිසංස්කරණය කරන ලද කිඹුල්වානා වැව.

16. පාණ්ඩවාපි - පඬුවස්නුවර ප්‍රදේශයේ පිහිටි ප"ඩාවැව ලෙස හඳුනාගෙන ඇත. එම රජු මෙම වැව විශාල කර තිබේ. පැරණි බිසෝකොටුවඅ වැව් බැම්මඅ රළපනාව හා පිට වානේ සාක්ෂි හඳුනාගත හැකිය.

බතලගොඩ වැව පැරණි වාරි නිර්මාණයක් ලෙස හඳුනාගෙන තිබේ. සෘජුවම දැදුරු ඔය ආශ්‍රිතව ඉදිකර තිබූ මෙම වැවේ ආසන්නයෙන් ලැබී තිබෙන පුරාණ ඉදිකිරීම් සාධක ක්‍රි.පූ. අවසාන සමයට අයත්ය (Brohier. 1979 පි. 7). කුමාරදාස (ක්‍රි.ව. 513-522) රජු විසින් හා කල්‍යාණවතී (ක්‍රි.ව. 1202-1208) රැජිණ විසින් බතලගොඩ වැව ප්‍රතිසංස්කරණය කර තිබේ. වැව් බැම්මේ තිබෙන පුවරු ලිපියෙන් කල්‍යාණවතී රැජිණ මෙම ප්‍රදේශයේ කළ සංවර්ධන කාර්යයන් පිළිබඳව තොරතුරු ලබාගත හැකිය.

දක්ඛිණ දේශාධිපතිව සිටි පළමුවන පරාක්‍රමබාහු රජුගේ කාලය තුළ දැදුරු ඔය නිම්නයේ වැව් නිර්මාණය හා ප්‍රතිසංස්කරණය සම්බන්ධයෙන් වර්ධනීය ස්වරූපයක් පෙන්නුම් කරයි. මිට අමතරව වංසකතාවල සඳහන් නොවන පුරාණ වැව් කිහිපයක් ද හඳුනාගැනීමට හැකිවිය. මේ අතරින් ඇතැම් වැව් වර්තමාන ප්‍රතිසංස්කරණයන්ගෙන් පසු භාවිත කරන අතර, සමහරක් සම්පූර්ණයෙන් ම විනාශවී ගොස් තිබේ. එවැනි වැව් බොහෝමයක ශේෂව තිබෙන්නේ තැනින් තැන බිඳී ගිය වැව් බැම්ම පමණකි. වැවට අදාළ සෙසු නිර්මාණාත්මක අංග විනාශ වී ගොස් තිබේ. පුරාණයේ දී ඉදිකරන ලද නමුත් පසුව සිදුකළ ප්‍රතිසංස්කරණයන්ගෙන් පසුව භාවිතයට ගැනෙන වැව්වල පුරාණ තාක්ෂණික අංග වර්තමානයේ දී දැකගත නොහැකිය. පුරාණ නටබුන් ඉවත්කර එම ස්ථානවල නව ගොඩනැගීම් සිදුකිරීම මෙම විනාශයට බලපාන ලද ප්‍රධාන හේතුවකි.

5. සමාලෝචනය

"ශ්‍රී ලංකාවේ පැරණි ජල කළමනාකරණ ක්‍රමවේදය මඟින් වර්තමානයට ලබාගත හැකි ආදර්ශය" යන තේමාව ඔස්සේ ඉදිරිපත් කරනු ලබන මෙම පර්යේෂණ පත්‍රිකාව සඳහා පාදක වූයේ මා විසින් දැදුරු ඔය නිම්නයේ පැරණි වාරි කර්මාන්ත සම්බන්ධයෙන් සිදුකරන ලද අධ්‍යයනයන්ගෙන් ලබාගත් තොරතුරුය. දැදුරු ඔය ආශ්‍රිතව නිර්මාණය කෙරුණ වැව් හා අමුණු අතර සම්බන්ධතාවය පිළිබඳව අධ්‍යයනය කිරීමේ දී පැහැදිලි වන කාරණයක් වූයේ අමුණක් ඉදිකිරීමේ මූලික පරමාර්ථය සෑම විටම වැවකට ජලය සැපයීමක් ම නොවන බවය. වැවට ජලය සපයන අතරතුර එම ඇළ මග දෙපස කෘෂි බිම් සඳහා ජලය සැපයීම ද සිදුකර තිබේ. සූකර නිජ්ජර, කොට්ඨබද්ධ ආදී අමුණුවලින් ඇරඹෙන ඇළ මාර්ගවලින් ඒ බව පැහැදිලි වේ. මිට අමතරව ඇතැම් ඇළ මාර්ග සෘජුවම කෙත්බිම් කරා ජලය සැපයීම සඳහා පමණක් ම ඉදිකරන ලදි. දෝරදත්තික හා ජජ්ජර නිජ්ජර අමුණින් ඇරඹෙන ඇළ මාර්ගය මිට නිදසුනකි. එම ඇළ මාර්ග අවට පරීක්ෂා කිරීමේ දී එම භූමිය කෙත්බිම් සඳහා යෝග්‍ය වූයෙන් ඒ සඳහා අවශ්‍ය ජලය ඇළ මාර්ග ඔස්සේ නිකුත්කිරීමට කටයුතු යොදා ඇති බව පෙනේ.

දැදුරු ඔයේ සූකර නිප්ජර අමුණ, මාගල් වැව හා ඒ ආශ්‍රිත කෙත්බිම් අතර පවතින සම්බන්ධතාවය පිළිබඳ පරීක්ෂා කිරීමේ දී පැහැදිලි වන්නේ අමුණේ දායකත්වයෙන් වැව නිරතුරු ක්‍රියාකාරීව පැවති බවය. ඒ අනුව වැව් යටතේ වූ කෙත්බිම් දෙකන්නයේම වගා කිරීමට හැකි වූ බව අනුමාන කළ හැකිය. වැවේ ප්‍රමාණය හා එමගින් පෝෂණය වූ කෙත්බිම් ප්‍රමාණය අනුව පැහැදිලි වන්නේ වැවේ දැරිය හැකි උපරිම ජල ධාරිතාවය එම කෙත්බිම් සඳහා ප්‍රමාණවත් නොවන බවකි. මේ නිසා සූකර නිප්ජර අමුණ මගින් නිරන්තර ජල සැපයුමක් මාගල් වැවට ලබාදී තිබේ. වැවේ ක්ෂය වන ජල ප්‍රමාණය එම සැපයුම මගින් සපුරාගැනීමට හැකිවීමෙන් කෙත්බිම් සඳහා අවශ්‍ය සම්පූර්ණ ජල ප්‍රමාණය නිකුත් කිරීමේ හැකියාව ලැබී තිබේ. මිට අමතරව අමුණු මගින් ජලය සැපයූ විශාල වැව් ජල ගබඩා ලෙස ද ක්‍රියාකරන්නට ඇති අතර එම වැව්වලින් ඒ අවට පිහිටි කුඩා වැව්වලට ජලය සම්පාදනය කිරීමට හැකිවීම නිසා එම වැව් සමග වූ කුඹුරු ද සාර්ථක ලෙස වගාකරන්නට ඇත. තවද මාගල් වැව යටතේ වූ උප වැව් පුරවාලීමෙන් අනතුරුව එම වැව් යටතේ වූ කෙත්බිම් වගාකරන්නට ඇත. මෙම සියළු කාර්යයන් සඳහා ප්‍රයෝජනයට ගෙන ඉතිරි වූ ජලය (වෙල්පහු වතුර) නැවත කොටියබද්ධ අමුණට ඉහළින් දැදුරු ඔයට එකතු කිරීමෙන් එම අමුණ සඳහා ජලය නැවත ප්‍රයෝජනයට ගැනීමට හැකිවිය.

පළමුවන පරාක්‍රමබාහු රාජ්‍ය සමය ශ්‍රී ලංකාවේ වාරි කර්මාන්ත ඉතිහාසයේ ස්වර්ණමය අවධිය ලෙස සැලකිය හැකිය. මෙම රජු විසින් තනන ලද හෝ ප්‍රකෘතිමත් කරන ලද වැව්, අමුණු, ඇළ මාර්ග හා සොරොව් සංඛ්‍යාවන්හි ප්‍රමාණය ඉතා විශාලය (මව. පරි. 68 හා 79). මේ සම්බන්ධයෙන් ඓතිහාසික මූලාශ්‍රවල මෙන්ම පුරාවිද්‍යාත්මක සාධකවලින් තොරතුරු ලබාගත හැකිය. මේ අනුව මිට සමකාලීනව පුරාණ ලෝකයේ පැවති උසස්ම වාරි තාක්ෂණය පළමුවන පරාක්‍රමබාහු රාජ්‍ය සමයේදී ශ්‍රී ලංකාවේ පැවති බව නිගමනය කිරීමට පිළිවන. ඔහුට මෙවැනි විශිෂ්ඨ සේවයක් වාරි කර්මාන්තය සඳහා ඉටුකිරීමට අවශ්‍ය මූලික පසුබිම හා පුහුණුව ලැබුණේ හෙතෙම දක්ඛිණ දේශයේ පාලකයාව සිටිමින් දැදුරු ඔය නිම්නයේ වාරි කර්මාන්ත දියුණු කිරීමෙනි.

දැදුරු ඔය නිම්නයේ ඉදිවුණු අමුණු, ඇළ මාර්ග හා වැව් පරාක්‍රමබාහු රාජ්‍ය සමය වනවිට එකිනෙකට බද්ධ වූ වාරි පද්ධතියක් ලෙසින් ක්‍රියාත්මක වන අයුරින් ගොඩනගා තිබේ. "අභියෝගය ජයගැනීම" යන සංකල්පය මේ සඳහා සෘජුවම බලපා ඇත. මේ අනුව දැදුරු ඔය ආශ්‍රිතව බිහිවූයේ එම නිම්නයට ම කේන්ද්‍රගත වූ ස්වාධීන වාරි පද්ධතියක් බව නිගමනය කළ හැකිය. ඒකාබද්ධ ව්‍යාපාරයක් ලෙස මෙම පද්ධතිය ගොඩනැගීමෙන් අපේක්ෂා කරන්නට ඇත්තේ ජලය අඩු වැඩිවීම අතර නිරතුරු වෙනස්වන ස්වරූපයකින් යුතු දැදුරු ඔයෙහි ජලයෙන් උපරිම ප්‍රයෝජනය ලබාගැනීමය. මේ සඳහා පූර්ව සැළසුමක් හා සංවිධානයක් තිබුණු බව පැහැදිලිය. උපයෝගීත්වය නිසි ලෙස හඳුනාගෙන එයට ගැලපෙන පරිද්දෙන් මෙම වාරි නිර්මාණ ස්ථාන ගතකර තිබේ. ජලය නමැති ස්වාභාවික සම්පතේ එක් තැනක සිට තවත් තැනකට ගලා යන ස්වභාවය නිසි අයුරින් පුරාණ වාරි තාක්ෂණයේදී ප්‍රයෝජනයට ගත් අයුරු දැදුරු ඔය වාරි මාර්ගවලින් මොනවට පිළිබිඹු වේ.

මෙම පද්ධතියේ ක්‍රියාකාරීත්වය නිසා ක්‍රමානුකූල ජල සංසරණයක් ඇති වේ. මෙමගින් ජලය අවස්ථා ගණනාවකදී ම භාවිතා කිරීමට හැකිවන බැවින් ජලය ක්ෂයවීම අවම කරගැනීමට ද හැකියාව ඇත. මෙවැනි ජල සංසරණ වර්ග දෙකක් දැදුරු ඔය නිම්නයෙන් හඳුනාගැනීමට පිළිවන.

I. අමුණ - වැව - කෙත්බිම් අතර ජල සංසරණය.

II. අමුණ - කෙත්බිම් අතර ජල සංසරණය.

දැදුරු ඔය වාරි පද්ධතිය නිර්මාණය කිරීමේ දී මෙවැනි ජල සංසරණ ඒකක ගනනාවකගේ සම්බන්ධතාවයක් තිබෙන පරිද්දෙන් ගොඩනගා ඇත. මිට අමතරව අතු ගංගා ඔස්සේ එන ජලය ද ප්‍රයෝජනයට ගැනීමෙන් අනතුරුව දැදුරු ඔයට එකතු කිරීමෙන් නැවත වතාවක් භාවිතයට ගැනීමේ අවස්ථාව සළසා ඇත. මේ අනුව පැහැදිලි වන්නේ දැදුරු ඔය නිම්නයේ ජලයෙන් ඒ වන

විට උපරිම ප්‍රයෝජනය ගෙන තිබෙන බවකි" පළමුවන පරාක්‍රමබාහු රජු දක්ඛිණ දේශාධිපතිව සිටි සමයේ ඉදිරිපත් කළ:

> "අහසින් වැටුණ එකද දිය බිඳක් පවා මනුෂ්‍යය ප්‍රයෝජනයට නොගෙන මුහුදට ගලා නොයා යුතුය"

යන ප්‍රකාශය තහවුරු වන ආකාරයෙන් දැදුරු ඔය ආශ්‍රිත වාරි පද්ධතිය ඉදිකර තිබෙන බව මේ අනුව නිගමනය කිරීමට පිළිවන.

අමුණු හා වැව් ප්‍රධාන කොටගත් මෙම වාරි පද්ධතියේ විහිදීම නිසා ප්‍රදේශයේ තිබෙන වියළි ස්වභාවයෙන් යුතු පාරිසරික තත්ත්වයේ පාලනය වීමක් එකල සිදුවන්නට ඇති බව අනුමාන කළ හැකිය. මෙම පද්ධතිය උපරිම තත්ත්වයෙන් ක්‍රියාත්මක වුණු අවධියේ නිරන්තරයෙන් අමුණු, ඇළ මාර්ග, වැව් හා කෙත්බිම් අතර ජලය සංසරණයවීමක් සිදුවූ අතර එම ජලයෙන් කිසියම් ප්‍රමාණයක් වාෂ්පීකරණ ක්‍රියාවලිය මගින් වායුගෝලයට එකතුවීම නිසා ප්‍රදේශය සිසිල් ස්වභාවයකින් යුක්ත වන්නට ඇත. එලෙස සංසරණය වන ජලයෙන් තවත් කොටසක් පොළවට උරා ගැනීම සිදුවන අතර මේ නිසා ප්‍රදේශයේ භූගත ජල මට්ටම ඉහළයාම සිදුවේ. මෙවැනි හේතූන් මගින් ප්‍රදේශයේ වනාන්තර හා දිගු කාලීන බෝග සරුවීමෙන් සමකාලීන පාරිසරික තත්ත්වයේ පැහැදිලි වෙනසක් එකල තිබෙන්නට ඇත. මෙම තත්ත්වය නිසා භූමිය මතුපිට ජලයේ ආරක්ෂාවීම සිදුවේ. ඒ හේතුවෙන් ප්‍රදේශයේ දිය උල්පත් හා ස්වභාවික කුඩා ජල මාර්ග ක්‍රියාත්මක තත්ත්වයෙන් පවතින්නට ඇත. මේ නිසා එවැනි ජල මාර්ග ආශ්‍රිතව ගොඩනැගුණු කුඩා වැව්වල ජලය රැස්වීමෙන් එම වැව් යටතේ වගාකරන කෙත්බිම් වඩාත් සාර්ථක ප්‍රතිඵල ගෙන දෙන්නට ඇති බව නිගමනය කළ හැකිය.

දැදුරු ඔය නිම්නයේ විනාශවී ගොස් තිබෙන වැව් විශාල ප්‍රමාණය සම්බන්ධයෙන් පරීක්ෂාකරන විට පැහැදිලි වන්නේ සශ්‍රීක ප්‍රදේශයක සංවිධානාත්මක ලෙසින් ජනාවාස පිහිටුවාගත් විශාල ජන පිරිසක් සිටි බවය. එහෙත් මෙම වැව් සියල්ලම කෙටි කාලීන ක්‍රියාවලියක ප්‍රතිඵලයක් ලෙස හැඳින්විය නොහැකිය. අනුරාධපුර මුල් යුගයේ සිට ක්‍රමයෙන් වැඩි වූ ජනතාවගේ කෘෂිකාර්මික හා වෙනත් ජල අවශ්‍යතාවයන් සපුරාලීම පිණිස මෙම වාරි නිර්මාණ විවිධ අවස්ථාවන්හි දී ඉදිවන්නට ඇත. පළමුවන පරාක්‍රමබාහු රජු විසින් දැදුරු ඔය නිම්නයේ ලොකු - කුඩා සියළු වාරි කර්මාන්ත සම්බන්ධ වන සේ වඩාත් සංවිධානාත්මක සුවිශාල වාරි පද්ධතියක් නිර්මාණය කරන ලද්දේ මෙම කලාපය තව දුරටත් සශ්‍රීක කිරීමේ අදහස ඇතිවය. එහෙත් මෙම තත්ත්වය පොළොන්නරු රාජධානිය බිඳවැටීමත් සමගම එතරම් කාලයක් පැවතුණේ නැත. ඉන් අනතුරුව එළඹුණු දඹදෙණි යුගයේ හා කුරුණෑගල යුගයේ දී මෙම වාරි කර්මාන්ත යම්තාක් දුරකට ක්‍රියාකාරී ස්වභාවයකින් පවතින්නට ඇත. ඉන් පසු මෙම වාරි පද්ධතිය ක්‍රමයෙන් විනාශ වී යන්නට ඇති බව අනුමාන කිරීමට පිළිවන.

දැදුරු ඔය නිම්නයේ වාරි පද්ධතිය බිඳවැටීමට තුඩු දුන් ප්‍රධාන හේතුව ලෙස සැලකිය හැක්කේ දේශපාලන අස්ථාවරත්වය නිසා වාරි කර්මාන්තයට තිබුණු රාජ්‍ය අනුග්‍රහය නොලැබීමෙන් ඒවා නිසි පරිදි නඩත්තු නොවීමය. ඒ සමගම ජනතාව මෙම ප්‍රදේශ අතහැර සුවිසල් වාරිමාර්ග කටයුතු අනවශ්‍ය වූ නිරිතදිග තෙත් කලාපයට සංක්‍රමණය වීම සිදුවිය. මේ හේතුවෙන් ප්‍රදේශය ජනශූන්‍ය වූ අතර ඉතිරි වූ කුඩා ජන කණ්ඩායම් සඳහා තම කෘෂි කාර්මික අවශ්‍යතා සපුරා ගැනීම පිණිස කුඩා වාරි ක්‍රම ප්‍රමාණවත් වන්නට ඇත. විශාල වාරි මාර්ග නඩත්තු කිරීමේ ශක්තියක් එම ජනතාවට නොමැති වීමෙන් ඒ කෙරෙහි පැවති අවධානය ක්‍රමයෙන් අඩුවී යාම නිසා මෙම ඉදිකිරීම් ක්‍රමයෙන් දුර්වල වන්නට ඇති බව අනුමාන කළ හැකිය. පශ්චාත් කාලීනව එළඹී විවිධ ස්වභාවික විපත් හා මානව ක්‍රියාකාරකම්වල ප්‍රතිඵල ලෙස මෙම වාරි පද්ධතියේ සුවිශේෂී ඉදිකිරීම් විනාශවී යන්නට ඇත.

වර්තමානයේ දැදුරු ඔය නිම්නය වඩාත් වියළි සහගත තත්ත්වයකට පත්වීමට හේතුවූ ප්‍රධාන කාරණය ලෙස හඳුනාගත හැක්කේ අනාදිමත් කාලයක් පුරා මෙම නිම්නයේ ක්‍රියාත්මක වූ ලොකු

කුඩා වාරි නිර්මාණ සියල්ල ඒකරාශි වූ පැරණි වාරි කර්මාන්ත ජාලය බිඳ වැටීමය. නිම්නයේ පිහිටි යකඩපත වැව, මාදතු වැව, හාතිගම්මන වැව, පඩා වැව වැනි විශාල වැව් විනාශවී යාම, කුඩා ග්‍රාමීය වැව් විශාල ප්‍රමාණයක් අතහැර දැමීම හා දැදුරු ඔය ආශ්‍රිත අමුණු පද්ධතිය බිඳ වැටීම වැනි හේතූන් මත අවශ්‍යය ජල සම්පාදනය ක්‍රමවත් ලෙස සැළසීමට නොහැකිවීම හේතුවෙන් මෙම තත්ත්වය ඇතිවූ බව පැහැදිලිය.

පරිශීලිත ග්‍රන්ථ

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පර්යේෂක - හෙක්ටර් කොබ්බෑකඩුව ගොවි කටයුතු හා පුහුණු කිරීමේ ආයතනය

සාරාංශය

වසර 1954 සිට 2007 දක්වා ශ්‍රී ලංකාවේ වී ගොවිතැන් කළ මුළු බිම් ප්‍රමාණය අක්කර 1,031,611 සිට 1,298,864 දක්වා වැඩි වී ඇත. මෙයට ප්‍රධාන දායකත්වයක් සපයා ඇත්තේ මහවැලි සංවර්ධන කඩිනම් වැඩසටහනයි. වී අස්වැන්න ද මෙම වකවානුව තුල හෙක්ටයාරයට මෙ.ටොන් 1.5 ක් සිට 4.385 දක්වා වර්ධනය වී ඇත. විශාල වියදමක් දරමින් සැපයෙන ජලය ප්‍රශස්තව භාවිතා කර උපරිම ප්‍රතිලාභයක් රටට ගෙනදිය යුතුව ඇත. ඒ සඳහා යොමු වූ අධ්‍යයනයක් ඉදිරිපත් කරන මෙම පත්‍රිකාව සඳහා හුරුළුවැව, නාච්චදූව, නුවර වැව, රාජාංගන වැව, කවුඩුල්ල, පරාක්‍රම සමුද්‍රය සහ මින්නේරිය ජලාශ ආශ්‍රිතව සිදු කෙරන ලදි. වාරිමාර්ග දෙපාර්තමේන්තුවෙන් හා වාරි ජල කළමනාකරණ අංශයේ තොරතුරු පදනම් කරගෙන මෙම අධ්‍යයනයේ දී යල සහ මහ කන්න තුළ ජලය බෙදා ඇති ආකාරය, අස්වැන්න හා වගා තීව්‍රතාව විමසා බලන ලදි. යල හා මහ කන්න තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව සෙවීම සඳහා ප්‍රතිපායන විශ්ලේෂණය සිදු කර ඇත. එමගින් අක්කරයක වී වගා කිරීම සඳහා සැපයිය යුතු වූ ජල ප්‍රමාණය ගණනය කර ඇත. මහ කන්නය තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව ප්‍රතිපායන (Regression) **විශ්ලේෂණය දත්ත 35 ක් ඇසුරින් සිදු කර වාරි ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව** A = **3.349558** IWS **-1578.8 බව ලැබී ඇත. මෙහි** IWS = **වාරි ජල සැපයුම (අක්කර අඩි) හා** A = **වී වගා බිම් ප්‍රමාණය (අක්කර) වේ. මහ කන්නය තුල නිර්නය සංගුණකය** (Coefficient of Determination R^2) **0.831201 වී ප්‍රතිපායන සංගුණකය** (Regression Coefficient R) **0.911702 විය. මහ කන්නයේදී වී වගා කිරීම සඳහා අක්කර අඩි 3.35 ක පමණ වාරි ජල ප්‍රමාණයක් සැපයිය යුතු බව ලැබී ඇත. එමෙන්ම යල කන්නය තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව** A = **4.492131**IWS + **2391.724 මගින් දැක්වේ. එනම් යල කන්නය තුල වී වගා කිරීම සඳහා අක්කර අඩි 4.49 ක පමණ වාරි ජල ප්‍රමාණයක් සැපයිය යුතු බව පෙනී යයි. නිර්නය සංගුණකය** (R^2) **0.90367 වී ප්‍රතිපායන සංගුණකය** (R) **0.950616 විය. වර්ෂා ජලය ලැබෙන නිසා මහ කන්නයේ අගය යල කන්නයේ අගයට වඩා අඩු වී ඇති බව පෙනී යයි. මෙම අගයන් කන්නය අනුව මෙන්ම ජලාශය හා ලැබුණු වැසි ප්‍රමාණය වැනි දේශගුණික සාධක අනුව වෙනස් වේ. නාච්චදූවේ 2004 යල කන්නයේදී ජල අක්කර අඩි 0.9 ක් පමණ ද 2007දී ජල අක්කර අඩි 10 ක් පමණ ද වී වගාව සඳහා වාරි ජලය යෙදවීමට සිදුවීමෙන් එය පැහැදිලි වේ. වී නිෂ්පාදනයේ දී ජල ඵලදායීතාව යන්නෙන් වාරිජල ඝන මීටරයක් මගින් නිපදවිය හැකි වී කිලෝ ගණන දක්වා ඇත. යල කන්නයේ මෙම අගයන් සැලකූවිට උපරිම අගය වන ඝන මීටරයට වී කිලෝ 0.61 පෙන්වා ඇත්තේ 2007 වසරේ නුවර වැවයි. නාච්චදූව ජල ඵලදායීතාව අතින් අවම මට්ටමක ඇත එය 2005 දී එය 0.12 ක් වී ඇත. ජල ඵලදායීතාව වැඩි ජලාශවල අතිරේක වගා බිම් ඇත්නම් වගා කිරීමට ජලය ලබාදීම වී නිෂ්පාදන අංශයෙන් වඩාත් හිතකර වෙයි. මහ කන්නයේ**

උපරිම අගය වන ජල ඝන මීටරයට වී කිලෝ 1.1 පෙන්වා ඇත්තේ 2003/04 වසරේ නාච්චදූව වැවයි. 2002/03 දී නුවර වැව ජල ඵලදායීතාව අතින් ඝන මීටරයට වී කිලෝ 0.21 වැනි පහළ මට්ටමක ඇත. වී නිෂ්පාදනය සලකන විට ජල ඵලදායීතාව වැඩි ජලාශවලට වාරි ජලය ලබා දීමේ ප්‍රමුඛතාවක් දැක්වීම වඩාත් හිතකර වෙයි. ජලාශවල ජලය හිඟ යල කන්න වලදී පැවතිය හැකි වර්ෂාපතනය වැඩි නම් පමණක් වී වගාව සිදු කිරීමටත් එය අඩු නම් ගණනය කිරීමකින් පසු කොටසක වෙනත් භෝග වගා කිරීමත් ඵලදායී බව පෙනී යයි. සෑම වැවකම වගාවන් සඳහා අවශ්‍ය ජල ප්‍රමාණය, ලැබිය හැකි වර්ෂාව හා පවතින ජල ප්‍රමාණය ඇසුරින් වගා කරන බිම් ප්‍රමාණය ගණනය කර වගාව ඇරඹිය යුතුය. පසුව සතිපතා ජලය නිකුත් කර නිකුත් කිරීමට හැකි ශේෂව ඇති ජල ප්‍රමාණයත් වාරි ජල සම්පාදනය සඳහා යොදාගත යුතු ප්‍රමාණයත් සලකා අතිරේකව වගාවන් සඳහා ජලය නිකුත් කිරීම ඉතා ප්‍රවේශමින් සිදුකල යුතු වේ.

1. හැඳින්වීම

වසර 1954/55 දී ලක්දිව වී ගොවිතැන යටතේ වූ බිම් ප්‍රමාණයන් ප්‍රධාන, ගම්බද වාරිමාර්ග කර්මාන්තය යටතේ හා වැසි ජලයෙන් පමණක් වගාකළ බිම් ප්‍රමාණයන් පිළිවෙලින් අක්කර 269,853, 292,669 හා 469,089 ලෙසින් මුළු ප්‍රමාණය 1,031,611 ක් විය. නමුත් ශ්‍රී ලංකා මහ බැංකු (2008) දත්ත අනුව 2006/07 මහ කන්නයේදී වී ගොවිතැන් කල මුළු බිම් ප්‍රමාණය හෙක්ටයාර 525,643 (අක්කර 1,298,864) වේ.

මෑත ඉතිහාසයේ ප්‍රධානතම වාරි ජල සම්පාදන ව්‍යාපෘතිය මහවැලි සංවර්ධන කඩිනම් වැඩසටහනයි. එමගින් කලින් තිබූ වැව් ගණනාවකට මහවැලි ජල සම්පාදනය කිරීම මගින් තිබුණ වගා බිම් ප්‍රමාණය සංවර්ධනය කෙරුණු අතර එමගින් කන්න දෙකම වගා කිරීම මගින් නිෂ්පාදනය වැඩි කිරීමට පියවර ගැණිනි. මහවැලි ගංගාධාර සංවර්ධන වැඩසටහනට අනුව වැව්වලට ජලය සැපයීම මගින් වගා බිම් ප්‍රමාණය වැඩිවීම පහත 1 වගුවෙන් පෙන්නුම් කෙරේ.

වගුව 1. මහවැලි ගංගාධාර සංවර්ධන වැඩසහටනට අනුව වැව්වලට ජලය සැපයීම මගින් වගා බිම් ප්‍රමාණය වැඩිවීම

වැවේ නම	ධාරිතාවඅක්කර/අඩි	කලින් වපසරියඅක්කර	දැනට වපසරියඅක්කර
හුරුළුවැව	55,000	8,000	15,700
නාච්චදූව	45,100	5,280	6,274
නුවරවැව	36,000	1,700	2,400
පදවිය	67,500	10,000	19,000
මහකනදරාව	24,000	4,000	6,700

මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත හා ඇමරිකා එක්සත් ජනපදයේ ක්‍රියාකාරී දූත මණ්ඩලය - 1961

හුරුළුවැව, නාච්චදූව, නුවර වැව, රාජාංගන වැව, කවුඩුල්ල, පරාක්‍රම සමුද්‍රය සහ මින්නේරිය ජලාශ සැලකුවිට පරාක්‍රම සමුද්‍රය හැර ජලාශ සඳහා මහවැලි ජලය ලබා දෙන අතර සඳහා පරාක්‍රම සමුද්‍රයට මොරගහකන්ද ව්‍යාපාරය සම්පූර්ණ වූ පසු ජලය සැපයෙනු ඇත.

හෙක්ටර් කොබ්බෑකඩුව ගොවි ක්ටයුතු හා පුහුණු කිරීමේ ආයතනය (හෙ.කො.ගො.ප.පු.ආ) පොළොන්නරු දිස්ත්‍රික්කයේ කවුඩුල්ල, මින්නේරිය හා පරාක්‍රම සමුද්‍රය යන ජලාශ තුළින් ජලය බෙදා හැරීම පිළිබඳව අධ්‍යයන වාර්තාවක් සකස් කරන ලදී. (ගිරාගම 2008). එම අධ්‍යයනයේදී ජලය බෙදාහැරීමේදී භාවිතා කරන ක්‍රමවේදය සහ යල සහ මහ කන්න තුළ ජලය බෙදා ඇති ආකාරය විමසා බලන ලදී.

2. ක්‍රමවේදය

මෙම පර්යේෂණ පත්‍රිකාව සඳහා හුරුළුවැව, නාච්චදූව, නුවර වැව, රාජාංගන වැව, කවුඩුල්ල, පරාක්‍රම සමුද්‍රය සහ මින්නේරිය ජලාශ ආශ්‍රිතව අධ්‍යයනය සිදු කරන ලදි. වාරිමාර්ග දෙපාර්තමේන්තුවෙන් හා වාරි ජල කළමනාාකරණ අංශයේ තොරතුරු පදනම් කරගෙන මෙම අධ්‍යයනයේ දී ජලය බෙදාහැරීමේ දී සහ යල සහ මහ කන්න තුළ ජලය බෙදා ඇති ආකාරය, අස්වැන්න හා වගා තීව්‍රතාව විමසා බැලේ.

යල හා මහ කන්න තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව සෙවීම සඳහා ප්‍රතිපායන විශ්ලේෂණය (Regression Analysis) සිදුකර ඇත. එමගින් අක්කරයක වී වගා කිරීම සඳහා සැපයිය යුතුව ජල ප්‍රමාණය (m) ගණනය කර ඇත. මහ හා යල කන්න තුල ජල සැපයුම (IWS) අක්කර අඩි හා වී වගා බිම් ප්‍රමාණය (A) අක්කර අතර සම්බන්ධතාව A = m (IWS) + C ලෙසින් දක්වමු.

විවිධ ජලාශ යටතේ අක්කරයක වී වගාව සඳහා අවශ්‍ය ජලය අක්කර අඩි ගණන හා ඒකක වී ප්‍රමාණයක් නිපදවීම සඳහා යෙදිය යුතු ජල ප්‍රමාණය ගණනය කර ඇත.

පොලොන්නරුව දිස්ත්‍රික්කයේ ප්‍රධාන ජලාශ තුනක් ඇයුරින් පසුගිය වසර පහ තුලත් 2008 දීත් වාරි ජලය නිකුත් කිරීම පිළිබඳව සොයා බලන ලදි.

3. ප්‍රධාන මහා වාරිමාර්ග හතක් පිළිබඳ අධ්‍යයනයේ ප්‍රතිඵල

3.1 වගා තීව්‍රතාව

වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත අනුව යල, මහ කන්නවලදී හා වාර්ෂික වගා තීව්‍රතාවන් (Cropping intensities) වගුව 2 න් දැක්වේ. ඒ අනුව වාර්ෂික වගා තීව්‍රතාවන් 2003 සිට 2007 කාලය තුල 1.755 හා 1.899 දක්වා වැඩි වී ඇත. මේවායින් පොලොන්නරුව ජලාශ තුනේ වාර්ෂික වගා තීව්‍රතාවන් 2003 සිට 2007 කාලය තුල 2.00 සිට 2.056 දක්වා වැඩි වී ඇත. නමුත් හුරුළුවැව හැර අනුරාධපුර දිස්ත්‍රික්කයේ වැවුවල වාර්ෂික වගා තීව්‍රතාවන් 2.00 ට අඩු අගයක පවතින බව වගුවෙන් පැහැදිලි වේ. මෙයට ප්‍රධාන හේතුව වන්නේ ප්‍රමාණවත්ව වාරි ජලය නොලැබීමයි. ඒ බව වගු අංක 2න් පැහැදිලි වේ.

වගුව 2. යල මහ කන්නවලදී හා වාර්ෂික වගා තීව්‍රතාව

ජලාශය	මහ 02/03	යල 2003	එකතුව	මහ 06/07	යල 2007	එකතුව
හුරුළුවැව	1.039	1	2.039	1.040	0.427	1.467
නාච්චදූව	0.318	1	1.318	1.116	0.739	1.855
නුවර වැව	0.25	1	1.25	1.042	0.896	1.937
රාජාංගන වැව	0.835	0.84281	1.677	0.922	0.929	1.851
කවුඩුල්ල	1	1	2	1.08	1.080	2.16
මින්නේරිය	1	1	2	1.003	1.022	2.024
පරාක්‍රම සමුද්‍රය	1	1	2	0.999	1	1.999
සාමාන්‍යය	0.777	0.977	1.755	1.028	0.870	1.899

මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

3.2 කන්නයට ජලය නිකුත් කල අවසාන දින හා එදිනට වැවුවල ජලධාරිතා

කන්නය ජලය නිකුත් කල අවසාන දින හා එදිනට වැවුවල ජලධාරිතාවන් පිළිබඳ තොරතුරු වගු අංක 3 න් දැක්වේ. ඒ අනුව යල කන්නය අවසානයේ දී වැවුවල ජලධාරිතාවන් ඉතා අඩු මට්ටමක පවතින අතර මහ කන්නය අවසානයේ දී වැවුවල ජලධාරිතාවන් සාපේක්ෂව වැඩි මට්ටමක පවතිබව පෙනී යයි. මහ කන්නය තුළ ලැබෙන වැස්ස හේතුවෙන් හා මහවැලි ජලය ලැබීම හේතුවෙන් මහ කන්නය අවසානයේදී වැවු වල ජලප්‍රමාණයන් වැඩි වී ඇති බව සැලකිය හැකිය. මහ කන්නය අවසන් ජල නිකුතුව සාමාන්‍යයෙන් මාර්තු මාසයේ දී සිදු කර ඇති අතර නුවර වැව හා හුරුළු වැවේ එය 2005/06 හා 2006/07 දී පෙබරවාරිවලදී සිදු කර ඇත.

වගුව 3. මහ කන්නයට ජලය නිකුත් කල අවසාන දින හා එදිනට වැවුවල ජලධාරිතා

ජලාශය	ජලධාරිතාව අක්කර අඩි	2004/2005 අවසන් ජල නිකුතුව		2005/2006 අවසන් ජල නිකුතුව		2006/2007 අවසන් ජල නිකුතුව	
		දිනය	ජල අක්කර අඩි	දිනය	ජල අක්කර අඩි	දිනය	ජල අක්කර අඩි
හුරුළුවැව	54,964	24/03/05	(61.18) 33,630	3/03/06	(51.27) 28,180	20/02/07	(54.21) 29,800
නාච්චදූව	45,155	18/03/05	(90.49) 40,860	5/03/06	(83.71) 37,800	26/03/07	(70.53) 31,850
නුවර වැව	36,075	10/03/05	(87.64) 31,615	20/02/06	(85.93) 31,000	23/02/07	(58.68) 21,170
රාජාංගන වැව	81,635	11/03/05	(91.43) 74,640	2/03/06	(94.24) 76,930	18/03/07	(94.23) 76,930
කවුඩුල්ල	104,010	18/03/05	(87.01) 90,500	3/03/06	(88.45) 92,000	7/03/07	(85.09) 88,500
මින්නේරිය	110,009	11/03/05	(86.05) 94,665	2/03/06	(69.62) 76,593	20/03/07	(80.71) 88,792
පරාක්‍රම සමුද්‍රය	109,000	11/03/05	(100) 109,000	3/03/06	(100) 109,000	22/03/07	(100) 109,000

මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

වගුව 4 ට අනුව යල කන්නය අවසානයේ දී වගාවන් සඳහා ජලය නිකුත් කිරීමත් වර්ෂාව අඩුවීමත් නිසා වැවුවල ජලධාරිතාවන් ඉතා අඩු මට්ටමක පවතින බව පෙනීයයි. කන්නය අවසානයේ දී වගාවන් සඳහා ජලය නිකුත් කිරීම බොහෝවිට අගෝස්තු මාසයේ දී සිදු වුවද සමහර අවස්ථාවල සැප්තැම්බර් මුල් සතිය දක්වා ජලය සපයා ඇති බව පෙනී යයි. ජලය සපයන මුළු කාලය අවම කර ගැනීම මගින් වාෂ්පීකරණය හා පස තුලට කාන්දු වීමෙන් සිදුවන ජල හානි අඩු කරගත හැකි අතර එය අතිරේකව බිම් ප්‍රමාණයක් වගා කිරීමට යොදාගත හැකි වේ. මෙම ජලාශවලින් පරාක්‍රම සමුද්‍රයේ අවම ජල ප්‍රමාණය අක්කර අඩි 45,200 ක් පැවතී ඇති අතර මෙයට වඩා ජලය නිකුත්කිරීමෙන් පරාක්‍රම සමුද්‍රය යටතේ වැඩි බිම් ප්‍රමාණයක් වගා කලහැකි වේ. වසර 2005 සැලකූවිට රාජාංගන වැව, කවුඩුල්ල, මින්නේරිය හා පරාක්‍රම සමුද්‍රයේ වැඩි ජල ප්‍රමාණයක් අවසන් ජල නිකුතුවෙන් පසු ඉතිරි වී ඇත. මෙම ප්‍රමාණයත් 2007 පැවති මට්ටම දක්වා නිකුත් කලා නම් අතිරේක වී වගාවන් සිදුකල හැකිවනු ඇත. එබැවින් එවැනි අවස්ථා සොයා බලා කටයුතු කිරීමට පියවර ගත යුතුය.

වගුව 4. යල කන්නය ජලය නිකුත් කල අවසාන දින හා එදිනට වැවුවල ජලධාරිතා පිළිබඳ තොරතුරු.

		2005 අවසන් ජල නිකුතුව		2006 අවසන් ජල නිකුතුව		2007 අවසන් ජල නිකුතුව	
ජලාශය	ජලධාරිතාව අක්කර අඩි	දිනය	(ජලධාරිතා %) ජල අක්කර අඩි	දිනය	(%) ජල අක්කර අඩි	දිනය	(%) ජල අක්කර අඩි
හුරුළුවැව	54,964	5 සැප් 05	(23.61) 12,975	6 අගෝ 06	(41.71) 22,925	6 අගෝ 07	(23.61) 12,975
නාච්චදූව	45,155	17 අගෝ 05	(26.02) 11,750	6 සැප් 06	(16.28) 7,350	29 අගෝ 07	(19.58) 8,840
නුවර වැව	36,075	22 අගෝ 05	(20.79) 7,500	28 අගෝ 06	(36.95) 13,330	20 අගෝ 07	(22.18) 8,000
රාජාංගන වැව	81,635	21 අගෝ 05	(49.00) 40,005	2 සැප් 06	(36.38) 29,700	26 අගෝ 07	(32.86) 26,825
කවුඩුල්ල	104,010	26 අගෝ 05	(32.05) 33,332	31 අගෝ 06	(33.17) 34,500	23 අගෝ 07	(16.63) 17,300
මින්නේරිය	110,009	27 අගෝ 05	(23.72) 26,093	1 සැප් 06	(15.00) 16,506	1 සැප් 07	(17.90) 19,697
පරාක්‍රම සමුද්‍රය	109,000	20 අගෝ 05	(45.32) 49,400	31 අගෝ 06	(48.17) 52,500	6 අගෝ 07	(41.47) 45,200

මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

3.3 සමස්ත ජලාශ හතේ ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව

- මහ කන්නය තුල

මහ කන්නය තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව සමීකරන (1) න් දක්වා ඇත. ප්‍රතිපායන (ඵුතටුබ්බිඹළක්) විශ්ලේෂණය (දත්ත 35 ක් ඇසුරින්) සිදුකර ඇති අතර අදාල සංඛ්‍යාන තොරතුරු ඇමුණුම 1 න් දක්වා ඇත. නිර්නය සංගුණකය (ඣුජීජීසජඝුකඛ ුජී ෑඹුඨවිසකකවඛළක ච^2) 0.831201 වී ප්‍රතිපායන සංගුණකය (ඵුතටුබ්බිඹළක ඣුජීජීසජඝුකඛ ච) 0.911702 විය. අක්කරයක වී වගා කිරීම සදහා අක්කර අඩි 3.35 ක පමණ වාරි ජල ප්‍රමාණයක් සැපයිය යුතුව ඇත. වර්ෂා ජලය ලැබෙන නිසා මෙම අගය යල කන්නයේ අගයට වඩා අඩු වී ඇති බව පෙනී යයි.

සමීකරණ 1 - මහ කන්නය තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව

A = 3.349558 IWS -1578.8 ---------------------------------(1)

මෙහි IWS = වාරි ජල සැපයුම (අක්කර අඩි)
A = වී වගා බිම් ප්‍රමාණය (අක්කර)

- යල කන්නය තුල

යල කන්නය තුල ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව සමීකරණ (2) න් දක්වා ඇත. ප්‍රතිපායන (Regression) විශ්ලේෂණය (දත්ත 35 ක් ඇසුරින්) සිදුකර ඇති අතර අදාල සංඛ්‍යාන තොරතුරු ඇමුණුම 2 න් දක්වා ඇත. නිර්නය සංගුණකය (Coefficient of

Determination R^2) **0.90367** වී ප්‍රතිපායන සංගුණකය (Regression Coefficient R) **0.950616** විය. අක්කරයක වී වගා කිරීම සඳහා අක්කර අඩි **4.49** ක පමණ වාරි ජල ප්‍රමාණයක් සැපයිය යුතුව ඇත.

සමීකරණ 2

A = 4.492131IWS + 2391.724-------------------------------(2)

3.4 ඒකක බිමක වී වගා කිරීමට අවශ්‍ය වාරි ජල ප්‍රමාණය

පහත වගුව 5 (අ) න් දැක්වෙන්නේ යල කන්නයේ අක්කරයක වී වගාකිරීම සඳහා යෙදියයුතු වාරි ජල අක්කර අඩි ප්‍රමාණයයි (Water Duty). ජලාශ සියල්ල සඳහා සාමාන්‍ය අගය අඩි 4.88 බව පෙන්නුම් කර ඇත. මෙහි අඩු අගයන් පෙන්නුම් කර ඇත්තේ මින්නේරියෙනි (පස් අවුරුදු සාමාන්‍යය අඩි 3.678). පොලොන්නරුව ජලාශ අතරින් පරාක්‍රම සමුද්‍රය විශාල අගයන් පෙන්නුම් කර ඇත. සියලු ජලාශ අතරින් නාච්චදූවේ මෙම අගයන් විශාල වේ (පස් අවුරුදු සාමාන්‍යය අඩි 6.106). විශේෂයෙන් 2007 වසරේදී අගය අඩි 10 ඉක්මවා ඇත. මෙය අයහපත් හා දුර්වල ජල භාවිත තත්වයක් බව පෙනී යයි. මෙම වසරේ (2007) අනිත් ජලාශ සියල්ලේ සාමාන්‍ය අගය වන අඩි 5.77 සැලකුව ද ජල අඩි 4.3 ක් පමන අතිරේකව යොදා ඇත. පවතින වැසි තත්වය වැනි සාධක මත මෙම අගය වෙනස් විය හැකිය. පොලොන්නරුව අගයන්ගෙන් පරාක්‍රම සමුද්‍රයේ අගය තරමක් විශාල වේ. එයට හේතුව විය හැක්කේ ජල හානිය හා බිම් සැකසීමට විශාල ජල ප්‍රමාණයක් යොදා ගැනීම විය හැකිය. මෙයට විසඳුම් ලෙස කිරිඳිඔය ව්‍යාපාරයේ යල් කනනයේ දී යොදාගන්නා ආකාරයට මෙන් ආරම්භක වැස්සෙන් බිම් සැකසීම වැනි ක්‍රම යොදා ගතහැකිය (Giragama, 2007).

වගුව 5 (අ). යල කනනයේ දී අක්කරයක වී වගා කිරීම සඳහා භාවිතා කළ ජල අක්කර අඩි ප්‍රමාණය

ජලාශය	2003	2004	2005	2006	2007	සාමාන්‍ය
හුරුළුවැව	3.315681		6.316175	5.041078	4.611031	4.820991
නාච්චදූව	5.711198	0.932282	5.659513	8.192135	10.033	6.105626
නුවර වැව	5.607203		5.032972	5.09107	3.318132	4.762344
රාජාංගන වැව	4.570214	8.399376	4.741885	4.920639	5.232322	5.572887
කවුඩුල්ල	4.909478		4.059885	4.333116	3.662796	4.241319
මින්නේරිය	3.327473	3.220356	3.869155	4.187514	3.787382	3.678376
පරාක්‍රම සමුද්‍රය	5.298604	4.75707	5.230507	5.622876	4.896507	5.161113
සාමාන්‍ය	4.677122	4.327271	4.987156	5.341204	5.07731	4.882013

මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

පහත වගුව 5 (ආ) න් දැක්වෙන්නේ මහ කන්නයේ අක්කරයක වී වගා කිරීම සඳහා යෙදිය යුතු වාරි ජල අක්කර අඩි ප්‍රමාණයයි (Water Duty). ජලාශ සියල්ල සඳහා සාමාන්‍ය අගය අඩි 3.41 බව දැක්වේ. එය යල කන්නයේ අගයට වඩා අඩුය. යල කන්නයට වඩා වර්ෂා ජලය ලැබීම එයට හේතුවයි. මෙහි අඩු අගයන් පෙන්නුම් කර ඇත්තේ හුරුළුවැවෙනි (පස් අවුරුදු සාමාන්‍යය අඩි 2.415436). පොලොන්නරුව ජලාශ අතරින් පරාක්‍රම සමුද්‍රය විශාල අගයන් පෙන්නුම් කර ඇත. සියලු ජලාශ අතරින් නුවර වැවේ මෙම අගයන් විශාල වේ (පස් අවුරුදු සාමාන්‍යය අඩි 4.228179). ජලාශ හතේ සාමාන්‍ය අගය 2002/3 වසරේ දී අගය අඩි 4.37 වෙද්දී 2004/5 දී අඩි 2.93 වී ඇත. පවතින වැසි තත්වය වැනි සාධක මත මෙම අගය වෙනස් විය හැකිය. පොලොන්නරුව අගයන්ගෙන් පරාක්‍රම සමුද්‍රයේ අගය තරමක් විශාලවන අතර අවම අගය කවුඩුල්ල

වගුව 5 (ආ). මහ කන්නයේ දී අක්කරයක වී වගා කිරීම සඳහා භාවිතා කළ ජල අක්කර අඩි ප්‍රමාණය

ජලාශය	2002/03	2003/04	2004/05	2005/06	2006/07	සාමාන්‍ය
හුරුළුවැව	1.988109	3.063643	2.167157	2.286038	2.572235	2.415436
නාච්චදූව	6.810175	4.748591	1.977088	2.41644	4.876006	4.16566
නුවර වැව	7.972228	3.113223	3.276721	2.951501	3.827221	4.228179
රාජාංගන වැව	5.129108	4.090289	4.688975	3.07353	3.742264	4.144833
කවුඩුල්ල	2.321945	2.824175	2.347889	2.550873	2.462233	2.501423
මින්නේරිය	2.579612	2.403019	2.627519	2.591227	3.024019	2.645079
පරාක්‍රම සමුද්‍රය	3.800726	3.605069	3.486161	3.319907	4.734907	3.789354
සාමාන්‍ය	4.3717	3.406858	2.938787	2.741359	3.605555	3.412852

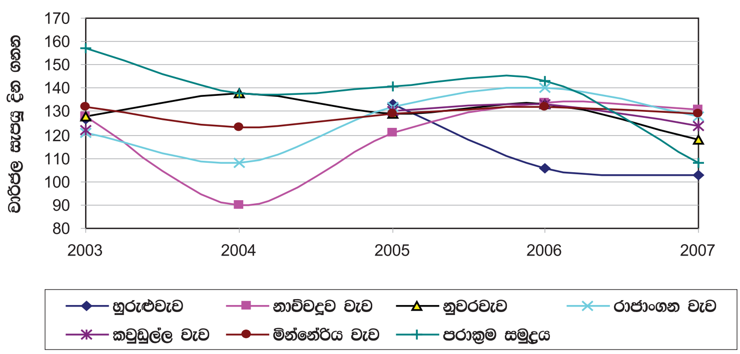
මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

පෙන්නම් කරයි. එයට හේතුව විය හැක්කේ ජල හානිය හා බිම් සැකසීමට විශාල ජල ප්‍රමාණයක් යොදාගැනීම විය හැකිය.

3.4.1 යල කන්නයේ වාරි ජලය සැපයූ දින ගණන

වසර 2003 සිට 2007 දක්වා යල කන්නයේ වාරි ජලය සැපයූ දින ගණන වෙනස් වී ඇති ආකාරය රූපය 1න් දැක්වේ. 2007 වන විට හුරුළුවැව හා පරාක්‍රම සමුද්‍රයේ අගයයන් දින 110 ට වඩා අඩු වී ඇත.

රූපය 1. යල කන්නයේ වාරි ජලය සැපයූ දින ගණන.



3.5. වී අස්වැන්න වෙනස්වීම

යල හා මහ කන්නවල වී අස්වැන්න 2002/03 මහ කන්නයේ සිට 2007 යල කන්නය දක්වා වෙනස්වන ආකාරය වගුව 6 න් දක්වා ඇත. ඒ අනුව 2006/7 මහ කන්නයේදී සෑම ජලාශයක් යටතේම උපරිම වී අස්වැන්නක් ලැබී ඇත. අවම අස්වැන්නක් පොලොන්නරුව ජලාශවලට ලැබී ඇත්තේ 2002/03 මහ කන්නයේදී ය. 2004 යල කන්නයේදී අනුරාධපුර ජලාශ යටතේ අවම අස්වැන්නක් 2003 යල කන්නයේදී පෙන්නුම් කර ඇතත් පොලොන්නරුව ජලාශයන්හි දී ඉහළ අගයක් ගෙන ඇත.

වගුව 6. යල මහ කන්නවල වී අස්වැන්න (අක්කරයට බුසල්)

ජලාශය	මහ 02/03	යල 03	මහ 03/04	යල 04	මහ 04/05	යල 05	මහ 05/06	යල 06	මහ 06/7	යල 07
හුරුළුවැව	100	90	92		90	83	113	130	118	80
නාච්චදුව	97	95	116		134	59	85	59	108	100
නුවර වැව	103	102	123	78	115	101	116	101	134	122
රාජාංගන වැව	87	70	112	70	111	106	75	100	140	120
කවුඩුල්ල	98	100	104		98	110	50	130	100	100
මින්නේරිය	89	100	110	110	100	110	110	100	119	100
පරාක්‍රම සමුද්‍රය	92	110	111	103	120	100	100	110	120	100

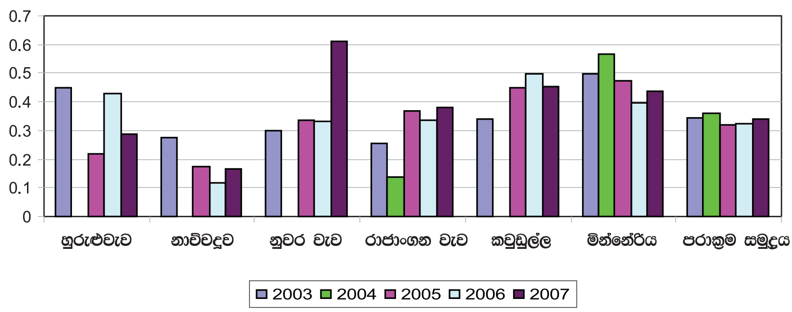
මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

3.6 වී නිෂ්පාදනයේදී ජල ඵලදායීතාව

- **යල කන්නය**

වී නිෂ්පාදනයේදී ජල ඵලදායීතාව යන්නෙන වාරිජල ඝන මීටරයක් මගින් නිපදවිය හැකි වී කිලෝ ගණන දක්වා ඇත. යල කන්නයේ මෙම අගයන් රූපය 2 හි දක්වා ඇත. උපරිම අගයක් පෙන්වා ඇත්තේ 2007 වසරේ නුවර වැව වන නමුත් වසර 5 ම සලකන විට කවුඩුල්ල හා මින්නේරිය වැඩි අගයක් පෙන්වා ඇත. එබැවින් කවුඩුල්ල හා මින්නේරියට වාරි ජලය සැපයීම වඩාත් හිතකර බව පෙනී යයි. නාච්චදූව ජල ඵලදායීතාව අතින් අවම මට්ටමක ඇත. ජල ඵලදායීතාව වැඩි ජලාශවලට ජලය ලබාදීම වී නිෂ්පාදන අංශයෙන් වඩාත් හිතකර වෙයි.

රූපය 2. ජලාශවල යල කන්නයේදී වී නිෂ්පාදනයේ දී ජල ඵලදායීතාව.

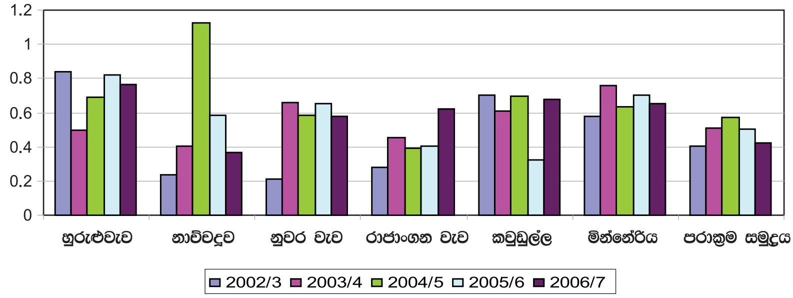


මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

- **මහ කන්නය**

මහ කන්නයේ මෙම අගයන් රූපය 3 න් දක්වා ඇත. උපරිම අගයක් පෙන්වා ඇත්තේ 2003/04 වසරේ නාච්චදූව වැව වන නමුත් වසර 5 ම සලකන විට හුරුළුවැව, කවුඩුල්ල හා මින්නේරිය වැඩි අගයක් පෙන්වා ඇත. එබැවින් හුරුළුවැවට, කවුඩුල්ලට හා මින්නේරියට වාරි ජලය සැපයීම වඩාත් හිතකර බව පෙනී යයි. රාජාංගනය ජල ඵලදායීතාව අතින් පහළ මට්ටමක ඇත. වී නිෂ්පාදනය සලකන විට ජල ඵලදායීතාව වැඩි ජලාශවලට වාරි ජලය ලබාදීමේ ප්‍රමුඛතාවක් දැක්වීම වඩාත් හිතකර වෙයි. පරාක්‍රම සමුද්‍රයේ මෙම අගයන් ඝන මීටරයට වී කිලෝ ග්‍රෑම් 0.4 හා 0.6 අතර වේ. මෙය තරමක් අඩු අගයක් වන නමුත් යල කන්නය සමග සසඳන විට ඉහළ අගයකි.

රූපය 3. ජලාශවල මහ කනනයේදි වී නිෂ්පාදනයේදි ජල ඵලදායීතාව.



මූලාශ්‍රය- වාරිමාර්ග දෙපාර්තමේන්තුවේ දත්ත

4. පසුගිය වසර පහ තුල පොලොන්නරුව දිස්ත්‍රික්කය තුල ඇති මහා වාරිමාර්ගවල ජලය නිකුත් කිරීම

පොලොන්නරුව දිස්ත්‍රික්කයේ මහා වාරිමාර්ගවලදී ව්‍යාපාර තුනක් ඇසුරින් 2002 -2007 වසරවල දත්ත ඇසුරින් මූලික තොරතුරු දක්වා ඇත. එබැවින් වැවුවල ඇති ජල ප්‍රමාණය වගාවන්ට අවශ්‍යතාව අනුව (පසුගිය වසරවල වාරි ජල සැපයුම් මධ්‍ය අගය සලකා වී වගා අක්කරයකට අවශ්‍ය ජලය අක්කර අඩි ගනණ ගණනය කර ඇමුණුම 1) ජලය නිකුත්කරනු ලැබේ. වියලි හෝ තෙත් කන්නයක් බව සලකා වර්ෂාව ලැබීම සැලකිල්ලට ගෙන වගාවේ අවශ්‍යතාව අනුව නිකුත් කරන ජලය ප්‍රමාණය තීරණය කරනු ලැබේ. වී වගා බිම් ප්‍රමාණය තීරණය කිරීම සඳහා සරළ සූත්‍රයක් නොමැති අතර ඉහත දැක්වෙන ආකාරයට ගණනය කරන බව සඳහන් කරන ලදි.

4.1 කවුඩුල්ල ව්‍යාපාරය

කවුඩුල්ල ව්‍යාපාරයේ මුළු ධාරිතාව අක්කර අඩි 104,010 ක් වන අතර හොරොවු මට්ටමට පහළින් ජල සම්පාදනයට භාවිතා කල නොහැකි අක්කර අඩි 4500 ක් වේ. මෙහි හොරොවු දෙකක් ඇති අතර ඉහළ හොරොවුව උපරිම ජල මට්ටමට වඩා අඩි 25 ක් පහළින් ඇති අතර පහළ හොරොවුව උපරිම ජල මට්ටමට වඩා අඩි 30 ක් පහළින් ඇත. ඉහළ හොරොවුවෙන් ජලය නිකුත් කර වගාබිම් වෙත යැවීමට ජල ප්‍රමාණය අවම වශයෙන් අක්කර අඩි 25,000 ක් විය යුතුය. මෙහි සම්මත වී වගා බිම් ප්‍රමාණය අක්කර 12,500 ක් වේ. 2002 පසු මහ කන්නය තුළත් 2006 හා 2007 යල කන්න තුලත් සම්මත වගා බිම් ප්‍රමාණය ඉක්මවා වී වගාකර ඇති බව පෙනී යයි.

පසුගිය කන්නවල ජලය නිකුත් කිරීම බැලූවිට 2007 වසරේ යල් කන්න අවසානයේ ශේෂ ජල ප්‍රමාණය 16.63% දක්වා අඩුවන තුරු වාරි ජලය නිතුත් කර ඇත (වගුව 7). වසර 2004 නියගයක් පැවති බව අප්‍රේල් – අගොස්තු වර්ෂාපතනය මිමී 61.1 වීමෙන් පෙනී යයි. ඊට පෙර වසරවල අවශ්‍ය වූයේ නම් තරමක් වැඩි ජල ප්‍රමාණයක් නිතුත් කල හැකිව තිබුණි. මෙහිදී වන සතුන්ගේ පානය හා අනිතුත් පාරිසරික අවශ්‍යතා සඳහා ජලය රඳවා ගතයුතු වේ.

වගුව 7. කවුඩුල්ල ව්‍යාපාරයේ පසුගිය කන්නවල ජල භාවිතය

මහ කන්නය	2002/03	2003/04	2004/05	2005/06	2006/07
පලමු ජල නිතු.ත්කල දිනය	1-දෙසැ 2002	10-නොවැ 2003	15-නොවැ 2004	10-ඔක් 2005	26-ඔක් 2006
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	35,750	31,300	34,625	30,600	34,200
එය ධාරිතාවේ පුතිශතයන් ලෙස	34.37	30.09	33.29	29.42	32.88
වගාකල බිම් පුමාණය අක්කර	5,334	13,177	12,500	13,190	13,500

පසු සම්බන්ධයි

වගුව 7. කවුඩුල්ල ව්‍යාපාරයේ පසුගිය කන්නවල ජල භාවිතය. *(පෙර සම්බන්ධයි)*

මහ කන්නය	2002/03	2003/04	2004/05	2005/06	2006/07
අවසන් ජල නිකුත්කල දිනය	5-අප්‍රේල්-2003	15-මාර්තු-2004	18-මාර්තු-2005	3-මාර්තු-2006	3-මාර්තු-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	101,000	22,923	90,500	92,000	88,500
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	97.11	22.04	87.01	88.45	85.09
යල කන්නය	2003	2004	2005	2006	2007
පළමු ජල නිකුත්කල දිනය	30-අප්‍රේල්-2003	ජලය නිකුත් කලේ නැත	18-අප්‍රේල්-2005	20-අප්‍රේල්-2006	21-අප්‍රේල්-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	98,300		98,172	104,000	82,000
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	94.51	0.00	94.39	99.99	78.84
වගාකල බිම් ප්‍රමාණය අක්කර	12,500		12,500	13,190	13,501
නිකුත්කල මුළු ජල ප්‍රමාණය අක් අඩි	61,368	0	51,073	57,558	49,451
අවසන් ජල නිකුත්කල දිනය	30-අගෝ-2003		26-අගෝ-2005	31-අගෝ-2006	23-අගෝ-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	34,625		33,332	34,500	17,300
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	33.29	0.00	32.05	33.17	16.63
අප්‍රේල් – අගොස්තු වර්ෂාපතනය	180.4	61.1	312.4	261.6	187.2
වැවේ මුළු ධාරිතාව අක් අඩි 104,010	හොරොවු මට්ටමෙන් පහළ ධාරිතාව අක් අඩි 4,500				

4.2 මින්නේරිය ව්‍යාපාරය

මින්නේරිය ජලාශයේ මුළු ධාරිතාව අක්කර අඩි 110,009 ක් වන අතර හොරොවු මට්ටමට පහළින් ජල සම්පාදනයට භාවිතා කල නොහැකි අක්කර අඩි 4000 ක් වේ. හොරොවුවෙන් ජලය නිකුත් කර ඇල මාර්ග ඔස්සේ වගාබිම් වෙත යැවීමට ජල ප්‍රමාණය අවම වශයෙන් අක්කර අඩි 15,000 ක් විය යුතුය. මෙහි සම්මත වී වගා බිම් ප්‍රමාණය අක්කර 22000 ක් වේ. මහවැලි ව්‍යාපාරය මගින් මින්නේරිය වෙත ලැබෙන ජලය ප්‍රමාණය මැයි වන විට රජරට දෙසට යොමු කෙරේ (ඇමුණුම රූපය 1). වසර 2002 න් පසු මහ කන්නවල ද 2006 හා 2007 යල කන්නවල ද සම්මත වී වගා බිම් ප්‍රමාණය ඉක්මවා වගා කර ඇති බව වගුව 8 න් පෙනේ.

වගුව 8. මින්නේරිය ව්‍යාපාරයේ පසුගිය කන්නවල ජල භාවිතය.

මහ කන්නය	2002/03	2003/04	2004/05	2005/06	2006/07
පළමු ජල නිකුත්කල දිනය	25-නොවැ-2002	10-නොවැ-2003	16-නොවැ-2004	20-නොවැ-2005	9-නොවැ-2006
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	91,731	77,626	82,327	48,493	70,915
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	83.38	70.56	74.84	44.08	64.46
වගාකල බිම් ප්‍රමාණය අක්කර	10,931	25,000	22,000	24,999	22,065
අවසන් ජල නිකුත්කල දිනය	28-මාර්තු-2003	15-මාර්තු-2004	11-මාර්තු-2005	2-මාර්තු-5006	20-මාර්තු-2007
එදිනට වැවේ ජල ධාරිතාව අක් අඩි	110,614	30,051	94,665	76,593	88,792
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	100.55	27.32	86.05	69.62	80.71

යල කන්නය	2003	2004	2005	2006	2007
පළමු ජල නිකුත්කල දිනය	20-අප්‍රේල්-2003	20-මැයි-2004	20-අප්‍රේල්-2005	22-අප්‍රේල්-2006	25-අප්‍රේල්-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	107,624	39,042	108,540	108,843	10,532
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	97.83	35.49	98.66	98.94	9.57
වගාකල බිම් ප්‍රමාණය අක්කර	22,000	14,500	22,000	24,999	22,475
නිකුත්කල මුළු ජල ප්‍රමාණය අක් අඩි	73,204	46,695	85,121	93,228	85,121
අවසන් ජල නිකුත්කල දිනය	30-අගෝ-2003	20-අගෝ-2004	27-අගෝ-2005	1-සැප්-2006	1-සැප්-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	29,146	9,420	26,093	16,506	19,697
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	26.49	8.56	23.72	15.00	17.90
අප්‍රේල් –අගෝස්තු වර්ෂාපතනය	403.4	117.3	386.4	141	176.6
වැවේ මුළු ධාරිතාව අක් අඩි 110,009		හොරොවු මට්ටමෙන් පහල ධාරිතාව අක් අඩි 4,000			

පසුගිය කන්නවල ජලය නිකුත් කිරීම බැලූ විට 2006 හා 2007 වසරේ යල් කන්න අවසානයේ ශේෂ ජල ප්‍රමාණය 16.5% හා 19.69% දක්වා අඩුවන තුරු වාරි ජලය නිකුත් කර ඇත (වගුව 2). 2004 වසරේදී නියගය පැවතීම නිසා ජල මට්ටම පහළ බැස ඇත. අනිත් වසරවල අවශ්‍ය වූයේ නම් වන සතුන්ගේ පානය හා අනිකුත් පාරිසරික අවශ්‍යතා සඳහා අක්කර අඩි 15,000 ට වැඩි ජල ප්‍රමාණයක් රඳවා ගෙන අතිරික්තය ජල සම්පාදනය සඳහා නිකුත් කල හැකිව තිබුණි. එක් එක් ජලාශ සඳහා අවශ්‍ය මත්ස්‍ය සම්පත රැක ගැනීමේ හා වෙනත් පාරිසරික හේතු මත රඳවා ගතයුතු ජල ප්‍රමාණය පිළිබඳ සැලකිල්ලට ගනිමින් ඉතිරි ජල ප්‍රමාණය වගාවන් සඳහා නිකුත් කිරීම සඳහා කටයුතු කිරීමට උපරිම උත්සාහයක් ගතයුතු වේ.

4.3 පරාක්‍රම සමුද්‍ර ව්‍යාපාරය

පරාක්‍රම සමුද්‍රයේ මුළු ධාරිතාව අක්කර අඩි 109,000ක් වන අතර හොරොවු මට්ටමට පහළින් ජල සම්පාදනයට භාවිතා කල නොහැකි ජල පරිමාව අක්කර අඩි 15,000 ක්වේ. හොරොවුවෙන් ජලය නිකුත් කර කිලෝ මීටර් 30 පමන දිග ඇල මාර්ග ඔස්සේ වගාබිම් වෙත ජලය යැවීමට වැවේ ජල ප්‍රමාණය අවම වශයෙන් අක්කර අඩි 35,000 ක් වත්වීම උචිත වේ. මහවැලි ව්‍යාපාරය මගින් ජලය පරාක්‍රම සමුද්‍රය වෙත නොලැබෙන (ඇමුණුම රූපය 1) නමුත් මහවැලි බී කලාපයෙන් එන ජලය ලැබීම මෙම මට්ටමින් ජලය යොමු කිරීමට හැකියාව ඇති වී තිබේ. මෙහි සම්මත වගා බිම් ප්‍රමාණය අක්කර 25,000 ක්වේ.

පසුගිය කන්නවල ජලය නිකුත් කිරීම සැලකූ විට 2006 හා 2007 වසරේ යල් කන්න අවසානයේ ශේෂ ජල ප්‍රමාණය 48.17% හා 41.47% දක්වා අඩුවන තුරු වාරි ජලය නිකුත් කර ඇත (වගුව 9). නමුත් 2005 හා 2007 වසරවල යල් කන්න අවසානයේ ජල නිකුත් කල දිනයට නිකුත් කල හැකිව ශේෂව තිබුන ජල ප්‍රමාණය නිකුත් කලහැකි මුළු ජල ධාරිතාවේ ප්‍රතිශතයක් ලෙස ගත්විට ශේෂ ජල ප්‍රමාණය 19% හා 13% වේ.

පානය සඳහා පරාක්‍රම සමුද්‍රයෙන් දිනකට ජලය ඝන මීටර් 6000 පමණ සාමාන්‍යයෙන් ලබා ගන්නා බවත් (ජලය උපරිම වශයෙන් ඝන මීටර් 6500) ජල සම්පාදන හා ජලාපවාහන මණ්ඩලයේ ඉංජිනේරු මහතා සඳහන් කරයි. ඒ අනුව මසකදී ජලය අක්කර අඩි 146 පමණ සාමාන්‍යයෙන් ලබාගන්නා බවත් (ජලය උපරිම වශයෙන් අක්කර අඩි 158) පමණ එනම් මාස පහක කාලයක් සඳහා ජලය අක්කර අඩි 730 පමණ සාමාන්‍යයෙන් ලබා ගන්නා බවත් (ජලය උපරිම වශයෙන් අක්කර අඩි 790) පමණ අවශ්‍ය වේ. නමුත් සැප්තැම්බර් මස වැසි නොලැබුනහොත් පානය සඳහා

වගුව 9. පරාක්‍රම සමුද්‍ර ව්‍යාපාරයේ පසුගිය කන්නවල ජල භාවිතය.

මහ කන්නය	2002/03	2003/04	2004/05	2005/06	2006/07
පලමු ජල නිකුත්කල දිනය	5-නොවැ-2002	20-ඔක්-2003	1-නොවැ-2004	10-ඔක්-2005	20-ඔක්-2006
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	48,600	56,862	60,900	56,250	63,500
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	44.59	52.17	55.87	51.61	58.26
වගාකල බිම් ප්‍රමාණය අක්කර	10,121	30,000	25,000	29,988	24,999
අවසන් ජල නිකුත්කල දිනය	14-මාර්තු-2003	15-මාර්තු-2004	11-මාර්තු-2005	3-මාර්තු-2006	22-මාර්තු-2007
එදිනට වැවේ ජල ධාරිතාව අක් අඩි	110,400	108,113	109,000	109,000	109,000
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	101.28	99.18	100.00	100.00	100.00
යල කන්නය	2003	2004	2005	2006	2007
පලමු ජල නිකුත්කල දිනය	25-මර්තු-2003	14-අප්‍රේල්-2004	1-අප්‍රේල්-2005	10-අප්‍රේල්-2006	20-අප්‍රේල්-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	106,200	104,100	109,000	109,000	82,000
එය ධාරිතාවේ ප්‍රතිශතයන් ලෙස	97.43	95.50	100.00	100.00	75.23
වගාකල බිම් ප්‍රමාණය අක්කර	25,000	25,000	25,000	25,000	25,000
නිකුත්කල මුළු ජල ප්‍රමාණය අක් අඩි	132,465	118,927	130,519	140,248	122,413
අවසන් ජල නිකුත්කල දිනය	29-අගෝ-2003	30-අගෝ-2004	20-අගෝ-2005	31-අගෝ-2006	6-අගෝ-2007
එදිනට වැවේ ජල ප්‍රමාණය අක් අඩි	54,800	28,593	49,400	52,500	45,200
එය මුළු ධාරිතාවේ ප්‍රතිශතයන් ලෙස	50.28	26.23	45.32	48.17	41.47
එදිනට නිකුත් කලහැකි ශේෂ ජල ප්‍රමාණය අක් අඩි	39,800	13,593	34,400	37,500	30,200
එය නිකුත් කලහැකි මුළු ජලයේ % ලෙස	36.51	12.47	31.56	34.40	27.71
අප්‍රේල් –අගෝස්තු වර්ෂාපතනය	201	114	414	243	236
මුළු ධාරිතාව අක් අඩි 109,000		හොරොවු මට්ටමෙන් පහල පරිමාව අක් අඩි 15,000			

අවශ්‍ය ජල ප්‍රමාණය මෙයට වැඩි වේ. මෙයට අමතරව වන සතුන්ගේ පානය හා අනිකුත් පාරිසරික අවශ්‍යතා සඳහා ජලය රඳවා ගතයුතු වේ. යල කන්නයේ නිකුත්කල මුළු ජල ප්‍රමාණය ජලාශයේ ධාරිතාව ඉක්මවන බව වගුවෙන් පෙනී යයි. මේ අනුව 2004 වසරේදී නියගය පැවතීම නිසා ජල මට්ටම සොරොවු මට්ටමටත් වඩා පහළ බැස ඇති බව පෙනෙන අතර. අනිත් වසරවල අවශ්‍ය වූයේ නම් තරමක් වැඩි ප්‍රමාණයක් ජල සම්පාදනය සඳහා නිකුත් කල හැකිව තිබුණි.

5. වර්ෂාපතනය, උත්ස්වේදනය හා අක්කරයක වී වගාවට අවශ්‍ය ජල ප්‍රමාණය

5.1 වර්ෂාපතනය

පහත අංක 10 වගුවෙන් දැක්වෙන ආකාරයට මින්නේරිය වර්ෂාමාන දත්තවල තිස් අවුරුදු සාමාන්‍ය අගය සැලකූ විට මැයි, ජූනි, ජූලි මාසවල වැසි අඩු බව පෙනී යයි. 1931-1990 ට වඩා 1961-1990 සාමාන්‍ය මාසික වර්ෂාපතනයේ අඩුවීමක් පෙන්නුම් කරයි. මෙම තත්වය අනුව ඉදිරියේදී වඩාත් බාහිර ජල සැපයුම් යොදාගැනීමට සිදුවිය හැකි බව පෙන්නුම් කරයි.

වගුව 10. වර්ෂාපතනය වෙනස්වීම හා තිස් අවුරුදු සාමාන්‍ය අගයන් (මි.මී.).

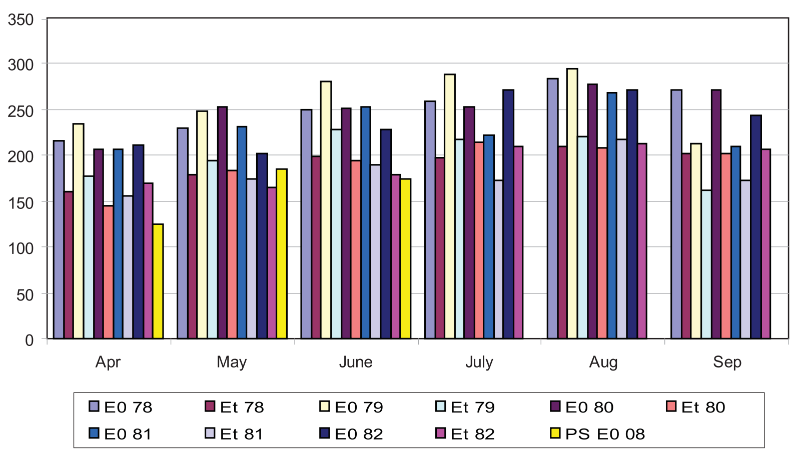
	දියසේන පුර 1982	කවුඩුල්ල 1982	මින්නේරිය (31-60)	මින්නේරිය (61-90)	දියසේන පුර 2008	කවුඩුල්ල 2008	මින්නේරිය 2008	අංග මැඩිල්ල 2008
ජනවාරි	60	66	227	132.7	87	86.1	69.9	129
පෙබරවාරි	0	0	104	87.4	52	112.3	113.7	134
මාර්තු	0	0	82	70	202	271.1	194.5	287.5
අප්‍රේල්	144	182	144	100.2	84	90.5	183.7	96
මැයි	76	134	85	57.6	0	0	0	13
ජූනි	23	14	4	4.2	0	0	0	0
ජූලි	11	0	36	45.9				
අගෝස්තු	0	25	57	37				
සැප්තැම්බර්	112	164	68	97				
ඔක්තෝම්බර්	296	165	185	203.5				
නොවැම්බර්	436	419	271	271.8				
දෙසැම්බර්	378	244	335	344.7				

2008 මැයි, ජූනි, මාසවල වැසි නැති වීම අගෝස්තු මස අවසානය දක්වා ජලය ඉතාමත් ප්‍රවේශමින් අස්වැන්නට හානියක් නොවන ලෙස සැපයීමට කටයුතු යොදා ගත යුතු වෙයි.

5.2 උත්ස්වේදනය

විශේෂයෙන් යල කන්නය තුල වාෂ්පීකරණ හා උත්ස්වේදනය වැඩි අගයක පැවතීම නිසා (රූපය 4). වැඩි ජල ප්‍රමාණයන් අවශ්‍ය වේ. වර්ෂාව අඩුවීම හා වැවුවල ඇති ජල ප්‍රමාණය පානයට හා වාරි ජල සැපයීමට යොදා ගැනේ. විශේෂයෙන් ජූනි, ජූලි හා අගෝස්තු මාසවල වාෂ්පීකරණ හා උත්ස්වේදනය වැඩි අගයක පැවතීම නිසා එම අවශ්‍ය ජලය තබා ගැනීම වගාව හොඳින් පවත්වාගෙන යාමට ප්‍රයෝජනවත් වේ.

රූපය 4. වාෂ්පීකරණ උස්වේදනය (මි.මී.).



6. 2008 යල කන්නය තුල ජල භාවිතය

2008/07/15 දින වනවිට කවුඩුල්ල, මින්නේරිය හා පරාක්‍රම සමුද්‍රය වැවුවල නිකුත්කර දැනට නිකුත් කිරීමට හැකි ශේෂව ඇති ජල ප්‍රතිශතයන් පිළිවෙලින් 24.23, 27.95 හා 38.45 විය (වගුව 11). එම ප්‍රමාණයත් සති හයක් වාරිජල සම්පාදනය හා පානය සඳහා යොදාගත යුතු නිසා අතිරේකව වී වගාවන් සඳහා ජලය නිකුත් කිරීම ඉතා ප්‍රවේසමින් සිදුකල යුතු බව පෙනේ. නමුත් ඉහතින් දක්වා ඇති කන්න අවසානයට සති හයකට පෙර ශේෂයන් බැලූ විට පරාක්‍රම සමුද්‍රය හැර අනිත් වැවුවල හොඳ ජල නිකුත් කිරීමක් කර ඇති බව පෙනී යයි. මෙම ශේෂ ජල ප්‍රමාණයන් වඩාත් හොඳින් භාවිතා කිරීමට පියවර ගත යුතුව ඇත.

වගුව 11. ජල ධාරිතාවන් හා දැනට ජලය ඇති ප්‍රමාණයන් (යල කන්ණය 2008)

			15/07/2008 දිනට		
	මුළු ධාරිතාව අක් අඩි	ඇලවල්වලින් ජලය යැවීමට අවශ්‍ය අවම ජල ප්‍රමාණය අක් අඩි	ශේෂ ජල ප්‍රමාණය අක් අඩි	නිකුත් කලහැකි ජල ප්‍රමාණය අක් අඩි	නිකුත් කලහැකි ජල ප්‍රමාණය ධාරිතාවේ ප්‍රතිශතයක් ලෙස
කවුඩුල්ල	104,000	25,000	50,200	25,200	24.23
මින්නේරිය	110,000	15,000	45,744	30,744	27.95
පරාක්‍රම සමුද්‍රය	109,000	35,000	76,800	41,800	38.35

කන්න රැස්වීමේදී ඇති කරගත් එකගතාවන්ට බාහිරව වගා කරන බිම් ප්‍රමාණයන් පිළිබඳව ව්‍යාපාර කමිටුව දැනුවත් කර නොමැතිවීම ගැටලුවක් වී ඇත. උදාහරණයක් වශයෙන් 2008 මැයි 29 දින පැවති පරාක්‍රම සමුද්‍ර ව්‍යාපාර කමිටු රැස්වීමේදී ගොවි සංවිධාන 19 කින් ලබාගත් තොරතුරු අනුව රක්ෂිත අක්කර 597 ක හා ගොඩබිම් අක්කර 961.5 ක වී වගාව සිදුකර ඇති බවට වාර්තා වී ඇත.

7. නිගමනය

සමීකරණ 1 න් දැක්වෙන ආකාරයට මෙම ජලාශ හතේ දත්ත අනුව මහ කන්නය තුල ජල අක්කර අඩි 3.35 යෙදීමෙන් අක්කරයක වී වගාව සිදුකල හැකිය. යල කන්නය තුල ජලාශ හතේ ජල සැපයුම හා වී වගා බිම් ප්‍රමාණය අතර සම්බන්ධතාව සමීකරණ 2 න් දක්වා ඇති අතර ඒ අනුව අක්කර අඩි 4.49 ක් යෙදීමෙන් අක්කරයක වී වගාව සිදුකල හැකි බව පෙනී යයි. නමුත් පැවතිය හැකි වර්ෂාපතනය ද එක් එක් ජලාශය සඳහා වගුව 8 න් දක්වා ඇති යල කන්නයේ වී වගාවට අවශ්‍ය ජල ප්‍රමාණය මෙන්ම මහ කන්නය සඳහා එම අගයන් සැලකිල්ලට ගෙන වගාකල හැකි බිම් ප්‍රමාණය තීරණය කිරීම කන්න රැස්වීමේදී සිදුකල යුතුව ඇත. මෙලෙසින් වැඩි බිම් ප්‍රමාණයක් වගා කිරීමට අවකාශ සලසා ගත හැකි වේ.

යල මහ කන්නවල වී අස්වැන්න දැක්වෙන වගුව 7 හා වී නිෂ්පාදනයේදී ජල ඵලදායීතාව දැක්වෙන රූපය 1 හා 2 යොදා ගනිමින් හා නව වර්ෂා හා වාෂ්පීකරණ උත්ස්වේදනය තත්වයන් සැලකිල්ලට ගනිමින් එක් එක් ජලාශ සඳහා ජලය නිකුත්කිරීම සිදු කිරීම සඳහා සැලසුම් කිරීමෙන් අගනා ජල සම්පතින් උපරිම ප්‍රයෝජනයක් ගත හැකිවනු ඇත.

අක්කරයක වී වගා කිරීම සඳහා අක්කර අඩි ප්‍රමාණයන් ජලාශ අනුව විශාල පරාසයක අගයන් ගන්නේ වර්ෂා හා වාෂ්පීකරණ උත්ස්වේදනය තත්වයන් මත පමණක් නොවන බව වාරිමාර්ග ඉංජිනේරු මහත්ම මහත්මීන් ද සඳහන් කරයි. ඒ අනුව ජල හානිය අවම කිරීමට ප්‍රධාන ඇලවල්

හා බෙදුම් ඇලවල්වල අලුත්වැඩියා කටයුතු නිසි ලෙස කල යුතු අතර එමගින් ජල හානිය අවම විමට අමතරව අගාවතේ පිහිටි කුඹුරුවලට අපහසුතාවයකින් තොරව ජලය ලබාදිය හැකිවේ.

අධ්‍යයනයට අතිරේකව ගොවි සංවිධාන හා ගොවිමහතුන් ජලය පිරිමැස්මකින් යුතුව පාවිච්චි කිරීම සඳහා බිම් සැකසීම සඳහා ගන්නා කාලය අවම කිරීම (සති දෙකක් දක්වා) හා වල් මර්ධනය කිරීම සඳහා ජලය යොදාගැනීම හා පොහොර යෙදීම ජලය අඩු අවස්ථාවේ සිදුකිරීමෙන් අතිරේක ජල භාවිතය අවම කිරීම, බෙදුම් ඇලවල් හා කෙත්ඇලවල්වලදී සිදුවන ජල හානිය අවම කිරීම හා කන්න රැස්වීමේදී ඇති කරගත් එකගතාවන්ට අනුව වගාවන් සිදුකිරීමට කටයුතු කරන්නේ නම් අතිරේකව වී වගාවන් සඳහා වැඩිපුර ජලය නිකුත් කිරීමට ඉදිරියේදී කටයුතු කල යුතුය.

එමෙන්ම වැවුවල ජලය පවතින ප්‍රමාණය අනුව කන්න රැස්වීමේදී ඇති කරගත් එකගතාවන්ට බාහිරව වගා කරන බිම් ප්‍රමාණයන් වේ නම් ඒ පිළිබඳව ව්‍යාපාර කමිටුව දැනුවත් කර එයට නිවැරදි දත්ත පවත්වාගෙලයන යාම අවශ්‍ය වේ. නිසි ජල සැපයුමක් වගාවන් සඳහා ලබාදීමට අතිරේක වී වගාවේ දත්ත සැපයිය යුතුය. මෙම තොරතුරු නිසි ලෙස ලබාදීමෙන් වාරිමාර්ග නිලධාරීන්ට අවශ්‍යතාවට අනුව ජලය ලබාදීමට අවකාශ සැලසීම උචිතය.

විශේෂයෙන් පරාක්‍රම සමුද්‍රය වෙත මහවැලි බී කලාපයෙන් එන අතිරේක ජලය එයට යොදවාගත හැකිවේ. මින්නේරිය හා කවුඩුල්ල වෙත එන මහවැලි ජලය ද හොඳින් හානි අඩු වනසේ භාවිතා කිරීමෙන් ගොඩ වගාවන් සඳහා ජලය ලබාදීමට හැකි වේ. නමුත් වර්ෂාව බලාපොරොත්තු අයුරින් නොලැබුනහොත් මහවැලි ජලය අතිරේකව මෙම වැවු වෙත එවීමට සිදුවිය හැකිය. කන්න රැස්වීමේදී පැමිණි එකගතාවයන් අනුව කටයුතු කිරීමත් නිලධාරීන් හා ගොවි මහතුන්/ ගොවි සංවිධාන අතර සුහද සම්බන්ධතාවක් තබා ගනිමින් නිවැරදි දත්ත (වගා බිම් හා බෝග පිළිබඳව) ලබාදිය යුතුය. ඇල මාර්ග ප්‍රතිසංස්කරණ කටයුතු කඩිනමින් කිරීමට හැකි නම්, එමගින් අපතේ යන ජලය රැක ගැනීමට හා එයින් අතිරේක වගාවන් සඳහා ජලය ලබාදීමට ඇති අවකාශය වැඩිය. විශේෂයෙන් පොළොන්නරුව දිස්ත්‍රික්කයේ ගොඩ වගාවන් ලෙස ඇති වාර්ෂික භෝග යල කන්නය තුළ වියළී යයි. මේ ලෙස ජලය නිසි ලෙස කළමනාකරණය කල හැකි නම්, හොඳ කෘෂි නිෂ්පාදනයක් සිදු කර රටේ සංවර්ධනයට දායකවීමට එම ගොවීන්ට අවස්ථාව ඇති බව පෙනී යයි.

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ඇමුණුම 1

මහ කන්නයේ ප්‍රතිපායන සංඛ්‍යාන තොරතුරු

Multiple R	0.911702
R Square	0.831201
Adjusted R Square	0.826086
Standard Error	13083.28
Observations	35

ANOVA

	df	*SS*	*MS*
Regression	1	2.78E+10	2.78E+10
Residual	33	5.65E+09	1.71E+08
Total	34	3.35E+10	

	Coefficient	*Standard Error*	*t Stat*
Intercept	-1578.8	4262.654	-0.37038
Acs	3.349558	0.262762	12.74751

ඇමුණුම 2

යල කන්නයේ ප්‍රතිපායන සංඛ්‍යාන තොරතුරු

SUMMARY OUTPUT	
Multiple R	0.950616
R Square	0.90367
Adjusted R Square	0.900459
Standard Error	12808
Observations	32

ANOVA

	df	*SS*	*MS*
Regression	1	4.62E+10	4.62E+10
Residual	30	4.92E+09	1.64E+08
Total	31	5.11E+10	

	Coefficient	*Standard Error*	*t Stat*
Intercept	2391.724	4081.383	0.586007
Acs	4.492131	0.267773	16.77587

Surface Runoff Estimation Over Heterogeneous Canal Commands Applying Medium Resolution Remote Sensing Data with the SCS-CN Method

Priyantha Jayakody and Nilantha Gamage
International Water Management Institute, Colombo, Sri Lanka

Abstract

The precise estimation of surface runoff from rainfall is critical for water resource management. In the recent past, remote sensing and Geographic Information System (GIS) technologies have been widely used in the estimation of surface runoff from watersheds, and from agricultural fields in particular. This is due to the inherent ability of remote sensing to capture spatial heterogeneity of surface parameters such as land use and land cover. This could lead to better performances of surface runoff simulation models. Surface runoff volume/rate estimation involves quantifying the amount of rainfall exceeding infiltration and initial abstractions which must be satisfied before the occurrence of runoff.

The widely accepted SCS curve number method was employed to calculate surface runoff, using a combination of remotely-sensed land use/land cover and hydrometrological data in the Punjab canal command areas. Land use/Land cover maps for four cropping seasons, Rabi 2004-05, Kharif 2005, Rabi 2006-07 and Kharif 2007 were derived using red and near infrared bands of MODIS 8 day products. The existing soil map was reclassified into hydrological soil groups and rainfall data were interpolated using the inverse distance method to represent the spatial rainfall values of each canal command.

The results show that CN values vary from 70 to 95 during the study period. The highest CN value of 94.4 is during the Kharif 2005 season. Meanwhile the runoff-coefficient is changing from 0.01 to 0.25 and 0.01 to 0.43, respectively, during Rabi 2004/05 and Rabi 2006/07. During Kharif 2005 and Kharif 2007, the runoff-coefficient varied from 0.01 to 43 and 0.01 to 0.45, respectively. The study shows that the SCS curve number method can be used for runoff estimation with the help of remote sensing products and GIS technologies from catchments where gauging data is not available.

Introduction

The precise estimation of surface runoff from rainfall is critical for water resource management. In the recent past, the use of remote sensing and Geographic Information System (GIS) technologies have been widely used in the surface runoff estimation of watersheds, and particularly from agricultural fields. This is primarily because a good runoff model has to include spatially variable geomorphologic parameters such as rainfall, soil characteristics, and land use change (Shih 1996; Melesse and Shih 2000a, 2000b). Many methods for estimating runoff exist (Haan et al. 1982; Chow et al. 1988). Runoff volume or rate estimation involves estimating the amount of rainfall exceeding infiltration and initial abstractions, which must be satisfied before the occurrence of runoff. Infiltration excess runoff can be estimated using different techniques. The USDA, Natural Resources Conservation Service-Curve Number (NRCS-CN) is a widely used method that combines remotely-sensed land use data and soils information to determine soil's abstraction. This report presents an application of the curve number method with remote sensing products for estimating runoff in the Punjab irrigation command in Pakistan, and demonstrates the practical importance of how Remotes Sensing and Geographic Information Systems work in similar contexts.

SCS Curve Number Method

The SCS-CN method for estimating direct runoff volume has become widely used as a tool for drainage design, particularly for impoundment structures on un-gauged watersheds (Haan et al. 1982; USDA-SCS 1985, 1986). The equation used (1) has three empirically based parts, based on data from a large number of gauged watersheds distributed throughout the United States (Haan et al. 1982). The first part holds that the ratio of the amount of actual retention, (F), to maximum potential watershed storage, (S), is equal to the ratio of actual direct runoff volume, (Q), to the effective rainfall (total rainfall, P, minus initial abstraction, I_a).

$$\frac{F}{S} = \frac{Q}{(P - I_a)} \qquad (1)$$

Where $F = P - I_a - Q$, by theory. All terms are volumes (expressed as mm). It is also assumed that:

$$I_a = 0.2S \qquad (2)$$

Where I_a is the portion of the rainfall that will not appear as runoff. Substituting (2) into (1) and solving for Q gives the typical expression of the SCS-CN method (Haan et al. 1982; McCuen 1982):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3)$$

Where $P > I_a$. and

(4) $$S = \frac{25{,}400}{CN} - 254$$

Where the SCS curve number, CN (unit-less, ranging from 0 to 100), is determined from Table 1, based on land-cover, hydrologic soil group (HSG), and antecedent moisture condition (AMC).

Table 1. Five-day antecedent rainfall according to AMC condition.

	Five-day Antecedent Rainfall (mm)	
AMC condition	Dormant season	Growing season
I	< 12.5	< 35
II	12.5 – 27.5	35-52.5
III	> 27.5	> 52.5

If the AMC condition is I then the following formula is applicable.

(5) $$CNI = \frac{4.2 * CNII}{(10 - 0.058 * CNII)}$$

If the AMC condition is III, then following formula is applicable.

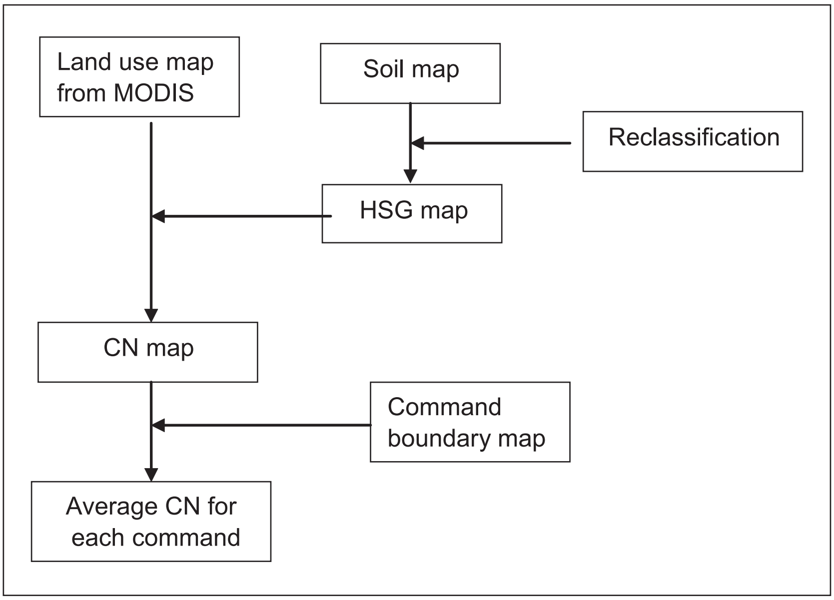
(6) $$CNIII = \frac{23 * CNII}{(10 + 0.13 * CNII)}$$

Methodology

Land use maps for the four seasons (Rabi 04/05, Kharif 05, Rabi 06/07 and the Kharif 07) were generated using MODIS 250 m 8-day time series for the respective seasons. The already available soil map was used for Hydrological soil group categorization. Rainfall data were interpolated using the inverse distance method to represent the relevant rainfall values for each of the 22 commands separately. The flow chart for the detailed procedure is shown in Figure 1.

Soil map was reclassified into hydrological soil groups according to their soil properties and crossed with land use maps to get the curve number maps for the season. The same processes were repeated four times for four seasons. Weighted averages were taken to

Figure 1. Flow chart for the procedure used.



represent the curve numbers for individual commands. Equation (7) explains the method (A and TAW are sub area and total area of particular canal command).

$$CN\ (Weighted) = \frac{\sum(CN \times A)}{TAW} \tag{7}$$

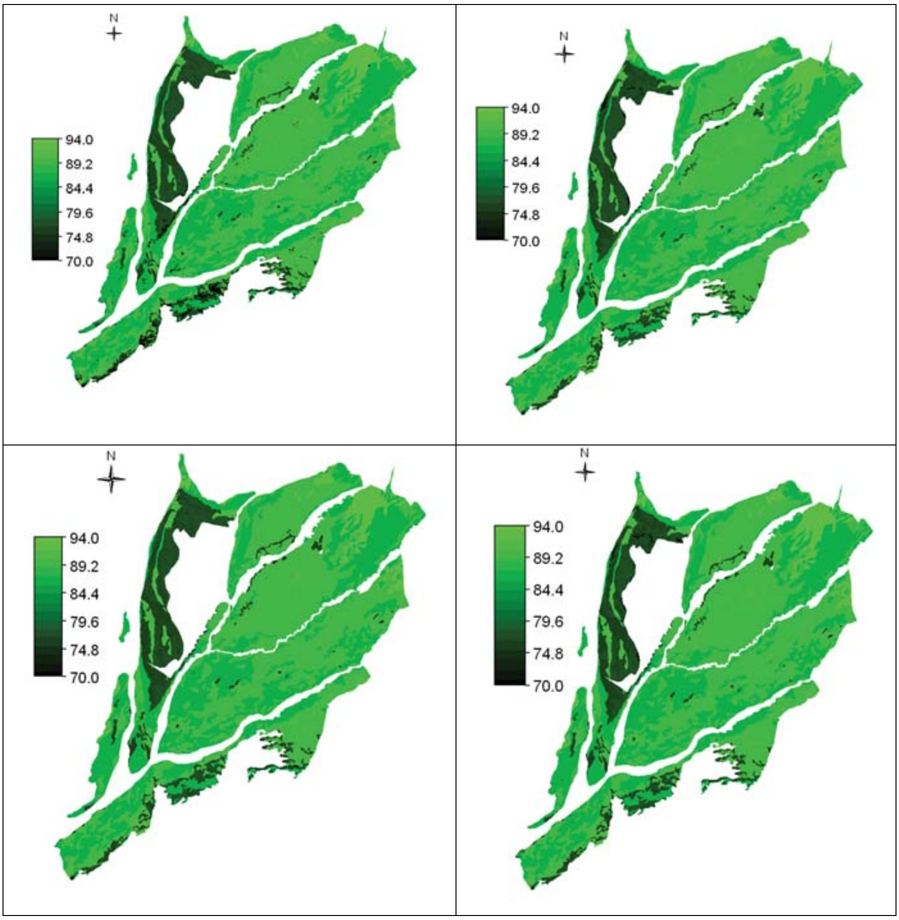
Daily runoff was calculated for the individual 22 commands for the study period and then was summarized to monthly and seasonal values.

Results and Discussion

Curve Number Variations

The results show that curve number values vary from 70 to 95 along the entire irrigation canal commands during the study period. Higher CN values are observed in Kharif seasons as more agricultural lands appear in land use maps. The highest CN value for the study area is 90.4 during Kharif 2005 season in the upper part of the command. Figure 2 below shows the CN variation during the four seasons.

Figure 2. Curve number variation during the study period; Rabi 04/05, Kharif 05, Rabi 06/07 and Kharif 07 (top left to right bottom).



Seasonal Runoff Generation

Runoff process is governed by land use, soil types, and rainfall. With the given conditions, land use and soil types are constant, and rainfall plays a major role in runoff generation. Rainfall volume, intensity and the distribution determine the amount of runoff escape from the canal command. The first two seasons (Rabi 04/05 and Kharif 05) show low runoff values due to less rainfall compared to the Rabi 2006/2007 and Kharif 2007 seasons that had higher rainfall. The lower Chenab canal shows the highest runoff (25 %) during Rabi 2004/2005 season and the Muzaffagarh canal command shows the highest runoff (43 %) during the Kharif 2005 season. Generally the canal command in the upper most part and the lower most part of the irrigation scheme shows high runoff compared to the canal commands in the middle part of the irrigation scheme. This is a result of spatial distribution of soil type, land use and rainfall along the whole command. Tables 2 and 3 show predicted runoff for individual canal commands during different seasons.

Table 2. Seasonal rainfall and runoff predicted using the SCS method for the 22 canal commands for Rabi 2004/2005 and Kharif 2005.

Season/Canal commands	Rabi 04/05			Kharif 05		
	Rainfall (mm)	Runoff (mm)	% runoff	Rainfall (mm)	Runoff (mm)	% runoff
Upper Jehlum Canal	281	21	7	469	98	21
Lower Jehlum Canal	258	43	17	374	65	17
Marala Ravi Link Canal	277	10	4	440	78	18
Upper Chenab Canal	236	4	2	477	106	22
Lower Chenab Canal	197	48	25	336	78	23
Central Bari Doab Canal	217	12	5	461	141	31
Upper Depalpur Canal	216	3	1	388	66	17
Lower Bari Doab Canal	170	9	5	217	4	2
Lower Depalpur Canal	185	1	0	252	6	2
Pakpattan Canal	154	1	1	137	1	1
Fordwah Canal	148	0	0	88	0	0
Sadiqia Canal	145	0	0	106	0	0
Haveli Canal	194	31	16	257	40	15
Sidhnai Canal	173	31	18	152	58	38
Mailsi Canal	142	24	17	168	72	43
Bahawal Canal	126	27	21	149	46	31
Thal Canal	253	38	15	354	49	14
Chashma Right Bank Canal	203	30	15	269	31	12
Rangpur Canal	184	21	11	194	49	25
Muzaffargarh Canal	146	20	13	136	48	35
Dera Ghazi Khan Canal	90	0	0	73	1	2
Panjnad Canal	57	1	2	41	0	1

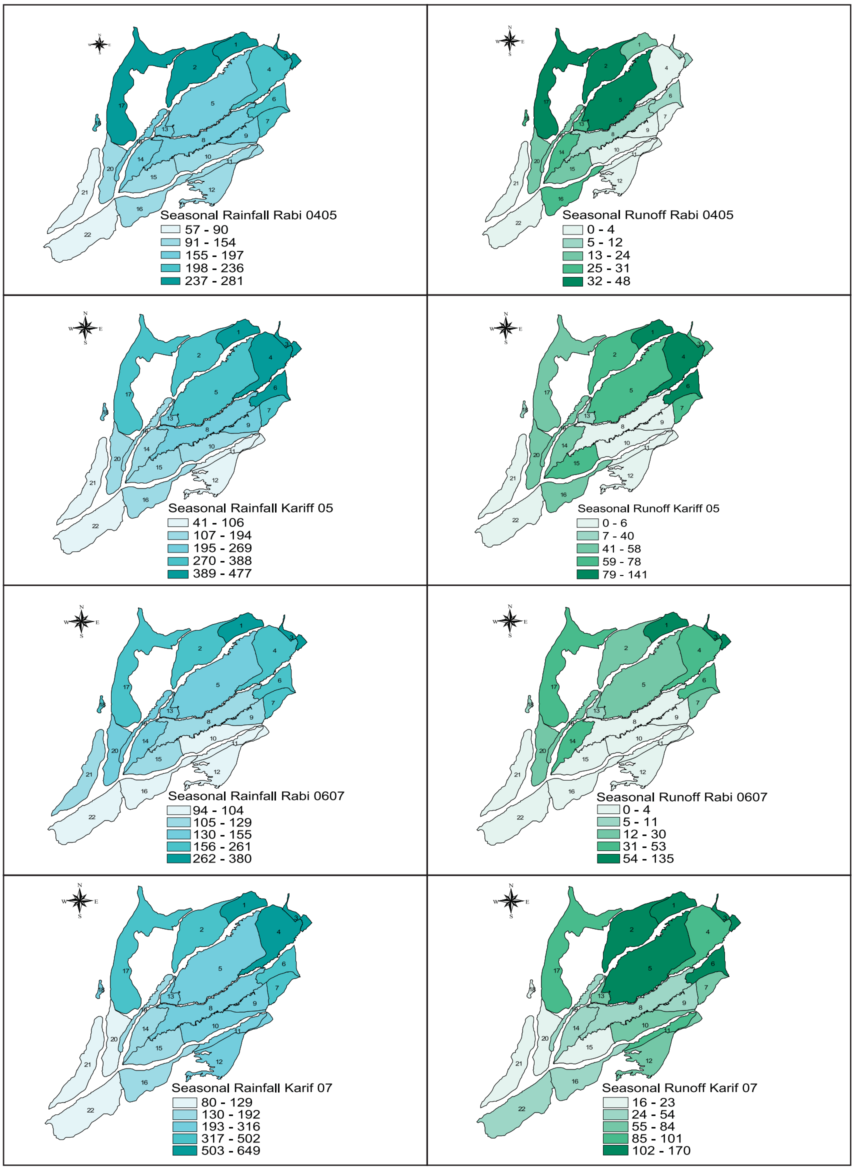
Both Rabi 2006/07 and Kharif 2007 show significant amounts of runoff. During Rabi 2006/2007 upperparts and the lower part canal commands show higher runoff. During Kharif 2007 seasons, no significant differences between the lower and upper part were observed. The Marala Ravi Link Canal shows 43 % runoff during Rabi 2006/2007 and Panjnad Canal shows 49 % of the runoff during the Kharif 2007 seasons. Those are the canal commands which give the highest runoff.

Table 3. Seasonal rainfall and runoff predicted using the SCS method for the 22 canal commands for Rabi 2006/2007 and Kharif 2007.

Season/Canal commands	Rabi 06/07			Kharif 07		
	Rainfall (mm)	Runoff (mm)	% runoff	Rainfall (mm)	Runoff (mm)	% runoff
Upper Jehlum Canal	380	122	32	635	135	21
Lower Jehlum Canal	216	30	14	475	154	32
Marala Ravi Link Canal	315	135	43	649	170	26
Upper Chenab Canal	261	44	17	554	98	18
Lower Chenab Canal	134	19	14	313	142	45
Central Bari Doab Canal	228	53	23	502	128	25
Upper Depalpur Canal	194	24	12	444	83	19
Lower Bari Doab Canal	117	2	2	283	47	17
Lower Depalpur Canal	129	2	2	316	54	17
Pakpattan Canal	94	2	2	252	67	27
Fordwah Canal	95	4	5	250	101	40
Sadiqia Canal	100	2	2	248	82	33
Haveli Canal	141	6	4	299	84	28
Sidhnai Canal	153	37	24	152	35	23
Mailsi Canal	113	2	2	163	22	14
Bahawal Canal	99	0	0	151	34	23
Thal Canal	256	34	13	374	95	25
Chashma Right Bank Canal	202	11	5	257	19	7
Rangpur Canal	155	20	13	192	35	18
Muzaffargarh Canal	137	18	13	129	23	17
Dera Ghazi Khan Canal	111	1	1	104	16	15
Panjnad Canal	104	2	2	80	39	49

Areas where high rainfall occurs normally experience higher runoff but there are locations where it is not true as shown in Figure 3. This is mainly due to land use, which plays a major roll in generating runoff. The upper parts of the irrigation command receive comparatively higher rainfall and hence significant runoff generation.

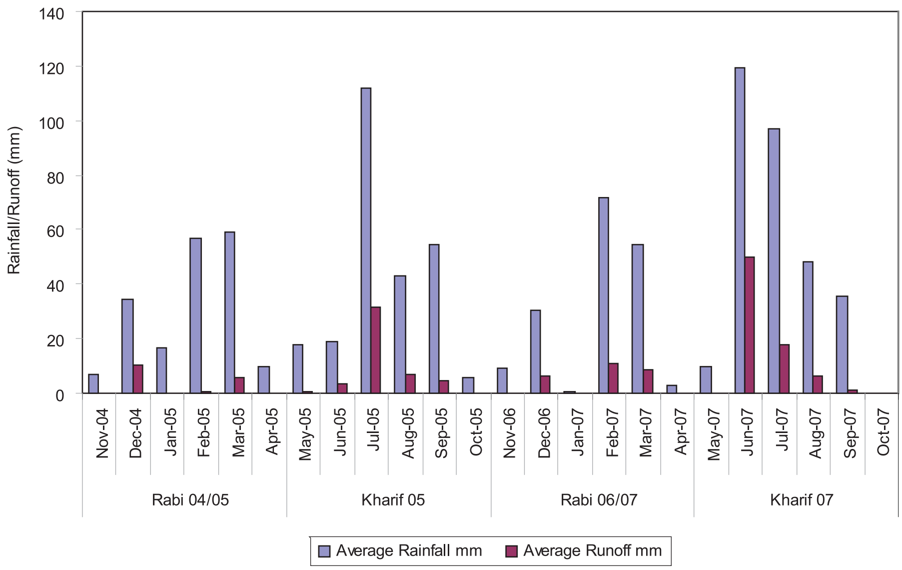
Figure 3. Spatial distribution of seasonal rainfall (mm) and runoff (mm) over canal commands.



Monthly runoff

Monthly Runoff was calculated for four seasons for 22 canal commands. Data were averaged over the whole irrigation scheme for easy explanation. Figure 4 shows that higher rainfall values are not always associated with higher runoff and instead depend on the distribution of the rainfall. The Kharif season generally shows higher runoff values compared to the Rabi seasons.

Figure 4. Monthly rainfall runoff variation during the four seasons (averaged over irrigation scheme).



Conclusions

Rabi 2004/05 and Kharif 2005 seasons show low runoff values due to less rainfall when compared to the Rabi 2006/07 and Kharif 2007 seasons that reported higher rainfall. This indicates that rainfall significantly affects the volume and the rate of runoff. This study demonstrates RS and GIS as a useful supportive tool for runoff estimation and to help understand the spatial variability of these processes. MODIS data is suitable for large scale applications. The study shows that the SCS curve number method can be used for runoff estimation with the help of remote sensing products and GIS technologies from catchments where gauging data are not available.

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Water for Food Conference - June 9-11, 2009 - List of Attendees

1. Chaminda Sidath Bandara, Research Officer, Hector Kobbekaduwa Agrarian Reserach and Training Institute. 114, Wijerama Mawatha, Colombo 7. Tel: 2696981 ext: 323. Email: *chaminda.sidath@gmail.com*
2. Badra Kamaladasa, Deputy Director of Irrigation, Irrigation Department. P.O. Box 1138, Colombo. Tel: 2581837 Email: *bkamaladasa@gmail.com*
3. Y. M. Dayabandara Yapa, Research Assistant, Department of Export Agriculture. Research Station, Matale. Tel: 066-4460850.
4. Salma Peiris, Senior Program Management Specialist, USAID. 44, Galle Road, Colombo 4. Tel: 777703909 Email: *speiris@usaid.gov*
5. G. G. A. Godaliyadda, Director of Irrigation, Irrigation Department. 238, Bauddaloka Mawatha, Colombo 7. Tel: 2588879, 718008174 (private), Email: *ggagodaliyadda@yahoo.com*
6. Indika Sampath Ariyatilaka, Research and Development Assistant, Department of Export Agriculture. Research Station, Matale. Tel: 066-2222945,0718077468 / 081-2463284 (private), Fax: 066-2222822 Email: *dgis@email.com*
7. Wasantha Palugaswewa, Regional Director of Irrigation, Irrigation Department. Airport Road, Anuradhapura. Tel: 718291413.
8. Dhammage Ariyaratne, Regional Director of Irrigation - Colombo, Irrigation Department. 238, Bauddhaloka Mawatha, Colombo 7. Tel: 2588668, 77377654 (private).
9. Anusha Rashanthie Warnasooriya, Meteorologist, Department of Meteorology. Bauddhaloka Mawatha, Colombo 7. Tel: 2676259, 2973836 (private), Fax: 2698311, Email: *rashanthie@yahoo.com*
10. A. B. S. Nandalal, Regional Director of Irrigation - Moneragala, Irrigation Department. Moneragala. Tel: 718008061.
11. R. S. Wijesekera, Assistant General Manager (Hydro), Water Resources Board. 2A, Hector Kobbekaduwa Mawatha, Colombo 7. Tel: 2694835, 071-8357376 (private), Email: *wijesekeraranjith@yahoo.com*
12. Lalani Imbulana, Director (Preparedness Planning), Disaster Management Center. BMICH, Bauddhaloka Mawatha, Colombo 7. Tel: 077-3957898 (private), Email: *indra.imbulana@gmail.com*
13. J. A. T. P. Gunawardena, Director, Department of Agriculture. Socio Economic and Planning Center, Department of Agriculture, Peradeniya. Tel: 081-2388081, 081-2385477 (private), Email: *tgunawardena@gmai.com*
14. D. S. de Alwis, Director General, Mahaweli Authority of Sri Lanka. 500, T. B. Jayah Mawatha, Colombo 10. Tel: 2687238, 0772-282838 (private), Fax: 2687391.
15. K. G. Janaka Karunasena, Scientific Officer, National Science Foundation. 47/5, Maitland Place, Colombo 7. Tel: 714491582, Fax: 2694754, Email: *janaka@nsf.ac.lk*
16. K. P. Kumbukage, Research Officer for Additional Director, Fruit Crop Research and Development Center. Kananwila, Horana. Tel: 034-2261323, Fax: 034-2261323.
17. Ravindra Hewavitharana, Commissioner General, Department of Agrarian Development. 42, Marcus Fernando Mawatha, Colombo 7. Tel: 777557158, Fax: 2691060.
18. S. C. Wanigasuriya, Principal Scientist, RRDI. Bentota. Tel: 034-2275173, Email: *agricbentota@slt.lk*
19. H. A. Sumanasena, Research Officer (SLSS), Department of Export Agriculture. Research Station, Matale. Tel: 066-2222945, 066-2244297 (private), Fax: 066-2222822, Email: *hsumanasena@yahoo.com*
20. Chamindi Kudahetty, Geologist, Water Resources Board. 2A, Hector Kobbekaduwa Avenue, Colombo 7. Tel: 2669440, 071-8139069 (private), Email: *ck1978hetty@yahoo.com*

21. G. B. Giragama, Director (Development) SLUDA. Gatambe, Peradeniya, Tel: 0812-575061, 071-2021292 (private), Email: *gbgiragama@gmail.com*

22. K. Premakumar, Dean/Agriculture, Eastern University of Sri Lanka. Faculty of Agriculture, Eastern University of Sri Lanka, Chenkaladi. Tel: 065-2240530, 065-2246063 (private), Fax: 065-2240740, Email: *kanagaprem@yahoo.com*

23. E. Sumanadasa, Regional Director of Irrigation. Irrigation Department, New Town, Polonnaruwa. Tel: 027-2222361, 071-4410641 (private), Fax: 027-2222361.

24. P. Sivarajah, Senior Lecture and Head of Department, Eastern University of Sri Lanka. Department of Agric. Economics, Faculty of Agriculture, Eastern University of Sri Lanka, Chenkaladi. Tel: 065-2240759, Email: *sivaponniah@yahoo.com*

25. P. A. D. A. Kumara, Research Officer, National Aquatic Resources Agency (NARA). Crow Island, Mattakkuliya, Colombo 15. Tel: 2521005, 071-6370630 (private), Fax: 2524430, Email: *padajithkumara@yahoo.com*

26. Ananda Mallawatantri, Assitant Resident Representative UNDP. 202, Bauddhaloka Mawatha, Colombo 7. Tel: 0773 444146, Email: *ananda mallawatantri@undp.org*

27. R. G. Wickramaratne, Regional Director of Irrigation - Puttalam. Irrigation Department, Irrigation Office, Puttalam. Tel: 077-9784482.

28. D. A. Athukorala, Research Officer, National Aquatic Resources Research and Development Agency (NARA). Crow Island, Mattakkuliya, Colombo 15. Tel: 2521000, 071-4437251 (private), Email: *athuko@nara.ac.lk*

29. K. Mullegamgoda, Programme Officer, World Food Program. 6, Joseph Lane, Colombo 4. Tel: 077-3887493, Email: *kithsiri.mullegamgoda@wfp.org*

30. J. Katupotha, Professor, University of Jayewardenapura. Department of Geography, University of Jayewardenapura, Gangodawila, Nugegoda. Tel: 071-8011540, 060-2087696 (private), Email: *katupotha@gmail.com*

31. A. H. G. Mithrasena, Deputy Director (Research) RRRDC. RRRDC, Bombuwela. Tel: 034-2281673, 038-2237620 (private), Fax: 034-2281673, Email: *mithrasena@yahoo.com*

32. S. Mohanarajah, Regional Director of Irrigation, Irrigation Department. P. O. Box 2, Batticaloa. Tel: 065-2223195, 065-2222034 (private), Fax: 065-2224780, Email: *mohanarajah@sltnet.lk*

33. P. B. Dharmasena, Free Lance Consultant. 227, Government Quarters, Mahailuppallama. Tel: 777613234, Email: *dharmasenapb@yahoo.com*

34. P. P. G. Dias, Deputy Director, Irrigation Department. Hydrology Division, Irrigation Department, Bauddhaloka Mawatha, Colombo 7. Tel: 2581636, 723565834 (private), Fax: 2581636, Email: *ddhydrology@gmai.com*

35. H. P. S. Somasiri, Director General of Irrigation, Irrigation Department. Bauddhaloka Mawatha, Colombo 7. Tel: 071-8008080.

36. D. B. Wickramasinghe, Additional Director, Natural Resources Management Center (NRMC). P. O. Box 52, Peradeniya. Tel: 0812 388355, Fax: 0812 388355, *nrmcdoa@sltnet.lk*

37. Namika Raby, Professor, California State U-Long Beach. 1250, Bellflower Blvd, Long Beach, CA 90840, USA. Tel: 562 985 5186, 771674727 (private), Email: *nraby@csulb.edu*

38. S. M. S. B. Niyangoda, Chair, SLWP. 127, Sunil Mawatha, Pelawatte, Battaramulla. Tel: 777880627.

39. H. J. K. Kurukulasooriya, Project Leader, Plan Sri Lanka. 621/13, Godage Mawatha, Anuradhapura. Tel: 0714 222218, Email: *jagath.harischandra@plan-international.org*

40. M. R. D. L. Kulathunga, Research Officer, Department of Agriculture. RARDC, Aralaganwila. Tel: 071 4466176.

41. C. Kudagamage, Director General, Department of Agriculture. Peradeniya. Tel: 081 2388331.
42. Tilak Attanayaka, Dean, Faculty of Agriculture and Plant Management, University of Wayamba. Makandura, Gonawila (NWP). Tel: 031 2299704, Email: *dpstga@yahoo.com*
43. Senani Karunaratne, Lecturer, University of Wayamba. Faculty of Agriculture and Plant Management, Wayamba University, Makandura, Gonawila (NWP). Tel: 718298994, Email: *senawu51@gmail.com*
44. J. Jayasekara, Director, Coconut Research Institute. Lunuwila.Tel: 031 2255809, 2809270 (private), Fax: 031 2257391, Email: *director@cri.lk*
45. S. S. Sivakumar, Deputy Director of Irrigation Irrigation Department. Station Road, Vavuniya. Tel: 024 2220632, Fax: 024 2222347, Email: *sssivaddim@sltnet.lk*
46. Anoja Seneviratne, Assistant Director, Disaster Management Centre. 2-203, BMICH, Colombo 7. Tel: 2670048, Email: *anoja@dmc.gov.lk*
47. Shanthi de Silva, Professor and Head of Department, The Open University of Sri Lanka. Department of Agric. Eng., Faculty of Engineering, The Open University, Nawala, Nugegoda. Tel: 2881323, Email: *csdes@ou.ac.lk*
48. K. Nagathasan, Deputy Director, Department of Agriculture. Extension Training Division, Department of Agriculture, Peradeniya. Tel: 081 2388340, 0777 602565 (private).
49. Ivan de Silva, Secretary, Ministry of Irrigation and Water Management. Jawatte Road, Colombo 7. Tel: 077 3040857, Email: *desilva.ivan@yahoo.com*
50. I. R. Perera, Team Leader, Practical Action. 5, Lional Ed. Mawatha, Colombo 5. Tel: 2829412, 2703303 (private).
51. Shamalee Amuwala, Undergraduate, University of Colombo. Colombo 3. Tel: 071 8087727 (private).
52. Sulakohika Senalankadhikara, Student, University of Colombo. Colombo 3. Tel: 077 9093327 private).
53. Sisira Saddhamangala Withanachchi, Assistant Lecturer, University of Colombo. Department of Political Science and Public Policy, University of Colombo, Colombo 3. Tel: 071 6595795, Email: *sisira.cmb@gmail.com*
54. Muditha P. Perera, Lecturer, University of Peradeniya. Department of Geography, University of Peradeniya, Peradeniya. Tel: 077 6657847, Email: *mudithpras@gmail.com*
55. L. B. A. S. Balasuriya, Junior Professional (Researcher), Centre for Poverty Analysis (CEPA). 29, Gregory's Road, Colombo 7. Tel: 2676955-8, 071 6630560 (private), Fax: 2676959, Email: *amila@cepa.lk*
56. A. M. S. Perera, Programme Assistant, Department of Agriculture. Socio Economics and Planning Center, Department of Agriculture, Peradeniya. Tel: 081-2388206, 071 8118237 (private).
57. I. Jinadarie de Zoysa, Director, Horticultural Crops Research and Development Institute. Gannoruwa, Peradeniya. Tel: 081-2388011-3, 081 2385639 (private), Fax: 081-2388234, Email: *dirhordi@yahoo.com*
58. Upali Wickramaratna, Director (Eng.), Ministry of Irrigation and Water Management. 11, Jawatta Road, Colombo. Tel: 2554034, Email: *upaliwic@sltnet.lk*
59. A. D. H. Muthukuda, Director, Plant Quarantine Department of Agriculture. Gannoruwa, Peradeniya. Tel: 081-2388044, Email: *scppl@sltnet.lk*
60. Tanuja Ariyananda, Director, Lanka Rain Water Harvesting Forum. 28/3A, Subadrarama Lane, Nugegoda. Tel: 5524612, Email: *tanuja@sltnet.lk*
61. W. G. Gnanadasa, Irrigation Engineer, Irrigation Department. CO-PD's Office, PEACE Project, Anuradhapura. Tel: 071-8025537.

62. W. G. Somaratne, Advocacy and Programme Policy Manager, OXFAM Australia. Sri Lanka Office, 15, Rohini Road, Colombo 6. Tel: 077 2960284, Email: *wgsomaratne@yahoo.com*

63. D. M. N. Banda, Provincial Director of Agriculture (Uva), Provincial Department of Agriculture. Office of the Provincial Director of Agriculture, Ratwatte Road, Badulla. Tel: 055 2222318, 2229318, 077 3593593 (private), Fax: 055 2229318.

64. Uditha Dissanayake, Senior Agronomist World Vision. 1119/2/1, Madarana Road, Colombo 8. Tel: 077 3428459, Fax: 5337151, Email: *uditha_dissanayake@wvi.org*

65. Palitha Wadduwage, Provincial Director of Agriculture (NWP), Provincial Department of Agriculture. Dambulla Road, Kurunegala. Tel: 037-2220126, 037-2232271 (private), Fax: 037-2222325.

66. T. P. Alwis, Director (ITI), Irrigation Department. ITI, Galgamuwa. Tel: 037-2253780.

67. T. N. N. Priyadarshani, Programme Assistant (Agriculture), Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Tel: 037-2259881, 071-4928153 (private), Fax: 037-2259881, Email: *tnnpriya@yahoo.com*

68. W. M. U. K. Rathnayake, Research Officer, Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Tel: 037-2259881, 071-4432745 (private), Fax: 037-2259881, Email: *upulr@yahoo.co.uk*

69. W. Weerakoon, Senior Agronomist, Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Tel: 037-2259881, 071-5337037 (private), Fax: 037-2259881, Email: *rice@sltnet.lk*

70. W. M. J. Bandara, Research Officer, Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Tel: 037-2259881, 071-4489332 (private), Email: *wmj.bandara@yahoo.com*

71. D. N. Sirisena, Research Officer, Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Tel: 037-2259881, Email: *rice@sltnet.lk*

72. W. D. S. Abeywickrama, Institutions Development Officer, Irrigation Department. R. D. I. Office, Deberawewa, Tissamaharamaya. Tel: 071-8082726.

73. P. C. Senaratne, Director, Irrigation Department. P. O. Box 1138, Colombo 7. Tel: 071-8008070.

74. T. Selliah, Professor, University of Peradeniya. Faculty of Agriculture, University of Peradeniya, Peradeniya. Tel: 081-2395507, Fax: 081-2395500, Email: *sthiru@pdn.co.lk*

75. P. C. Samarawickrama, Livelihood Programme Officer, Caritas Sri Lanka. 133, Kynsey Road, Colombo 8. Tel: 2693989, 077 1935348 and 2696990 (private), Email: *prasannasa@gmail.com*

76. S. M. Weerasinghe, Regional Director of Irrigation, Irrigation Department. RDI Office, Irrigation Department, Ampara. Tel: 077 3848380, 2622357 (private).

77. Frank Niranjan, Senior Research Officer, Sri Lanka Council for Agricultural Research Policy. 114/9, Wijerama Mawatha, Colombo 7. Tel: 2697103, Email: *niranjanfr-03@yahoo.com*

78. Bopitiya, Agrarian Development Officer, Department of Agrarian Development. ASC, Ratmalawinna, Balangoda. Tel: 071 4447867.

79. K. Herath, Research Officer, Hector Kobbekaduwa Agrarian Research and Training Institute. 114, Wijerama Mawatha, Colombo 7. Tel: 071 8220021, Email: *herathda@yahoo.com*

80. P. Mahadurage, Project Director, Agribusiness Promosion, Research and Training, Mahaweli Authority of Sri Lanka. 500, T. B. Jayah Mawatha, Colombo 10. Tel: 071-4803353, Email: *piyathilakam@yahoo.com*

81. Jayamina Udhara Munasinghe, Undergraduate, Rajarata University. 124, Saman Mawatha, Sirimal Uyana, Ratmalana. Tel: 0772 701044, 0777 701044 (private), Email: *udhara_7@yahoo.com*

82. Dinesh Pathiraja, Student. Tel: 072 3478753, Email: *dkpathiraja@gmail.com*

83. Chandana Rohana Withanachchi, Senior Lecturer, Rajarata University. Mihintale. Tel: 071 6123596, 060 2370153 (private), Email: *withanachchic@yahoo.com*

84. S. R. S. A. de Silva, Deputy Director (Research), RARDC. Regional Agri. Research & Dev. Center, Aralaganwila. Tel: 027 5671054, 066 2233528, Email: *agardes@yahoo.com*

85. Nandani Samarasinghe, Institutional Development Officer, Irrigation Management Division. Bauddhaloka Mawatha, Colombo 7. Tel: 071 2504515, 071 8031009 (private)

86. L. W. P. Warnasooriyage, Resident Project Manager, Irrigation Management Division. Bauddhaloka Mawatha, Colombo 7. Tel: 2504515.

87. K. C. Boomini Arachchi, Irrigation Engineer, Irrigation Department. I&WM Branch, Irrigation Department, Bauddhaloka Mawatha, Colombo 7. Tel: 2583004, 034 2226054, Fax: 2583004, Email: *kboomini@yahoo.com*

88. Dasarath Jayasuriya, Manager, Water Prediction, Bureau of Meteorology. 700, Collins Street, Docklands Vic 3008, Australia. Tel: 61409893706 (private), Email: d.jayasuriya@bom.gov.au

89. Ranjith Mahindapala, Country Representative IUCN - International Union for Conservation of Nature. 53, Horton Place, Colombo 7. Tel: 2694094, Fax: 2682470, Email: *ranjith@iucnsl.org*

90. A. P. Sanjaya Fernando, Lecturer, Rajarata Univeristy. Faculty of Agriculture, Rajarata University, Puliyankulama, Anuradhapura. Tel: 077 9643667, Email: *prageethaps@yahoo.com*

91. C. J. Liyanaarachchi. Tel: 071 4477520 (private), Email: *jaliya@myself.com*

92. Junichiro Yamada, Engineer, JICA. JICA Sri Lanka Office, DHPL Building, 42, Nawam Mawatha, Colombo 2. Tel: 0777 872823, Email: *jyamada2008@nitmail.jp*

93. D. A. D. N. C. Wimalaratne, Chairman, Rural and Community Development Cooperation. 21, Pirivena Road, Naranpitiya, Panadura. Tel: 4998800, Email: *nimaindu@hotmal.com*

94. D. C. S. Elakanda, Project Director - DSWRP Mahaweli Authority of Sri Lanka. 500, T. B. Jayah Mawatha, Colombo 10. Tel: 2675315, 077 3540350 (private), Email: *elamrrp@sltnet.lk*

95. D. D. P. Witharana, Engineer (Water Management), Department of Agrarian Development. 42, Sir Marcus Fernando Mawatha, Colombo 7.

96. D. D. Prabath Witharana, Engineer (Water Management), Department of Agrarian Development. 92, Sir Marcus Fernando Mawatha, Colombo 7. Tel: 4320839, Email: *watmngcolombo@yahoo.lk*

97. Janitha Liyanage, Professor in Chemistry, University of Kelaniya. Department of Chemistry, University of Kelaniya, Kelaniya. Tel: 071 4264812, Email: *janitha@kln.ac.lk*

98. Thilani Padmajani Munaweera, Research Officer Hector Kobbekaduwa Agrarian Research and Training Institute. 114, Wijerama Road, Colombo 7. Tel: 2696981, 071 8051710 (private), Email: *hilanimunaweera@yahoo.com*

99. S. D. K. Seneviratne, Research Officer Hector Kobbekaduwa Agrarian Research and Training Institute. 114, Wijerama Road, Colombo 7. Tel: 2696981, 077 3905469 (private), Email: *sanjaanmil@yahoo.com*

100. P. S. Rodrigo, Management Assistant, Irrigation Department. Co-Project Director's Office, Irrigation Department, Airport Road, Anuradhapura. Tel: 071 4490772, Email: *tmpsrodrigo@yahoo.com*

101. Karin Fernando, Senior Professional, Center for Poverty Analysis (CEPA). 29, Gregory's Road, Colombo 7. Email: *karin@cepa.lk*

102. Sasindu Gunawardana, Research Assistant University of Kelaniya. Faculty of Science, University of Kelaniya, Kelaniya. Tel: 077 3361343.

103. Sarala Damunupola, Student. Sri Sudharshana Ramaya, Nilpanagoda.

104. Anushka Manori Gunaratne, Research Assistant, University of Wayamba. Department of Agriculture and Fisheries, Wayamba University. Tel: 071 4235789, Email: *menokmp@yahoo.com*

105. Sunanda Jayakody, Senior Lecturer, University of Wayamba. Makandura, Gonapeenuwala.

106. R. M. K. Kumarihamy, Research Assistant Center for Environmental Studies. University of Peradeniya, Peradeniya. Tel: 077 5707067, Email: *kumarirmk@yahoo.com*

107. A. M. Ranasinghe, Scientific Officer, National Science Foundation. 45/7, Maitland Place, Colombo 7. Tel: 2696771-3 ext 140, Email: *amalir@nsf.ac.lk*

108. S. N. Jayawardena, Research Officer, Rice Research and Development Institute. Batalagoda, Ibbagamuwa. Email: *senarathjayawardena@yahoo.com*

109. Athula Senaratne, Research Fellow, Institute of Policy Studies. 99. St. Michael's Road, Colombo 3. Tel: 2431368 ext 408, 077 6432472 (private), Email: *athula@ips.lk*

110. Sanjeewani Marasinghe, Programme Officer, Plan-Sri Lanka. No. 6, Claessen Place, Colombo 5. Tel: 777298827, Email: *sanjeewani.marasinghe@plan-international.org*

111. Dhammika Dayawansa, Senior Lecturer University of Peradeniya. Department of Agric. Eng., University of Peradeniya, Peradeniya. Tel: 081 2395467, 071 4446763 (private), Fax: 081 2395454, Email: *dammid@pdn.ac.lk*

112. U. D. Ariyaratna, Environmental Engineer, Green Friend.

113. T. S. Samarasena, Student, University of Colombo. University of Colombo, Colombo. Tel: 2402585, 077 6023978 (private), Email: *charundya@yahoo.com.au*

114. E. R. N. Gunawardena, Professor, University of Peradeniya. Department of Agricultural Engineering, University of Peradeniya, Peradeniya. Tel: 081 2395455, 081 2389209, Email: *minalgun@pdn.ac.lk*

115. Ranjith Premalal de Silva, Professor, University of Peradeniya. Department of Agricultural Engineering, University of Peradeniya, Peradeniya. Tel: 777801712, Fax: 081 2395454, Email: *rpdesilva@pdn.ac.lk*

116. Mohamed Najim, Senior Lecturer, University of Kelaniya. Faculty of Science, University of Kelaniya, Kelaniya. Tel: 2903402, Email: *mnajim@kln.ac.lk*

117. H. Dasarathasiri Gunawardhana, Senior Professor, University of Colombo. Department of Chemistry, University of Colombo, Colombo 3. Tel: 2503367, 276552 (private), Fax: 2503367, Email: *hdg@chem.cmb.ac.lk*

118. S. C. Udagedara, Student, University of Kelaniya. Faculty of Science, University of Kelaniya, Kelaniya. Tel: 0715 696659, Email: *uscudagedara@gmail.com*

119. Kanchana Wickramasinghe, Research Officer, Institute of Policy Studies. 9, St. Michael's Road, Colombo 3. Tel: 0722 860728, Email: *kanchana@ips.lk*

120. Vindya Hewawasam, Research Assistant, Ministry of Environment and Natural Resources. 342, Air Resource Management and International Relations, Pitakotte, Kotte. Tel: 2816970, 0773631013 (private), Fax: 4410236, Email: *eeconga@yahoo.com*

121. R. L Perera, Environment Management Officer, Ministry of Environment and Natural Resources. 342, Suite House Building, Pitakotte Junction, Kotte. Tel: 2816970, 071 4242297 (private), Fax: 4410236, Email: *ruchi74@gmail.com*

122. Thusitha Amarasekara, Postgraduate Student, PGIA. PGIA, University of Peradeniya, Peradeniya. Tel: 071 4479148, Email: *thusithaamarasekara@yahoo.com*

123. Zvi Feler, Business Development Manager, Netafim Ltd. 10, Hashalom Road, Tel Aviv, Israel. Tel: 972 86724747, Email: *zvi.feler@netafim.com*

124. M. A. A. Madurapperuma, Temporary Lecturer, The Open Univeristy of Sri Lanka. The Study Center, The Open University of Sri Lanka, 24 Post, Bandiwewa, Jayanthipura, Polonnaruwa. Tel: 27 2225776, Fax: 27 2225776, Email: *buddhika_dilhan@yahoo.com*

125. Nethmini Perera, Project Officer, Institute of Policy Studies. 99, St. Michael's Road, Colombo 3. Tel: 2431368, Email: *nethmini@ips.lk*

126. B. V. R. Punyawardena, Research Officer, Department of Agriculture. NRMC, Department of Agriculture, Peradeniya. Tel: 071 415967, 081 2218510 (private), Fax: 081 2388333, Email: *nrmcsltnet@lk*

127. Namalee Madawalagama, Chief Engineer, Irrigation Department. AM Branch, Irrigation Department, Bauddhaloka Mawatha, Colombo 7. Tel: 2744295, Email: *namalee_madawalagama@yahoo.com*

128. Kusum Athukorala, NetWwater. No. 7, St. Mary's Lane, Colombo 15. Tel: 2521604, Email: *kusum@itmin.net*

129. Eranda K. Gunathilaka, Lecturer, University of Sabaragamuwa. Department of Surveying and Geodesy, Faculty of Geometrics, University of Sabaragamuwa, Belihuloya. Tel: 077 3976577, Email: *erandakan@gmail.com*

130. A. L. Wickramanayake, University of Sabaragamuwa. University of Sabaragamuwa, Belihuloya. Tel: 077 2072337 (private).

131. Nalaka Duminda Perera, University of Sabaragamuwa. University of Sabaragamuwa, Belihuloya. Tel: 077 2072388.

132. Dinesh Nishantha, Director, Young Dawn Foundation. 514, Iriyavatiya Road, Dalugama, Kelaniya. Tel: 2671152 (private), Email: *nishantha7uk@yahoo.com*

133. Thiranka Ariyaratne, Irrigation Engineer, Dam Safety Project. Mahaweli Authority of Sri Lanka, 500, T. B. Jayah Mawatha, Colombo 10. Email: *thiranka@yahoo.com*

134. Priyanka Dissanayake, Environment Scientist, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

135. Priyantha Jayakody, Research Officer, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

136. Geethika Yapa, Head, Research Division, National Science Foundation. 47/5, Maitland Place, Colombo 7. Tel: 2687991, 2823054 (private), Fax: 2694754, Email: *geethika@nsf.ac.lk*

137. Amila Silva, Irrigation Engineer, Irrigation Department. Irrigation Department, Bauddhaloka Mawatha, Colombo 7. Tel: 077 4287831, Email: *amila_rugby@yahoo.com*

138. K. P. A. Dharmaratne, Deputy Director, Disaster Managemet Centre. 2-222, BMICH, Bauddhaloka Mawatha, Colombo 7. Tel: 2670002 - ext. 234, 077 3957899 (private), Fax: 2670079, Email: *eoc@dmc.gov.lk*

139. Alexandra Evans, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

140. Madar Samad, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

141. K. Jinapala, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

142. Ranjith Ariyaratne, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

143. Nishadi Eriyagama, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

144. Aditi Mukherji, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

145. David Molden, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

146. Tushaar Shah, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

147. Sithara Atapattu, Consultant, IWMI.

148. Sanjiv De Silva, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

149. Sonali Senaratne Sellamuttu, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

150. Mark Giordano, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

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152. Herath Manthritilake, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

153. Pay Drechsel, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.

154. Priyanie Amerasinghe, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.
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156. Mir Matin, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.
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158. Mohideen Sadir, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.
159. Sarath Gunasinghe, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.
160. Ranjith Alankara, IWMI. 127, Sunil Mawatha, Pelawatte, Battaramulla.
161. C. R. Panabokke. 439/8, Sudharshana Mawatha, Nawala, Rajagiriya.
162. V. K. Nanayakkara, Director, Hector Kobbekaduwa Agrarian Research and Training Institute. 114, Wijerama Mawatha, Colombo 7.
163. Kamal Karunagoda, Agricultural Economist, Department of Agriculture. Socio Economic & Planning Division, Department of Agriculture, P.O Box 1, Peradeniya.
164. M. M. M. Aheeyar, Head, Environmental and Water Resource Management Division, Hector Kobbekaduwa Agrarian Research and Training Institute. 114, Wijerama Mawatha, Colombo 7.
165. H. M. Jayathilake, Director (Irrigation and Water Management), Irrigation Department. 238, Bauddhaloka Mawatha, Colombo 7.
166. D. J. Bandaragoda. 449, Pansala Para, Thalawatugoda.
167. Sarath Abayawardana, CEO, National Science Foundation. 47/5, Maitland Place, Colombo 7.

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Postal Address
P O Box 2075
Colombo
Sri Lanka

Location
127 Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Telephone
+94-11-2880000

Fax
+94-11-2786854

E-mail
iwmi@cgiar.org

Website
www.iwmi.org

International Water Management Institute

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