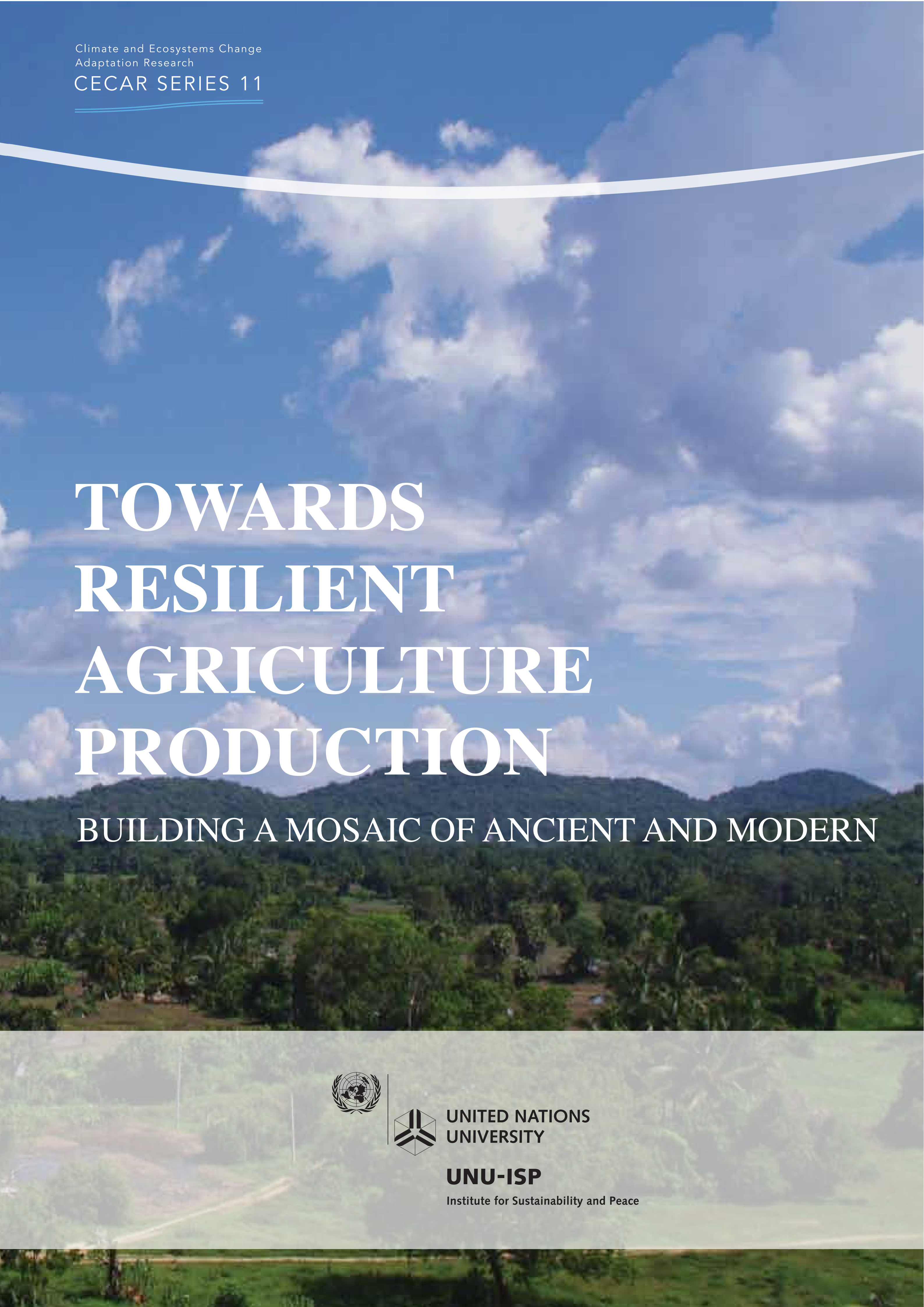

Climate and Ecosystems Change
Adaptation Research
CECAR SERIES 11

TOWARDS RESILIENT AGRICULTURE PRODUCTION

BUILDING A MOSAIC OF ANCIENT AND MODERN

UNITED NATIONS
UNIVERSITY

UNU-ISP
Institute for Sustainability and Peace

TOWARDS RESILIENT AGRICULTURE PRODUCTION IN RURAL ASIA

Report on CECAR-ASIA project funded by the Ministry of Environment, Government of Japan

United Nations University Institute for Sustainability and Peace

Edited by

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CONTENTS

PREFACE

This report documents the activities of the on going research project 'Climate and Ecosystems Change Adaptation Research in Asia (CECAR-ASIA)' funded by the Ministry of Environment of the Government of Japan. The objective of the research is to propose measures to enhance the resilience of rural production systems in rural Asia focussing on thee countries in Asia, namely; Indonesia, Sri Lanka and Viet Nam. Research teams from the University of Tokyo, Japan, the United Nations University, Institute for Sustainability and Peace (UNU-ISP), Tokyo, Japan and the Research Institute for Humanity and Nature (RIHN) in Kyoto, Japan conducts the research in collaboration with the counterpart universities in the three countries; Gadjah Mada University, Indonesia, University of Peradeniya, Sri Lanka, and Vietnam National University, Vietnam. The project studies both traditional and modern rural production systems to understand their strengths and weaknesses in terms of productivity, efficiency and resilience and proposes measures to improve resilience of the systems while retaining efficiency as much as possible to improve the livelihoods of the farmers.

The project span is from 2011 to 2013 and the outcome of the research will be summarised to help policy makers in the three countries to upscale and apply the research outcomes to enhance livelihoods and improve agriculture resilience to future shocks, especially those related to climate change.

The present report focuses the mainly on the activities carried out by the UNU-ISP. The topics cover building mosaics of traditional and modern irrigation systems in Sri Lanka, conjunctive use of ground water and surface water in Sri Lanka, home gardens services in Sri Lanka, Viet Nam and Indonesia, and use of remote sensing mapping to enhance understanding of ecology surrounding irrigation tanks.

For the study in Viet Nam, we are very much thankful for the kind support and arrangements made by Professor Mai Trong Nhuan, the President of the Vietnam National University and his team for their unreserved support and enthusiasm in conducting this research.

We are very much thankful to the University of Peradeniya, especially Professor S. B. Weerakoon, the Dean of Engineering Faculty, for his enthusiastic engagement in research and excellent logistical support. The field work support of Professor Nimal Gunatileka and Professor Gamini Hitinayake on Kandyan Home gardens study are acknowledged with deep gratitude. We are indebted to the unreserved support of Central Engineering Consultancy Bureau and the Irrigation Department for Sri Lanka for the excellent partnership we could build in carrying out this study.

We acknowledge the invaluable support and contributions provided to us by the Gadjah Mada University team of Professor Tumiran, Dean of the faculty of Engineering, Prof. Irham who lead the research team in Indonesia, Professor Dharmanto and Professor Rahman Sudiyo.

Last, but not least we would like to express our sincere gratitude to the Ministry of the Environment, Japan for financial support.

Srikantha Herath, UNU-ISP

1

INTRODUCTION TO THE CECAR-ASIA PROJECT

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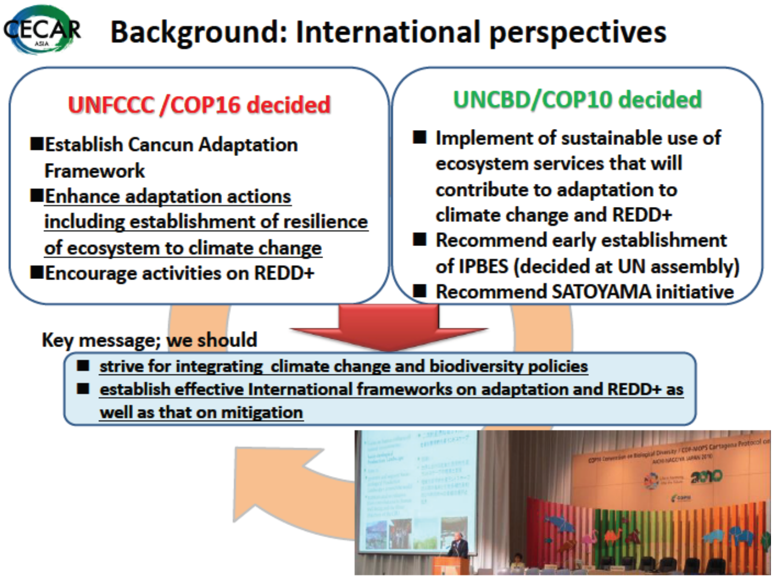
United Nations University, Institute for Sustainability and Peace has initiated a three year research project, supported by the Environment Research and Technology Development Fund (ERTDF), Ministry of the Environment, Japan spanning from the financial year 2011 to 2013. The objective of the research is to analyze traditional and modern agricultural systems to understand their strengths and weaknesses in terms of efficiency, productivity and resilience. Through the study pragmatic proposals will be made that enhances the resilience of combined modern and traditional mosaic of agriculture production systems. The research targets a comparative study of 3 countries, Indonesia, Sri Lanka and Vietnam.

1.1 BACKGROUND

Asia is home to a number of traditional agricultural landscapes that have withstood climate variability and varied societal changes for over thousand years. Their sustainability is due to high degree of resilience that is brought about by integrated resource management, maintenance of material cycles, supporting a variety of societal and ecosystems services, etc. However, the productivity of such systems is not high and it is difficult to support the modern day lifestyles by their agricultural output alone. On the other hand modern agricultural systems are highly productive and efficient to cater to high demands of present day populations and economic growth. However, these systems are highly optimized and run the risk of failure with changes to existing climate and ecosystems state. Is it possible to develop a framework to integrate the use and management of these two types of systems so that the total system resilience as well as productivity can be enhanced? This is the research question the project try address through a comparative study of 3 types of traditional and modern agriculture systems in three countries.

Internationally, United Nations Framework Convention on Climate Change (UNFCCC) initiative of Conference of Parties (CoP) 16 held in Cancun, Mexico has decided upon the establishment of the Cancun framework extending beyond the Bali action plan. Five major clusters of discussion had been on the implementation, support, institutions, principles and stakeholder involvement. It has particularly enhanced the adaptation action plans including the added value of the resilience concept. One of crucial implementation strategies had been augmenting the role of The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) with the inclusion of the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (shortly called as REDD+ for practical purposes). Meantime, the United Nations Convention on Biological Diversity (UNCBD) and the Conference of Parties (CoP) 10 held in Nagoya, Aichi Prefecture, Japan in 2010 has adopted the 'Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity'. It has recommended the sustainable use of ecosystems services to contribute to the adaptation of climate change and REDD+. It has also recommended the early establishment of the Intergovernmental Platform for Biodiversity and Ecosystems Services (IPBES) which was decided in the United Nations General Assembly and the SATOYAMA initiative. It should be noted that 'Satoyama' corresponds to the rural agricultural landscapes in the Japanese language which typifies the harmonious coexistence between the nature and the human beings (Takeuchi, Brown, Washitani, Tsunekawa, & Yokohari, 2003). These initiatives show the intersection of discussion and the importance of integrating climate change and biodiversity discussion and the subsequent policies including that of the international frameworks and the local level initiatives balancing the top-down and bottom-up approaches for policy and implementations.



Background: International perspectives

UNFCCC /COP16 decided

- ■Establish Cancun Adaptation Framework
- ■Enhance adaptation actions including establishment of resilience of ecosystem to climate change
- ■Encourage activities on REDD+

UNCBD/COP10 decided

- ■ Implement of sustainable use of ecosystem services that will contribute to adaptation to climate change and REDD+
- ■ Recommend early establishment of IPBES (decided at UN assembly)
- ■ Recommend SATOYAMA initiative

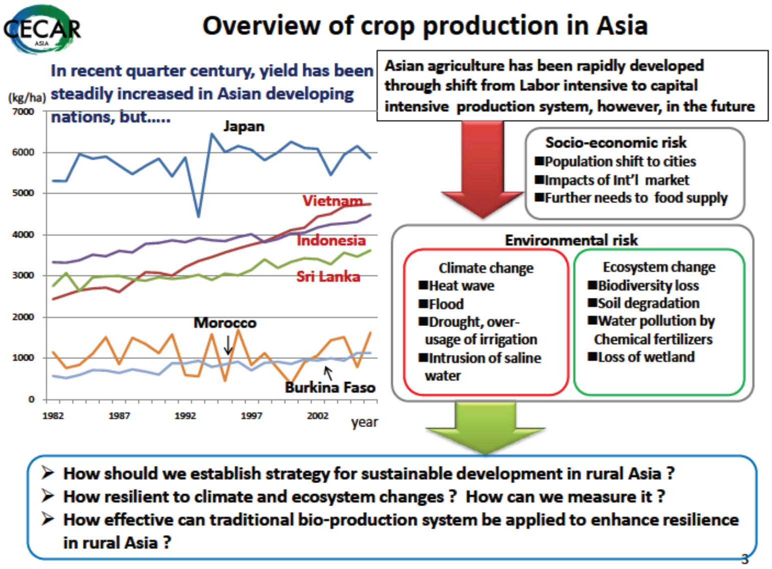
Key message; we should

- ■ strive for integrating climate change and biodiversity policies
- ■ establish effective International frameworks on adaptation and REDD+ as well as that on mitigation

1.2 OVERVIEW OF THE CROP PRODUCTION IN ASIA

Though the steady increase of yield has been observed in the developing countries in Asia, it is far below compared to the developed countries such as Japan. The development has been observed through the shift from the traditional labor intensive phenomenon to the capital intensive production systems mostly owing to the mono purpose farmlands emerged in the recent past. But Socio-economic risks are many: Population shift from the agricultural rural areas to the cities had been ever increasing. With the globalized world, international market changes make very sensitive differences. With the population not settling within the coming decades the need for the food supply is also increasing. These socio-economic concerns are exacerbated with the environmental risks most critically the climate change and the change in the natural ecosystems. Climate change increases already critical challenges such as the heat wave, flood, droughts, overuse of irrigated water, intrusion of saline water, sea level rise and myriad others. On the other hand ecosystem changes include biodiversity loss, soil degradation, water pollution by chemical fertilizers, loss of the wetland to name a few. In the background of these concerns, three major questions are:

1. How should we establish the strategies for the sustainable development in rural Asia?
2. How to be resilient to climate and ecosystem changes and how can we measure it?
3. How effectively the traditional bio-production system could be applied to enhance resilience in rural Asia?



Overview of crop production in Asia

In recent quarter century, yield has been steadily increased in Asian developing nations, but.....

Asian agriculture has been rapidly developed through shift from Labor intensive to capital intensive production system, however, in the future

Socio-economic risk
- Population shift to cities
- Impacts of Int'l market
- Further needs to food supply

Environmental risk

Climate change
- Heat wave
- Flood
- Drought, over-usage of irrigation
- Intrusion of saline water

Ecosystem change
- Biodiversity loss
- Soil degradation
- Water pollution by Chemical fertilizers
- Loss of wetland

- How should we establish strategy for sustainable development in rural Asia ?
- How resilient to climate and ecosystem changes ? How can we measure it ?
- How effective can traditional bio-production system be applied to enhance resilience in rural Asia ?

1.3 RESEARCH FRAMEWORK

CECAR-Asia project's research framework tries to design the conceptualization with three major systems namely (i) bio-production system (ii) social system (iii) ecosystem. Given the background of these critical embedded with the systems CECAR-Asia has taken three major thematic clusters in designing the research framework:

1. Collaboration of climate change and biodiversity policies – This is an attempt to see the climate change and biodiversity policies in an integrated manner instead of trying to handle them as separate entities. Since the environment is made up of complex elements involving ecosystems, climate, biosphere and myriad others need for integrated assessment becomes very critical.
2. Introducing the concept of resilience into global environmental policy – Resilience acknowledges that ensuring absolute safety is almost impossible. For an example, 2011 Great East Japan Disaster has mostly occurred in the regions which have arguably had the rigorous preparation against the same potential disasters (Mimura, Yasuhara, Kawagoe, Yokoki, & Kazama, 2011). Hence, resilience which is about the capacity that society or ecosystem absorbs shocks and disturbances without losing its character while retrieving from the changes should be the guiding principle in constructing the global environmental policy.

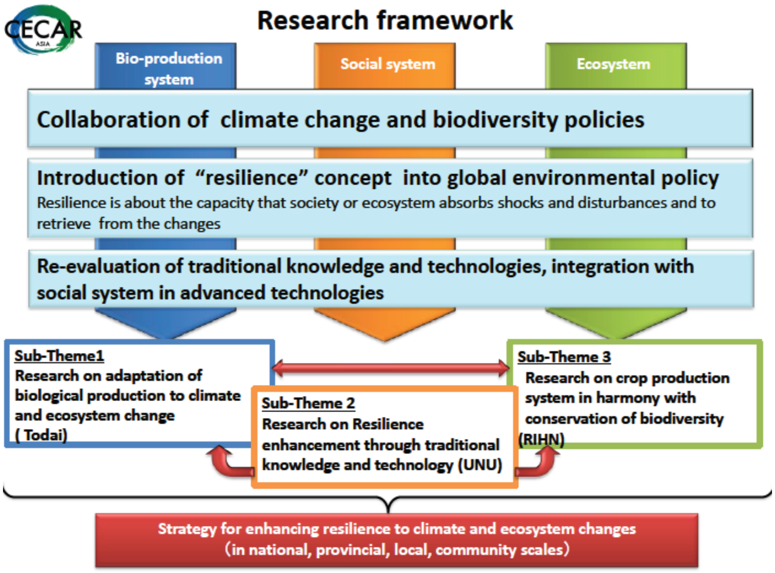
3. Re-evaluation of traditional knowledge and technologies along with the integration of the social systems and the modern technologies – Traditional knowledge and technologies offer a huge wealth of knowledge which had evolved over centuries through the successful implementation. This vast wealth of knowledge has be seen and to be made compatible with the modern societies and technologies.

CECAR-Asia project answering to the call of these major three questions, along these three thematic clusters were developed including three major contributing institutions focusing on:

1. Research on adaption to climatic and ecological changes of biological production systems (The University of Tokyo)

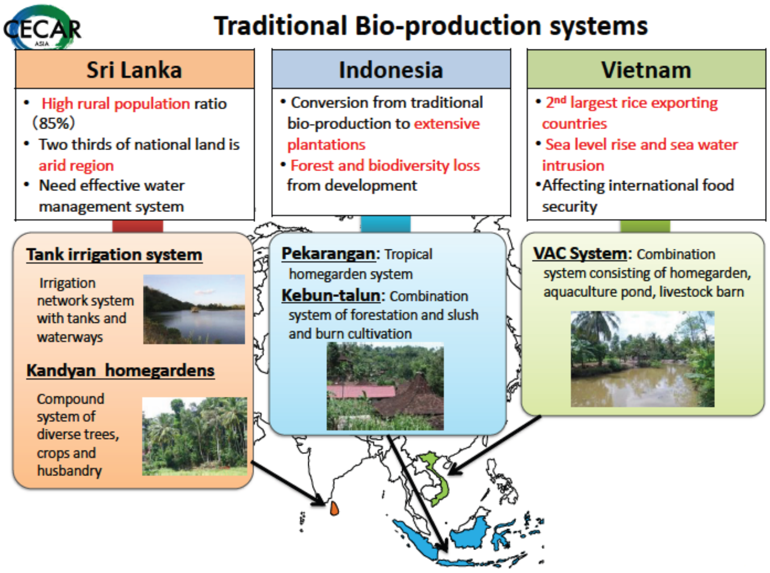
2. Research on methods to strengthen resilience through traditional knowledge and skills (United Nations University)

3. Research on biological production systems in harmony with biodiversity protection (Research Institute for Humanity and Nature)



1.4 TRADITIONAL BIO-PRODUCTION SYSTEMS IN ASIA

As explained earlier CECAR-Asia project involves three different countries in Asia namely Sri Lanka, Indonesia and Vietnam. All three countries are fast growing possessing the typical challenges of the developing countries. Sri Lanka is a medium sized island in the Indian Ocean at the southern tip of Indian subcontinent. It has a high rural population ratio of 85%. Two third of the national land is arid and seriously in need for an efficient water management system. In Sri Lankan context, Sri Lankan ancient irrigation systems and Kandyan home gardens were selected to conduct the studies on strengthening social resilience and promote sustainable development of communities in the Asian region. Indonesia is a large country with the combination of many islands. The conversion from traditional bio-production to extensive commercial plantations was done in the recent past. It includes the forest and biodiversity loss from the development plans. CECAR-Asia focuses on Pekarangan -the traditional homegarden system and the Kebun-talun - the combinational system of forestation and the slush and burn cultivation system. Vietnam is one of the fastest developing countries and it is the 2nd largest rice exporting country. It was reporting to be potentially suffering from the challenges such as the sea level rise and the sea water intrusion to name a few.



Traditional Bio-production systems

Sri Lanka
- High rural population ratio (85%)
- Two thirds of national land is arid region
- Need effective water management system

Tank irrigation system: Irrigation network system with tanks and waterways

Kandyan homegardens: Compound system of diverse trees, crops and husbandry

Indonesia
- Conversion from traditional bio-production to extensive plantations
- Forest and biodiversity loss from development

Pekarangan: Tropical homegarden system

Kebun-talun: Combination system of forestation and slush and burn cultivation

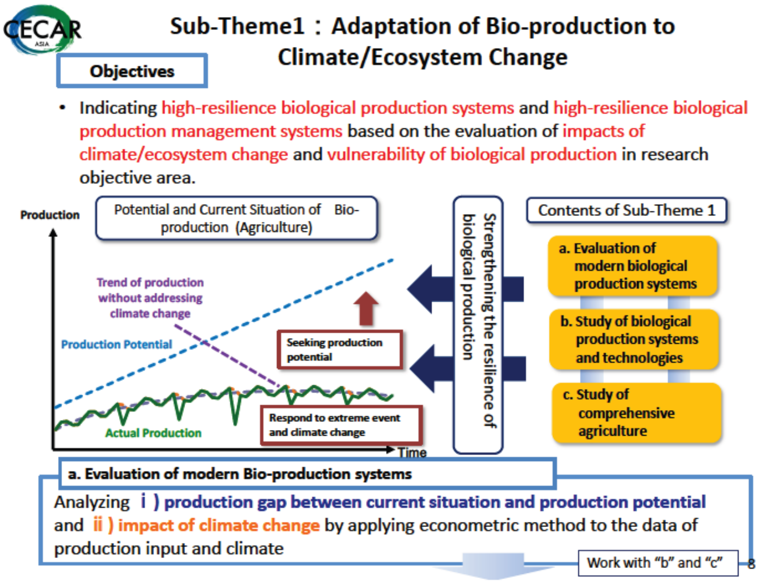
Vietnam
- 2nd largest rice exporting countries
- Sea level rise and sea water intrusion
- Affecting international food security

VAC System: Combination system consisting of homegarden, aquaculture pond, livestock barn

1.5 SUBTHEMES OF CECAR-ASIA

1.5.1 *Subtheme 1 - Adaptation of Bio-Production to Climate and Ecosystems Change*

Subtheme 1 is coordinated by the University of Tokyo. It broadly works on the high-resilience production systems and the high-resilience production management systems based on the evaluation of impacts of climate and ecosystems change. It is also expected to indicate the vulnerability of the biological production systems. It will also evaluate the biological systems which are modern and their relevance in building the high resilience systems. Econometric data is expected to be analyzed in understanding the production gap between the potential and the current output along with the challenges of climate change.



Sub-Theme1 : Adaptation of Bio-production to Climate/Ecosystem Change

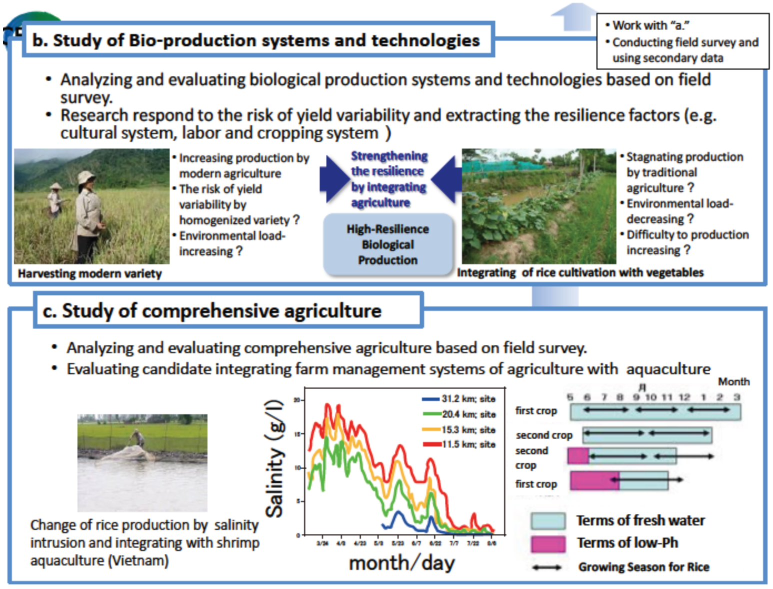
Objectives

- Indicating high-resilience biological production systems and high-resilience biological production management systems based on the evaluation of impacts of climate/ecosystem change and vulnerability of biological production in research objective area.

a. Evaluation of modern Bio-production systems

Analyzing ⅰ) production gap between current situation and production potential and ⅱ) impact of climate change by applying econometric method to the data of production input and climate

Second component of the subtheme two is to study the bio-production systems and technologies. Analyzing and evaluating the biological productions are expected to be completed through the field surveys covering these countries. Research is expected to respond to the risk of yield variability and to extract the resilience factors such as the cultural system, labor, cropping pattern and myriad others. Thirdly the focus is about the comprehensive agriculture such as integrating the farm management and the incorporation of aquaculture in the farming communities.



b. Study of Bio-production systems and technologies

- Work with "a."
- Conducting field survey and using secondary data

- Analyzing and evaluating biological production systems and technologies based on field survey.
- Research respond to the risk of yield variability and extracting the resilience factors (e.g. cultural system, labor and cropping system)

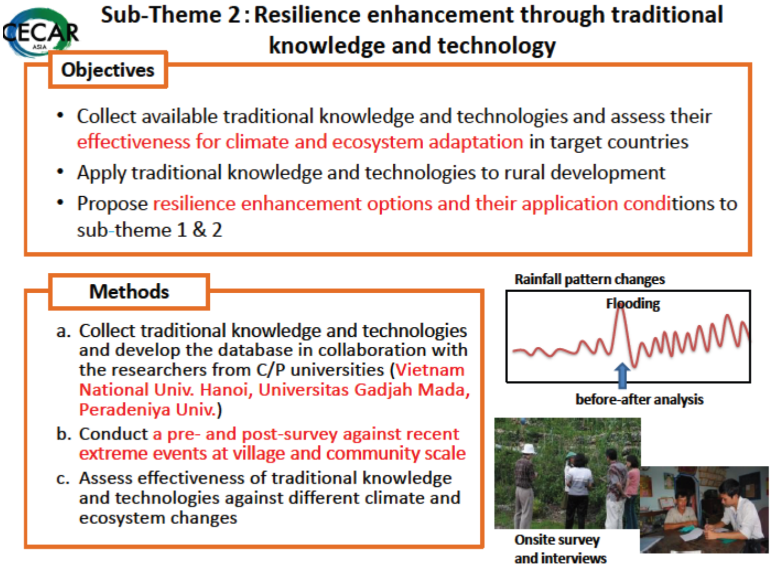
c. Study of comprehensive agriculture

- Analyzing and evaluating comprehensive agriculture based on field survey.
- Evaluating candidate integrating farm management systems of agriculture with aquaculture

Change of rice production by salinity intrusion and integrating with shrimp aquaculture (Vietnam)

1.5.2 *Subtheme 2 - Resilience Enhancement through Traditional Knowledge and Technology*

United Nations University Institute for Sustainability and Peace (UNU-ISP) coordinates the subtheme 2. It is expected to collect the traditional knowledge and technologies to assess the effectiveness for climate and ecosystem adaptation in target countries namely Sri Lanka, Indonesia and Vietnam. After the compilation of these traditional knowledge and technologies it is expected to see their relevance in applying these technologies for the rural development in target countries. With the combination of modern and traditional systems resilient enhancement options and their application conditions are expected to be proposed under the subtheme 2. Collection of these knowledge and technologies are expected are jointly done with the counterpart universities in the relevant countries namely the University of Peradeniya Sri Lanka, Gadjah Mada University Indonesia and Vietnam National University in Vietnam. Noting the recent increased extreme events the surveys would be conducted before and after the extreme events in the village and the relevant community levels. Also, the effectiveness of these traditional knowledge systems would be tested against the extreme events.



Sub-Theme 2 : Resilience enhancement through traditional knowledge and technology

Objectives

- Collect available traditional knowledge and technologies and assess their effectiveness for climate and ecosystem adaptation in target countries
- Apply traditional knowledge and technologies to rural development
- Propose resilience enhancement options and their application conditions to sub-theme 1 & 2

Methods

a. Collect traditional knowledge and technologies and develop the database in collaboration with the researchers from C/P universities (Vietnam National Univ. Hanoi, Universitas Gadjah Mada, Peradeniya Univ.)
b. Conduct a pre- and post-survey against recent extreme events at village and community scale
c. Assess effectiveness of traditional knowledge and technologies against different climate and ecosystem changes

Figure 1 shows the matrix of the components included in the subtheme 2. It amalgamates the plausible options coming from the modern Vs traditional systems, country specific systems, SWOT analysis and others in a diagrammed way.

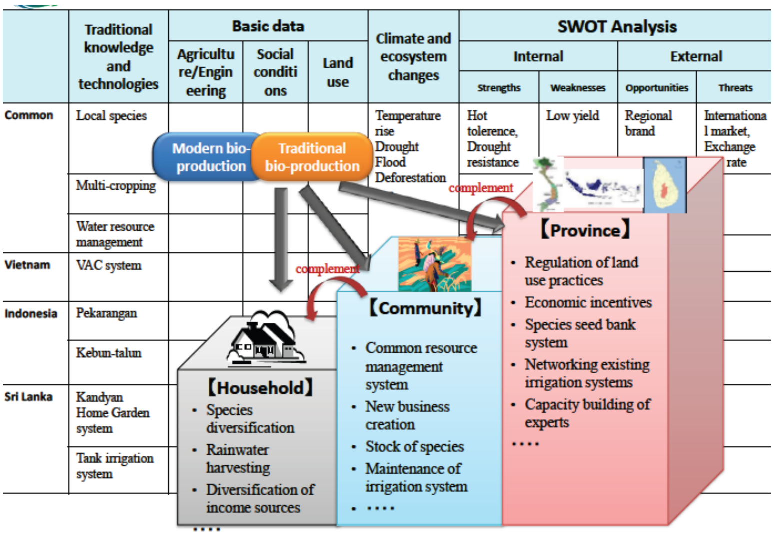


Figure 1: Matrix for Resilience Enhancement through Traditional Knowledge

1.5.3 *Subtheme 3 - Bio -Production System in Harmony with Conservation of Biodiversity*

Subtheme 3 is coordinated by the Research Institute for Humanity and Nature (RIHN) in Kyoto, Japan. The objectives of this subtheme includes the assessment of the recent and traditional crop production systems with regard to the ecosystem services, understanding and revealing the response of the ecosystems to external shocks such as flood and drought, suggesting the optional crop production systems contributing to strengthen the resilience and finally developing the mosaic crop production system consisting of the ancient and the modern crop production systems. It is expected to be carried out through the environmental traceability method namely the isotope and chemical analysis, developing inventory of the ecosystem services and by examining the response of the farmers and the ecosystem to the shocks coming externally through the field surveys such as the reconnaissance method and questionnaires. Figure 2 shows the methodological framework employed for the subtheme 3. It explains the eventual target of developing mosaic crop production system based on the lessons from the modern crop production systems and the traditional crop production systems. While the modern systems are expected to contribute to the development of the technology with low input traditional systems are anticipated to strengthen the resilience component of the expected mosaic systems.

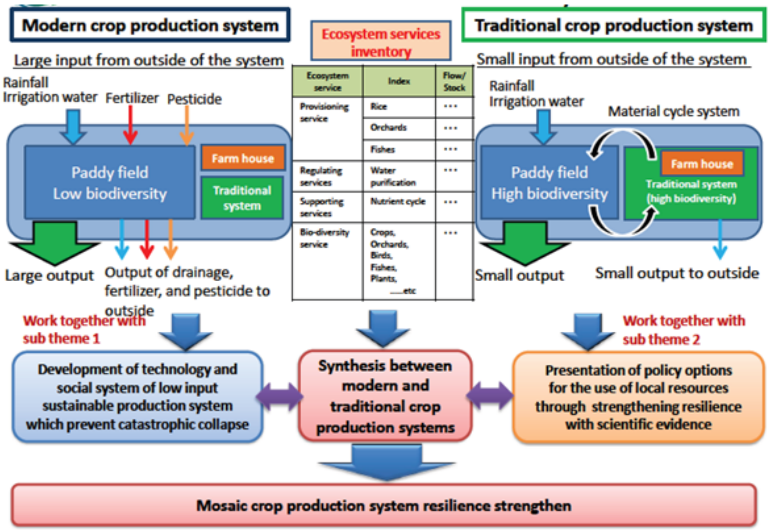
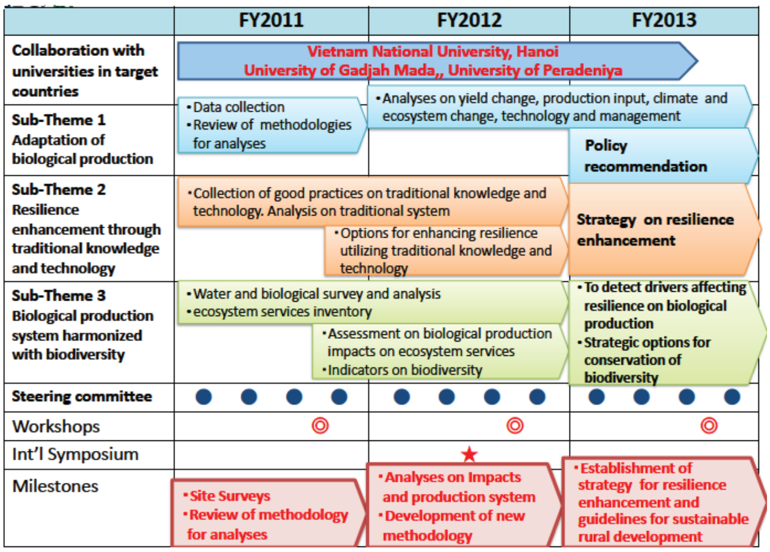


Figure 2: Methodological Framework of the Subtheme 3

1.6 TIME SCHEDULE OF THE CECAR ASIA PROJECT



	FY2011	FY2012	FY2013
Collaboration with universities in target countries	Vietnam National University, Hanoi University of Gadjah Mada,, University of Peradeniya		
Sub-Theme 1 **Adaptation of biological production**	• Data collection • Review of methodologies for analyses	• Analyses on yield change, production input, climate and ecosystem change, technology and management	**Policy recommendation**
Sub-Theme 2 **Resilience enhancement through traditional knowledge and technology**	• Collection of good practices on traditional knowledge and technology. Analysis on traditional system • Options for enhancing resilience utilizing traditional knowledge and technology		**Strategy on resilience enhancement**
Sub-Theme 3 **Biological production system harmonized with biodiversity**	• Water and biological survey and analysis • ecosystem services inventory • Assessment on biological production impacts on ecosystem services • Indicators on biodiversity		• To detect drivers affecting resilience on biological production • Strategic options for conservation of biodiversity
Steering committee	● ● ● ●	● ● ● ●	● ● ● ●
Workshops	◎	◎	◎
Int'l Symposium		★	
Milestones	• Site Surveys • Review of methodology for analyses	• Analyses on Impacts and production system • Development of new methodology	• Establishment of strategy for resilience enhancement and guidelines for sustainable rural development

Figure 3: Time Schedule of the CECAR-Asia Project

2

BUILDING MOSAICS OF TRADITIONAL AND MODERN AGRICULTURE SYSTEMS

[1]Herath, S., [1]Mohri, H., [1]Mishra, B.K., [1]Wong, P., [2]Sampath, D.S., [2]Weerakoon, S. B., [1]Atapattu, S., [1]Woldie, D.

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ABSTRACT

This paper briefly describe the current research project in Sri Lanka under UN-CECAR framework supported by Ministry of Environment, Japan, executed by the United Nations University, Institute for Sustainability and Peace, and the University of Peradeniya, Sri Lanka. The main focus of the project is enhancing livelihoods of farmers and resilience of agriculture production systems against global change by building a mosaic system of traditional and modern irrigation systems.

2.1 INTRODUCTION

Asia is home to a number of traditional agricultural landscapes that have withstood climate variability and varied societal changes for over thousand years. Their sustainability is due to high degree of resilience that is brought about by integrated resource management, maintenance of material cycles, supporting a variety of societal and ecosystems services, etc. However, the productivity of such systems is not high and it is difficult to support the modern day lifestyles by their agricultural output alone. On the other hand modern agricultural systems are highly productive and efficient to cater to high demands of present day populations and economic growth. However, these systems are highly optimized and run the risk of failure with changes to existing climate and ecosystems state. Is it possible to develop a framework to integrate the use and management of these two types of systems so that the total system resilience as well as productivity can be enhanced? This is the research question the project try address through a comparative study of 3 types of traditional and modern agriculture systems in three countries. The project, termed **CECAR-Asia** involves Sri Lanka, Indonesia and Vietnam. In Sri Lankan context, Sri Lankan ancient irrigation systems and Kandyan home gardens were selected to conduct the studies on strengthening social resilience and promote sustainable development of communities. In Indonesia CECAR-Asia focuses on Pekarangan -the traditional homegarden system and the Kebun-talun - the combinational system of forestation and the slash and burn cultivation system. In Vietnam the focus is on VAC system which is a combination of agriculture and livestock farming. After the compilation of traditional knowledge and technologies it is expected to see how modern scientific methods can complement these technologies for the rural development in target countries. A mosaic system consisting of modern and traditional systems is expected to improve overall resilience of the system and improve livelihoods to all farmers through the increases in productivity. Collection of traditional knowledge and technologies are expected be jointly done with the counterpart universities in the three countries; namely the University of Peradeniya Sri Lanka, Gadja Mada University in Indonesia and National University of Viet Nam in Hanoi.

2.2 METHODOLOGY

The study on enhancing resilience and productivity of irrigation systems is composed of three components.

GROUNDWATER IN NOTHERN PROVINCE IRRIGATION Investigation of ground water potential for irrigation needs for a diversified crop calendar and the options for ground water recharge

USE OF SHORT TERM RAINFALL FORECASTS Incorporating short-term rainfall forecasts for irrigation supply decision making in Mahaweli H using bulk water allocation system

MOSAIC OF TRADITIONAL AND MODERN IRRIGATION SYSTEMS Water allocation and water distribution mechanism study in the Deduru Oya system to identify optimal water allocation among traditional and modern systems and type of farmer organizations for managing in waster distribution.

In this paper, the first two items are only briefly mentioned where as more detailed description of the Mosaic System is made.

2.2.0.1 *Groundwater as a potential remedy to immediate water needs*

Kilinochchi district, located in the northern part of Sri Lanka, had lagged behind its development due to 30-year-armed-conflict.Poverty rate in the district is as much as 64% for entire district, which is unusually high rate considering 23% for national average (Asian Development Bank 2011). Nearly 60% of residents do not have safe water intake points for water for sanitation and drinking, and waterborne disease often occurs in the district. More and more returnees resettled after the ends in 2009 and the district starts to develop again. In the absence of functioning surface water distribution, ground water can play a major role in meeting the water demands of the returning population. The available estimates of annual water demand in the district stands at 333 million (m^3), and more than 99 per cent is utilized for agricultural usage (Amarasignhe et al. 1999).

Since there is no perennial river in the district, water supply is greatly dependent on the groundwater. However, groundwater investigation and development of groundwater in the district had not been implemented due to the war. IWMI (Amarasignhe et al. 1999) reported the water budget at district wise including the groundwater usage. This is very useful to analyze the current water usage in the district, but spatial data is more useful to consider the development plan for decision makers. This demand needs to be updated in light of the civil war and the recovery status. Therefore, estimating the groundwater potential spatially in the district by numerical modeling can be a significant contribution in planning sustainable development for the region. A groundwater modeling of the region has started under the CECAR Asia project to address this need. Estimates of how much water is available in Kilinochchi Area for sustainable development (the amount of water for environmental sustainability is set as 25 per cent of the potential groundwater storage according to the past studies (Panabokke and Perera 2005). Numerical modeling of ground water potential can help in investigating this limit too.

2.2.1 *Short term rain forecasts and Bulk water allocation in Mahaweli H*

The System H covers the area in the Kala Oya basin westwards up to the Anurdhapura - Puttalm road, on the North, the Kalawewa Right bank Yoda Ela (Nava Jayaganga) and on the South, the Left Bank Balaluwewa , Yoda Ela of Kalawewa - Usgala- Siyamblangamuwa Ganga right up to Rajangane served by its Left Bank Canal. Land under the Kandalama and Dambulu Oya reservoirs also fell within System H as also the older settlement areas in Rajangane, the Kagama-Kattiyawa and Usgala-Siyambalangamuwa (Mahaweli Authority of Sri Lanka, 2012).

Main focus of the research project in the area is the improvement of the water allocation in the rice farming systems using real time forecasts. Current success of the irrigation system in this areas is due to the participatory water management program where the Mahaweli development authority manage the macro-scale system and carryout bulk water allocation to farmer association, who are responsible for crop planning and farm level water distribution. Currently the water conservation efforts made by the farmer association is not rewarded as there is no water right recognition. With the use of weather forecasts, a further saving of water use may be possible and the water thus may be saved upstream and credited to those who made the savings possible later in the season or in the next season. The potential to improve water management using weather forecasts firstly, and secondly the introduction of incentives based on savings will be studies in this component. Figure 4 shows a sample rainfall forecasts at 4km resolution for the region.

2.3 MOSAIC OF TRADITIONAL AND MODERN IRRIGATION SYSTEMS

Deduru Oya the 6th largest river basin in Sri Lanka, originating from Matale Hills in west of Kandy, running most of its length through the North Western Province was selected for the study under the recommendation of the Irrigation Department. The river is 115km long and has a catchment area of 2623km^2. It has numerous tributaries and basin with a number of small and large tanks.

The main study will be focused in study area 3. A major irrigation scheme, Daduru Oya project is now underway in this region. The new irrigation reservoir will create new large rice farming area, feed a number of small scale ancient irrigation sytems and at the same time will carry out transboundary water supply irrigation systems further north. The figure **??** shows the reservoir location and the current dam construction with the construction of left and right hand feeder canals. The Deduru Oya reservoir with a basin area of 1400 km^2 receives an average annual rainfall of 1628 mm. The rainfall in

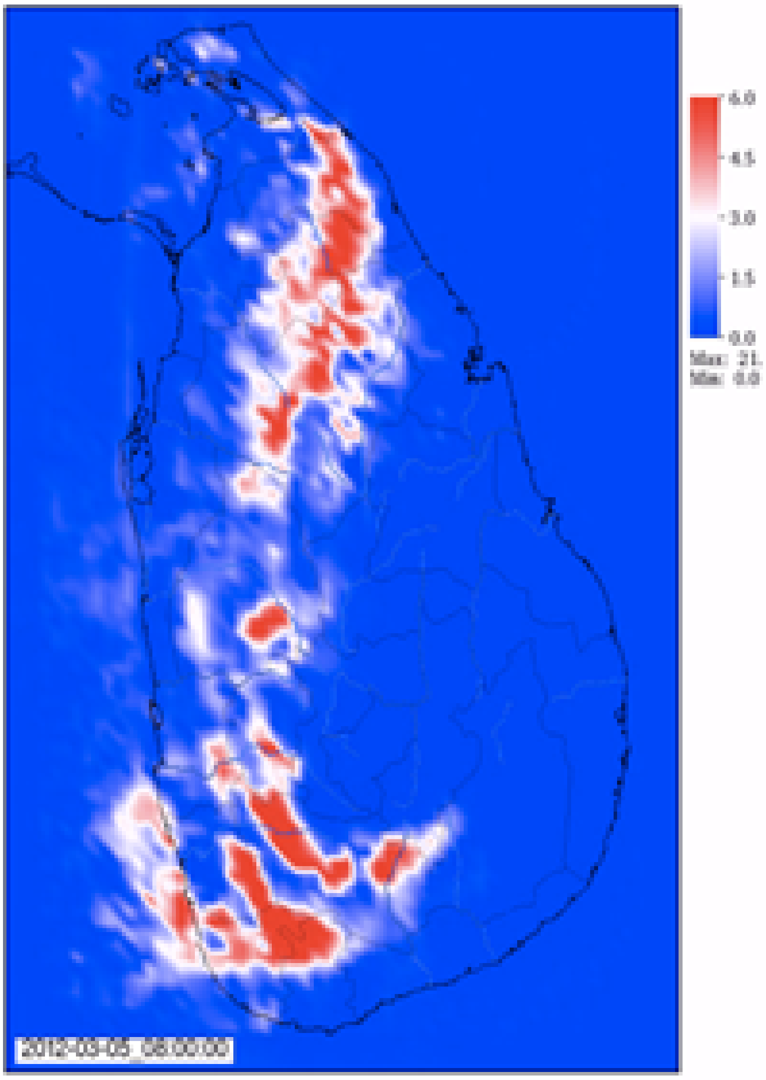

Figure 4: Rainfall forecasts at 4 km

the basin has a significant temporal variation and thus the flow in the Deduru Oya carry flash floods during rainy season and very low flow during dry season. Presently, it releases about 1600 MCM of water to the sea annually. It has several weirs across it to divert water for irrigation although there is no single major reservoir intercepting the Deduru Oya at present. There is need to store flood water carried by Deduru Oya for use during lean season especially for irrigation.

The Deduru Oya left bank (LB) canal which is being constructed under the Deduru Oya reservoir project will supply water to augment a large number of existing storage-based ancient irrigation systems in the left bank of the Deduru Oya. The multi-purpose Deduru Oya reservoir constructed across the Deduru Oya will have 75 MCM and the LB main canal starting from it will be 44.1 km long and will have a discharge capacity of about 7.1 m^3/s The proposed irrigable area under LB canal is about 3000 ha which includes existing 2400 ha of paddy under augmented existing irrigation systems and new 600 ha of Other Field Crops (OFC) by lift irrigation. RB canal is a trans-basin canal to augment water supply to Iginimitiya reservoir which is located in Mee Oya basin. Under Mee Oya basin it is proposed to develop 1000 ha of irrigable area along the trans-basin canal and 4115ha in the Mee Oya basin.

In addition, an area of 3000 ha is proposed under Ridi Bendi Ella scheme by regulating water supply from Deduru Oya reservoir (Table 1).

Table 1: Details of existing and proposed irrigable areas by Deduru Oya Reservoir (Pre-feasibility Report)

Canal	LB canal	RB canal	Ridi Bendi Ela	Total
Existing irrigable area(Ha)	2400	4715	2400	9515
Proposed irrigable area (Ha)	600	400	600	1600

Three study sites have been selected to carry out studies to understand issues related to mosaic management systems;

1. Independent modern system
2. Modern and Ancient Systems in parallel, but not connected
3. Ancient system fed by the modern system

The major components of the study are as follows.

1. Develop optimal water allocation plans/algorithms based on micro-macro hydrological and irrigation model
2. Assess and propose participatory water management arrangements for the above three types of irrigation systems with a strong emphasis on equity as the basis for resource management.
3. Assess the potential use of conjunctive groundwater resources to enhance livelihoods of farmer communities through vegetable and cash crop cultivation in upland.

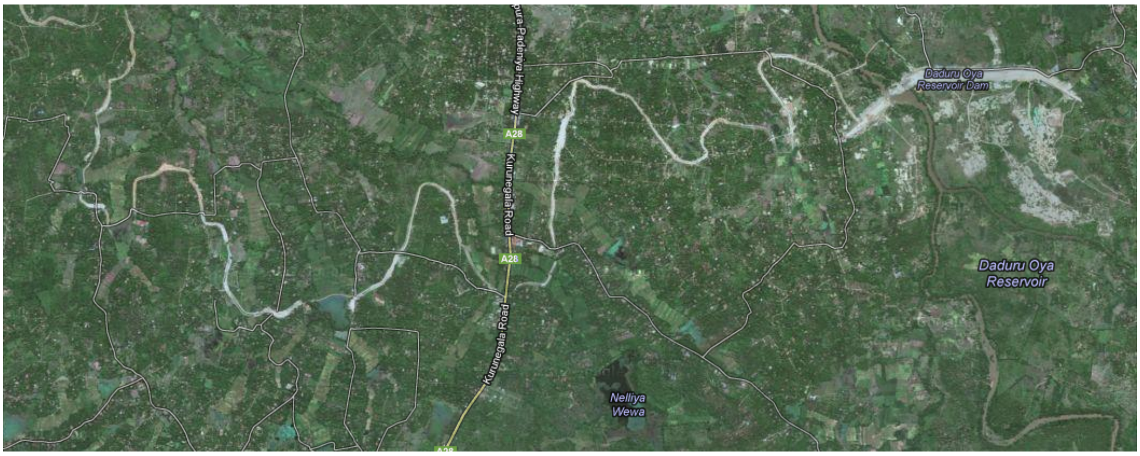

Figure 5: Feeding ancient irrigation tanks from the new system's feeder canals

2.3.1 *Inflow Estimation*

Hydrological Modeling System (HEC-HMS) developed by US Army corps of Engineers in USA was used for simulating inflows at existing small tanks in the development area under LB canal. For the calibration of the model Tittawella Wewa tank in Kurunegala district which has a catchment in the same ago-climatic region and hydrologically similar to the small tank catchments was used. The catchment area in Tittawella tank is 2.95 km^2 and the tank has a capacity of 0.31MCM. Daily observed hydro-meteorological data including rainfall and runoff are available for the period of May 1995 to March 1997 (Irrigation Department). Calibration and validation of the HEC-HMS model was performed using rainfall and runoff data of Jan 1996 to Dec 1996 and May 1995 to Dec 1997 periods respectively. After validation, calibrated model is applied for the study area to generate inflows to each small tank.

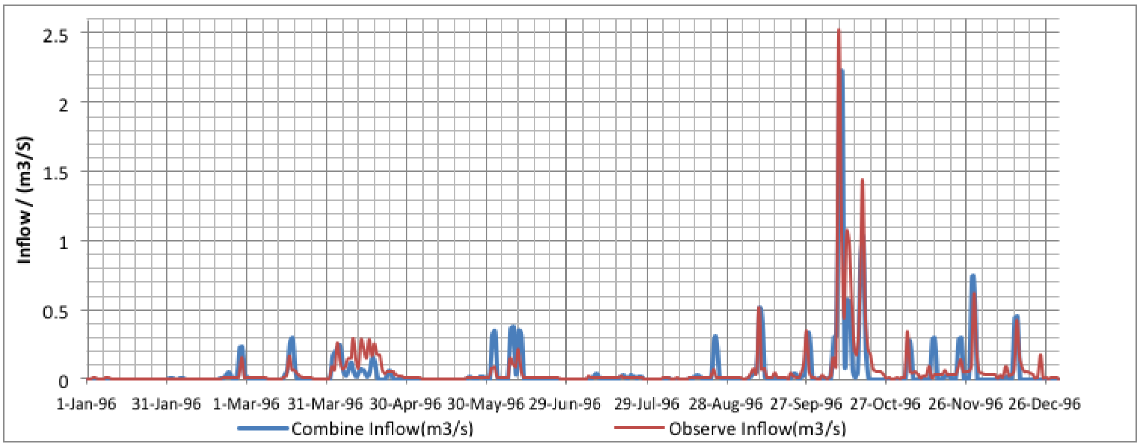

Figure 6: Calibration of Inflows

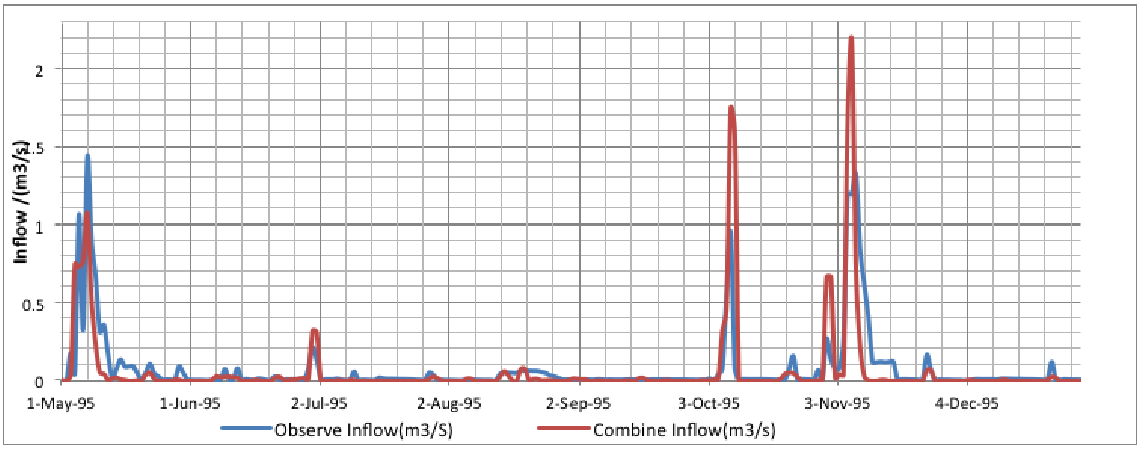

Figure 7: Validation of Inflows

2.3.2 *Demand Simulation*

Irrigable area under LB canal was lumped to 34 demand sites with small tank-based irrigable areas and directly fed irrigated areas according to the geographic distribution. The demand node distribution along the LB canal is shown in Figure 8. Current and future water supply demand status and water allocation for irrigation water requirements is evaluated under each demand sites. Water Evaluation And Planning (WEAP) model (developed by the Stockholm Environment InstituteÕs, U.S. Center) is used to investigate scenarios of cropping intensity improvements in the LB canal of Deduru Oya basin. LB canal is modeled as diversion links and analysis was carried out under two different scenarios of with and without LB canal. Irrigation water requirement was calculated assuming 105 day low land paddy will be cultivated. Rainfall data at Nikaweratiya station in year 1999, Mahailuppallama reference crop evapotranspiration rates and crop factors for each growth stages were used for the calculation of crop water requirements. Accordingly, computations of irrigation water requirements were made using 60% application efficiency and 75% conveyance efficiency. (Pre-feasibility study report of Deduru Oya and Mee Oya river basins Development Project). In order to understand the water requirements, 3 types of basic simulations were carried out as follows:

CURRENT STATUS Estimate unmet demand under the current conditions

FUTURE WITH ONLY THE DEDURU OYA RESERVOIR Estimate the deficit if the current small tank contribution is disregarded.

IRRIGABLE AREA UNDER MOSAIC SYSTEM Estimate the irrigation deficit under combined mosaic system.

The Figure 9 shows the unmet demand under current irrigation supply from the traditional small tank irrigation systems without the Deduru Oya scheme. Figure 10 shows that the proposed Deduru Oya scheme can meet the total irrigation demand for the year 1999 conditions even without the additionally of small tank systems. However, it should be noted that the assessment was done by summing up 157 different irrigation schemes to 34 major nodes where it was assumed the allocated water can be distributed in an efficient manner. Further studies on continuous simulation covering variability of rainfall and specific characteristics of each of the water demand node is necessary to understand the reliability of the irrigation water supply.

2.3.3 *Water Distribution*

A study was conducted to evaluate different equity aspects of modern jointly-managed major irrigation system of Bulk Water Allocation (BWA) implemented in Mahaweli H and a few locally-managed minor schemes in Deduru Oya Basin Area in order to draw mutual lessons. Intensive semi-structured interviews were carried out in both areas with relevant officers, farmer leaders and farmers of different gender, landholding status, landholding sizes and income whenever possible. Questions were designed along different equity aspects of rights, decision-making, water allocation, actual distribution of water, access to information, and conflict resolution. Water management institutions at different levels are found to face different equity issues. several water management guidelines were drawn as common lessons from both case studies, among which are measurable water entitlement that addresses heterogeneity, local capacity building that includes risk management, design and operation that addresses environmental sustainability, short term flexibility and long term adaptivity, mutual trust and relationship between service providers and users, and an integrated approach across horizontal and vertical levels. Analyzing irrigation systems along equity

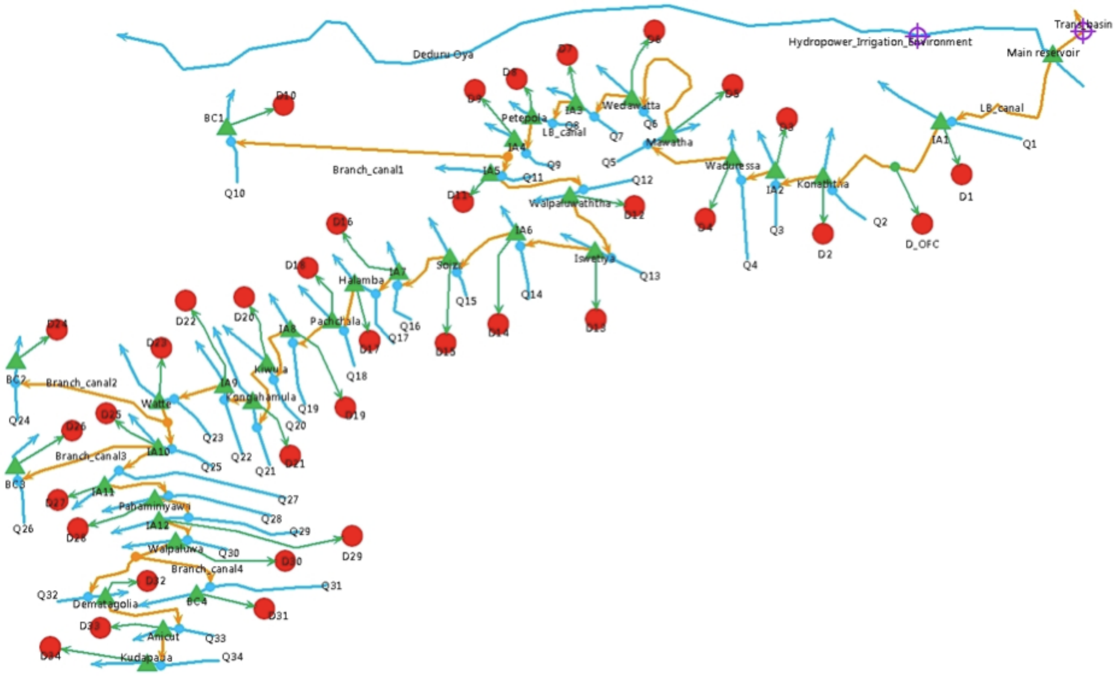

Figure 8: Configuration of LB canal and demand nodes

aspects is proven to be constructive and comprehensive in providing understanding for sustainable water management. It is also recognized that water management discourse is not meaningful by its own, but needs to be viewed and supported in an integrated manner with land, agricultural, environmental and even political issues.

The biggest difference between Mahaweli H and Deduru Oya Project area is that the former organize people to fit into physical structures while the latter construct physical structures to fit into existing social organization. The former is monotonous while the latter possess diversity in social structures. These existing social structures should be respected as they take the form today through accumulation of experiences and wisdom, catering to the environment they are situated in. Sustainability of these social organizations is time-proven, though it might seem to be less efficient or productivity-orientated than the modern system. The new project can bring new water

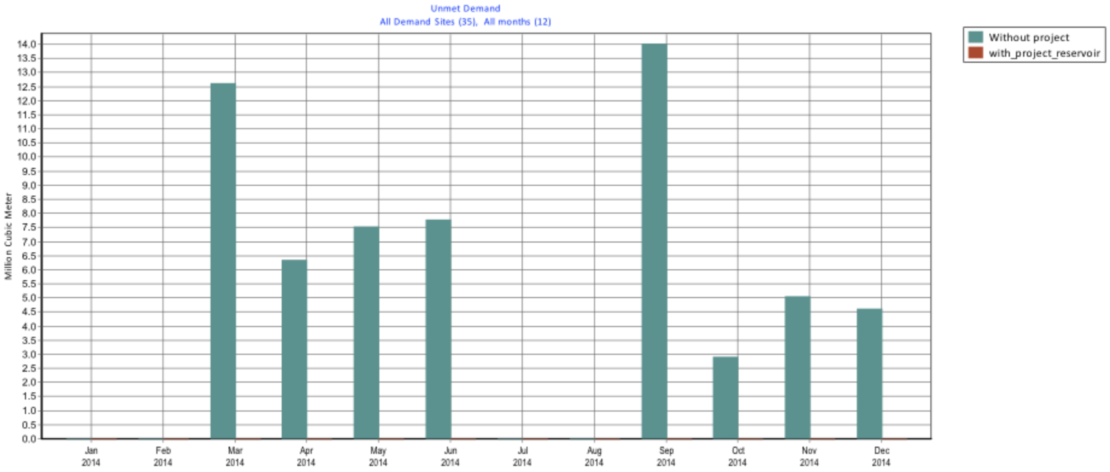

Figure 9: Unmet demand under current irrigation supply

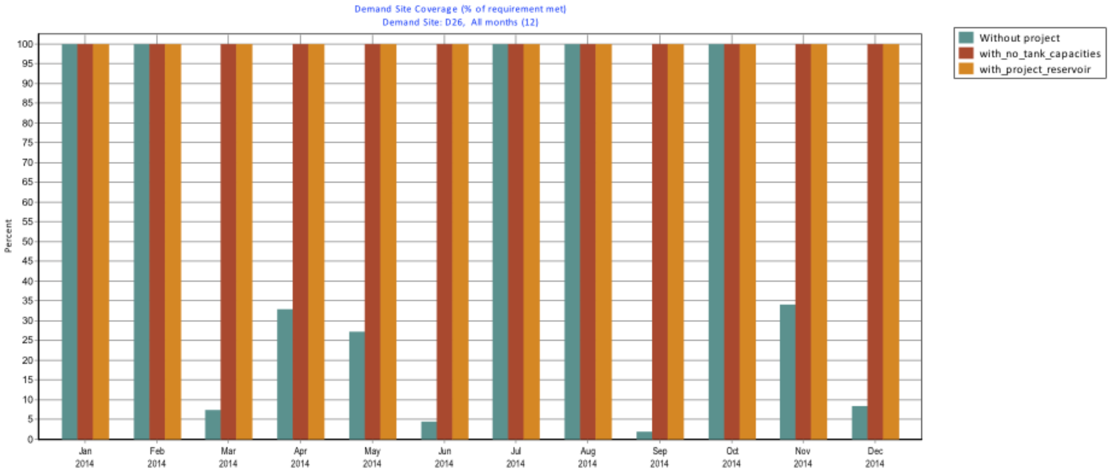

Figure 10: Irrigation water availability for the LB canal with the Deduru Oya Project

and new management concept to the area, but it should not aim to abolish or substitute established institution completely, especially those around tank villages.

It is also important to note that BWA is designed for canal irrigation, and thus not necessarily implementable in all schemes, as it needs to be supported with the right physical settings. Preliminary assessment suggests that BWA is unsuitable to be implemented in tank village schemes under level crossing in Deduru Oya Reservoir Project. For other non-tank schemes in the project rely solely on canal irrigation, BWA remains viable. However, BWA should first be pilot tested, evaluated by farmers, improved and retested before any meaningful conclusion can be made.

2.4 CONCLUDING REMARKS

This paper outlines an ongoing study that studies various facets of rural agriculture production systems, both modern and new, to find ways to incorporate resilience of traditional systems to reduce vulnerability of modern systems to global changes, especially climate change induced shocks. It is imperative that improving livelihoods should accompany environmental and social harmony.

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3

ASSESSING WATER SUPPLY AND DEMAND MANAGEMENT SCENARIOS IN DEDURU OYA RESERVOIR PROJECT, SRI LANKA

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ABSTRACT

Climate and Ecosystem Change Adaptation Research in Asia (CECAR-Asia) Project aims to enhance resilience of rural community by integrating traditional and modern agricultural systems. Deduru Oya Reservoir Project largely fits in the scopes of CECAR-Asia project by augmenting traditional irrigation tanks supply with reservoir water supplies. Decision support system tools can be effective for water allocation, supply and demand management analysis. In this research, Water and Evaluation Planning (WEAP) tool has been used as a decision support system tool to evaluate water supplies and demands in nearly completed Deduru Oya Reservoir Project System, Sri Lanka. The main objective of this study is to test the water balance under different management scenarios. Hydroclimatic, tank storages and crop data are based on field and office visits. A conceptual rainfall-runoff model, Simhyd, has been employed to generate tank inflows. Cropwat enabled to estimate irrigation water requirement for rice crops, the main agricultural water demand. Study results indicated that reservoir supply alone in normal climatic condition is well enough to meet all the water requirements. Optimal water allocations will lead nearly no water shortages in the Deduru Oya region with many fold increments in paddy crop production.

3.1 INTRODUCTION

Sri Lanka is well known for its hydraulic civilization. The history of irrigation in Sri Lanka goes back to more than two thousand years. Traditionally, people of Sri Lanka have largely depended on water from the small tank cascades for domestic and agricultural use. In recent years, these tanks are considered to be less effective due ethnic conflict and lack of maintenance. This has led to serious operational problems in many irrigation systems, the worse being the inability to irrigate the planned area. Rapid population growth, increasing agricultural water demands and climate change have posed additional challenges. Recently, attempts have been made to revive the traditional water resources systems. Government of Sri Lanka has been emphasizing on agricultural development through the renovation of traditional irrigation works (Godaliyadda et al, 1998). Many irrigation systems have been either rehabilitated or being rehabilitated to assure more reliable water supplies to farmlands. Deduru Oya Reservoir project is one of the several under-rehabilitation projects.

Deduru Oya (river) Basin is one of the major river basins of Sri Lanka Sri Lanka flowing through Kandy, Matale, Kurunegala and Puttalama Districts. The Deduru Oya basin has a catchment area of 2623 km^2 (Figure 11). The starting point of Deduru Oya is at the central mountains of the country and it falls out to the sea after traveling about 115 kilometers. The Deduru Oya has a number of tributaries and the basin contains a number of small and large tanks (Samarasinghe et al., 2000). Annual rainfall in Deduru Oya region varies from 1100 mm to 2600 mm (Figure 12). The rainfall pattern in the basin shows two clear peaks in the months of April/ May and October/November and the minima are in February and August. Evaporation in the area is averaged 1250 mm.

Farmers in Deduru and adjacent Mee Oya basins complain non-availability of an assured water supply for the agricultural areas. Large part of the agricultural land is paddy crops (Figure 13). The paddy is cultivated in the area adjacent to the water tank and related canal network which were constructed during the ancient time. Potential water resources in the basin are: direct rainfall, stream flow, surface (tanks) water storage and groundwater storage. Quantity of water availability varies spatially and temporally across the basin significantly. There are very low flows in the stream usually during January, February, July and August months. Surface water resources in Deduru Oya are highly influenced by the climatic pattern and topography (Figure 14). The water available with the rainfall and collected in the existing tanks is not sufficient for two season cultivation. Seventy percent of annual rainfall in the region flows to ocean without being utilized in any way to serve needs of the local population. As a result, an optimal level of agricultural development has not been achieved.

Deduru Oya reservoir project is aimed to exploit the Deduru Oya water resources in improving the cropping intensity of existing agricultural lands under tank irrigation systems and developing new agricultural lands in the Mee Oya and the Deduru Oya basins in view of enhancing productivity (Figure 15). The project, on completion, with about 45 km long left bank main canal, 33 km long right bank transbasin canal and 27 km long branch canals will be able to irrigate over 11,115 ha (Table 2). The proposed dam site with a catchment area of 1400 km^2 is located about 300 meters upstream of the existing Ridi Bendi Ella anicut. The Project envisages construction of a 75 MCM reservoir with two sluices and eight radial gated spillways. The 2.4 km long earthen dam with full supply level of 70m above mean sea level will result inundation of 2000 ha land.

CECAR-Asia, a research project on climate and ecosystem change adaptation, aims to study resilience enhancement that can be brought about by integrating traditional and modern agricultural systems. Developing and testing of water supply and demand management scenarios for under-construction Deduru Oya Reservoir project is one of the research focuses. This is important for the improvement of food security and livelihoods in the region as the traditional irrigation tanks in recent decades have been less effective in meeting the increasing irrigation water demands. Additionally, the project will have a hydropower plant with 1.5 MW downstream of dam site. This study explored on balancing the water supplies and demands through alternative water allocation arrangements.

Figure 15-16 provides a schematic view of different elements of the Deduru Oya water management systems. Major water demand consists of paddy

Components	Irrigable area(ha)		
	Exsisting	Proposed	Total
Daduru Oya basin			
LB canal	2400	300	2700
Ridibendi Ella(D/S)	2400	600	3000
RB canal	1000	300	1300
Mee Oya basin using transbasin canal			
Iginimitiya	2640	0	2640
Radavi Bendi ela	210	400	610
Tabbowa tank	865	0	865
Total	9515	1600	11115

Table 2: Details of existing and proposed irrigation area under Deduru Oya Reservoir Project

crop irrigation water, hydropower and environmental requirements. Cropwat, a decision support tool developed by the Land and Water Development Division of FAO, has been employed for the calculation of paddy crop irrigation water requirements. Hydropower station of 1.5 MW (3 units of 0.5 MW capacity) which will be located just downstream of the reservoir use irrigation and environmental release from the proposed reservoir. According to feasibility study project report, a discharge of 7 m^3/s will be necessary to be released for the generation of 1.5 MW hydropower. Flow requirements for environmental use have been based on literature review. Direct rainfall, tank storages and Deduru Oya flows are water supply elements. Field and office visits helped to collect data on hydroclimatology, tank systems and farmlands. A conceptual rainfall runoff model, SimHyd, was employed to estimate inflows to the ancient tanks. Deduru Oya inflows at dam site are based on project feasibility study report. Finally, water evaluation and planning (WEAP), an integrated water resources management tool, was employed to assess the water supply and demand management scenarios for the Deduru Oya Reservoir Project systems.

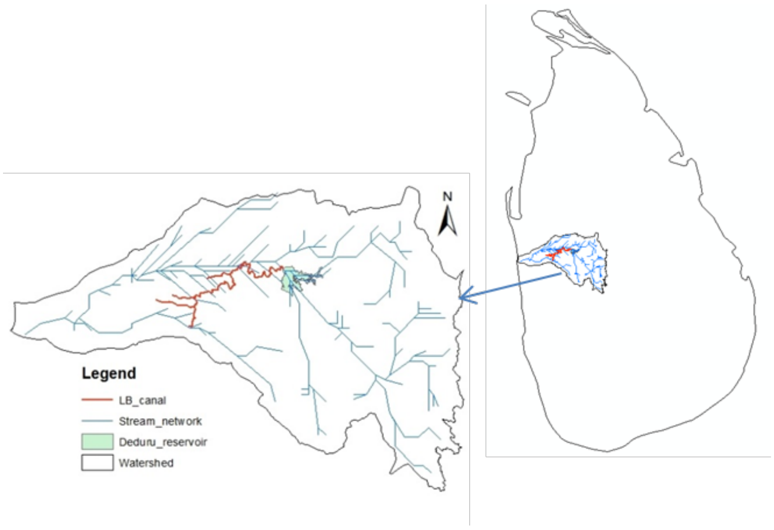


Figure 11: Location of Deduru Oya basin

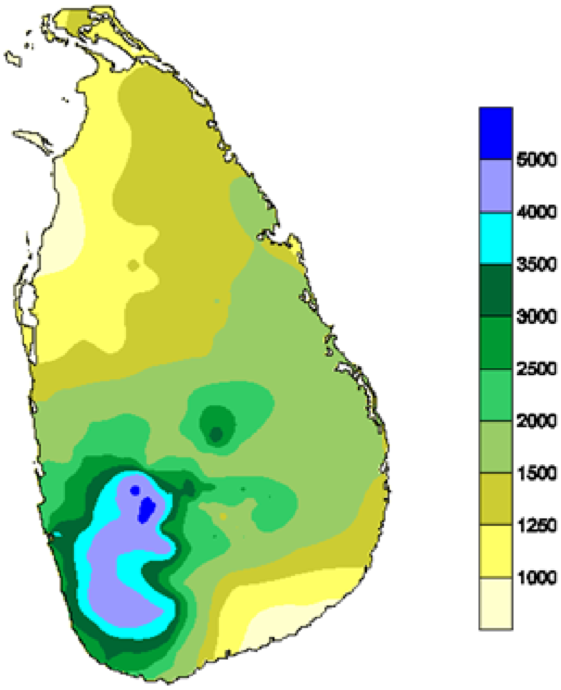


Figure 12: Annual rainfall in Sri Lanka (Source: Department of Meteorology, Sri Lanka)

3.2 ENVIRONMENTAL FLOW REQUIREMENT

There is an increasing awareness of the need to release some minimum water along a river to ensure the continued functioning of ecological process that provide much needed goods and services for human use and maintenance of biodiversity. Water which is allocated and made available for maintaining ecological processes in a desirable state is referred as the instream flow requirement, environmental flows, or environmental flow requirement. The allocation of water to satisfy environmental uses initially developed out of the need to release from dams minimum flows to ensure the survival of often a single aquatic species with high economic value. However, the provision of environmental flows that attempt to preserve natural flow characteristics such as timing, frequency, duration and magnitude of flows is considered important for the sustenance of fresh water ecosystems, since the flow regime is one of the major drives of ecological processes on a river. The practice of environmental flow requirement began as a commitment to ensuring a 'minimum flow' in the river, often arbitrarily fixed at 10% of mean annual runoff (World Commission on Dams, 2000). However, this 'minimum flow' approach may not be appropriate for safeguarding essential downstream environmental conditions of the river system. In this study, a minimum of 10% normal climatic year monthly river discharge has been ensured as environmental flow requirement for testing the water supply and management scenarios.

3.3 IRRIGATION WATER REQUIREMENT

Calculation of irrigation water requirement needs crop, climate and soil datasets of the study area. Paddy (rice) is the main crop in the region

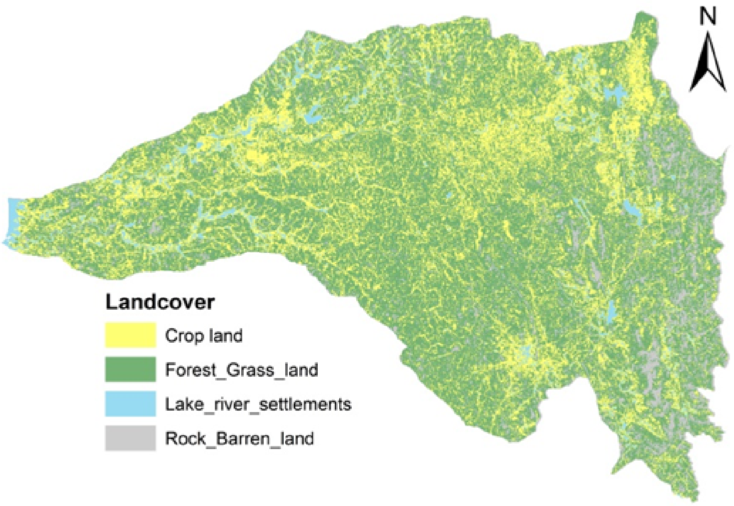


Figure 13: Land cover map based on 30m Landsat satellite imagery

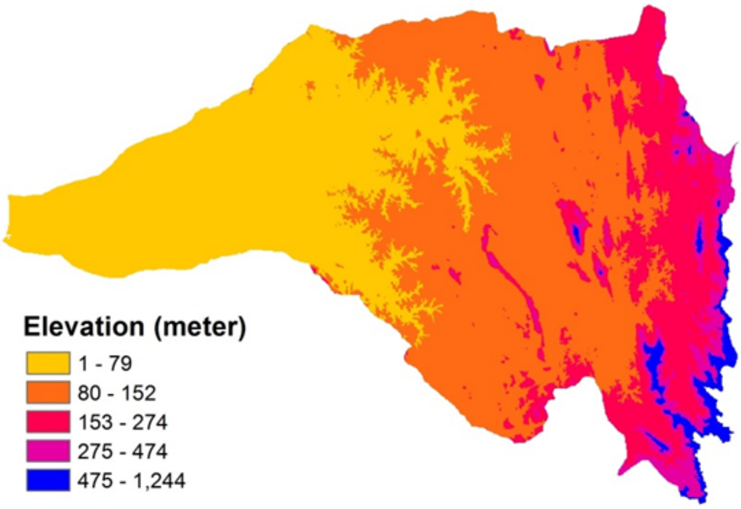


Figure 14: Digital Elevation model based on 90m SRTM data

accounting for most of the agricultural water demand. The climatic data includes reference evapotranspiration and rainfall. This study used the Cropwat model by FAO Land and Water Development Division for calculation of irrigation water requirement. The irrigation water requirement is defined as the difference between the crop water requirements and the effective rainfall (FAO, 1998). The primary objective of irrigation is to apply water to maintain crop evapotranspiration when rainfall is insufficient. Crop water requirements (CWR) refers to the amount of water required to compensate for the evapotranspiration loss from the cropped field. Estimation of the crop CWR is derived from crop evapotranspiration (crop water use) which is the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc). The climatic data (ETo and rainfall) used for the calculations of IWR is based on Batalagoda station (Dharmarathna et al., 2011). Information on soil data is based on textural properties ISRIC-WISE global soil data (Batjes, 2008). The soils in the area are predominantly coarse textured, ranging from loamy to sandy loam in the surface horizons and from sandy loam to clay in the subsurface horizon. Red loamy soil type was assumed for the study area after reviewing textural information and ’preliminary assessment of surface water

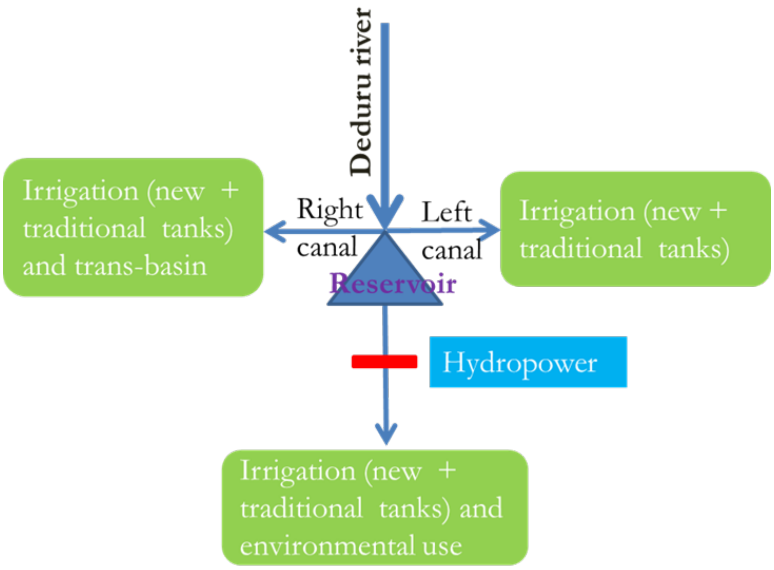


Figure 15: Schematic diagram of Deduru Oya Reservoir Project system

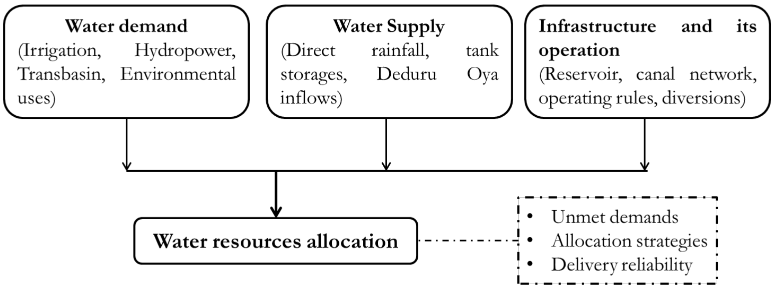
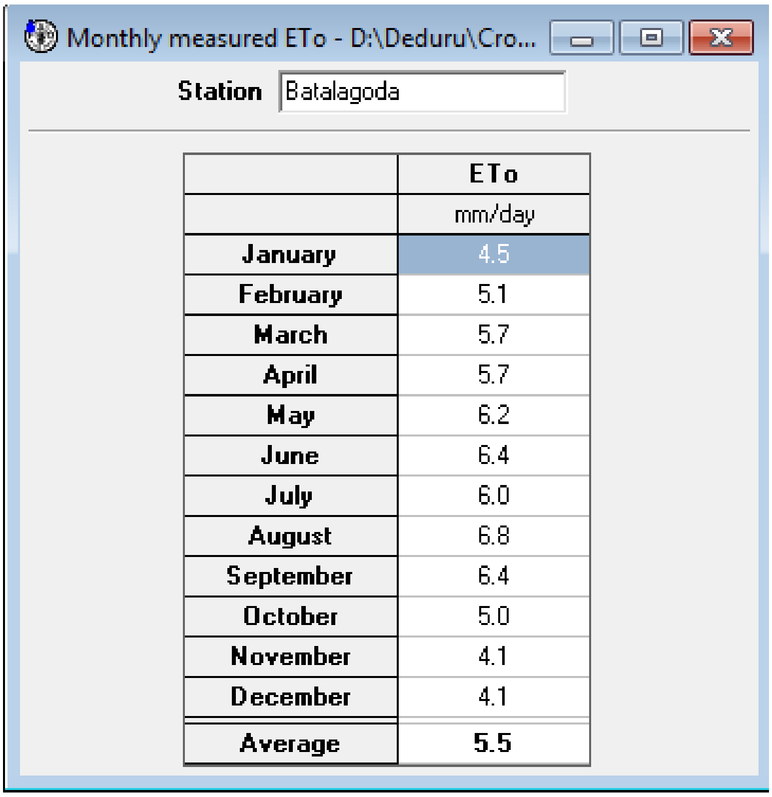


Figure 16: Schematic of water supply and demand management

resources' by Wickramaarachchi (2004). Soil parameters are based on the standard values for Red loamy soil in the Cropwat model sample data sets. Calculation of IWR at scheme level for a given year is the sum of individual CWR calculated for each irrigated crop. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing CWR for each cropping period. Calculation of scheme IWR has been illustrated using Table 3-8 in Cropwat model windows. Annual irrigation water requirement with system efficiency 0.5 (application efficiency 0.7 × conveyance efficacy 0.7) and 0.6 was found to be 24354 and 20295 cubic meter per hectare respectively. Monthly variation of the irrigation water is shown in Figure 17. Total irrigation demands in left, right and downstream side is presented in Table 9.

3.4 INFLOWS ESTIMATION TO ANCIENT TANKS

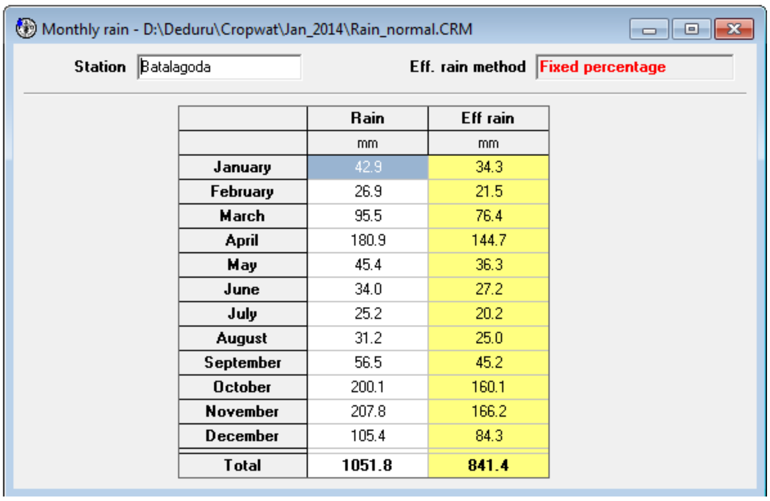
SimHyd, a conceptual rainfall runoff model, was used to simulate daily inflows towards to the left bank ancient tanks (Figure 18). SimHyd model has been extensively used for various applications (Podger, 2004; Chiew and Siriwardena, 2005). The SymHyd model is a component of the rainfall-runoff library (RRL) produced by Cooperative Research Centre for Catchment Hydrology, Australia. The structure of SimHyd and the algorithms describing water movement into and out of the storages are shown in Figure 19. In this



Station: Batalagoda

	ETo
	mm/day
January	4.5
February	5.1
March	5.7
April	5.7
May	6.2
June	6.4
July	6.0
August	6.8
September	6.4
October	5.0
November	4.1
December	4.1
Average	5.5

Table 3: Reference evapotranspiration at Batalagoda climate station

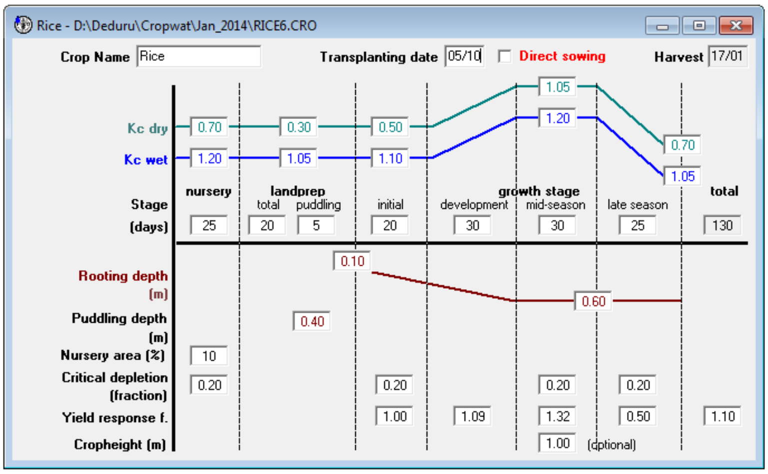


Station: Batalagoda

Eff. rain method: Fixed percentage

	Rain	Eff rain
	mm	mm
January	42.9	34.3
February	26.9	21.5
March	95.5	76.4
April	180.9	144.7
May	45.4	36.3
June	34.0	27.2
July	25.2	20.2
August	31.2	25.0
September	56.5	45.2
October	200.1	160.1
November	207.8	166.2
December	105.4	84.3
Total	1051.8	841.4

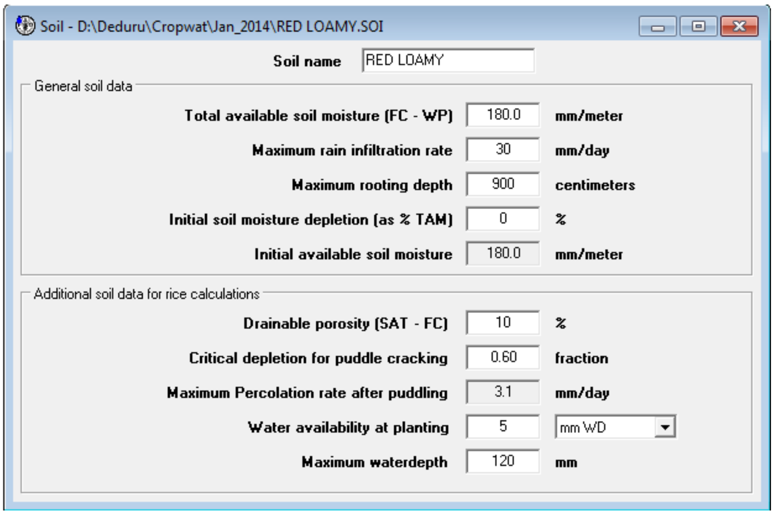
Table 4: Monthly normal rainfall and effective rainfall after surface run off and deep percolation at Batalagoda climate station



Crop Name Rice **Transplanting date** 05/10 ☐ **Direct sowing** **Harvest** 17/01

	nursery	landprep total	landprep puddling	initial	development	mid-season	late season	total
Kc dry	0.70	0.30		0.50		1.05	0.70	
Kc wet	1.20	1.05		1.10		1.20	1.05	
Stage (days)	25	20	5	20	30	30	25	130
Rooting depth (m)				0.10		0.60		
Puddling depth (m)		0.40						
Nursery area (%)	10							
Critical depletion (fraction)	0.20			0.20		0.20	0.20	
Yield response f.				1.00	1.09	1.32	0.50	1.10
Cropheight (m)						1.00	(optional)	

Table 5: Details on different stages of rice crop growth



Soil name RED LOAMY

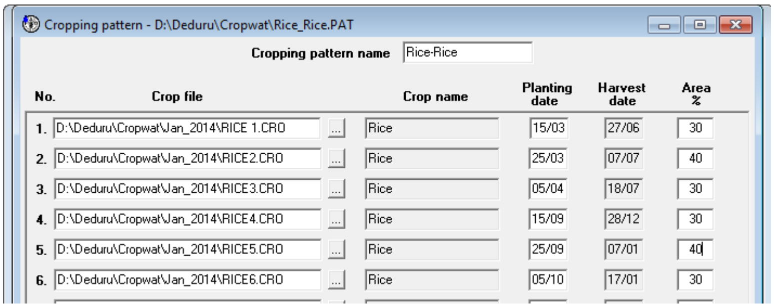
General soil data

Total available soil moisture (FC - WP)	180.0	**mm/meter**
Maximum rain infiltration rate	30	**mm/day**
Maximum rooting depth	900	**centimeters**
Initial soil moisture depletion (as % TAM)	0	**%**
Initial available soil moisture	180.0	**mm/meter**

Additional soil data for rice calculations

Drainable porosity (SAT - FC)	10	**%**
Critical depletion for puddle cracking	0.60	**fraction**
Maximum Percolation rate after puddling	3.1	**mm/day**
Water availability at planting	5	mm WD
Maximum waterdepth	120	**mm**

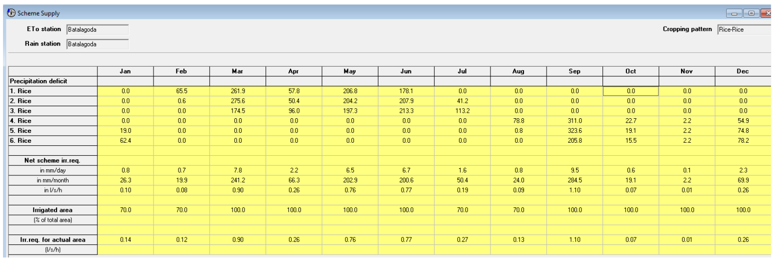
Table 6: Soil parameters as in FAO



Cropping pattern name Rice-Rice

No.	**Crop file**	**Crop name**	**Planting date**	**Harvest date**	**Area %**
1.	D:\Deduru\Cropwat\Jan_2014\RICE 1.CRO	Rice	15/03	27/06	30
2.	D:\Deduru\Cropwat\Jan_2014\RICE2.CRO	Rice	25/03	07/07	40
3.	D:\Deduru\Cropwat\Jan_2014\RICE3.CRO	Rice	05/04	18/07	30
4.	D:\Deduru\Cropwat\Jan_2014\RICE4.CRO	Rice	15/09	28/12	30
5.	D:\Deduru\Cropwat\Jan_2014\RICE5.CRO	Rice	25/09	07/01	40
6.	D:\Deduru\Cropwat\Jan_2014\RICE6.CRO	Rice	05/10	17/01	30

Table 7: Cropping pattern for a year



ETo station Batalagoda **Cropping pattern** Rice-Rice
Rain station Batalagoda

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Rice	0.0	65.5	261.9	57.8	206.8	178.1	0.0	0.0	0.0	0.0	0.0	0.0
2. Rice	0.0	0.6	275.6	50.4	204.2	207.9	41.2	0.0	0.0	0.0	0.0	0.0
3. Rice	0.0	0.0	174.5	96.0	197.3	213.3	113.2	0.0	0.0	0.0	0.0	0.0
4. Rice	0.0	0.0	0.0	0.0	0.0	0.0	0.0	78.8	311.0	22.7	2.2	54.9
5. Rice	19.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	323.6	19.1	2.2	74.8
6. Rice	62.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	205.8	15.5	2.2	78.2
Net scheme irr.req.												
in mm/day	0.8	0.7	7.8	2.2	6.5	6.7	1.6	0.8	9.5	0.6	0.1	2.3
in mm/month	26.3	19.9	241.2	66.3	202.9	200.6	50.4	24.0	284.5	19.1	2.2	69.9
in l/s/h	0.10	0.08	0.90	0.26	0.76	0.77	0.19	0.09	1.10	0.07	0.01	0.26
Irrigated area	70.0	70.0	100.0	100.0	100.0	100.0	70.0	70.0	100.0	100.0	100.0	100.0
(% of total area)												
Irr.req. for actual area	0.14	0.12	0.90	0.26	0.76	0.77	0.27	0.13	1.10	0.07	0.01	0.26
(l/s/h)												

Table 8: Scheme irrigation water requirements

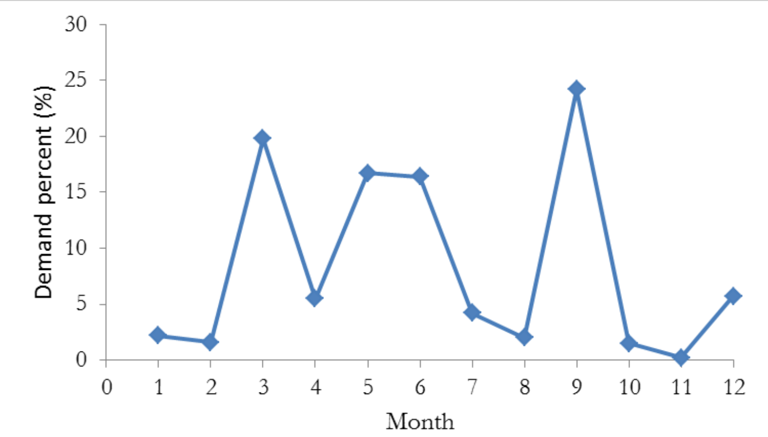


Figure 17: Monthly variation of the irrigation water requirements

	Irrigation water requirement					
Month	m3/ha	Monthly variation (%)	Left bank for 2700 ha in m3/s	Right bank for 1300 ha inside Deduru basin in m3/s	Transbasin to Mee Oya basin for 4115 ha in m3/s	Downstream for 3000 ha in m3/s
Jan	536	2.2	0.540323	0.260155	0.8234916	0.60035842
Feb	387	1.6	0.43192	0.207961	0.6582775	0.47991071
Mar	4821	19.8	4.859879	2.339942	7.4068156	5.39986559
Apr	1348	5.5	1.404167	0.67608	2.140054	1.56018519
May	4071	16.7	4.103831	1.975918	6.2545419	4.55981183
Jun	3992	16.4	4.158333	2.00216	6.337608	4.62037037
Jul	1018	4.2	1.02621	0.494101	1.5640196	1.14023297
Aug	482	2	0.485887	0.233946	0.7405279	0.53987455
Sep	5892	24.2	6.1375	2.955093	9.3540046	6.81944444
Oct	363	1.5	0.365927	0.176187	0.5577005	0.40658602
Nov	52	0.2	0.054167	0.02608	0.082554	0.06018519
Dec	1393	5.7	1.404234	0.676113	2.1401564	1.56025986

Table 9: Total irrigation water requirements in left, right and downstream schemes

model, daily rainfall first fills the interception store which is emptied each day by evaporation. The excess rainfall is then subjected to an infiltration function that determines the infiltration capacity. The excess rainfall that exceeds the infiltration capacity becomes infiltration excess runoff. Moisture that infiltrates is subjected to a soil moisture function which diverts the water to the stream (interflow), groundwater store (recharge) and soil moisture store.

Calibration and validation of the rainfall-runoff model was carried out using hydroclimatic data at Tittawela tank. The Tittawela tank has drainage area of 2.95 km2. Calibration of the model was performed over the period 1995/05/01 to 1995/12/31. The model performance is illustrated by comparing observed daily and simulated daily stream flow values over the period 1996/01/01 to 1997/03/31. The performance correlation between modeled and observed daily flow is shown in Figure 20-21. The calibrated/validated rainfall-runoff model enabled generation of daily inflows to the ancient tanks using respective drainage area and climatic data. Thiessen polygon technique has been used for estimating coverage areas of different rainfall stations in left bank canal side (Figure 22). The model possesses both manual as well as automatic optimization facilities for parameter calibration. In this study, SCE-UA (shuffled complex evolution university of Arizona) option was selected for carrying automatic optimization. The Nash-Sutcliffe coefficient (E) of efficiency was used as a measure of the model performance (Nash and Sutcliffe, 1970). The E value describes agreement between all modeled (Qm) and observed (Qo) runoffs, with E=1.0 indicating that all the modeled runoffs are same as the recorded runoffs (Equation 1). The Nash Sutcliffe coefficient for the calibration and validation was found as 0.93 and 0.69 respectively.

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_0^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_0^t - Q_0^t\right)^2} \tag{1}$$

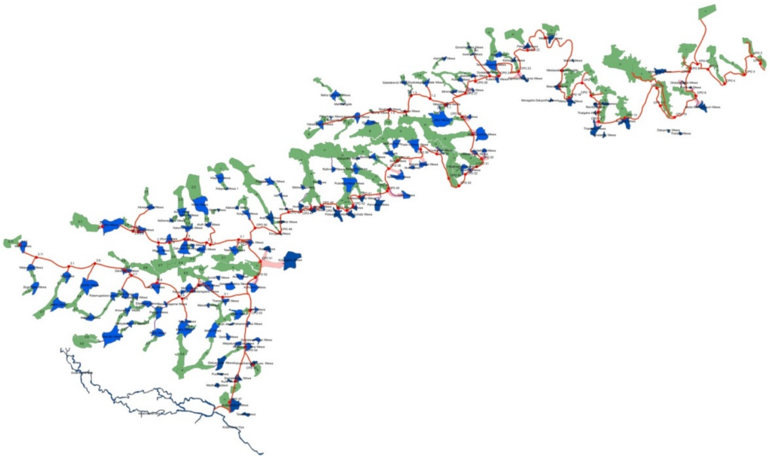


Figure 18: Ancient tanks and their irrigation areas along the Left Bank Canal network

3.5 WATER BALANCE

Water balance is necessary to be made for detecting the condition of water demand and available discharge at the intake. Analysis of water balance is usually based on normal (mean) and 80% (wet) flow (Juwono1 et al., 2012). Normal and dry year corresponds to the amount of flow with 50% and 80probability of exceedance respectively. Monthly normal and dry flow in Deduru Oya near reservoir site for the period of 1970-1995 has been estimated for developing and testing the water supply and demand management scenarios for normal and extreme drought conditions (Figure 23). Comparison of water surplus and deficit based on normal and 20% reliable monthly flow in the Deduru Oya Reservoir Project system is presented in Table 10.

3.6 WATER SUPPLY AND DEMAND MANAGEMENT SCENARIO ANALYSIS

There are several tools which are designed to assess water supply and demand management in river basins. WEAP model was preferred because

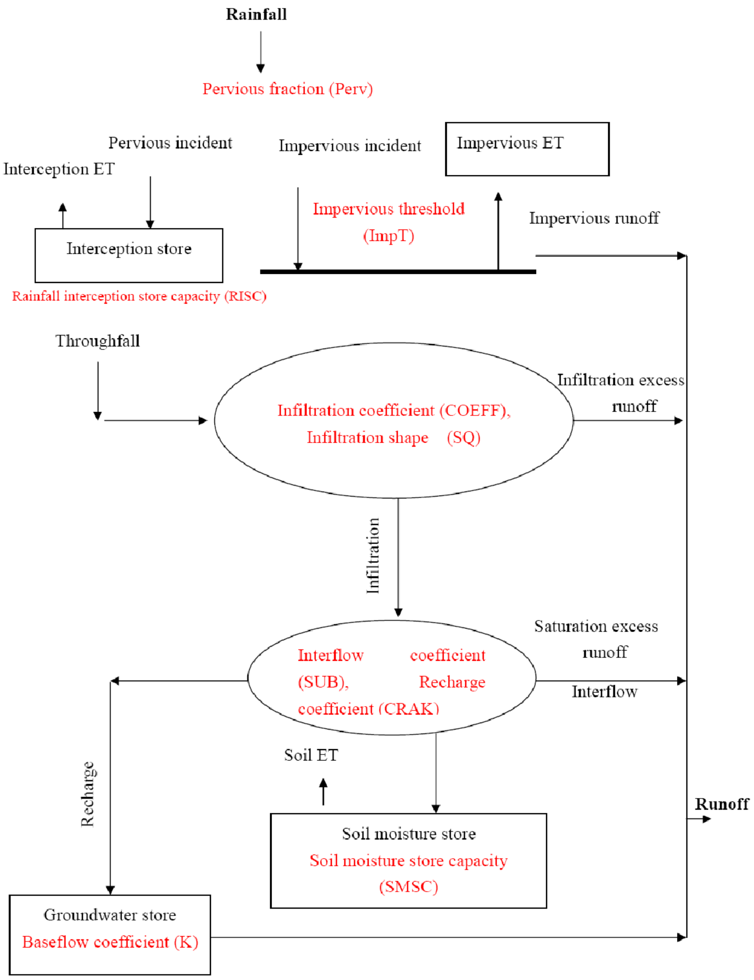


Figure 19: Structure of SimHyd rainfall-runoff model

of its robustness and ease of use for developing and testing the water supply and demand management (Hussein and Weshah, 2009; Holf et al., 2007) . The WEAP model is GIS based integrated water resources management tool that integrates different water supplies and demands at catchment scale. WEAP was developed by the Stockholm Environment Institute. The WEAP model uses the basic principle of water balance accounting. WEAP represents a particular water system, with its main supply and demand nodes and the links between them, both numerically and graphically. Users specify allocation rules by assigning priorities and supply preferences for each node; these preferences are changeable, both in space and time. WEAP then employs a priority-based optimization algorithm and the concept of equity groups to allocate water in times of shortage. The simplicity of representation means that different scenarios can be quickly set up and compared and it can be operated easily. Water allocation to demand sites is done through linear programming solution. Therefore demand site satisfaction is maximized subject to the mass balance, supply preferences, demand priority and other constraints. Figure 24 shows schematic view of study area at WEAP platform.

Scenario analysis enables to answering of 'what if' questions such as: what unmet demands can be expected if current trends are projected into the future?; What alternative allocations could be?; How should reservoirs be operated? The following scenarios were created for developing and testing water supply demand management scenarios:

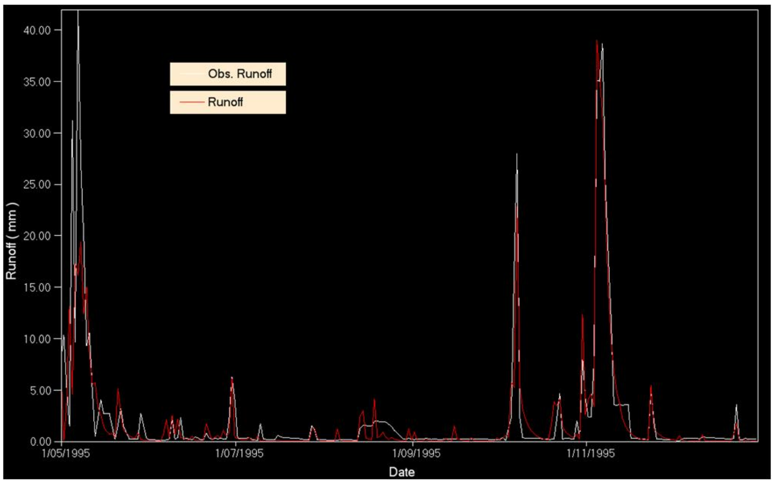
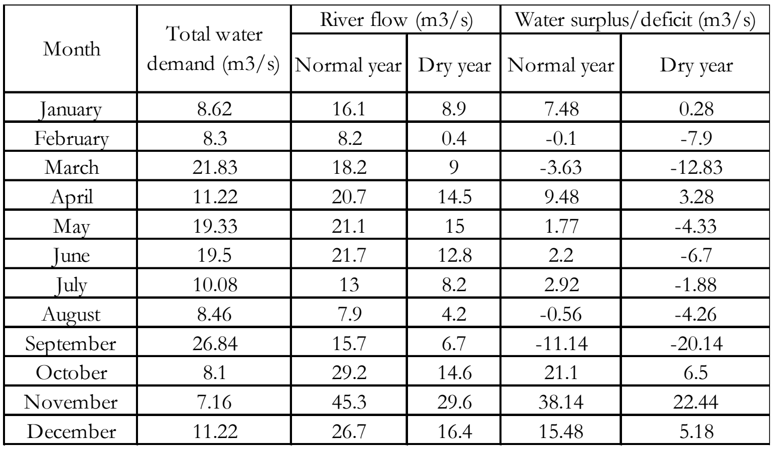


Figure 20: Comparison of observation and simulation daily runoff over calibration periods



Month	Total water demand (m3/s)	River flow (m3/s)		Water surplus/deficit (m3/s)	
		Normal year	Dry year	Normal year	Dry year
January	8.62	16.1	8.9	7.48	0.28
February	8.3	8.2	0.4	-0.1	-7.9
March	21.83	18.2	9	-3.63	-12.83
April	11.22	20.7	14.5	9.48	3.28
May	19.33	21.1	15	1.77	-4.33
June	19.5	21.7	12.8	2.2	-6.7
July	10.08	13	8.2	2.92	-1.88
August	8.46	7.9	4.2	-0.56	-4.26
September	26.84	15.7	6.7	-11.14	-20.14
October	8.1	29.2	14.6	21.1	6.5
November	7.16	45.3	29.6	38.14	22.44
December	11.22	26.7	16.4	15.48	5.18

Table 10: Comparison of surplus/deficit water in normal and dry climatic year

- Tanks only for two cultivation season (Figure 25-26): Graphs of coverage and unmet water demands point out that most tank supplies alone are not able to meet the two season irrigation water requirements. Water shortages occur in the month of March, May, June and September.

- Tanks only with single Maha season cultivation (Figure 27-28): Excluding few tanks, most of tanks are able to meet Maha season irrigation water requirements. Water shortage occurs for some of the tanks in September. However, tanks with full demand coverage are more than 75%.

- Reservoir supply only (Figure 29): Reservoir supply in normal climatic year is well enough to meet all the irrigation, hydropower and environmental flow requirements.

- Tanks and reservoir supply with normal climate year inflows: obviously well enough to meet all the water demands.

- Tanks and reservoir supply with dry climatic year inflows (Figure 30): In dry climatic year, tanks and reservoir supplies are not well enough to meet the all the water demands. Alternative water allocations need to be considered. Water shortage occurs in the month of September.

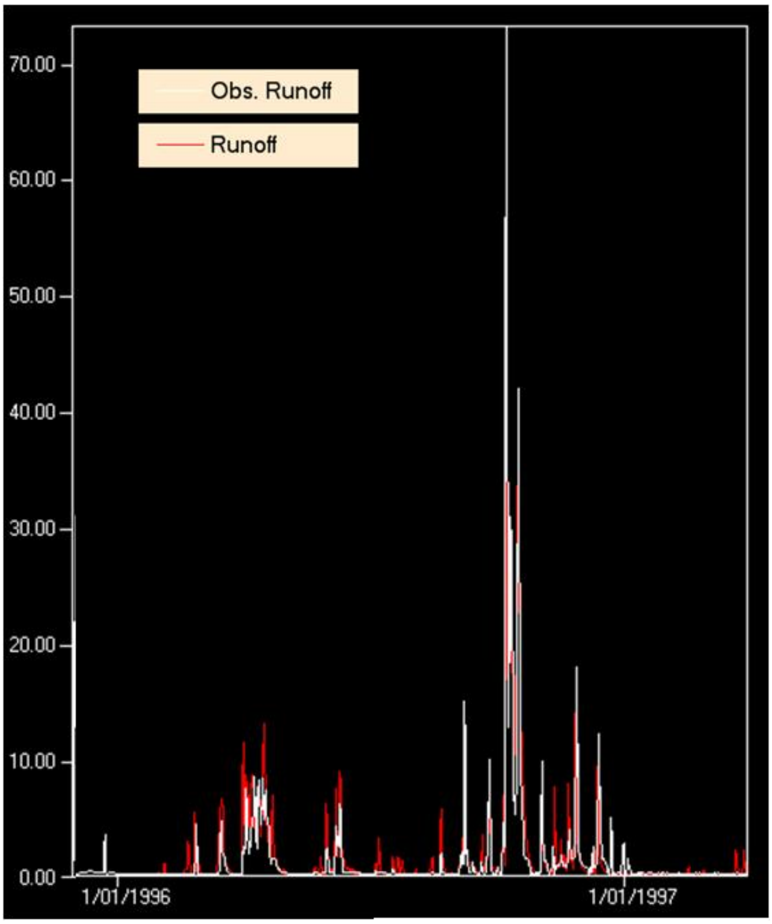


Figure 21: Comparison of observation and simulation daily runoff over validation periods

- Tanks and reservoir with dry year climatic inflows and improved system efficiency (Figure 30): This scenario was modelled to assess the impact of improved irrigation efficiency. Water saving by minimizing conveyance and application losses will enable tanks and reservoir to meet all water demands largely. With increased water saving in tanks (i.e. allocating higher priorities for tank filling in months other than September) for the use in September other months than September, there will be nearly zero water shortages.

3.7 CONCLUSIONS

The main goal of this study is to evaluate water supply and demand management scenarios using WEAP model for the ongoing Deduru Oya Reservoir project. WEAP results reveal that traditional tanks are highly important to meet the water shortages in the dry climatic year. Existing tanks with larger storage than demands can be used to supplement other tanks. Additionally, water loss reductions and optimal reservoir operation with alternative water demand priorities and allocations can play important role to meet water shortages in dry climatic year. Accurate data is important to perform such analysis. Cropwat model successfully enabled to estimate rice crop irrigation water requirement. The estimated irrigation water requirement was found to be similar to that of Sri Lankan counterpart. Alternative agricultural practice (e.g., plantation time) can help in addressing unmet demands. A conceptual

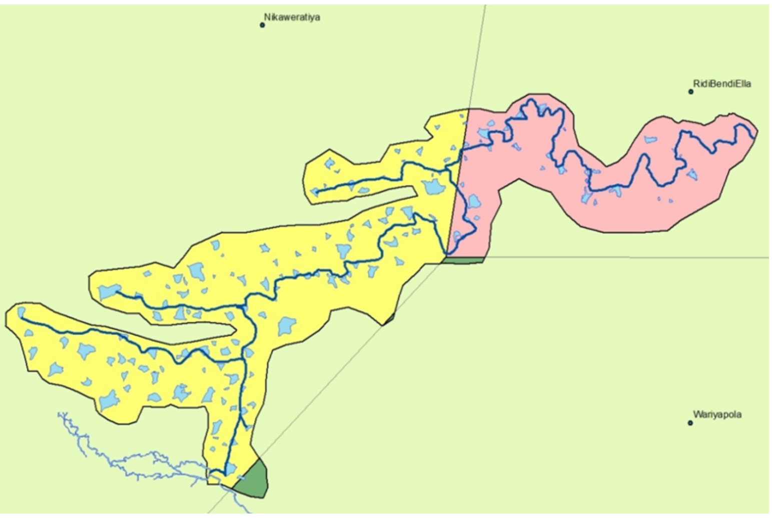


Figure 22: Thiessen polygons for estimating rainfall coverage area over the LB canal region

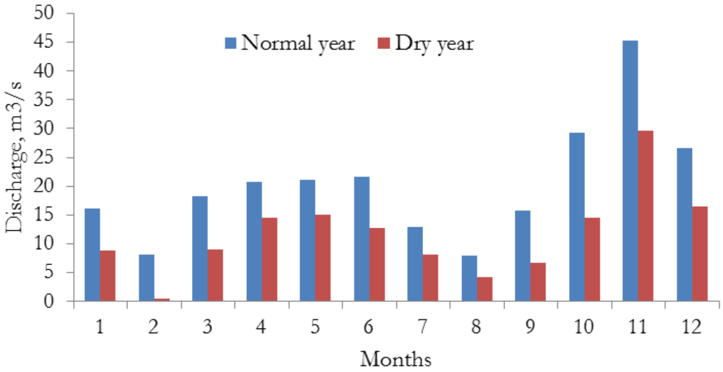


Figure 23: Deduru Oya flow near reservoir during normal and dry climatic year

rainfall-runoff model, Simhyd, enabled generation of tank inflows. Calibration and validation results indicated that the modelled results were good. However, the model can perform better with availability of long observation hydroclimatic data.

The Deduru Oya Reservoir project with optimal water allocation will resolve water scarcity problems. With the completion of the Deduru Oya reservoir project, paddy cultivation will be increased by many folds. The productivity of not only paddy but also other highland crops, including vegetables and fruits, will increase many fold contributing further to the socio-economic betterment of the agricultural families. Additionally, all neighboring areas will be benefitted through the replenishment of groundwater aquifers.

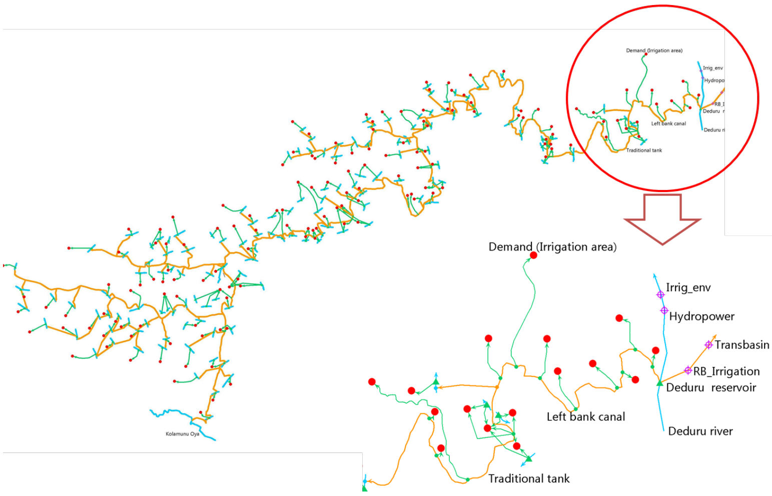


Figure 24: Schematic view of Deduru Oya Reservoir Project system at WEAP platform

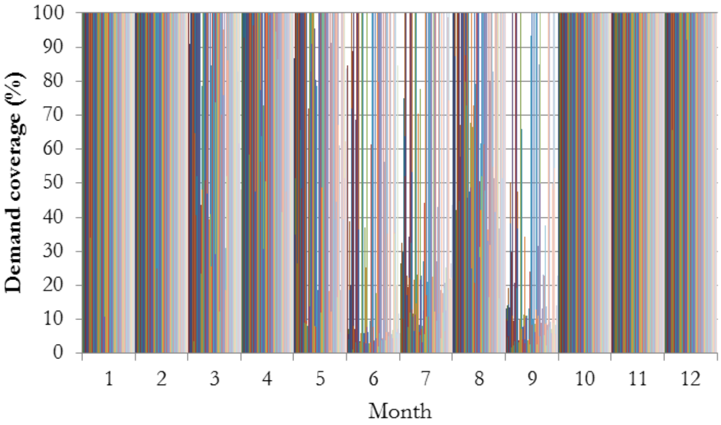


Figure 25: Demand coverage for 134 LB tank irrigation systems with no reservoir supply

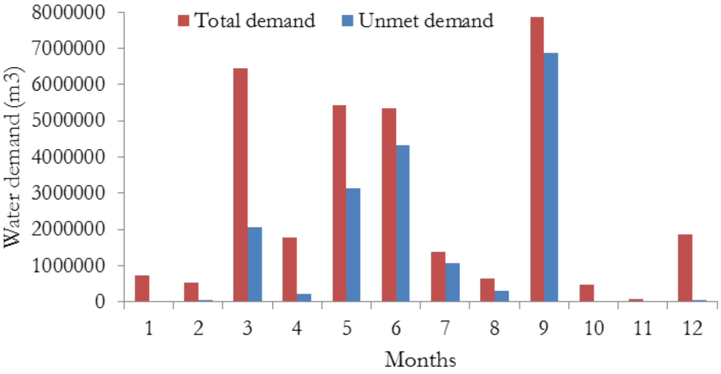


Figure 26: Total unmet water demands for 134 LB tank irrigation systems with no reservoir supply

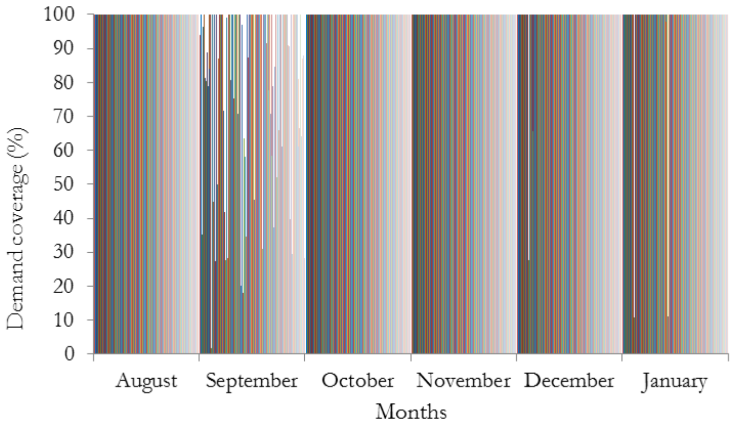


Figure 27: Demand coverage for 134 LB tank irrigation areas with single cultivation (Maha season) and no reservoir supply

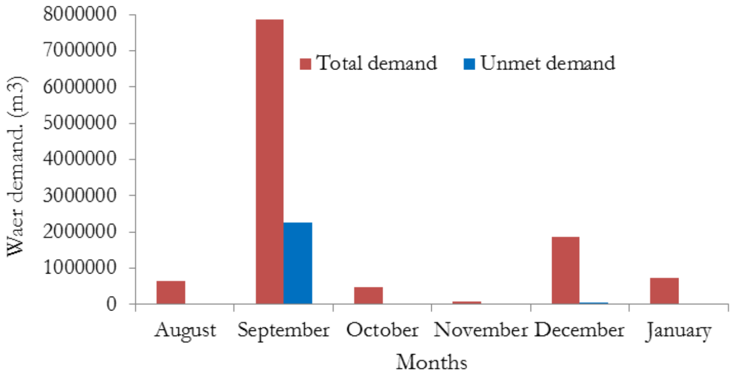


Figure 28: Comparison of total unmet water demands for 134 LB tank irrigation areas with single cultivation (Maha season) and no reservoir supply

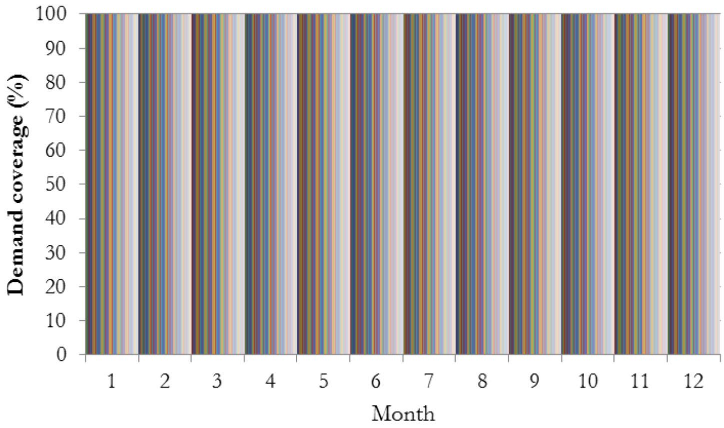


Figure 29: Demand coverage for 134 LB tank irrigation areas with reservoir supply only

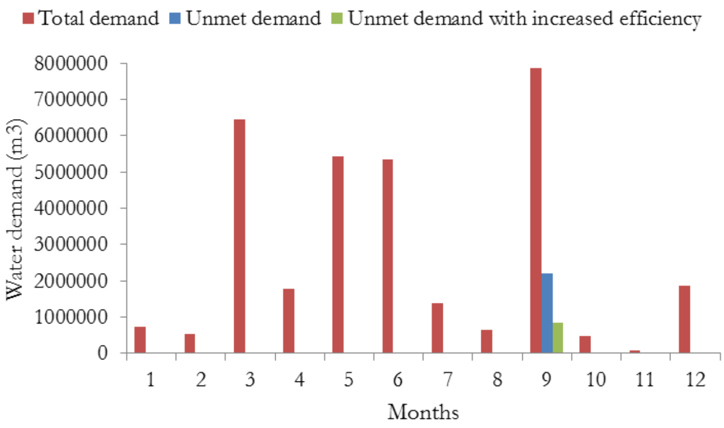


Figure 30: Total unmet demand for 134 LB tank irrigation areas in dry years with tanks and reservoir supplies

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4

USE OF GEOSPATIAL TECHNIQUES TO ASSESS THE ROLE OF TRADITIONAL WATER BODIES WITH RESPECT TO VEGETATION CONDITION

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ABSTRACT

Sri Lanka being an agrarian country, the role of water is important for agricultural production. In Sri Lanka, various tank cascade systems, earthen dams and distribution canals have been accepted as few of the most complex ancient traditional water systems of the world. Rainfall, surface water, groundwater and run-off are linked with each other and have close interactions to land cover classes such as forests and agriculture. The monitoring of vegetation conditions can show subsurface manifestations of groundwater. In this study, an effort to understand the role of traditional water reservoirs and groundwater recharge was made using remote sensing techniques. We have analysed various vegetation indices such as Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI-2), Soil Adjusted Vegetation Index (SAVI), Tasselled Cap transformation analysis (TCA-Brightness, Greenness and Wetness) and their relations with the existence of soil, vegetation and water. Result shows that EVI, SAVI and TCA based Greenness Index indicates good relationship with the vegetation conditions as compared to other indices. Therefore, these indices could play a crucial role in depicting the interaction between soil, vegetation and water.

4.1 INTRODUCTION

Sri Lankan economy depends on agricultural production. Therefore, irrigation water is the main requirement for high production. Correspondingly, Sri Lanka has more than 12,000 functioning irrigation schemes covering approximately 500,000 hectares (Brohier, 1934, Sakthivadivel et al., 1996). It has a network of thousands of man-made lakes and ponds locally known as tanks. Some are functional while others are abandoned. Many are thousands of years old and almost all show a high degree of sophistication in their construction and design (Bandara et al., 2010). These tanks store water during the rainy season and are used for various purposes such as groundwater recharge, irrigation, drinking, livestock, domestic use, etc. in dry season. They are the life line of village economies and human well-being in the dry zones of Sri Lanka, and support aquatic ecosystems (Bandara et al., 2010). These tanks are not isolated but interconnected and often found in clusters forming part of a hydrologically integrated system, which is known as a cascade system (Madduma, 1985; Panabokke, 2002). The cascade system addresses three main disaster related issues i.e. drought, flash floods and land degradation (Renault et al., 2000).

The long civil war between Sri Lankan Government and the Liberation Tigers of Tamil Eelam (LTTE) has caused significant hardships for the population, social and physical aspects and the economy of the country (Gunawardena, 2011). After having been displaced by war, residents return to their villages and started their livelihood. According to the census report by the Department of Census and Statistics in Sri Lanka, the population has jumped from 23,625 in 2009 to 112,875 in 2012 in Killinochi district (Population and Housing, 2012). This study explores the role of traditional water bodies and their potential to groundwater recharge and vegetation condition in northern part of Sri Lanka, which was severely affected by war.

Remote sensing data have significant potential to monitor the vegetation conditions at regional to global scale, given the synoptic coverage and multi-temporal observations (Avtar et al., 2011). Recent remote sensing techniques have been widely used to obtain information about various phenomenon and changes on the earth surface at various spatio-temporal scales based on spectral reflectance properties of various objects on the earth surface. Satellite data can also be used to monitor the eco-environmental parameters such as rainfall, soil type, geomorphology, land use/land cover, elevation, slope, etc., and their impacts on the vegetation conditions and growth (Verbesselt et al., 2006). Vegetation conditions can be studied using spectral response of vegetation (Mbow et al., 2004). It varies through topographical and hydrogeological conditions. Scanlon et al., 2005 studied about the impact of land use and land cover change on groundwater recharge and quality because different types of land uses have different rates of recharge potential.

Optical sensor based spectral signatures have been proved useful for estimating a range of vegetation conditions and biophysical parameters such as biomass, height, growth stages (Avtar et al., 2012a; 2012b; Avtar et al., 2013a; 2013b), leaf area index (LAI) and the absorptivity of photosynthetically active radiation (APAR), etc. (Turner et al, 2002; Inoue et al., 2008). Various vegetation indices (VIs) derived from satellite data are widely used. These VIs are algebraic combinations of different spectral bands to minimize the external effects such as solar radiation, atmospheric effects, etc. (Gilabert et al., 2002). The NDVI is most widely used to assess different aspects of plant processes and their spatio-temporal changes (Myneni et al., 1994; Verbesselt et al., 2006; Gu et al., 2007). Based on these spectral properties, we can monitor various objects and their physical conditions. However, remote sensing techniques (mostly optical data) cannot provide information about the sub-surface features because it mostly observes the surface properties of objects except for Ground Penetrating Radar (GPR). Therefore, to monitor the sub-surface properties like groundwater recharge and its relation with the vegetation, we need to monitor the vegetation conditions. The aim of this study is to investigate the potential of remote sensing techniques to monitor various water reservoirs in Sri Lanka and their role in groundwater recharge and vegetation conditions. Various vegetation indices (NDVI, SAVI, EVI, TCA, etc.) have been used to monitor vegetation conditions near and far from water reservoirs. Based on this information, we have investigated the interaction between vegetation conditions, groundwater recharge and the role of reservoirs.

4.2 STUDY AREA

The climate of Sri Lanka is generally characterized as tropical type. Sri Lanka is divided into three climatic zones i.e. the wet zone, dry zone and intermediate zone. The test site is located in the dry zone between latitudes 9°9′56.23“ to 9°28′4.58″ N and longitudes 80°18′31.28“ to 80°35′58.26“E. The area is situated in Kilinochi and Mullattivu province of northern Sri Lanka. There are two distinct seasons, wet and dry. The average temperature is between 28°C to 30°C for the year. January and May are the coolest and hottest months, respectively. The average annual rainfall in dry zone is 1300 mm per year (Bandara, 2003). Most of the rainfall occurs during the Maha season, which occurs from October to January and brings rain to the Northern and Eastern regions of Sri Lanka. The dry season (Yala season) varies from May to September. Figure 31 shows the location of the study area.

Figure 31: Location of the study area

No.	Sensors type	Acquisition date	Resolution
1	Landsat-5 TM	11/09/1994	30 m
2	ALOS AVNIR-2	28/03/2007	10 m
3	ALOS PALSAR FDB	21/06/2007	12.5 m
4	ASTER GDEM	2010	30 m

Table 11: Satellite data used

4.3 MATERIAL AND METHODS

4.3.1 *Field data*

Field work was conducted in March, 2013 for the collection of ground truth data. Garmin Global Positioning System (GPS) Oregon450 was used to collect ground truth data. GPS camera was also used to collect GPS photos of various land cover types. This information was used as a training data for supervised classification of the satellite data. Status of water tanks and vegetation types were also recorded as an evidence for verification of results. The Ministry of Environment Japan's budget (CECAR-Asia) was used to conduct field survey on the test site. The University of Peradeniya in Sri Lanka also contributed to the field survey.

4.3.2 *Satellite data*

In this study, Landsat data was obtained from US Geological Survey's Glovis. We used the Landsat-5 Thematic Mapper (TM) image, which were clouds free. It was very difficult to get clouds free data in this region. Other remote sensing data such as Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) and Phased Array L-band type Synthetic Aperture Radar (PALSAR) were also acquired from Japan Aerospace Exploration Agency (JAXA). AVNIR-2 and Landsat data were visually interpreted to know the various land cover in the study area. ASTER GDEM data was also used to know the elevation and slope of the area. Table **??** shows the list of the satellite data used and their acquisition. Environment for Visualizing Images (ENVI) and ArcGIS 10.1 software were used to pre-process satellite images such as radiometric calibration, atmospheric correction, and geometric correction.

4.3.3 *Satellite data processing*

4.3.3.1 *Landsat data processing*

The Landsat Thematic Mapper (TM) acquired the information about various objects on the earth surface and stores this information as a digital number (DN) with a range between 0 and 255. DN values were converted to reflectance using two steps process. The first step is to convert DN to radiance using the bias and gain values specified in the header file of Landsat data. The second step is to convert radiance value to reflectance (Moran et al., 2001; Thome, 2001).

$$L_\lambda = gain \times DN + bias \tag{2}$$

where, $L\lambda$ is the radiance value, DN is the pixel value, gain is the gain value of a specific band and bias is the bias value of a specific band

$$\rho\lambda = \pi \times d^2/ESUN_\lambda \times \cos\theta s \tag{3}$$

where, ρλ = Unitless plantary reflectance, Lλ = spectral radiance (from 1), d = Earth-Sun distance in astronomical units, $ESUN\lambda$ = mean solar exo-atmospheric irradiances and θs = solar zenith angle in degree

4.3.3.2 *AVNIR-2 data processing*

Digital numbers (DN) in each band of the AVNIR-2 were converted to reflectance. First, we converted DN value to radiance and later on radiance to reflectance (Saunier et al., 2006).

$$Lsat = (DN + a) \times UCC \tag{4}$$

where, Lsat is the sensor radiance, a represents the absolute calibration coefficients contained in the header file, and UCC is the Unit Conversion Coefficient, which is different for each image band and also depends on the gain setting that was used to acquire the image.

$$R = \pi.Lsat/E\cos\theta \tag{5}$$

where, R is spectral reflectance, Lsat is sensor radiance, E is the spectral solar irradiance, and Î¸ is the solar zenith angle.

4.3.3.3 *PALSAR data processing*

PALSAR Fine Beam Dual polarimetric (FBD) data was processed. The digital number (DN) was converted to the normalized radar cross section (NRSC or σ0). The backscattering coefficient was calculated using the following equation (Shimada et al., 2009).

$$\sigma^0 = 10 \times \log_{10}\left(DN^2\right) - 83 \tag{6}$$

All the satellite data were co-registered with Landsat-5 TM orthorectified data.

4.3.4 *Vegetation indices calculation*

Standard data processing techniques were used to process various remote sensing data. Various vegetation indices derived from satellite sensors (AVNIR-2 and Landsat) were used to investigate the interaction of soil, water and vegetation based on spectral reflectance. The most common and widely used vegetation index is the NDVI developed by Rouse et al., 1974. Despite its intensive use, the relationship between the NDVI and the vegetation is known to be strongly affected by soil reflectance (Huang et al., 2013). Therefore, other vegetation indices such as SAVI, EVI-2 and TCA were also used (Huang et al., 2002; Lillesand et al., 2007). The SAVI was developed as modification of the NDVI to correct for the influence of soil brightness when vegetation cover is low (Gilabert et al., 2002). EVI is developed to identify the changes in areas having high vegetation. It reduces the influence of atmospheric conditions on vegetation index. The TCA corresponds to the brightness, greenness and wetness developed by Kuth and Thomas (1976) based on spectral analysis of the growth of wheat in the fields. The following equations show the relationships of various indices with different bands of satellite data.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red}) / (\mathrm{NIR} + \mathrm{Red}) \tag{7}$$

$$\mathrm{SAVI} = (\mathrm{NIR} - \mathrm{Red}) / (\mathrm{NIR} + \mathrm{Red} + 0.5) \times 1.5 \tag{8}$$

$$\mathrm{EVI} - 2 = 2.5 \times (\mathrm{NIR} - \mathrm{Red}) / ((1 + \mathrm{NIR}) + (2.4 \times \mathrm{Red})) \tag{9}$$

$$\mathrm{TCA} = Brightness, Greenness, Wetness \tag{10}$$

4.4 RESULTS AND DISCUSSION

4.4.1 *Land use/land cover map of the study area*

Land use/land cover (LULC) classification is an important application of remote sensing, which involves extraction of thematic information from satellite data. It determines the spectral relationship between spectral signatures and various classes that are of interest to the user (Wulder et al., 2008). LULC information is also useful for effective management of land resources and policy designing. Various classification approaches have been developed to classify satellite data. In this study, we applied maximum likelihood classification (MLC) technique. AVNIR-2 data acquired on March 2007 was used to generate LULC map of the area with the help of field data. The study area was classified into six classes viz. forest, agriculture, scrub land, barren land, water and built-up area with home garden (figure 32).

Most of the study area is covered by forest followed by agricultural area. The main agricultural crops are rubber, coconut, chili, onion, etc. Water bodies cover about 4.3% of land area to supply water for agriculture and other purposes. Built-up area and home garden covers 12.8% of the area. AVNIR-2 data is not very much suitable to identify the small built-up area because most of the houses are very sparse and covered by vegetation. Therefore, result shows misclassification between built-up area and agricultural area.

Table 12 represents area and percentage of various land cover classes. The most common method to access the accuracy of classification is the confusion matrix (Avtar et al., 2013b, c). The error matrix shows a tabulated view of map accuracy which allows the calculation of specific measures such as overall accuracy and user's and producer's accuracies (Congalton, 1991). Table 13 illustrates the confusion matrix of MLC. The overall accuracy of the classification is 76.2% with 0.71 Kappa coefficient. Most of the misclassification is between built-up and agricultural areas.

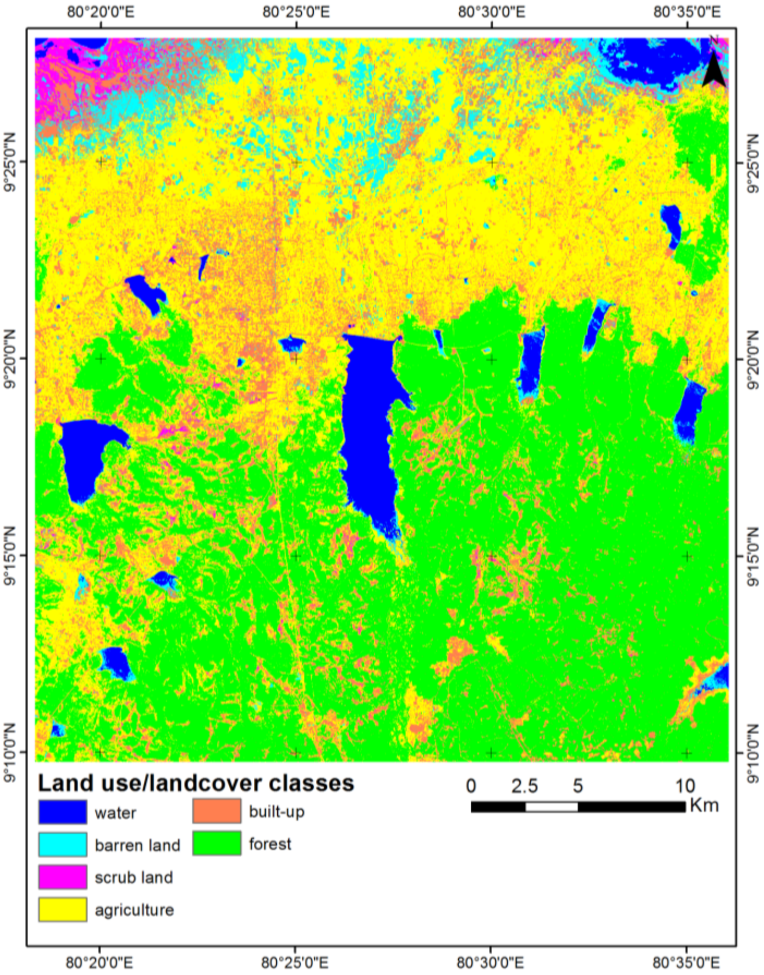

Figure 32: AVNIR-2 based land use/land cover map

4.4.2 *Water body extraction*

The area has major and minor irrigation schemes. Some of them are under repair and reconstruction from the war. However, it is a good strength for the development of agriculture in the area after reconstructing them. Table **??** shows the various water tanks in the study area and their capacity (Provincial Statistical Information, 2012). The biggest tank of this area is Iranamadu tank with an area about 20 sq. km. We have extracted water bodies based on satellite data using band thresholding of near infrared band (band 4). The result shows that band threshold works well with optical data (Landsat-5 TM and AVNIR-2) as compared to PALSAR data because PALSAR data gave some unrealistic results. This was mainly because most of the paddy lands covered with water was categorized as water bodies. Because of soil moisture effects, PALSAR data is not suitable to extract water bodies in the area and

No.	Class	Area (km2)	Percentage
1	Water	47.5	4.3
2	Barren land	55.7	5.1
3	Scrub land	13.0	1.2
4	Agriculture	392.1	35.6
5	Built-up	141.2	12.8
6	Forest	450.3	40.9
Total		1099.8	100.0

Table 12: Percentage of different LULC classes

	Reference data								
	Class name	Forest	Barren land	Scrub land	Agriculture	Built-up	Water	Total	User's accuracy
Classified data	Forest	36	0	0	2	0	0	38	94.7
	Barren land	0	19	5	1	1	2	28	67.9
	Scrub land	0	3	17	2	2	0	24	70.8
	Agriculture	1	2	3	22	4	0	32	68.8
	Built-up	0	2	2	6	12	0	22	54.5
	Water	0	1	0	0	0	19	20	95.0
	Total	37	27	27	33	19	21	164	
		97.3	70.4	63.0	66.7	63.2	90.5		

Table 13: Confusion matrix for accuracy assessment

No.	Name of tank	District division	Capacity (Cubic meter)	Depth (m)	AVNIR-2 (March, 2007) based area (sq km)	Landsat (September, 1994) based area (sq km)
1	Udayarkaddu Kulam	Puthukudigiruppu	8023799.4	3.06	2.62	0.12
2	Piramanthan Aru Kulam	Kandawalai	3858331.2	2.92	1.32	0.61
3	Visuamadu Kulam	Puthukudigiruppu	3725115.1	2.76	1.35	0.50
4	Kalmadu Kulam	Kandawalai	11288825.7	3.96	2.85	0.51
5	Iranamadu Tank	Karachchi	131365815.6	6.57	19.98	6.88
6	Akkarayam Kulam	Karachchi	26149814.9	3.67	7.12	4.11
7	Puthumurippu	Karachchi	3647405.7	2.25	1.62	0.47

Table 14: Various tanks in the study area

PALSAR data shows overestimation of the water bodies. Figure **??** shows the water reservoirs map of the area based on Landsat-5 TM and AVNIR-2 data. This extracted water reservoirs data can be used to investigate the temporal changes of water volumes in various reservoirs and their seasonal changes. Figure 33 clearly shows that the volume of water just after rainy season (AVNIR-2 data in March, 2007) is higher than the volume of water after dry season (Landsat TM data September, 1994). This is mainly because of water utilization during dry season for irrigation and other purposes. Table 14 also shows the area of various reservoirs extracted using Landsat and AVNIR-2 data. This study reveals that we can use satellite data to track the seasonal and temporal variations of water volume in various reservoirs.

4.5 ROLE OF VEGETATION INDICES (VIS)

In this study, we evaluated the performance of remote sensing indices related to vegetation-water interaction. We analysed various VIs to understand the vegetation dynamics and role of hydrological conditions near the reservoirs. Vegetation condition is useful to show sub-surface manifestation of the groundwater (Singh et al. 2010). Therefore, various vegetation indices based on optical data were used to infer the vegetation conditions. Figure 34 shows the Landsat TM based NDVI (figure 34) and AVNIR-2 based NDVI (figure 34), respectively. The value of NDVI in vegetative areas is higher than other land cover types. AVNIR-2 based NDVI (figure 34b) shows higher values when compared with Landsat TM based NDVI (figure 34a). This is mainly because the AVNIR-2 data was acquired just after the rainy season (March) when vegetation has higher growth rates as compared with Landsat data acquired just after the dry season (September). During the dry season with high temperatures and no rainfall, vegetation has low growth rate and chlorophyll that cause a decrease in NDVI (Verbesselt et al., 2006) that is clearly seen in figure 34a as compared to 34b. Figures 34a and 34b also show

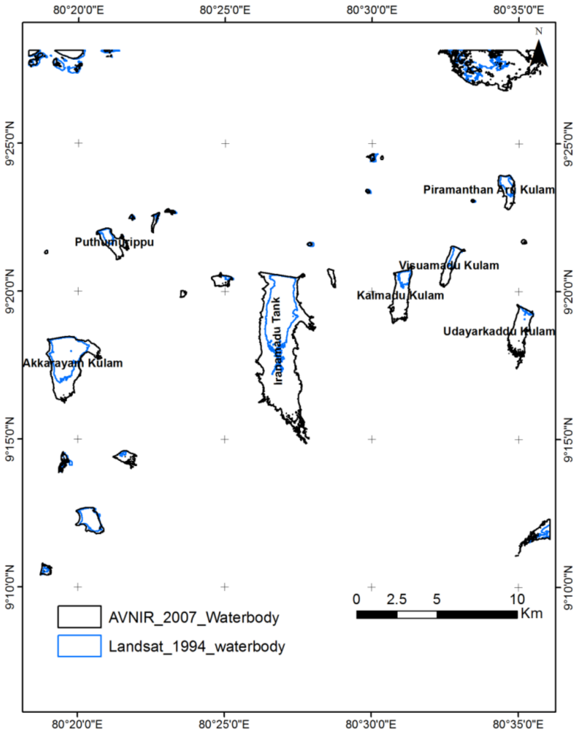

Figure 33: Seasonal variation of the water reservoirs Landsat 11/09/1994 and AVNIR-2 28/03/2007 based water body extraction

that NDVI is not a suitable parameter to distinguish the vegetation condition between areas near and far from the reservoirs because their NDVI values are almost equal. This might be because of the effects of soil reflectance as noticed by other researchers as well (Huang et al., 2013). Therefore, we have also analyzed other vegetation indices to minimize the effects of soil reflectance such as SAVI, EVI and TCA.

SAVI was developed as a modification of the NDVI to minimize soil influences on canopy spectra by incorporating a soil adjustment factor (Gilabert et al., 2002). Figures 35a and 35b clearly show that the value of the SAVI is higher in the vegetation near water reservoirs when compared with vegetation far away from water reservoirs. The black circle clearly shows the higher value of SAVI in the vegetation near the water reservoirs. Figures 36a, and 36b show the Landsat TM based EVI-2, and AVNIR-2 based EVI-2, respectively. The value of the EVI is higher in the vegetative areas that are near to the water reservoirs as compared to those far away from the reservoirs (figure 36a and 36b). The black circle clearly shows the higher value of EVI in the vegetation near water reservoirs.

We further investigated the role of TCA to monitor vegetation and water interaction. Figures 37a, 37b, 37c, and 37d show the Landsat TM based brightness Index, Greenness Index, wetness Index and R:G:B composite of TCA Index, respectively. Brightness Index is related to variations in soil background reflectance. The agricultural area, barren land and scrubland show high value of brightness as compared to forest area (figure 37a). Greenness Index is related to variations in the vigor of green vegetation. High value of Greenness Index is observed in the vegetative areas near the reservoir as compared to those far away from the reservoirs (figure 37b). The value of

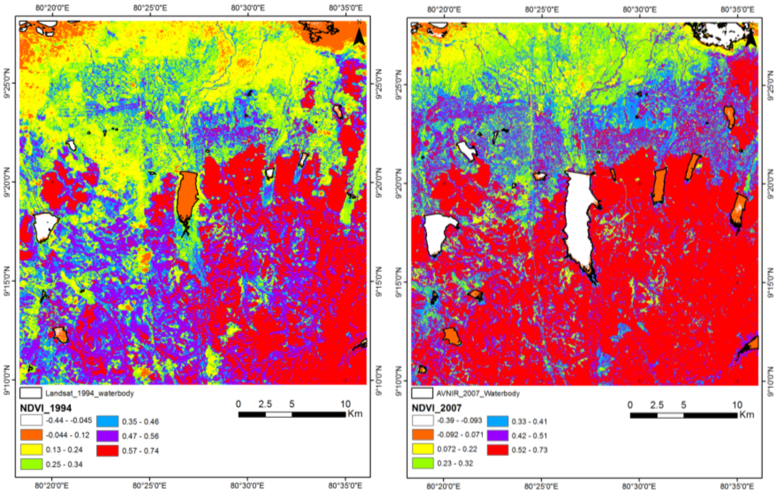

Figure 34: (a) Landsat-5 TM based NDVI and (b) AVNIR-2 based NDVI

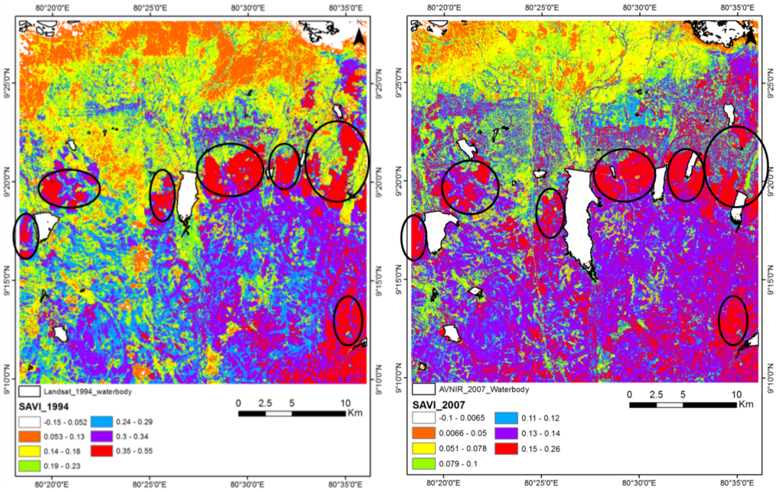

Figure 35: (a) Landsat-5 TM based SAVI and (b) AVNIR-2 based SAVI

Greenness Index in agricultural, barren and scrubland is very low because of low vegetation during dry season. The high Greenness Index value represents healthy vegetative area in tasseled cap image. This is confirmed by overlapping EVI image (figure 36a) on Greenness Index image (figure 37b) and it is found that high EVI areas have high values of Greenness Index. Wetness Index is related to soil wetness properties. The value of wetness Index is higher in forest areas and water bodies as compared to agricultural, barren and scrubland (figure 37c). This is mainly because the Landsat data was acquired just after dry season so the soil was very dry with less moisture as compared to the forest near the water reservoirs having high wetness Index. R:G:B colour composite also shows that vegetation near the water reservoir (black circles) is brighter than the vegetation far from the reservoir (figure 37d). Therefore, this study shows that vegetation near the water reservoir has high value of EVI, SAVI and TCA based Greenness Index, which represent healthy condition of vegetation as compared to the vegetation far from the water reservoir. This study also reveals that the density of water reservoir is also an indicator of vegetation condition because the high dense vegetation exists near the eastern side of the area where Iranamadu kulum, Kalmadu kulam, Visuamadu kulum and Udayarkaddu kulam tanks are present. So we can say that, water reservoirs help in groundwater recharge because the vegetation conditions near the reservoirs are better than the vegetation far

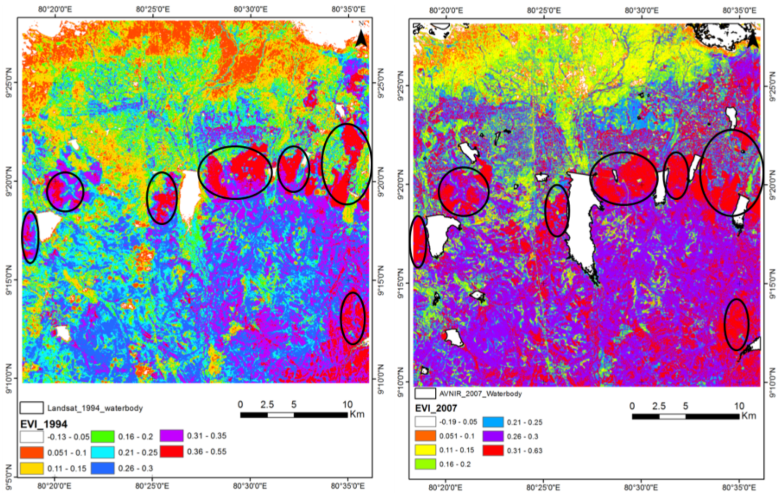

Figure 36: (a) Landsat-5 TM based EVI and (b) AVNIR-2 based EVI

away from the reservoirs. Reservoir density is also a contributing factor to vegetation conditions and groundwater recharge. Therefore, studies about spatial distribution and their capacity is also essential. Furthermore, we will investigate various texture and data fusion techniques to generate a relationship between interactions of surface water, groundwater and vegetation conditions.

4.6 CONCLUSION

In Sri Lanka, traditional cascade system is useful for various purposes such as groundwater recharge, irrigation, drinking, livestock and domestic use, among others. Therefore, their preservation and resource management is necessary. Remote sensing techniques are useful to monitor seasonal and temporal changes in water reservoirs therefore can be used for sustainable water resource use. The performance of vegetation indices is useful to monitor the interaction between vegetation and water. Various vegetation indices can provide evidence about sub-surface information about groundwater recharge based on vegetation conditions. Results showed that EVI, SAVI, Greenness Index can be used to predict the interaction between groundwater and vegetation conditions. SAVI, EVI and Greenness Index clearly show that their values are higher for vegetation near the water reservoirs when compared to vegetation far from reservoirs. This study could be useful in planning and management of groundwater by suitably locating water reservoirs spatially. Further research is needed to investigate the performance of various texture and data fusion techniques to investigate the role of water bodies in groundwater recharge and vegetation conditions.

4.7 ACKNOWLEDGEMENT

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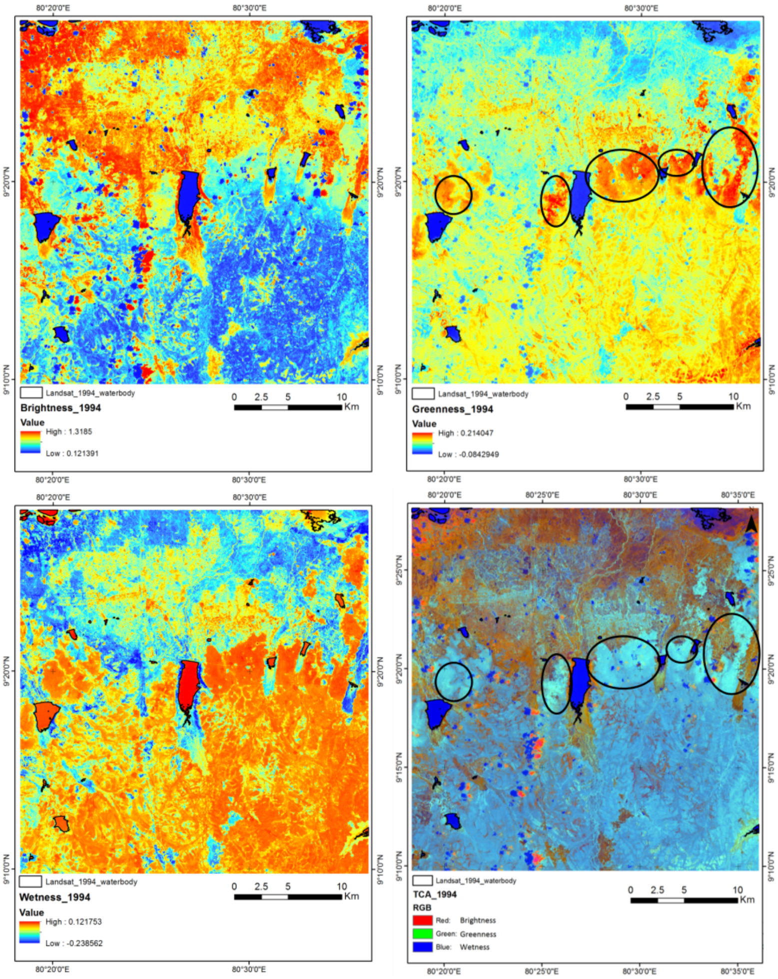

Figure 37: Landsat TM based Tasselled Cap Transformation (a) Brightness index (b) Greenness index (c) Wetness index (d) R:G:B colour composite of brightness, greenness and wetness index

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5

GROUNDWATER MODELING DATA PREPARATION: KILINOCHCHI DISTRICT, SRI LANKA

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5.1 introduction

Fresh water is one of the most essential resources for people and land ecosystem. History proves that abundance of freshwater has boosted the development of civilization, and vice versa. But freshwater only accounts for three per cent of all the existing water resources in the Earth, so seeking for the freshwater is always of great importance especially for people in arid regions. In this context, groundwater has played a significant role for because groundwater is:

1. the most affluent freshwater resources;
2. much more conservative against weather change due to low discharge rate;
3. free of pathogenic bacteria in most cases, and
4. the closest water resources for many rural communities

In reality, the number of those who relied on the groundwater resources for their lives as the only accessible resource is estimated at least 1.5 billion (Clarke et al. 1996). However, the amount of groundwater abstraction has been dramatically increasing because of population burgeoning and development of industry, which has often been implemented in haphazard manner. This is facilitating adverse results such as river cut-off, land subsidence and groundwater salinization. Therefore, appropriate management of groundwater is necessary for the sustainable development.

Kilinochchi district, located in the northern part of Sri Lanka, had been impeded in its development due to 30-year-armed-conflict. Poverty rate in the district is as much as 64 per cent in the district, which is an unusually high rate considering 23 per cent for national average (Asian Development Bank 2011). Nearly 60 per cent of residents do not have safe water sources for sanitation and drinking, and waterborne disease often occurs in the district. This is mainly because the groundwater which is the only source of water resources is polluted as a result of industrial activities such as mining (Munasignhe et al. 2011). Moreover the impact of tsunami showed the vulnerability of the groundwater resources in Northern Sri Lanka. In this context many proposals such as 'A river for Jaffna' project are being proposed to expand the available water and boost agricultural activities to turn the Northern lagoon area into the fresh water lake. Likewise, the

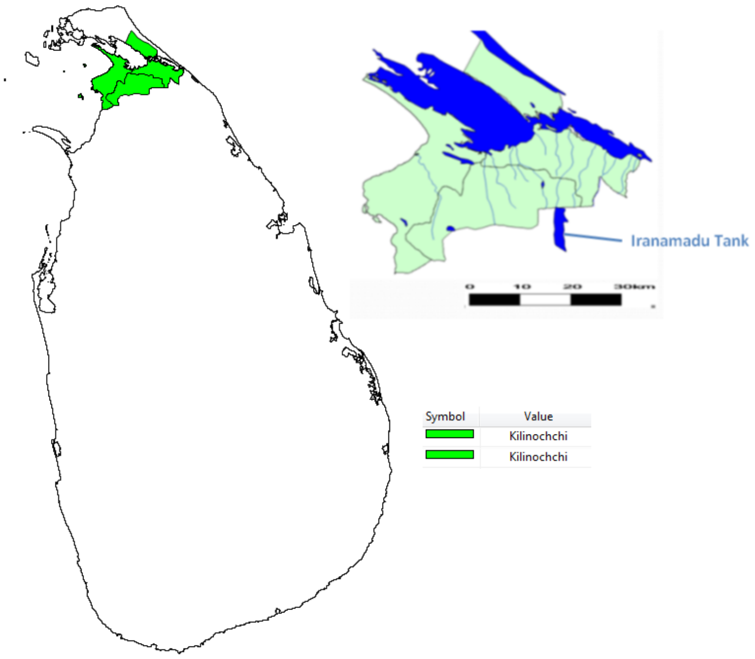


Figure 38: The map of Sri Lanka and Kilinochchi District

enhancement of the irrigation scheme from the Iranamadu tank, which is the main reservoir for farmers in Kilinochchi, is implemented for better access to the water.

More and more returnees resettled after the end of ethnic conflict in 2009 and the district starts to develop again; which can cause environmental degradation due to over abstraction of groundwater. Annual water demand in the district is estimated as 333 million m^3, and more than 99 per cent is utilized for agricultural usage (Amarasignhe et al. 1999). Since there is no perennial river in the district, water supply is greatly dependent on the groundwater. However, groundwater investigation and development of groundwater in the district had not been carried out in recent years due to the war. IWMI (Amarasignhe et al. 1999) reported the water budget at district wise including the groundwater usage. This is very useful to analyze the current water usage in the district, but spatial data is more useful for decision makers involved in development planning. Therefore, estimating the available water spatially in the district by numerical modelling can be a significant benchmark to consider sustainable development. In this paper setting up of a geographical information system (GIS) for numerical modelling is reported.

5.2 ISSUE

Estimate how much water is available in Kilinochchi Area for sustainable development (the amount of water for environmental sustainability is set as 25 per cent of the potential groundwater storage according to the past studies (Panabokke and Perena 2005).

5.3 METHODOLOGY

In order to estimate the amount of available groundwater resources with MODFLOW 2005, the following data sets should be prepared;

- Fundamental spatial data
  - Location of target area and distribution of soil type, landuse, elevation, and climatic data such as precipitation and evapotranspiration.
- Soil data
  - Hydraulic conductivity (horizontal direction), Infiltration rate (vertical direction), each depth of horizontal soil layers, maximum and minimum soil moisture content
- Initial Hydraulic (or piezometoric) heads
  - It can be determined by modeling at steady state
- Aquifer Top and Bottom levels
  - The depth of aquifer and impermeable confining layer
- Aquifer properties
  - Transmissivity, Specific Yield, and leakage coefficient
- Aquifer geometry
  - In many cases, aquifers are assumed as homogeneous and isotropic; however, this is one of the biggest causes of uncertainty. Especially for aquifers that consist of limestone formations (eg. shallow karstic aquifer and deep confined aquifer), heterogeneity and variability of its property is significantly high due to its structure.
- Well data
  - Well location, depth of wells, drilling data, abstraction rate, water table logs with time

For a preparation of the spatial data, Water Resource Board (WRB), National Water Supply and Drainage Board (NWS&DB), Geological Surveys and Mines Bureau (GSMB), International Water Management Institute (IWMI), Integrated Strategic Environmental Assessment (ISEA), United States Geological Survey (USGS) and German Technical Cooperation (GTZ) publications were used. Data preparation and the output of spatial results are carried out with NK-GIAS a GIS software developed by the Nippon Koei Co. Ltd. in Japan.

5.4 DATA PREPARATION

- Administrative Map of Kilinochchi (DIVA-GIS 2012)
  - Kilinochchi district lies between approximately 9.21 and 9.61 degree in Latitude and 79.9 and 80.6 degree in Longitude (including three small western islands). Total land area of the district is 1205 km^2 and water area is $74km^2$.
- Spatial distribution of topography in Kilinochchi District (USGS 2010)
  - Much of Kilinochchi district is covered by low peneplain which is generally less than 10m from mean sea level. The land is undulating and rising up to 55m height towards south boarder of Kilinochchi district.

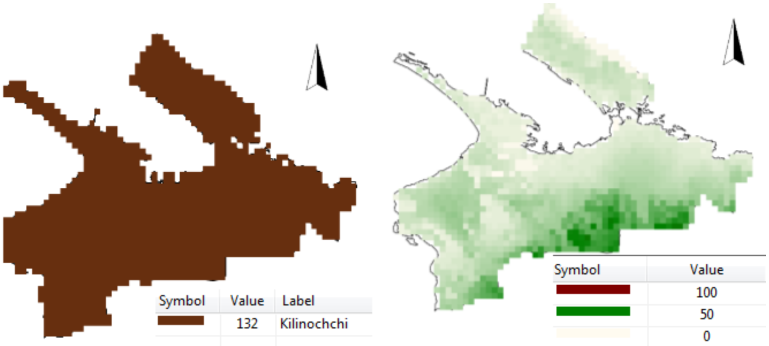


Figure 39: Kilinochchi District, and Elevation Map (1 km resolution)

- Rainfall distribution map
  - Since there is no available rainfall station data in Kilinochchi district, Thiessen polygon method from neighbor districts data (Jaffna, Mannar and Trincomalee district) was carried out. Result shows the most areas has the same rainfall feature as the one in Jaffna (1249.7 mm/y) whereas there is a slight tendency that annual rainfall amount decreases from the east to west part of the district.
- Land use map (Centre for Remote Sensing 1989)

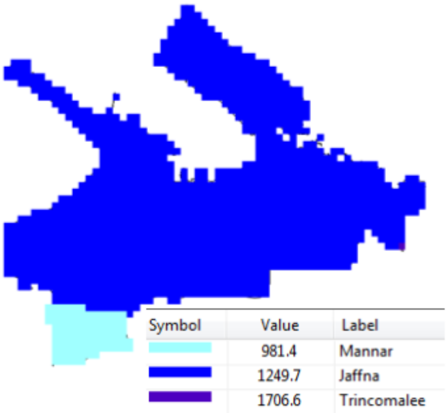


Figure 40: Rainfall distribution in Kilinochchi

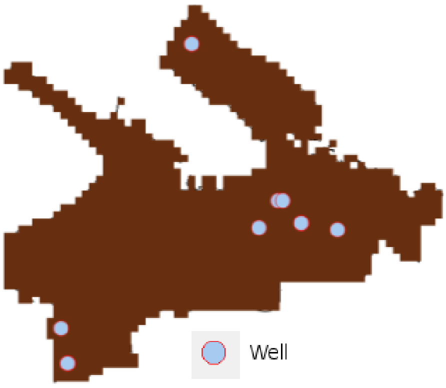
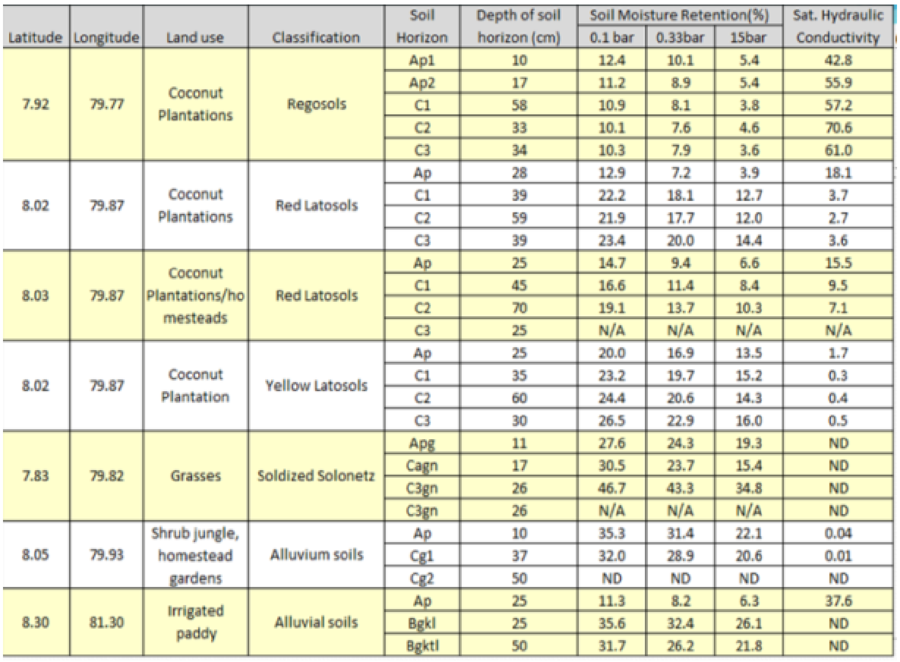


Figure 41: Identified well location in Kilinochchi



Latitude	Longitude	Land use	Classification	Soil Horizon	Depth of soil horizon (cm)	Soil Moisture Retention(%)			Sat. Hydraulic Conductivity
						0.1 bar	0.33bar	15bar	
7.92	79.77	Coconut Plantations	Regosols	Ap1	10	12.4	10.1	5.4	42.8
				Ap2	17	11.2	8.9	5.4	55.9
				C1	58	10.9	8.1	3.8	57.2
				C2	33	10.1	7.6	4.6	70.6
				C3	34	10.3	7.9	3.6	61.0
8.02	79.87	Coconut Plantations	Red Latosols	Ap	28	12.9	7.2	3.9	18.1
				C1	39	22.2	18.1	12.7	3.7
				C2	59	21.9	17.7	12.0	2.7
				C3	39	23.4	20.0	14.4	3.6
8.03	79.87	Coconut Plantations/homesteads	Red Latosols	Ap	25	14.7	9.4	6.6	15.5
				C1	45	16.6	11.4	8.4	9.5
				C2	70	19.1	13.7	10.3	7.1
				C3	25	N/A	N/A	N/A	N/A
8.02	79.87	Coconut Plantation	Yellow Latosols	Ap	25	20.0	16.9	13.5	1.7
				C1	35	23.2	19.7	15.2	0.3
				C2	60	24.4	20.6	14.3	0.4
				C3	30	26.5	22.9	16.0	0.5
7.83	79.82	Grasses	Soldized Solonetz	Apg	11	27.6	24.3	19.3	ND
				Cagn	17	30.5	23.7	15.4	ND
				C3gn	26	46.7	43.3	34.8	ND
				C3gn	26	N/A	N/A	N/A	ND
8.05	79.93	Shrub jungle, homestead gardens	Alluvium soils	Ap	10	35.3	31.4	22.1	0.04
				Cg1	37	32.0	28.9	20.6	0.01
				Cg2	50	ND	ND	ND	ND
8.30	81.30	Irrigated paddy	Alluvial soils	Ap	25	11.3	8.2	6.3	37.6
				Bgkl	25	35.6	32.4	26.1	ND
				Bgktl	50	31.7	26.2	21.8	ND

Table 15: Representative soil property values of each soil classification (data from Soil Science Society of Sri Lanka and Canadian Society of Soil Science 2009)

  - This is used to identify impervious area due to human activity such as roads, homesteads and cropland. According to the map from Centre for Remote Sensing (1989), most west side of Kilinochchi is covered with natural forest with few paddy areas, while the east area manly consist of paddy areas and homestead.

- Type of soil (Integrated Strategic Environmental Assessment (ISEA) 2011)

  - This is prepared primarily to estimate the infiltration rate. The representative properties (moisture retention, saturated hydraulic conductivity) for each soil type is prepared from the soil investigation data from Soil Science Society of Sri Lanka and Canadian Society of Soil Science (2009)

- Type of aquifers (ISEA 2011)

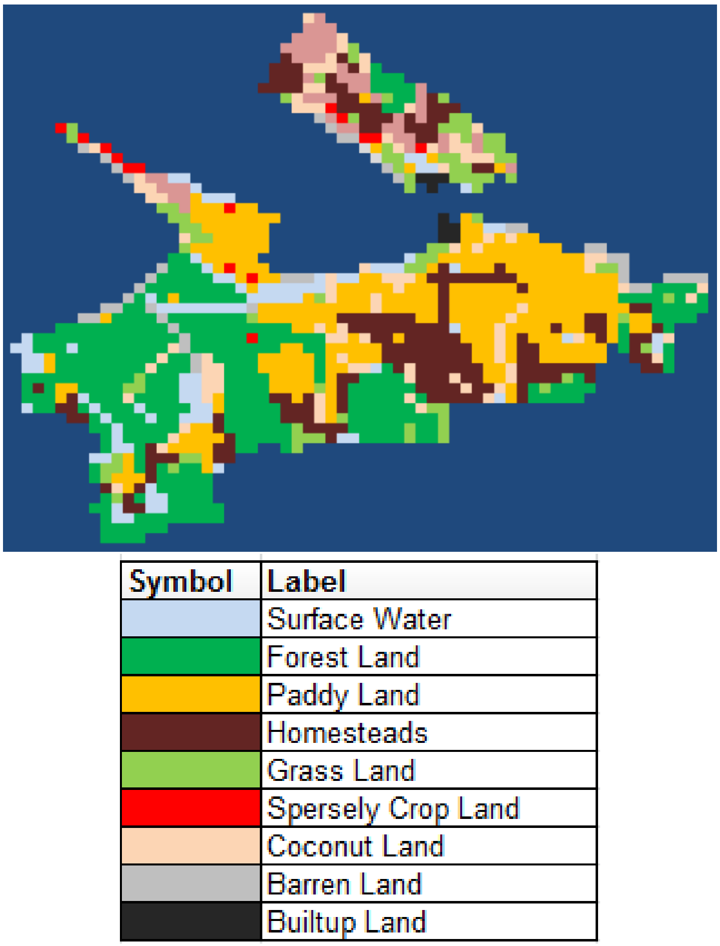
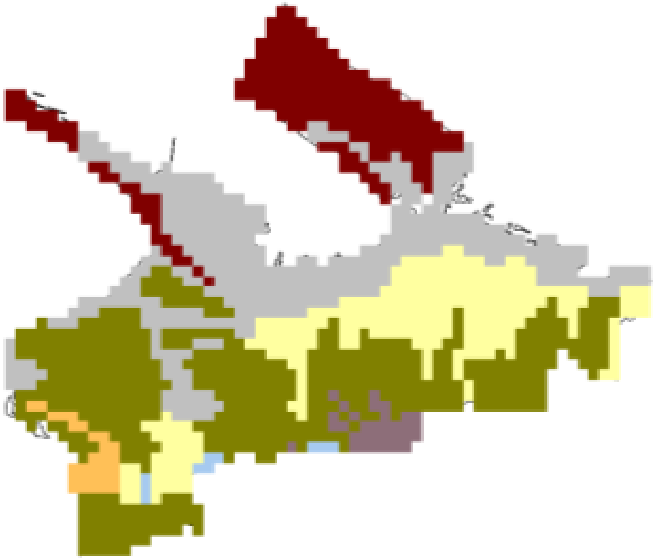


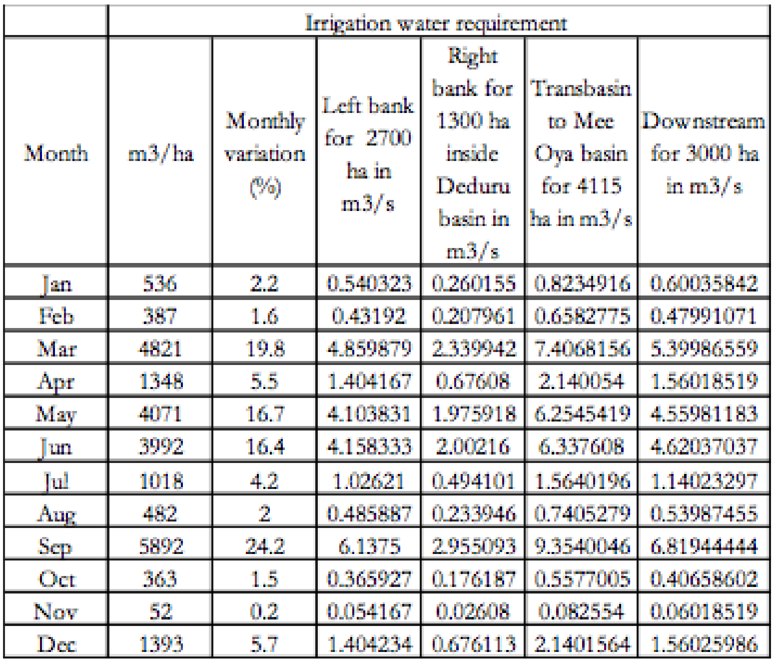
Figure 42: Land use distribution in Kilinochchi district

– According to the WRB report, there are mainly three types of aquifers in the region: Shallow Aquifers on Coastal Sands, Deep Confined Aquifer and Alluvium Aquifer. Shallow Coastal Sands aquifer is located on the North and West part of Kilinochchi, and underlain by clay and Miocene limestone. GTZ reported the safe yield for this type of aquifer in Trincomalee District (Kodituwakku & Pathirana 2003). The report indicates high percolation ability of the soil with more than 90% of infiltration from precipitation; therefore, this zone is a precious renewable water resources area.

Deep confined aquifer can be usually found at a depth of more than 60 meters. It occurs within sedimentary limestone and sandstone formations, and is recharged relatively quickly through faults. Potential groundwater storage is estimated based on the thickness of the limestone formation by WRB, and it is found that very productive amount of water exists in the aquifer. For example, Mulankavil Basin, which covers the west part of Kilinochchi district, has 9 Million Cubic Meter (MCM) annual safe yield (Panabokke and Perera 2005). However, high capital investment for well construction due to its depth and land mines obstruct the groundwater exploitation (IWMI 2005).

Alluvium aquifer occurs around current or old river system within unconsolidated sedimentary formations. The size of the aquifer





	Irrigation water requirement					
Month	m3/ha	Monthly variation (%)	Left bank for 2700 ha in m3/s	Right bank for 1300 ha inside Deduru basin in m3/s	Transbasin to Mee Oya basin for 4115 ha in m3/s	Downstream for 3000 ha in m3/s
Jan	536	2.2	0.540323	0.260155	0.8234916	0.60035842
Feb	387	1.6	0.43192	0.207961	0.6582775	0.47991071
Mar	4821	19.8	4.859879	2.339942	7.4068156	5.39986559
Apr	1348	5.5	1.404167	0.67608	2.140054	1.56018519
May	4071	16.7	4.103831	1.975918	6.2545419	4.55981183
Jun	3992	16.4	4.158333	2.00216	6.337608	4.62037037
Jul	1018	4.2	1.02621	0.494101	1.5640196	1.14023297
Aug	482	2	0.485887	0.233946	0.7405279	0.53987455
Sep	5892	24.2	6.1375	2.955093	9.3540046	6.81944444
Oct	363	1.5	0.365927	0.176187	0.5577005	0.40658602
Nov	52	0.2	0.054167	0.02608	0.082554	0.06018519
Dec	1393	5.7	1.404234	0.676113	2.1401564	1.56025986

Figure 43: Soil distribution in Kilinochchi district

tends to depend on the river scale, and aquifer thickness is estimated 10 to 35 meters in large river system.

- Well data
  - According to the WRB database (2010), 26 water table data at the time of construction of wells, 6 yield data, 30 well depth data and 16 overburden depth data are available, though there are no detailed location and elevation data at each well. Therefore, wells shown in the figure is approximate.

5.5 BASIN WISE WATER BUDGET

It is possible to determine the groundwater recharge by considering water budget in the system even though no perennial stream exists due to high

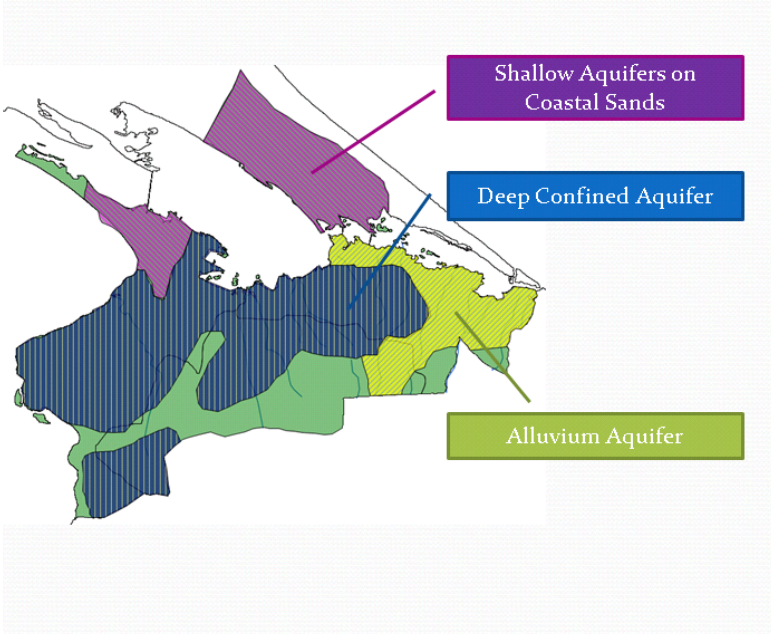


Figure 44: Main Aquifer System in Kilinochchi district

evapotranspiration rate and long-dry (yala) season. Annual water budget of each basin is available from a WRB study. Long term average data generally provides the steady state information, so basin wise water budget can be approximated to:

$$P - R - EVT = 0$$

where
P = precipitation, R = discharge to the sea, and EVT = evapotranpiration.

Furthermore, Discharge to the sea can be divided by Surface Runoff and Groundwater recharge. Surface runoff volume can be estimated based on the landuse distribution. Table 16 shows dominant landuse type and surface runoff rate, and evapotranpiration rate to precipitation at each basin. Values for Groundwater recharge and evapotranspiration in Thoravil Aru (basin No. 78), for example, were prepared as shown in Figure 46.

5.6 REQUIRED DATA

It is practically impossible to use measured field data for all the cells; moreover, In terms of the groundwater data availability only a few published reports on Kilinochchi district are available. However, some additional field data need to be obtained to calibrate the model as well as to verify results. The data listed below are the main missing data at present for model calibration and validation.

- Well data in Kilinochchi (water table with time series, drill logs)
    - Time series data and stratigraphic information of the region are not available.

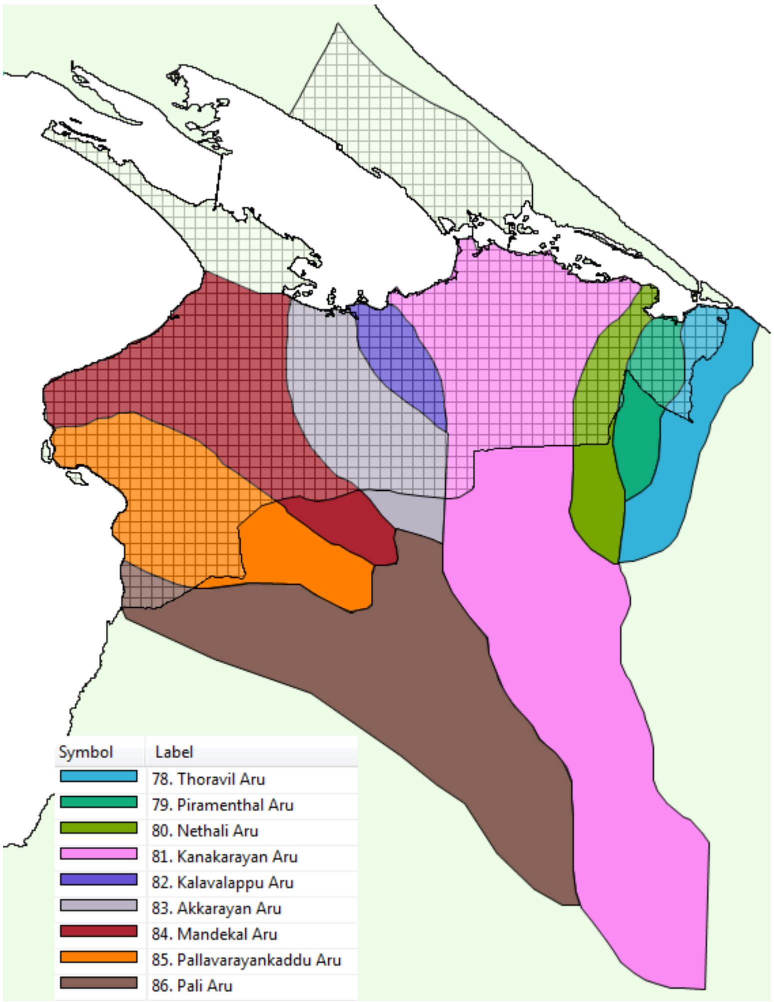


Figure 45: Basin distribution that covers Kilinochchi District (source: irrigation department and survey department database cited from UN Water 2006)

- Aquifer and aquitard property for each type of aquifer (transmissivity, storativity, storage coefficient, leakage factor) from pumping tests.
- Soil property (hydraulic conductivity, saturated moisture content, extinction moisture content, specific yield, etc.)
  - Representative value in other areas in Sri Lanka are used at present in lieu of observations.
- River Discharge time series

5.7 CONCLUSION

Preparing direct local data is essential to obtain reasonable results because groundwater condition greatly depends on local geology and soil types that generally varies over a wide range. However, groundwater status in Kilinochchi district has not been surveyed very much. Moreover, data discrepancies in fundamental information such as geological and soil structures can be seen because these data are not compiled by a single institution.

Basin No.	Basin	Major Land Type	Estimated Rs rate _maha	Estimated Rs rate _yala	EVT rate
78	Thoravil Aru	Forest (59.3%)	0.20	0.04	0.65
79	Piramenthal Aru	Forest (33.3%), Homesteads (30%)	0.15	0.0375	0.71
80	Nathali Aru	Paddy (46.8%)	0.10	0.02	0.71
81	Kanakarayan Aru	Paddy (50.6%)	0.10	0.02	0.72
82	Kalavalappu Aru	Homesteads (38.2), Paddy (32.7%)	0.15	0.0375	0.72
83	Akkarayan Aru	Paddy (35.5%), Forest (29.5%)	0.15	0.0375	0.71
84	Mandekal Aru	Forest (64.9%)	0.20	0.05	0.70
85	Pallavarayankadd Aru	Forest (55.0%)	0.20	0.05	0.69
86	Pali Aru	Forest (63.2%)	0.20	0.05	0.70
N1	No Name 1	Paddy (43.8%)	0.10	0.02	0.70
N2	No Name 2	Coconut (24.1%), Homestead (21.9%)	0.05	0.01	0.70

Table 16: Major landuse type, surface runoff (Rs), and evapotranpiration values at each basin

Therefore, data unification is also important to facilitate the understanding of groundwater potential in Kilinochchi district. The Dam Safety and Water Resources Planning Project (DSWRPP) is, however, constructing the Hydro-Meteorological Information System with WRB. It is a platform for integrating information relating groundwater including geology, aquifer properties, groundwater usage and quality, etc. The DSWRPR project is expected to enhance the understanding of water resources and support more detailed studies in the area.

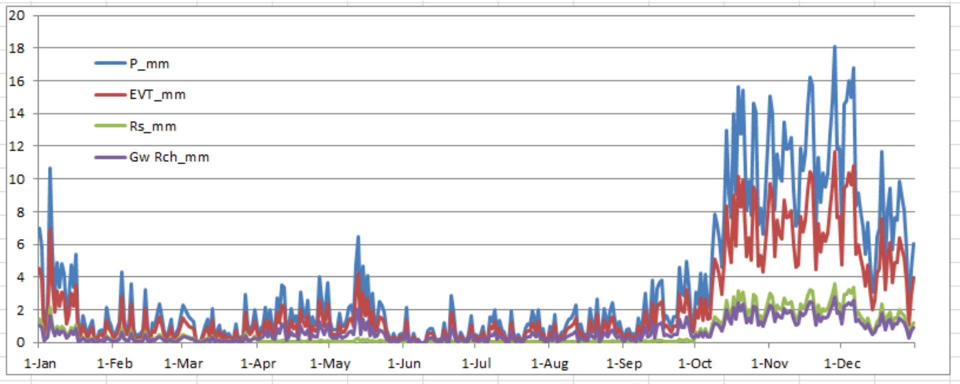


Figure 46: Water Budget of Thoravil Aru

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6

ECOSYSTEM SERVICES OF TRADITIONAL HOMEGARDENS IN INDONESIA, SRI LANKA AND VIETNAM

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6.1 INTRODUCTION

Homegarden has been developed and practiced different places in the world and especially for rural people; it is a main resource of food security. Although the definition of homegarden is varied, Christanty (1985) defines, as a land-use system that has structure resembling a forest and that combines the natural architecture of a forest with species fulfilling the social, economic, and cultural needs of the people. Nair (2006) emphasized that the homegarden practices have been developed and modernized in recent years, which inevitably leads it more commercialized and forming to fit in the urban environment. Homegarden is not only providing foods but various benefits to human-being and nature. According to the conceptual framework of the Millennium Ecosystem Assessment (MA 2003, 2005), the homegarden is an important source of various ecosystem services and contributes to the maintenance of local biodiversity. The MA framework of assessment focuses mainly on linkages between ecosystem services and human well-being, while recognizing that people take decisions concerning ecosystems based on considerations of human well-being as well as intrinsic value of species and ecosystem (MA2005). The MA framework also assumes that a dynamic interaction exist between human and ecosystems, with changing human conditions leading to change in ecosystems and with changes in ecosystems causing changes in human well-being (MA 2005). Apart from this, social, cultural, economic factors also alter the human condition and various natural factors influence the ecosystems. Homegarden ecosystem is a type of landscape, which are intensively managed and modified by humans to avail ecosystem services. The ecosystem services are the benefits people obtain from ecosystem, including provisioning, regulating, cultural and supporting services (MA 2005). These includes provisioning services such as food, fiber (timber and fuel), genetic resources, natural medicines and nutrition; regulating services affect climate, air quality, soil erosion regulation, water purification, pest regulation and pollination; cultural services offers recreational, aesthetics and spiritual benefit; supporting services such as soil formation and nutrient cycling (MA 2005). Furthermore, homegardens contribute to both ecological and social sustainability (Peyre et al. 2006).

6.2 THREE STUDY COUNTRIES

Various homegarden systems have evolved in different places in the world. As this paper focuses on three countries in Asia, Indonesia, Sri Lanka and Vietnam, each region has different characteristics depending on socio-economic and geographic conditions as one of their landuse forms, although other countries like India or Bangledesh have very similar homegarden systems. (Bardhan et al. 2012, Kabir and Webb 2008, Kumar and Nair 2004, Nair and Kumar 2006, Nair and Sreedharan 1986)

Indonesia is the largest island nation in the world and has diverse land-use patterns and various bio-production systems. The development of oil palm plantations has been a major driving force for changes in rural landscape in Indonesia. There are various homegarden systems in different area (Kaya et al. 2002, Kehlenbeck and Maass 2004, Michon and Mary 1994). Pekarangan is a typical traditional homegarden system in Java, Indonesia, which basically managed by individuals and growing various products including timber, vegetables, fruits and so on. (Wiersum 2006)

Sri Lanka had the highest percentage of rural population among Asian nations, which was 85% in 2010 (World Bank, 2011). Kandyan homegardens play an important role both as a link to agricultural and natural landscapes and as an income source in the midlands of Sri Lanka (Pushpakumara et al. 2010).

Vietnam is the second largest rice exporting country in the world, and has shown rapid economic growth as a socialist country with relatively stable political conditions and flexible economic policies. Agricultural production in Vietnam is expected to expand, but such a trend may cause significant changes in rural land-use and traditional bio-production systems, including the VAC system. VAC, a traditional integrated agriculture-aquaculture (IAA) system in Vietnam, stands for Vuon-Ao-Chuong in Vietnamese, which translates to Garden-Pond-Livestock pen. This integrated farming system has spread to all over the country.

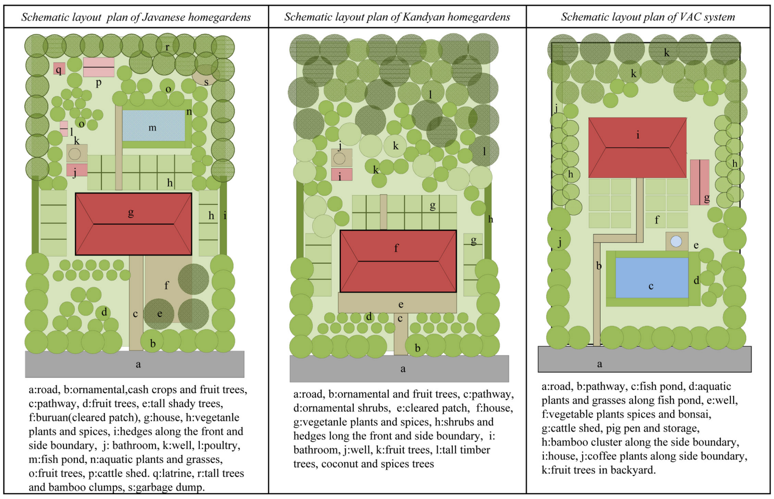
In addition, this study initiated a new research project to investigate a strategy to enhance resilience to climate and ecosystem changes utilizing traditional bio-production systems in rural Asia. The project supported by the Ministry of the Environment, Japan, from 2011 to 2013, selected Indonesia, Sri Lanka, and Vietnam as the case study areas. We know that homegarden systems exist in areas other than Asia as well, but as a pilot comparative study on homegarden systems, it was reasonable to start the study from these three countries, all in the Asian region. Table **??** lists biophysical and socio-economic features of these three countries.

The homegarden is a traditional land-use system that has evolved from prehistoric times (with hunters and gatherers), through ancient civilizations, to the modern era. Hutterer (1984) reported that the homegardens of Java originated in the seventh millennium B.C. The historical sketch suggests that they were attached to temples, palaces, elite residences, and the homes of common people. An old Javanese charter mentioned homegarden systems in AD 860 (Terra 1954), and in modern times, Raffles published the first report on homegardens in 1818. In Indonesia, the homegarden system originated in Central Java and parts of East Java, and spread to West Java in the mid-18th century (Terra 1954).

Early references to a garden in ancient Sri Lankan literature resembling modern-day homegardens can be found in the ancient epic Ramayana. The garden, called Ashok Vatika, was the site where King Rama's wife Sita was imprisoned by King Ravana of Lanka (Puri and Nair 2004; Kumar and Nair 2004). This garden type has evolved into a multistoried vegetation plot established by rural families around their homes using an ingeniously selected mixture of multiple-use species of both indigenous and exotic origin with complementary ecological characteristics (Gunatilleke et al. 1993). In the Kandyan region, rural and semirural tree gardens were also referred to as forest gardens owing to their social functions and links to the local natural forests (McConnell 2003). They present a highly diversified, economically viable crop-mix system evolved through centuries and found in the Kandy, Matale, and Kurunegala districts in the midlands of Sri Lanka (Perera and Rajapakse 1991; Jacob and Alles 1987).

Vietnamese IAA or the VAC system originated in the Red River delta and the midlands of northern Vietnam (Trinh et al. 2003), which optimize land for carrying out various agri-aquacultural activities in dwelling houses. Implementation of the Doi Moi policy in 1986 promoted the VAC system with an aim to increase and stabilize the nutritional standard of the poor rural people (Luu 2001); consequently, integrated farming has spread drastically all over Vietnam (Nguen 1997). The VAC system is especially found in irrigated lowlands, rainfed uplands, and peri-urban areas (Luu 2001), and now almost 44% of all Vietnamese households have such a system (Phong et al. 2003).

Several of the common differences among the three homegardens are related to the position of service area and species layout as shown in the figure **??**. All serfvices such as toilets, bathrooms, wells, smaller fishponds, cattle sheds, and garbage dumps are located in the backyard of the Javanese garden, thus this area is larger than the front yard. The VAC system is opposite of this, with the front yard encompassing a bigger area with a larger fishpond, cattle shed well that are well-organized in front of the house. In Kandy homegardens, a pond and cattle shed are rarely seen. Poultry is common in all the homegardens located in back yards. In both Javanese and Kandy homegardens, ornamental species, fruit trees, and cash crop species are planted in the front yard for aesthetic and security reasons, while vegetable plants and spices, some fruit trees and fiber trees are in the back yard. Vegetables and other plants are planted in front of the house in the VAC system.


Schematic layout plan of Javanese homegardens

Schematic layout plan of Kandyan homegardens

Schematic layout plan of VAC system

Figure 47: Schematic layout plan of homegarden systems

6.3 ECOSYSTEM SERVICES AND HOMEGARDEN

Homegarden system provides key ecosystem services that may be conceptualized as: provisioning, regulating, cultural and supporting services. Apart

Location/Country	Indonesia	Sri Lanka	Vietnam
Local name	Pekarangan	Kandyan gardens	VAC system
Population density (km^2)	7001	500–699	1.1–13.9 (person/ha)[5]
Eco-zone	Humid; medium altitude and lowlands	Humid; medium altitude	Red River delta: Tropical to subtropical, Midlands: Tropical and subtropical, Lowlands: Tropical, Mekong delta: Tropical
Rainfall (mm)	1800–2400	2000–2500	1388–1900
Altitude range (m amsl)	0–6001	400–1000	1–80
Temperature (°C)	22–29	24–26	26–29.5
Relative humidity (%)	Average 75	65–80 (day) and 75–90 (night)	82
Number of vertical canopy	51	3–5	N/A
Dominant soil type	Reddish brown latosol to brown latosols	Reddish brown latosol to immature brown loam	North: Loam and sandy loam, Central: Bazan, South: Alluvial clay, Mekong deSlta: Clay
Slope of land (%)	Varied	10–40	Varied
Land tenure	Privately owned2	Mainly privately owned	Privately owned (allocated by government)
Typology	Traditional and commercial		Traditional, commercial, mixed
Market orientation	Subsistence/commercial	Commercial with subsidiary subsistence	Subsistence/commercial
Net income	6.6–55.7% of total income with an average of 21.1% depending on size, family needs, and composition of homegardens3	30–50% of household income[4]	30–60% of family income

Table 17: Biophysical and socio-economic features of homegardens in the study area

(Sources) 1: Fernandes and Nair (1986), 2: Wiersum (1982), 3: Soemarwoto (1987), 4: Pushpakumara et al. (2010), 5: General Statistics Office of Vietnam (2011) from that homegardens serve as habitat for a large range of flora and fauna and thus help in conserving the biodiversity.

6.3.1 *Provisioning Services*

Homegardens provides food in the various forms like food crops, fruits, vegetables, livestock, aquaculture and wild plants and animal food products. Crops and livestocks are the main products for most of homegardens. The diversity of crops in homegarden is reflected in species composition of various plant categories; food crops, fruits, vegetables, medicinal and spices trees and plants. As you can see in the table 18, very diverse products are harvested in each country. Animal husbandry is an integral part of homegardens, and the choice of animal species is determined by various factors like socio cultural, environmental, financial and religious concerns (Soemarwoto 1987). Milk and egg production provide nutritional security to the rural households and a source of additional income. Animal waste provides manure required to maintain soil fertility and production sustainability. But in Kandyan gardens, the livestock component has relatively less importance (McConnell 2003). A variety of livestock can be found in different VAC households. Pigs, cows, ducks and chickens are common in most places. Such livestock is raised not only to sell or consume but also to use in ceremonies such as weddings or funerals (Tran 2003). Livestock excretions are also fully utilized to fertilize gardens and fishponds (Luu 2001). Aquaculture has been spotted as a main source of food security in terms of income generation and consumption. Increasing of global as well as local demands for aquaculture is greater than ever (Ahmed et al, 2002. and Muir, 2005). Aquaculture is one of three functions of the traditional homegarden in Vietnam. Total production has been dramatically increased over the years, as of the 2002 is almost triple the number of 1990 (Vinh, 2005). Although the diversification of species in the pond is quite rich, the intensification can be seen especially close to big cities like Hanoi (Edwards, 2010). Fiber, genetic resource. natural medicine, and nutrition are also key services of homegarden.

Provisioning services			Javanese homegardens	Kandyan homegardens	VAC system
Food	Crops	Major food crops	Rice, maize, coconuts, taro, sweet potato, cassava, yam, ganyong, spinach, wing bean, eggplant, leafy vegetables, etc.	Rice, maize, green gram, cowpeas, cassava, coconut, jackfruit, sweet potato, taro, yam, juggary and treacle from fish tail palm.	Rice, corn, sweet potato, citrus, black bean, cassava, yam, banana, coconut, jackfruit, banana, luffa, orange pomelo, longan, kumquat, spinach
		Major cash crops	Coconut, banana, orange, mango, jackfruit, papaya, guava, coffee, clove,etc.	Cacao, cloves, cocoa, coconut, banana, coffee, jackfruit, mahogany,nutmeg, pepper and other spices, teak, jak and other timber trees, etc.	Bamboo, pineapple, jackfruit, guava, papaya, banana, lime, orange,pomelo, lychee, pear chilies, kangkon (in the fishpond), etc[8]
	Livestock		Chickens, cows, goats and sheep[7]	Poultry and cattle5: 15% of householders rear livestock[1]	Buffalo, cow, pig, chicken, duck[10]

6.4 regulating services

Recent studies on ecosystem services and environmental benefits of agroforestry system highlighted various regulating services offered by agroforestry systems (Jose 2009; Rao et al. 2007). Regulating services include functions such as sequestration of carbon from atmosphere, soil erosion regulation, waste treatment, water purification, pest regulation and pollination which helps in maintaining a sustainable supply of many provisioning services provided by homegardens.

6.5 cultural services

Studies have shown that culture strongly influences the selection of plants cultivated in homegardens. In Javanese homegardens, medicinal plants, used to treat and protect against diseases as a way to a healthy life, are more than vegetable plants. In contrast, in Sudanese homegardens, more vegetables and ornamentals are planted to suit their eating and visual preferences, respectively; the people also prefer neat gardens. Terra (1954) concluded that intensive homegardening is found in societies with matrilineal traits. Also, homegardens play an important social role in the community life of the Javanese people. Every homegarden has a clear patch shaded by tall trees for children to play and elders to interact with each other during their free time. The gardens are also an important social status symbol (Martadihardja et al. 1980). Traditional homegardens are generally bounded by a live fence of shrubs or small trees that allow easy access to fetch water, collect medicines, and pass through. There is no concept of trespassing, thus homegardens help enhance the social network within the community. In addition, the traditional concept of Rukun Tetangga allows free sharing of homegarden

Provisioning services		Javanese homegardens	Kandyan homegardens	VAC system
	Aquaculture	Fishpond as a part of system	NA	Carps, robu, mrigal, mud carp, tilapia (Limited number of case), soft shell turtle, frogs, snakehead fish, and catfish[8]
	Wild plant and animal food products	Weed species used for herbal medicine, roofing, vegetables, and fodder[7]	Local breeds of chicken, eggs, goat and cow milk[4]	Guava, vegetables, longan, lychee, chilies, cassava, bamboo[9]
Fiber	Timber	Important source of building material e.g., Sandoricum koetjape, crescentia cujete, jack fruit	Supplies 48% of the total sawlog demand of the country[3]	Importance source of building materials and sawlog
	Fuel wood	Supplies 40–80% of the rural fuel wood 6 e.g., Laban, bamboo, muntingia calabura	Supplies 38% of the total biomass fuel demand of the country[3]	Block wattle, litchi, guava, Melia azendarach, Casuarina equistifolia, Mangifera, and bamboo[8]
Genetic resources		Provides habitat for small wild animals such as birds, reptiles, and amphibians	Provides habitat for a wide range of species, from soil micro life to insects, including pollinators, and from crops, trees to mammals, birds, and other wildlife[4]	Provides habitat for small wild animals such as birds, reptiles, amphibians, insects and plants crops
Natural medicines		Extracts from medicinal plant provides treatment against various diseases and is consumed as a way of healthy life style	Most herbs and trees are used medicinally[1] e.g., Turmeric, ginger, vanilla, areca palm, clove, nutmeg, etc.	Plenty herbs and medicinal plants used medicinally such as ginger, clove, artemisia, etc.
Nutrition		Supplies 18% calories and 14% proteins[2], and provides vegetable proteins, carbohydrates, vitamins, and minerals	NA	NA

Table 18: Provisioning services provided from homegarden systems

Sources; 1: Pushpakumara et al. (2010), 2: Ochse and Terra (1937), 3: Gunathilake (1994), 4: Pushpakumara (2000), 5: Perera and Perera. (2000), 6: Wiersum (1977), 7: Soemarwoto et al. (1985), 8: Vien (2003), 9: Trinh et al. (2003), 10: Luu (2001).

products among relatives and neighbors, thereby fostering equitability within the social fabric of the community.

Kandyan gardens serve as a place for intra-family interaction since outside labor is minimally employed. They also set avenues for exchanges in rural villages, such as medicinal output to the needy from the available garden in the village. In addition, they offer a place to meet, for children to play, and other mini social gatherings such as neighbors visiting to check other's wellbeing. Kandyan homegardens have exploited tourism by introducing tourists to spice gardens having unusual species, local herbs, medicinal plants, etc. However, tourism has not been developed in the homegardens of Java, which also have a potential to develop agro-tourism.

For VAC farming, cultural value is significant for most farmers in Vietnam. In general, farmers did not have much choice in decision-making before the Doi Moi renovation, for instance, in selecting which plants to grow. On the other hand, the homegarden is primarily the household's choice, although some communes have a policy to undertake certain farming activities. Some fruit species, such as palm fruit, vine, and lime, are culturally important for rural population. These products are often used for festivals and weddings. Tet, the Vietnamese New Year, is one of the biggest festivals in the country, and the fruits used for the festival are determined by the types cultivated by the home gardener (Trinh et al. 2003).

6.6 SUPPORTING SERVICES

MA (2003) explains Supporting services that it is different from provisioning, regulating, and cultural services in that their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people (MA 2003 p.40). Supporting services includes soil formation, photosynthesis, primary production, nutrient cycling, water cycling (MA 2005). The tropical forests are sustainable because of the dynamics of litter production, decomposition, and the subsequent bio-element release which also occurs in a Javanese homegarden having greater litter fall than that of a typical forest (Gajaseni et al. 1999).

Thus Homegarden system is a sustainable approach to improve soil fertility by nutrient cycling and maintaining organic matter, carbon content, and soil structure. It needs attention by the scientific societies to carry out field studies and coordinated research work to highlight the importance of homegarden system in nutrient cycling and soil formation.

6.7 HOMEGARDEN AND BIODIVERSITY

In understanding the aspects contributing to the biodiversity of homegardens the resilience and evolution of the system itself has to be studied (Galluzzi et al. 2010), though conservation of biodiversity in the tropical landscapes could be made through the agroforestry systems it has largely ignored the homegardens (Webb & Enamul, 2009). In some Javanese homegardens, 78 bird species belonging to 38 families, including 13 legally protected species, were found (Soemarwoto and Conway 1992). However, a detailed inventory list and studies focusing on the biodiversity of homegardens are lacking in

Indonesia. Many endangered species that are diminishing in other areas of Indonesia tend to be protected in homegardens. In addition, many seeds and crops imported from other countries have been adapted for cultivation in most areas of Indonesia. Apart from providing key ecosystem services, Kandyan homegardens are a habitat for a large range of flora and fauna, thereby connecting agriculture with the natural landscape and thus helping conserve biodiversity against the risk of population fragmentation and the need for gene flow, species dispersal, and migration increase (Pushpakumara et al. 2010). They are repositories of germplasm of numerous species (Pushpakumara 2000) and are important for ex situ conservation of germplasm by providing a gene bank. The presence of a high level of fruit tree diversity, various niche specialization, feeding materials, nest specialization, and very low level of disturbances (Pushpakumara et al. 2010) enable high levels of faunal diversity in Kandyan homegardens. In Kandyan homegardens, Hitinayake and Ekanayake (1999) recorded 12 mammal species belonging to 5 orders and 7 families and a total of 35 birds belonging to 5 orders and 14 families, including 5 endemic species. South Vietnamese homegardeners, well known for traditionally growing a variety of fruits, have tree selection procedures and distinguishable layouts for their homegardens (Nguyen 1995). According to Trinh (2003), although there can be seen some trends of monoculture in VAC farmers, however level of biodiversity remaining high in most of places.

6.8 DRIVERS OF CHANGE IN HOMEGARDEN SYSTEMS

Homegardens are dynamic and capable of responding to the socioeconomic changes resulting from rural transformation and diversification of rural livelihood (Peyre et al., 2006). Wiersum stated that commercialization is leading to more specialized cultivation system and generating more primary produtcion activities for rural population resulting in changes in farming and homegarden system (Wiersum 2006). In order to adapt to the socioeconomic changes the subsistence oriented homegardens are increasingly becoming more commercially oriented. Although the impacts of such changes are diffenrent in every region, depending on intesity of rural or urban transformation and sosio-economic changes, the homegardens are showing different trends in development. According to Wiersum (2006) the main trends are; extension in areas of homegardens and changes in structure and composition due to incresing commercialization. And the drivers of change are mainly; socio-economic changes, commercialization, population growth, change in farming system, scientific innovations in health care sector, introduction of invasive alien plant species, inheritance, urbanization, climate change, over exploitation and pollution.

External market demand has led to cash crop production and monoculture, which affect species diversity; thus the structure of the homegardens, which plays an important role in the various provisioning and regulating features, is being affected. Scientific innovation in medicinal and healthcare sector has a strong impact on the usage and validity of traditional medicinal plants in homegardens (Kumar and Nair 2004). The outcome of commercialization is increased production which is obtained by increased use of inputs in the form of pesticides and fertilizers, thus changing a system defined as "low yield, low input, and low risk to a system of high yield, high input, and high risk" (Soemarwoto and Conway 1992). Commercialization is also disrupting the social services of homegardens as well as the social fabric of the village by reducing equitability and causing fences to be installed around the homestead as a security measure for cash crops (Abdoellah et al. 2006).

Another threat to the traditional homegarden is the intentional and unintentional introduction of invasive alien plant species such as Acacia spp., Eucalyptus spp., Mimosa invisa, Mikania micrantha and Calliandra calothyrsus (Richardson et al. 2004; Kumar and Nair 2010). Exchange of seed material through botanical gardens has been one of the major modes of deliberate introduction of alien plant species into the country or an ecosystem (Marambe et al. 2003). Similarly, seed exchange among homegardens may be one of the major sources of escaped alien plant species. Spread of aggressive exotics along with structural changes in rural bioproduction systems could reduce floristic diversity in the homegarden (Kumar and Nair 2010).

Population growth is an indirect driver that has caused land use changes including fragmentation of landholding, which leads to a decline in the average size of homegardens, thereby decreasing income and switching farmers to off-farm employment (Christanty et al. 1986). In addition, because of urbanization, homegarden areas are reduced to cater to the housing demand. In this way, the stable and sustainable system providing various ecosystem services is now being threatened by various human-induced drivers that directly and indirectly affect the services offered by homegardens.

As Lewis (1954) argued, inequity is often led by a shift from traditional farming activities to modern sectors. In Vietnam, rapid economic growth, expansion of markets, population growth and societal changes have made social and economical inequities especially between urban and rural areas in the country. Social and economical inequities in the country have led farmers to choose non-farming activities and abandoning their farmlands as well as homegardens. Moreover, recent changes in consumption and demand-supply relationship as a consequence of industrialization also influence rural farming activities (Mergenthaler et al. 2009; Nguyen and Winters 2011; Nguyen 2011).

Climate change is also considered to bring significant and additional threat to homegarden systems (Pushpakumara et al. 2010). Many farmers in three countries recognized some recent changes in rainfall pattern, temperature, sea level and extreme events like floods and drought at local scale, but scientific assessment of the climate change impact on homegarden systems has not been conducted yet.

In addition to climate change impacts, other direct drivers such as over exploitation and pollution (MA 2005) may have a negative impact on ecosystem services from homegarden systems. For example, in a village near Yogyakarta, fish ponds is one of the typical components of homegardens, but some of them have been abandoned or converted to other use such as livestock (cattle) production due to deterioration of water quality and price increase of feedstock (interview with local farmers on 5 January 2012).

6.9 CONCLUSION

This comprehensive study on the traditional homegardens in Indonesia, Sri Lanka, and Vietnam was performed by means of literature review, field observation, and a set of professional workshops along the MA framework. Nearly 100 relevant articles were collected and examined for this study, although literature or information on homegardens and their ecosystem services are still considerably inadequate for evaluating the complete picture of efficacy, particularly in regard to global changes. Moreover, most studies focus on ecological structure or a specific ecosystem service in a particular study area.

Only a limited number of studies take a comprehensive look at the ecosystem services provided by homegardens on a regional scale. According to this review, homegardens have many functions: as a source of income, place for communication, and a means of conserving traditional culture, biodiversity, and agrodiversity. On the basis of the review of garden components in the study areas, such as spatial layout, temporal or spatial scales, and diversity or functions, we conclude that characteristics and functions of homegardens differ both on a regional and local level within each system. In the study areas of Indonesia, Sri Lanka, and Vietnam, traditional homegardens still exist even after recent socioeconomic changes and the impact of other types of change. These homegardens maintain high ecosystem diversity and provide several ecosystem services. One of the main challenges in the future will be to integrate such traditional homegardens with modern technology and the global economy to enhance the system's resilience. Recently there is an attempt to promote products of homegarden farmers in Kandy to the international market by getting international certifications such as EU organic and USDA National Organic Programme. Further empirical research is also required for evaluating the contribution of the homegarden system for providing resilience against climate and ecosystem changes. Various recent global initiatives, such as the Satoyama Initiative, may become a strong force for encouraging more scientific communities to investigate small and middle scale socioecological production systems such as traditional homegardens in different parts of the world.

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7

KANDYAN HOME GARDENS: AN AGRO-ECOLOGICAL HERITAGE OF SRI LANKA

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ABSTRACT

Home gardens, also known as forest gardens, are traditional agro-forestry systems widely acknowledged in humid tropical regions for their agro-biological diversity, sustainable economic productivity and resilience to environmental vagaries. In Sri Lanka, these traditional home gardens have been a dominant form of land-use in and around the Kandyan districts in the 'mid-country' region and represent an agro-ecological heritage evolved over many centuries. As such, they represent a culturally influenced land-use system involving anthropogenic management of tree- shrub- herb- and climber species of utility value. In their physiognomy, these home gardens are analogous to a natural forest and sometimes include livestock too, all within the precinct of an individual homestead. These gardens vary in structure and composition with climate, elevation and to some extent with owner's' choice.

At the landscape level, the mosaic of home gardens are situated usually on higher ground bordering paddy fields in the valleys. This is the closest analogue to a natural forest landscape in the Kandyan region. During the early growth period of paddy, this verdant landscape is aesthetically very pleasing and a potential visitor attraction. Kandyan home gardens are excellent examples of a mixed-spatial arrangement of vegetation that is characterized by their complexity of structure and a multitude of functions. They are often visited by a wide array of animal species from neighbouring forests and some function as pollinators, fruit and seed dispersers and predators of home garden plant species. The high animal diversity found in Kandyan home gardens serve as mobile links and improve connectivity among natural forest fragments within the region.

The floristic composition of Kandyan home gardens may vary depending on the individual preferences, but collectively they harbour a rich genetic diversity, hence is a valuable germplasm collection of food, fruit, spice, timber, medicinal, fodder and other horticultural species. Kandyan home gardens are world-renowned for the variety of spice (nutmeg, clove pepper, ginger, turmeric, cardamom), fruit (jak, mango, durian, pomelo, avocado) and other (jak, coconut, arecanut, bread fruit) species they harbour, both indigenous and exotic origin.

With the current global concern over climate change and its mitigatory strategies initiated (such as Clean Development Mechanism (CDM) and

Reduction in Emissions from Deforestation and Degradation (REDD+)), the carbon stocks and the sequestration potential of Kandyan Home Gardens with their rich biodiversity conservation and sustainable management has much potential as both adaptive and mitigatory strategies for climate change.

These Kandyan home garden systems are superior to other land use systems at regional and local level since they have the potential to provide a synergy between increased food production, poverty alleviation and environmental preservation thus providing a traditional path towards achieving Millennium Development Goals.

7.1 INTRODUCTION

Kandyan home gardens, also known as Kandyan forest gardens, are a multifunctional productive land use system widespread in the mid-country districts of Sri Lanka. This verdant multi-tiered analogue forest ecosystem exemplifies a highly diversified portfolio of perennial mixed cropping comprising a variety of tree and shrub crops with multiple uses and to a lesser extent livestock (Perera and Rajapaksa 1991; Perera and Perera, 1997; Pushpakumara et al. 2010). They are often found interspersed with low-lying wetland rice paddy ecosystem as an aesthetically blended verdant ridge-slope-valley catenary landscape mosaic. The terraced paddy fields merging into these mixed home garden landscape along hill slopes in the upper elevational Kandyan districts symbolizes the human ingenuity in crafting a delicate balance between optimal economic diversity with ecological sustainability, enriched by religio-cultural traditions passed down over generations. This complex and hence, risk-averse production system comprise a diverse array of perennial crops provisioning a variety of vegetables, roots, tubers, fruits, medicinal plants, sugar products, spices timber and fuelwood (Jacob and Alles 1987, Pushpakumara et al. 2010). Such a repertoire of popularly known 'traditional health foods' produced by remarkably low inputs of external agro-chemicals has continuously provided high levels of nutritional and dietary diversity to households while medicinal species, spices and tree species provide substantial additional income (Hitinayake et al. 1996). Consequently, they have been maintaining a better livelihood from a broader range of market and subsistence products (Pushpakumara et al. 2010).

Kandyan home gardens thus appear to be unique in their floristic and functional diversity, physiognomy, management style and are generally considered at its best manifestation as an epitome of ecological and economic sustainability in Sri Lanka (Perera and Rajapaksa, 1991). The main contributors to the sustainability of these home garden systems are the biophysical attributes such as efficient nutrient cycling offered by multispecies composition, conservation of bio-cultural diversity, product diversification as well as nonmarket values of products and services, and social and cultural values including the opportunity for gender equality in managing the systems (Kumar and Nair, 2004). Socio-culturally, home-gardening fits well with the traditional farming systems and established village lifestyles. These systems have probably evolved over centuries of cultural and biological transformations and they represent the accrued wisdom and insights of farmers who have interacted with environment, without access to exogenous inputs, capital or scientific skills (Kumar and Nair, 2004).

7.2 SPICE TRADE IN ANCIENT HISTORY

Among the market products, Kandyan home gardens are world-renowned for some of the spices such as cloves, nutmeg, pepper, ginger and turmeric they produce. These spices together with Cinnamon and Cassia have known to be commercially traded among countries of Asian civilization since antiquity and eventually found their way in to the Middle East before the beginning of the Common Era (CE). The Greco-Roman World soon followed, by trading along the Incense route and the Roman-India Routes in the 1st century CE according to the Periplus Maris Erythraei, (Periplus of the Erythraean Sea - http://en.wikipedia.org/wiki/Spice-trade). This spice trade flourished well into the medieval periods when the economically important Silk Road and spice trade routes were blocked by the Ottoman Empire ca. 1453, with the fall of the Byzantine Empire. This spurred exploration by the European nations, motivated initially by the finding of a sea route around Africa and triggering the Age of Discovery.

During the Middle Ages, spices were as valuable in Europe as gold and gems and the single most important force driving the world's economy. The lack of refrigeration and poor standards of hygiene meant that food often spoiled quickly and spices were in great demand to mask the flavour of food that was far from fresh. Fierce competition among European nations for control of the spice trade was the driving force behind the colonization of India and other Asian lands.

At different times, the Portuguese, Dutch, French, Spanish, and English established monopolies over various parts of the spice trade. This period saw empires founded and fortunes made and was also characterized by brutal conquests, piracy, and greed. This era saw the formation of trading empires such as the Dutch as well as British East India Company.

By the year 1511, the Portuguese were in control of the spice trade of the Malabar coast of India and Ceylon (Sri Lanka). The main product brought back to Lisbon was black pepper. Piper nigrum was as valuable as gold in the age of discovery. In the 16th century, over half of Portugal's state revenue came from West African gold and Indian pepper and other spices. The proportion of the spices greatly outweighed that of gold.

The Portuguese monopoly on the pepper trade ended with the entry of the Dutch into the trade war at the end of the 16th century and Holland took the cinnamon trade in Ceylon in 1658. England was also emerging as a major player in this spice trade war in the 1600s and gradually consolidated their power in the region through the British East India Company in the 1780s. By the 1800's almost everything that once belonged to Portugal and Holland was controlled by the British which they virtually monopolized until its colonial rule ended since mid-twentieth century.

7.3 SPICE ECONOMICS

The spices and beverage crop sector has been an important sub-sector of the economy of Sri Lanka. While spices contribute about 0.56% to the total Gross Domestic Product, its share in the foreign exchange earnings from agricultural products is about 8.4%. Spice based activities provide employment for about 470,000 persons which is about 10% of the agricultural labour force.

In addition, these mixed home gardens provide environmental services by reducing land degradation and improving soil and hydrological properties.

Presently, the export market share of the all spices has increased from 1.30% (2004) to 2.4% (2010) showing that the spice industry of Sri Lanka is becoming an important source of foreign exchange generation (Central Bank of Sri Lanka Annual Report 2011; Export Agriculture Department, Kandy, 2009).

7.4 ECOSYSTEM SERVICES AND ENVIRONMENTAL BENEFITS FROM KANDYAN HOME GARDENS

In addition to these important economic and social benefits, the Kandyan Home Garden system also provides key ecosystem services and habitats for a range of flora and fauna (Pushpakumara et al. 2010). Kandyan home gardens are found in several regions of the ancient Kandyan Kingdom and its immediate surroundings, which include the present day districts of Kandy, Matale, Kurunegala, Kegalle, Ratnapura, Nuwara Eliya, Badulla and Moneragala or parts thereof, encompassing mid-elevational ridge-valley landscape of south-central Sri Lanka. A number of studies have listed well over hundred plant species cultivated in Kandyan home gardens (Hitinayake et al. 1999; Jacob and Alles 1987; Mendis, 1980; Perera and Rajapaksa, 1991; Pushpakumara et al. 2010; Hochegger, 1998), They may have been either intentionally selected by traditional farmers through generations or naturally established through dispersing animal vectors thereby harbouring a rich heritage of potentially valuable agricultural biological diversity.

In contextualizing this ancient agrobiodiversity heritage of Sri Lanka to modern times as described in the Millennium Ecosystem Assessment (MA), the Kandyan home gardens contribute in no small measure in i) provisioning services (food, fresh water, fuelwood, fiber, biochemical, genetic resources) ii) regulating services (local climate & water regulation, soil stabilization, water purification, disease regulation, pollination & maintenance of a complex food web) iii) cultural services (spiritual, cultural, aesthetic, recreational, inspirational and educational). In addition, these home gardens provide supporting services (soil formation, nutrient cycling, primary production) necessary for procuring all other ecosystem services required for human well-being. A deeper and holistic understanding of scientific principles of these multispecies systems and recognizing their socio-cultural attributes will have much to offer in the development of sustainable agroecosystems in this era of climate change with looming food and water security issues. Further research on economic valuation of the tangible as well as intangible products and services, principles and mechanisms of resource sharing in mixed plant communities, and realistic valuation and appreciation of hitherto under-recognized benefits such as carbon sequestration and cultural tourism will provide a sound basis for formulating appropriate policies for better realization and exploitation of the benefits of home gardens (Kumar and Nair, 2004).

The ridge-slope-valley catenary landscape in the south-central Sri Lanka is a good example depicting the International Man and the Biosphere concept in conservation and integrated sustainable management of natural and agroforestry heritage of Sri Lanka. The relict patches of natural forests often left on ridges and upper steep-slopes represent the core zone which gradually merge into home gardens in the middle and lower slopes which act as a kind of a buffer zone with rice fields in valleys and terraced lower slopes representing a transition zone. This mosaic of land use provides regulatory services such as amelioration of local climate and provisioning of perennial water supply, slope stabilization and soil formation.

7.5 RESTORATION OF MIXED-SPECIES ANALOGUE FORESTS

This land use matrix also provides connectivity among fragmented natural forests facilitating the movement of pollinators, seed dispersers and even predators thus maintaining a complex, yet fragile food webs across the entire landscape while facilitating gene flow among forest fragments via multi-tiered home gardens. However, this delicate balance of the food web is disrupted in some instances to the extent of smooth functioning of home garden system by the explosion of populations of animal pests, in particular. Among these, the wild boar, torque monkey, porcupine and the gray hornbill are more widespread in Kandyan home gardens and they are on the increase much to the consternation of the home garden practitioners. This may, at least be partly due to the reduction in habitats for top carnivores in the fragmented forest-scape. Such instances have often resulted from the reduction of natural forests below a critical minimum for maintaining viable populations of top predators such as civet cats and jackals in this mid country landscape. Replacement of these natural forests with large scale tea plantations during European colonization and subsequent abandoning of some of them due to lower productivity have lead to the development of fire-prone grasslands locally known as 'pathanas' drastically affecting the populations of these predators. The establishment of exotic monoculture plantations of Pinus caribaea in these grasslands on hill crests and upper slopes for conservation of water and arresting of soil erosion has fallen far short of desired outcomes with growing public antipathy towards them. These exotic gymnospermous monocultures are a poor substitute for the natural forest that they eventually replaced with and are having a simpler food web unintegrated with that of the home garden system. These barren landscapes of fire affected pine plantations do not harbor the pollinators, seed dispersers and predators that the natural forests once gave refuge to and as such, while most generalist pollinators and seed dispersers are sustained in home gardens, they do not serve as safe havens for the top carnivores and predators of animal pests leading to their uncontrolled population growth. These monoculture plantations therefore, are not the best substitutes for natural forests and home gardens, environmentally, biologically and even socio-culturally. Therefore, a strong case is made for conversion of these monoculture plantations to multi-storied and multi-functional analogue forests of broad-leaf species giving due consideration for plant-animal interactions amongst them that would maintain healthy checks and balances of incumbent biotic populations through natural processes of biological control. Successful pilot studies have been carried out in converting Pinus monocultures in to mixed species and multiple-use assemblages of broad-leaf species providing a matrix for a number of medicinal and other utility species to be inter-planted with (Gunatilleke et al. 2005 and references therein).

7.6 THREATS TO KANDYAN HOME GARDENS

Urbanization and population increase leading to unplanned land use, pollution and fragmentation are among the foremost threats to the existence of Kandyan home gardens (Pushpakumara et al. 2010). Furthermore, a serious threat of recent origin is the damage caused to the plants and their produce by expanding populations of wild animals such as torque monkey, wild boar, porcupine and the gray horn bill . Out-migration of rural population resulting in reduction of labour availability coupled with market fluctuations also have lead to the neglect of home gardens in some of the rural outposts of Kandyan districts, particularly those bordering protected forest reserves. However, with the emerging interest in ecotourism, those in strategic locations have turned around their fortunes considerably through internalizing the economic value of the biodiversity they contain and the ecosystem services they provide.

7.7 KANDYAN HOME GARDENS - NEW AND EMERGING HORIZONS

1. Fair trade marketing strategies: Some entrepreneurial private sector companies like Bio Foods (http://www.biofoodslk.com) have developed innovative export-oriented marketing strategies of organically grown and sustainably produced herbs and spices while providing direct benefits to the participating rural communities. An organization of small organic farmers groups registered as a Fair Trade certified tea and spice producers under the Fair Trade Labelling Organization (FLO) has been established by this company providing opportunities for livelihood improvement, environmental amelioration and religio-cultural and social well being of the communities involved. Some of them are from marginalized and poverty-stricken regions of the country thus contributing directly towards achieving Millennium Development Goals (MDG 2000) while giving due consideration in restoring healthy relationships between ecosystem services and human well-being as defined in the Millennium Ecosystem Assessment (MA 2005).

2. Carbon sequestration in Kandyan Home Gardens. The traditional agroforestry systems such as Kandyan home gardens with long rotation cycles and variable rotation lengths of incumbent species are recognized as a major potential sink sequestering significant quantities of C in the multi-storied above ground plant biomass as well as in their below-ground biomass while providing a range of benefits for human well-being (Montagnini and Nair, 2004). Consequently, these systems have been proposed as candidates for mitigation strategies under Kyoto Protocol such as Clean Development Mechanism (CDM) and the Reduced Emissions from Deforestation and Forest Degradation along with conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) (Pandey 2002; Albrecht and Kandji 2003; Montagnini and Nair 2004). In Sri Lanka too, inventorying plant cover and estimating carbon sequestration potential in Kandyan home gardens have been initiated (Dissanayake et al. 2009; Anon 2012). These recent trends in valuation of various ecosystem services including their contributions in mitigating carbon dioxide emissions to the atmosphere through development of capital markets in carbon trading for the benefit of local land owners would provide exciting opportunities to sustain this national agro-ecological heritage of Sri Lanka. These home garden systems are superior to other land use systems at regional and local level since they provide a synergy between increased food production, poverty alleviation and environmental preservation.

3. Restoration of home gardens for livelihood development & ecotourism promotion: Therefore, it is most fitting that the Government of Sri Lanka under the 'Mahinda Chinthanaya – Vision for the Future' has launched the Divi Neguma programme which aims to support agriculture, small scale industries and fisheries and livestock activities to support household units to be self-sufficient and financially secure. During the initial phase, one million home gardens have been selected for this programme giving priority for the cultivation of vegetables and fruits for local consumption. In Kandyan districts, this could be extended to include spice plants, too.

Likewise, under the tourism development programme, traditional home stays are being promoted and the Kandyan Home Gardens with local chieftains' hereditary 'manor houses' have become increasingly popular as a specialized category of smaller 'Boutique Hotels' for ecotourists who wish to experience the traditional life styles in the sylvan tranquil of a Kandyan home garden.

In time to come, these would become popular among the Sri Lankan expatriates domiciled overseas and also the local urban elite who would wish to experience the country cottage types holidays

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APENDIX

CECAR-ASIA PROJECT: SUMMARIES OF THREE LAUNCHING WORKSHOPS IN VIETNAM, SRI LANKA AND INDONESIA

CECAR-ASIA has organized regional meetings with local counterparts to start the research projects in the three target countries. This section provides a summary of workshops and the discussions.

8.1 CECAR-ASIA KICK-OFF WORKSHOP IN VIETNAM

Venue: Vietnam National University, Ha Noi Date: 30th July 2011

The workshop was co-organized by VNU, University of Tokyo, UNU-ISP and RINH to launch the regional research4 project on 30th July 2011 at VNU in Hanoi city. The event was started with opening speech by Prof. Mai Trong Nhuan, President of VNU to cerebrate successful launching of the CECAR-ASIA project and promised the cooperation to carry out the research activities in Vietnam. Prof. Nhuan emphasized that the importance of sustainability in resource management and future climate impacts on these related areas. Prof. Kazuhiko Takeuchi, Professor of University of Tokyo and Director of UNU-ISP introduced the overall concepts and plans of CECAR-ASIA project, "Strategy to enhance resilience to climate and ecosystem changes utilizing traditional bio-production system in rural Asia" as a project leader. Prof. Takeuchi pointed out that innovative and dynamic background of this project, which is combining two global initiatives, UNFCCC and UNCBD's discussions; it is to strive for integrating climate change and biodiversity policies as well as establish effective International frameworks on adaptation and REDD+ as well as that on mitigation. Dr. Matsuda explained activities and framework of sub-theme 1, which focuses adaptation of biological production to climate and ecosystem change. Prof. Kurokura, Professor of University of Tokyo, followed up detail plans and past experiences/research on fisheries in Vietnam and the importance of the research which will be conducted with local counterparts. Dr. Srikantha Herath, Senior Academic Programme Officer of UNU-ISP and Mr. Hideyuki Mohri, Programme Associate of UNU-ISP introduced sub-theme 2's overall framework of the research on "resilience enhancement through traditional knowledge and technology" and review studies of traditional homegarden and irrigation systems in Vietnam, Sri Lanka and Indonesia. Prof. Kenichi Abe, RINH briefly explained the activity plan of theme 3 "crop production system in harmony with conservation of biodiversity". Prof. Abe illustrates the role of VAC farming as a "shadow economy" for households and historical evidences in the country.

The VNU research team gave basic information of climate change impacts in Vietnam and potential research fields. Prof. Nhuan showed the figures and current status of climate change impacts in the national level of the country. Various scientists have already reported the adverse impacts of

Figure 48: Kick-off meeting in VNU, 30th July 2012

climate change, especially impacts of sea level rise in the coastal areas should be seriously considered according to the President of VNU. Finally Potential field sites were introduced by Dr. Hoang Van Thang, director of CRES, VNU who has been working in the climate change adaptation research in Vietnam. Dr. Thang brought out two background information in the two field sites, Ba Vi district and Tan Linh district. Ba Vi is the largest districts in Hanoi, where North East to the capital and consist of 30 communes. Almost half of the total area is mountainous and Tan Vien, the highest mountain in the region, reaches 1296m. Population is 261,654, and recently the place has been attracted as a great potential in tourism. Giao Thuy district is located in the coastal zone, where east to Hanoi. Giao Thuy has potentially various natural resources, including biological, land, water and mineral resources. Giao Thuy has a Lamsar site, Xuan Thuy National Park where has great aquaculture diversity and biodiversity, especially well known in numerous bird species.

National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC

Figure 49: A map of field visit sites

A general discussion followed on refining the objectives and the methodology to be adopted. Dr. Herath (UNU-ISP) presented a framework that can be used to understand and respond to global change challenges by enhancing community resilience (Figure 50).

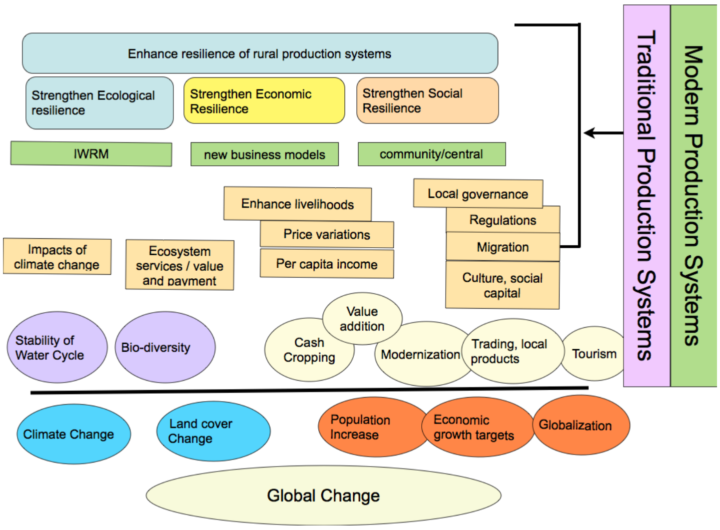

Figure 50: Framework for enhancing community resilience for responding to global change challenges

8.2 CECAR-ASIA KICK-OFF WORKSHOP IN SRI LANKA

Venue: Hotel Topaz, Kandy Date: 17th - 20th September 2011

University of Peradeniya hosted a kickoff workshop of CECAR-ASIA project in Sri Lanka on 17th September and organized field visits from 18th to 20th September. Prof. S.B.S.A. Abayakoon, the Vice Chancellor of University of Peradeniya, opened the workshop with the Welcome Speech. He warmly welcomed the Japanese research group to the workshop and emphasized importance of a long collaboration with UNU-ISP and further cooperation. Following the speech by the Vice Chancellor, Prof. S.B. Weerakoon, Dean of Faculty of Engineering, introduced Sri Lankan participants in the workshop and overall structural plan for the newly launched project on traditional knowledge and technology in Sri Lanka. The research group focuses ancient irrigation and traditional homegarden in the country.

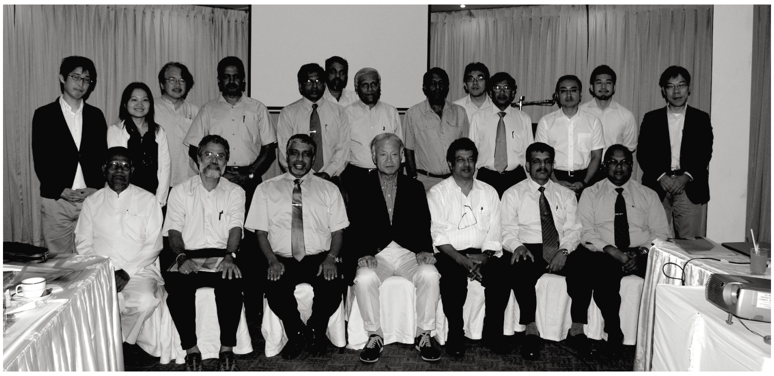

Figure 51: A kick off meeting in Sri Lanka on 17th September 2011

The kick off meeting consisted of two sessions, first half is introduction of the CECAR-ASIA and research plan by Japanese colleagues, and session 2 is presentations by Sri Lankan scholars on traditional knowledge and technology, which is followed by open discussion. Prof. Takeuchi introduced the overall concept of CECAR-ASIA project. There are three pillars in the CECAR-ASIA research framework to make strategies for enhancing resilience to climate and ecosystem changes; 1) Collaboration of climate change and biodiversity policies, 2) introduction of "resilience" concept into global environmental policy and 3) re-evaluation of traditional knowledge and technologies, integration with social system in advanced technologies. Dr. Matsuda explained overall strategies in sub-theme 2, which focuses on Adaptation of biological production to climate and ecosystem change. Dr. Matsuda explained methodologies on the analysis particularly on Stochastic Frontier Model. Secondly Dr. Herath shared past experiences and plans for this 3-year project, how to establish a mosaic systems with traditional and modern schemes. Mr. Mohri, UNU-ISP followed with explaining homegarden studies, and introduced review studies done by research team. Finally Dr. Kume, RINH, introduced definition of resilience, which is a key concept for the whole project. He uses "BIG DOG" <http://www.youtube.com/watch?v=cNZPRsrwumQ> as a metaphor of resilience to illustrate.

In the session 2, Prof. Gunatilleke had a presentation on "Kandyan homegarden" and introduced history, ecological as well as social perspectives of the traditional homegarden system. Prof. Bandara gave a brief introduction of Globally Important Agriculture Heritage Systems (GIAHS), which initiated by Food and Agriculture Organization of United Nations (FAO), and introduced 3 traditional Sri Lankan agricultural systems, 1) tank- based cascade agricultural systems, 2) forest gardens, and 3) ancient and spring-based agricutlral systems. Finally participants discussed future needs of the research and detail planning on the 3-yaer project in Sri Lanka.

AGENDA	
Welcome Speech	S.B.S.A. Abayakoon, University of Peradeniya
Opening Remarks	S.B. Weerakoon, University of Peradeniya
Session 1	
Introducing the CECAR-ASIA initiative	Kazuhiko Takeuchi, University of Tokyo and United Nations University
Research on Adaptation of Biological Production to Climate and Ecosystem Change	Hiroyuki Matsuda, University of Tokyo
Research on Resilience Enhancement through Traditional Knowledge and Technology	Srikantha Herath and Hideyuki Mohri, United Nations University Institute for Sustainability and Peace
Research on Crop Production System in Harmony with Conservation of Biodiversity	Takashi Kume, Research Institute for Humanity and Nature (RINH)
Session 2	
Kandyan Home Gardens- An Agro-Ecological Heritage of Sri Lanka	I.A.U.N. Gunatilleke, Faculty of Science, University of Peradeniya
Globally Important Agricultural Heritage Systems (GIAHS)- FAO Initiative and Reconnaissance Surveys in Sri Lanka	C.M. Madduma Bandara, Emeritus Professor, University of Peradeniya
Discussion	

8.3 CECAR-ASIA KICK-OFF WORKSHOP IN INDONESIA

Venue: Gadjah Mada University, Indonesia Date: 6th - 8th January 2012

Prof. Ir. Tumiran, Dean of Engineering, Gadjah Mada University opened the workshop and briefly introduced the University's past works on climate and ecosystem change. Gadjah Mada University has significantly contributed into UN-CECAR, particularly for developing postgraduate level curriculums in climate change. The University hosted a UN-CECAR conference and workshops in 2010, the workshops focused on curriculum development especially in the areas of climate change adaptation and resilience. There was an extensive discussion on the collaborative research on traditional bio-production systems in Indonesia after the speech by Prof. Tumiran. A concept of "Triple E" introduced by Dr. Sudiyo is an important perspective in the joint research project to identify the systems. Triple E concept is to consider Ecology, Equity and Economy as the main factors of environmental management. For instance in the water management, ecology focuses Sustainable environmental conservation as natural resources. Equity is related to dynamics and variability of community's social condition and conflict potential due to policy and implementation. Finally Economy gives direction to welfare through "added value" efforts of natural resources. Each of the aspects has roles in the livelihood perspective. Ecology-Livelihood means suitability of the land to support cultivation, particularly agro production that needs constant water supply.

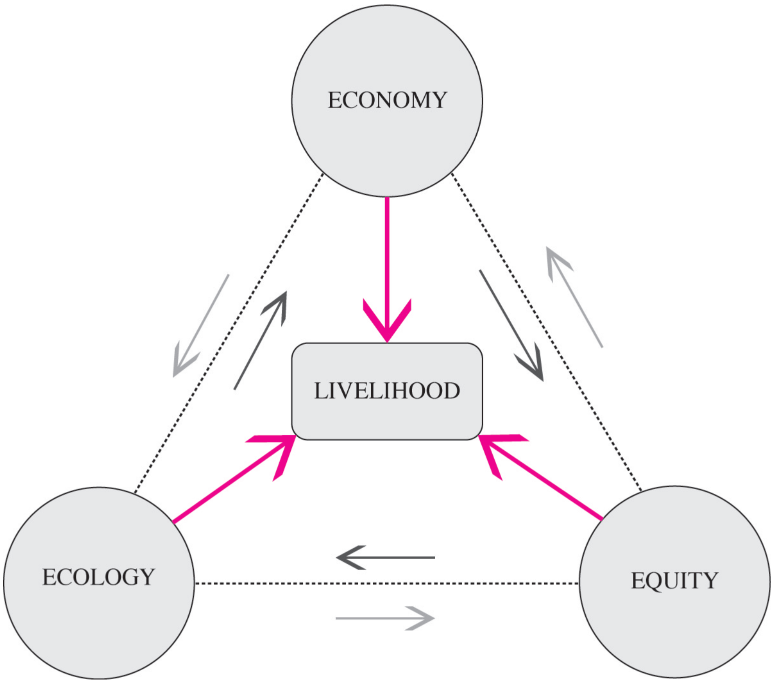

Figure 52: Trip E concept diagram

No	Name	Faculty
1	Ir. Tumiran, M.Eng., Ph.D	Engineering
2	Rahman Sudiyo, ST., MT., Ph.D	Engineering
3	Dr. Ahmad Agus Setiawan, ST., M.Sc	Engineering
4	Dr. Ali Awaludin, ST, M.Eng.	Engineering
5	Dr. Ir. Rachmad Jayadi, M.Eng.	Engineering
6	Ir. Darmanto Dip. HE, MSc.	Engineering
7	Intan Supraba, ST., M.Sc	Engineering
8	Dr. Muhammad Ali Imron	Forestry
9	Prof. Dr. Ir. Irham, MSc.	Agriculture
10	Dr. Subejo, SP., M.Sc.	Agriculture
11	Ir. Anjal Ani Asmara, M.Si.	Agriculture
12	Prof. Dr. Didik Indradewa, Dip.Agr.St.	Agriculture
13	Arini Wahyu Utami, SP.,M.Sc.	Agriculture
14	Dyah Woro Untari, SP.,M.Sc.	Agriculture
15	Dr. Jangkung HM, SP.M.Ec.	Agriculture
16	Dr. Suadi, S.Pi., M.Sc.	Agriculture

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