ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

CAPaBLE Programme Final Report

Project Reference Number: CBA2015-06NSY-Silva

Escalating Small Hydropower Development and Aquatic Biodiversity of Mountain Streams in Sri Lanka

Water Resources Science & Technology, Sri Lanka,
eils.wrst@gmail.com

WRST

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"Escalating Small Hydropower Development and Aquatic Biodiversity of Mountain Streams in Sri Lanka"

Final Report submitted to APN

OVERVIEW OF PROJECT WORK AND OUTCOMES

Preliminary studies revealed that negative impacts of poorly designed small hydropower plants are very diverse; primarily effect on aquatic biota in terms of population decline and eventual species extinction including fish species endemic to Sri Lanka (Silva & Davies, 1986; Silva, 1993; Silva et al., 2013; 2014; 2015). At present, in Sri Lanka, about 600 stream sites have been identified as potential sites and about 150 plants have already been in operation in various river basins. Further, 1-2 km stream stretch had been notably affected at each small hydropower plant. In most cases, the developers do not maintain ecological flows, which is a requirement according to the Environmental Act of Sri Lanka. The negligence of the developers and poor understanding of the relevant authorities have led a devastating damage to the mountain stream ecosystems in terms of aquatic biodiversity and goods and services provided to the riparian communities. Therefore, Water Resources Science and Technology (WRST), a non-profit making company registered under guaranteed sought financial assistance from Asia-Pacific Network for Climate Change Research (APN)under CAPaBLE programme to carry out project with a view to build up the awareness of different categories of stakeholders in small hydropower generation sector, namely, small hydropower developers, consultants to developers, environmental officers, and relevant policy makers on the importance of correct design and operation of environmentally sustainable small hydropower plants. It is also anticipated convey the message to the riparian communities in hill country landscape. The WRST was successful to be a grantee for an award of US$ 20,000 under the CAPaBLE programme (2015/2016) to carry out the following activities as proposed in the project entitled ‘Escalating Small Hydropower Development and Aquatic biodiversity in Mountain Streams in Sri Lanka”.

Activity I. Preparation of Brochure/Leaflet highlighting the negative impacts of poorly designed and incorrectly opening small hydropower plants to be distributed among the village headmen of the mountainous Districts.

Activity II. Preparation of handbook entitled “Small Hydropower Development and Environment – A case Study on Sri Lanka”

Activity III. Preparation of a Wall Photograph depicting endangered endemic fishes inhabiting hill streams to be distributed among Divisional Secretariats of Mountainous Districts.

Activity IV. Conduct a Two-day training workshop for Environmental Officers on “Stream Ecology and Environmental Flow”

Activity V. Conduct a one-day awareness programme for District Secretaries of mountainous Districts on “Hill Stream Landscape in Sri Lanka”

The expected outcomes of the project were;

- ☐ Sustainability of ecologically sensitive, critical stream sites as national assets.
- ☐ Aquatic biodiversity in hill streams rich in fishes endemic to Sri Lanka
- ☐ Environmental officers with sound knowledge on negative and positive impacts and malpractices of small hydropower plants
- ☐ Introduction of teaching Stream Ecology and Environmental flow at academic institutes

- Upcountry communities vigilant on environmental conservation.
- A handbook providing information on small hydropower development and aquatic biodiversity – A case study of Sri Lanka,
- Publications in peer reviewed journals for dissemination of knowledge
- Awareness of SAARC countries in the Asia Pacific region and the other parts of the world on positive and negative effects of small hydropower generation

The project activities were carried out from May 2015 to June 2016 according to the well-planned timeline with the help of the voluntary staff of WRST. Brochures/leaflets were distributed among about 32500 *Grama Niladharis* (Village Headmen) while getting positive responses from some of them. The handbook was written by two authors on "Small Hydropower and Environment" and it contains important and comprehensive information according to the reviewers. Seventy-two persons representing 23 government and non-government institutions including some universities actively participated in the two-day residential workshop held at Kotamale International Training Institute located in the hill country on "Stream Ecology and Environmental flow". The handbook on Small Hydropower authored by E.I.L. Silva and E.N.S. Silva was launched during the inaugural session and it was distributed among all participants of the workshop. During the two-day training workshop, a vast area with important disciplines was highlighted by the resources persons whereas panel discussions exposed the current status of mini-hydropower operation in Sri Lanka. An informal network was also formed during the workshop to further examine this environmental and socio-economic issue. A comprehensive dialogue followed by a panel discussion organized by Environmental Foundation Limited in collaboration with Lanka Jalani (Global Water Partner) was held in Colombo as an immediate event. Construction of two hydropower projects was suspended by court orders due to malpractices.

Wall photographs depicting endangered endemic fishes inhabiting hill streams in Sri Lanka as reported in IUCN Red Data List and recent publications were prepared to distribute among Divisional Secretariat Divisions where the people in the area visit to get the livelihood assistance in different forms provided by the government. This is the place where most of the environmental officers carry out their duties and meets general public. As the last project activity, one-day awareness programme was conducted on "Hill Stream Landscape in Sri Lanka" for the Divisional Secretaries of the mountainous Divisional Secretariat Divisions. They are the responsible government authorities of land and water resources of the respective territory and their approval is compulsory for the acquisition of land or water resources for any development activity. Their knowledge on the importance of natural resources to be intact to sustain the environment was enhanced by veteran subject specialists. They were also enlightened on the heavy rains, floods and landslides occurred in the country with the onset southwest monsoonal rain and how to implement management strategies and adaptation under disaster situations. Because it is well known that the hydropower development promotes landslides, which can be more pronounced in the future under climate change scenarios in monsoon Asia. The project was completed successfully within proposed time period producing anticipated outcomes.

Non-technical summary

Energy is important for the mankind to perform their daily needs. Hydropower is considered as one most benign modes of energy generation without many environmental problems compared to other methods of power generation, especially fossil fuel burning, which emits greenhouse gases, the main culprit of climate change. Although, small hydropower plants generate the least amount of greenhouse gases, poor construction and incorrect operation in large numbers by arresting mountain streams, exert a larger environmental and socio-economic damage than building large dams, as they dry up long stretches of stream channels and de-route of water via artificial channels and canals. Weirs or dams built across streams without bypass facilities block upstream fish movement and destroy breeding and nursery grounds of fish. Rainwater collected in small ditches in dried up stream stretches are excellent breeding habitats for pathogenic organisms. People living along the stream between the dam and the powerhouse have no water for their daily activities. Nevertheless, reported studies on this tragedy are scanty. APN-funded project carried out by Water Resources Science and Technology on Small Hydropower and Environment, passed this message to the people living in remote mountainous villages, the government officers responsible for inspection of mini-hydropower plants and the higher officials those who approve and grant permission for construction and operation of mini-hydro, through distributing leaflets and conducting training and awareness programmes.

Keywords: Small Hydropower, e-Flows, Hill Streams, Endemic Fish, Sri Lanka

Objectives

The main objectives of the project were;

1. Convince the relevant authorities, the gravity of poorly designed and scientifically unsound establishment and operation of small hydropower plants on aquatic biodiversity with special emphasis on endemic fish species

2. Build up the awareness of the divisional secretaries of up country divisional secretariat divisions on the importance of correct site selection, proper construction and operation, implementation of mitigation measures and monitoring of small hydropower generation.

3. Enhance the knowledge of relevant environmental officers on ecological flow and biological integrity of stream ecosystems.

4. Build up the awareness of up country riparian communities how to be vigilant with natural resources associated development activities.

5. Disseminate the environmental issues associated with small hydropower plants, locally, regionally and in global context

Amount received and number years supported

The Grant awarded to this project was:
US$ 20,000 for one year

Activities undertaken

Activity I: Preparation of a brochure in English and Sinhala, which highlights the impacts of small hydropower development on aquatic environment and livelihood of riparian communities

Activity II: Preparation a wall photograph depicting hill stream fish fauna native and endemic to Sri Lanka with their status as given in IUCN Red Data Book.

Activity III: Preparation of a handbook entitled "Small Hydropower and Environment – A case study on Sri Lanka" to be distributed among the environmental officers, divisional secretaries, up country school libraries, environment related NGOs and relevant government institutes.

Activity IV: Two-day training workshop on "Stream Ecology and Environmental Flow".

Target Group: Provincial and District environmental officers

Venue: Kotmale International Training Institute (KITI) located closer to Kandy (hill capital)

Resource persons: From IWMI, WRST, University of Ruhuna, and Central Environment Authority (CEA), Ceylon Electricity Board (CEB)

Programme: Day 1, Lectures; Day 2, Field Visit (morning) and Discussions (afternoon)
During this programme, the brochure and the handbook were distributed among the participants

Activity V: One-day awareness programme on "Hill Stream Landscape in Sri Lanka".

Target Group: Divisional Secretaries of eleven Districts (viz., Kandy, Matale, Nuwara Eliya, Badulla, Ratnapura. Kegalle, Kalutara, Galle, Matara and Monragala), which have 71 divisional secretariats in the mountainous landscape

Venue: University of Peradeniya, Kandy (the hill capital)

Resource persons: From WRST, IWMI, University of Peradeniya,

Programme: Lectures were delivered by subject specialists with special emphasis on small hydropower projects. During this programme, the brochure, wall photograph and handbooks were distributed among the participants

Results

Awareness building of about 3250 Village Headmen (*Grama Niladharis*) of remote villages in 71 Divisional Secretariat Divisions of 10 Districts in Sri Lanka on environmental and social impacts associated with the establishment of mini-hydropower plants.

Training of 71 participants representing 23 government institutions and non-governmental organizations, in energy, environmental, water resources, and land resources sectors and universities on Stream Ecology and Environmental flow.

Awareness building of 20 Divisional Secretaries, the custodians of the land water resources of the country on the importance of the conservation and management of natural resources to sustain nation's biodiversity and endemism.

Formation of a Network of non-governmental organizations for lobbying when aquatic resources related environmental issues that can exert effects on climate change emerge**.**

Relevance to the APN Goals, Science Agenda and to Policy Processes

The outcomes of the project carried out under a CAPaBLE programme funded by APN (e.g. knowledge base, awareness, networking and dissemination, and expert and organizational system linkages) are eventually owned by the local stakeholders of the country and member countries of the SAARC region to some extent. By all materials produced and the knowledge transferred through the project, it is ensured that Sri Lanka, as well as the other nations of the SAARC region, will consider and promote the balance between environment and sustainable development intact with climate change impacts. Being an inter-governmental network, APN is concerned with how developing nations identify the climate change impacts and how they face the challenges by themselves to achieve the goals. The project carried out by WRST has clearly demonstrated that the cumulative effect of multiple operations of small hydro exerts an impact greater than that of large hydro dams that may significant impact on climate change. The potential negative impacts through the establishment of unwarranted small hydropower generation projects on aquatic biodiversity and riparian communities are obvious. Sri Lanka also has been identified as a vulnerable nation to global climate change impacts. APN programme linked with the pertinent government institutes of member countries to catalyze Global Change research, providing financial support is unprecedented since the local resource persons in the developing countries can handle their own problems at a low cost.

Self-Evaluation

The two-day training programme was evaluated by participants. At the end of the programme a self-evaluation form, shown below was circulated among the participants. WRST is highly satisfied with the ranking and comments given by the participants. The project output over the time can be tracked by the following, events, exercises, activities etc.

- ☐ Human agitations, picketing and demonstrations against mini-hydropower
- ☐ Court cases filed requesting suspension of construction of mini-hydro development
- ☐ Mini-hydro is becoming an agenda item in many district council meeting
- ☐ Newspaper reports appear on mini-hydropower issues.
- ☐ TV channels highlight issues associated with mini-hydro
- ☐ Special TV programmes are held

- ☐ with subject specialists on small hydropower development

Finally, APN-funded project activities conducted by the WRST were discussed with Chairman of the Committee on the Public Enterprises (COPE), Hon. Sunil Handunneththi, a Member of the Parliament, who highlighted the issues related to small hydropower development in Sri Lanka at the Southern Province Coordinating Committee Meeting chaired by the HE The President of Sri Lanka.

Evaluation Form: (confidential)

Two-day Training Workshop on "Stream Ecology and Environmental Flow"

at

Kotmale International Training Institute (KITI)

9-10, March 2016

Tick or underline the most relevant answer

1. Workshop topic: **a.** timely **b**. general **c**. irrelevant
2. Lecture tiles: **a.** very relevant **b.** moderate **c.** irrelevant
3. Resource persons: Rank between 1and 10 based on their contribution to the theme

Resources Person	1	2	3	4	5	6	7	8	9	10
1. Dr. HearathManthrithilake										
2. Attny. JagathGunawardena										
3. Eng. Nimal Kanaththawatte										
4. Eng. W.G. Gnanadasa										
5. Ms. Kannthi De Silva										
6. Dr. W.A.H.P.Guruge										
7. Prof. E.I.L. Silva										

4. Overall contribution to your knowledge base: **a.** poor **b.** moderate **c**. sufficient
5. Material provided: **a.** insufficient **b**. sufficient **c**. more than enough
6. Time allocated for discussion: **a.** insufficient **b**. sufficient **c**. more than enough
7. Clarity of presentations: **a.** sufficient **b**. moderate **c**. to be improved
8. Services provided by the WRST: **a.** sufficient **b**. moderate **c**. to be improved
9. Logistic support provided by the organizers: **a.** sufficient **b**. moderate **c**. to be improved
10. Board and lodging: **a.** sufficient **b**. moderate **c**. to be improved

Thank you for your cooperation!

Potential for Further Work

The APN-funded project on Small Hydropower Development and Environment carried out by WRST laid the foundation to look closely and correctly on the entire process of establishment of small hydropower in Sri Lanka, from the submission of a proposal to the Ceylon Electricity Board (CEB) up to the connection of power supply to the national grid. Different integrated components of the entire process of small hydropower generation can examine by relevant subject specialists. For example, an economist can evaluate whether financial estimates are correct or not while ecologists can investigate whether endemic fish are affected or not. More importantly, it is necessary to examine the cumulative effect of small hydropower operation on landscape eco-hydrology and vegetation biology and in turn global climate change. There are many weakness and malpractices in the process of small hydropower generation in Sri Lanka, which are not very conducive to the environment and riparian communities. Therefore, certain policy decisions have to be taken by the authorities responsible for this sector in order to restore the existing system. In addition, a standard formula should be derived to evaluate small hydropower development in terms of socio-economic benefits and long term environmental cost in comparison with other alternative sources of energy such as solar and the wind**.**

Publications

Silva, E.I.L. (2016). Small Hydropower and Hydrological Networks in Mountain Landscape in Sri Lanka. The Environment Monitor XVI (1-3), 17-26.

Silva, E.I.L., Jayawardhana, R.A.S.N., Liyanage, N. P.P. and Silva, E.N.S. (2015). Effects of construction and operation of mini-hydropower plants on fish fauna endemic to Sri Lanka – A case study on Kelani River basin, In the Proceedings of the Water Professional Day 2015,pp. 45-55.

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Lanka - A case study on Kelani River basin, In: Proceedings of Water Professional Day 2015, pp. 115-125.

Acknowledgments

We are grateful to International Water Management Institute (IWMI) for providing funds for initiating studies on the distribution of physical structures in Mahaweli waters and to Uva Wellassa University for allocation of a research student to examine the potential impacts of a cascade of mini-hydropower plants on Wee Oya in the Kelani River basin on riverine fish fauna. Further, we are thankful to the resource persons those who delivered lectures at the two- training workshop and awareness programme.

Preface

The Mahaweli Authority of Sri Lanka (MASL) requested the Water Resources Science and Technology (WRST) through International Water Management Institute (IWMI) to examine whether there is a significant impact of construction and operation of Small Hydropower Plants (SHP) on hill stream fish fauna in Sri Lanka. The study was focused on headwater stream networks of Mahaweli and Walawe River basins. This study revealed that poorly constructed and incorrectly operating small hydropower schemes, exert significant negative impacts on stream ecosystems and also on the livelihood of riparian communities to some extent. Further, it was realized that the project developers as well as the government authorities are either ignorance or do not understand the gravity of this issue. This was encouraged to apply for a grant from Asia Pacific Network for Climate Change Research (APN) for building up the awareness of different stakeholders on small hydropower development and it impacts on the environment and riparian communities.

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1. Introduction

The construction and operation of small hydropower plants (SHP) by arresting mountain streams are categorized as the eco-friendly technology of power generation than building large dams, because their relatively smaller inundation areas behind the weirs and downstream bed exposure. Nevertheless, SHP exerts multiple negative impacts on the local environment, riparian communities, and aquatic biodiversity but reported studies on this disaster are scanty. In many countries in the Asia-Pacific region, the establishment of SHP has exempted from rigorous EIA or IEE procedure due to low capital investment. However, remarkable negative impacts of SHP are essentially ecological and inevitable; on riverine and riparian biota, ecosystem function and processes, fish migration etc., due to curtailed ecological integrity by discontinuum of stream flow (Bhushan et al., 2013). In the context of the diversity of power generation projects, small hydropower generation being viewed to a greater extent as environmentally benign alternative energy source, with green and renewable technology compared with large dams and thermal or coal power plants, as it has no effect on climate change because of minimum Greenhouse Gas (GHG) emission (Egrea & Milewski, 2002). Nevertheless, hydropower turbines, dams, and tunnels have negative impacts on native fish populations (Silva, 1993) as many riverine fish species migrate upstream for spawning (Silva & Davies, 1986; Arthington, 2006). Further, de-routing of the hydrological network in mountain landscapes decreases the stability of the overburden leading to earth slips and landslides under heavy rains (Professor. Jinadasa Katupotha, personal communication).

Besides, the present knowledge and findings have revealed that principles of ecosystem science need to be more fully integrated into water resources planning and management (Poff, 2009). Unfortunately, these aspects have been totally or partially ignored by project approving agencies in the Asia Pacific region when permissions are granted to establish and operate small hydropower plants on hill streams that are highly rich in endemism and vulnerable to human interventions. Certainly, many economic benefits can provide to human society from maintaining healthy aquatic and riparian ecosystems, compared with the high cost involved and difficulties in restoring degraded ecosystems (Bernhardt et al., 2005). Conservation and management of headwater streams are very stringent in developed countries and they discourage the establishment of small hydropower schemes implementing various strategies. But, apparently, various groups that are engaged in this sector (e.g., engineers, environmental officers, custodians of land and water, entrepreneurs, and remote riparian communities) are not aware or least knowledgeable of the value of goods and services provided by the ecosystems that are in equilibrium.

Certainly, hydropower is a clean source of energy, since it burns no fuel and does not generate greenhouse gases (GHGs) to a greater extent, other pollutants, or wastes associated with fossil fuels or nuclear power. However, a fair amount of methane gas will be emitted, mainly during the construction and inundation of the reservoirs due to decomposition of a fraction of the flooded organic biomass (forests, peat lands, and other soil types) and an increase in the aquatic wildlife and vegetation in the reservoir (Hydro Quebec 2009). Attempts have been made to highlight the above justification when EIAs were submitted for the approval of SHP in Sri Lanka. In contrast, hydropower is mainly criticized for its negative environmental impacts on local ecosystems and habitats as mentioned before. On the other hand, inundation of mountain landscape to a greater extent may promote earth slips and landslides, which is not uncommon in Sri Lanka. These environmental hazards may aggravate in the future along with high rainfall frequencies predicted for the hill country of Sri Lanka as a result of climate change. This was experienced in Sri Lanka during the third week of May 2016 with the onset of southwest monsoons. Continuous heavy rains resulted in flooding in the lowland ok Kelani River and massive landslides in the hill country killing hundreds of people. One person was washed off and died when the weir of the Gurugoda Oya mini-hydropower plant, in the Kelani River basin was opened under heavy rains. The climate change impacts and the alteration of rainfall and temperature regimes can affect hydropower generation. SHP with fewer storage capacities is more vulnerable to climate change, as storage capacity provides more flexibility in operations. Although hydropower systems may benefit from more storage and generation capacity, expansion of such capacities may not be economically and environmentally justified (Madani & Lund, 2012). Therefore, it is necessary to enhance the knowledge and understanding of the responsible parties on this unworthy venture. The primary objective of the activities proposed in the project is to enhance the knowledge base of the policy makers with non-scientific background on the importance of hill stream landscape and young environmental officers on very specific scientific concepts of ecological integrity and sustainability of stream ecosystems.

In essence, it is imperative to build up the awareness and enhance the capacities of different stakeholder groups who are engaged in this lucrative business rather than a socio-economic development. On the other hand, direct or indirect beneficiaries in this industry are many and therefore well-armoured by political power and bureaucrats. In Sri Lanka, about 600 stream sites that have 400 MW generation capacities have been identified as potential sites for establishment of small hydropower plants, exclusively based on potential water heads and about 145 plants generating about 300 MW have already been in operation, and many are under construction. This is the fastest small hydropower development in the region. Unfortunately, none of them maintain the environmental flow downstream the weir (dam). The negligence of the developers and poor understanding of the relevant authorities have led a devastating damage to mountain stream ecosystems in Sri Lanka. The situation may be more or less similar or worst in the other developing countries in the Asia-Pacific region. Further, global climate change impacts may affect these systems adversely, although small hydropower plants are eco-friendly in terms of greenhouse gas emission. Therefore, it is imperative to emphasize the gravity of this issue to the relevant sectors while enhancing the awareness and capacities of stakeholders of different levels to achieve the development goals in a sustainable manner. Therefore, it was decided to conduct programmes on capacity building through dissemination of information, training workshops and enhancement of awareness to achieve the following objectives;

- Disseminate the environmental and socio-economic issues associated with small hydropower plants among, riparian communities, environmental officers, environmentalists, decision-makers and other relevant stakeholders.

- Convince the relevant authorities the gravity of poorly designed and scientifically unsound construction and operation of small hydropower plants on aquatic environment with special emphasis on endemic and migratory fish species
- Pass the message to the engineers and scientists who are engaging in project design and preparation of impact assessment reports respectively to be correct and accurate in their preparations

The project expected the following outcomes;

- Avoid approving ecologically sensitive, critical stream sites for establishment of small hydropower plants
- Conservation of aquatic biodiversity of hill streams to a certain extent to protect endemic and indigenous catadromous migratory fishes
- Administrative officers with sound knowledge on negative and positive impacts and malpractices of small hydropower plants

- ☐ Riparian communities in the mountainous landscape to be vigilant on environmental conservation.
- ☐ A handbook entitled "Escalating small hydropower development and environment – A case study on Sri Lanka" to be used by relevant officers and university teachers
- ☐ Publications in peer-reviewed journals

2. Project Methodology

The project was carried out for a period of one year from May 2015 to June 2016 through a series of activities as outlined below;

Activity I: Preparation of a brochure in English and Sinhala, which highlights the impacts of small hydropower development on the aquatic environment and livelihood of riparian communities.

Activity II: Preparation a wall photograph depicting hill stream fish fauna and endemic to Sri Lanka with their status as given in Red Data Book.

Activity III: Preparation of a handbook entitled "Small Hydropower Development and Environment – A Case Study on Sri Lanka" to be distributed among the environmental officers, divisional secretaries, up country school libraries, environment-related NGOs and relevant government institutes. The chapter plan of the handbook is as follows;

i. Contents
ii. Acknowledgments
iii. Preface

Chapter 1 Small Hydropower Power
Chapter 2 Small Hydropower in Sri Lanka
Chapter 3 Approvals to Develop a Mini-hydropower Project
Chapter 4 Environmental Clearance
Chapter 5 Designing and Physical Structures
Chapter 6 Construction, Operation and management
Chapter 7 Hill Stream Fishes
Chapter 8 Environmental, Ecological and Social Impacts
Chapter 9 Mitigation and Monitoring
Chapter 10 Conclusions and Recommendations

Bibliography

GLOSSARY

The draft manuscript of the handbook was reviewed by a Small Hydropower designing engineer and a hydrologist.

Activity IV: Two-day training workshop was conducted on "Stream Ecology and Environmental Flow" at Kotmale International Training Institute (KITI) located closer to Kandy (hill capital) for Provincial and district environmental officers and other relevant persons. During the workshop, lectures were delivered by subject specialists outsourced from International Water Management Institute (IWMI), Department of Irrigation, (ID), WRST, Central Environment Authority (CEA), Ceylon Electricity Board (CEB) and University of Ruhuna. The programme consisted of lectures, a field visit to Kotmale Hydropower station and Atabage Mini-hydropower plant and panel discussion with resources persons. During this programme, the brochure and handbook were distributed among the participants

Activity V: One-day awareness programme on “Hill Stream Landscape in Sri Lanka” was conducted at the Post Graduate Institute of Agriculture (PGIA) of University of Peradeniya, located closer to Kandy for Divisional Secretaries of six up country Districts (viz., Kandy, Matale, Nuwara Eliya, Badulla, Ratnapura and Kegalle) and several other Divisional secretaries in Kalutara, Galle, Matara and Monaragala in the Districts, which have mountainous areas in certain divisions. The programme was conducted at the Post Graduate Institute of Agriculture (PGIA) of the university of Peradeniya. During the programme, lectures were delivered by two subject specialists outsourced from the University of Peradeniya, a Hydrologist from the IWMI and the Chairman of Water Resources Science and Technology. In addition, Prof, Jinadasa Katupotha of the University of Sri Jayawardenepura was invited to deliver a special lecture on “Heavy Rains, Floods, and Landslides” as the hill country experienced extreme weather events and natural disasters (landslides and earth slips) during this period with the onset of monsoon rains. During this programme, the brochure, wall photograph and handbook were handed over to each participant

Timeline: The proposed activities were compartmentalized into different time lines from May 2015 to June 2016 as shown in the chart below to avoid overlapping of activities. The first activity, the preparation of the brochure in Sinhala and English was commenced in July 2015 with the announcement of the grant award. The second activity, the preparation of the wall photograph, which depicts endangered freshwater fishes with their IUCN status stretched over five months from September 2015 to January 2016. Separate drawings were done by an artist for each fish species as it is necessary to maintain the copyright. The names of the fishes on the wall photograph were highlighted in the Sinhala language, the-the mother tongue of Sri Lanka enabling the local people to read when it is displayed in the Divisional Secretariats. The wall photograph was formatted by employing Illustrator software. The third activity, the preparation of Handbook on “Small hydropower Development and Environment – A Case Study on Sri Lanka” was started simultaneously with the wall photograph and completed writing, editing, and formatting by the end of February 2016. When completed each chapter, a relevant subject specialist was consulted for review the chapter and subsequently incorporated of his comments and suggestions. Preparation of the cover page and artworks for the inside figures were done by a graphic expert outsourced from the University of Kelaniya. Before inviting the participants for the two-day training workshop, Heads of the key government institutes responsible for energy and environmental sectors (e.g., Sustainable Energy Authority [SEA], Ceylon Electricity Board [CEB], Public Utility Commission of Sri Lanka [PUCSL], Central Environmental Authority [CEA], Irrigation Department [DI], Ministry of Environment and Natural Resources, National Building Research Organization [NBRO]) were made aware of the programme through personal meetings or telephone conversation. Formal invitations were sent the Heads of the Institutes to send their nominees.

A pre-visit was made to KITI during the second week of February 2016 to inspect the facilities and to make other necessary arrangements. Two-day Training Workshop was conducted during 9-10, March 2016. The last activity, a one-day awareness programme for

Divisional Secretaries was initiated in April 2016 by contacting District Secretaries to get their consent for the participation of Divisional Secretaries in the programme. Subsequently, formal invitations were sent to the Divisional Secretaries during the first week of May 2016. A pre-visit was made to Post Graduate Institute of Agriculture (PGIA) of the University of Peradeniya during the second week of May 2016 to inspect the auditorium facilities and to make other necessary arrangements. The one-day awareness programme was held on the 27th, May 2016.

Timeline for project activities

Project Activities	**Year(2015/16)**											
	J-15	**A**	**S**	**O**	**N**	**D**	**J-16**	**F**	**M**	**A**	**M**	**J**
Preparation of brochure	■	■										
Preparation of wall photographs			■	■	■	■	■					
Preparation of handbook			■	■	■	■	■	■				
Training workshop							■	■	■			
Awareness programme										■	■	■

3. Results & Discussion

The APN-funded project conducted by Water Resources Science and Technology (WRST)during 2015/2016 demonstrated the potential impacts of unwarranted development of small hydropower in Sri Lanka on stream biodiversity including endemic and migratory fish, livelihood of riparian communities and stability and equilibrium of hydrological network in the mountainous landscape. Project activities were successfully carried out according to the stipulated timeline and results are discussed here under four subheadings;

- ☐ Dissemination
- ☐ Training
- ☐ Awareness and
- ☐ Benefits

Dissemination: The brochure prepared in English and Sinhala, which highlights the impacts of small hydropower development on the aquatic environment and livelihood of riparian communities was posted to each and every village headman of *Grama Niladhari* Division (GN Division). In Sri Lanka, the territory has divided into nine Provinces, and each province is further divided into a number of Districts. Each District is further divided into a number of Divisional Secretariat Divisions (DSD), which has a number of GN Divisions. The number of GN Divisions varies according to the size and population of the territory of the Divisional Secretariat Division (Table 1). Following the distribution of the brochure, many village headmen (*Grama Niladharis*) telephoned the WRST office and inquired about the brochure and expressed their wiliness to further support of the activities of nature. Some *Grama Niladharis* gave information about the mini-hydropower plants that are in operation and under construction in the respective areas under their purview. In addition, brochures prepared in English were posted to the Institution under Power and Energy [e.g. Sustainable Energy Authority (SEA), Ceylon Electricity Board (CEB), Public Utility Commission of Sri

Lanka (PUCSL)] and the respective government Institutes that are authorized as Project Approving Agencies in the Environmental Act. This institute is outlined below;

- ☐ Department of Irrigation (DI)
- ☐ Department of Wildlife Conservation (DWC)
- ☐ Department of Forest (DF)
- ☐ Central Environmental Authority (CEA)
- ☐ Urban Development Authority (UDA)
- ☐ Geological Survey and Mines Bureau (GSMB)
- ☐ National Building Research Organization (NBRO)
- ☐ Mahaweli Authority of Sri Lanka (MASL) and
- ☐ Board of Investment of Sri Lanka (BOI)

Table 1. Provinces, Districts, Divisional Secretariat Divisions and *Grama Nildhari* Divisions where small hydropower schemes can be developed

Province	District	Number of DSDs	Number of GNDs
Central	1.Kandy	13	692
	2.Matale	06	308
	3.Nuwara Eliya	05	479
Sabaragamuwa	4.Ratnapura	12	409
	5.Kegalle	09	392
Southern	6.Galle	05	202
	7.Matara	04	141
Uva	8.Badulla	13	501
	9.Moneragala	02	068
Western	10.Kalutara	02	056
Total		**71**	**3248**

Besides, the brochures were also circulated among the participants who attended the two-day workshop and the awareness programme and international and local Non-Governmental Agencies (e.g., IUCN, UNDP, UNICEF, USAID, Rainforest Protectors, Centre for Environmental Justice, Environmental Foundation Ltd, Sevalanka Foundation, Federation of Wildlife Conservation, World Vision, Lanka Council on Water Falls etc.). In addition, activities of the APN-funded project on small hydropower and environment advertised and announced in WaterLanka e-newsletter, which is circulated quarterly among about 3500 local and international readers by the Water Resources Science and Technology. In response to the advertisement appeared in the WaterLanka e-newsletter on two-day training workshop on "Stream Ecology and Environmental Flow", many requests received for participation. Accordingly, organizers decided to honour several requests including university teachers as it is important for dissemination.

Training: As it is a fairly new scientific discipline, Sri Lankan universities hardly conducted courses in Stream Ecology. The key officers attached either to the Central Environmental Authority or the Ministry of Environment and Natural Resources were not trained on Stream Ecology. Further, environmental flow, which describes the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being is a newly discussed issue throughout the world with the development of major and small hydropower generation (Jones, 2002, Dyson et al., 2003). Besides, there is an increasing trend around the world, supported by national and regional policies and legislation, to conserve or restore the ecological health and functioning of rivers and their associated wetlands for human use and biodiversity (Acreman & Dunbar, 2004). Therefore, it was decided that training on stream ecology and environment flow is an additional advantage to those who are engaged in the small hydropower sector. Initially, it was planned to train environmental officers attached to the Central Environmental Authority and relevant officers of the authorized project approving agencies. However, there was a demand from the universities and environment related non-government agencies to participate in the programme, which was held at KITI for two consecutive days (9-10, March 2016).

Seventy-one participants representing twenty-three government and non-government organizations including universities actively participated in the training programme. During the inaugural session, the handbook entitled on "Small Hydropower Development and Environment – A case Study on Sri Lanka" authored by E.I.L. Silva and E.N.S. Silva was launched. Lectures were delivered by relevant subject specialists outsourced from International Water Management Institute (Stream water Resources and Hydrology). Irrigation Department (Flow Regulation), Central Environmental Authority (EIA and Existing Law), Water Resources Science and Technology (Stream Ecology), Ceylon Electricity Board (Small Hydro Technology), University of Ruhuna (Environmental Flow). Discussions were held following each technical session and major environmental and social issues related to two mini-hydropower development namely, Koskulana mini-hydropower project and Aanda Dola mini-hydropower project were raised by the participants. Koskulana mini-hydropower plant was under construction arresting Koskulana River (a tributary of Kalu River), which borders the Northern Buffer Zone of the Sinharaja Rainforest, a designated World Heritage Site. Aanda Dola (means a stream of eels) mini-hydropower plant was also under construction on a tributary of Gin River, which harbours the highest number of endemic fish species in Sri Lanka.

In addition, participants raised many questions from the resource persons. It was brought to the notice that the Central Environmental Authority has no capacity monitor conduct mentoring programmes on operation and mitigation management due to financial constraints and lack of human resources. And also the CEA agreed that certain developers violate the rules and regulations although they were warned repeatedly. With respect to environmental flow CEA has not developed a standard method yet as it is a complex issue and anticipating to apply a derivation from the "Flow Duration Curve" of the respective stream according to the sources of Central Environmental Authority. Further, there are plenty of legislations in Sri Lanka for the protection and conservation of natural resources including streams and but they are not properly implemented in most cases due to political interferences and some other reasons according to the Environmental lawyer who delivered the presentation on existing laws on natural resources of Sri Lanka. With respect to granting permission to develop mini-hydropower projects, the CEA has authorized Provincial Directors to give approval considering mini-hydro development has no significant impacts on environment although they are prescribed projects. Accordingly, panel discussions followed by technical sessions were informative and thought-provoking.

One of the major outcomes of the training programme was the formation of an informal network among four non-government organizations (Water Resources Science and Technology, Rainforest Protectors, Environmental Foundation Ltd. and Centre for Environmental Justice). Subsequently, Environmental Foundation Ltd. in collaboration with Lanka Jalani (Global Water Partnership) organized and conducted a dialogue followed by a panel discussion on the 31st of March 2016 on Policy Implementation and Community Concerns Resulting from the Approval Process for Mini Hydropower Plants. Villagers of the Dellawa protested in front of the Galle Town Council against the Aanda Dola mini-hydropower project. The construction of both Koskulana and Aanda Dola mini-hydropower projects have been temporarily suspended now by the authorities and have been subjected further review. Further, the District Irrigation Engineer, Galle and Matara Districts, also a participant of two-day Training Workshop informed HE The President of Sri Lanka who presided the Matara District Coordinating Committee Meeting on the 4th of July 2016 that

Initial Environmental Report (IEE) submitted to the Central Environmental Authority (CEA) for the approval of Aanda Dola mini-hydropower project contained erroneous information and inaccuracies. HE The President requested the Director General of the CEA to submit a report to him within one week on this particular issue. The Project Leader, APN-funded project on small hydropower and environment was invited by Chairman of the Committee on the Public Enterprises (COPE), Hon. Sunil Handunneththi, a member of the parliament to discuss the present status of small hydropower development in the country. The discussion was very fruitful and he requested a comprehensive summary report on the present status of small hydropower development in Sri Lanka to be handed over to HE The Presented. Chairman of the COPE also promised to discuss this issue with SEA and CEB with a view to changing existing procedures of granting permission for small hydropower projects and evaluation method of IEE and EIA reports related to small hydropower projects.

Awareness: In Sri Lanka, Divisional Secretaries are the custodians of land and water, and their prior approval is compulsory for the crown land acquisition for construction and development of mini-hydropower plants. Nevertheless, primarily, being social science graduates Divisional Secretaries are not aware of the importance of ecosystems, biodiversity, and endemism in the mountainous landscape. On the other hand, there is evidence that Divisional Secretaries are benefited by the Project Developers, which is not uncommon in developing countries. Although formal invitations were sent to all Divisional Secretaries in the mountain areas as shown in Table 1, only 20 District Secretaries or their representatives were participated in the awareness programme. It was primarily due to the disaster situation occurred in the hill country as well as lowland areas of the Kelani River basin as results of continuous heavy rains, landslides, and floods. Several of the Divisional Secretaries informed their inability to participate in the programme as they have to attend emergency meetings, evacuation programmers and distribution activities of relief aids to the victims. Nevertheless, the programme was very productive and successful since most of Divisional Secretaries of unaffected areas participated in the programme. Some requested to postpone the programme enabling them to attend. Sources persons highlighted the reasons for the present disaster situation of the country attributing human intervention with the water and forest resources of the mountainous landscape. They also highlighted the negative impacts of de-routing of the hydrological network in the mountainous landscape, hydropower development and its linkage to landslides and earth slips.

During the discussion period, it was brought to the notices that Sri Lanka is not considering yet the incorporation of fish bypasses or other means to hydropower generation projects, neither small nor major, giving examples of several major hydropower development projects that are under construction (e.g., Moragahakanda and Kalu Ganga Projects, Uma Oya, Project, Moragolla Project and Broadlands Project). Nevertheless, young Divisional Secretaries expressed their willingness to collaborate and corporate with the organizations like WRST for the conservation and management of natural resources of the country. The handbook entitled “Hydropower Development and Environment – A Case Study on Sri Lanka” and the Wall Photograph, which depicts the critically endangered endemic fishes evolved Sri Lanka’s mountainous landscape were handed over to the participants. Arrangements with the Ministry of Home Affairs and Public administration are in progress to deliver the handbook and the Wall Photographs to the Divisional Secretaries those who could not attend the Awareness Programme. The chairman of the WRST was appeared on two TV channels on the invitation to discuss the Small Hydropower Development associated environmental and social problems. The negative impacts of stream flow regulation on riverine fish fauna (endemic and migratory) in Sri Lanka were highlighted in scientific literature since mid1980’s (Silva & Davies, 1986; Silva, 1993; Silva et al., 2013; 2014; 2015), but escalating hydropower development did not care the devastating damage done to the aquatic ecosystems and biodiversity although stringent rules and legislation are in place. The activities conducted for a period of one year (2015/2016) with the support of the grant awarded by the APN under a CAPaBLE programme it was possible to pass the message from the grass root level Village Headman to HE The President of the country that the generation of hydropower must be in compliance with ecosystem sustainability.

Benefits: Since the inception of mini-hydropower development in the early 1900s the riparian communities in the hilly landscape of Sri Lanka knew virtually nothing about mini-hydro but the government initiated small micro level projects, less than 100 kW at several sites with the community participation. Most of them were abandoned after some time due to poor maintenance and social conflicts. The developers of the mini-hydropower projects approached the communities demonstrating enormous benefits to the riparian community such as job opportunities during construction and operation, access roads to the village and with many other promises for sundry benefits. This approach of the developers reaches the community mainly through the chief priest of the village temple in many cases. But they never talked to the villagers that they will lose the access to stream water at a certain stretch, between the weir and the powerhouse, in some cases, it is several kilometres depending on the capacity of the power plant. Nevertheless, villagers were not benefited from mini-hydropower projects. The power generated by the project will be transmitted to the national grid. The road will lead only to the powerhouse, few casual hands will be used during construction and very few skilled people operate the powerhouse. When the *Grama Niladhari* (Village Headman) received the brochure/leaflet sent by the WRST, which shows the other side of the coin, in many cases, they passed the message to the villagers if he/she was not benefited. That is how agitations, demonstrations, and picketing started against mini-hydropower projects towards the end of 2015.

The two-day training workshop benefited many groups in different ways. This is the first time in Sri Lanka a workshop that was entirely devoted to stream ecology and environmental flow was held. Voluntary participation of several young university lecturers, from the University of Peradeniya, Uva Wellassa University, Wyamba University of Sri Lanka, Institute of Fundamental Studies, Jaffna University, and the Ocean University of Sri Lanka, and a professor at the Eastern University is an indication of the needs of the subject knowledge. The handbook on “Small Hydropower and Environment” will be a good aid for them to teach the university students. Environmental Officers represented the Central Environmental Authority, Mahaweli Authority of Sri Lanka, Irrigation, Forest and Wildlife Conservation Departments and Engineers represented several organizations certainly benefited exposing to new knowledge base, which includes;

- ☐ Stream ecology and environmental flows,
- ☐ Ancient vs modern streamflow regulation in Sri Lanka
- ☐ Existing legislation and law on natural resources exploitation
- ☐ EIA process in Mini-hydro Development and
- ☐ Small Hydro Technology
- ☐

The handbook will be a reference material or a guide for many officers and engineers who are participating technical advisory committees in decision-making processes.

The Divisional Secretaries, the custodians of land and water resources of the respective territories under their purview, need scientific knowledge on natural resource conservation and management. They hardly know about mini-hydropower technology and the biodiversity endemic to a particular territory. They have benefited by listing to renowned academics on special subject areas like;

- ☐ Specific Features of Hill Stream Landscape in Sri Lanka
- ☐ Hydrological Network of Mountainous Landscape
- ☐ Water Resources Management in Mountainous Landscape
- ☐ Heavy Rains, Floods, Landslides and Managements

The Wall Photograph and the Handbook will also be important reference guides to have in their offices.

Apparently, Sri Lanka has benefited in many ways from the outcomes of the APN-funded project conducted during 2015/2016 by Water Resources Science and Technology (WRST). Chairman/CEO of WRST was privileged to present a paper entitled “The effects of escalating small hydropower development on hill stream fish fauna endemic to Sri Lanka” ASIA2016 organized by International Journal on Hydropower, held during1-3, March 2016 in Vientiane. Lao, PDR. He was also invited to deliver the keynote presentation at the National Conference on Water for People, Water by People, held in Lahore, on the 19th, March 2016 to commemorate World Water Day. He delivered the keynote speech entitled “Small hydropower and Hydrological Networks in Mountain Landscape in Sri Lanka”. The following are the further evidence to show that the project outcomes have also benefited the region.

1. Project leader has been invited to review a manuscript emitted “Downstream community impact lesson for future: case study of multipurpose Nam Mang hydropower Project in Lao PDR submitted to Sky Journal of Agriculture Research

2. Invitation to write an article on current water issues in Sri Lanka to a monthly magazine called "JALASANWAAD" (means discussion on water) publish by Indian Council for Water & Culture, for its special issue, "Integrated Lake Basin Management"

In the original proposal submitted to APN, it was proposed to hold a one-day seminar in Colombo on “Small hydropower Development and Aquatic Biodiversity” for key stakeholders and decision makers in hydropower development sector in Sri Lanka and relevant invitees from SAARC countries. It was anticipated to organize this seminar in collaboration with the Ministry of Environment and Renewable Energy and South Asia Co-operative Environment Programme (SACEP). The outcomes of this meeting could have documented as seminar proceedings. Initial discussions were also held with the Ministry of Environment and Renewable Energy and SACEP.

4. Conclusions

Poorly designed and incorrectly operating mini-hydropower schemes certainly exert devastating damages to the stream ecosystems, the stability of hydrological network of mountainous landscapes, and the livelihood of riparian communities. Apparently, this is an organised misfortune handled by a group of intermingled beneficiaries that include many stakeholders in different sectors, who knows virtually nothing about the processes and functions of nature.

The cumulative effect of multiple operations of small hydro on hydrology and landscape ecology is greater than the operation of a major dam. The effects of cluster operation of small hydro on climate change to be investigated.

Private sector involvement in development activities exploiting natural resources will certainly exert devastating damages to the environment in developing countries because of poor understanding and opportunistic nature of a majority of entrepreneurs who are strongly linked with political stalwarts.

The project proposals and IEE or EIA reports submitted for the construction and operation of mini-hydropower projects must be evaluated by subject specialists with proven track records. This should be done by national expert panels selected on the basis of their publications appeared in peer-reviewed journals. In this regard qualified hydrologists, aquatic ecologists with ichthyological background and socio-economists specialized on rural livelihoods should be included in the expert panels.

5. Future Directions

The WRST has achieved several objectives such as capacity building, eye-opening for awareness, and informal networking by performing different activities under this project within a short period of time but cannot be satisfied to a greater extent since concrete solutions are yet be reached. Therefore, it is imperative to keep the riparian communities vigilant and developers and their associates alert. Scientists or so-called consultants must be encouraged to provide correct information when they assess environmental impacts. Special emphasis should be paid by project financing agencies (egg., State and private sector banks) on project estimates as the developers overestimate the real cost as they have to satisfy many stakeholders. The Central Environmental Authority and other project approving agencies have no capacity to carry out follow-up monitoring of operational activities of mini-hydropower plants, therefore a mechanism should be developed at least to revisit the small hydropower plants in operation. In addition to impacts on biodiversity and livelihood of riparian communities, de-routing of hydrological network mountainous landscape may be affected by global climate change events such as rainfall variability and extreme drought condition. This aspect should be examined not only at local level but also at the regional level as global climate change scenarios are very pronounced in monsoon Asia.

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Appendices

Two-day Training Workshop
"Stream Ecology & Environmental Flow"
Venue: Kotmale International TrainingInstitute (KITI)
Dates: 9-10, March 2016
Programme
Day 1
8.30 -9.00: Registration
9.00-9.30: Inaugural Session and launching the book written on " Environment and Mini Hydropower Development"
9.30-10.00: Introduction to the Training Workshop by Prof. E.I.L. Silv (WRST)

10.00-10.30: TEA BREAK

10.30-11.30: Mountain Streams in Sri Lanka and their Potential for Human Well-being. By Dr. Herath Manthrithilake (IWMI)
11.30-12.30: Introduction to Stream Ecology by Prof. E.I.L. Silva (WRST)

12.30-13.30: LUNCH BREAK

13.30-14.30: Stream Ecology and Ecosystem Linkageby Prof. E.I.L. Silva(WRST)
13.30-14.30: Ancient vs Modern River Regulation by Eng. W.G. Gnadasa (Dept. Irrigation)

16.00-17.00 OPEN DISCUSSION

Field visit to either to Kotamale Dam or Atabage Weir (optional)

Day 2

8.30 - 9:30: Small Hydro Technology by Mr. Nimal. Kanaththawatte (Former Chief Mechanical Engineer, CEB)
9.30-10:30: Existing Law on Environmental Flow By Mr. Jagath Gunawardena (Attorney at Law, Consultant to CEA)

10.30 -11:00: TEA BREAK

11:00 -12:00: EIA Process in Mini Hydropower Development by Mrs Kanthi De Silva (Director EIA, CEA)
12.00-12:30: Open Discussion

12.30-13.30: LUNCH BREAK

13.30-14.30 Environmental Flow Dr. Wimal Guruge University of Ruhuna)
14.30-15:00: OPEN DISCUSSION
15.00-15:30: Final Remarks by Prof. E.I.L. Silva
15:30-16:00Award of Certificates

End Programme

Participant List: Two-day Training Workshop

Name	Affiliation	Mobile	E-mail
Dr. R.H.S. Suranjan Fernando	CABRE	+94 750118842	sasurh@gmail.com
Mr. B.D. Ajith Amarasinghe	CEA	+94 714092576	ajithamarasinghe6772@gmail.com
Ms. A. M. S. P.K. Seneviratne	CEA	+94 718133445	ceacpo@gmail.com
Ms. L. Seuwandi Wickramasinghe	CEA	+94 714440296	sew82lasa@gmail.com
Mr. K.G.S. Jayawardana	CEA	+94 718376267	samaranathajajayawardana@gmail.com
Mr. R.V. Kulawardena	CEB	+94 714288766	roshanvajira@yahoo.com
Mr. U.N.Piyasiri	CEB	+94 719253558	piyasiriun@yahoo.com
Mr. R.Samantha Gunasekara	SLC	+94 718442985	Samantharg555@gmail.com
Ms. Chamila Weerathunghe	EFL	+94 718774939	projects@efl.lk
Prof P. Vinobaba	EU	+94 776359265	Vino_peria2004@yahoo.co.uk
Mr. Isuru Alawatte	DF	+94 718581618	isuruak@gmail.com
Ms. W.S.Aluwihare	DF	+94 718078524	dfokan@yahoo.com
Mr. R.P.S.I.K Gunathilake	DF	+94 716811048	dforat@yahoo.com
Ms. M.A.T.R. Kularatne	DF	+94 718329355	thulaniruchika@yahoo.com
Mr.W. D. N. Ravindra Prasad	DF	+94 718319560	wdnrprasad@yahoo.com
Mr. G.R.P.B. Senaratne	DF	+94 718187472	pribassa@yahoo.com
Mr.K.M.G. Kumarasiri	DF	+94 552226203	dfo_badulla@yahoo.com
Mr. M. Heenetigala	DF	+94 812232873	dfokan@yahoo.com
Mr. K.G. Sepala	DF	+94 412232957	dfomtr@yahoo.com
Mr. V.G.L. Chandana	DF	+94 812232873	dfokan@yahoo.com
Mr.W.M.P.S.Palamakumbura	DF	+94 812232873	dfokan@yahoo.com
Mr. P.R. Dhananjaya De Silva	GSMB	+94 778712694	Prdhananjaya@gmail.com
Mr. L A Fernando	GSMB	+94 714967312	fernandogsmb@gmail.com
Mr. H K.M Gunasekera	GSMB	+94 714910133	kushanagunasekera@yahoo.com
Mr. S. T. Kalubandara	GSMB	+94 81 2421294	kandy@gsmb.gov.lk
Eng. Mrs. K.P.A. Nishadi	DI	+94714958450	dicp.irrigation@gmail.com
Eng.S.R. Weeraratne	DI	+94714958450	dicp.irrigation@gmail.com
Eng. H.M.G. Kumarasiri	DI	+94714958450	dicp.irrigation@gmail.com
Eng. N.P. Koswatte	DI	+94714958450	dicp.irrigation@gmail.com
Eng. B.H.P. Gunaratne	DI	+94714958450	dicp.irrigation@gmail.com
Eng. V.G.L.E. Chandana	DI	+94714958450	dicp.irrigation@gmail.com
Eng. M.J.M. Kaleel	DI	+94 812420491	dicp.irrigation@gmail.com
Eng. Deepika Thirimahavithan	DI	+94718077039	digmd.irrigation@gmail.com
Ms. Kalani Hennayake	MASL	+94 757330249	darshika.hennayaka@yahoo.com
Mr. Mangala Jayaratne	MASL	+94 767482712	mdmawodanu@gmail.com
Mr. P. Anuradha Kumara	MASL		anuruddha.env.masl@gmail.com
Ms.Nilmini Liyanaarachchhi	MASL		sjnilmini@gmail.com
Mr. Amith Priyadharshana	MASL	+94 718215603	amithpry@gmail.com
Mr. Dammika Pitigala	MASL	+94 719332876	pitigaladsk@yahoo.com
Mr. C.K.B. Mathagama	MASL		
Mr. J.M.D.G. Bandara	MASL		
Mr. Ajith U K Ethugala	Megapolis	+94 721290126	ethugalascdp@gmail.com
Ms. Savinthri Sinhara	Megapolis	+94 719353354	savi.sinhara@gmail.com
Mr. E.D.M. Epasinghe	NARA	+94 718197804	edmepasinghe@gmail.com
Ms. Nadeesha Hettige	NARA	+94 716336032	nadeeshahettige7@gmail.com
Ms. R.R.A. Ramani Shirantha	NARA	+94 757330249	ramanishirantha@hotmail.com
Ms. Shyamali Weerasekara	NARA	+94112521009	shyamalikaww@gmail.com
Ms. Sardhanee Dias	NBRO	+94 716874653	sardhanee@yahoo.com
Ms. Thushani Seneviratne	NBRO	+94 716874798	thushasen@gmail.com
Mr. Namal Prasantha Athukorala	NIFS	+94 778075442	Namal_athu@yahoo.com
Mr. W. A. Shiran Chamika	OU	+94 714385905	shiranchamika@gmail.com
Mr. V.T.Kelum Dayarathhna	OU	+94 786290629	sciencekelum@yahoo.com
Mr. C.P. Gunasena	RFP	+94 777181928	Cpg810@gmail.com

Mr. SamanPerera	RFP	+94 767692672	samankumaraguptha@gmail.com
Mr. J.S.Thirimahavithana	RFP	+94 714456271	jagaththrima@gmail.com
Ms. K. Imashi Kavirathna	SEA	+94 714530483	niluimashi80@gmail.com
Ms. NKASalika Lankeshini	SEA	+94 712159597	shalika@energy.gov.lk
Mr. Dayantha S. Digamadulla	UOJ	+94 784807263	Sheandiga90@gmail.com
Ms. M.M.J.G.C.N. Jayasiri	UoP	+94 775989885	Nishanka.jayasiri@gmail.com
Ms. Nayanaka Wickramsinghe	UoP	+94 716785273	nayanaka131@gmail.com
Ms. Sewwandi Wijesuriya	UoP	+94 784950409	sew2512@gmail.com
M. H. Chithrasena	WLCD	+94 552245744	No email
G. Lakashaman Perera	WLCD	+94472235107	No Email
Mr. R. A. S. N. Jayawardhana	WRST	+94 713179896	Sameera1602nilanka@gmail.com
Dr. Sevvandi Jajakody	WUSL	+94 772036130	sevvandi_jayakody@yahoo.com
Dr. W.M.H.K. Wijenayake	WUSL	+94 718129770	Hiranya_kelum@yahoo.com
Mr. N. P. P.Liyanage	UWU	+94 714064654	npvsr@yahoo.com
Ms. R M G N Rajapaksha	UWU	+94 713387486	Gayanirajapaksha123@yahoo.com
Mr.J. D. Mahesh Senevirathna	UWU	+94 722246416	dumiaz@gmail.com
Ms. G.G.N.Thushari	UWU	+94 710342075	thusharin@gmailcom
Ms. Dhammika Peiris	W-Vision	+94 713179896	Dammika_peiris@wvi.org

Addresses

CABRE: Centre for Applied Biodiversity Research and Education, 45/5, Peradeniya Rd. Kandy, SL
CEA: Central Environmental Authority104, Parisara Piyasa, Denzil Kobbbekaduwa Mw , Battaramulla, SL
CEB: 50, Sir Chiththapama A Gardiner Mw, P.O. Box 540, Colombo 2, SL
DF :82, Forest Department, Sampathpaya, Rajamalwatte Rd, Battaramulla, SL
DI: Department of Irrigation,230, Bauddhaloka Mw, P.O. Box 1138Colombo 7, SL
EPL: Environmental Foundation (Guarantee) Ltd. 146/34. HavelockRd. Colombo 8., SL
EU: Department of Zoology, Eastern University, Vantharumoolai,Chnkaladi, Batticaloa, SL
GSMB: Geological Survey and Mines Bureau, 549, Epitamulla Rd. Pitakotte, SL
MASL: Mahaweli Authority of Sri Lanka, 500, T.B. Jaya Mawatha, Colombo 10,SL
Mega polis: Ministry of Mega polis and Western Development, 17/18 Floor Suhurupaya, Battaramulla, SL
NARA. National Aquatic Resources Research and Development Agency,Crow Island, Colombo 15. SL
NBRO: National Building Research Organization, 99/1, Jawatta Rd, Colombo 5. SL
NISF: national Institute of Fundamental Studies, Hantana Rd, Kandy, SL
OU: Sri Lanka Ocean University, Tangalle, SL
RFP: Rainforest Protectors, No: B2 Thewaththa, Egoda Melahena, Wadduwa, SL
SEA: Sri Lanka Sustainable Energy Authority, Block 5, First Floor, BMICH, Bauddhaloka Mw. Colombo 7, SL
SLC: Biodiversity Unit, Department of Sri Lanka Customs, Customs House, Main Street, Colombo 11, SL
UOJ; Department of Zoology, P.O. Box 57, Thirunelvely, Jaffna, SL
UOP: Department of Zoology, University of Peradeniya, , Peradeniya , SL
WLCD: Department of Wildlife Conservation, 811/A, Jayanthipura Rd, Battaraulla,SL
WRST; Water Resources Science and Technology, 77/2. Hettiyawatte, Elapitiwela, Ragama, SL
WUSL: Department of Aquaculture and Fisheries, Wyamaba University of Sri Lanka, Makandura, SL
UWU: Department of Animal Science, Uva Wellassa university, Passara Rd, Badulla. SL
WV: Research/WASH, World Vision, 1119/2/1, Maradana Rd, Colombo 8, SL

One-day Awareness Programme on "Hill Scream Landscape in Sri Lanka"
Venue: Post Graduate Institute of Agriculture (PIGA), University of Peradeniya, Old Galaha Rd, Peradeniya.

Date: 27,May 2016

PROGRAMME
9.00-9.10 Welcome Address – Mr E.N.S. Silva (Managing Director, WRST)
9.10-10.00: Present Status of Hill Streams in Sri Lanka, Prof. E.I.L. Silva (Chairman, WRST)

10.00-10.30: TEA BREAK

10.30-11.30: Mountainous landscape of Sri Lanka- Prof Nimal Gunatilleke
11:30-12:30: Hydrological Network n the Mountains and it Downstream Linkages Dr. Herath Manthrithilake (IWMI)

12.30-13.30: LUNCH BREAK

13.30-14.30: Water Resources Management in Mountain Landscape - Prof.M.T.M. Mowjood
14:30-15:30Heavy Rains, Floods, Landslides and Management, Prof. Jinadasa Katuptha

15.30-15.45: TEA BREAK

15.45-16:00: Concluding l Remarks- Prof. E.I.L. Silva

Participant List: One-day Awareness Programme

Name	DSD	Telephone	E-mail Address
Niroshana Karunathilake	Laggala	+9466 2275200	No-email
T.B. Lalith Kumara	Kolonna	+94 452260238	buddhikalaithkumara@gmail.com
M. Ruwandika	Kotmale	+94 522259567	m.ruwandika@yahoo.com
G.S.S.W. Kumarathunga	Doluwa	+94 812425519	S_kumarathunga@yahoo.com
D.M.C.K.K. Gunarathne	Panvila	+94 812472236	ds@panvila.ds.gov.lk
W.M.T.S.K. Weerasinghe	Meddumbara	+94 812374077	Thushariweerasinghe06@yahoo.com
D.M. Amila Wijerathne	Balangoda	+94 452287538	adsbalangoda@gmail.com
J.P.U.K. Jayarathne	Dethota	+94 714471113	ds@doluwa.ds.gov.lk
B.M.B.M.A. Batugedara	Kuruwita	+94 452262228	b.m.bhagya@gmail.com
G.R.I. Galledanda	Nuwara Eliya	+94 252234022	galledanda74@gmail.com
E.T. Nuppehewa	Udunuwara	+94 812316818	Thironi.nupehewa463@gmail.com
I.A.S.D. Edirimanna	Hanguranketha	+94 812369929	samanthiidirimanna@gmail.com
W.M.D.B. Wickremasinghe	Pasbagekorale	+94 522222138	ds@pasbagekorale.ds.gov.lk
D.P.G. Renuka	Imbulpe	+94 452287236	dpgrenu@gamail.com
J.M.U R. Jayaweera	Ella	+94 572228517	upuljayaweera@gmail.com
T.K.E.D.Gunasekara	Imbulpe (LO)	+94 452287236	tkedgunasekara@yahoo.com
K.P.K.L.D. Maduwanthi	Matale	+94 662222223	ds.mtaale@gov.lk
L.L.A.Amarasekara	Meegahakiula	+94 552245789	ds@meegahakiula.ds.gov.lk
A.M. Dayananda	Doluwa	+94 714400317	ds.doluwa@gov.lk
A.Navarathe	Hanguranketha	+94 717039019	Info.gov@haguranketha.ds.lk
Special Invitees			
Bimsara De Alwis	DCK	+94774872214	Bimsarav.dealwis@gmail.com
K.S.K.Perera	RFP	+94 777181928	samankumaraguptha@gmail.com
C.P. Gunasena	RFP	+94 767692672	cpg810@gmail.com
K.A.I.D. Koralagedara	PGIA	+94 812388318	Postgraduate Student
W.M.S.M. Wijekooon	PGIA	+94 812388318	Postgraduate Student
S. Gunasekara	SLC	+94 718442985	Samantharg255@gmail.com
R.Sudhrashani	PGIA	+94 812388318	sudharshaniraja@gamail.com
W.S. Dandeniya	UoP	+94 812395218	warshisd@gmail.com
D. Pitigala	MASL	+94 719332876	pitigaladsk@yahoo.com
R.B. Silva	WRST	+94 812388318	Postgraduate Student
NilankaJayawardhana	WRST	+94 713179896	Sameera1602nilanka@gmail.com
Indika Dilrukshi	PGIA	+94 812388318	Indikadilrukshi166gmail.com

NB: DCK, Dharmaraja College Kandy
REP, Rain Forest Protectors
PGIA, Post Graduate Institute of Agriculture
SLC, Sri Lanka Customs (Bio Diversity Unit)
UoP, University of Peradeniya
MASL, Mahaweli Authority of Sri Lanka
WRST, Water Resources Science and Technology

Funding sources outside the APN

- International Water Management Institute (IWMI)
  US$ 6,000 for preliminarily Studies
- Mahaweli Authority of Sri Lanka, Transport Board and Lodging for preliminary studies
- Water Resources Science and Technology, Approximately US$ 2,000 for Studies on mini-hydropower plants on fish fauna of Wee Oya in Kelani River basin,

List of Young Scientists

The young scientists listed in the following table involved in the project activities at different stages at a different level. Mr. E.N.S. Silva involved in overall project management and field studies together with Mr. Dammika Pitigala and Mr. Sujith Rangana Fernando. Mr. Nuwan Liyanage, a young lecturer of the Department Animal Science of Uva Wellassa University helped in the project planning and field investigation of stream fishes in the Wee Oya. Mr. Nilanka Jawarwadhana fully engaged in the examination of mini-hydropower plants in Wee Oya, a tributary stream of the Kelani River. Mr. Rachana Bathika Silva covered overall computer logistics of the WRST office. According to their views, all young scientists gained a fair amount of training through the project activities and also became co-authors of scientific publications within a short period.

Name	Affiliation	Telephone	E-mail Address
Mr. E. N.S. Silva	WRST	+94 774064654	Sandeep.drck@gmail.com
Mr. N. P. P.Liyanage	UWU	+94 714064654	npvsr@yahoo.com
Mr. R Bathika Silva	UoK	+94 717327986	rachanasilva@gmail.com
Mr. N. Jayawardhana	WRST	+94 713179896	Sameera1602nilanka@gmail.com
Mr. Dammika Pitigala	MASL	+94 719332876	pitigaladsk@yahoo.com
Mr. Sujith Fernando	UWU	+94 714064654	Sujithrangana86@gmail.com

Addresses
MASL: Mahaweli Authority of Sri Lanka, 500, T.B. Jaya Mawatha, Colombo 10,SL
WRST; Water Resources Science and Technology, 77/2. Hettiyawatte, Elapitiwela, Ragama, SL
UoK: Faculty of Science. Dept. of Mathematics and Computer Science University of Kelaniya, Kelaniya, SL
UWU: Department of Animal Science, Uva Wellassa University, Passara Rd, Badulla. SL

Acronyms and abbreviations

APN	Asia-Pacific Network for Climate Change Research
BOI	Board of Investment
CEA	Central Environmental Authority
CEB	Ceylon Electricity Board
CEO	Chief Executive Officer
COPE	Committee on the Public Enterprises
DF	Department of Forest
DI	Department of Irrigation
DSD	Divisional Secretariat Division
DWC	Department of Wildlife Conservation
EIA	Environmental Impact Assessment
GHG	Greenhouse Gases
GN	Grama Niladhari
GSMB	Geological Survey and Mines Bureau
HE	His Excellency
IEE	Initial Environmental Examination
IUCN	International Union for Conservation of Nature
IWMI	International water Management Institute
KITI	Kotmale International Training Institute
MASL	Mahaweli Authority of Sri Lanka
NBRO	National Building Research Organization
PDR	People Democratic Republic
PGIA	Post Graduate Institute of Agriculture
PUCSL	Public Utility Commission of Sri Lanka
SAARC	South Asia Association for Regional Cooperation
SACEP	South Asia Co-operative Environment Programme
SEA	Sustainable Energy Authority
SHP	Small Hydropower
UDA	Urban Development Authority
UNDP	United Nation’s Development Programme
UNICEF	United Nation’s Children’s Fund
USAID	United States Aids for International Development
WRST	Water Resource a Science and Technology

Abstracts published

1. Abstract submitted to Water Professional Day, 2015

The effects of construction and operation of mini hydropower plants on fish fauna endemic to Sri Lanka - A case study on Kelani River basin

E.I.L. Silva[1]* R.A.S.N. Jayawardhana[2] N.P.P. Liyanage[3], and E.N.S. Silva[2]
[1]Water Resources Science and Technology, 77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka,[2]Undergraduate Programme, Animal Science and Export Agriculture, University of Uva Wellassa, Badulla, Sri Lanka, [3]Department of Animal Science and Export Agriculture, University of Uva Wellassa, Badulla, Sri Lanka,

*Corresponding author: E-mail: eils.mecamp@gamail.com

Abstract

The establishment of small hydropower schemes has become a lucrative business today considering streams and rivers as hydraulic systems rather than living ecosystems. It is assumed that the negative effects of construction and operation of small hydropower are small because of relatively small generation capacities in comparison to large hydropower projects. The operation of small hydropower plants in Kelani River basin was investigated with special emphasis on power generation capacities and affected stream stretches between the intake weir and the powerhouse. Detailed studies were conducted at Wee Oya, a major tributary of the Kelani River on habitat alteration and fish fauna endemic to Sri Lanka in relation to small hydropower operation. The Kelani River has 31 mini hydropower plants with total generation capacity of 56 MW ranging from 0.060 MW to 9.928 MW per plant. The results show that the length of the affected stream stretch is a function of the generation capacity of the power plant. The percentage of natural stream loss is high in Kehelgamuwa Oya (60.3 %) and Maskeliya Oya (62.9%) due to the establishment of major hydropower schemes whereas the high percentage of natural stream loss computed for Seethawaka Ganga (43.8 %) can be attributed to the large number of mini-hydropower plants. A marked decline in fish population and a number of endemic fish species were found in the Wee Oya, which has four mini hydropower plants within24 km stream length with 32.5% loss of natural stream. Although, 18endemic fish species have been recorded from the Kelani River basin, only four species were reported from the Wee Oya during the present study.

2. Abstract submitted to ASIA2016, held in Lao

The effects of escalating small hydropower development on hill stream fish fauna endemic to Sri Lanka

E.I.L. Silva[1]*R.A.S.N. Jayawardhana[2]and E.N.S. Silva[2]
[1]Water Resource Science and Technology Consultants, 77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka,[2]Undergraduate Programme, Animal Science and Export Agriculture, Uva Wellasa University, Passara Rd, Badulla, Sri Lanka

*Corresponding author, E-mail: eils.mecamp@gamail.com

Abstract

Small hydropower (SHP) generation by arresting mountain streams is being viewed as environmentally benign energy source, compared with large dam sand fuel fossil combustion as it has no effects on global climate change (Egrea & Milewski 2002). They can, however, exert multiple negative effects locally especially, on riverine and riparian ecosystems and eventually on aquatic biodiversity and human health of riparian communities, but reported studies on these aspects are hardly any (Bhushan et al. 2013). Ecological risk of cascade operation of SHPP established on the trunk stream poses adverse effects, as it leads to almost drying up of the natural river channels during the dry season (Bhushan et al. 2013, Silva et al. 2013) whereas MHPPs affect not only fish but also the ecological integrity of lotic ecosystems. Apparently, present knowledge and findings have fuelled that principles of ecosystem science need to be fully integrated into water resources planning and management (Poff 2009). Unfortunately, these aspects have been totally ignored by project approving agencies in developing countries when permissions are granted to establish and operate SHPPs on hill streams that are rich in endemism. Nevertheless, developing countries pose direct or indirect taboos or rigid environmental legislation discouraging entrepreneurs. If SHPPs are designed, constructed, monitored and managed stipulating correct norms, can minimize effects on the ecosystems and c some eco-friendly examples are there in the western world as well shown for ancient irrigation in Sri Lanka by Silva et al. (2014).

Sri Lanka has the SHP potential of about 400 MW and the government encouraged and facilitated private sector to undertake the development of SHP ventures with flexible power purchasing agreements as the country has already tapped almost every potential sites for large hydropower developments. A request was made by the Mahaweli Authority of Sri Lanka (MASL) to Water Resources Science and Technology (WRST) through International Water Management Institute (IWMI) to examine whether there is a significant impact of construction and operation of SHPPs on hill stream fish fauna. The preliminary results revealed that the construction and operation of seven MHPPs within 23 km stretch on Sudu Ganga (= River) in the Mahaweli River basin has significant negative impacts on fish fauna (Silva et al., 2013). As Sri Lanka is identified as a biodiversity hotspot with rich endemic ichthyofauna, confined to hill streams, the study was extended to headwater streams of the entire country with a grant awarded by Asia Pacific Network for Climate Change Research (APN). Therefore, the study was focused on collating necessary information to determinethe gravity of poorly designed and scientifically unsoundconstruction and operation ofsmall hydropower plants on ichthyofaunaendemictoSri Lanka with a view to transferring knowledge on the significance of maintaining ecological flow in streamsand rivers to sustain aquatic biodiversity evolved for millions of years.

Necessary data were collected from relevant government institutes (viz., Sustainable Energy Authority, Central Environmental Authority, Ceylon Electricity Board, Public Utility Commission of Sri Lanka and Mahaweli Authority of Sri Lanka). Field visits were made to 61 SHPPs in the Mahaweli River basin and an extensive study was conducted on five SHPPs (physical structures and operations) established on Wee Oya (= Stream) in Kelani River basin, which also included fish sampling. Google Pro images were used for validation of geographic positions and estimation of stream lengths between the weir and the powerhouse (ASS= Affected Stream Stretch) along 25 km stream stretch in Wee Oya and other MHPPs.

The development of MHP was commenced in 1993 and 142 plants generating 302 MW were connected to the national grid by the end of 2014 while another 37 plants are under construction. Although plant designs indicate projects as run-of-river systems, none of the visited projects did not maintain environmental flow between the weir and powerhouse creating dead stream stretches unless lateral tributary inputs are available. ASS of Wee Oya was 7.2 km for 24 km stream stretch, which includes five MHPPs whereas AAS was 340 km for 142 MHPPs that are in operation in the central highlands. The number of hill stream fishes in Sri Lanka is 50 belonging to eleven families of which 35 are endemic. Of the endemic fishes, 26 are found only hill streams between 100 -1000 m AMSL where their type habitats are located. Fourteen endemic fishes restricted to hill streams have been recorded from the Kelani River of which ten species were found in Wee Oya before the construction of the first MHPP in 2005. The present study found only three endemic fishes restricted to hill streams where water is brought to the mainstream from lateral tributaries. The results demonstrate devastating effects of inappropriate construction and incorrect operation of MHPPs on stream habitats and ichthyofauna endemic to Sri Lanka as reported on several occasions (Silva and Davies 1986, Silva 1993, Arthington et al. 2006, Poff 2009, Bhushan et al. 2013, Silva et al. 2013). This situation is worse than the operation of large hydropower with respect to the extent of ASSs. The effects of exposed stream beds on ecological integrity and human health of riparian communities are to be investigated.

References

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Silva, E.I.L, Herath, M. Piyathilake, M.D. and Ramani, S. 2013. Cascade of mini-hydropower plants on Sudu Ganga and its potential impacts on riverine fish fauna In: Proceedings of Water Professional day 2013 (pp 115-125)

Silva, E.I.L.,H. Manthrithilaka, D. Pitigala and E.N.S. Silva2014. Environmental flow in Sri Lanka: ancient anicuts vs modern dams. Sri Lanka J. Aquat. Sci.19: 3-14

3. Abstract submitted to World Water Day 2016, held in Lahore, Pakistan

Small Hydropower and Hydrological Network in Mountain Landscape in Sri Lanka

E.I.L. Silva
Water Resources Science and Technology, 77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka, E-mail: eils.mecamp@gamail.com

*****Corresponding author, Email: eils.mecamp@gmail.com

Abstract

The terrain of Sri Lanka has been divided into 103 drainage basins but only ten rivers rise from the Central Highlands in the wet zone (e.g., Mahaweli, Maha, Kelani, Kalu, Gin, and Nilawala, Walawe, and Kirindi). The Mahaweli River, the longest and the largest river basin of the island has 57 mini-hydropower plants in operation that generate 113 MW while another few are under construction. Establishment of mini-hydropower plants has disrupted 77.3 km long stream stretches due to non-availability of stream flow between the weir and powerhouse of each SMP plant. The total affected (disrupted) stream stretch (ASS) within the Mahaweli basin due to small hydropower plants is 77.3 km. In contrast, loss of stream stretches due to major hydropower schemes (i.e., Upper Kotmale, Kotmale, Victoria, and Randenigala-Rantambe) on Mahaweli River is 33.3 km, which generates 810 MW. Thirty-two mini hydropower plants with 55.61 MW generation capacity are in operation on the Kelani River basin creating 47.3 km dead stream stretches. The affected stream stretch is 41.9 km resulting from five major hydropower schemes in the Kelani River basin (i.e., Wilmasurendra, Old Lakshapana, Canyon, New Lakshapana and Polpithiya), that generates 353MW.

Twenty-eight mini hydro-power plants with generation capacity 70 MW are in operation on the Kalu River basin while disrupting 29 stream kilometres when major hydropower project (Kukule Ganga) also taken into account. There are fourteen mini-hydropower plants having 26.84 MW generation capacity on the Walawe River basin resulting in are in 17.3km dead stream length. Ten mini-hydropower plants are in operation on other four rivers (Gin Ganga, Kirindi Oya, Ma Oya, and Nilwala Ganga) that rise from the Central Highlands and generate 15 MW while disrupting 9.4 km stream length. Accordingly, construction and operation of143small hydropower schemes on hill streams in the Central Highland of Sri Lanka since early 1990 to 2015 has resulted in stream water to flow 225 km through conduits, concrete canals, penstocks, and tailraces disrupting downstream flow and sediment transport, seepage and recharge in turn entire hydrological network. This has significant effects on riverine endemic fishes, stream bank vegetation and the livelihood of riparian communities. Nevertheless, authorities have granted permission for another 87 projects with installation capacity of about 139MW.

4. Abstract submitted to Research Symposium of Uva Wellassa University Sri Lanka

Reference No: ARC/2015/

Effects of Cascade Min-hydropower Plants on Some Aspects of Eco-hydrology of Wee Oya in Kelani River Basin

R.A.S.N Jayawardhana[1]N.P.P Liyanage[1], E.I.L Silva[2]

[1]*Department of Animal Science, UvaWellassa University,Badulla, Sri Lanka.*

[2]*Water Resources Science and Technology, Ragama, Sri Lanka.*

The establishment of small hydropower schemes has become a lucrative business today considering streams and rivers as hydraulic systems rather than living ecosystems. It is assumed that the negative effects of construction and operation of mini-hydropower plants are negligible because of relatively minor generation capacities in comparison to large hydropower projects. The operation of small hydropower plants in Kelani River basin was investigated with special emphasis on power generation capacities and affected stream stretches between the intake weir and the powerhouse. Detailed studies were conducted further at Wee Oya, a major tributary of the Kelani River on habitat alteration and fish fauna endemic to Sri Lanka in relation to small hydropower operation. The Kelani River has 31 mini hydropower plants with total generation capacity of 56 MW ranging from 0.060 MW to 9.928 MW per plant. The results show that the length of the affected stream stretch is a function of the generation capacity of the power plant. The percentage of natural stream loss is high in Kehelgamuwa Oya (60.3 %) and Maskeliya Oya (62.9%) due to the establishment of major hydropower schemes whereas the high percentage of natural stream loss computed for Seethawaka Ganga (43.8 %) can be attributed to a large number of mini hydropower plants. Although 18 endemic fish species have been recorded from the Kelani River basin, only four species were reported from the Wee Oya, which has 4 mini hydropower plants within 24 km stream length with 32.5 % loss of natural stream in the present study. Significant declinations of fish populations and endemic fish varieties in Wee Oya have denoted the negative effects on aquatic biodiversity, emphasizing immediate conservational requirements.

Keywords: Cascade Mini-hydropower Plants, Affected Stream Stretches, Fish endemic to Sri Lanka, Eco-hydrological aspects

Full Papers published

1. Paper published in the proceedings of Water Professional Day- 2015

The effects of construction and operation of mini hydropower plants on fish fauna endemic to Sri Lanka - A case study on Kelani River basin

E.I.L. Silva[1]* R.A.S.N. Jayawardhana[2] N.P.P. Liyanage[3] and E.N.S. Silva[2]
[1]Water Resources Science and Technology, 77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka,[2]Department of Animal Science and Export Agriculture, Uva Wellassa University, Badulla, Sri Lanka

*Corresponding author: E-mail: eils.mecamp@gamail.com

Abstract

The establishment of small hydropower schemes has become a lucrative business today considering streams and rivers as hydraulic systems rather than living ecosystems. It is assumed that the negative effects of construction and operation of small hydropower are small because of relatively small generation capacities in comparison to large hydropower projects. The operation of small hydropower plants in Kelani River basin was investigated with special emphasis on power generation capacities and affected stream stretches between the intake weir and the powerhouse. Detailed studies were conducted at Wee Oya, a major tributary of the Kelani on habitat alteration and fish fauna endemic to Sri Lanka in relation to small hydropower operation. The Kelani River has 31mini hydropower plants with total generation capacity of 56 MW ranging from 0.060 MW to 9.928 MW per power plant. The results show that the length of the affected stream stretch is a function of the generation capacity of the power plant. The percentage of natural stream loss is high in Kehelgamu Oya (60.3 %) and Maskeliya Oya (62.9%) due to previously established major hydropower schemes whereas the high percentage of natural stream loss computed for Seethawaka Ganga (43.8 %) can be attributed to the large number of mini-hydropower plants. A marked decline in fish population and a number of endemic fish species were found in the Wee Oya, which has four operational mini hydropower plants within24 km stream length with 32.5% loss of natural stream. Although, 18endemic fish species have been recorded from the Kelani River basin, only three species were reported from the Wee Oya during the present study.

Introduction

Small hydropower (SHP) generation by arresting mountain streams is being viewed as environmentally benign energy source compared with large dams and fuel fossil combustion as it has no effects on global climate change (Egrea and Milewski 2002). They can, however, exert multiple negative effects locally, especially on riverine and riparian ecosystems and eventually on aquatic biodiversity and human health of riparian communities, but reported studies on these aspects are hardly any (Bhushan et al. 2013). Ecological risk of cascade operation of SHP established on the trunk stream poses adverse effects, as it leads to almost drying up of the natural river channels during dry season (Bhushan et al. 2013, Silva et al. 2013) whereas small hydropower plants affect not only fish but also ecological integrity of lotic ecosystems. Apparently, the present knowledge and findings have fuelled that principles of ecosystem science need to be fully integrated into water resources planning and management (Poff 2009). Unfortunately, these aspects have been ignored to a greater extent by project approving agencies in developing countries when permissions are granted *to establish and operate SHPPs on hill streams that are rich in endemism. Nevertheless, developed countries pose direct or indirect taboos or rigid environmental legislation discouraging entrepreneurs with respect to small hydropower development. If SHPPs are designed, constructed, monitored and managed stipulating correct norms, can minimize the effects on the ecosystems and some eco-friendly examples are there in the western world as well as shown for ancient irrigation in Sri Lanka by Silva et al. (2014).*

Sri Lanka has the SHP potential of about 400 MW according to Ceylon Electricity Board and the government has encouraged and facilitated private sector to undertake the development of SHP ventures with flexible power purchasing agreements as the country has already tapped almost every potential sites for large hydropower developments. A preliminary study conducted on Mahaweli Areas by Water Resources Science and Technology (WRST)revealed that the construction and operation of seven SHPPs within 23 km stretch on Sudu Ganga (= River) in the Mahaweli River basin has significant negative effects on fish fauna (Silva et al.,2013). As Sri Lanka is identified as a biodiversity hotspot with rich endemic ichthyofauna confined to hill streams, the present study extended to the headwater streams of the Kelani River with special emphasis on Wee Oya, flowing from See Forth to Yatiyantota. The focus of the extended study was to collate necessary information to determine the gravity of poorly designed and scientifically unsound construction and operation of small hydropower plants on ichthyofauna endemic to Sri Lanka with a view to transferring knowledge on the importance of maintaining ecological flow in streams and rivers to sustain aquatic biodiversity evolved for millions of years.

Materials and methods

1.1. Study site

Kelani River, the 4th longest river in the country (145 km) with the 2nd largest watershed (2292 sq km) drains exclusively the wet zone including the central mountain massif and discharges 5389 MCM annually into the Indian Ocean. The watershed of the Kelani River receiving maximum rainfall of 5500 mm/yr is located in densely populated and most fertilized wet zone of the island with elevation ranging from mean sea level to above 2000 m AMSL. The river basin is boarded by Kalu Ganga in the highland and Bolgoda Lake in the lowland from South and the Hatton Plateau and Dolosbage Hills from east and northeast respectively. The northeast and northwest boundaries of the watershed are marked by the divide between the westward flowing rivers, the Maha Oya and Attanagalu Oya respectively. The headwaters of the Kelani River rise on the western flanks of the central mountain massif (Peak Wilderness) as Hambantota Oya and Maskeliya Oya. Both tributaries have been arrested creating two hydropower reservoirs namely Castlereagh and Maussakelle respectively. The Kehelgamu Oya, rises as the Hambantota Oya has been dammed again at Norton Bridge for generation of hydropower and then flows parallel to Maskeliya Oya until they merge together at Broadlands Estate forming the Kelani River proper. The Kelani River turns almost westward and flows up to the Pallegama Estate where it turns northwards twice (with a westward bend) before it intercepts Yatiyantota town and merges with Wee Oya (Figure 1). The river turns south-westward at Yatiyantota town and flows4.8 km downstream up to Karawanella town where it shows a sharp northward turn and flows further 3.2 km downstream up to Ruwanwella town where it bends south-westward and merges with Gurugoda Oya, which receives water from Ritigaha Oya on its left bank. Seethawaka Ganga, the largest left bank tributary of the Kelani River merges with the mainstream 10 km downstream of Ruwanwella township (Figure 1).

The Seethawaka Ganga, whose headwater tributaries are rising from Kitulgala-Maliboda range drains the area by five main tributaries called Kadiran Oya, Mandagal Oya, Halthura Oya, Naye Ganga, and Magal Ganga. The confluence of these tributaries gives rise to the Magala Ganga, which is also fed by three other tributaries on its right bank (Panamura Oya) and left bank (Miyanavita Oya and Kumburugama Oya) forming Seethawaka Gganga. After the confluence with Seethawaka Ganga, the Kelani River flows westward up to Crow Island while receiving several minor left and right bank tributaries and empties into the Indian ocean (Figure 1).

Wee Oya: Wee Oya (Oya= stream), a left bank tributary, which merges with the mainstream of the Kelani River at Yatiyantota rises from Dolosbage hills and Ampana forest. The stream draining the Dolosbage hills merges with Monera Ela whose headwaters are confined to Ampana forest forming Wee Oya, which is also fed by Kandal Oya and Aandha Dola on its left bank and several other minor tributaries on its way to Yatiyantota. Between See Forth and Yatiyantota, the Wee Oya flows parallel to the Yatiyantota-Ginigathhena road (B482) for 25 kilometres with a steep gradient performing a diverse flowing pattern including waterfalls, riffles, pools, and cascades. Some lateral tributaries and the mainstream of Wee Oya contribute to form several waterfalls including Olu Ella, the fifth highest waterfall (200 m) of the country, which merges into the Wee Oya at Punugala on its left bank.

Preliminary data on mini hydropower development in the Kelani River basin were collected from relevant government institutes (viz., Sustainable Energy Authority, Central Environmental Authority, Ceylon Electricity Board, and Public Utility Commission of Sri Lanka). With reference to available geographical coordinates, Google Earth Pro images were used to locate the mini-hydropower schemes that are in operation or under construction in the Kelani River basin. Following the validation of geographic positions of mini hydropower plants, the stream lengths between the weir and the powerhouse designated as Affected Stream Stretch (ASS) were estimated for each mini-hydropower project. Field visits were also made to over 20 SHPPs or MHPPs (mini hydropower plants) in the Kelani River basin and an extensive study was conducted on four MHPPs (physical structures and operations) established on the Wee Oya (viz., Wee Oya, Punugala, Amanawela and Monara Ela) and the proposed weir site of the Berannawa MHPP was also visited. In addition, observations were made on riparian vegetation and water distribution between the intake weir and powerhouse of the four mini hydropower projects.

Fish samples were collected using cast nets and hand traps and species were identified with the help of field guides. Further information were collected from riparian community on the local names offish found in the Wee Oya before the construction and operation of mini-hydropower plants. In addition, the endemic fishes restricted to hill streams in Sri Lanka and reported from the Kelani River basin were collected from literature (Deraniyagala 1952, Pethiyagoda 1991, Shirantha 2004, De Silva et al. 2015). EIA/IEE reports, the basis for granting permission to establish mini-hydropower plants on the Wee Oya examined carefully with special emphasis on fish fauna, project design plans, mitigation measures and environmental flow. Data analysis was comparative in nature and attempts were made to exhibit the results in graphical forms and correlation analysis.

Results and Discussion

Since the inception of the construction and operation of SHPPs in Sri Lanka in the 1990s, 31 SHPPs constructed in the Kelani River basin have been connected to the national grid by the end of 2014. These power plants generate 56 MW and another five are under construction (Table 1). Although plant designs indicate projects as run-of-river systems, none of the visited projects in the Kelani River basin did not maintain required flow between the weir and powerhouse creating dead stream stretches unless lateral tributary inputs were available. Table 1 also shows the total lengths of affected stream stretches (ASS) in major tributaries of the Kelani River. In the case for Kekelagamu Oya and Maskeliya Oya, downstream dead stream lengths of Castlereagh and Maussakelle reservoirs and Norton and Canyon ponds were also added to the ASS.A significant linear relationship was found between the generation capacity and the ASS (Pearson Correlation = 0.817; p = 0.000).The

Kehelguamu Oya and Maskeliya Oya had the longest affected stream stretches amounting 27.3 km and 25.5 km respectively resulting in 60.3 % stream loss in Kehelgomu Oya and it was 62.9% for Maskeliya Oya. Extremely high stream losses in two major tributaries were primarily due to the construction of major hydropower reservoirs (Castlereagh and Maussakelle) and storage ponds (Norton and Canyon) without facilitating downstream environmental flows. The highest number of mini hydropower plants has been established in the Seethawaka Ganga sub-watershed compared to the other watersheds (Table 1). In Seethawaka Ganga watershed, except Magal Oya SHPP (9.90 MW) the majority of the other SHPPs has the generation capacity of less than 1.00 MW (Table 1).

In addition, the Seethawaka Ganga had the longest cumulative stream stretch affected by the construction of mini hydropower plants (43.8 %). The values of percentage stream loss for the Guguguda Oya and Ritigaha Oya sub-watersheds were 11.7% and 10.8% respectively whereas it was 32.5% for the Wee Oya. Low hydropower generation and subsequent low affected stream stretch in Gurugoda Oya and Ritigaha Oya may be attributed to the relief of the terrain and the water resource potential of the sub-watersheds. In the case of Wee Oya, four hydropower plants have the generation capacity of11.8 MW (Figure 2). Nevertheless, instead of natural stream stretches, there were isolated stagnant pools, exposed bedrocks and dried up ripple areas between the weir and the power house in all four cases in the Wee Oya, or in other words a dramatic alteration of natural habitats. The same situation may occur in other sub-watersheds of the Kelani River head waters, which has103.9 km of affected stream stretches due to the establishment of 31 small hydropower operations.

The number of hill stream fishes in Sri Lanka is 57 belonging to 12 families of which 44 are endemic (De Silva et al. 2015). Of the endemic fishes, 34 are found only in hill streams between 100 -1000 m AMSL, where their type habitats are located. Eighteen endemic fishes restricted to hill streams have been reported from the Kelani River by various authors (Deraniyagala 1952, Pethiyagoda 1991 Shirantha 2004, De Silva et al. 2015) of which five species were found in Wee Oya in 2005 before the construction of the first MHPP, Wee Oya mini-hydropower plant. The present study found only four endemic fishes restricted to hill streams where water is brought to the mainstream from lateral tributaries (Table 2). The number of fish species reported in other EIA/IEE reports is also given Table 2. It is a common practice to indicate a least number of fish species in EIA/IEE reports. Although these reports are in public domain there are difficulties to access them in certain cases. The results of this study demonstrate devastating effects of inappropriate construction and incorrect operation of hydropower on running water ecosystems and ichthyofauna endemic respective area as reported at several occasions (Silva and Davies1986, Silva 1993, Arthington et al. 2006, Poff 2009, Bhushan et al. 2013, Silva et al. 2013). The situation is worse in the case of small hydropower operation than that of large hydropower with respect to the extent of affected stream stretches. The effects of exposed stream beds on ecological integrity and human health of riparian communities are to be investigated.

Conclusions

The negative effects of incorrect and unacceptable operations of mini-hydropower plants in Sri Lanka on endemic fish fauna as result of alteration and elimination of type habitats are obvious. Evidence are there for declining and vanishing of endemic fishes from hill streams over the last two decades with escalating small hydropower development. Many stakeholders including so-called consulting scientists are responsible for this pathetic ecological crime.

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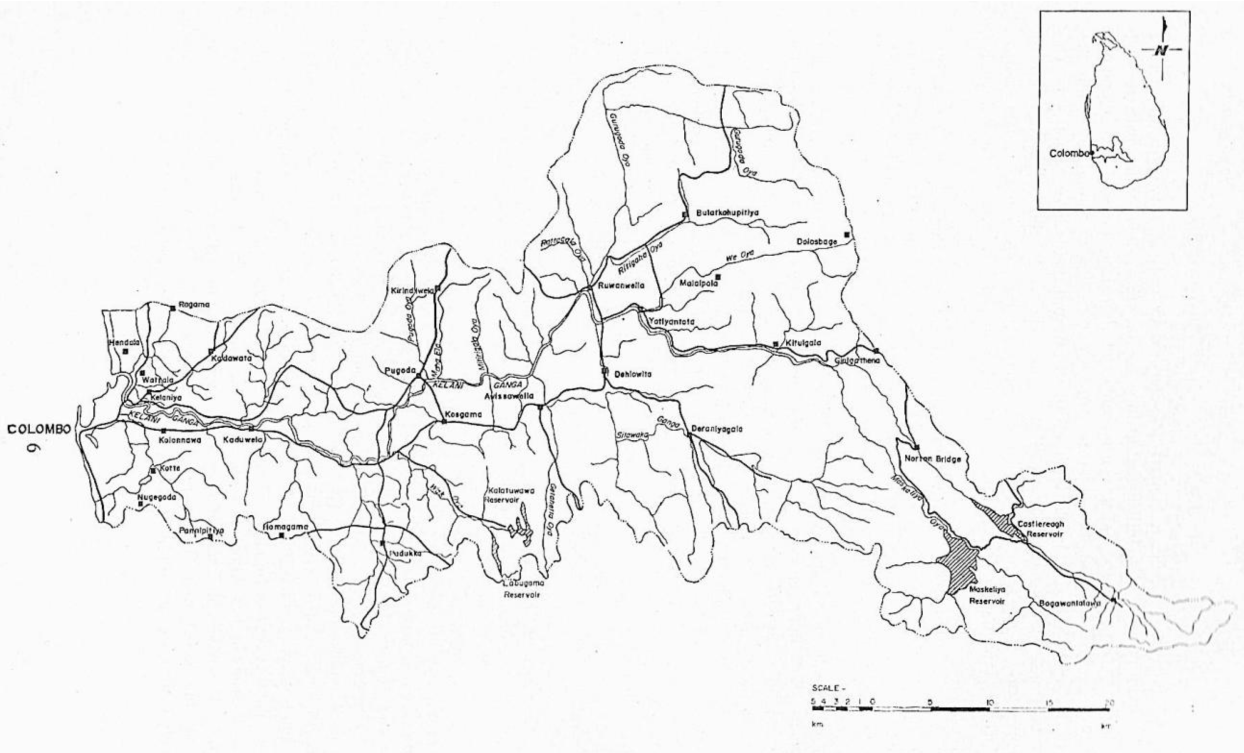

Figure 1. Map of Kelani River basin

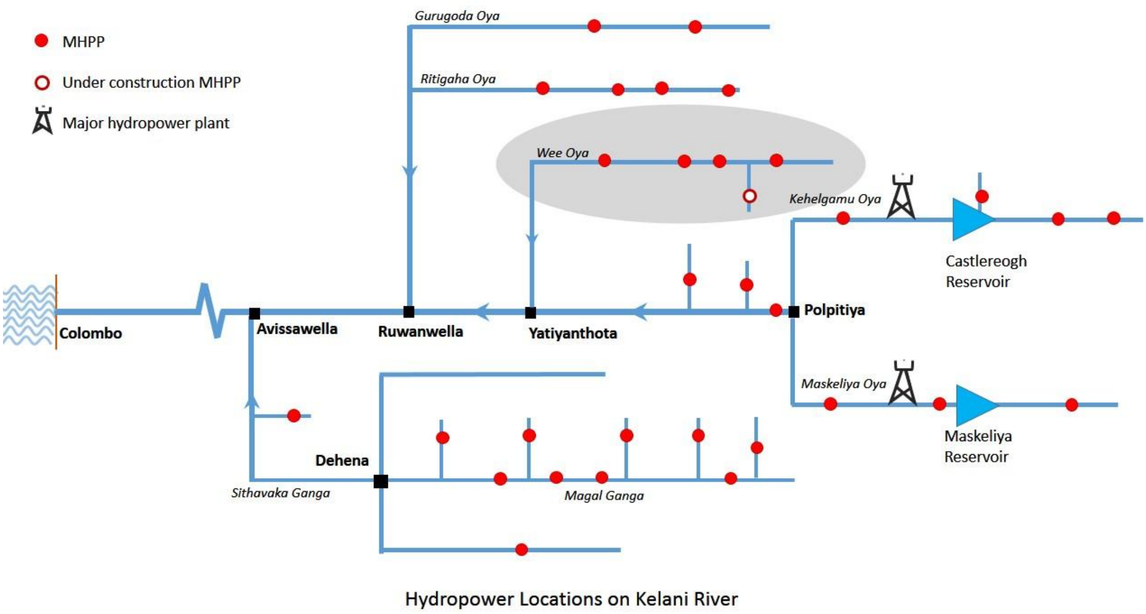

Figure 2. Schematic diagram of Wee Oya denoting locations of small hydropower plants

Table 1. The name, year of commissioned (YOC)and the generation capacities of mini hydropower plants in major tributaries of Kelani River and the total lengths of affected stream stretch (ASS) in each sub-watershed.

	Mini-hydropower Plant	Tributary/length (km)	Capacity (MW)	YOC	ASS (km)
1	Kehelgamu Oya	Kehelgamu Oya (45.3 km)	3.000	2007	27.3
2	Kirkoswald		4.000	2011	
3	Brunswick Estate	Maskeliya Oya (40.5 km)	0.600	2004	25.5
4	Kiriwaneliya		4.650	2011	
5	Pathanahenagama		1.800	2013	
6	Monaraela	Wee Oya (24 km)	1.800	2014	7.80
7	Amanawala		1.000	2009	
8	Punagala		3.000	2012	
9	Wee Oya		6.000	2005	
10	Ritigaha Oya I	Ritigaha Oya (26.5 km)	0.400	2003	2.87
11	Ritigaha Oya II		0.800	2005	
12	Upper Ritigaha Oya		0.640	2014	
13	Gangaweraliya		0.300	2009	
14	Battalgala	Gurugoda Oya (39.3 km)	0.100	2002	4.61
15	Gurugoda Oya		4.450	2006	
16	Ganthuna		1.200	2010	
17	Gonagamuwa		0.750	2013	
18	Bopekanda	Seethawaka Ganga (45.7 km)	0.350	2012	20.14
19	Miyanawita		0.600	2004	
20	Magal Ganga		9.928	2008	
21	Upper Magal Ganga		2.400	2002	
22	Ellapita Ella		0.550	1999	
23	Mandagal Oya		1.284	2000	
24	Nakkawita		1.008	2004	
25	Minuwan Ella		0.640	2001	
26	Halathura Ganga		1.300	2009	
27	Karawila Ganga		0.750	2004	
28	Gomala Oya		0.800	2006	
29	Hemingford		0.180	2005	
30	Nadurana Oya		0.350	2012	
31	Indurana	Minor tributary	0.060	2012	0.74

Table 2. Hill stream endemic fishes reported from Kelani River by different Authors, from the Wee Oya during the present study and included in four EIA/IEE reports and their IUCN status (CR, critically endangered; EN, endangered; VU, vulnerable and NT, near threatened)

Family/Species	Kelani River	Present Study	EIA/IEE Report					IUCN status
			1	2	3	4	5	
Family: Balitoridae								
Acanthocobitis urophthalmus	√							EN
Schistura notostigma	√							NT
Family: Belontiidae								
Belontia signata	√	√	√					EN
Malpulutta kretseri	√							CR
Family Channidae								
Channa ara	√							EN
Family: Cyprinidae								
Dawkinsia srilankensis	√	√	√					CR

Devario Sp Processus	√							NT
Pethia cumingii	√							VU
Pethia reval	√							EN
Puntius titteya	√	√	√					VU
Systomus asoka	√					√	√	CR
Systomus pleurotaenia	√							VU
Laubucavaruna	√							CR
Rasboroides vaterifloris	√		√	√				EN
Garra ceylonensis	√	√	√	√	√	√	√	EN
Family Gobiidae								
Sicyopus jonklaasi	√							EN
Family Nemacheilidae								
Acanthocobitis urophthalmus	√							EN
Schistura notostigma	√							NT

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Small Hydropower and Hydrological Networks in Mountain Landscape in Sri Lanka

E.I.L. Silva

Water Resources Science and Technology, 77/2, Hettiyawatte, Elapitiwela, Ragama, Sri Lanka,

E-mail: eils.mecamp@gamail.com

Abstract

The terrain of Sri Lanka has been divided into 103 drainage basins but only seven rivers rise from the Central Highlands in the wet zone (i.e., Mahaweli, Maha, Kelani, Kalu, Gin, Nilawala. Walawe, and Kirindi). The Mahaweli River, the longest and the largest river basin of the island has 57 small hydropower plants (SHP) with 113 MW generation capacity in operation while another few are under construction. The establishment of mini-hydropower plants has disrupted 77.3 km long stream stretches due to non-availability of stream flows between the weir and powerhouse of each SHP plant. In addition, loss of stream stretches due to major hydropower schemes (i.e., Upper Kotmale, Kotmale, Victoria, and Randenigala-Rantambe) on Mahaweli River is 33.3 km, which generates 810 MW. Thirty-two mini hydropower plants with 55.61 MW generation capacity are in operation on the Kelani River basin creating 47.3 km dead stream stretches. The affected stream stretch is 41.9 km resulting from five major hydropower schemes in the Kelani River basin (i.e., Wilmasurendra, Old Lakshapana, Canyon, New Lakshapana and Polpithiya) that generates 353 MW. Twenty-eight small hydropower plants with generation capacity 70 MW are in operation on the Kalu River basin while disrupting 29 stream kilometres when the major hydropower project (Kukule Ganga) also taken into account. There are fourteen mini-hydropower plants having 26.84 MW generation capacity on the Walawe River basin resulting in 17.3 km dead stream length. Ten mini-hydropower plants are in operation on other four rivers (Gin Ganga, Kirindi Oya, Ma Oya, and Nilwala Ganga) that rise from the Central Highlands and generate 15 MW while disrupting 9.4 km stream length.

Accordingly, construction and operation of 143 small hydropower schemes on hill streams in the Central Highland of Sri Lanka since early 1990 to 2015 have resulted in stream water to flow 225 km through conduits, concrete canals, penstocks, and tailraces disrupting downstream flows and sediment transport, seepage and recharge, in turn, the entire hydrological network. This has significant effects on riverine endemic fishes, stream bank vegetation and the livelihood of riparian communities. Besides, authorities have granted permissions for another 87 small hydro projects with the installation capacity of about 139 MW. The water resources development in Sri Lanka since ancient time to date is fascinating. The ancient hydraulic civilization, which shows the indigenous knowledge in water resources development is world famous. The modern water resources development in Sri Lanka devoted mainly for hydropower development is a mix of western technology local manpower. Recent developments of small hydropower in Sri Lankan are essentially private sector ventures adapted from western technology giving least concern on environment and remote riparian communities highlighting there no significant impacts either on the environment or respective riparian communities because they are small, which is totally incorrect.

Introduction

Streamflow regulation is a common human exercise since ancient time although it had been done by beavers even before the human civilization. Running water is regulated by man for a variety of purposes namely for irrigation, flood control, hydropower generation, water abstraction etc. Although stream flow regulation for irrigation, flood control, and water abstraction are done by means of simple conventional methods, hydropower generation is involved a fair amount of modern technology. This is primarily a tapping of potential energy of water masses located in the higher elevation, which is transformed into kinetic energy and also dissipates when the moving water mass hits stream banks or rocks or drag along the stream bottom when flows downstream due to gravitational forces. Nevertheless, the downstream water flow of streams and rivers is purely not a hydraulic system as it carries dissolved and suspended organic and inorganic matter including living organisms. Therefore, it is considered as a fluvial system. In addition, they also transport bed load material, replenish groundwater resources and link material cycles between the land and the ocean. Accordingly, there are many evolutionary established biogeochemical cycles between the land and the ocean which are extremely important to sustain the planet earth.

Streamflow regulation for hydropower generation either by constructing low head reservoir systems or run-of-river systems in the case of small hydropower generation certainly disrupts evolutionarily established biogeochemical cycles and, in turn, natural equilibrium of the respective watershed. A recent publication in Science reported that the world’s most biodiverse river basins; the Amazon, Congo, and the Mekong are experiencing an unprecedented boom in construction of hydropower dam (Winemiller et al. 2016). According to the authors, these projects address important energy needs, but advocates often overestimate economic benefits and underestimate far-reaching effects on biodiversity and critically important fisheries. Current site-specific assessment protocols largely ignore cumulative impacts on hydrology and ecosystem services as for ever more dams are constructed within a watershed (Grill et al., 2015). Silva (1993) highlighted the potential impacts of discontinuum of Mahaweli River in Sri Lanka by constructing a cascade of five dams across the mainstream of the river, totally ignoring the importance of river continuum on endemic and native fish fauna. Dams either large or small inevitably important for the economic development and quality of life but invariably reduce the fish diversity and also block movements that connect populations and enable migratory species to complete their life cycles.

Historical Background: Ancient Ceylon is reputed for her hydraulic civilization achieved through trans-basin diversions and construction of irrigation tanks since pre-Christian era, which has direct bearings with early human settlements in the dry zone. Two types of ancient systems were prominent; 1. Partial diversion of some of the major rivers to achieve inter-basin transfer, 2. Creation of storage tanks to feed the downstream command areas of rice paddy. In addition, a large number of medium scale storage tanks had been created in the north central dry zone either by arresting seasonal rivers or tributaries or by transferring water. Thousands of small shallow seasonal tanks of the ancient category, which collect water only during rainy seasons from their own catchments and dry off at the end of the dry seasons, were also in existence in the dry zone of the island.

The ancient hydraulic civilization crumbled around 12th century AD, and reasons led to the fall down remain still unclear. Attempts have been made to explain the collapse in relation to several factors such as foreign invasions and following the loss of water experts, refuse of soil fertility, epidemics, and famine. Nevertheless, the cleverness of water engineering of ancient Ceylonese had gradually disappeared with shifting monarchies from dry zone to wet zone. Portuguese and Dutch (1505-1795), constructed canal networks for flood protection and navigation confined only to urban areas in Colombo and western and north-western coasts. Today, most of them have deteriorated and converted into dull waterways. Hydrological changes resulted from the construction of Old Dutch canal gradually transformed Muthurajawela, once very fertile rice fields into marshes.

Since independence in 1948 to date, Sri Lanka has accomplished several major hydropower and multi-purpose schemes by damming and diversion of upland rivers and creating new reservoirs and augmenting existing ones. Major developments in Kelani River resulted in two hydropower reservoirs namely Castlereagh and Maussakelle in the upper watershed. Senanayake Samudra, the largest surface water body in the country (7,760 ha) was created in 1951 by damming the Gal Oya at Inginiyagala. Chanidrkawewa and Udawalawe reservoirs were built on the Walawe River during 1963-1968. The upstream of the Walawe River was arrested by a hydro-dam creating the Samanalawewa in 1992. Construction of Lunugamvehera reservoir on the Kirindi Oya, upstream of the existing ancient reservoirs was completed in 1986 to transfer water via Badagiriya tank for downstream irrigation. The Mau Ara reservoir was constructed by amalgamating the Malala Oya with Mau Ara, a left bank tributary of Walawe river in 2003, The most recent surface water development in the country was the completion of Handapanagala and Weheragala reservoirs in the Kirindi Oya basin of the southern province in 2009 whereas a multipurpose reservoir was completed across Deduru Oya in the Kurunegala District in 2015.

Mahaweli Development: The government embarked on a multipurpose Mahaweli Development Programme (MDP) in 1970 on the recommendations made by the UNDP/FAO to provide irrigation facilities to 365,000 ha and hydroelectric power generation with an installed capacity of 507 MW. This project was recommended for stepwise completion over a period of thirty years. In the first phase of this project, a regulatory-weir (barrage) constructed at Polgolla transferred Mahaweli water to Amban Ganga (=River) through 5.4 km long tunnel then to Kala Oya and Yan Oya from newly build Bowatenna reservoir through 8.2 km tunnel while augmenting several existing irrigation tanks. Excess water of the Kalawewa-Balaluwewa reservoir system is conveyed through Jaya Ganga augmenting the major tanks in Anuradhapura district.

In 1980, the government accelerated the second phase of MDP and completed within a period of six years although scheduled to complete within 30 years. This includes four major hydro-dams (i.e. Kotmale, Victoria, Randenigala, and Rantembe) in a cascade and interlinking of Maduru Oya with Mahaweli river creating Ulhitiya-Rathkinda storage tanks and Maduru Oya reservoir with several medium and minor perennial tanks. The newly built water bodies flooded an area of about 15,000 ha, changing the entire hydrological network of the Central Mahaweli Valley and the Dry Zone Plain. The natural course of the Mahaweli River is still in existence although it empties water not only into the Koddiyar bay and Verugal coast but also into Dutch bay in the Puttalam lagoon via the Kala Oya and to Vendaloosan bay via the Maduru Oya. The flow pattern, channel morphology, discharge volume, sediment transport of Mahaweli River may certainly have been changed now as a result of changes that have taken place since the ancient time to date.

Rapid flows of perennial rivers draining the mountain landscape of the country were arrested at deep valleys first creating canyon shape deep reservoirs then transferred through tunnels and penstocks for hydropower generations. Most of the major hydro potential in Sri Lanka has been developed since the early 1950s and they are delivering valuable low-cost electricity to the country (Table 1). Since the commissioning of the first hydroelectric power plant in 1950, hydroelectricity has played a major role in power generation in Sri Lanka. The largest share of electricity generation came from major hydropower projects until the mid-1990s. The Sri Lanka's power sector was dominated by hydropower until 1996, and almost 94 percent of the annual power demand in 1995 was met via hydropower generation. Despite several hydropower capacity additions, the share of hydropower showed a reducing trend since the mid-1990s due to the non-availability of new potential sites that are economically feasible for hydropower development. Currently, hydropower stations are operated to meet both peak and base electricity generation requirements.

Small Hydropower in Sri Lanka

The history of harnessing hydropower in Sri Lanka dates back to the British colonial era, during which hydropower was used as the main sources of energy in large tea factories located in the hilly terrain of the central highland. Since the beginning of the tea industry, small hydropower was the main source of power for the tea factories, and many factories were intentionally located closer to perennial streams or brooks to tap their gravitational energy. Initially, factories and powerhouses were placed together, as power had to be transmitted to the machinery by line shafts and belts. Later, direct current (and still later, alternating current) generators became more readily available, and powerhouses were built at further downhill from the factory to maximize the head for effective power generation.

After the World War II, the relative advantage of SHP rapidly declined owing to the installation of large-scale storage-type hydro schemes, which began to supply the first stages of a national grid. Further, many of the mini-hydro and thermal systems were near their end of life at this time, needing extensive repairs or total replacement. These issues, together with the prospect of low-cost and reliable electricity supplies, acted as strong incentives for the tea industry to switch over to the national grid operated by the Ceylon Electricity Board (CEB). By 1975, when the tea estates were nationalized, less than one-third of them had retained their SHP systems in operational stage. The decline further continued after nationalization and by 1984, only 5 percent SHPs were in operation. The Practical Action (former Intermediate Technology Development Group), jointly with CEB, made a significant contribution to the revival of SHP development in Sri Lanka through technology development and strengthening of technical capabilities of Sri Lankan engineers and technicians.

Unavailability of potential sites for major hydropower development, associated inflation and high labour cost and environmental issues has led to exploring the potential of small hydropower in the country. Risk analyses, risk mediation measures, low-cost developments, selective procurement etc., adopted by engineers resulted in achieving positive results. Nevertheless, the major assumption forwarded in engineering context on small hydropower development was that small hydropower results in no adverse environmental and social issues, which is an incorrect and bias assumption to a greater extent.

Small hydropower sector and its potential in Sri Lanka have been overviewed and the country adheres to the small hydropower definition of 10 MW as the upper limit. By the end of 2014, 143 small hydropower plants were connected to the national grid and in operation in Sri Lanka, with an aggregated installed capacity of 287 MW. The most of them are owned by Independent Power Producers (IPPs). According to Sri Lanka’s Sustainable Energy Authority (SEA), the total economically feasible small hydropower potential in Sri Lanka is 400 MW with 600 potential sites. On the contrarily, the latest release (on 16 October 2015) of the Public Utility Commission of Sri Lanka (PUCSL), permission have granted for another 87 projects with installation capacity of about 139 MW.

Mahaweli River Basin: There are 57 mini-hydropower plants in operation in the Mahaweli River basin while another few are under construction. Figure 1 shows the number of MHPs in operation within each sub-watershed of the Mahaweli basin. Two cascades on Sudu Ganga and Hatton Oya are prominent in the Mahaweli River basin and the highest number of MHPs is in operation on the Hatton Oya followed by Atabage Oya, Hulu Ganga, and Nanu Oya sub-watersheds. The total disrupted or affected stream stretch (ASS) within the Mahaweli basin were estimated as 77.3 kilometres while generating 113 MW. In contrast, loss of stream stretches due to major hydropower schemes (i.e., Upper Kotmale, Kotmale, Randenigala-Rantambe, Ukuwela, and Bowetenna on the Mahaweli River is 33.3 km which generates 810 MW. The distribution pattern of mini hydropower plants in the Mahaweli river basin is shown in Figure 1. Three major hydropower schemes namely Moragahakanda, Kalu Ganga, and Uma Oya are under construction in the Mahaweli River basin. (Table 1)

Table 1. Major hydropower developments in Sri Lanka

Major hydro project	River Basin	Capacity (MW)MW)	Year of Commissioned
Old Lakshapana	Kelani River	53.5	1950
Wimalasurendra	Kelani River	50	1965
New Lakshapana	Kelani River	115	1983
Canyon	Kelani River	60	1983
Polpithiya	Kelani River	75	1974
Inginiyagala	Gal Oya	10	1951
Udawalawe	Walawe River	6	1969
Samanalawewa	Walawe River	120	1992
Ukuwela	Mahaweli River	40	1976
Nilambe	Mahaweli River	3.2	1988
Bowetenna	Mahaweli River	40	1981
Kotmale	Mahaweli River	201	1985
Victoria	Mahaweli River	210	1984
Randenigala	Mahaweli River	122	1986
Rantambe	Mahaweli River	49	1990
Upper Kotamale	Mahaweli River	150	2011
Kukule Ganga	Kalu Ganga	75	2003
Deduru Oya	Deduru Oya	1.5	2014
Total		**1381.2**	
Moragahakanda	Mahaweli River	40	Under Construction
Kalu Ganga	Mahaweli River	10	
Moragolla	Mahaweli River	40	
Broadlands	Kelani River	35	

Kelani River Basin: Thirty-two mini hydro power plants with 55.61 MW generation capacities are in operation on the Kelani River basin of which 12 are located on the Seethawaka Ganga (Figure 2), the major tributary of the Kelani River whose headwater tributaries drain Kithulgala-Maliboda range. The power generation capacity of these MHPs ranges from 0.060 MW (Indurana MHP) to 9.928 MW (Magal Ganga MHP). In Seethawa Ganga sub-watershed, seven MHPs have the capacity of less than 1.00 MW. Besides, the total lengths of affected stream stretch (ASS) in the Kelani River basin is 47 km where 32 MHPs are in operation to generate 55.61 MW. In contrast, the affected stream stretch is 47.3 km resulting from five major hydropower schemes (i.e., Wilmasurendra, Old Lakshapana, Canyon, New Lakshapana and Polpithiya) that are in operation while generating 353MW. Nevertheless, the Kehelguamu Oya and Maskeliya Oya have the longest affected stream stretches in the Kelani River basin. None of these hydropower schemes neither major nor are facilitated with downstream environmental flow in between the weir/reservoir and powerhouse release

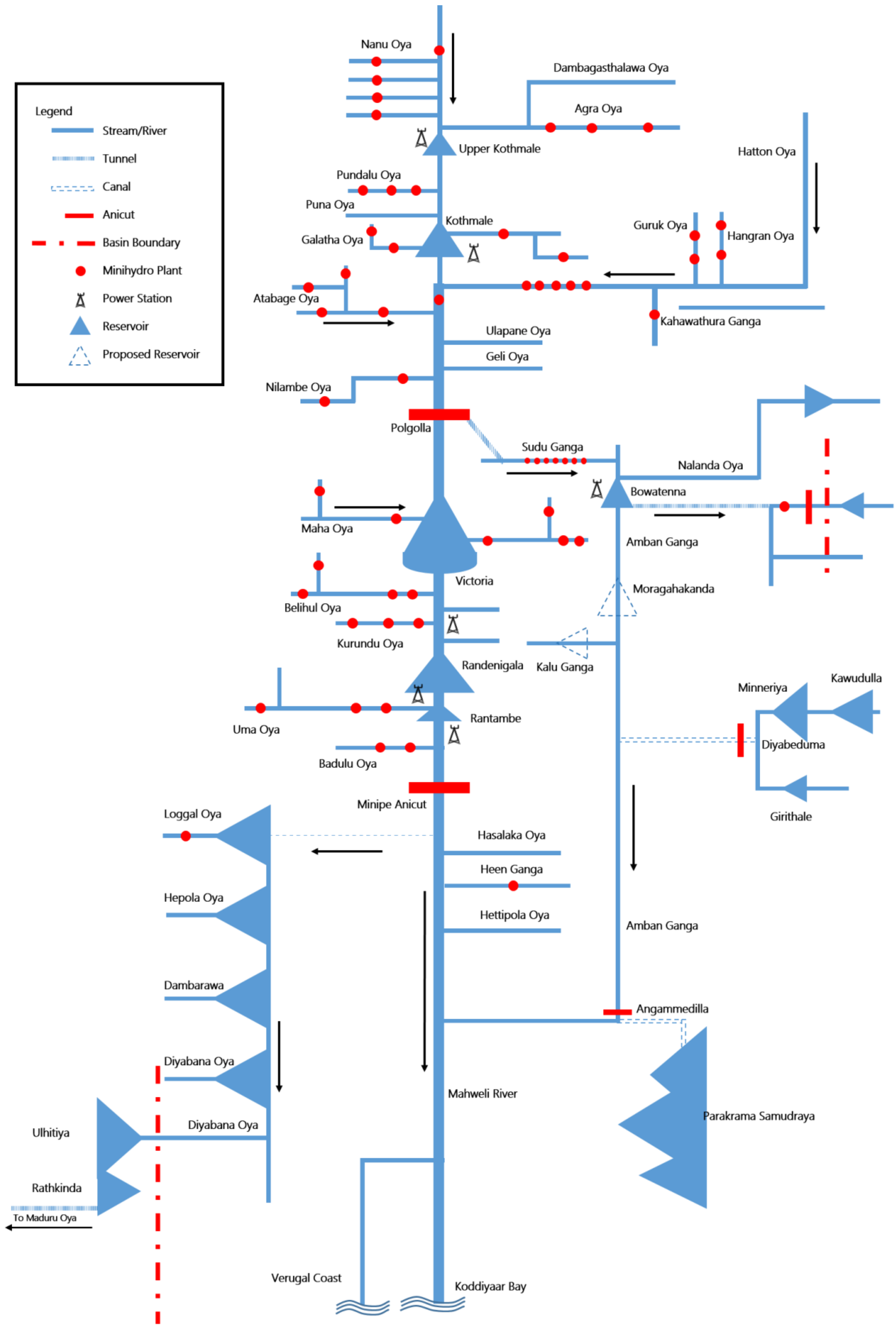

Figure 1. Schematic diagram of Mahaweli River basin depicting sites for mini-hydropower plants and other regulatory structures

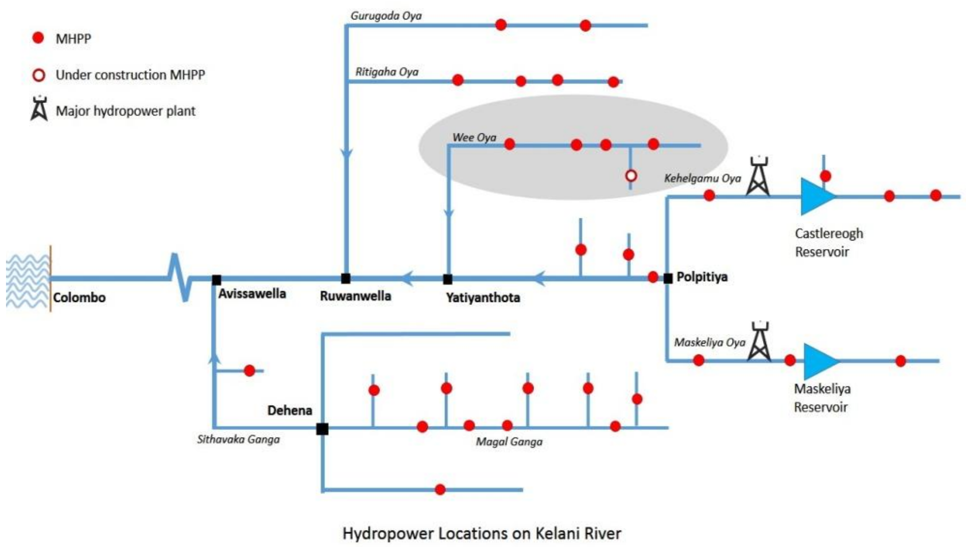

Figure 2. Schematic diagram of Kelani River basin depicting site for mini-hydropower plants and other regulatory structures

Kalu River Basin: Twenty-eight mini hydro-power plants of about 70 MW generation capacity are in operation on the Kalu River basin of which eight are located on Denawaka Ganga (Fig. 3). While headwater tributaries of Kalu Ganga rise from the foothills of Sri Pada mountain having two MHP plants, Kukule Ganga and Rath Ganga whose headwaters are confined to the Sinharaja Rain Forest and Peak Wilderness respectively have six and five mini-hydro power plants with more or less similar generation capacity, which is also similar to Wey Ganga that has only two MHP plants (Fig. 3). The total length of affected stream stretch (ASS) in the Kalu Ganga basin is 29.0 km when major hydropower projects are also taken into consideration (i.e., Kukule Ganga Hydropower Project), The Denawaka Ganga has the longest affected stream stretch (5.41 km) due to the establishment of seven mini hydro-power plants whereas more or less similar stream stretches have been disrupted in Kukule Ganga (4.21 km) and Kuru Ganga (4.04 km). Although Rath Ganga has five mini-hydropower plants the affected stream stretch is 3.3 km. As in Mahaweli and Kelani River basins, hydropower schemes in the Kalu Ganga basin too are not facilitated with the downstream environmental flow in between the weir/reservoir and powerhouse release.

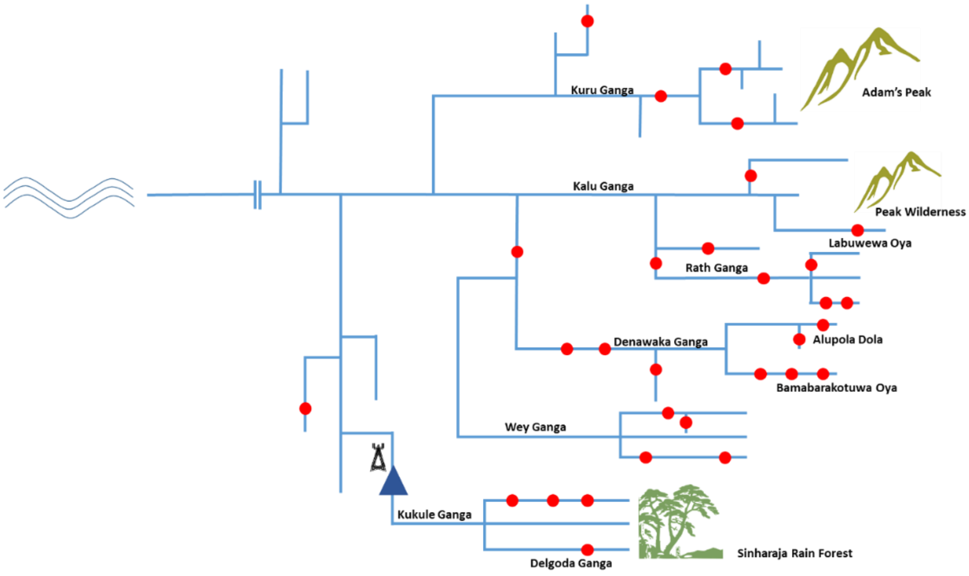

Figure 3. Schematic diagram of Kalu Ganga basin depicting sites for mini hydro-power plants and other regulatory structures

Walawe River Basin: Fourteen mini-hydropower plants having 26.84 MW generation capacity are in operation on the Walawe River (Fig. 4). The oldest mini-hydropower plants are located on the Rakwana Ganga sub-watershed and generation capacity ranges from 0.500 MW in Ranmudu Oya MHP plant to 5.00 MW of Bogandana MHP plant. In addition, Samanalawewa hydropower scheme generates 120 MW whereas 3.0 x 2 MW are generated by RB and LB releases of Udawalawa irrigation reservoir. There are no cascade mini-hydropower plants in the Walawe River basin perhaps due to shorter tributary lengths and the steepness of the upper basin. The total length of affected stream stretch (ASS) in the Walawe Ganga is 17.3 km because the major hydropower reservoir (Samanalawewa) has a continuous downstream flow due the leakage of water/ the downstream leakage water has been tapped at Mulgama by Mulgama mini-hydropower plant. In addition, another mini-hydropower plant is under construction at the immediate downstream of the Samanalawewa reservoirs to tap leakage water. Only twelve small hydropower projects are in operation in the other river basins (i.e.; Gin Ganga, Kirindi Oya, Maha Oya Maduru Oya and Nilwala Ganga), by the end of 2014 generating 21.95 MW within the range of 0.250 MW and 5.00 MW of which some of them are located in irrigation canals.

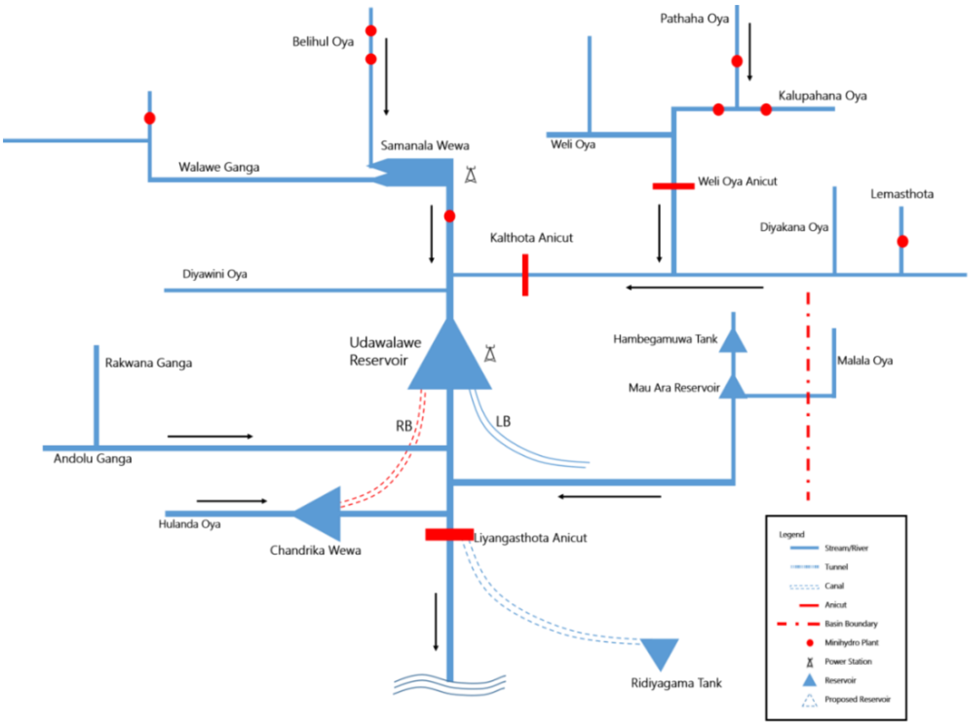

Figure 4. Schematic diagram of Walawe River basin depicting sites for mini hydro-power plants and other regulatory structures

4.0 Discussion

The overall picture of mini-hydropower distribution in Sri Lanka is amazing (Fig. 5). The entire hydrological network of the Central Highland has dramatically changed over the last two decades. The Government of Sri Lanka still did not realize the gravity of the problem with respect to eco-hydrology of the mountainous landscape, which also provides many services in addition to cash crops production namely tea and vegetables. It is well-known that the mountainous landscape of the island is the water tower, which supplies water to the other geographic regions of the island via surface run-off and underground flow. Besides, the natural hydrological network plays a vital role shaping the entire landscape features including its flora and fauna. The devastating disruption of natural system at unwarranted magnitude may lead to unprecedented consequences. Therefore, it is extremely important to pay equitable attention on the environment not in a superficial manner for the sake of doing but with realistic and in-depth ecological and geomorphologic understanding. A significant linear relationship was found between the generation capacity and the affected stream stretch (ASS) (Pearson Correlation = 0.817; p = 0.000) in the case of operational small hydropower plants.

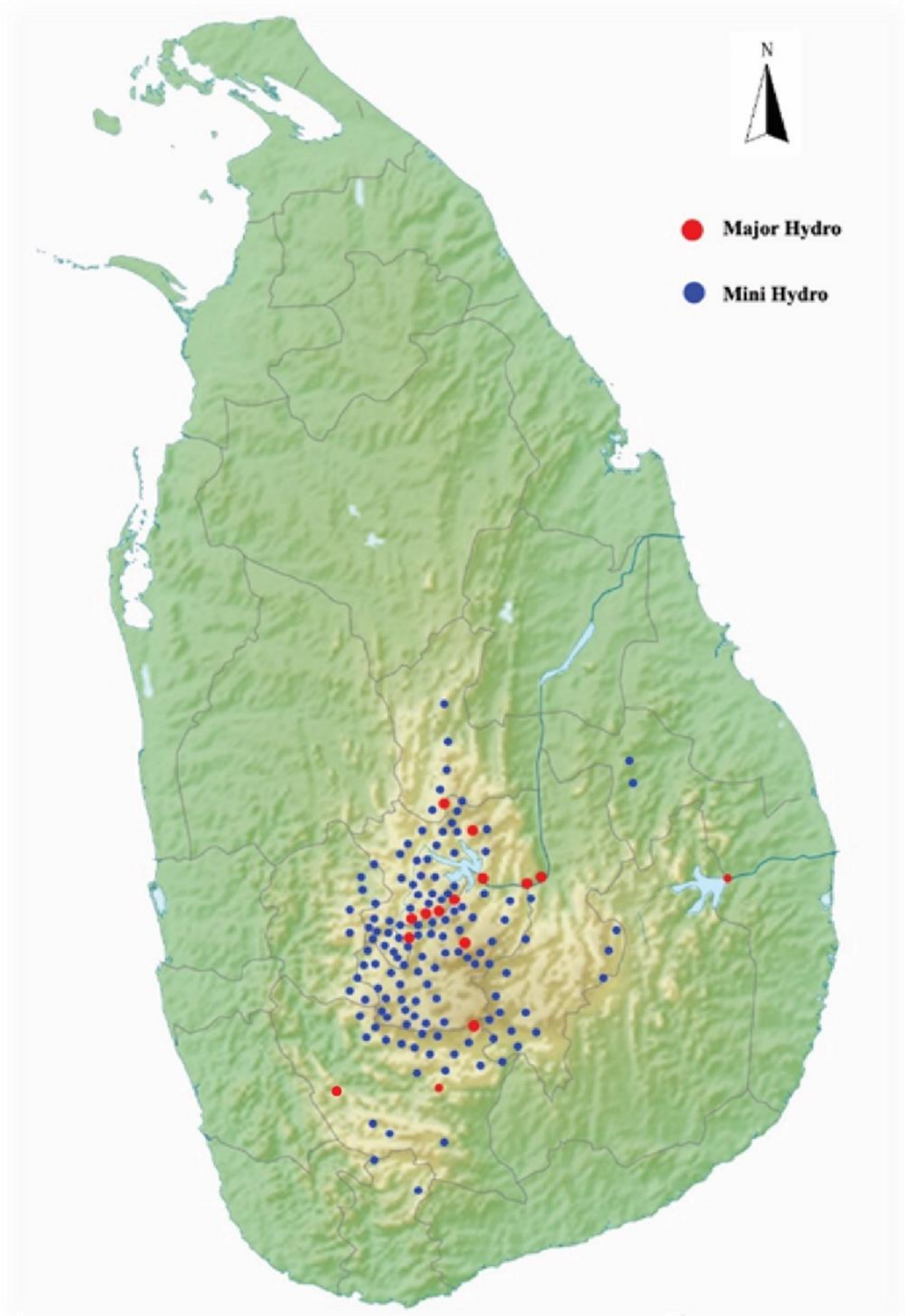

Figure 5. Distribution of major and small hydropower plants in Sri Lanka

Freshwater fishes in Asian rivers are susceptible to the anthropogenic threats resulting from deforestation, infrastructure development, stream flow regulation, diffused and point-source pollution and over-exploitation (Dudgeon 2000). The situation in Sri Lanka is also similar with several exceptions (e.g., urbanization, gem-mining, over-use of pesticides, ornamental fish trade, use of destructive fishing methods and introduction exotic fish) as reported by several authors (Senanayake and Moyle 1982, Wijeyaratne 1993, Pethiyagoda 1994, 2006, Gunasekara 1996, Bambaradeniya 2002). Most of these factors are interrelated with each other, but habitat degradation and impairment of water quality are among the main decisive factors attributable to population decline and gradual extinction. Fish species inhabiting agricultural watersheds are eco-physiologically substandard compared to their counterparts found in forested watersheds (Jayakody et al. 2011). Further, the negative effects of large dams on riverine fish fauna have been discussed in detailed in many instances (Silva 1993, Arthington et al. 2006, Poff 2009, Bhushan et al. 2013). Marked decline in two species of migratory eels native to Sri Lanka was observed following the construction of five trunk stream dams on the Mahaweli River (Silva 1993). The effects of a cascade of small hydro dams on Sudu Ganga (a major tributary of Amban Ganga) in Matale District (Silva et al. 2013) and on Wee Oya in the Kelani River basin (Silva et al. 2015) were highlighted and devastating negative effects of inappropriate and incorrect construction and operation of mini hydropower plants on fish fauna endemic to Sri Lanka were well addressed.

Evidently, the hydrological network of the mountainous landscape in Sri Lanka has dramatically changed by the construction of small and major hydro schemes. This has a significant effect on ecosystems balance, vegetation characteristics as well as wildlife. Silva et al (2016) showed the negative effects of the establishment of small hydropower on the distribution of hill stream endemic fishes in Sri Lanka, which is more elucidated compared to the previously described zoogeographic distribution of freshwater fishes into three regions (Mahaweli, Dry Zone, and Southwest Wet Zone) by Senanayake (1985). They found the highest number of endemic fishes in the headwaters of Kelani, Kalu, and Nilwala rivers and attributed to habitat availability whereas the lowest number of endemics in the Central Mahaweli Hills has resulted certainly from long-term alteration of hydrological network. Environmental clearance through IEE/EIA process is mandatory for the establishment of mini-hydropower projects in Sri Lanka. It is crystal clear that the authorities have not yet understood the cumulative effects of the establishment of many small hydropower schemes within small sub-watersheds. Further, IEE/EIA reports on small hydropower projects, which are heavily loaded on the carbon trade hardly address the issues on long-term effects on eco-hydro geological balance, vegetation characteristics and wildlife propagation. As shown by Silva et al. (2014) stream regulation in Sri Lanka under ancient hydraulic civilization was much more environment-friendly than modern systems that should be taken into consideration by modern engineering developments.

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