International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Predicting the Water Availability Under Land Use Scenarios and Climatic Change for Micro-hydro Power Generation in Sri Lanka Using PRA Tools

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Abstract: ***The objective of this study was to study the impact of land use and climatic change on the water availability for off-grid rural micro-hydro power generation. Five micro hydro sites from five districts were selected and land use features were identified using PRA tools namely, transact diagrams, land use maps and direct observations. Rainfall data of the sites were collected to characterize the sites. Present study clearly indicates that land use factors have to be considered when estimating water yield for micro hydro development. The difference between rainfall and water yield is high especially when catchments are covered with tree (taller) vegetation. Lowering of rainfall due to climatic change is going to have differential impacts on the actual water yield of the catchments depending upon the nature of its land use. Introducing water saving land use may be an option to increase the water yield. However, land use at a particular place is determined by many factors, which often have little or no relevance to hydrology of the areas.***

Key words: Land use, water yield, climate change, micro-hydro power generation, PRA tools

1. Introduction

A congenial ecosystem is a fundamental need for a reasonable standard of living of human beings. The climate plays a vital role, as it is part and parcel of the ecosystem. However, due to an array of reasons, the hydropower generation is very vulnerable to changes in climate. At a time when Sri Lanka is facing an acute power shortage, this needs special attention.

Intermediate Technology Development Group (ITDG), which has been working in the micro hydro sector since 1990s conducted a survey on the micro hydro potential in 10 selected districts in Sri Lanka, for the DFCC Bank, Energy Service Delivery (ESD) project[1,2]. These districts were perceived to have a higher micro hydro potential, which were not yet tapped. Total number of sites identified as feasible by studying the topological maps were, 1042. It was estimated that these sites have a potential to generate over 41 MW, according to the desk study. Out of this 531 sites were within the areas that are not yet connected to the national grid.

Later, sites identified as having the potential to set up micro hydro schemes were physically visited to verify the feasibility. Due to constraints in time and finance, only about 12% of the sites were selected randomly as the sample. However, it was alarming to note the differences between the theoretical expectations and the practical results at the seemingly potential sites. Some of the water resources identified were not existent or have dried up reducing the water supply drastically. The data for the theoretical compilations were based on the maps that have been drawn up around 1982-1984. Taking this situation into consideration, ITDG initiated a study to investigate into the possible causes for these differences.

Objective: To study the relationship of land use and climatic change on the water availability for off-grid village micro-hydro power generation in Sri Lanka.

2. Methodology

Present study was conducted during May-June, 2003. Five sites were selected for the study (Table 1). These were among the sites that showed highest variations in the theoretical identification and the physical verifications of the potential sites during the Field Verification study conducted in February-March, 2003 [3]. Rapid Rural Appraisal (RRA) tools, namely transact diagrams, land use maps and direct observations were developed to analyze the land use and topographical features [4]. Rainfall data of five micro hydro sites selected for the study were obtained from Natural Resource Management Center (NRMC), Peradeniya in order to characterize the sites. The study was conducted for the Intermediate Technology Development Group (ITDG).

Table 1: Sites selected for the study.

Site / District	*Location*	*Slope of the catchment %*
1. Kegalle	Ranahinkanda, Deraniyagala	30-40%
2. Ratnapura	Diyapota, Embilipitiya	100%
3. Matara	Paragala, Morawaka	75-100%
4. Moneragala	Walasella, Badalkubura	70-100%
5. Badulla	Makuldeniya, Koslanda	70-120%

It would have been ideal if long-term climatic data on these sites were available. However, lack of such information were overcame to some extent by using the findings of the Climatic Change Enabling Activity Project, Ministry of Environment and Natural Resources, Sri Lanka.

3. Results and Discussion

Water yield of catchments depends upon the rainfall received, land use and physical characteristics of catchments. In addition to above, it is useful to know the climatic characteristics including wind velocity, cloud-cover, relative humidity and ambient temperature that affect evapo-transpiration (ET) rate. However such site-specific data on ET is not available as databases.

3.1 Evidences for decline of rainfall

Rainfall

As mentioned earlier sites were characterized using rainfall data obtained from the Natural Resources Management Center (NRMC), Department of Agriculture. This clearly shows that two sites at Kegalle and Matara receive high and well-distributed rainfall when compared to other three sites. However plotting dry and wet spells by looking at daily or at least weekly rainfall could be lot more effective in making predictions of stream flow in the micro hydro sites.

Table 2. Rainfall characteristics of the study sites.

Site	*Dry periods*	*Total rainfall range (mm)*	*Climatic zone*
Kegalle	Dec-Feb	3000-5500	Wet zone
Ratnapura	Jan-Feb, June-Aug	500-1500	Intermediate zone
Matara	Jan-Feb	2800-5300	Wet zone
Moneragala	May-July, Aug-Sept	1750-2650	Intermediate zone
Badulla	Jan-Feb, June-Sept	1850-4775	Intermediate zone

3.2 Climatic change

Long-term data is essential to estimate the climatic changes. Hence, conclusions drawn from such studies conducted by other researchers [5,6] are quoted here:

The recent analysis conducted by Keerthisena and others have identified some evidence for climatic change [6]. They have stated that: "The climatic change that is taking place includes the increase of environmental temperature. Analysis of temperature data over a period of more than 100 years has shown that air temperature over Sri Lanka has been increasing slowly since1960. Higher temperatures have a direct influence on the rainfall regime of the country through enhanced convectional activity. Under such situations erosive rains could occur than before which will lead to land degradation through the removal of topsoil. Higher temperatures also increase organic matter decomposition. This will further enhance soil erosion and so increase land degradation".

MaddumaBandara and others [5] after studying the climatic change and its impact on the upper watersheds of hill country have stated that: "There are now strong indications to suggest that global climate change is now affecting the central islands in a significant way. Thus a statistically significant trend of declining rainfall and an increasing trendof temperature have been observed at NuwaraEliya. The magnitude of rainfall decline has been estimated to be around 20% over a period of about 100 years, while the temperature has increased by about 1.5^{o}C during the same period. An increasing trend has also been identified in the occurrence of thunderstorms".

The low rainfall in combination with high temperatures reduces the water availability. This trend is common to whole of Sri Lanka especially for wet zone areas (MaddumaBandara, *Pers. Com.*).

3.3 Land use in the catchments

In addition to rainfall and physical characteristics, catchment's water yield is also determined by its land use. Land use of the selected catchments is shown in the Table 3. Land use maps and transacts developed for the five sites are given in the Figures 1-5. It is clear from this data that rubber, tea and forest-trees are the dominant land use in the catchments. Vegetation at lower sinusial levels is rare at most sites as they dominated by tall or intermediate vegetation. Runoff is required to maintain stream flow in order to generate micro hydro-power. Runoff is mostly generated in the open or areas with surface vegetation. However, very small proportion of catchments is open or having surface vegetation (Table 3). They include open parts of home-gardens, roofs of houses and roads.

Table 3: Land use in the catchments of five selected sites

Land use category	*Keg-alle*	*Ratna-pura*	*Matara*	*Monera-gala*	*Bad-ulla*
Tall vegetation:					
Rubber	76	-	-	-	-
Natural forest	-	44	31	32	-
Forest plantations	-	-	-	23	12
Homegardens	12	18	22	07	13
Intermediate vegetation					
Tea	12	12	38	12	57
Cinnamon	-	11	04	-	-
Surface vegetation:					
Grasslands	-	-	-	26	18
Chena	-	09	-	-	-
Rice lands	-	06	-	-	-
Open areas	-	-	05	-	-
Total	**100**	**100**	**100**	**100**	**100**

Types of land use found in the catchments and their general characteristics are shown in the Table 4. Of the vegetation types rubber, home-gardens and natural forests tends to retain large quantities of water both in the vegetation and soil due to their larger surface area (that intercept a large quantity of water) and dense ground cover (which increases the infiltration rate and reduce the runoff). Tea plantations will have low rates of interception (due to smaller mass) but runoff would be low because of the presence of soil conservation infrastructure.

Table 4. Characteristics of the different land use types.

Type of vegetation	*Canopy cover*	*Ground cover*	*Runoff*	*Remarks*
Rubber	Dense	Dense	Low	Most are mature plantations with established ground cover
Home gardens	Dense	Dense	Low	Unmanaged gardens with dense canopy and thick leaf litter; some ground is covered with ferns
Tea lands	Dense	Low	Low	Smallholdings: dense & continues carpet of tea; runoff is low due to drains & terraces
Cinnamon	Dense	Dense	Low	Smallholdings: dense & continues canopy; runoff is low due to drains & terraces
Natural forest	Dense	High	Low	Dense canopy & ground cover

Forest plantations (Pine / Eucalyptus)	Dense	Low	High	Catches fire annually, hence ground cover is low or absent
Patana grasslands	-	Dense - seasonal	High (most of the year)	They catch fire during most dry seasons causing low ground cover & high runoff

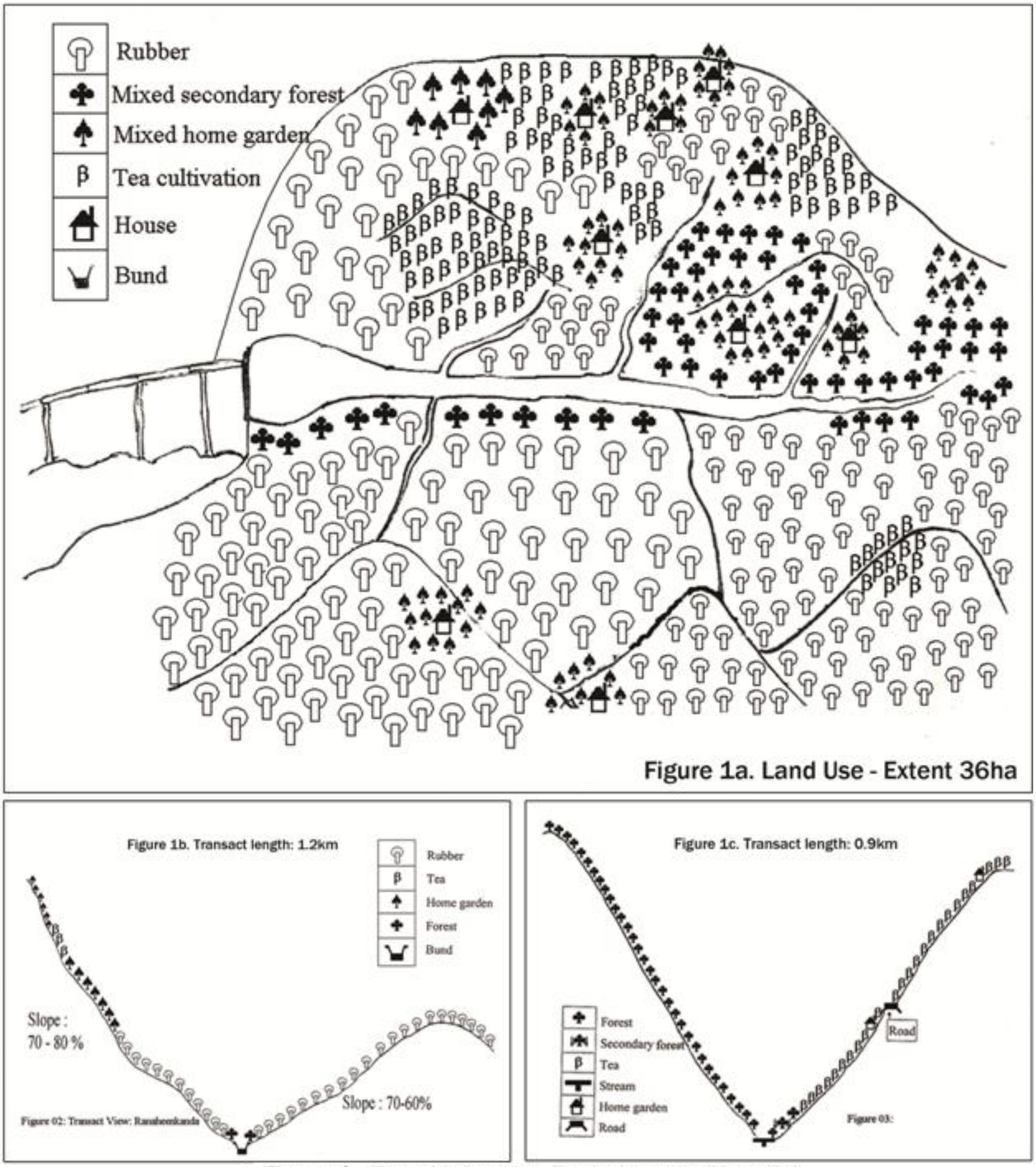

Figure 1 - Ranahinkanda, Deraniyagala (Kegalla)

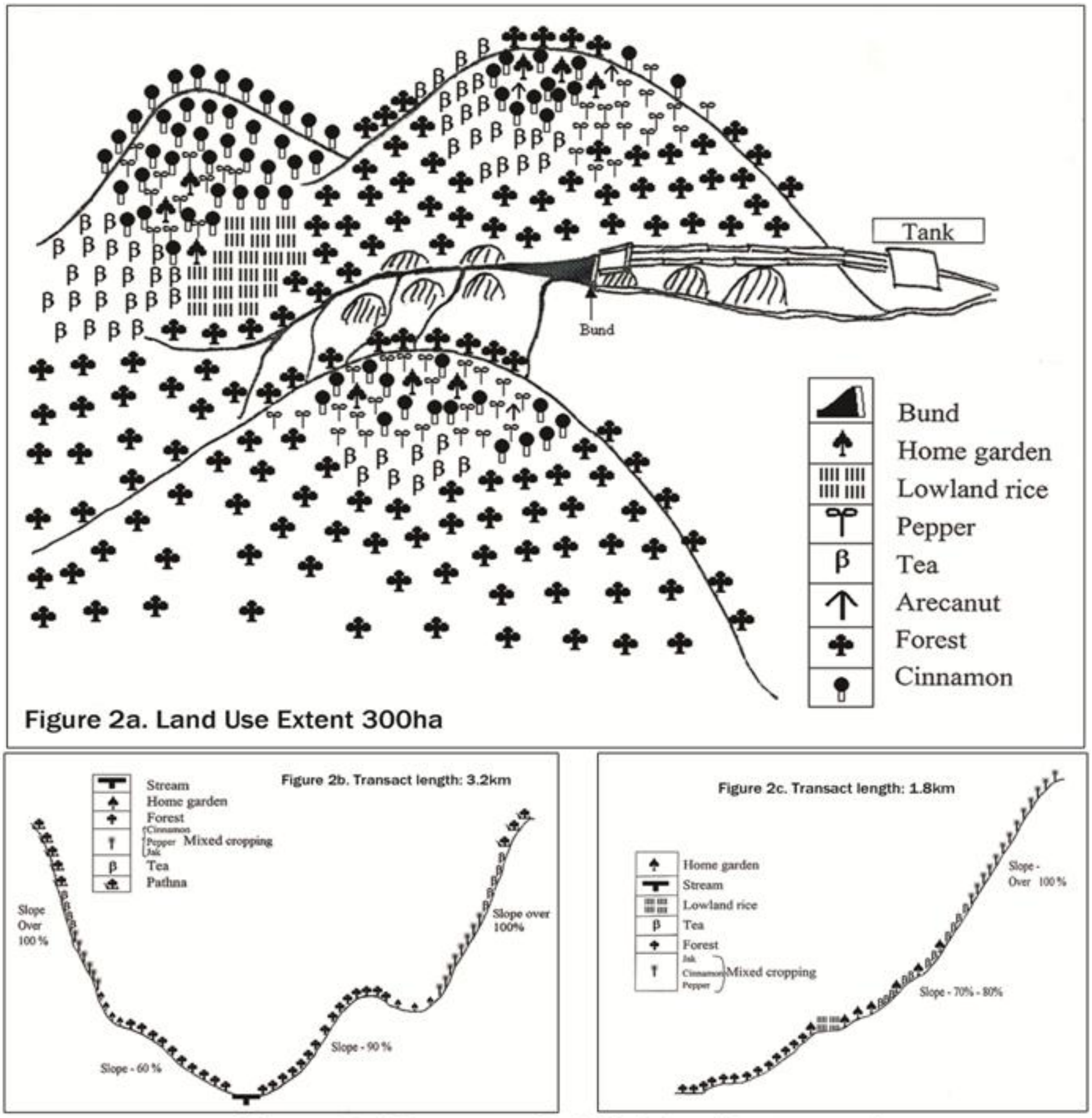

Figure 2a. Land Use Extent 300ha

Figure 2b. Transact length: 3.2km

Figure 2c. Transact length: 1.8km

Figure 2 - Diyapota, Embilipitiya (Ratnapura)

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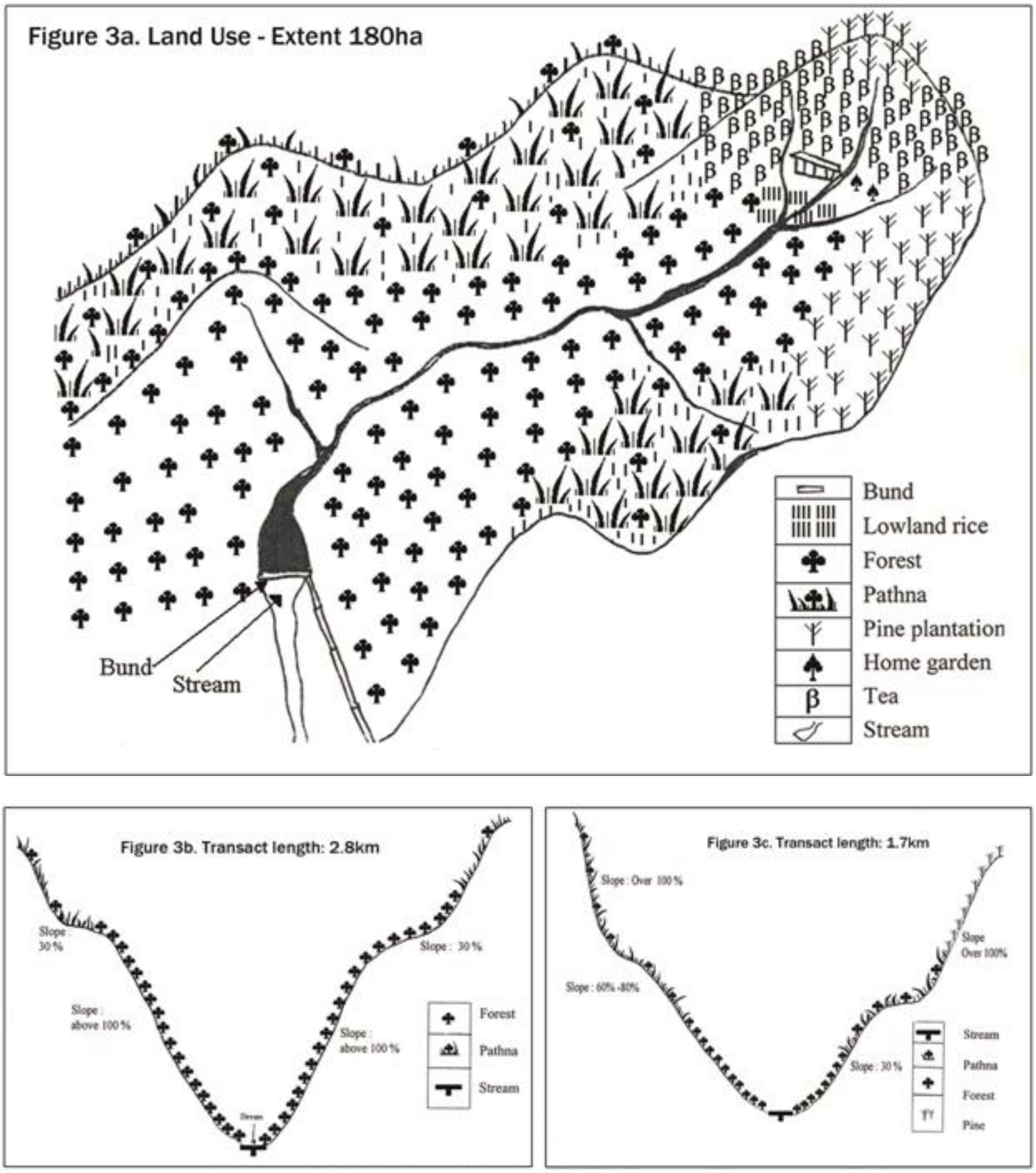

Figure 3 - Walasella, Badalkubura (Moneragala)

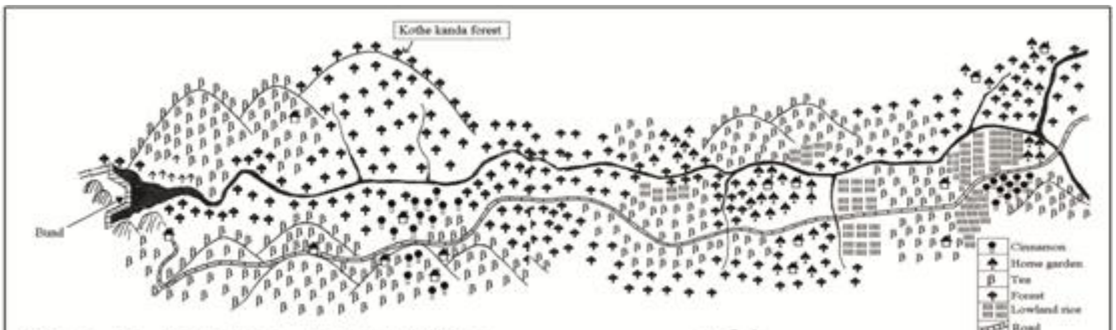

Figure 4a. Land Use - Extent 440ha

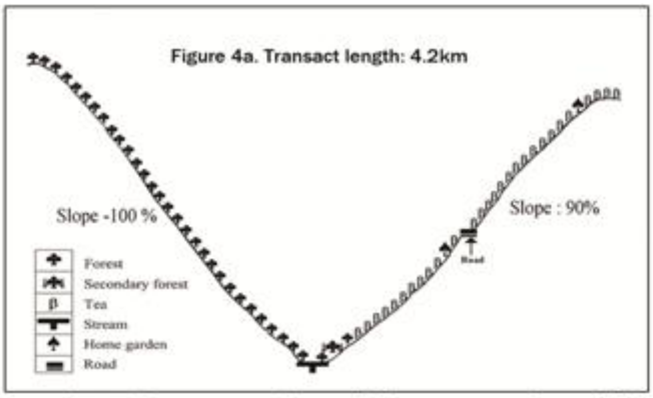

Figure 4 - Paragala, Morawaka (Matara)

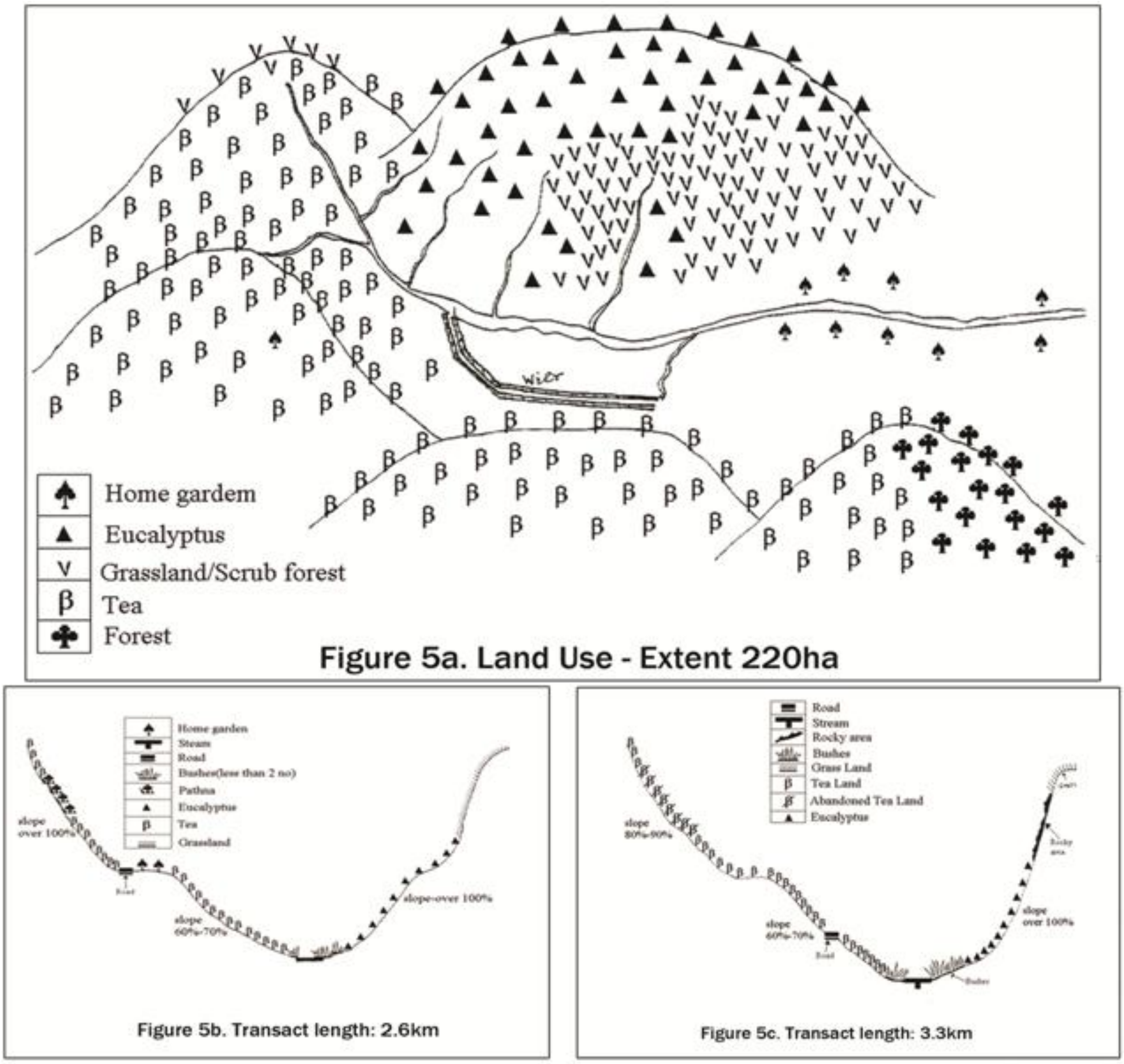

Figure 5 - Makuldeniya, Koslanda (Badulla)

3.4Relationships between the land use and water yield of the catchment

In this regard a review done by Finlayson in 1998 [7,8] on “Trees and Forests in the Upper Mahaweli Catchment: their effect on water yields and sedimentation” and “Effects of deforestation and tree planting on the hydrology of the Upper Mahaweli Catchment: a review of the published evidence” have stated some important relationships between land use and water yield based on the studies conducted in Sri Lanka. The relationships that are relevant to present study are stated below:

1) The natural forests at lower altitudes consume large quantities of water.
2) Forest plantations use large quantities of water.
3) In Sri Lankan conditions, grassland uses much less water, and can give equal soil protection, provided it is protected from severe burning.
4) Kandyan forest gardens probably consume water at about same rate as natural forests.
5) Trees used in agroforestry and isolated trees on farmland, also consume water in large quantities.
6) The literature is virtually unanimous in saying that forests do reduce wet-season discharges, but this mostly because they loose more water all the time than other vegetation, by interception and transpiration.
7) Hydrologists play down the famous "sponge" effect of forest soil. The modern literature is unanimous in saying that most forests do not increase, but reduce dry-season flows. Not only do forests use more water than other land uses, but also they tend to have deeper roots and take up water that other vegetation cannot reach in dry season.
8) The information emerging is said to reinforce the view that total water yields are trending downwards as tree cover increases. Putting together the currently accepted theories and general knowledge of the data, it is very probable that dry-season flow decreases with increases in tree cover.

3.5 Effect of the climatic change on the water availability at five catchments

Summary of land use in the five catchments are shown in Table 5. Based on this data it can be predicated that water losses to atmosphere due to vegetation will be high in the Kegalle site due to the presence of taller vegetation covering a large proportion of catchment (88%). It is moderate at Ratnapura, Matara and Moneragala sites. It should be very low at Badulla site.

Table 5: Land use in the catchments of five selected sites

Land use category	*Kegalle*	*Ratnapura*	*Matara*	*Mone-ragala*	*Bad-ulla*
Tall vegetation - Rubber, forests, home gardens	88	62	53	62	25
Intermediate vegetation - Tea, cinnamon	12	23	42	12	57
Surface vegetation - grasslands, chena, rice land	-	15	05	26	18
Total	100	100	100	100	100
Water losses - interception & transpiration	High	Mod.	Mod.	Mod.	Low

Key: Mod-Moderate

Water availability for micro hydropower generation at five sites was predicted and compared after considering main factors that affect water availability (Table 6). The factors considered included rainfall, land use characteristics and extent of catchments. The approximate extents of catchments of five micro hydro sites shows that catchment at Matara is large compared to other four sites especially Kegalle site (Table 6). Therefore water availability for power generation should be high at Matara site when compared to other four sites (especially when compared to Kegalle site). It is clear from these results that Matara site has relatively higher water availability therefore higher potential for micro hydropower generation when compared to other four sites.

Table 6: Predicting water availability for micro hydropower generation at five catchments verified during the study

Site	*Kegalle*	*Ratnapura*	*Mata-ra*	*Moneragala*	*Badulla*
Rainfall	Very High	Mod.	High	Mod.	Low-Mod.
Water losses (interception by trees, transpiration)	High	Mod.	Mod.	Mod.	Low
Approximate size of the catchment (ha)	36	300	440	180	220
Water availability	Mod.	Mod.	High	Mod.	Mod.

Key: Mod-Moderate

3.6 Causes for lowering water availability

The discussions held with persons maintaining the power stations indicated that present levels of power generation could be maintained right throughout the year at all five micro hydro sites investigated during the study. However, this is below the levels predicted by the DFCC Bank, Energy Service Delivery (ESD) project conducted by ITDG. The Field Verification also reported this low water availability in the catchments on Map Based Micro Hydro Potential study conducted by ITDG. Thisdifference between rainfall and stream flow (i.e. water yield form catchment) could be attributed to:

a) Causes related to land use and physical factors

- Study identified indirect evidence to suggest that there are high rates of water loss to atmosphere due to interception and transpiration because of the presence of taller vegetation (trees) in the catchment.
- Losses to atmosphere could be higher than expected as determined by the specific intensity and duration of rainfall (drying and wetting patterns of vegetation) and also the physical conditions prevailing in certain seasons (such as strong wind). However no site-specific evapo-transpiration data is available for these sites.

b) Causes related to climatic change

In addition to land use factors, increasing temperatures have undoubtedly increased the evapo-transpiration rates lowering water availability. Lowering rainfall due to climatic change will also continue to reduce the water availability.

In addition to general characteristics of catchment and streams, the following factors related to designing of micro hydro also have affected the head and capacity to generate power:

a) Cost and safety concerns when locating the weirs and turbines

b) Attempts to reduce cost for pipes
c) Wrong estimates of stream flow

3.7 Improving water yield

Following are suggested to improve the water yield from the catchment:
a) Controlling fires in grasslands
b) Introducing water saving land use whenever possible to reduce water losses to atmosphere
c) Planning the water movement in the catchment

4. Conclusions: What will happen if Rainfall Further Reduced?

The most important finding of the study is that the lowering of rainfall due to climatic change will have differential impact on the actual water yield due to the nature of land use of the catchment. Hence catchments identified as low and moderate water yield may go out of micro hydro-power potential when compared to sites identified as high (Table 6). Also it is safer to invest and establish micro hydro at sites that are identified to be with high water availability, as they are unlikely to face the problem of lowering of water yield due to climatic change in the near future.

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