Annex 17

Hydrologic and Climate Analysis

In Support of the Funding Proposal submitted to the Green Climate Fund (GCF) by Sri Lanka on "Strengthening Climate Resilience for Subsistence Farmers and Agricultural Plantation Communities Residing in the Vulnerable River Basins, Watershed Areas and Downstream of the Knuckles Mountain Range Catchment of Sri Lanka"

Compiled by IUCN Sri Lanka Country Office with inputs from

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List of Abbreviations

ADB	Asian Development Bank
AE	Accredited Entity for Green Climate Fund
FP	Funding Proposal
GCF	Green Climate Fund
GCM	Global Climatic Model
GOSL	Government of Sri Lanka
ha	Hectare (area of land)
HRU	Hydrologic Response Unit
IWMI	International Water Management Institute
km	Kilometer (distance)
LDSF	Land Degradation Surveillance Framework
LU	Land Use
MASL	Mahaweli Authority of Sri Lanka
MCM	Million Cubic Meters (Volume)
MI	Moisture Index (soil)
MMDE	Ministry of Mahaweli Development and Environment
MWSIP	Mahaweli Water Security Investment Programme
iTAP	Independent Technical Advisory Panel
IUCN	International Union for Conservation of Nature
PES	Payment for Ecosystem Services
PET	Potential Evapotranspiration
RCP 4.5	Representative Concentration Pathway for medium emission scenario
RCP 8.5	Representative Concentration Pathway for high emission scenario
RUSLE	Revised Universal Soil Loss Equation
SWAT	Soil Water Assessment Tool
UNDP	United Nations Development Programme
USLE	Universal Soil Loss Equation
WB	World Bank
WMO	World Meteorology Organization

Hydrologic and Climate Analysis: Strengthening Climate Resilience for Subsistence Farmers and Agricultural Plantation Communities Residing in the Vulnerable River Basins, Watershed Areas and Downstream of the Knuckles Mountain Range Catchment of Sri Lanka

1. Summary

The GCF's independent Technical Advisory Panel (iTAP), in its evaluation on this GCF submission, required the AE (IUCN) to provide a hydrological analysis to support the project design. In the preparation of this response AE worked with the World Agroforestry Centre (ICRAF), a joint modelling team consisting of Mahaweli Authority of Sri Lanka (MASL) and the International Water Management Institute (IWMI) and collate additional information and model basin hydrology as far as possible within the limitations imposed by available data in Sri Lanka, especially in the project area.

The proposed project aims to enhance the ability of populations, especially the smallholder subsistence farmers, to address climate induced shortages in relation to irrigation and drinking water by improving the resilience of farm and land management practices and climate proofing the natural ecosystems in the Knuckles/Amban Ganga highlands and lowlands. Climate smart project investments in agriculture and water sectors will ensure the resilience of agriculture and value-added livelihoods in the area while protecting and complementing the public investments of Moragahakanda multipurpose irrigation scheme and other development programmes. In achieving its objectives, the risks related to increased temperatures; changes to rainfall frequency and intensity; and the impacts of extreme events that cause extended droughts, frequent floods, severe landslides, and silting of reservoirs and tanks, which increase the vulnerabilities of small-scale farmers, plantation operations and the natural ecosystems on which they depend are mitigated.

The project area consists of upstream and downstream sections with upstream exhibiting low fog interception, high surface runoff/erosion causing hydrological droughts and sedimentation of tanks. Water shortages are anticipated in the irrigated agricultural downstream areas subjected to rising temperatures and increasing frequency of agricultural drought. Key project activities will include participatory governance and adaptive planning, establishment of climate adaptation information portals and advisory services, improved access to agricultural water supply and affordable renewable energy, participatory selection and implementation of best-fit climate-adaptive land management options to suit ecosystems, and value chain upgrading—to include product development, value-adding processes, farm business enterprises and standards and market access. The six-year project aims to induce transformative change and develop replicable financial models, electronic transaction systems and incorporate ecosystem payments into planning as a resilience model. The project will also facilitate the development of a participatory exit strategy to build local capacity to sustain project achievements and subsequent progress in the post-project period.

Primary measurable benefits of the project will include: i) 1.3 million people (51.4 % women) who will benefit from the adoption of diversified, climate-resilient livelihood options; ii) 346,000 hectares of upland and lowland agro-ecosystems and natural ecosystems protected and made more resilient in response to climate variability and change.

Climate analysis at monthly resolution demonstrated predicted increase in deficits of water available for crop growth, measured as the moisture index (MI), which is rainfall divided by potential evapotranspiration, in key crop growing months of January and May in the downstream paddy area,

leading to increasing frequency and severity of agricultural droughts. The upstream area exhibited hydrologic drought conditions in the months of April to May.

The estimated water deficit for crop production[1] (using median values across an ensemble of 19 GCMs) was **80.03 Mm^3 in January and 24.44 Mm^3 in May or a total reduction of 104.48 Mm^3** in the downstream project area. This deficit due to climate influence can be potentially offset by a predicted median **annual increase in rainfall (from August to October) in the upstream project area equivalent to 237.61 Mm^3**, which would be enough to mitigate the deficit through irrigation, if commensurate water capture, storage and distribution infrastructure are in good order, as the project proposes to ensure.

To put this in perspective, the combined storage capacity of the Nalanda (15 Mm^3), Bowatenna (26 Mm^3) and Moragahakanda (521 Mm^3) reservoirs collecting water from the upstream area is 562 mm^3. Given the bimodal rainfall distribution and two downstream cropping seasons they can be expected to be filled twice per year. There are also shifts in seasonality affecting both plantation and seasonal crop agronomy that need to be considered in land use planning aspects including the refined modelling and estimations during the project period.

The simulation results using Soil Water Assessment Tool (SWAT) indicated a potential reduction of sediment delivery, which could be due to proposed land cover improvements of up to 24% depending on climate scenarios modelled. The sediment delivery in high rainfall months was reduced by proposed project interventions on land cover alone and are likely to have underestimated since the spatial and temporal resolution of the model precludes inclusion of effects of increased rainfall intensity. For example, SWAT modelling does not capture, specific erosion control measures on cultivated land (e.g. contour hedgerows), roadside (reducing acceleration of run-off) and streamside (sediment trapping) interventions, as well as enhanced upstream water storage resulting from rehabilitation of tanks and ponds (enhancing recharge). Due to these limitations, the initial hydrological modelling using RCP 4.5 and RCP 8.5 predicted lower future rainfall and in turn less sedimentation, which is also identified by IPCC as a weakness. However, these limitations can be addressed during the project by onsite measurements including hourly rainfall measurements.

The positive benefits by the project are justified by this analysis when coupled with collated information on sediment yield studies and experience in the adjacent Upper Mahaweli Watershed. In the Upper Mahaweli Watershed, most of the key tanks have been silted within a short period of operation that underline the need to take conservation measures to protect the recent extensive Government investments in the Moragahakanda, Kalu Ganga, Bowatenna and Nalanda reservoirs within the project area. This conclusion is further strengthened by linking to the Mahaweli Water Security Investment Programme (MWSIP), the Climate Smart Irrigated Project and the GCF/UNDP project in Malwathuoya to rehabilitate tanks in downstream areas to improve water storage and use efficiency in the downstream area, where the proposed project will complement with strategic investments in promoting locally adapted improvements in rice agronomy.

The analysis of rainfall events indicated increasing frequency of high intensity rainfall events in the upper catchment justifying the upper catchment cover increases, erosion control, stream side and roadside interventions and rehabilitation of old water storage.

[1] Calculated for the entire downstream area

The information available confirms the following.

1. That without intervention, the climate induced erosion and sedimentation of tanks/reservoirs would increase with higher rainfall intensity into the future and erosion estimates are linked to already observed and predicted intensified rain events. These will represent more than half of the effect (likely more than the 56-67% estimated with models at coarse spatial and temporal resolution), while PET effects are 100% due to climate change, indicating that the project funding requested is in line with the contribution of climate change to the problems addressed.
2. That erosion reduction in the upper catchment is a critical adaptation measure to maintain reservoir storage capacity. The proposed spatially targeted project interventions involving land use best practices and roadside and streamside water/sediment flow management can mitigate the impact of climate induced reduction of reservoir volumes while enhancing the volumes in tanks to encourage higher water holding and recharge.
3. That the volumes of water available through increased upstream rainfall and maintaining storage in the upstream catchment, in combination with other GOSL investments and the proposed extension of more water efficient rice cultivation practices, are sufficient to meet water requirements for irrigated rice cultivation in the downstream area, given changes in rainfall, temperature and PET in downstream area to 2050, as provided in the Roeland Kindt's (2019) soil moisture index[2] related report (also Annexure 16b to FP).
4. GOSL is already committed to a levy on hydropower generation that is fed back to catchment management as a PES mechanism, while the project will explore harnessing income streams from the Cess on export crops, project interventions such as green listing and welfare payments to smallholders to finance catchment management actions, with a view to transitioning to capturing increased revenue from value chain upgrading associated with sustainable land use to sustain these mechanisms beyond the project duration.
5. The project proposed three major **upstream** interventions to regulate water flow and erosion—streamside protection and road drainage management; establishing village tanks, ponds and irrigation networks; and, restoring forest mosaic landscapes, have been justified based on the hydrologic and climate analysis. Two further **upstream** interventions a) involving sustainable intensification of smallholder production/value addition and plantations[3] (to sustain non-erosive land use) and one intervention covering both **upstream** and b) **downstream** areas on sustainable intensification of irrigated rice involving the use of agroecological intensification methods[4] that increases water use efficiency and hence reduce the demand for water[5] are being proposed. In downstream water use efficiency improvements this project will leverage with ongoing investments by the World Bank and UNDP/GCF as in para 67 of FP.

[2] Roeland, K. 2019. Project Based Climate Analysis with Moisture Index. 2019. https://www.dropbox.com/s/36lxz2ounfll3lh/Sri%20Lanka%20climate%20change%20analysis%20with%20Moisture%20Index%20November%202019.pdf?dl=0

[3] Plantation land use in Sri Lanka represents a colonial legacy. Project interventions target smallholders, contexts where plantation workers (amongst the most vulnerable people in the project area) lease land from plantation companies and landscape restoration measures that regulate water and erosion creating conditions in which plantation companies will invest in sustainable land use. Tax is levied on export crops that can be fed back into sustainable land use.

[4] The Global Commission on Adaptation (GCA) has recommended adopting agroecological approaches to build resilience of small-scale food producers. See ADAPT NOW: A GLOBAL CALL FOR LEADERSHIP ON CLIMATE RESILIENCE and more specifically Sinclair, F., Wezel, A., Mbow, C., Chomba, S., Robiglio, V., and Harrison, R. 2019. "The Contribution of Agroecological Approaches to Realizing Climate-Resilient Agriculture." Rotterdam and Washington, DC. Available online at www.gca.org.

[5] System of Rice Intensification (SRI) detailed in the proposal involves locally adapted practices that reduce water demand (by up to 50%) through intermittent irrigation also known as alternative wetting and drying (AWD). "Strategies for Survival." *Nature Plants* 3, no. 12 (December 2017): 907–907. https://doi.org/10.1038/s41477-017-0081-x.

2. Sedimentation Dynamics and Estimations

2.1. Main Reservoirs in the Upstream Project Area Impacted by Upland Erosion

The project targets halting climate change induced sediment flow to maintain the storage capacity of major reservoirs coupled with rehabilitation of upstream water management networks. Project interventions will minimize siltation of large investments by Government, such as Moragahakanda Reservoir while providing a management approach to preserve the storage capacity of other reservoirs by climate induced sediment generation (intensity) and flow (volume). The upstream project area comprises a network of reservoirs amongst which water is transferred to several large reservoirs (Figure 1 and Figure 2).

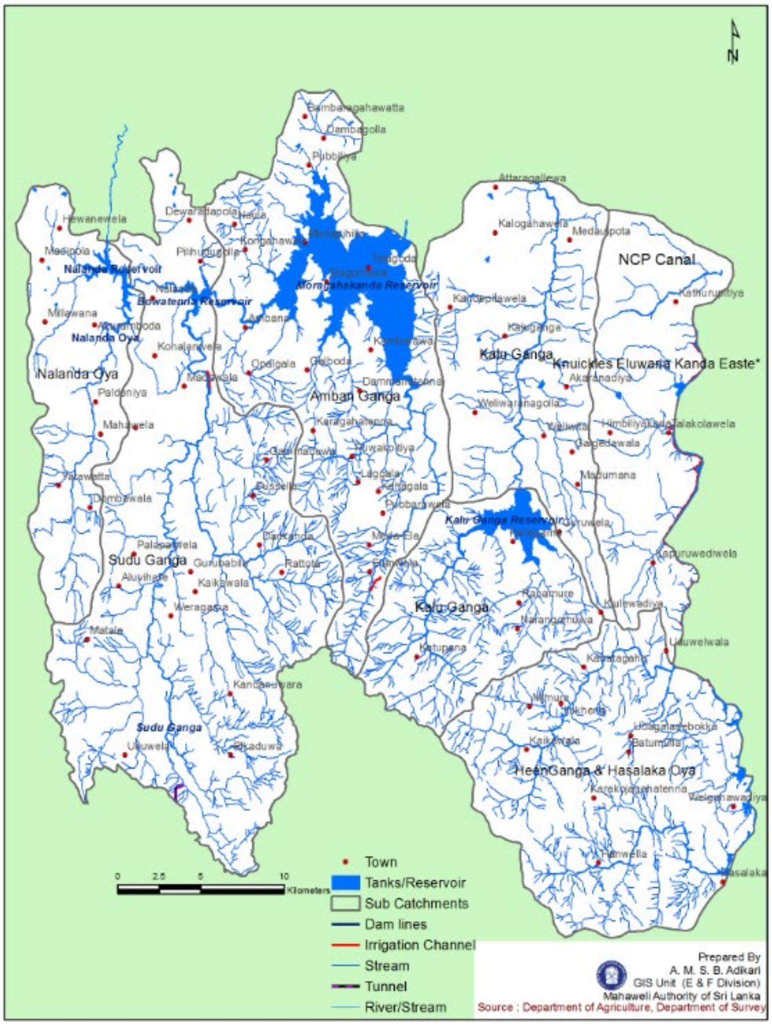


Figure 1: Key reservoirs within project upstream area

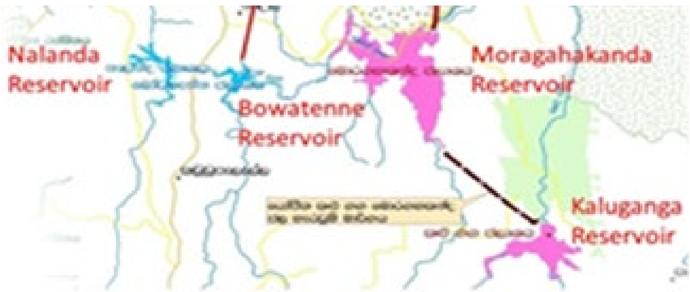


Figure 2: Interconnections of reservoirs

The water received by the Bowatenna Reservoir is distributed to both Nalanda and Moragahakanda reservoirs. In addition, the water received by the Kaluganga Reservoir is transferred to Moragahakanda *via* the proposed tunnel while the rest will be diverted to the Mahaweli System.

The entire system including the water management in the Upper Mahaweli River (upstream of the upper catchment of the project) is described in Figure 3 where again, the sediment transfer potential from Sudu Ganga to Bowatenna and Moragahakanda is identified. In addition, the Kalu Ganga Reservoir is being sedimented by the Kalu Ganga River. Detailed diagram of the entire Mahaweli Development Project is available in Attachment 1 to this document.

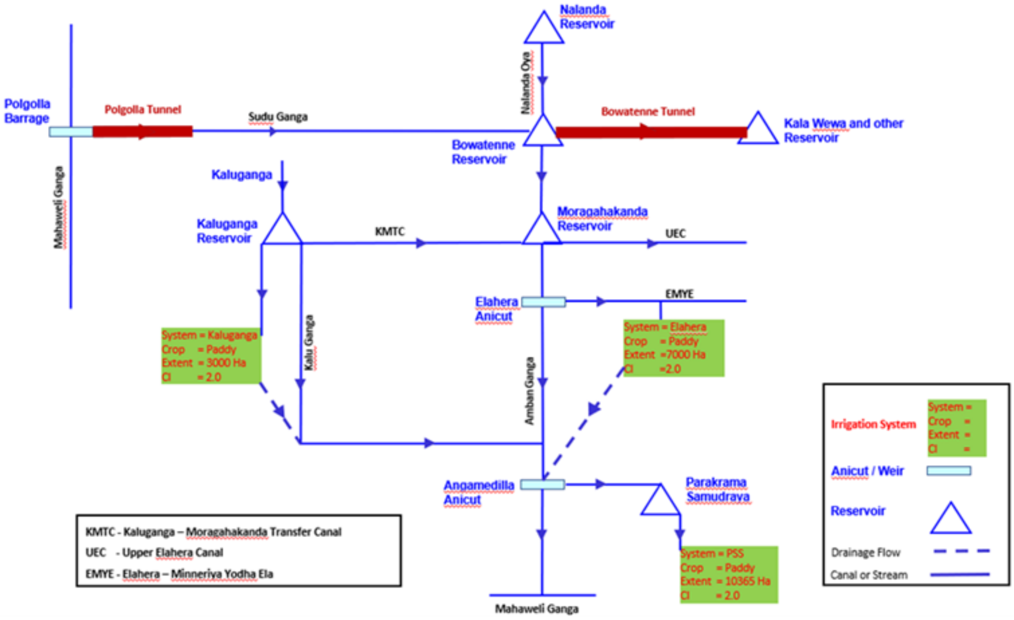


Figure 3: Network of irrigation schemes in Mahaweli System related to the project

2.2. Hydrological Modelling of the Amban Ganga Basin (Amban2)

2.2.1. SWAT Model

The Mahaweli Authority of Sri Lanka (MASL) has been using the SWAT (Soil & Water Assessment Tool)—a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. MASL used it to support the prefeasibility of the ADB funded "Mahaweli Water Security Investment Programme (MWSIP)", implemented by the Ministry of Mahaweli Development and Environment (MMDE)[6]. This model was used in the Amban Ganga Basin within the project area with the supervision and technical inputs of the International Water Management Institute (IWMI).

SWAT is a continuous time model that operates on a daily time step at basin scale. This model is used worldwide and is continuously under development and considered as a watershed hydrological transport model to predict the long-term impacts in large basins of management and timing of agricultural practices within a year (i.e. crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing). SWAT uses a two-level disaggregation scheme; a preliminary sub-basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

[6] May change the name under the new administration

2.2.2. Use of SWAT Model in the Amban Ganga Basin

Given available data, the best fit area that can be reliably modelled with respect to the upstream project area was selected. This is the Amban Ganga Basin (Amban2) that includes most of the project area, but excludes a portion to the south, south-east and west, while including an equivalent area beyond the project boundary to the north (Figure 4).

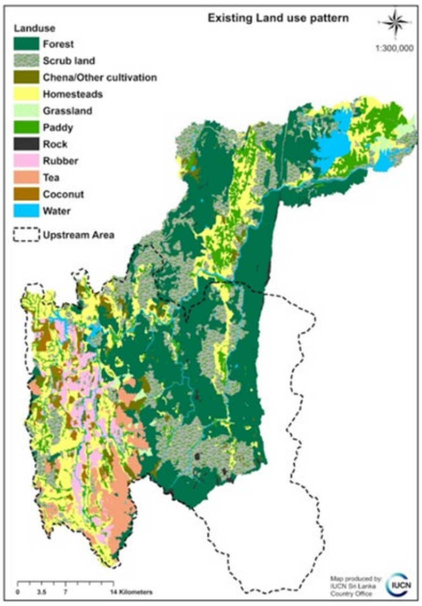


Figure 4: Amban2 geographic area used for SWAT modelling (current land use)

Basin Description: The Amban Ganga Basin (Amban2) comprises a catchment area of 1,700 km^2 (170,000 ha) extending from the western slope of the Knuckles Mountain Range as Sudu Ganga and up to the confluence of Amban Ganga and Mahaweli Ganga at Manampitiya.

The principal rivers within the basin are the Amban Ganga and Kalu Ganga. For the purpose of calibration and validation, two models are setup—namely, **AmbanEH** having a catchment area of 768.3 km^2 extending up to Elahera Gauge and the **Ambankalu** extending up to Pallegama Gauge having an area of 116.4 km^2.

The *key characteristics* relevant to the models are:

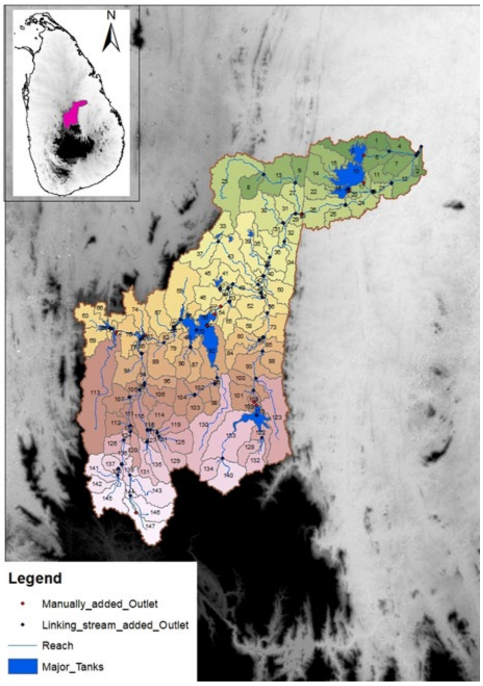


Figure 5: Basin map of Amban 2 with minor watersheds

- *Topography:* the Amban Ganga Basin (**Amban2**) is mostly mountainous with elevation ranging from 6 m asl at the confluence of Mahaweli to more than 1,869 m asl in the upper catchment. About 29.7% of the area is in the slope range of 0-10%, while 65.9 % is within 10-60% and only 4.4% is above the 60% slope range.
- *Land Use:* the predominant land uses are about 57% of natural forests and agro-forestry, about 21.4% are cultivated lands of which about 8.5% are irrigated paddy.
- *Soils:* due to the mountainous nature of the area, the soils are generally classified as heavy with moderate water holding capacities and moderate permeability.
- *Salient Features:* The reservoir projects that came along the main Amban Ganga are namely, Bowatenne and Nalanda having about 42 MCM of storage capacity during the latter half of the last century. There are two ancient Anicut Schemes (that channel water), namely Elahera and Angamedilla as well as some minor Anicut schemes. There is a trans-basin diversion from Bowatenne Reservoir to Kala Oya Basin, which came into operation in 1976. New reservoir projects namely Moragahakanda and Kalu Ganga are under the final stage of construction with about 835 Million cubic meters of storage capacity.

- *Climate:* Amban2 is situated in the intermediate climatic zone and receives 1,000-3,000 mm of rainfall, annually. Due to the mountainous nature of the area, the average annual temperature is moderate and being a high hilly area, it is quite windy as well.
- The number of rainfall stations in and around CMBSN are 25 of which 12 stations were used in AmbanEH, 3 in Ambankalu and 19 in the overall model.
-

2.2.3. Model Calibration and Validation

Elahera Guage

AmbanEH - Calibration (1976-1978): The *AmbanEH* area extends up to the Elahera gauging station. Measured daily, inflows of the Elahera gauging station and the daily Ukuwela diversions are available, while the measured digital data of the trans-basin diversion of the Bowatenne Reservoir is available in monthly time steps. Therefore, the calibration of the model was done on a monthly basis (See Figure 6 for comparison of simulated flow vs. measured flow and Table 1 for statistical comparison). The results show a good agreement between observed and simulated time series.

AmbanEH - Validation (1979-1981): The selected validation period also shows a good relationship between the two data series in terms of hydrograph and statistics as shown in **Figure 7** and Table 1 respectively, which are within a very good level of acceptability.

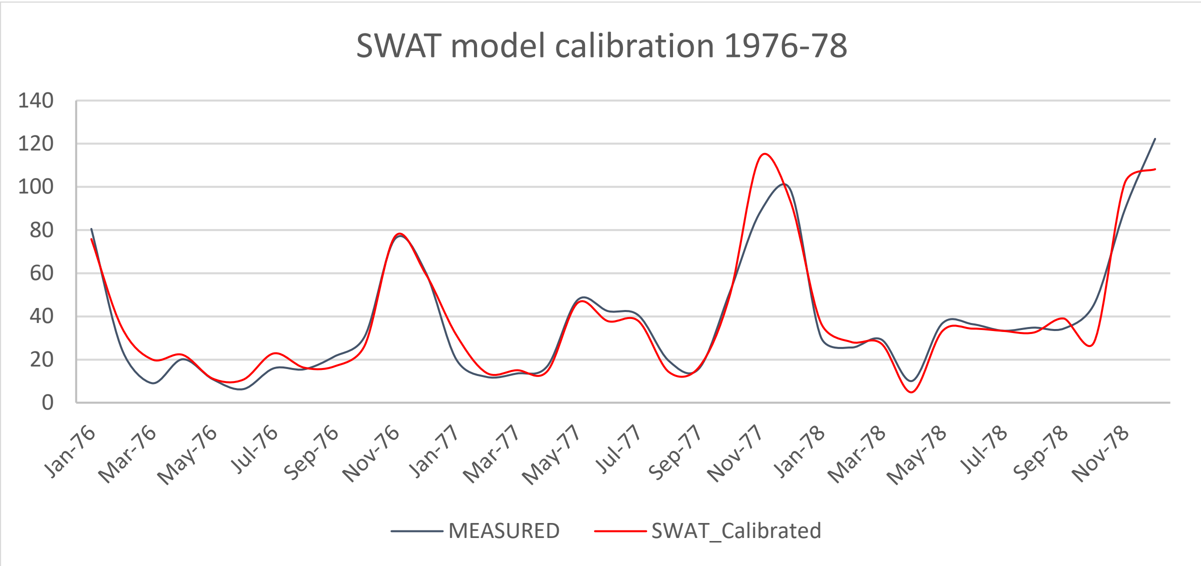


Figure 6: Calibration of AmbanEH model

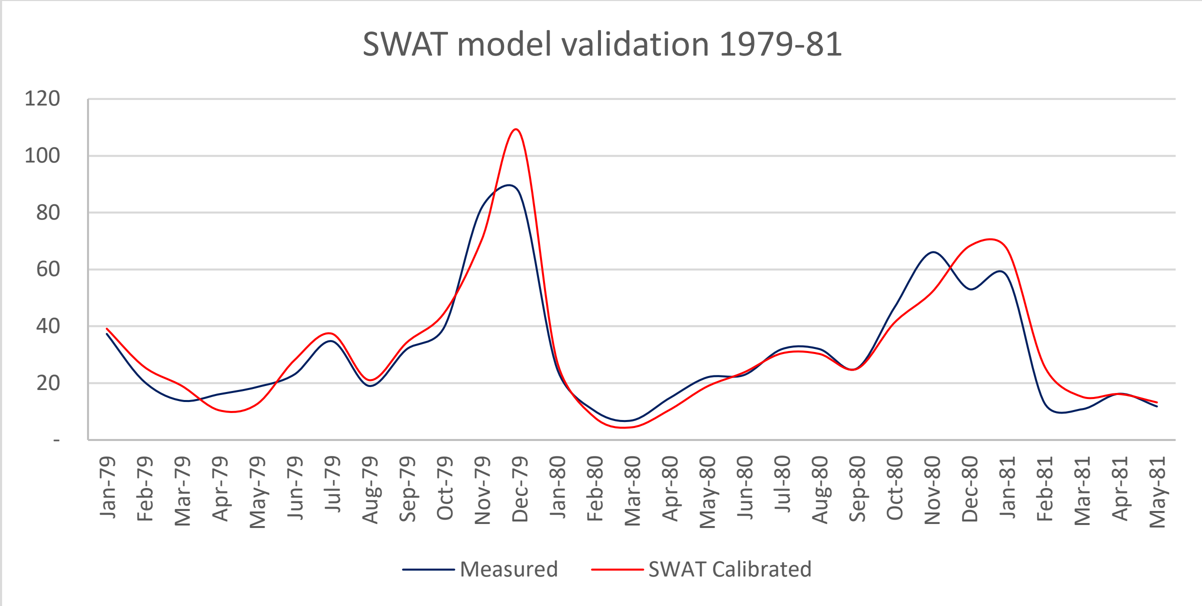


Figure 7: Validation of AmbanEH Model

Table 1: Comparison of Statistical Parameters of Calibrated and Validated flow series in AmbanEH

	1976 - 1978		1979 - 1981	
Stat Parameter	Gauged	Calibration	Gauged	Validation
Q=Average (m^3/s)	38.0	38.5	30.7	32.1
V=Volume (MCM/year)	1197.07	1214.30	968.08	1011.44
Correlation		0.97		0.95
Co. of Determination		0.93		0.90
Nash		0.93		0.87
PBIAS		-1.44		-4.48

Laggala (Pallegama) Guage

Ambankalu – Calibration (1990-1993): The Ambankalu basin includes the total catchment area up to the Laggala gauge. The operational data are available from October 1989 to September 2014 and Figure 8 and Figure 9 depict the plots of simulated curves for calibration and validation vs. measured series. Table 2 lists the final optimization results for both calibration and validation. There is a good agreement between the simulated curve and the measured one in calibration, but in validation the resulting parameters show some deterioration.

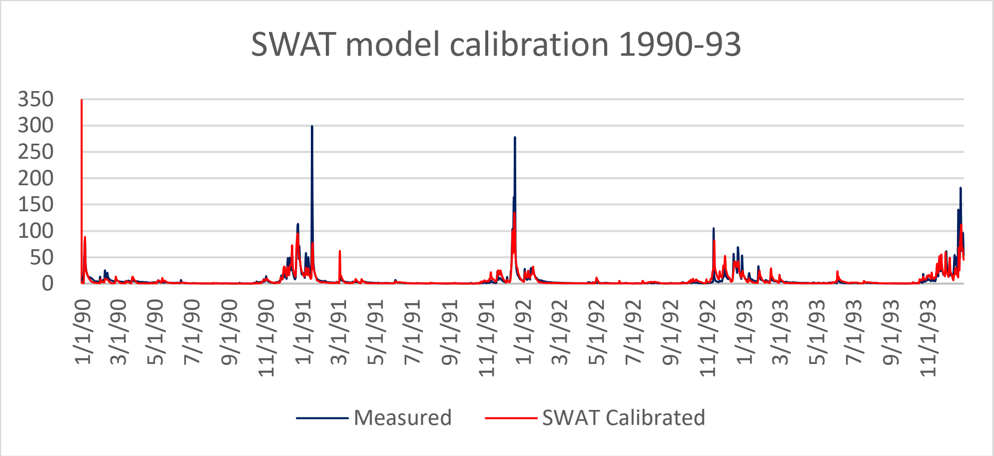


Figure 8: Calibration of SWAT Ambankalu Model 1990-1993

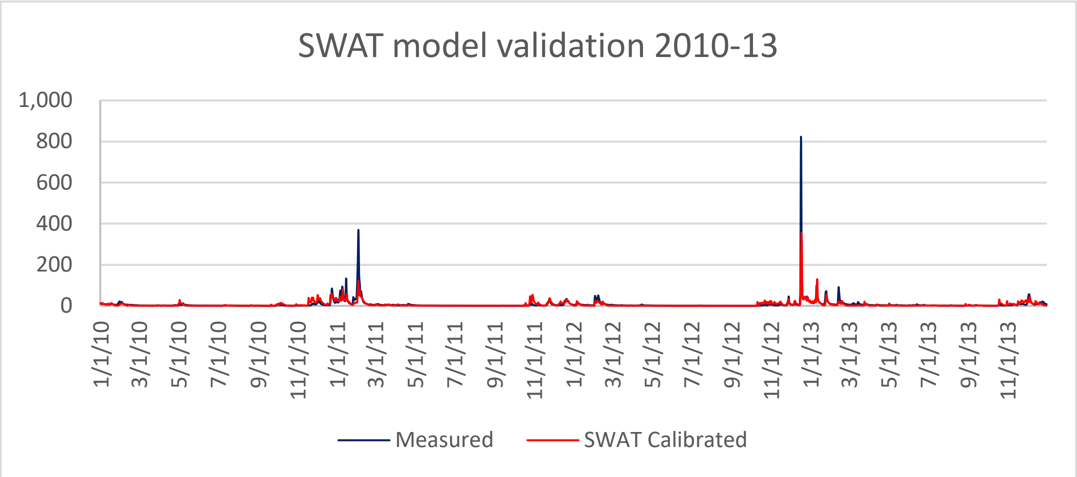


Figure 9: Validation of SWAT Ambankalu Model 2010-2013

Table 2: Comparison of Statistical Parameters of Calibrated and Validated Flow Series

	1990 - 1993		2010 - 2013	
Stat Parameter	Gauged	Calibration	Gauged	Validation
Q=Average (m^3/s)	6.70	6.10	7.13	6.13
V=Volume (MCM/year)	211.16	192.36	224.85	193.47
Correlation		0.81		0.75
Co. of Determination		0.66		0.56
Nash		0.64		0.52
PBIAS		8.90		13.96

2.2.4. Likely Impacts of Future Land Use Change

A likely future land use scenario following project intervention (Table 3 and Figure 10) was used to indicate the potential for land use interventions to reduce sediment yield.

Table 3: Current and post project land use

No	Landuse pattern	SWAT_LU	Landuse Current		Landuse Future	
			Area (km²)	Area %	Area (km²)	Area %
1	Forest	FRSE	608.75	35.81	822.93	48.41
2	Scrub Land	RNGB	357.78	21.05	168.19	9.89
3	Homesteads	PEAS	273.87	16.11	273.95	16.11
4	Paddy	RICE	141.27	8.31	141.30	8.31
5	Chena	AGRL	44.99	2.65	38.29	2.25
6	Rubber	RUBR	58.31	3.43	58.32	3.43
7	Tea	AGRC	76.72	4.51	60.08	3.53
8	Coconut	COCO	30.25	1.78	30.25	1.78
9	Water	WATR	78.37	4.61	78.33	4.61
10	Grassland	SPAS	16.49	0.97	15.16	0.89
11	Rock	UTRN	7.13	0.42	7.13	0.42
12	Wetlands	WETF	5.32	0.31	5.32	0.31
13	Urban Area	URMD	0.53	0.03	0.53	0.03

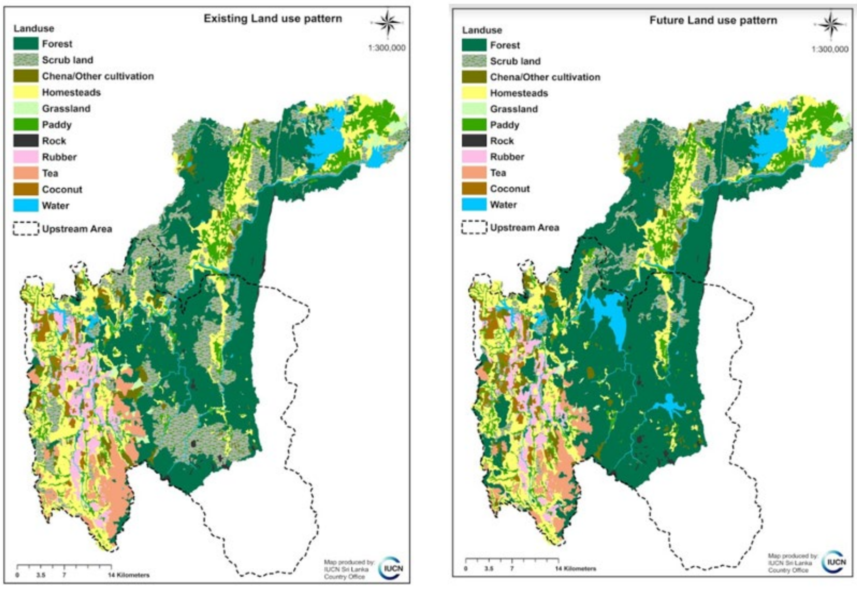


Figure 10: Current and post project land use

The validated model was used to predict water and sediment yields with a) changes to land cover as per the project—analog forestry and other changes as per Table 3, and b) to study the climate impact on sediment yields using historical (observed) and RCP 4.5 and RCP 8.5 predicted rainfall conditions.

Table 4: Monthly water and sediment yields under present land cover

MONTH	RAIN (MM)	SURF Q (MM)	LAT Q (MM)	WATER YIELD (MM)	ET (MM)	SED YIELD (T/HA)	PET (MM)
1	265.33	30.25	24.23	221.46	62.39	2.73	113.11
2	126.08	11.35	18.01	121.24	62.27	0.94	130.76
3	118.78	2.87	14.34	57.04	97.11	0.24	167.34
4	199.32	3.57	13.24	47.27	113.23	0.18	148.86
5	67.91	1.71	13.85	44.31	104.33	0.08	150.84
6	31.67	0.2	9.61	16.16	70.08	0.02	130.17
7	42.46	0.24	7.84	12.32	55.71	0.02	135.96
8	49.41	0.42	6.4	9.57	44.52	0.04	145.6
9	78.19	0.43	6.14	9.73	50.73	0.03	143.92
10	254.03	5.66	10.03	35.87	73.53	0.5	134
11	390.74	32.19	18.25	159.27	73.85	1.9	106.42
12	413.38	60.61	26.01	291.03	66.76	3.18	101.97
Annual	**2037.30**	**149.5**	**167.95**	**1025.27**	**874.51**	**9.86**	**1608.95**

Table 5: Water and sediment yields for project propose land cover

MON	RAIN (MM)	SURF Q (MM)	LAT Q (MM)	WATER YIELD (MM)	ET (MM)	SED YIELD (T/HA)	PET (MM)
1	265.31	30.52	22.1	210.3	60.46	1.64	112.48
2	126.08	10.96	16.54	115.17	61.53	0.45	130.29
3	118.77	3.07	13.18	54.79	100.24	0.19	167
4	199.29	4.46	12.05	44.63	115.29	0.34	148.59
5	67.9	1.74	12.56	39.27	107.47	0.11	150.12
6	31.65	0.28	8.69	14.39	74.16	0.04	129.91
7	42.46	0.25	7.06	11.06	62.39	0.03	135.61
8	49.41	0.54	5.74	8.77	51.9	0.08	145.58
9	78.18	0.56	5.48	8.67	57.33	0.06	143.56
10	253.96	6.3	8.9	31.47	79.65	0.64	133.11
11	390.78	31.24	16.25	142.03	75.3	1.68	105.49
12	413.35	59.5	23.53	271.25	67.07	2.28	101.08
Annual	**2037.14**	**149.42**	**152.08**	**951.8**	**912.79**	**7.54**	**1602.82**

SWAT simulations using historical rainfall, provided sediment deliveries and water yields for present land cover (Table 4) and project proposed land cover (Table 5). The results on the sediment delivery is compared in Table 6. Furthermore, the model predicts a marginal reduction in lateral flow with more canopy cover and an increase in evapotranspiration as anticipated.

Table 6: Sediment yield comparison due to land cover changes

	Month	Sediment Yield Current (t/ha)	Sediment Yield Future (t/ha)	Change
Jan	1	2.73	1.64	40%
Feb	2	0.94	0.45	52%
Mar	3	0.24	0.19	21%
Apr	4	0.18	0.34	-89%
May	5	0.08	0.11	-38%
Jun	6	0.02	0.04	-100%
Jul	7	0.02	0.03	-50%
Aug	8	0.04	0.08	-100%
Sep	9	0.03	0.06	-100%
Oct	10	0.5	0.64	-28%
Nov	11	1.9	1.68	12%
Dec	12	3.18	2.28	28%
Annual		**9.86**	**7.54**	**24%**

A 24% reduction in sediment delivery was indicated with the proposed cover increase by the project. Significant reductions of sediment deliveries are noted in the rainy months (Northeast Monsoon) from November to February (Table 6). Percentage values of erosion in drier months (April to September) were high bet magnitudes were small. Further, these results are averaged at monthly intervals, therefore, flash rain events of shorter durations (less than few hours) with potential for generating high sediments and inflows from the watershed are not visible in model results. In addition, the modelled land use change relates to overall areal extent of different types, whereas, the project proposes spatially targeted interventions to target erosion hotspots and the SHARED stakeholder engagement process to ensure participatory planning to adapt interventions to local context.

Table 7: Sediment delivery with and without project proposed land cover changes

MON	**Current Land Use**			**Future Land Use**		
	Historical	**RCP 45**	**RCP 85**	**Historical**	**RCP 45**	**RCP 85**
Jan	2.73	1.17	16.80	1.64	0.80	12.15
Feb	0.94	0.00	0.00	0.45	0.00	0.00
Mar	0.24	0.00	0.00	0.19	0.00	0.00
Apr	0.18	3.12	0.00	0.34	2.90	0.00
May	0.08	0.00	4.87	0.11	0.00	4.91
Jun	0.02	0.00	0.00	0.04	0.00	0.00
Jul	0.02	0.00	0.00	0.03	0.01	0.00
Aug	0.04	1.52	0.00	0.08	1.58	0.01
Sep	0.03	0.00	0.01	0.06	0.00	0.05
Oct	0.50	0.48	0.53	0.64	0.67	0.79
Nov	1.90	0.92	0.08	1.68	0.94	0.11
Dec	3.18	2.24	0.04	2.28	1.84	0.05
Annual	**9.86**	**9.45**	**22.33**	**7.54**	**8.74**	**18.07**

Table 7 provides a summary of sediment delivery under the no project scenario (current land use) vs project proposed land uses (future land use) for different climate regimes, namely, historical, RCP 4.5 moderate emission and RCP 8.5 high emission scenarios. Historical climate and land use aspect was discussed in Table 6. In terms of RCP 4.5 and RCP 8.5, the percentage of reduction of sediment yields were 8% and 19% as a result of enhancing green cover. However, these simulations do not consider the climate induced changes to the rainfall intensity or the targeted land use changes. Reduction of 19% sediment delivery under RCP 8.5 confirms the positive impact by green cover increase under a changing climate.

However, these reductions in Table 7 do not include the potential and anticipated reductions from roadside and streamside activities proposed in addition to the changes to the green cover.

2.2.5. Sensitivity of Parameters to Model Results

As the SWAT model is designed to use USLE to predict erosion (sediment) estimates, an attempt was made to test the sensitivities related to erosion parameters used in the SWAT model.

Soil Erodibility Factor (K_{USLE})

The model uses a K factor of 0.04, selected based on the typical land cover (experience) in the project area.

Table 8: Sensitivity of K factor on sediment delivery

Month	Sediment yield for Historical Rainfall (2001-2010) for Existing Land use (t/ha)						
	USLE_K=0.04 (Selected for the model)	USLE_K=0.15	USLE_K=0.12	USLE_K=0.09	USLE_K=0.06	USLE_K=0.03	USLE_K=0.01
Jan	**2.73**	10.16	8.13	6.11	4.08	2.05	0.69
Feb	**0.94**	3.48	2.79	2.1	1.4	0.7	0.24
Mar	**0.24**	0.92	0.73	0.55	0.37	0.18	0.06
Apr	**0.18**	0.65	0.52	0.39	0.26	0.13	0.04
May	**0.08**	0.3	0.24	0.18	0.12	0.06	0.02
Jun	**0.02**	0.07	0.05	0.04	0.03	0.01	0
Jul	**0.02**	0.06	0.05	0.04	0.03	0.01	0
Aug	**0.04**	0.15	0.12	0.09	0.06	0.03	0.01
Sep	**0.03**	0.1	0.08	0.06	0.04	0.02	0.01
Oct	**0.5**	1.83	1.47	1.1	0.74	0.37	0.13
Nov	**1.9**	7.06	5.65	4.25	2.84	1.43	0.48
Dec	**3.18**	11.78	9.43	7.1	4.75	2.39	0.81
Annual	**9.86**	**36.56**	**29.26**	**22.01**	**14.72**	**7.38**	**2.49**

While the K factor is sensitive to sediment delivery, in practice it is difficult to separate effects of climate change induced increase in rainfall intensity from land use changes because they interact strongly. Further, the rainfall data at high temporal resolution (hourly) that measure rainfall intensity are not available in Sri Lanka to support sediment modelling under extreme scenarios.

It is possible to explore the sensitivity of sediment yield to rainfall erosivity (R) and soil erodibility (K) dependent on land use, using the USLE (described above in relation to the Mahaweli catchment and below in respect to the Amban Ganga catchment that coincides closely with the upstream project area). With other parameters (slope - LS, cover - C and protection - P) held constant at average values for the catchment, sediment yield is 1.3 times more sensitive to R (K constant at 0.4) than K (R constant at 1,500) and the interaction of R and S is 3.0 times more sensitive than K alone and 2.2 times more sensitive than R alone (Figure 11). This indicates that the key driver of sediment yield is the interaction of increasing rainfall intensity with land use.

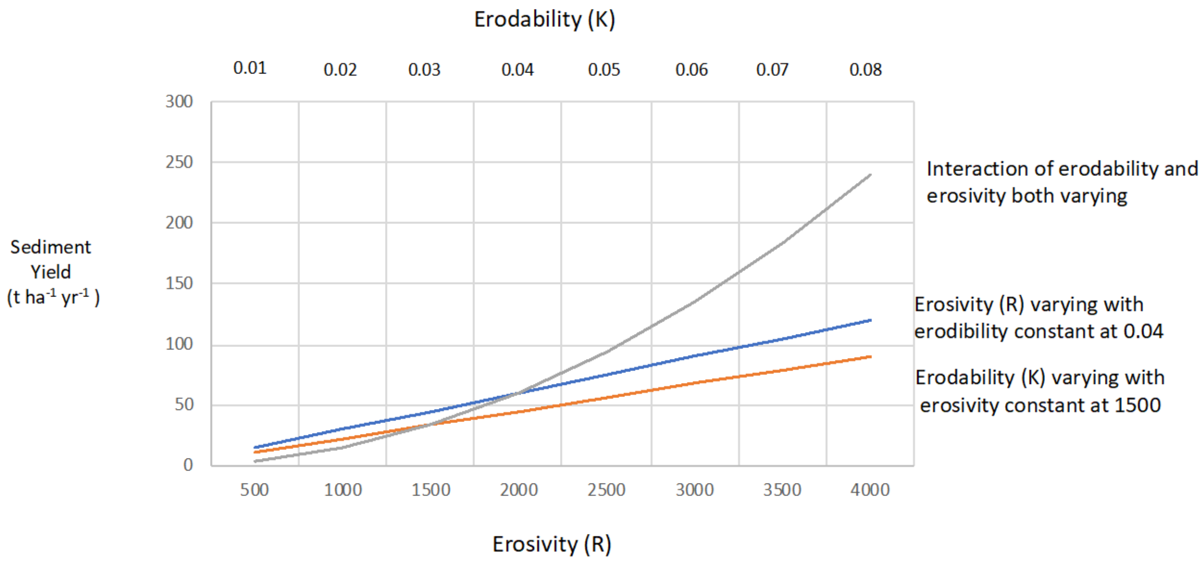


Figure 11: Sensitivity of sediment yield to rainfall erosivity and soil erodibility

While it is not possible to reliably quantify the attribution to climate change because rainfall data are not available at a sufficiently high temporal resolution for the project area, the indication from these results is that the impact of climate change represents something in the order of 67% of the sediment yield effect, commensurate with observed sedimentation in reservoirs (this likely is an underestimate because of the existence of rainfall intensity thresholds on erosion not taken fully into account here).

The catchment modelling using different land uses with historical rainfall in the earlier section indicated that the effects can be mitigated by targeted vegetation management and erosion control measures. Generally, sediments are deposited over the upper rim of the reservoirs affecting their active storage capacity. Loss of this critical active capacity impacts both irrigation and power generation.

As presented in the Feasibility Study (Annex 2 to the Funding Proposal), the above SWAT modeling is complemented by a USLE estimation in the Kambarawa Ganga sub-catchment in the basin. It uses current land use data to quantify erosion using RUSLE[7] for the central part of the upstream catchment. Assuming this is representative of the whole area and a sediment delivery ratio of 20% exists, there would be sediment transport of 947,919 t yr^{-1}. This equates to a potential reduction in reservoir storage capacity of 533,204 m^3 yr^{-1} (using average sediment retention and sediment weight to volume

[7] Revised Universal Soil Loss Equation adapted for use in Sri Lanka. Fayas, Cassim Mohamed, Nimal Shantha Abeysingha, Korotta Gamage Shyamala Nirmanee, Dinithi Samaratunga, and Ananda Mallawatantri. "Soil Loss Estimation Using Rusle Model to Prioritize Erosion Control in KELANI River Basin in Sri Lanka." *International Soil and Water Conservation Research* 7 (2) (June 1, 2019): 130–37. https://doi.org/10.1016/j.iswcr.2019.01.003.

conversion factors from previous analysis of Sri Lankan reservoir siltation[8]). Properly targeted project interventions are expected to reduce sedimentation to a negligible level, that would, assume progressive erosion control during the project duration representing a retention of 13.86 Mm^3 of storage capacity by 2050, almost equivalent to the entire capacity of the Nalanda Reservoir.

These results confirm that change in rainfall has a large effect on sediment yield. With no change in land use, sediment yield is more than doubled (56% increase) for RCP 8.5 scenario over historical rainfall, confirming the contribution of climate change to the increase in sediment yield.

The analysis also indicates that the overall land use change can mitigate these effects, but only to a certain extent (8-24%, depending on predicted rainfall). This confirms the appropriateness of the integrated ecosystem-based adaptation approach and its constituent interventions proposed in the project that use satellite image analysis to target erosion hotspots and specific erosion control measures (such as contour hedgerows) within cultivated land rather than relying on only overall land use change to make impact, as well as the focus on roadside and streamside interventions to tackle accelerated run-off and trap sediment, respectively. The project will co-ordinate these interventions through nested-scale, participatory planning processes that will be established under the governance objective (3.1) and supported by extension of options suitable to different local contexts through capacity development of rural advisory services in 3.2.

[8] Herath M. Gunatilake & Chennat Gopalakrishnan (1999) The Economics of Reservoir Sedimentation: A Case Study of Mahaweli Reservoirs in Sri Lanka, International Journal of Water Resources Development, 15:4, 511-526. https://doi.org/10.1080/07900629948736

3. Sedimentation Experience in Neighboring Watersheds

3.1. Upper Mahaweli Watershed and Reservoir Siltation

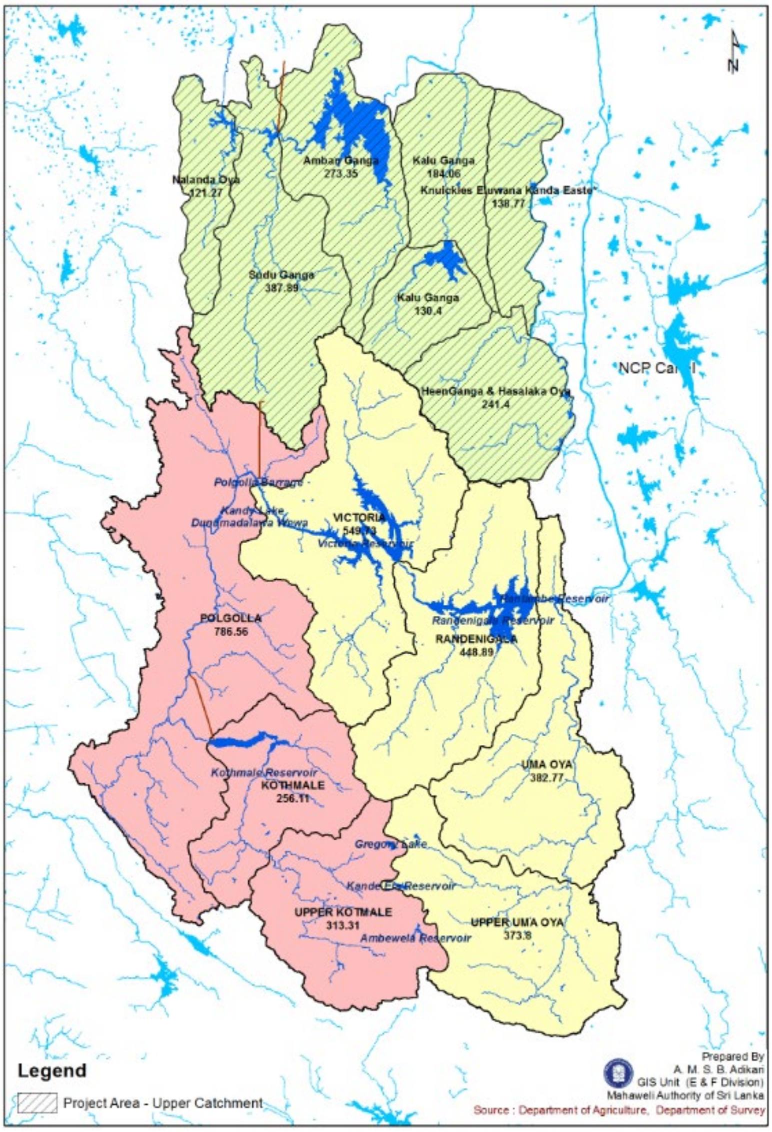


Figure 12: Upper Mahaweli Watershed (pink and yellow) and project upper catchment area (green)

Most relevant information on sedimentation experience were from the adjacent Upper Mahaweli Project area (area marked in yellow and pink), south of the upper catchment area of the project (green).

Key reservoirs built under the Mahaweli Project such as Kotmale, Victoria, Randenigala and Rantembe have been in operation for some time and the sedimentation rates are known. The sedimentation at the same level can be expected at the new reservoirs (Moragahakanda, Kalu Ganga etc.) within the project area.

H.R. Wallingford Limited (UK)[9] – HRW completed a hydrographic survey on the reservoirs to determine sedimentation rates and to predict the future sedimentation rates. The survey revealed a historically low sedimentation rate for large reservoirs of Kotmale and Victoria for the period from 1985 to 1993. However, the sedimentation rates in small reservoirs of Polgolla and Rantembe were very high. According to the survey, the storage capacity at the Polgolla barrage (the entry point of water to the project area) has been reduced by 56% over a 17-year period[27]. The Rantembe Reservoir had a reduced its storage capacity to 72 % from the original capacity three-year after operation. Prediction of future sedimentation rates in Rantembe has indicated that its storage capacity will fall to 32% by the year 2020.

Randenigala and Victoria are the second and third largest reservoirs in Sri Lanka that contribute to the irrigation of about 100,000 ha of dryland rice as well as for hydropower generation. Reduced reservoir

[9] Wallingford H.R. (1995). Sedimentation Studies in the Upper Mahaweli Catchment, Sri Lanka. HR Wallingford Ltd., Oxon, UK. .40p.

capacity would highly impact food production and green power concepts that are promoted in Sri Lanka's future development strategies. Arruppola (2016[10]) reports that the Mahaweli Basin has experienced very high intensity rainfall in short periods in the recent years, leading to soil erosion, activating landslides and transporting soil mass to reservoir bodies.

Experience of Mahaweli Authority as summarized by Aruppolla (2016) and the Wallingford study indicated the following sedimentation challenges in the upper Mahaweli reservoirs that is relevant to the Bowatenna, Morgahakanda and Kalu Ganga reservoirs in the project area.

Rantembe Reservoir

Original Volume (1900)	=	10.9 MCM	(Table 19, HRW)
Predicted Volume (2010)	=	3.9 MCM	(Table 19, HRW)
Actual Volume (2015)	=	5.95MCM	(MASL Hydrographic Survey)

Observation: The expected rate of sediment transportation 20t/ha/year may have remained unchanged or may be increased in the passage of time for 30 years. But the reservoir flushing may have contributed to maintain the capacity.

Randenigala Reservoir

Original Volume (1985)	=	860.0 MCM	(MASL Data)
Measured Volume (2016)	=	801.5MCM	(MASL Data)
Expected Sediment Inflow	=	0.946MCM/Year	(HRW/Wallingford)
Calculated Volume Reduction to (2017)	=	30 MCM	(30X0.946)
Actual Volume Reduction	=	58.5 MCM	(860– 801.5MCM)

Observation: The actual annual volume reduction is around 2 MCM/Year and **200% higher than the prediction. This could be due to fast degradation of watershed.**

Victoria Reservoir

Original Volume (1985)	=	717.53 MCM	(HRW – Table 16)
Volume as at (1993)	=	713.08 MCM	(HRW – Table 16)
Sediment Transport Rate Calculated	=	0.908 MCM	(HRW – Table 16)
Reduction of Volume (32 years)	=	29 MCM	(0.908X32)

Observation: Victoria catchment could not be discussed isolating the adjacent Randenigala catchment, as it could be assumed that the Randenigala sediment rates may be transferred to the Victoria catchment also. Hence, 2 or 3 MCM/year loss would be assumed for Victoria.

[10] Engineer S.R.K. Arruppola, Mahaweli Authority of Sri Lanka (personal communication) https://www.dropbox.com/s/blk49bqgwxbp44n/Mr.%20Aruppola%27s%20paper%20on%20Watershed%20Management%20in%20Mahaweli%20River%20upper%20catchment%201.docx?dl=0

3.2. Minor Watersheds and Erosion Rates

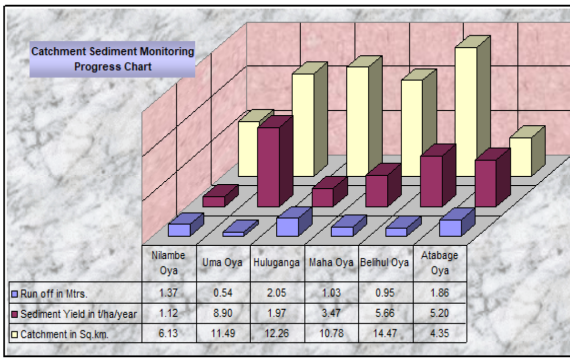


Figure 13: Minor watershed level erosion rates

Minor watershed level studies conducted by the Upper Mahaweli Watershed Project by the Mahaweli Authority of Sri Lanka indicated that the erosion estimates at minor watersheds vary from 1.12 t ha^{-1} per annum to 8.9 t ha^{-1} per annum for catchments varying in size between 4 km^2 to 14 km^2 (400 ha to 1,400 ha). These rates are comparable with the SWAT model results reported earlier.

The erosion estimations for the Upper Mahaweli watershed area indicated that the soil loss from conventional tea seedling plots (without specific soil conservation measures) was as high as 75 t ha^{-1} yr^{-1} (7,500 t km^{-2} ha^{-1} yr^{-1}). Soil loss from tea seedling plots in the upcountry (>1000 m asl) and the mid-country (300-600 m asl) was predicted as 4,600 t km^{-2} y^{-1} and 1,850 t km^{-2} y^{-1} respectively, using the USLE for current land use configurations.

In contrast, soil losses under vegetative-propagated tea land were as low as 200 t km^{-2} y^{-1} (Table 1). Higher soil losses (5,200 t km^{-2} y^{-1}) – (2 to 52 t/ha per annum) were reported from un-mulched plots, during the same monsoon rainfall conditions. Erosion rates during replanting under different settings were reported as 3,690-4,750 t km^{-2} y^{-1} (37 to 48 t/ha per annum). Soil losses under tobacco, capsicum and carrot were 7,000 t km^{-2} y^{-1}, 3,800 t km^{-2} y^{-1} and 1,800 t km^{-2} y^{-1}, respectively.

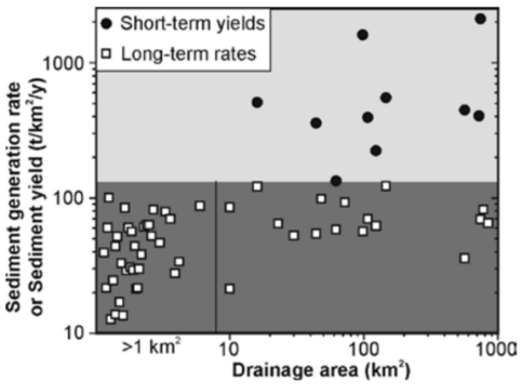


Figure 14: Sediment delivery short to long-term

These results need to be considered in the context that short term measurements over large drainage areas generally predict higher sediment yields than longer term measurements in smaller drainage areas (Figure 14. These quantitative assessments clearly indicate that large quantities of soil are being removed from conventionally managed land under tea seedling and seasonal crops. Plantation crops were introduced in the colonial era with tight erosion control practices. High rates of erosion observed recently, represent an interaction between the conventional land use with less erosion control related investments, partly due to poor produce prices and increasing rainfall erosivity due to climate change.

3.3. Sediment Delivery in Streams

The suspended load in the Mahaweli River measured near the Botanical Gardens, Peradeniya was from 130,000-820,000 t y^{-1}, which translated into a maximum sediment yield of 11.5 t km^{-2} y^{-1}, by dividing by the catchment's upstream area, again comparable with the sediment delivery observed in SWAT modeling which was 9.8 t/ha per annum. Based on these measurements and assuming a typical sediment delivery ratio of 10%, a soil loss of 115 t km^{-2} y^{-1} from the upper catchment was documented by Hewawasam (2010). However, with anticipated increases in the intensity of rains due to climate change, the assumption of 10% potential delivery from land to streams may have to be increased in the future for similar land uses.

The Netherlands Engineering Consultants monitored the suspended loads at two locations, at Peradeniya and Weragantota, below the Upper Mahaweli Catchment (UMC) over the two periods, June-July and October-November in 1983. The average annual sediment yields for the period of 1950 to 1982 were estimated by applying sediment rating curves to monthly discharge. The sediment yield of the UMC above Peradeniya was 420 t km^{-2} y^{-1} (4.2 t/ha per annum). With the anticipated climate induced high intensity rainfall events these sediment loads may increase. Two values for sediment loads passing Weragantota were calculated as 1,600,000 t y^{-1} prior to 1975 and 500,000 t y^{-1} after 1975. This difference is due to trapping of sediments at Pologolla and Minipe barrages, which were constructed after 1975 indicating the large amount of sediment that has silted in the Pologolla barrage as reported by Hewawasam (2010[11]). Further, the recent Hydrographic Survey at Randenigala found around a 10% loss of capacity (60 MCM). If a similar rate is assumed for Victoria, it will have lost around 60-70 MCM of its capacity. In addition, the Rantembe and Polgolla reservoirs too are severally affected with sedimentation, with sediments from their respective watersheds. Rantembe and Polgolla reservoirs are periodically flushed through bottom outlet gates during floods to maintain the capacity.

A sedimentation study carried out from April 1990 to April 1995 by H.R. Wallingford, UK, revealed that the Uma Oya erosion is at 15 t ha^{-1} yr^{-1} and 5 t ha^{-1} yr^{-1} for the other basins in Mahaweli. But present rates are expected to be much higher. The above-mentioned study and Aruppola (2016) recommends, increasing the tree cover in the Victoria and Randenigala watershed right bank area, approximately 500~600 km^2, as an immediate requirement to reduce silt deposit to these water bodies, which is in line with the cover intensification proposed in this project to protect the reservoirs in the project area. Tree cover in catchments regulates rainfall and infiltration contributing to reduction of flood risk (Carrol et al., 2004).

Land Use Types and Erosion

Table 9: Erosion rates in different land uses

Land use type	Area (km^2)	Soil loss (t km^{-2} y^{-1})
Dense forest	356.6	100
Degraded forest and scrubs	435.7	2500
Degraded grasslands	141.9	3000
Poorly managed seedling tea	3454.8	5200
Seedling tea with some conservation	252.7	1500
Vegetatively-propagated tea	114.9	200
Paddy	285.7	300
Home gardens	537.7	100
Shifting cultivation and tobacco	484.6	7000
Market gardens	163.6	2500

According to Hewawasam (2010), the areas under different land use types in the Upper Mahaweli watershed and the erosion rates in t km^{-2} per annum vary from a low rate of 100 t km^{-2} (1 t ha^{-1}) in dense forests to 7,000 t km^{-2} per annum (70 t ha^{-1} per annum) in shifting cultivation, based on historical rainfall figures, using USLE estimates modified to suit Sri Lanka conditions.

[11] T. Hewawasam. 2010. Effect of land use in the upper Mahaweli catchment area on erosion, landslides and siltation in hydropower reservoirs of Sri Lanka, J.Natn.Sci.Foundation Sri Lanka 38 (1): 3-14 (http://dl.nsf.ac.lk/bitstream/handle/1/6804/JNSF38_1_3.pdf?sequence=2)

4. Improvements for Water Balance in Upstream and Downstream Areas

4.1. Agriculture Seasons

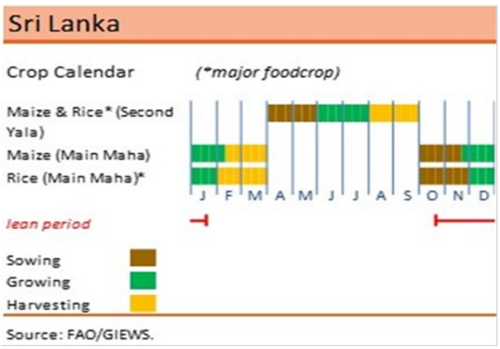


Figure 15: Agriculture seasons and practices

Yala and Maha are the two main agricultural seasons in the country. The Yala season corresponds to the South-West Monsoon of May to September whereas the Maha season corresponds to the North-East Monsoon of December to February.

Further in terms of paddy cultivation (primarily in lower catchment), the agronomic cycles are April – May (sowing period during Yala season), June – July (growing period during Yala season), October – November (sowing period during Maha season) and December – January (growing period during Maha season) – Figure 15

4.2. Climate Impact on Water Balance

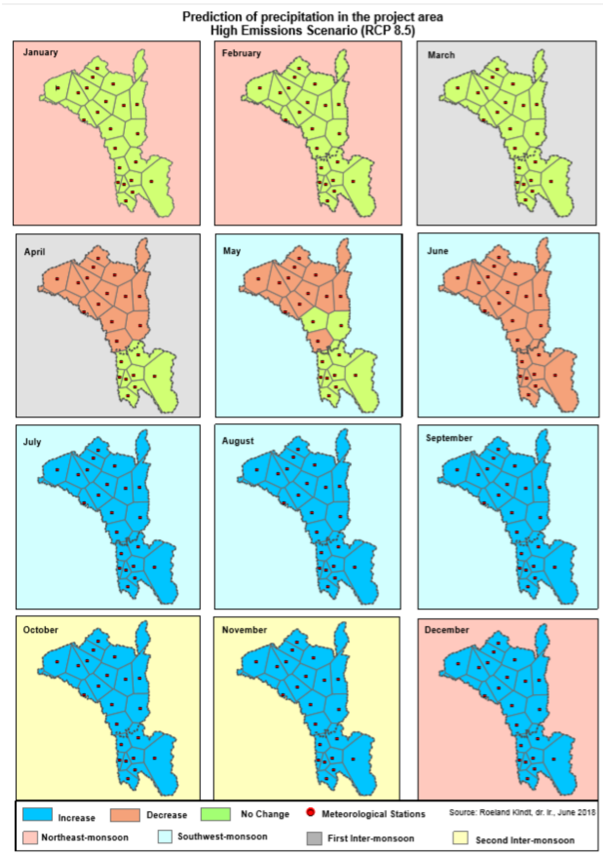


Figure 16: Rainfall predictions RCP 8.5

The climate projection for 2050[12] by Kindt (2018) indicated water deficits in April to June sowing period and early part of growing period in Yala season in the rice dominant lower catchment and rice growing season in Yala in upper catchment. This justifies the project interventions to enhance water storage in upper catchment resulting in increased water supply to downstream areas plus the water use efficiency interventions in downstream area.

Further, the climate prediction indicates excess rainfall (also see section on rainfall intensity) in soil preparation and sowing periods in both upper and lower catchments highlighting the need for soil conservation and enhanced storage capacity while working on stream sides and road sides to capture water and reduce sediment delivery as a result of expected increasing rainfall in the project area.

[12] Roeland Kindt. 2018 Climate Analysis for the project location - https://www.dropbox.com/s/cnylym4jhdv040b/Kindt%20Sri%20Lanka%20Precipitation%20Change%202018%20-%20NOV%2004%20V2.pdf?dl=0

The higher temperatures are predicted in the growing months in the downstream area indicating increased PET. In the downstream context, agricultural droughts (water deficits in crop growing seasons) are predicted to increase in frequency and severity.

Figure 17: Rainfall stations used in climate modelling

In the above analysis, the percentile data were calculated at 23 locations (stations) that represent the project area from the full data set of downscaled Global Climate Models (GCMs) available for Representative Concentration Pathways, RCP 4.5 (a medium emissions scenario with 19 GCMs available from WorldClim) and RC P8.5 (a high emissions scenario with 17 GCMs in WorldClim). Notations in the following of P_{min}, P_{max}, P_{10}, P_{25}, P_{75} and P_{90} refer to minimum, maximum and 10-25-75-90 percentile values calculated from the full range of GCM data sets at each location.

Applying the likelihood scale that was recommended by the Fifth Assessment Report of the IPCC (Mastrandea *et al.* 2011[13]) to mid-21st century climate change data available from WorldClim 1.4 (*i.e.* the version with most recent downscaled data from CMIP5), showed that **precipitation is likely to decrease in February** (a crop growing period in the Maha season) and **May** (a crop sowing period in the Yala season) for RCP 4.5 (for RCP8.5, decreases were predicted for April and May).

Downstream drought conditions

In January for RCP 4.5, the most extreme (P_{min}) GCM projects precipitation to decrease from 31 mm (Galgamuwa) to 66 mm (Dambulla) in lowland locations, a reduction of 38 (Galewela) to 55 (Nachchadoowa and Nuwaragam Palatha East) percent from baseline values. P_{10} data indicated a decrease of -22.2 to -50.8 mm (30 to 37 percent reduction), whereas P_{25} data showed a decrease of -16 to -40.5 (23 to 28%). In upland locations, the ranges were P_{min}[-54 to -108 mm][37 to 38%], P_{10}[-44 to -93.6 mm][30 to 34%] and P_{25}[-30 to -59.5 mm][20 to 22%].

In May to June for RCP 4.5, the following ranges were observed in lowland locations: P_{min}[-40 to -51 mm][51 to 54%], P_{10}[-19.6 to -24.4 mm][24 to 26%] and P_{25}[-8 to -10.5 mm][10 to 12%]. For the same months for RCP 8.5, the ranges were P_{min}[-37 to -51 mm][42 to 51%], P_{10}[-30.6 to -37.8 mm][37 to 41%] and P_{25}[-28 to -34 mm][33 to 37%].

Upland erosion in September to December and drought potential in April to May

Application of the likelihood scale revealed that precipitation is likely to increase in several months for the different RCPs at the project locations. The strongest signals were observed from September to December.

These increasing precipitations are linked to the project focus on erosion and degradation control at upland locations. For RCP4.5, ranges for September were P_{max}[+82 to +114 mm][82 to 85%], P_{90}[+48.4 to +72.4 mm][50 to 53%] and P_{75}[+32 to +48.4 mm][33 to 35%] and for October they were P_{max}[+151 to +181 mm][57 to 60%], P_{90}[+97.2 to +11.6 mm][37%] and P_{75}[+59.5 to +66.5 mm][22 to 23%] (there were no significant increases in November or December for RCP 4.5 according to the likelihood scale).

[13] Mastrandea *et al.* 2011 - The IPCC AR5 guidance note on consistent treatment of uncertainties: a common approach across the working groups

For RCP 8.5 and upland locations, ranges for September were P_{max}[+64 to +90 mm][63 to 66%], P_{90}[+58.2 to +85.4 mm][60 to 63%] and P_{75}[+45 to +64 mm][44 to 47%], for October they were P_{max}[+107 to +127 mm][40 to 42%], P_{90}[+103.8 to +120.8 mm][39 to 40%] and P_{75}[+75 to +93 mm][28 to 31%], for November P_{max}[+137 to +156 mm][45 to 48%], P_{90}[+110 to +132.4 mm][38 to 39%] and P_{75}[+69 to +82 mm][24%] and for December they were P_{max}[+152 to +233 mm][59 to 62%], P_{90}[+92 to +144 mm][37 to 38%] and P_{75}[+53 to +83 mm][21 to 22%].

In terms of upland drought conditions, in April, under RCP 4.5, P_{min}[-54 to -85 mm][49 to 50%], P_{10}[-25.8 to -43 mm][24 to 25%] and P_{25}[-10.5 to -16.5 mm][9 to 10%]. Also for RCP 8.5, P_{min}[-56 to -98 mm][52 to 56%], P_{10}[-39.6 to -63 mm][36 to 37%] and P_{25}[-35 to -53 mm][30 to 33%] for upland locations.

These increases point towards high erosion in those months as per RCP 8.5. In RCP 8.5, decreases were predicted for April and May again indicating potential hydrological stresses in those months in the sowing period.

4.3. Magnitude of Water Balance

The irrigation water requirement for dry zone paddy is projected to increase by 13% to 23% by 2050 due to reduced rainfall, increased PET and shorter rainfall duration[14]. The historical record (1952-2015[15]) shows increasing variability in the main Maha growing season of the paddy area across the country, sown and harvested (range 6 to 8 thousand ha over the last decade) as well as in the mean yield (range 3.6-4.4 t ha^{-1} over the last decade).

This observation is consistent with moisture index (rainfall divided by PET) projections from downscaled GCM analysis by Kindt (2019) that indicates increased downstream aridity in February, March and September and the need for extra irrigation water for rice cultivation in the downstream. At the same time, Kindt (2019) highlights the surplus moisture availability in the upstream area that can be channelled for downstream use if the storage capacity in reservoirs is maintained by controlling sedimentation and abandoned tanks in the upper catchment were restored as suggested by the project. From the ensemble of 19 downscaled GCMs[16] an increasing aridity in the downstream area is projected (calculated as the difference in moisture index from the baseline to 2050, for the key cropping months of January and May). This represents an increased water deficit for crop production[17] (using median values across the ensemble) of **80.03 Mm^3 in January and 24.44 mm^3 in May or a total reduction of 104.48 mm^3** in the lower catchment area. Hence, the moisture deficit due to climate influence can be potentially offset by a predicted median **annual increase in rainfall (from August to October) in the upstream catchment area equivalent to 237.61 mm^3** that would be enough to mitigate the deficit through irrigation if commensurate water capture, storage and distribution infrastructure are in place.

To put this in perspective, the combined storage capacity of the Nalanda (15 mm^3), Bowatenna (26 mm^3) and Moragahakanda (521 mm^3) reservoirs collecting water from the upstream area is 562 mm^3. Given the bimodal rainfall distribution and two downstream cropping seasons they can be expected to be filled twice per year. There are also shifts in seasonality affecting both plantation and seasonal

[14] De Silva, C. S. Weatherhead, E. K. Know, J.W., and J. A. Rodriguez-DIaz (2007). Predicting the impacts of climate change—A case study of paddy irrigation water requirements in Sri Lanka. Agricultural Water Management Volume 93, Issues 1–2, 16 October 2007, Pages 19-29. Elsevier

[15] http://www.statistics.gov.lk/agriculture/Paddy%20Statistics/PaddyStatsPages/PaddyStatsCharts.htm

[16] Probability approach using GCM predictions with more than two thirds are considered likely, following IPCC AR5 guidelines

[17] Calculated for the entire downstream area

crop agronomy that needs to be considered in land use planning work including the refined modelling and estimations during the project period. The projections suggest that collection, storage and transfer of upstream water to irrigate downstream paddy remains viable in the long-term and concurs with the GOSL adaptation focus on: regulating upstream flow and maintaining and increasing storage capacity; coupled with more efficient use of irrigation water downstream through adaptive crop agronomy, including agroecological practices that increase biological nitrogen fixation, nutrient and biomass cycling and the use of shade to reduce daytime temperature extremes experienced by the crop[18]. This is further confirmed by the Government investment under the World Bank funded Climate Smart Irrigation Agriculture Project as indicated in FP para 67 as a climate resilience measure.

4.4. Enhancing Water Use Efficiency in Downstream

The lower catchment project area comprised mostly of paddy (Figure 18). There are thousands of tanks, noted in blue color, built during ancient times to capture the Northeastern Monsoon rains and recharge ground water storage to support extensive paddy cultivation. The water from upstream watersheds contribute significantly to maintain the water levels, especially during dry seasons.

The water requirements are on the rise with intensive modern rice varieties and other cropping strategies in the area to enhance the cropping intensity and efficiency. The irrigation inefficiencies in the lower catchment areas in the Mahaweli Development Scheme vary between 35% to 90% (Figure 19) in both Yala and Maha. In that context the Government has invested in several mega projects such as the Mahaweli Water Security Investment Project through ADB that also includes the Morahahakanda, Kaluganga and Bowatenna water reservoirs[19] and the World Bank funded Climate Smart Irrigation Project, among others.

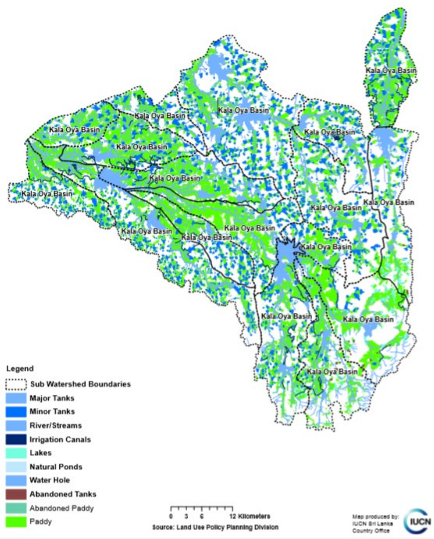


Figure 18: Paddy and tanks in lower catchment area

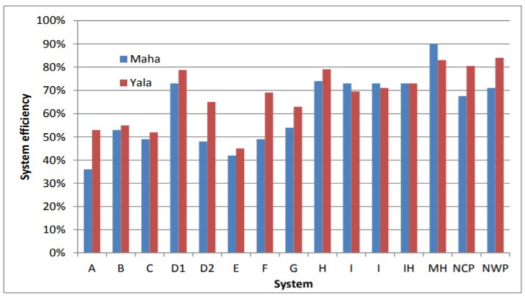


Figure 19: Irrigation efficiency in Mahaweli downstream systems

[18] Wangpakapattanawong P, Finlayson R, Öborn I, Roshetko JM, Sinclair F, Shono K, Borelli S, Hillbrand A, Conigliaro M. 2017. Agroforestry in rice-production landscapes in Southeast Asia: a practical manual. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand http://www.fao.org/3/a-i7137e.pdf

[19] Mahaweli Water Security Improvement Project - https://www.dropbox.com/s/2kn7cosqm8b0t0h/ADB%20North%20Western%20Province%20Canal%20Study.pdf?dl=0. The Mahaweli Water Security Investment Program ("investment program") will contribute to the implementation of major water infrastructure under the Mahaweli Development Program (MDP) for the transfer of water from the water rich central 'wet' zone to the 'dry' zones in the North Central and North Western Provinces for agriculture and domestic water consumption. The investment program includes three projects: (i) the Upper Elahera Canal Project (UECP); (ii) the North Western Province Canal Project (NWPCP); and (iii) the Minipe Left Bank Canal Rehabilitation Project (MLBCRP) with an expected annual water supply of more than 700 MCM from the Mahaweli River to the target systems**. The prefeasibility study identified a "Modification to the configuration of Moragahakanda and Kalu Ganga Reservoirs to Accommodate in the North Central Province Canal project (NCPCP)**

The Green Climate Fund joined the Government led effort by supporting to rehabilitate abandoned village cascade tanks along with increased water use efficiency implemented through UNDP. Therefore, the proposed project is not planning to engage in investments to repair tanks in the lower catchment area but complement other projects through targeted technical assistance to improve the water use efficiency to ensure the investments in the upper catchment are well utilized.

In the downstream, the project will focus on the efficient use of the water recovered through upstream interventions while taking advantage of the preserved reservoir and tank capacities with Government Investments, GCF Tank Restoration Investments *via* UNDP, World Bank Climate Smart Irrigation Project and ADB funded Mahaweli Water Security Investment Programme. While working with those investments, the project proposes to enable vulnerable smallholder farming communities (where households are in receipt of food security welfare payments from government[20]) to adapt to climate change.

The project proposes to couple upstream catchment management with sustainable intensification of irrigated rice in the downstream, involving the use of agroecological intensification methods[21] that increase water use efficiency and hence reducing the demand for water in the downstream. The system of rice intensification (SRI) detailed in the proposal involves locally adapted practices that reduce water demand (by up to 50%) through intermittent irrigation also known as alternative wetting and drying (AWD)[22] as well as targeted increases in tree cover that mitigate effects of elevated daytime temperatures that decrease rice productivity. The promotion of downstream agroecological practices is implemented under output 3.2 through further enhancing the capacity of rural advisory services to adapt options to local context using real time weather and market information.

The coupled upstream catchment management and downstream irrigation are connected *via* the development of novel payment for environmental service (PES) mechanisms under output 2.2. Three potential income streams have already been identified, a levy on hydropower generation, a levy on export crops used to incentivize best practices in plantations and the use of general taxation receipts to incentivize smallholder farmers to adopt sustainable land use practices, building on the existing system of welfare payments.

4.5. Targeted Erosion / Sedimentation Reduction Efforts

In the Funding Proposal Section C1 and C2 we show decadal progression of land degradation, associated with increased upstream rainfall and rainfall intensity (Section C2 para 51 to 58) and then target activities spatially to address the climate induced erosion. An increase of 7% in heavy rainfall days per year to 2050 were used and targeted activities were design spatially to address the climate induced erosion (representing 6% and 9% of the Nalanda Oya and Kala Oya catchments respectively) on the basis of universal algorithms were planned, but will be refined further through application of LDSF).

Because climate change induced erosion hotspots are embedded in community, estate and forest management units, the erosion control measures will only be sustainable where the plantation crop

[20] Poverty related data is on pages 62 and 63 of the Feasibility Report showing the number of people receiving welfare payments by Division in the project area. In 2017 in the upstream project area alone 6.4 billion SLR (over 7 m USD) in welfare payments were made to 276,000 families. Water regulation measures involve collective action at community level.

[21] The Global Commission on Adaptation (GCA) has recommended adopting agroecological approaches to build resilience of small-scale food producers. See ADAPT NOW: A GLOBAL CALL FOR LEADERSHIP ON CLIMATE RESILIENCE and more specifically Sinclair, F., Wezel, A., Mbow, C., Chomba, S., Robiglio, V., and Harrison, R. 2019. "The Contribution of Agroecological Approaches to Realizing Climate-Resilient Agriculture." Rotterdam and Washington, DC. Available online at www.gca.org.

[22] "Strategies for Survival." *Nature Plants* 3, no. 12 (December 2017): 907–907. https://doi.org/10.1038/s41477-017-0081-x.

or forest units continue to be sustainably managed requiring best practices, profitability and adapted management (for example where flowering times of plantation crops is shifting) over the matrix within which the hotspots are embedded. Targeting implementation through overlaying climate induced erosion prevalence on land cover ensures that the activities are commensurate with only what is necessary for sustainable climate change adaptation. The actual implementation will involve the use of enhanced evidence available from LDSF as applied by the governance structures established through project activities.

In terms of upstream regulation of water flow, the focus is on i) streamside protection and ii) management of accelerated run-off along the road network. These directly target reducing i) sediment transport and ii) flood generation associated with higher and more intense rainfall at the same time as enhancing water **availability for upstream crop production by better management of water for agriculture. This represents a modest proportion of the national effort on water management, targeted at the climate change induced impacts on upstream sediment flow generation and adaptation of upstream agriculture to more** increased variability in rainfall.

4.6. Roadside and Streamside Management

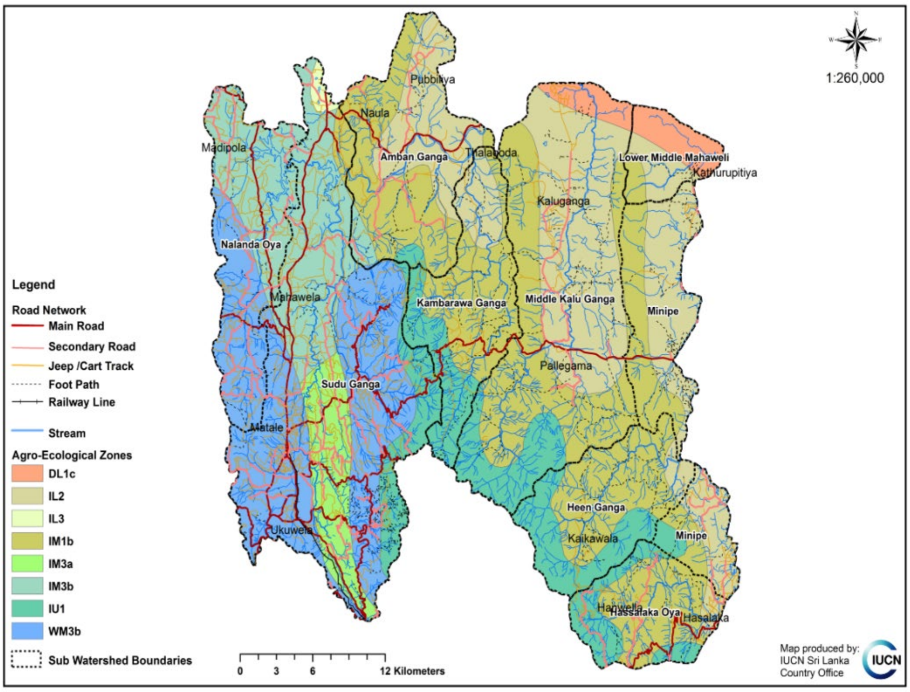


Figure 20: Roads and streams in different ecological zones in the upper catchment

In addition to land use interventions, the project proposes tackling accelerated run-off along the road network, by diverting water that can then be used by upstream smallholder farming communities in irrigation networks to increase their cropping intensity. Different types of roads and streams contribute to the silt loadings in the reservoirs, minimizing the water holding capacity. The proposed roadside and streamside work under output 1.1 to minimize the erosion potential and delivery of silt are in different rainfall zones with focus on the wet ecological zone that has about 440 km of road length providing the highest vulnerability to erosion (Figure 20 and Table 10). The project interventions not only reduce the silt loads but also enhance rainwater infiltration to ground water, thereby enhancing the storage of water to meet the water deficits in upstream as well as downstream project areas.

Table 10: Road lengths in different ecological zones in the upstream project area.

Eco-region	Agro Ecological Region	A Type Road Length (m)	AB Type Road Length (m)	B Type Road Length (m)	Secondary Minor Road Length (m)	Jeep & Cart Track Road Length (m)	Footpath Road Length (m)	Railway Road Length (m)	Total (m)
DL1c	LOW COUNTRY - D	-	-	5	-	22	-	-	27
IL2	LOW COUNTRY - I	2	0	57	36	319	24	0	438
IL3	LOW COUNTRY - I	1	0	0	0	4	0	0	5
IM1b	MID COUNTRY - I	14	0	26	19	173	20	0	252
IM3a	MID COUNTRY - I	0	0	30	5	99	4	0	138
IM3b	MID COUNTRY - I	20	0	26	19	254	1	9	328
IU1	UP COUNTRY - I	7	0	29	1	178	39	7	261
WM3b	MID COUNTRY-W	16	6	64	9	327	19	0	440
Total		**61**	**6**	**232**	**88**	**1,354**	**108**	**16**	**1,864**

Similarly, the streams are also located in ecological zones with different rainfall patterns with the activity targeted to trap sediment between cultivated areas and streams in the most vulnerable wet (WM3b) and intermediate zones (IM1b and IM3b) comprising 405, 771 and 375 km of stream / river lengths.

Table 11: Stream / river lengths by ecological zone in the upstream project area

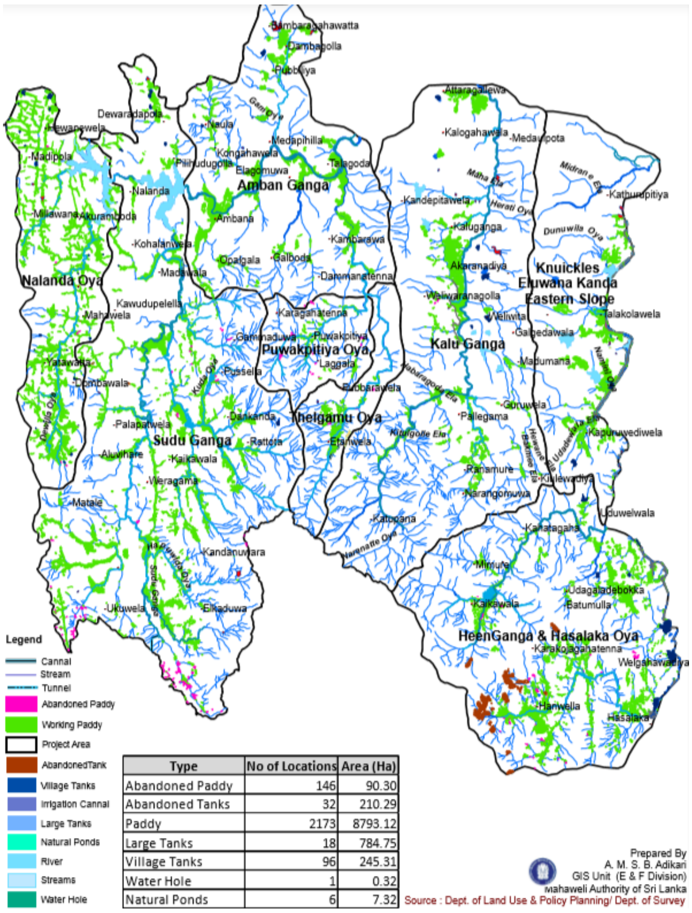
Ecological Zone	Ecological Region	River/ Stream Length (km)
DL1c	LOW COUNTRY - D	30
IL2	LOW COUNTRY - I	517
IL3	LOW COUNTRY - I	0
IM1b	MID COUNTRY - I	771
IM3a	MID COUNTRY - I	93
IM3b	MID COUNTRY - I	156
IU1	UP COUNTRY - I	375
WM3b	MID COUNTRY-W	405

4.7. Restoration of Abandoned and Silted Tanks in the Upstream Project Area

There are 32 tanks abandoned and another 18 large tanks and 96 village tanks that are semi-functioning (Figure 21).

Stimulated by the opportunity to capitalise on new water diverted from roadside management and the predicted increase in surplus water in the upstream catchment from August to September, the sediment removal and repair of these tanks will ensure their long-term water holding and recharge capacity and contribute to regulation of water flow across the catchment.

The project will invest in repairing these tanks and installing participatory conservation measures to enhance and maintain the water storage in the upper catchment where downstream water availability will also be supported through ground water and surface streams.



Type	No of Locations	Area (Ha)
Abandoned Paddy	146	90.30
Abandoned Tanks	32	210.29
Paddy	2173	8793.12
Large Tanks	18	784.75
Village Tanks	96	245.31
Water Hole	1	0.32
Natural Ponds	6	7.32

Figure 21: Village tanks, water holes and ponds in upper catchment

5. Rainfall Intensity and Extreme Events

5.1. Extreme Events

In literature, climate model simulations[23] (Hennessey *et al*., 1997) and empirical evidences confirm that the warmer the climates, owing to increased water vapour, the more intense the precipitation events (IPCC, 2007[24]), providing a direct influence between climate change and precipitation. Increasing temperatures lead to greater evaporation. However, the water holding capacity of air increases by about 7% per 1^0C warming, which leads to increased water vapour in the atmosphere and produces more intense precipitation events (Trenberth. K.E 2011[25]).

Despite the challenges in data availability (lack of hourly rainfall etc.), the potential extreme conditions due to climate change were studied with available methods and data. Two approaches used in this context involved study of extreme events in the site locations based on GCM models (by ICRAF) and use of historical high rainfall events by Dept. of Meteorology.

5.2. Historical Climate Trends

Extreme climate indices by Jayawardane et.al, 2018[26] as part of the World Meteorological Organization–Commission for Climatology (WMO–CCI)/World Climate Research Program (WCRP)/Climate Variability and Predictability (CLIVAR) project, used 20 synoptic stations in Sri Lanka for the period of 1981-2010 and included 80% of stations in the country. Results showed an increasing trend in precipitation indices such as increasing trend of maximum one-day precipitation, maximum five-day precipitation, and total precipitation on extreme rainfall days (R95p – heavy and R99p – very heavy). The increase in precipitation extreme trends indicates extreme rainfall events.

In Central Highlands, the Simple Daily Intensity Index, maximum 5-day precipitation and the percentile based extreme rainfall (95th and 99th) shows an increasing trend (Figure 22).

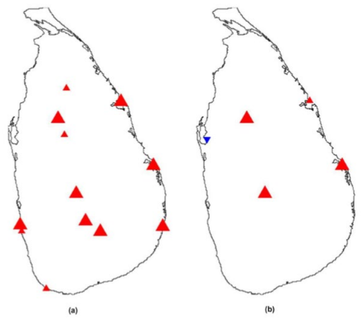


Figure 22: Trend in precipitation and intensity

The trends in annual total precipitation (a) and daily intensity of rainfall (b) indicate both increasing rainfall and intensity for the uplands (significant changes at the 5% level are indicated by large triangles and 10% level are indicated by small triangles).

[23] Hennessey, K.J., J.M. Gregory and J.F.B. Mitchell. 1997. Changes in daily precipitation under enhanced greenhouse conditions. Climate Dynamics, 13: 667-680.
[24] IPCC, 2007. Climate Change 2007. Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Eds. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Cambridge Univ. Press, Cambridge, U.K.
[25] Trenberth, K.E. 2011, Changes in Precipitation with Climate Change, Climate Research 47(1):123-138
[26] Shiromani Priyanthika, I. M.. Thanuja Darshika, D. W. T, Roshan C. Herath H. M., 2018, Recent Trends in Climate Extreme Indices over Sri Lanka, American Journal of Climate Change, 2018, 7, 586-599

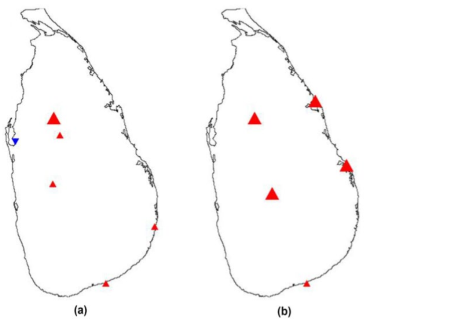


Figure 23: Trend in maximum precipitation

Trends for maximum one-day precipitation (RX1day) (a) and maximum 5-day precipitation (RX5day) (b) indicate an increasing trend in Central Hills but the lack of hourly rainfall data restrict further analysis on the intensity of the rainfall (significant changes at the 5% level are indicated by large triangles and 10% level are indicated by small triangles).

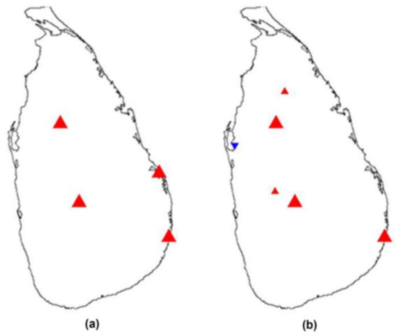


Figure 24: Trend in wet days

Trends for very wet days (a) and extremely wet days (b) indicate increasing trends (significant changes at the 5% level are indicated by large triangles and 10% level are indicated by small triangles).

5.3. Probability of Historical and Predicted Extreme Events

Figure 25: Rainfall stations around Knuckles

Using the historical climate information, Punyawardane and Premalal (2013)[27] studied extreme rainfall events and trends in the Central Highlands focusing on four districts, namely, Nuwara Eliya, Kandy, Matale and Badulla. Sixty-year daily rainfall data for the period from 1961-2010 were used for the analysis. The 95th and 99th percentile values of daily rainfall time series at Illukkumbura (near Knuckles), Matale, Elkaduwa, Pussellawa and Kandy (4 stations) from 1961-1990 were used as the threshold value to determine the heavy and very heavy rainfall events, respectively, during four seasons (First Inter Monsoon – FIM March to April; South West Monsoon – SWM May to September; Second Inter Monsoon – SIM October to November; and North East Monsoon – NEM December to

[27] Punyawardane, B.V.R. and Premalal, K.H.M.S., 2013, Do Trends In Extreme Positive Rainfall Anomalies in the Central Highlands of Sri Lanka Exist? Annals of Sri Lanka Department of Agriculture 2013. 15: 1-12

February). The results are summarized in Table 12 (99th Percentile) and indicated possible extreme rainfall over the study locations.

Table 12: Trend and statistical significance of extreme rainfall (daily) at 99th percentile

Station	FIM R^2 (p-value)	SWM R^2 (p-value)	SIM R^2 (p-value)	NEM R^2 (p-value)
Kandy	0.278 (0.117)	0.002 (0.901)	0.002 (0.904)	0.000 (0.964)
Pussellawa	0.006 (0.835)	0.037 (0.593)	0.473 (0.028)	0.341 (0.076)
Matale	**0.445 (0.035)**	0.027 (0.476)	0.069 (0.464)	**0.303 (0.099**)
Illukkumbura	0.324 (0.141)	0.000 (1.000)	**0.487 (0.054)**	0.007 (0.847)

For example, the First (Matale) and Second Inter Monsoon (Illukkumbura) and North East Monsoon (Matale) periods indicate at least one station recording significant increase in high intensity rains.

The predictions up to 2100 highlighted extreme rainy days in the intermediate zone based on moderate emission scenario (RCP 4.5) in both 95th and 99th percentiles using the daily rainfall data for the period 2010-2100. The median value obtained for four seasons for decadal periods were computed (Figures 26 and 27).

Table 13: Number of Very Heavy Rainfall (Decadal, 95th Percentile) with time

Period	Regression	R2	p-Value
First Inter-monsoon	**y = 0.825x + 21.986**	**0.1816**	**0.253**
Southwest Monsoon	**y = 3.1167x + 48.583**	**0.4422**	**0.051**
Second Inter-Monsoon	**y = 3.075x + 66.069**	**0.7899**	**0.001**
Northeast Monsoon	**y = 3.866x + 31.278**	**0.795**	**0.001**

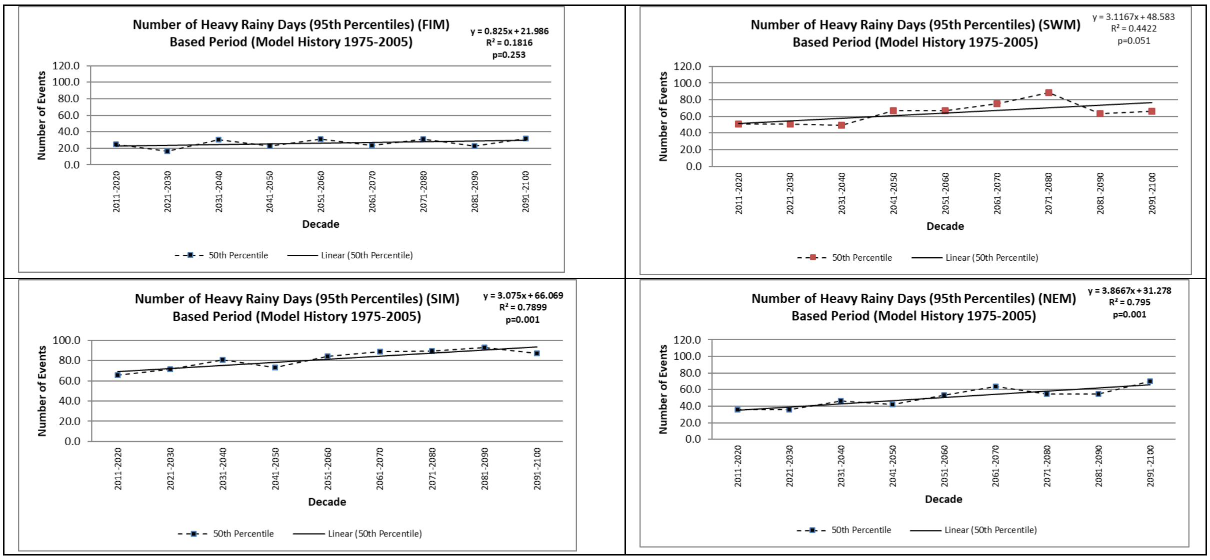


Figure 26: Trend in the 95th percentile values for precipitation events

Table 14: Number of Extremely Heavy Rainfall (Decadal, 99th Percentile) with time

Period	Regression	R2	p-Value
First Inter-monsoon	**y = 0.2583x + 6.375**	**0.1001**	**0.407**
Southwest Monsoon	**y = 1.2917x + 7.1528**	**0.9193**	**0.000**
Second Inter-Monsoon	**y = 0.2417x + 11.181**	**0.1906**	**0.240**
Northeast Monsoon	**y = 0.7167x + 9.1389**	**0.3874**	**0.073**

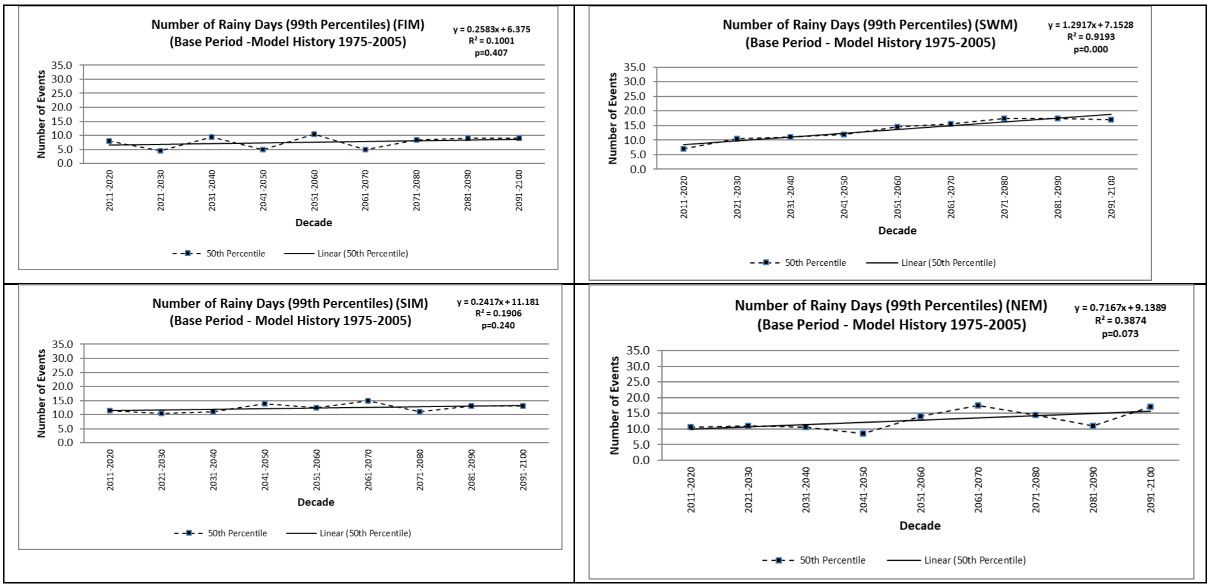


Figure 27: Observed high intensity rainfall events

This indicates that during the Southwest Monsoon and Northeast Monsoon periods, there may be significantly high intensity rainfall events based on the 99th percentile events in the project area.

6. Upscaling Potential and Conclusion

6.1. Upscaling Potential of Hydrologic Improvements

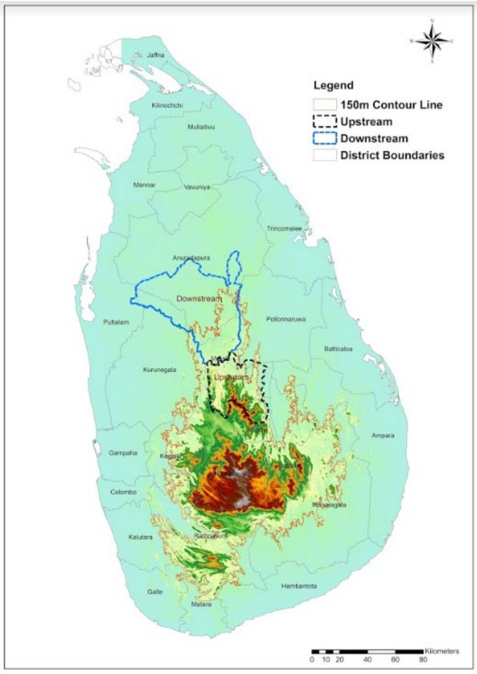


Figure 28: Highland areas with potential replication of project experience

The proposed GCF investment is aimed at establishing a national level integrated climate change and watershed resilience model that addresses aspects of surface water management, canopy related rainfall/fog interception, erosion control, prevention of sedimentation of tanks and reservoirs, stream-side and roadside management through a multistakeholder engagement process involving Government agencies, communities, plantation companies and subsistence farmers among others.

This national model on conserving Central Hills (steep lands above 150 m contour) to meet the climate challenges will also serve as the main pilot project for the GCF funded capacity building programme (Readiness Programme) starting November 26th, 2019.

The total areal extent of the Central Highlands is 14,100 square kilometres approximately and the GCF investment will directly support interventions in an area of 1,280 square kilometres (above the 150 m contour)—equating to 9% of the Central Highlands. The demonstrated results could then be expanded to cover the entire areal extent of the Central Highlands of the country and possibly adaptable to other countries such as the Southern Western Ghats region of India, which shares similar biophysical attributes and geological origin.

6.2. Conclusion

The climate signals we are responding to:

1. Rising temperatures and lower rainfall in key crop growing months that combine to increase aridity (manifest as a lower moisture index), hence more frequent and severe droughts reducing crop yields affecting both the upstream and downstream crop growing areas as well as direct effects of high temperatures on crops.
2. More variable and intense rainfall in upstream catchments, leading to flooding, accelerated land degradation (upstream) and sediment transport (that reduces storage capacity of reservoirs hence exacerbating effect of drought on downstream crops).
3. Combination of changing temperature and rainfall patterns changing flowering time of key export crops and hence crop choice and agronomy.

The climate effects are addressed directly by activities under output 1.1 that restore vegetation and regulate water flows (along roads and streams and over water storage and irrigation networks) in upstream catchments, and output 1.2 that make more efficient use of irrigation water for crop production in both upstream and downstream areas through improved rice agronomy, mitigate higher temperatures (through shade from agroforestry trees), intensify smallholder systems and restore and sustainably intensify upstream plantations. The approach is that sustainable management controls sediment transport (benefiting downstream communities by maintaining reservoir capacity) at the same time as providing livelihood benefits for estate workers upstream (restoration is required to create conditions within which private sector investment in continued plantation management can become profitable and therefore happen).

The activities under 2.1 (value chains) and 2.2 (PES) provide the finance that makes the direct activities in 1.1 and 1.2 possible while activities under 3.1 and 3.2 reconcile administrative and watershed boundaries and provide necessary information and governance to target interventions to efficiently address climate effects and monitor the impact of doing so.

This means that there is a problem complex caused by interacting elements of climate change that is addressed by enabling land users to adapt to the climate effects by tackling extant constraints (technical and in relation to finance, availability of information and governance mechanisms). This does not result in one-to-one correspondence between individual climate facts and activities but nested sets of climate effects and actions.

GOSL has already committed in the project proposal to implement the hydropower levy as a PES mechanism. There is already a Cess on export crops that pays for support services to the sector, and the project will explore possibilities to extend this to support catchment management together with other options for channeling some of the increased income envisioned from value chain upgrading under output 2.1 in both the plantation sector and amongst smallholder farmers to develop novel sustainable PES modalities from increased revenue associated with sustainable production.

In respect to the share of the problems being addressed that is due to climate change, the measures funded through this proposal are only a small part of the national effort, directly targeted at the climate change induced pressure on erosion/sediment load in the upstream catchment, consequent requirement for water regulation (and management) in the upstream catchment and adaptation of both upstream and downstream agriculture to adapt to climate change.

The activities are focused specifically on developing capacity to adapt that will leave a long-term effect in the national system while implementing measures to protect soils, water regulation and reservoir capacity in relation to immediate threats. It is expected that the lessons and capacity building efforts of this project will be upscaled in other parts of the Central Hills of Sri Lanka to meet the climate challenges through participatory adaptative approaches. The GOSL has dedicated the GCF capacity development funds to develop a detailed strategy for the fragile Central Hills and among other experiences the proposed project will provide the PES, LDSF, Green Listing and Land Use models for the Central Hills.

The original FP suggested to carry out detailed hydrologic and sediment transfer assessments, during the inception stage of the project, as part of the participatory planning process to target ecosystem-based adaptation measures. This involves capacity development in Sri Lanka in using combinations of nested-scale survey methods, satellite image analysis and installation of a network of automatic weather stations across the upstream project area to generate high resolution rainfall data, both spatially and temporally that will allow reliable determination of hydrologic and sediment transfer processes. This approach was proposed due to the information constraints in the project area to parameterize models and spatially target interventions at fine scale (that, in any case, requires a participatory process with local communities). Nevertheless, the iTAP recommendation helped to add more knowledge to the Funding Proposal, therefore the AE and the project team appreciate iTAP and GEFSEC efforts to improve the submission.

Attachment 1: Mahaweli Water Security Investment Programme

This programme will benefit by the availability of additional water due to upper catchment related extensive conservation and management measures and limited downstream water use efficiency promotions and demonstrations.

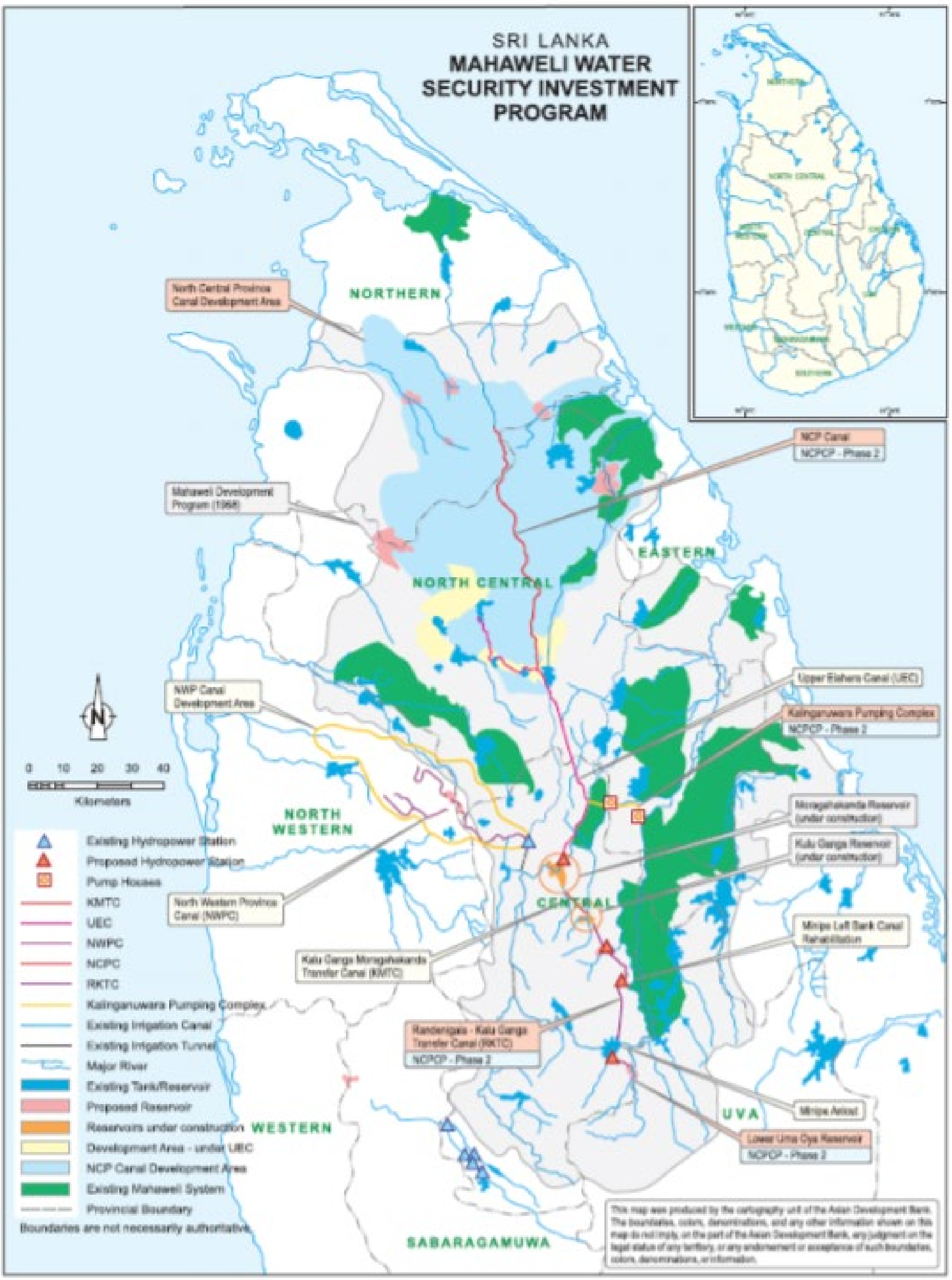
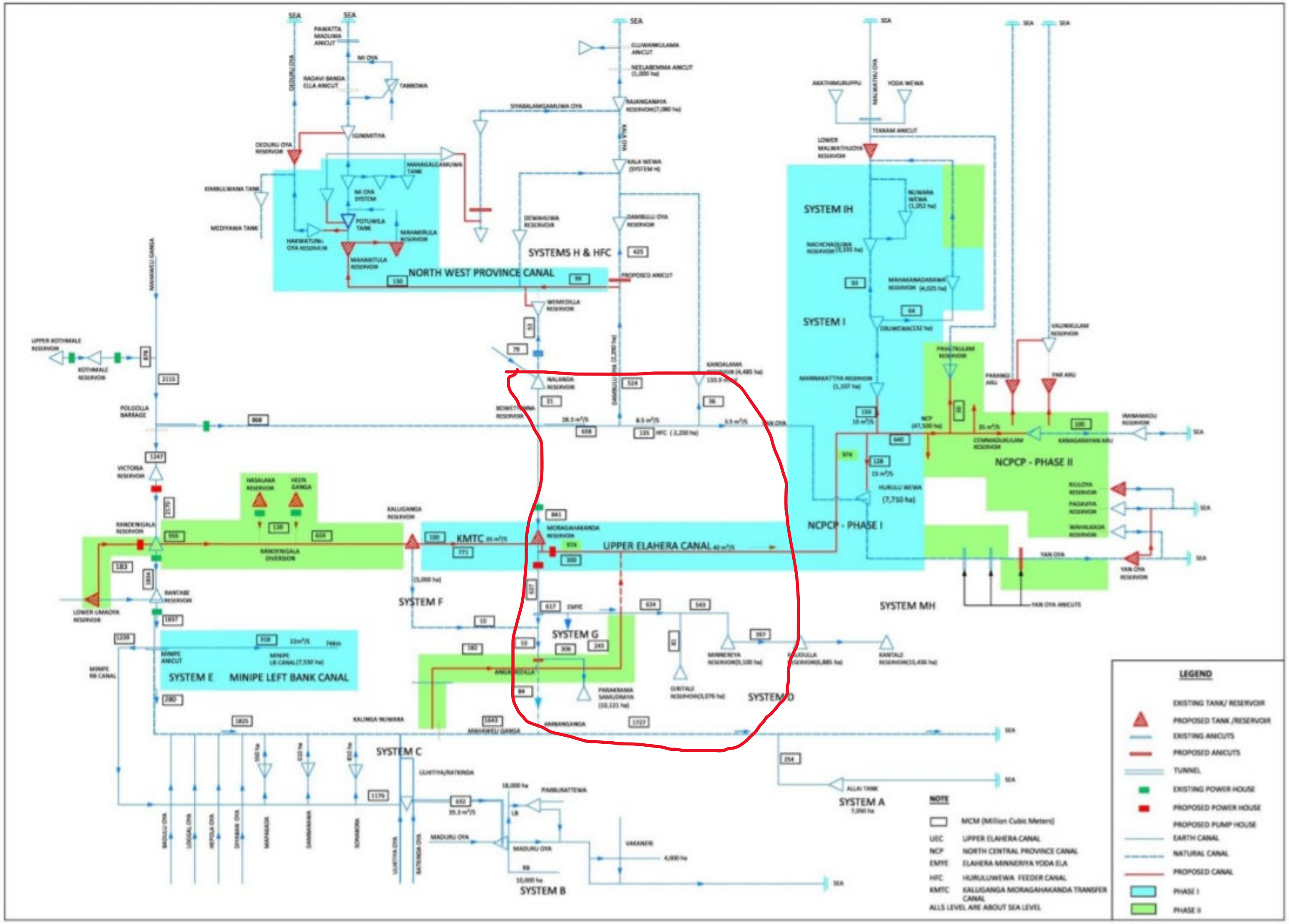


Figure 29: Mahaweli Water Security Investment Map



Project focus area

Figure 30: Diagram of the Mahaweli Development Programme