Technical Assistance Consultant's Report

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August 2018

Knowledge and Innovation Support for ADB's Water Financing Program

Sri Lanka: Water Accounting in Mahaweli River Basin

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For Asian Development Bank

Asian Development Bank

Water Accounting in Sri Lanka

The Mahaweli River Basin

Final report

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1 Executive Summary

1. The Asian Development Bank (ADB) is supporting the Mahaweli Water Security Investment Program, a major government water resources project in Sri Lanka. The aim of the project is to increase water and food security in the northern 'dry zone' of Sri Lanka by diverting untapped water from the country's largest river, the Mahaweli, which takes its source in the southern 'wet zone' to tanks and reservoirs in the dry zone for domestic water consumption and irrigation (ADB, 2017: Ending Water Scarcity in Sri Lanka's Dry Zone).

2. Water accounting can provide a coherent and consistent methodology for quantifying hydrological processes and the distribution of water over various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water.

3. The Water Accounting Plus system (WA+) is based on open access remote sensing data – in conjunction with open access GIS data and hydrological model output. WA+ communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets, tables and maps that are designed to be understood by people with technical and non-technical backgrounds alike. The WA+ framework is developed by IHE-Delft in partnership with the International Water Management Institute, the Food and Agriculture Organization, and the World Water Assessment Program.

4. The main objective of this project is to support the formulation of the proposed Mahaweli Water Security Investment Program (MWSIP) with an independent assessment of water fluxes and consumption in the Mahaweli River Basin through the application of the WA+ procedure to estimate, on a monthly scale, available and exploitable water resources

5. The main observations are:

- On a basin and yearly scale, the Mahaweli was found to have sufficient water resources under current conditions.
- Current abstractions were found to be sustainable at the basin scale
- Seasonal water availability is very variable. This has the following consequences:
    - Reliance on storages in the dry season
    - No utilizable flow left-over in dry season
    - High utilizable outflow during the months of Nov-Jan
- High inter-annual variability in water availability
- Water productivities were found to be low
    - potential for increased production without additional water supply
- Field application efficiencies are low
    - Irrigations amounts could be reduced further during times of high rainfall
    - On-farm water conservation techniques should be used

6. Note that this report describes main results only, all the accounting sheets will be made available on our http://www.wateraccounting.org.

2 Introduction

7. The Asian Development Bank (ADB) is supporting the Mahaweli Water Security Investment Program, a major government water resources project in Sri Lanka. The aim of the project is to increase water and food security in the northern 'dry zone' of Sri Lanka by diverting untapped water from the country's largest river, the Mahaweli, which takes its source in the southern 'wet zone' to tanks and reservoirs in the dry zone for domestic water consumption and irrigation (ADB, 2017: *Ending Water Scarcity in Sri Lanka's Dry Zone*).

8. The Sri Lankan climate is tropical and has two monsoon periods: the *Yala* season, which is the southwest monsoon from May to September, and the *Maha* season which is the northeast monsoon from December to February. The central wet zone benefits from two monsoon seasons while the dry zone receives rain from a single monsoon (Maha) and is subject to frequent droughts.

9. Rice is the main crop grown in Sri Lanka and rice self-sufficiency is one of the national policy objectives. At the same time, farmers are considering to cultivate higher value crops as diets are changing. The dry zone is a strongly agriculture based area and the MWSIP program aims to enable farmers to increase cropping intensities by switching from single to double cropping. Sri Lanka has a long tradition of irrigation and many tanks exist to store and distribute water. These tanks will be connected to the Mahaweli system to make use of excess water which is currently flowing out to the ocean unproductively (ADB, 2017).

10. Considerable progress has been made in many countries in processing and storage of basic geographic information systems (GIS) data. Yet routine access to this information contained in servers is often restricted to the host organization and the agency that "owns" the data. This limits the benefits that could be obtained by wider use and sharing with other agencies.

11. Information on water resources has to be coherent and synchronized in order to provide an integrated picture useful for the assessment of the problems and possible solutions. The current democracy on hydrological data does not provide the required data necessary to all stakeholders. This hampers the development of good water stewardship. Dissimilar sources of information and terminologies jeopardize the transparency necessary for joint decisions on water, land and ecosystems. Hence, there is a need for independently gathered water resources related data sets that can be commonly understood by all parties.

12. Water accounting can meet this requirement. It provides a coherent and consistent methodology that quantifies hydrological processes, water storage, base flow, and the distribution of water to various competing sectors. It also considers the consumption of water and the benefits and services - including ecosystem services - that result from that consumption, including the return flow of non-consumed water. A water accounting system based on open access earth observation satellite data for complete river basins - including transboundary basins - is therefore proposed: The Water Accounting Plus system (WA+). It goes beyond the classical description of water supply and water demand, and describes all hydrological and physical water management processes in a river basin.

13. The concept of conducting country water assessments as a means to plan for improved national water security was suggested in the ADB Water Operational Plan 2011-2020. Subsequently, the Asia Water Development Outlook 2013 made a first attempt to quantify national water security, using five key dimensions: (i) household water security, (ii) economic

water security, (iii) urban water security, (iv) environmental water security and (v) resilience to water related disasters. In 2013 and 2016, the National Water Security Index (NWSI) of Sri Lanka was Stage 2: Engaged.

14. At the core of the activity now proposed is a complementary "water accounting" procedure. Essential to the concept of the ADB country water assessments is the element of water demand forecasting, per economic sector (agriculture, industry, energy and municipal), vs. the surface water and groundwater resources for each (major) river basin.

15. This report follows an action plan submitted in October 2015 and reflects an approved proposal from IHE-Delft to assist ADB with water accounting.

16. The point of contact from ADB-SLRM is Senior Project Officer (Natural Resources and Environment) Dr. Palitha Bandara. The Principal Investigator from IHE-Delft is Dr. Wim Bastiaanssen. Dr. Claire Michailovsky, Water Accounting Expert of IHE-Delft, is responsible for the implementation of WA+ in the Mahaweli river basin.

3 Methodology

17. The Water Accounting Plus (WA+) framework is developed by IHE-Delft in partnership with the International Water Management Institute (IWMI), the Food and Agriculture Organization (FAO), and the World Water Assessment Program (WWAP). It is a multi-institutional effort that aims to provide a valuable and reliable source of information regarding presence and utilization of water resources. The WA+ framework communicates information on water storage, flows and fluxes for a variety of land use systems using a number of intuitive resource sheets that are designed to be understood by people with technical and non-technical backgrounds alike (see Figure 1 for an example of the current version of the WA+ Sheets).

18. The WA+ framework focuses on the use of public access remote sensing data in an effort to maintain a high level of transparency. Data products from the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) are provided free of charge for all users regardless of nationality and intended application. Datasets of topography, precipitation, evapotranspiration, soil moisture, net primary production, land use, water surface areas and water levels can be downloaded or determined from the raw satellite data.

19. The Water Accounting + reporting is based on sheets, tables and maps. Maps created from remote sensing, GIS and hydrological models form the basis of distributed computations on flows, fluxes and storage changes. This data is then compiled by Land Use - Land Cover (LULC) class. Class average values form the skeleton for presenting the results in tables. The results are also presented by means of tributaries and rivers; the monthly discharge at any point in the basin with a spatial resolution of 250 m can be computed.

20. Software has been developed to read data from various open access data sources and convert the input data into added value hydrological and water management information. All scripts are written in the Python language, a freeware which is highly suitable for the processing of spatial data sets. Supporting scripts are made for the conversion of the information into the standard WA+ fact sheets.

21. More background information can be found at www.wateraccounting.org. The software to perform computations and produce the accounting sheets is available free and open source on GitHub: https://github.com/wateraccounting.

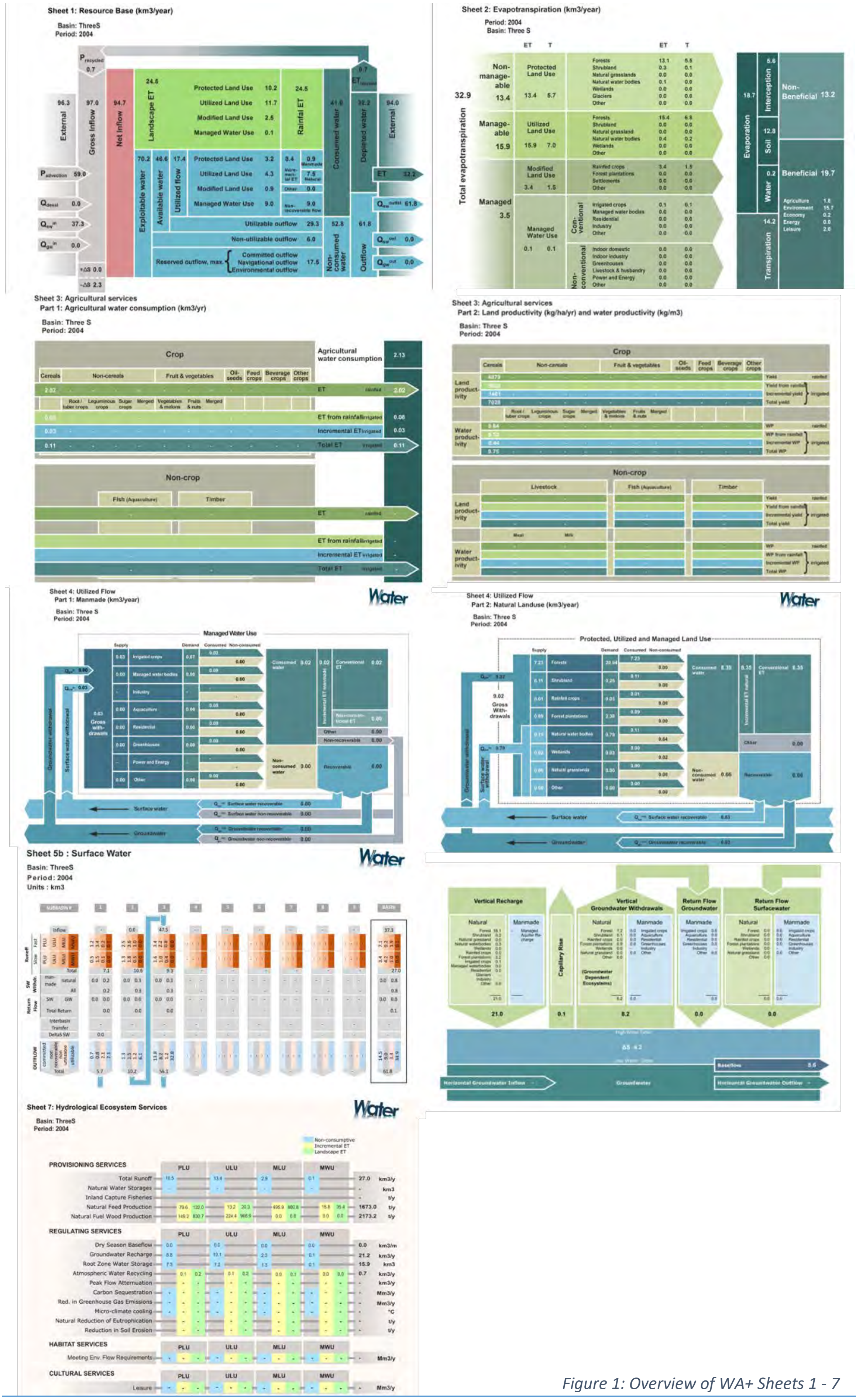

Figure 1: Overview of WA+ Sheets 1 - 7

4 Work Plan

4.1 Objectives

22. The main objective of this project is to support the Mahaweli Water Security Investment Program (MWSIP) with an independent assessment of water fluxes and consumption in the Mahaweli river basin.

23. The two main components of the project were defined as:

(a) Application of the WA+ procedure to estimate, on a monthly scale, available and exploitable water resources for the Mahaweli River Basin. Monthly and yearly accounts will be produced for three historical years covering wet (2011), dry (2008) and average (2006) conditions.

(b) Training and capacity building on the WA+ system, including but not limited to: basic hydrology, GIS, remote sensing data, WA concepts, interpretation of WA+ results. Certificates will be distributed to successful training participants.

24. Due to changes in the priorities of the recipient organization (Mahaweli River Basin Authority), trainings and capacity buildings could not be organized and only the inception meeting and workshop were carried out.

25. The WA+ project work in Sri Lanka started in August 2017 and will ended in July 2018.

4.2 Key Deliverables

- Standardized WA+ fact sheets 1-7, tables and maps uploaded on the www.wateraccounting.org open-access data repository, for the selected historical years in the period 2003-2012 (wet, dry and average year) with monthly time scales, and 250m resolution, for the Mahaweli basin.
- Water Security Diagnosis (i.e. interpretation of the produced fact sheets)
- Review of national and international experts
- Input into Country Water Assessment should it be undertaken in the future
- Input into Asian Water Development Outlook
- Inception and final report.

5 Preliminary data analysis

26. The WA+ procedure is strongly based on the use of Remote Sensing and open-access datasets. It is however important to validate (and possibly improve or correct) these data with locally obtained data to ensure reliable results. In the following section we present some of the in situ and remote sensing datasets which have already been obtained as well as some preliminary analysis.

5.1 Land Use Land Cover (LULC)

27. The land use land cover map is one of the key inputs for the WA+ procedure because it enables the split of water uses between different sectors as well as the computation of water and land yields per crop type. A detailed land cover map for the whole of Sri Lanka was shared by the Mahaweli Authority (Figure 2).

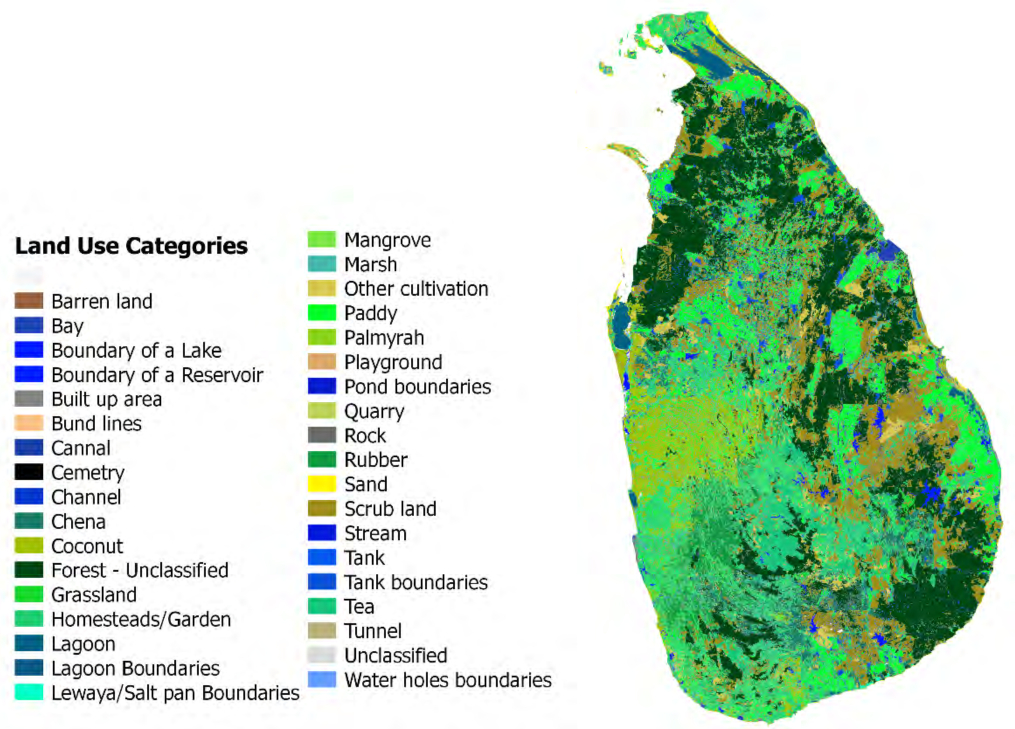

Figure 2: LULC map of Sri Lanka (shared by the Mahaweli Water Authority)

28. To produce the final Land Use Land Cover (LULC) map according to the standard Water Accounting + classification (80 possible classes), we combined the information from this map with other open access data, namely:

- the map of protected areas obtained from the World Database of Protected Areas (https://www.protectedplanet.net)
- irrigation map referring to the period 2000-2010, produced by the International Water Management Institute (http://waterdata.iwmi.org/applications/irri_area).

29. Figure 3 shows the final WA+ land use classification output obtained for the whole of Sri Lanka.

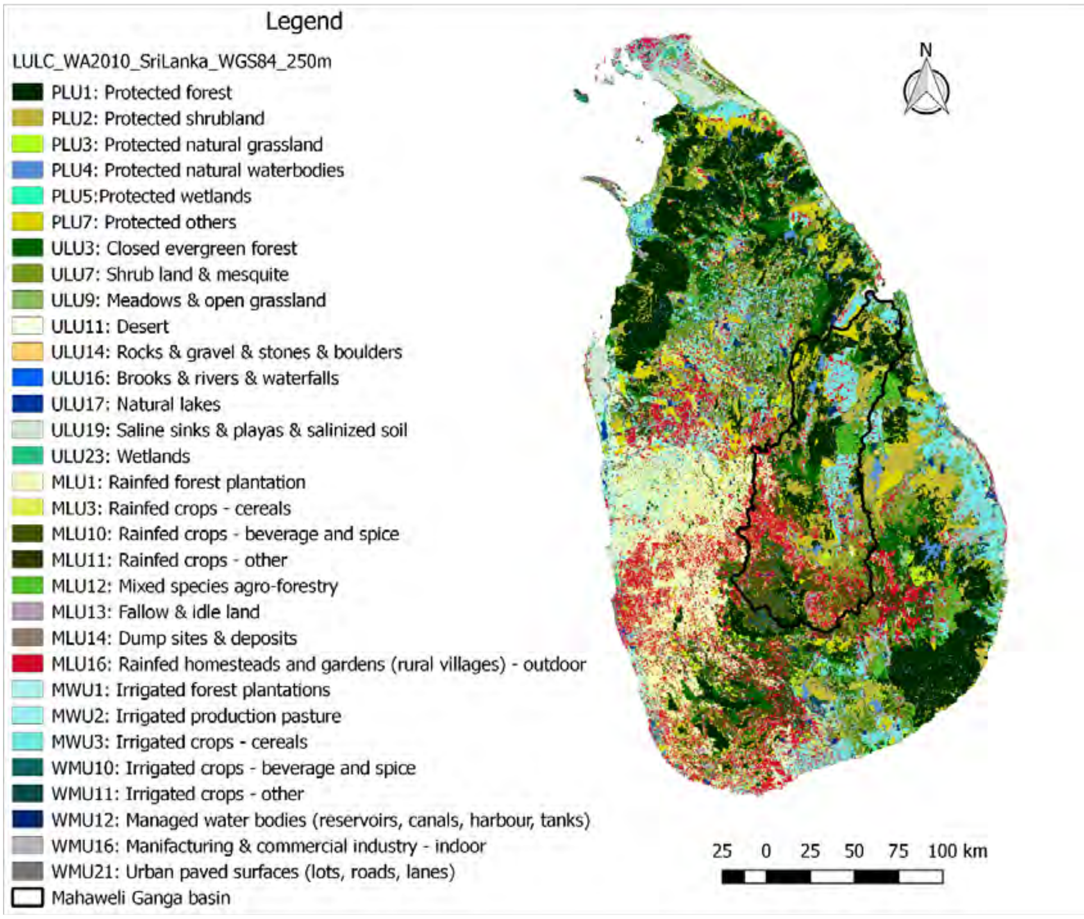

Figure 3: WA+ LULC classes present in Sri Lanka

30. The classes are grouped into 4 major management groups:

- Protected Land Use (PLU)
- Utilized Land Use (ULU): these are land uses which are still in their "natural" state but which are utilized. For example natural grasslands which are used for grazing.
- Modified Land Use (MLU): these are land uses which have been changed from their natural state, for example rainfed crops.
- Managed Water Use (MWU): these are land uses for which the water supply is directly managed, for example irrigated crops.

31. These distinctions are made as the water management options available will be different for each of these groups. The area covered by the major management groups is shown in Table 1.

Table 1: Area of the Mahaweli under the management types

	area km2	*area %*
PLU	3602.88	35.26
ULU	1804.02	17.65
MLU	3701.08	36.22
MWU	1110.24	10.87

5.2 Precipitation

32. Remote sensing precipitation data was collected for the Mahaweli River basin for the years 2003 to 2012 in order to perform a preliminary analysis and well the selection of the three historical years for final analysis. Precipitation data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is shown in Figure 4Figure 3. The years 2008, 2006 and 2011 were found to be driest, average and wettest conditions respectively.

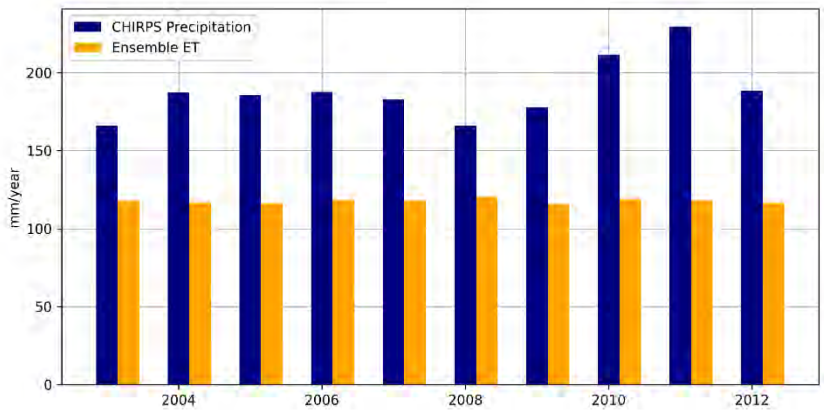

Figure 4: Yearly average precipitation from CHIRPS and ET from the Ensemble ET product for the Mahaweli river basin

33. However as higher quality data, in particular for soil moisture, in only available from mid-2008, it was decided to run the models for the years 2008-2012 and select the years 2009, 2012 and 2011 to represent dry, average and wet conditions in the basin.

34. Figure 5 shows the spatial variation across the basin as well as inter-annual variations in rainfall. Higher yearly precipitation is seen in the mountainous southern area (see topographic map in Figure 6) with values around 3000 mm/year, while in the northern dry zone yearly precipitation can be as low as 1200 mm/y in a dry year.

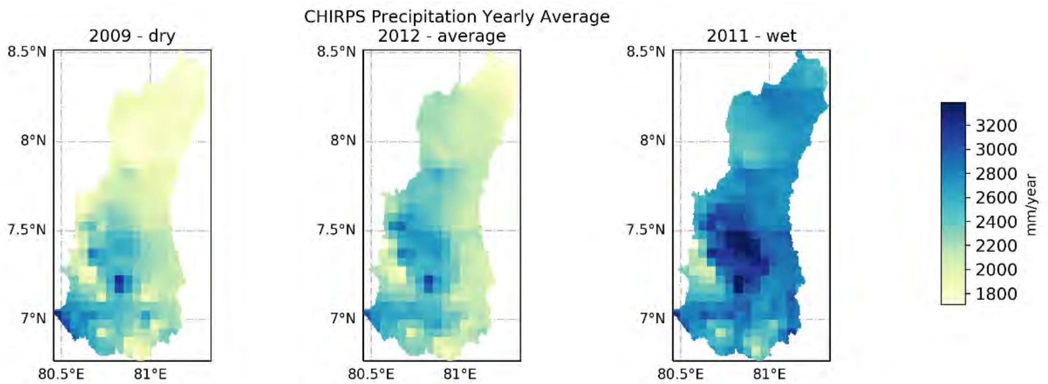

Figure 5: Precipitation from CHIRPS for a dry, average and wet year.

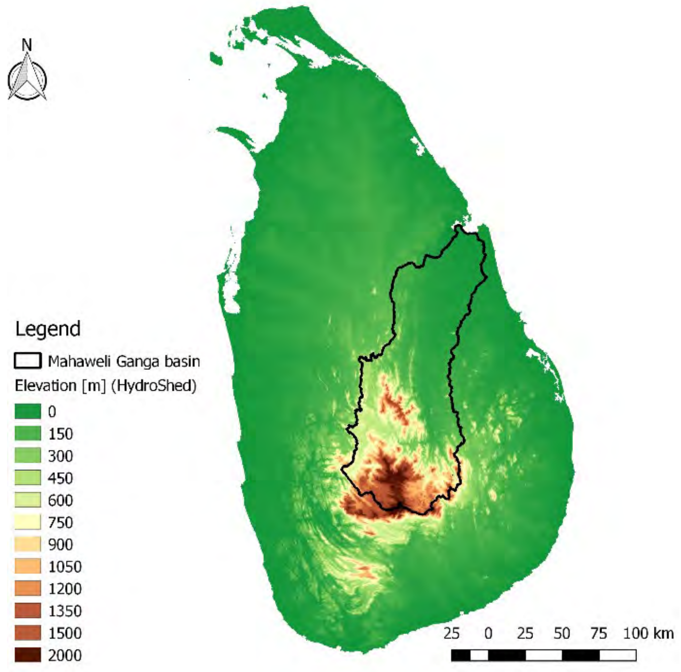

Figure 6: Topography of the Mahaweli River basin

35. In situ precipitation data obtained from the Mahaweli authority was compared to the CHIRPS data. The results can be seen in Figure 7. The overall match between in-situ and remote sensing precipitation was found to be satisfactory, and no corrections were applied to the CHIRPS dataset for use in the study.

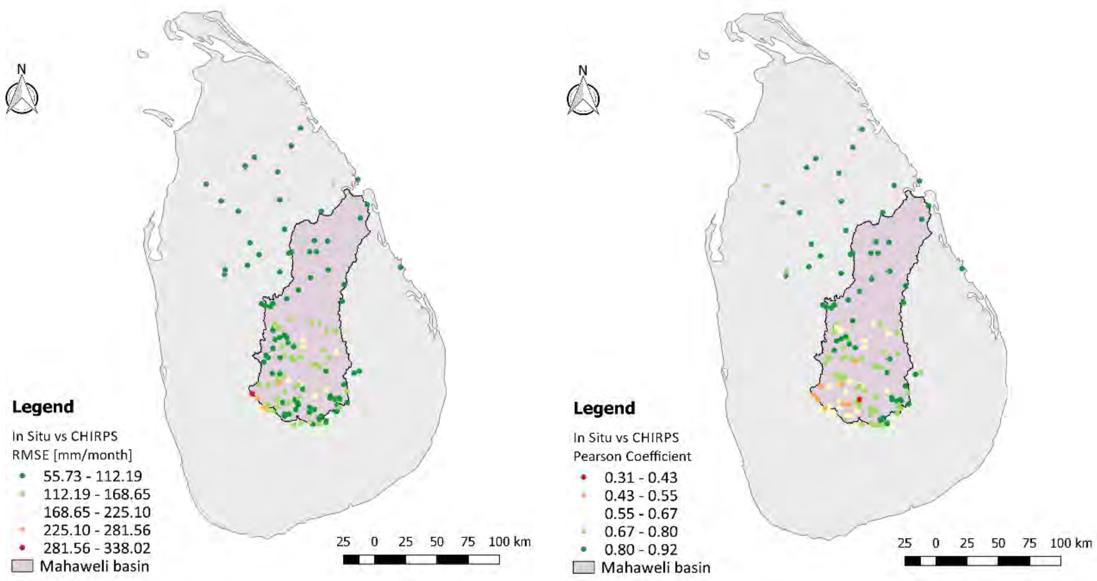

Figure 7: Location of in situ precipitation stations and comparison with CHIRPS data

5.3 Actual Evapotranspiration (ET) and Water Yield

36. Monthly maps of actual evapotranspiration at 250 m resolution were computed for the Mahaweli river basin for the period 2003-2012. This Actual ET dataset is the ensemble of seven global RS-based surface energy balance models (ETMonitor, GLEAM, CMRS-ET, SSEBop, ALEXI, SEBS, and MOD16) developed by IHE-Delft.

37. As an example in Figure 8, we show the yearly total Actual ET for the Mahaweli basin for a dry, average and wet year. Year to year variations in ET are not very pronounced with the average yearly values being around 1400 mm/year.

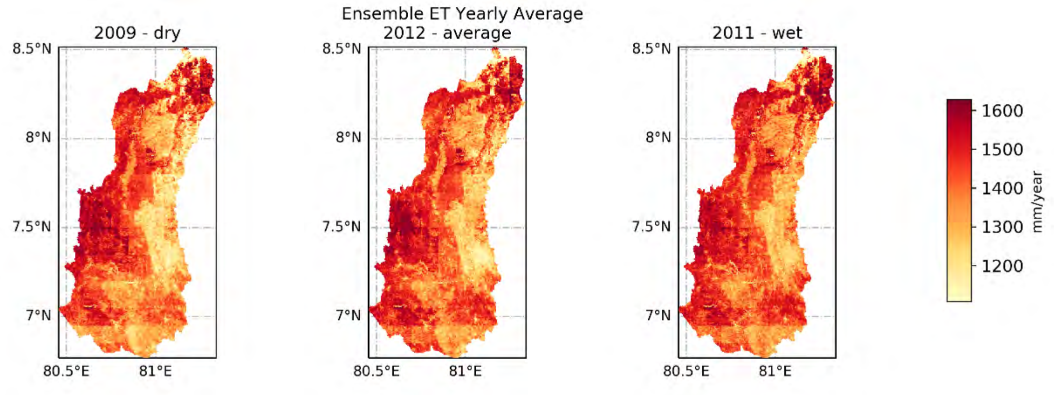

Figure 8: Ensemble ET for a dry, average and wet year

38. Water yield, which is defined as precipitation minus evaporation, can give a quick measure of water availability in a basin. Figure 9b shows that on a yearly basis water yield in the Mahaweli is positive. However, due to strong seasonal variations in rainfall, water yield is negative during the dry months (Figure 9a). The northern zone also shows negative water yields on longer timescales (Figure 9c).

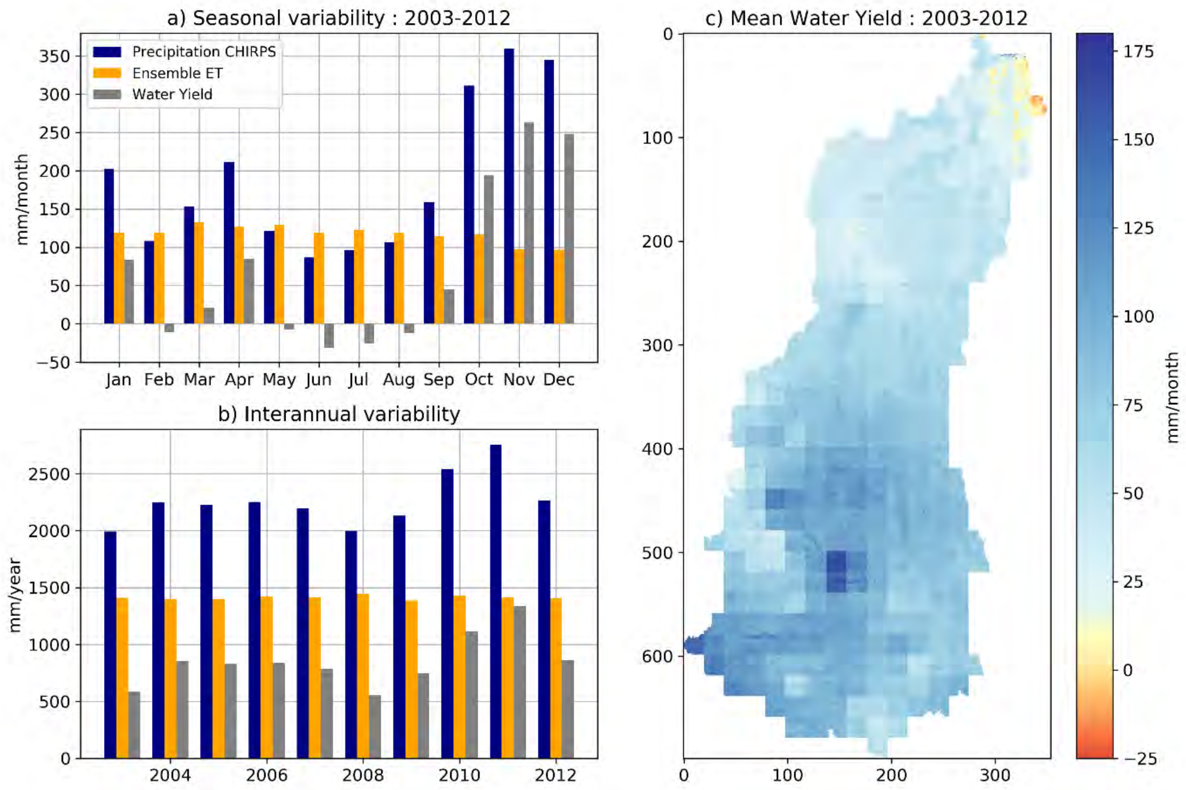

Figure 9: Temporal and spatial variability of precipitation and Evapotranspiration in the Mahaweli River Basin

39. Figure 10 shows the water yield for the three selected years. Areas with positive water yields receive more precipitation than is lost to ET while the reverse is true for negative water yields. In these areas some of the evaporated water does not originate from local precipitation, this behavior is typical of irrigated crops and downstream parts of catchments where floods occur.

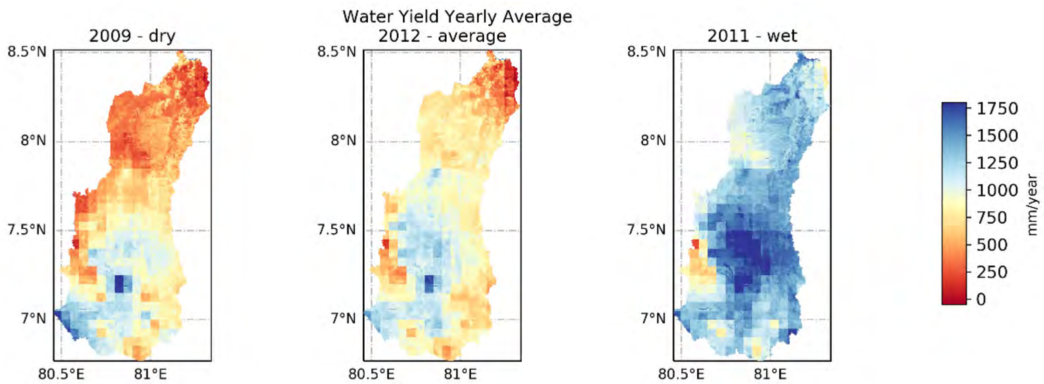

Figure 10: Yearly water yield for dry, average and wet conditions

5.4 Other In-Situ Data: Surface Water

40. The MWSIP program aims to divert untapped water from the Mahaweli and detailed information regarding the current state of surface waters is therefore paramount.

41. Data pertaining to surface waters was obtained from the Mahaweli Authority for 10 discharge stations within the basin boundaries, as well data for 8 reservoirs and tanks including water levels and in some cases in and outflows. The location of the in-situ monitoring stations for rivers and reservoirs is shown in Figure 11.

42. The WA+ framework estimates runoff using a remote sensing based water balance approach. This runoff is then routed to generate discharge every 250m along the course of the river. This model is however not calibrated and the in-situ discharge datasets will be used to validate model outputs.

43. In situ data for reservoir in and outflows will be used in the routing model as input data.

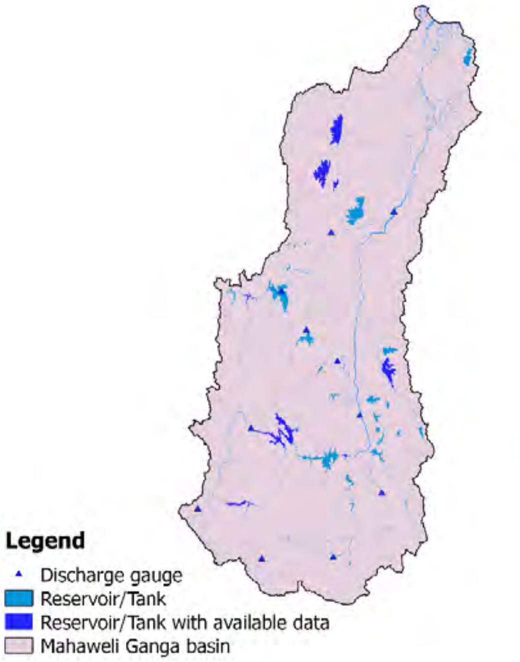

Figure 11: Surface water network and monitoring stations.

6 Summary of the Water Accounts

6.1 Basin scale water availability

44. Water availability in the Mahaweli river basin is highly spatially and temporally variable. The relative magnitudes of the inflows and outflows of the basin are presented in Figure 12.

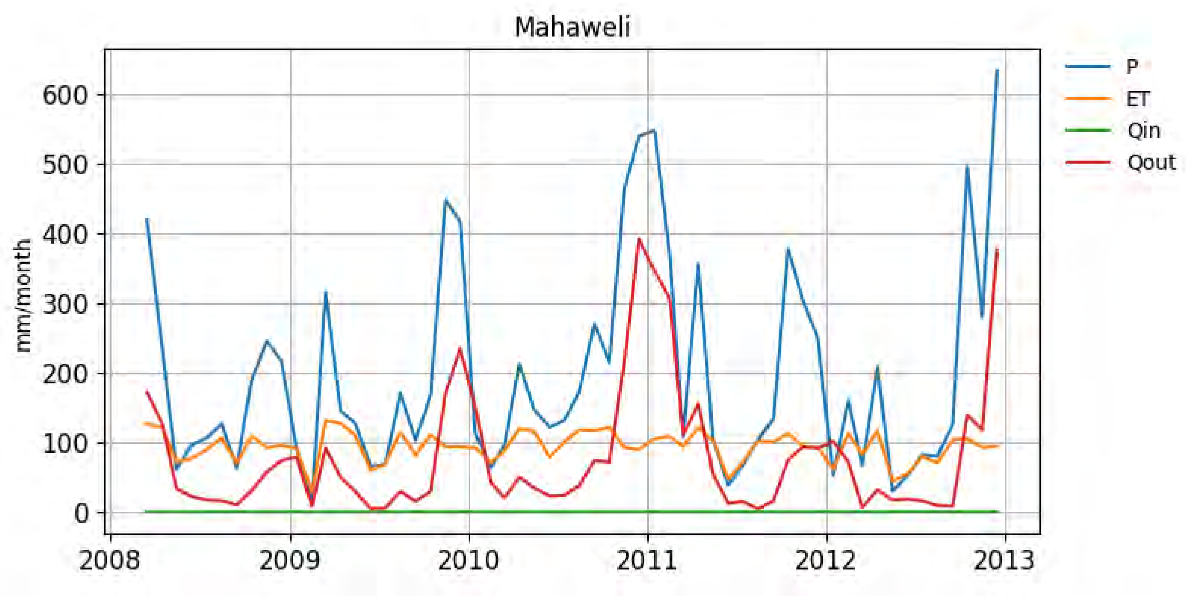

Figure 12: Inflows and Outflows

45. While on a basin and yearly scale water yield remains positive, it is negative in the months of February and May to August (Figure 9). Water yields are also much lower in the northern dry-zone than in the mountainous southern area (Figure 10).

46. Negative water yields can occur naturally, as water in natural storages evaporates during dryer months, but can also point to a reliance on ground and surface water storages during dry months for irrigation purposes.

47. On a yearly basis, the precipitation in the driest year was found to be 23% lower than that in the wettest year, while evapotranspiration only decreased by 2% (Table 2). ET represented 65% of precipitation for the driest year and only 51% for the wettest year.

Table 2: Summary of inflows and outflows

	Precipitation	ET	Delta S	Qin	Qout	Qin	Qout
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*m3/s*	*m3/s*
2009	2130	1384	-29	0	716	0	232.02
2012	2260	1400	-20	0	839	0	271.17
2011	2754	1414	-104	0	1236	0	400.66

48. Our analysis showed a small increase in water storage (positive Delta S in Table 2). The magnitude of these changes is between .9 and 3.8% of the precipitation and are therefore within the expected error of the input data and no major conclusions can be drawn based on the absolute values of the changes in storage. Our study showed no storage trend over the modelled years (2008-2012). The storage change derived from the Gravity Recovery and Climate Experiment (GRACE) showed a slight decreasing trend as shown in Figure 13.

49. In practical terms this means there might be a slight over drafting of water resources in the basin which while not yet critical should be monitored.

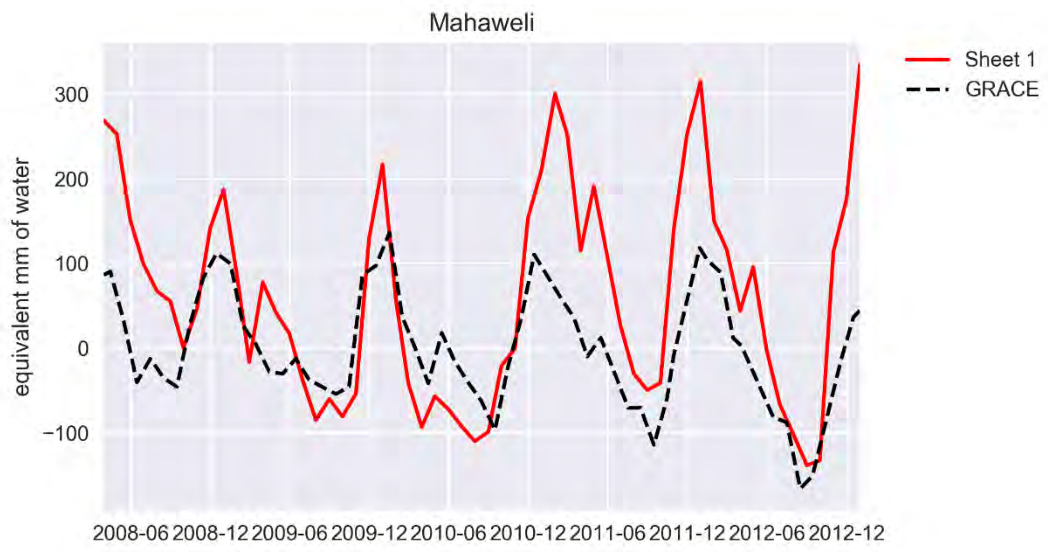

Figure 13: Modeled vs. GRACE basin storage variations

6.2 Water Consumption (ET) & Agricultural Production

50. Relative to precipitation, evapotranspiration (ET) has a lower inter-annual variability. The amount of water consumed through ET varies between 51 % of precipitation for the wettest year and 65 % of precipitation for the driest year analyzed.

51. While ET is higher for the wet year (2011), the portion of ET going to transpiration (T) and therefore directly linked to plant growth decreases for the wettest year (Table 3). This is typical of humid conditions.

52. The drop in transpiration and relative increase of evaporation (E) and interception (I) explains the drop in percentage of beneficial ET from above 66% for the average and dry years to 63% for the wet year (Table 3). This is because all transpiration is considered a beneficial water consumption as it represents a use directly contributing to pant growth and therefore the agricultural and economic sectors. Many other types of evaporative consumption (for example evaporation from the soil) are considered non-beneficial

Table 3: Summary of Sheet 2

	ET	E	T	I	Beneficial		Non Beneficial	
YEAR	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*% of ET*	*mm/yr*	*% of ET*
2009	1384	258	860	265	919	66	464	33
2012	1400	239	886	274	939	67	460	32
2011	1413	281	825	306	894	63	519	36

53. Crop water consumption is the water consumed through ET over cropped areas during the growing season. The average values for irrigated and rainfed areas are summarized in Table 4.

Table 4: Crop water consumption

	Crop Water Consumption	
	Rainfed	**Irrigated**
YEAR	*km3/yr*	*km3/yr*
2009	0.24	0.51
2012	0.25	0.48
2011	0.24	0.62

54. A useful measure of cropped areas is the land productivity expressed in kg/ha/year. Rice is the major crop grown in the Mahaweli. Our study found average land productivities between 3257 and 4438 kg/ha/year for irrigated rice (Table 5).

55. It should be noted that this study was carried out using a single land use map and therefore any changes over time in cropped or irrigated areas are not reflected in the results presented here.

56. Water productivity for irrigated rice was found to be between .62 kg/m^3 and .64 kg/m^3 for irrigated rice (Table 5). These values are below the global average of 1.1 kg/m^3 for paddy rice.

Table 5: Land and Water Productivity

			Land Productivity		Water Productivity	
			Rainfed	**Irrigated**	**Rainfed**	**Irrigated**
YEAR	**Crop Type**	**Crop Subclass**	*kg/ha/year*	*kg/ha/year*	*kg/m3*	*kg/m3*
2009	Rice	-		3654		0.64
	Rubber	-	954		0.06	
	Beverage crops	-	5025	5025	0.37	0.37
	Fruit & vegetables	Fruits & nuts	3454	3454	0.29	0.29
2012	Rice	-		3257		0.64
	Rubber	-	999		0.07	
	Beverage crops	-	5186	5186	0.37	0.37
	Fruit & vegetables	Fruits & nuts	3307	3307	0.26	0.26
2011	Rice	-		4438		0.62
	Rubber	-	899		0.06	
	Beverage crops	-	4664	4664	0.33	0.33
	Fruit & vegetables	Fruits & nuts	3100	3100	0.25	0.25

6.3 Water Supply

57. The total withdrawals in the basin were estimated using the WaterPix model. The model estimates additional supply based on the concept of green and blue ET: green ET is the evapotranspiration which can be explained by rainfall alone and can be computed using an empirical equation. If total measured ET is found to be higher than this value, we can assume that an additional source of water had to be added to generate the ET amounts measured, and from this calculate supply.

58. Withdrawals were found to vary by 30% over the years analyzed (see Table 6). The majority of the manmade withdrawals are used for irrigation purposes with these accounting for between 82 and 84% of gross withdrawals.

59. In Table 6, "other" consumed water refers to water not consumed through ET blue but nonetheless made unavailable to downstream users due to for example pollution.

Table 6: Basin wide withdrawals

	Manmade					Natural		
	Gross Withdr.	**Consumed**			**Non Cons.**	**Gross Withdr.**	**Consumed**	**Non Cons.**
		ETb	**ETb/Supply**	**Other**			**ETb**	
YEAR	*mm/yr*	*mm/yr*	*%*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*	*mm/yr*
2009	1168	286	24	156	724	287	275	11
2012	1734	362	20	246	1124	401	390	11
2011	1347	257	19	193	895	289	269	19

60. The fraction of the manmade supply consumed in the evaporative process varies between 19% for the wettest year and 24% for the driest year (Table 6). Note that blue ET (ETb in Table 6) is only the portion of total evapotranspiration that can be attributed to water supply, whether it be from manmade (f.ex. irrigation) or natural extractions (f.ex. groundwater used by deep rooting trees).

61. The low value of supply consumption through ET suggests that there is potential for reduction in amount of irrigation water without reduction in crop growth.

62. It should however be noted that the excess non-consumed water due to this low consumption can also be beneficial to the basin in particular through increased infiltration amounts contributing to both the recharge of groundwater and an increase in baseflow.

6.4 Surface Water & Discharge

63. The amount of runoff generated was estimated using the WaterPix model. The spatial distribution of natural runoff generation is shown in Figure 15, while Figure 15 shows the total runoff, including return flows from agricultural areas to surface water.

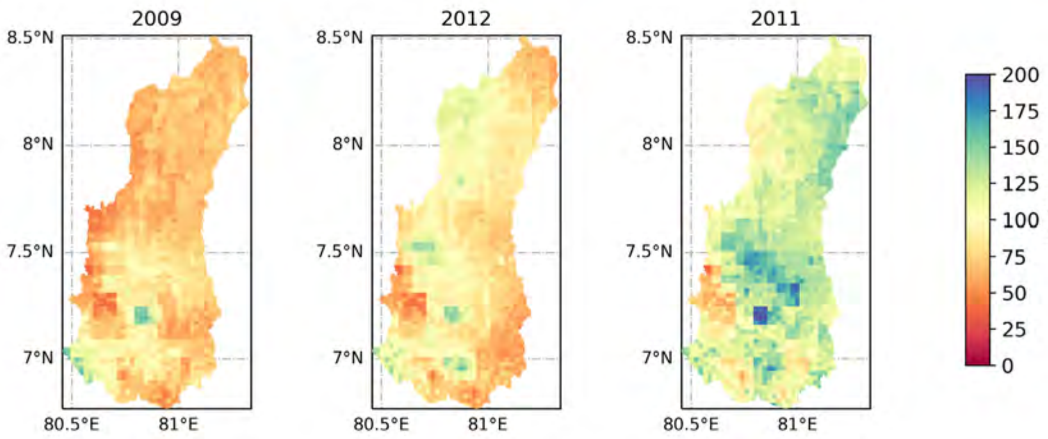

Figure 14: Average natural runoff

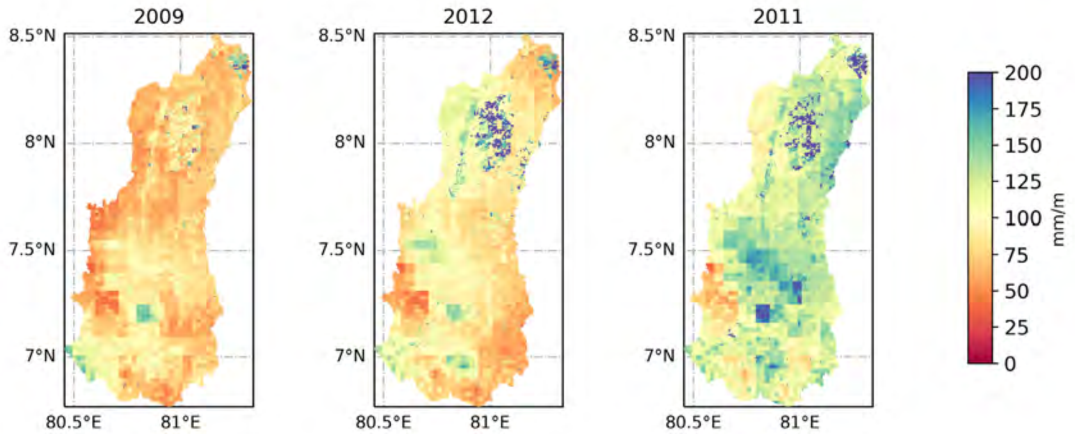

Figure 15: Average total runoff (including return flows)

64. For the accounting sheets reporting on surface water, the basin was split into 8 sub-basins as shown in Figure 16.

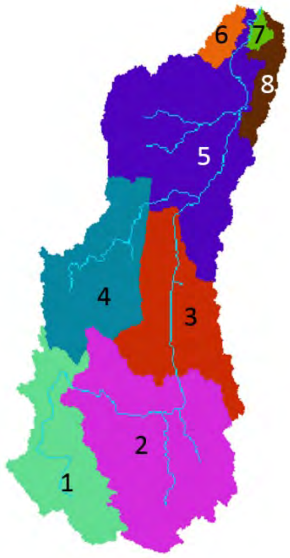

Figure 16: Subbasins and main drainage network

65. Table 7 shows the amount of runoff generated in each of the 8 subbasins.

Table 7: Naturl runoff generated in the 8 subbasins

		Total Natural Surface Runoff [km3/yr]							
		Subbasins							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
YEAR	**2009**	1.41	2.57	1.36	1.23	2.33	0.15	0.09	0.31
	2012	1.39	2.69	1.48	1.76	3.45	0.17	0.1	0.33
	2011	1.64	4.02	2.38	2.19	4.17	0.25	0.14	0.54

87. Discharge was estimated by routing the runoff using the SurfWat tool. The SurfWat tool also operates the removal of supply from surface water from the accumulated flows.

88. The reservoir simulation module of the tool is still under development, and their operation was not fully included in the study. This can explain that while there is general agreement in order of magnitude and timing of discharge (Figure 17), the high flows simulated in SurfWat for the most downstream station (Manampitiya) is those observed.

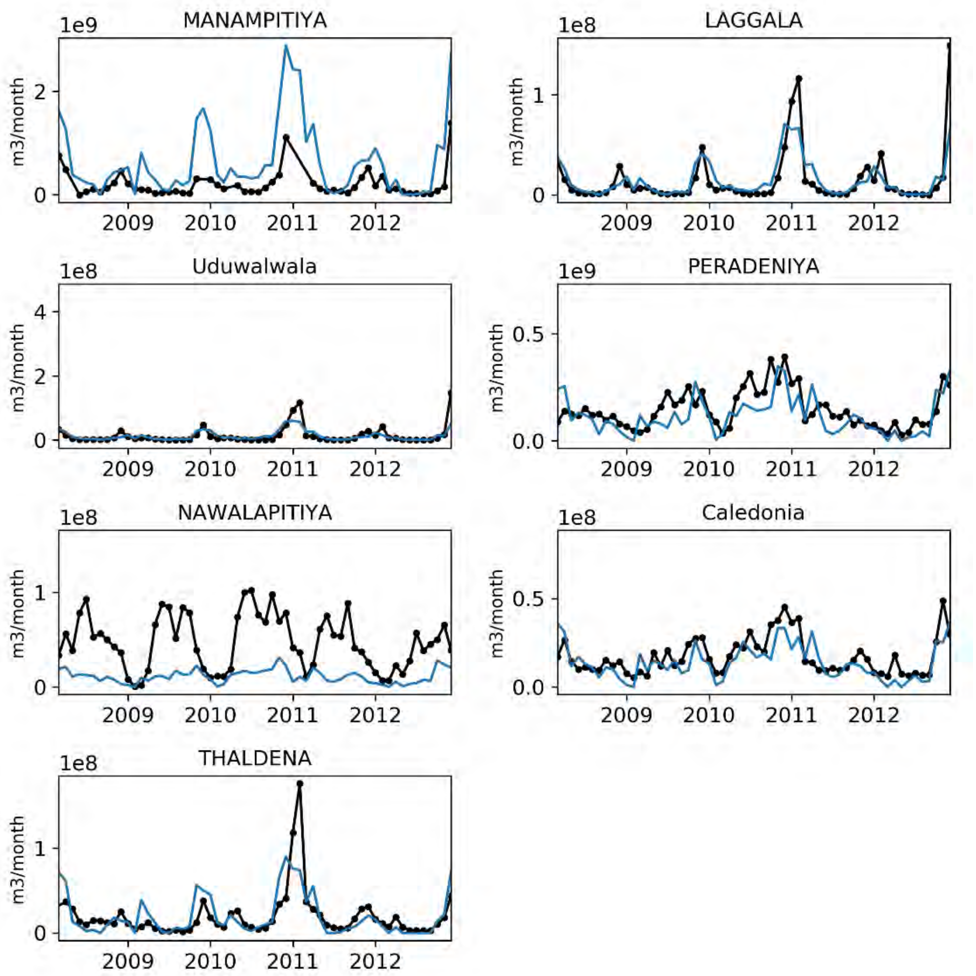

Figure 17: Estimated (blue) and in-situ (black) discharge

89. Figure 18 shows that each year, utilizable outflow in the basin falls to 0 during the dry season.

90. This indicates that any further water resource exploitation in the basin will need to rely on storages, surface or groundwater to avoid tapping into the committed flows. These committed flows are estimated environmental water requirements.

91. Considering the magnitude of utilizable outflows during the wet season, there is still potential for further development using surface water. Whether it be through storages to help spread out available water throughout the year or for interbasin transfers.

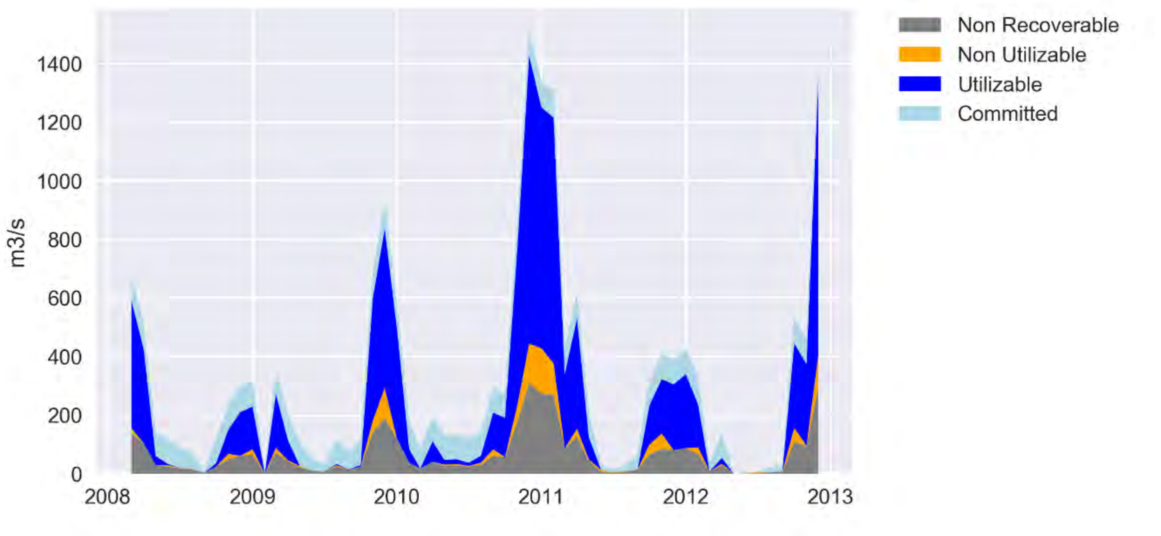

Figure 18: Utilizable and other outflows

7 Summary conclusions

7.1 Current conditions

- On a basin and yearly scale, the Mahaweli was found to have sufficient water resources under current conditions.
    - A small trend in decreasing of storages was observed in the GRACE data
- Seasonal water availability is very variable. This has the following consequences:
    - Reliance on storages in the dry season
    - No utilizable flow left-over in dry season
    - High utilizable outflow during the wet season
- High inter-annual variability in water availability
- Water productivities were found to be low
- Field application efficiencies are low

7.2 Perspectives & recommendations

- High utilizable outflows in the wet season can be stored for use in the dry season through carefully planned surface water storages
- Water storages may also be needed to mitigate annual-scale rainfall variations
- The MWSIP program aims to transfer water from the Mahaweli for development in the dry zone. High utilizable outflows in the wet season could be used for this purpose.
- With further model development, in particular the representation of current surface water storages, the analysis could be help better estimate any future shortages in bulk water supply to improve planning of future storages
- Low water productivities indicate potential for increased production without additional water supply
- Field application efficiencies are low
    - Irrigations amounts could be reduced further during times of high rainfall
    - On-farm water conservation techniques should be used

7.3 Study limitations:

- Current surface impoundments were not modeled in this study
- A single land use map was used for each basin, any land use changes (including extension of irrigated areas) over time are therefore not represented.