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Working Paper

Adaptation to Climate Variability in Sri Lanka: A Case Study of the Huruluwewa Irrigation System in the Dry Zone

Upali A. Amarasinghe, Giriraj Amarnath, Niranga Alahacoon, Mohamed Aheeyar,
Kiran Chandrasekharan, Surajit Ghosh and Toru Nakada

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Amarasinghe, U. A.; Amarnath, G.; Alahacoon, N.; Aheeyar, M.; Chandrasekharan, K.; Ghosh, S.; Nakada, T. 2021. *Adaptation to climate variability in Sri Lanka: a case study of the Huruluwewa Irrigation System in the Dry Zone*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 30p. (IWMI Working Paper 200). doi: https://doi.org/10.5337/2021.229

/ climate variability / climate change adaptation / irrigation systems / arid zones / tank irrigation / irrigation canals / irrigation management / land use / cropping patterns / water supply / water depletion / crop production / water use efficiency / irrigation efficiency / water productivity / water availability / drought / rainfall patterns / risk / resilience / water scarcity / water management / reservoirs / water spreading / catchment areas / water storage / groundwater recharge / water accounting / water policies / seasonal cropping / diversification / crop water use / consumptive use / farmers / farm income / remote sensing / geographical information systems / case studies / Sri Lanka /

ISSN 2012-5763
e-ISSN 2478-1134
ISBN 978-92-9090-931-6

Please send inquiries and comments to IWMI-Publications@cgiar.org

A free copy of this publication can be downloaded at:
https://www.iwmi.org/publications/iwmi-working-papers/

Acknowledgments

The authors are grateful for the assistance provided by the departments of Irrigation, Agriculture and Agrarian Services in Sri Lanka; the Chief Engineer and officers of the Huruluwewa Irrigation Management Division Office in Anuradhapura, Sri Lanka; and the Irrigation and Agrarian Services Department offices in Galenbindunuwewa and Anuradhapura, Sri Lanka. The feedback and comments provided by Dr. Herath Manthrithilake (Emeritus Scientist, IWMI) helped to improve the content of this paper. The authors gratefully acknowledge the funding provided by the Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan, and the CGIAR Research Program on Water, Land and Ecosystems (WLE).

Project

This research study was initiated as part of the project titled *Drought Monitoring and Forecasting to Enhance Agriculture Resilience and Improve Food Security in South Asia*.

Donors

MAFF
Ministry of Agriculture, Forestry and Fisheries
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RESEARCH PROGRAM ON Water, Land and Ecosystems
CGIAR

This research was carried out as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE) and supported by Funders contributing to the CGIAR Trust Fund (https://www.cgiar.org/funders/).

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Acronyms and Abbreviations

CCA	Canal Command Area
CF	Consumptive Fraction
CV	Coefficient of Variation
CWU	Consumptive Water Use
DC	Distributary Canal
DEM	Digital Elevation Model
DS	Divisional Secretariat
ERF	Effective Rainfall
EWP	Economic Water Productivity
FO	Farmer Organization
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEE	Google Earth Engine
GIS	Geographic Information System
HWT	Huruluwewa Tank
IMD	Irrigation Management Division
IRCWU	Irrigation Consumptive Water Use
IWMI	International Water Management Institute
NAP	National Adaptation Plan
NDVI	Normalized Difference Vegetation Index
NPC	Non-paddy Crop
ODK	Open Data Kit
PMC	Project Management Committee
PWP	Physical Water Productivity
RFCWU	Rainfall Consumptive Water Use
RPM	Resident Project Manager
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SCOR	Shared Control of Resources
SCS	Soil Conservation Service
TCWU	Total Consumptive Water Use
TWS	Total Water Supply
USAID	United States Agency for International Development
USD	United States Dollar
USDA	United States Department of Agriculture
WIZ	Water Influence Zone
WUE	Water-use Efficiency

Summary

This paper assesses how the Huruluwewa tank (HWT) irrigation system in the North Central Province of Sri Lanka adapts to climate variability. Irrigation systems contribute to more than 90% of the staple food production in Sri Lanka. It is a country that bears one of the highest climate risks in the world. Further, in the North Central Province, recurrent droughts are the bane of agriculture. In the HWT, the fifteenth largest canal irrigation system in the country, adaptation to climate variability happens on two fronts: changes made by the irrigation management to the water release regime; and changes in the cropping patterns practiced by farmers in the command area. Such adaptation measures ensure that the available water supply in the reservoir is adequate for 100% cropping intensity in each of the two cropping seasons, which, when combined with diversification of cropping patterns, enhances economic water productivity in terms of value per unit of consumptive water use. Such cropping patterns also increase farmers' incomes and resilience in low rainfall years. With proper conjunctive water management practices, the available tank storage can lead to high water-use efficiency and provide considerable socioeconomic benefits in the command area. The adaptation patterns implemented in HWT demonstrate how water-scarce irrigation systems in Sri Lanka can achieve higher economic water productivity, i.e., generate 'more income per drop'.

Adaptation to Climate Variability in Sri Lanka: A Case Study of the Huruluwewa Irrigation System in the Dry Zone

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Introduction

As early as 437–367 BC, the ancient kings of Sri Lanka built village tanks to meet the irrigation, household and livestock water needs of local communities (Brohier 1934, 1937). These tanks also met environmental water needs and contributed to the mitigation of impacts during floods and agricultural droughts (Dharmasena 2020). However, water shortages continue to affect Sri Lanka's Dry Zone, which is spread over the Northern, North Central and Eastern provinces of the country. There is growing concern over the impact of climate change and variability and extreme weather events on food production and food and livelihood security in Sri Lanka, particularly in the Dry Zone. While there is sufficient focus on the links between climate change and food security and impacts on crop production, little attention has been given to key dimensions of agricultural resilience, namely, crop diversification and improving irrigation water-use efficiency (WUE).

Moreover, today's population of 22 million is four times of what it was in the 1930s (GoSL 2020a). Also, intra- and inter-annual weather variability and exposure to floods and droughts have increased substantially (Abeysingha and Rajapaksha 2020). In general, the risk of hazards has increased manifold. According to Eckstein et al. (2019), Sri Lanka carried the second highest climate risk globally in 2017—with losses per unit of gross domestic product (GDP) at 1.24%, which is high among the most affected countries.

Floods are the most common natural hazard in Sri Lanka, followed by storms, droughts, landslides, etc. Since 2000, floods and droughts have accounted for 64% of the total incidence of natural hazards (Guha-Sapir et al. 2021), with economic losses due to floods estimated at over USD 2,234 million. Droughts, which mainly affect agriculture in the Dry Zone, have contributed to losses of over USD 45 million since 2000, with the agricultural droughts experienced in 2016 alone contributing over USD 25 million. The consensus is that the occurrence of extreme weather events has increased in recent years (Imbulana et al. 2010; Premalal and Punyawardena 2013). So, the need for accelerated adaptation to extreme weather events is higher than ever before (GoSL 2016).

Precipitation is the primary source for tank storage in Sri Lanka. It supports irrigated and rainfed farming systems in most parts of the country. It is these farming systems that are facing the brunt of the impact of meteorological and agricultural drought-driven water scarcities. Therefore, adaptation to water scarcities brought about by climate change is an urgent need in these areas (Williams and Carrico 2017). Some of the key policy and development interventions made in recent years have focused on climate adaptation of irrigated agriculture. They include the National Adaptation Plan (NAP), the Green Climate Fund (GCF) projects, the World Bank's Climate Resilience Improvement Project and the Climate Smart Irrigated Agriculture Project (World Bank 2018). These projects highlight the importance of climate adaptation to build resilience in tank-based and rainfed cultivation systems, and promote climate-smart agriculture to enhance the resilience of tank-based irrigation systems (GoSL 2016; GCF 2016, 2020; World Bank 2018). So far, climate adaptation investments in small tanks alone have exceeded hundreds of millions of dollars.

With a focus on the Huruluwewa tank (HWT) in the North Central Province of Sri Lanka, this paper assesses the country's experience of implementing adaptation in the face of increasing climate variability. It also investigates potential future opportunities for enhancing resilience in the HWT irrigation system.

Huruluwewa was one of the 16 tanks built by King Mahasena in the Dry Zone in the 1st century AD to provide an assured supply of water to paddy and other crops. These tanks were constructed in cascades to ensure that spillover from one tank flowed into the next, thus minimizing wastage. To this day, the tank system ranks among the finest works of its kind in the world (Jeya Raj 2014), and speaks of the skill of engineers in ancient Sri Lanka.

In the present context, it would be more apt to describe the Huruluwewa tank as a reservoir. Restoration work has been done on the tank in modern times, first in 1949 and again in 1958 (Arumugam 1969). Under the Mahaweli Development Project, the tank was augmented by constructing a feeder canal. However, as per local observations, not much water reaches the tank through the feeder canal because of pumping by farmers upstream. The HWT irrigation scheme is currently classified as a major irrigation system—defined as one with a command area exceeding 1,000 ha (ID 2021). It is the fifteenth largest among 107 major irrigation systems in Sri Lanka. It supplies water to a canal command area (CCA) of 4,445 ha. Additionally, there are about 340 medium irrigation systems with command areas between 80 ha and 1,000 ha. Further, there are thousands of small tanks, mainly spread over the Dry Zone, with command areas less than 80 ha. The major and medium irrigation systems provide much-needed food, and hence nutritional security, to populations living in the area served by them. Together, they contribute more than 90% of the total paddy production in a country where the staple food is rice (GoSL 2020b). Given the current context of climate change, crop diversification is a potential adaptation strategy (Hirji et al. 2017; Amarasinghe et al. 2021a) in Sri Lanka. Field observations on the land- and water-use patterns prevailing in the HWT irrigation system show that this is already happening. For instance, surface water releases depend on the type of crops cultivated, water rotation intervals, etc., which are decided at the Kanna meetings (seasonal planning meetings). The Irrigation Department is now promoting crops other than paddy (which use both surface water and groundwater for irrigation) in Huruluwewa. In addition, there are many schemes, such as Udawalawe, that mainly focus on promoting non-paddy crop (NPC) cultivation. The main aim of HWT water managers is to diversify to NPCs in the *yala* season (from April to September).

Most of the groundwater in Huruluwewa accrues through the deep percolation of return flows of surface irrigation. Therefore, the lessons learned from HWT on mitigation and adaptation to weather variability would be useful for similar activities in the other major and minor tank-based irrigation systems, which are likely to bear the brunt of climate change impacts in the future (Eriyagama and Smakhtin 2010).

Our analysis used the water influence zone (WIZ) approach to assess canal irrigation performance (Amarasinghe et al. 2021a). The WIZ includes the irrigation system's command area, a buffer zone outside the command, and any area irrigated with lift irrigation from the reservoir. Performance assessment focuses on changes in the water-use pattern, irrigation WUE, and productivity. WUE is the ratio of total crop consumptive water use (CWU) to water supply. Productivity has physical (kg/m^3) and economic (USD/m^3) dimensions.

Performance analysis with the WIZ approach, introduced originally in the Sina irrigation system in Maharashtra, India, captures the benefits of reusing return flows of canal irrigation both inside and outside the command area (Amarasinghe et al. 2021a, 2021b). We selected the Sina irrigation system to compare the performance of Huruluwewa because the analysis of Sina had taken into account the indirect benefits occurring outside the command area as well. In fact, many irrigation system performance assessments, even those based on satellite data, ignore indirect benefits (Bandara 2003) and restrict their geographical focus to just the command area. However, there is evidence that canal irrigation systems generate substantial benefits outside the command area too (Bhatia et al. 2007).

The Sina analysis used satellite data, Google Maps and Open Data Kits (ODKs) to generate an accurate picture of land-use, cropping and water-use patterns. By analyzing data using disruptive technologies, the Sina study revealed a completely different view of irrigation performance than what was suggested by the official figures (Amarasinghe et al. 2021a). We used a similar analytical approach to measure the performance of the Huruluwewa Irrigation System. This paper assesses how the HWT's performance relates to climate adaptation and mitigation benefits and agricultural and water productivity. The findings of our analysis will be useful for the numerous climate adaptation programs now being implemented, spending hundreds of millions of dollars.

Our water accounting and productivity analysis identifies the constraints to, and opportunities for, enhancing resilience. The main focus is on economic water productivity (value or profit per cubic meter of water use), which can be a tool for water-scarce irrigation systems to plan future adaptation activities. We begin this analysis with a brief synopsis of the Huruluwewa Irrigation System, followed by an outline of the methodology of our analytical approach. The section *Results* presents the changes observed in water supply and water-use patterns, cropping and production patterns, and productivity levels. In the section *Comparison with the Sina Irrigation System*, we highlight the opportunities available to enhance Huruluwewa's resilience in the future. We conclude the paper with some policy recommendations for the Huruluwewa Irrigation System in particular, and for major canal irrigation systems in Sri Lanka in general.

Synopsis of Huruluwewa Irrigation System

Sri Lanka has nine provinces, 25 districts and 325 administrative divisions under Divisional Secretariats (DS). The Huruluwewa tank (HWT) is located in the jurisdiction of the Galenbindunuwewa Divisional Secretariat in Anuradhapura district (Figure 1). Climatically, it falls in the Dry Zone, which is spread over the Northern, North Central and Eastern provinces and accounts for 52% of the country's land area. The other two climatic zones in Sri Lanka are the Intermediate and Wet zones. The Wet Zone is spread over the southwestern and central provinces, and accounts for 25% of the country's land area. The average annual rainfall in the Wet, Intermediate and Dry zones is > 2,500 mm, 1,750-2,500 mm and < 1,750 mm, respectively.

The HWT lies in the Yan Oya River Basin, the sixth largest among the 103 river basins in the country. The average annual runoff of all the basins adds up to about 50 billion cubic meters (Bm^3). However, many of the smaller river basins are closed or are approaching closure, meaning that where there used to be flows to the sea earlier, there are virtually none for several months of the year now (Seckler 1996; Molle 2008). The Yan Oya Basin has an average annual surface runoff of 0.34 Bm^3. However, it too is a closing basin: Flows during the *yala* season (April-September) are only 10% of the annual runoff (Amarasinghe et al. 1999). This is partly due to high intra-annual rainfall variation and high depletion of water for agriculture. Yan Oya may already be a closed basin, even in good rainfall years, if water depletion accounts for the basin's environmental water requirement (Smakhtin 2008).

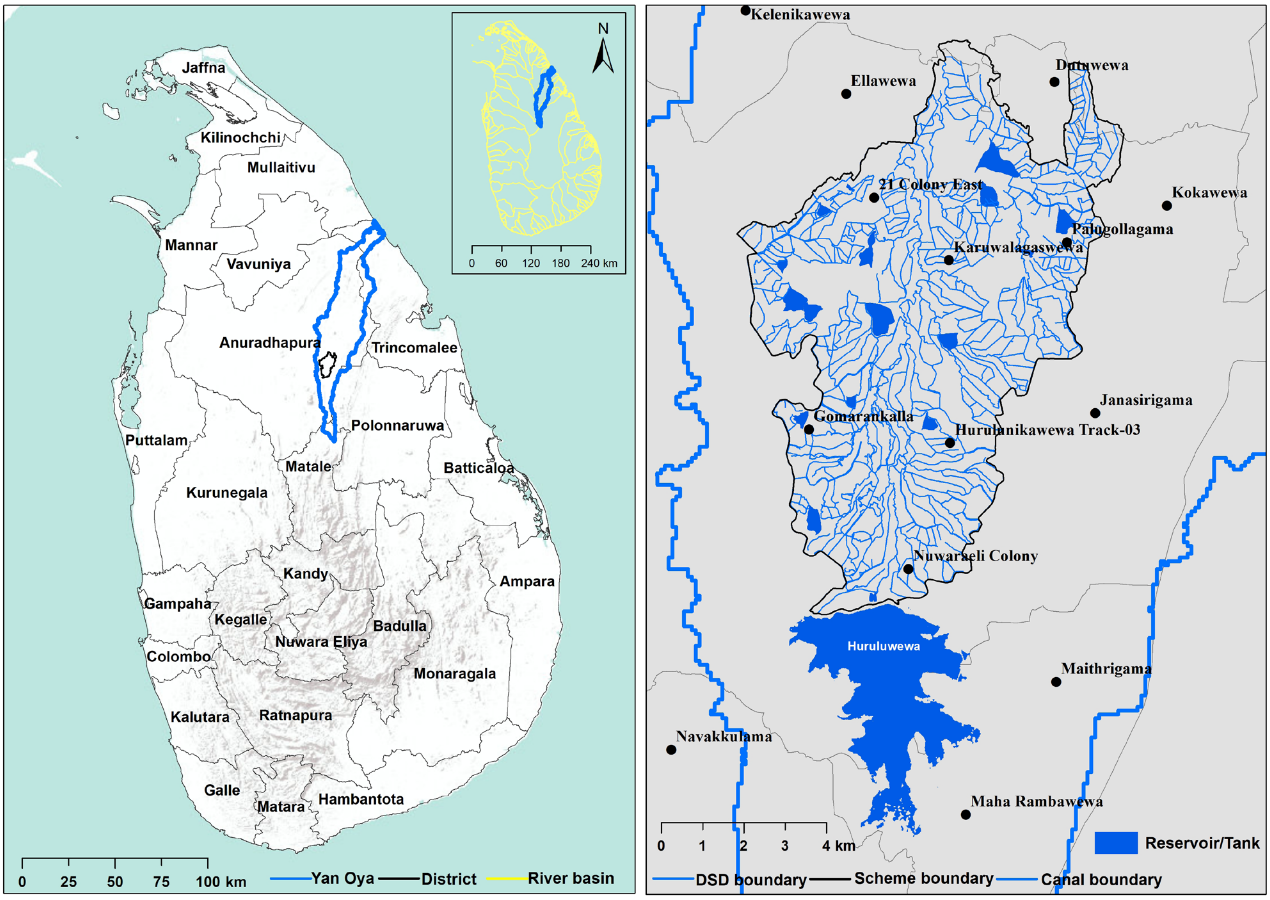

Figure 1. Map showing the boundary of the Huruluwewa Irrigation System in the North Central Province of Sri Lanka.
Source: Authors.
Note: DSD – Divisional Secretariat Division.

Both intra- and inter-annual rainfall variability is very high in the HWT catchment (Figure 2). The annual precipitation recorded at the Huruluwewa rain gauge is 1,486 mm with a 29% coefficient of variation (CV). The average rainfall in the dry (*yala*) season is 427 mm, with a CV of 39%. However, recent climatological trend assessments show an increasing rainfall trend in the Dry Zone (Wickramagamage 2016; Naveendrakumar et al. 2018; Nisansala et al. 2020; Alahacoon and Edirisinghe 2021). Nevertheless, there is a consensus of climate projections that Sri Lanka's Dry Zone is getting drier with longer dry spells, and the Wet Zone is getting wetter with extreme rainfall events (Ratnayake and Herath 2005; Chandrapala 2007; Premalal 2009; Eriyagama et al. 2010; Punyawardena and Premalal 2013).

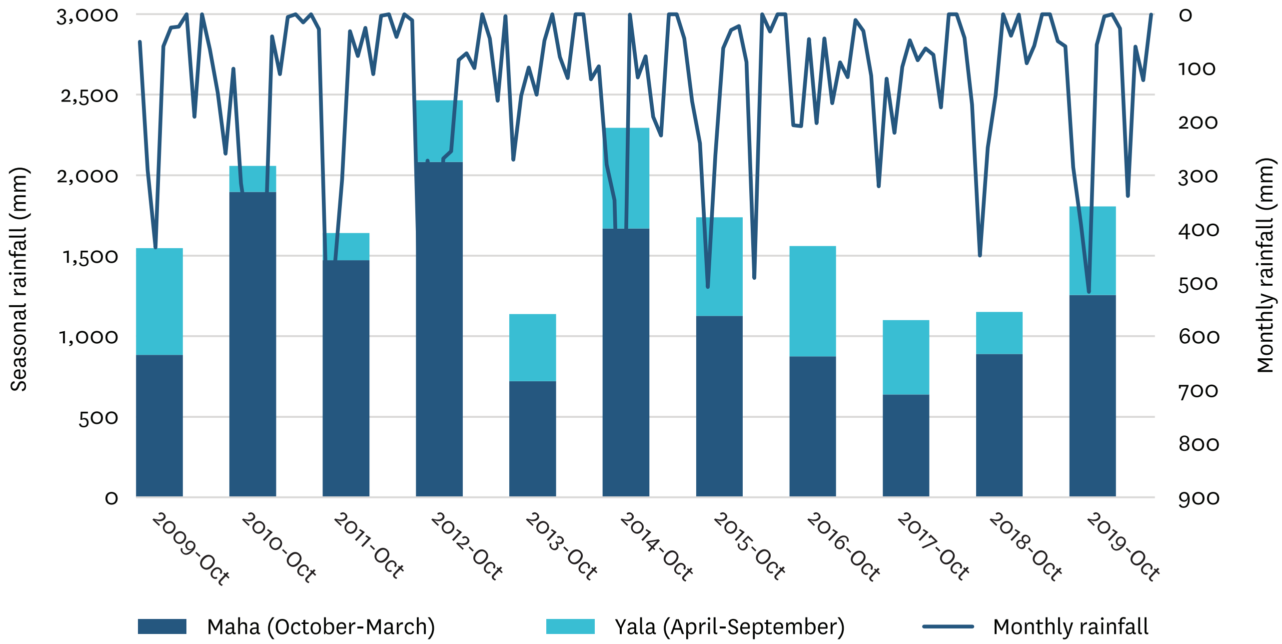

Figure 2. Monthly and seasonal rainfall trends in the Huruluwewa catchment, North Central Province, Sri Lanka.
Source: Rainfall data from the Department of Meteorology, Sri Lanka.

The annual average total rainfall in the Yan Oya Basin is 2.19 Bm^3. However, as the Huruluwewa reservoir is located upstream, its storage can only hold 67.65 Mm^3 of rainfall. During two years since 2000, the reservoir water level was barely above the dead storage level of 8.38 m and, consequently, there were no irrigation water releases for the *yala* season (Figure 3). In fact, the whole of Sri Lanka, and the Dry Zone in particular, experienced one of the most severe droughts in 2016-2017, and as a result, suffered some of the highest agricultural production losses in recent years.

Interbasin water transfers from the Mahaweli Basin to Yan Oya, through the feeder canal to the Huruluwewa tank, were envisaged to mitigate the water deficit in the HWT. However, due to substantial pumping from the canal along the way, hardly any water reaches Huruluwewa. So, the level of water in HWT is affected by rainfall variability, which is very high at present. In fact, the tank released no water for irrigation for two years since 2015 (Figure 3). This situation makes adaptation to climate change critically important in order to ward off the impact of variability of water supply to HWT.

Climate adaptation was a major focus area of a research and development project 'Shared Control of Resources' (SCOR) implemented in the Huruluwewa and Upper Nilwala watersheds by the International Water Management Institute (IWMI) in collaboration with the United States Agency for International Development (USAID) in the 1990s (Batuwitage 1994). The project introduced crop diversification by including vegetables and oilseeds in the *yala* (dry) season cropping patterns. Farmers did not see discernible impacts, however, and it is not clear whether the diversification trend seen since 2015 in the Huruluwewa command area (Figure 4) was due to the push factor of SCOR or the pull factor of increased climate variability and other risks. The diversification trend could also be due to the recent Mahaweli Water Security Investment Program funded by the Asian Development Bank, although there are no data to link the inputs of the water security project to the diversification trend. Recent research studies adopting a water accounting and modeling approach (Molden et al. 2001; Berundharshani and Munasinghe 2015) showed farmers increasing cropping intensity, economic water productivity (i.e., value per unit of consumptive water use), incomes and water-use efficiency through crop diversification in the Huruluwewa Irrigation System.

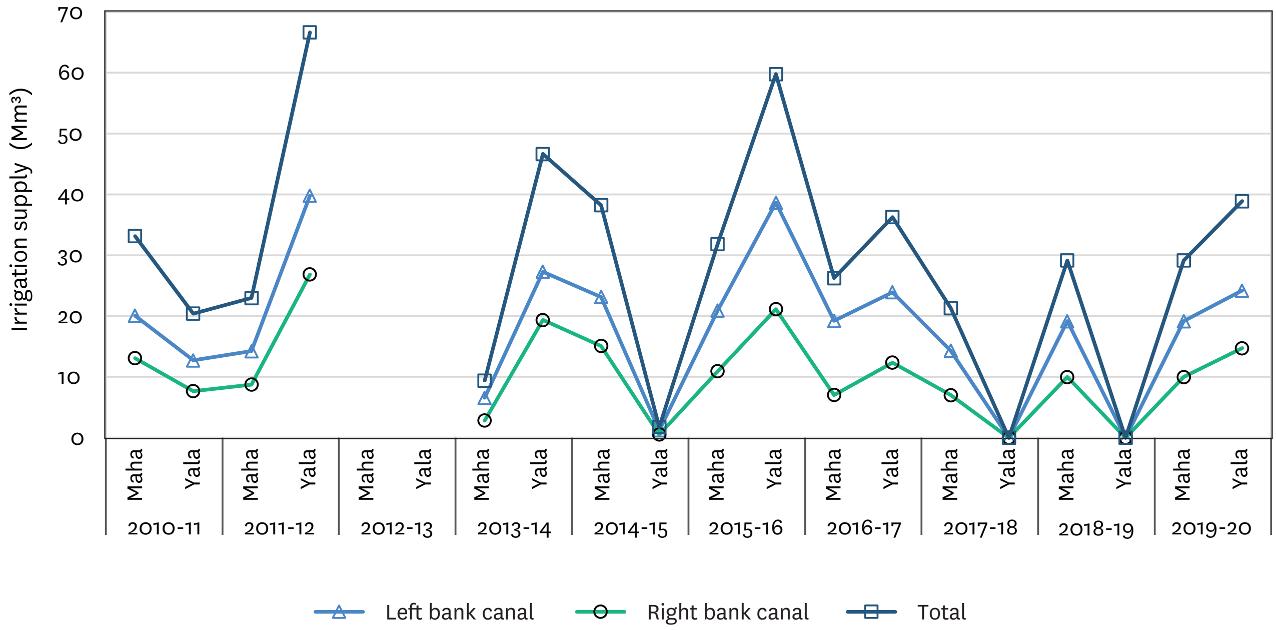

Figure 3. Irrigation water supply from the Huruluwewa reservoir.

Source: Reservoir release data are from the *Hydrological Annuals* published by the Irrigation Department in 2010-11 and 2019-20.[1]

Note: Data for the 2012-2013 *maha* and *yala* seasons are not available.

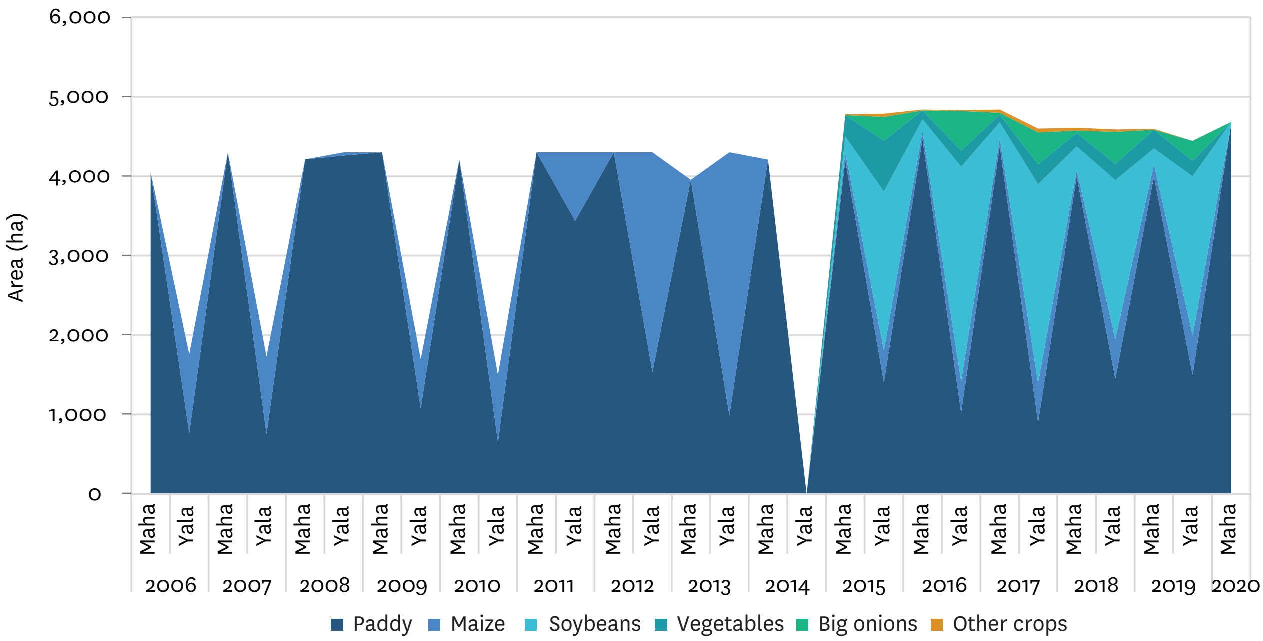

Figure 4. Cropping patterns in the canal command area of HWT.

Source: Authors.

[1] https://www.irrigation.gov.lk/index.php?option=com_content&view=article&id=299&Itemid=206&lang=en

The Huruluwewa Irrigation System has a command area of 4,453 ha (Figure 5) with two major canals: the left bank and the right bank canals (a central canal accounts for only a negligible proportion of total cropped area and total water releases in the irrigation system). The Irrigation Department and the Irrigation Management Division (IMD) manage the water releases to the left and right bank canal command areas. The designed command areas of the two canals are 2,914 ha and 1,296 ha, respectively (Abeysekara et al. 2015).

Irrigation below the distributary canal (DC) level is managed by farmer organizations (FOs), which are established on the basis of each DC's command area. There are 18 FOs at present, of which 11 are on the right bank and 7 on the left bank. A federation of all FOs takes collective decisions at the scheme level.

The Huruluwewa Irrigation System has a Project Management Committee (PMC) consisting of representatives of FOs (president/secretary/treasurer) and scheme-level officers from the line agencies. These include irrigation and agricultural agencies, banks and others relevant to the farming operation. The PMC, jointly managed by farmers and officials, is responsible for preparing seasonal plans. It coordinates actions by different agencies, facilitates communication and resolves disputes between farmers and agencies and among FOs at PMC meetings, which are held once a month.

The PMC is chaired by the Resident Project Manager (RPM), who is appointed by the IMD, and acts as the main catalyst for strengthening the FOs. In addition to the regular PMC meetings, water management committee meetings are held at the divisional irrigation engineer's office during water issue periods, especially when water issue by rotation is practiced. The water management committee consists of a representative from each FO (usually the water master), the RPM, the irrigation engineer and engineering assistants. Normally, there are three water management committee meetings per month during the water issue period.

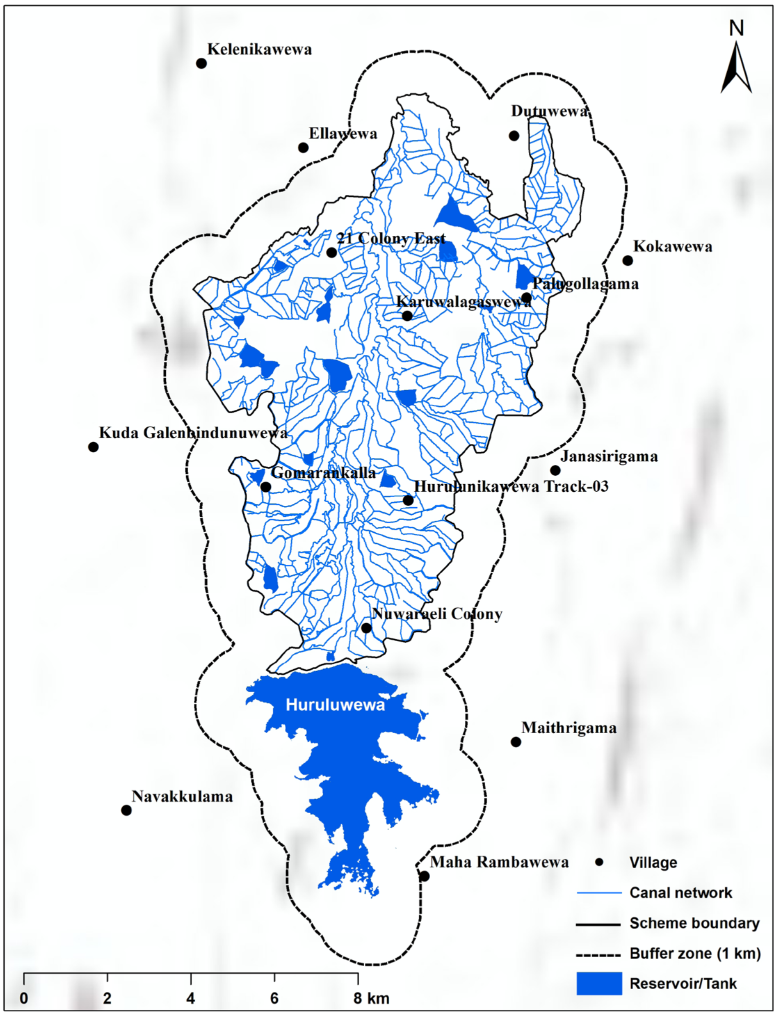

Figure 5. Geographic information system (GIS) map of the Huruluwewa Irrigation System and background Digital Elevation Model (DEM) and key locations.
Source: Authors.

Methodology

Water Influence Zone

The WIZ approach looks at benefits at three levels. The primary benefits are those assessed at the level of the CCA. The second level of benefits occur outside the command area, in the buffer zone which uses the return flows of irrigation in the CCA (Figure 5). The third order of benefits occur in the reservoir catchment area which receives water directly pumped from the reservoir or from groundwater recharged by the reservoir. The WIZ approach is a departure from the general CCA-centric irrigation performance assessment.

In this assessment, we consider a 1 kilometer buffer zone holding 5,180 ha beyond the command area. Ideally, selection of the buffer zone should be based on groundwater modeling, which would accurately assess the zone of influence of groundwater return flows outside the CCA. However, with no information on groundwater aquifers or monitoring in the area, it was not possible to follow the modeling approach.

The HWT catchment area is 8,067 ha, of which only 2,520 ha fall within the WIZ. The CCA includes both irrigated and highland areas (in the Huruluwewa tank CCA, farmers were allocated 2 ha of land with irrigation supply and some living space in the highland area). The total area of focus in the CCA is 6,920 ha, including 4,445 ha of potentially irrigable CCA. The total area of the WIZ is 14,620 ha, which is more than three times the irrigable CCA.

Analytical Approach

The analytical framework for our paper includes the following assessments:

(1) Land-use and cropping patterns
(2) Water supply and depletion patterns
(3) Crop production and productivity
(4) Irrigation performance
(5) Adaptation strategies to weather extremes
(6) Strategies for enhancing climate resilience

Land-use Patterns

Our study used Sentinel-1 (synthetic aperture radar [SAR]-based) and Sentinel-2 (optical) satellite imagery to assess the land-use and cropping patterns in the Huruluwewa Irrigation System. Sentinel-1 has imagery with 10 m resolution, and Sentinel-2 has both 10 m and 20 m resolution. The final land-use classification map has 10 m resolution. Sentinel-1 time-series images for each cropping season formed the primary data set for our study. For the *yala* season, available cloud-free Sentinel-2 images were combined with Sentinel-1 data sets. Sentinel-2 imagery was not used for the *maha* season as it is affected by clouds. A group of additional variables from these images captures the health of the vegetation (normalized difference vegetation index [NDVI]), the rate of growth (slope of the time-series profile) and the spatial pattern of the vegetation (Gray Level Co-occurrence Matrix texture parameters) (Haralick et al. 1973).

For land-use classification, we used a combined data set of original and derived satellite bands. Ground truth data collected from 55 locations developed the crop signature. Google Earth images provided the signatures for non-agricultural classes such as permanent vegetation, water bodies and settlements. The images were classified using the Random Forest Classifier (Breiman 2001) to identify the land-use classes with major crop types. Table 1 shows the official statistics relating to HWT, maintained by the Irrigation Department.

Table 1. Rainfall, irrigation supply and cropped area in the Huruluwewa Irrigation System.

Factor	Season	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018-	2018-2019
Cropped area (ha)	*Maha*	4,210	4,300	4,300	3,956	4,209	4,777	4,837	4,837	4,608	4,593
	Yala	1,500	4,300	4,300	4,300	0	4,787	4,832	4,598	4,588	4,443
	Total	5,710	8,600	8,600	8,256	4,209	9,564	9,669	9,435	9,196	9,036
Rainfall (mm)	*Maha*	885	1,897	1,472	2,082	721	1,669	1,127	876	638	891
	Yala	663	161	170	383	417	625	613	684	462	260
	Total	1,548	2,058	1,642	2,465	1,138	2,294	1,740	1,560	1,100	1,151
Irrigation diversion (Mm^3)	*Maha*	33.2	23.0	NA	9.4	38.2	31.9	26.2	21.3	29.1	29.1
	Yala	20.4	66.6	NA	46.7	1.8	59.8	36.3	0.0	0.0	38.9
	Total	53.6	89.6	NA	56.1	40.0	91.7	62.5	21.3	29.1	68.0

Source: Irrigation diversion data are from the IMD office of Huruluwewa; cropped area figures are from the Agrarian Services Center of Galenbindunuwewa DS division.
Note: NA = Not available.

Water Supply and Depletion

We used the water accounting methodology of Molden (1997) to assess water supply and depletion in the Huruluwewa WIZ. The agricultural benefits derived from HWT storage included benefits from both process (irrigation within the CCA) and non-process (crops in the highlands and catchment) evapotranspiration in the three land units: CCA, buffer zone and catchment.

Benefits accruing from process depletion in the CCA were treated as direct benefits; all other kinds of non-process beneficial depletion were treated as indirect benefits. Evaporation from the reservoir surface and fallow or built-up lands was treated as non-process non-beneficial depletion.

Rainfall

Water supply has three components: Effective rainfall (available as *in situ* soil moisture), canal irrigation supply and groundwater. In Huruluwewa, there was very high rainfall (more than 2,000 mm) in three of the past 10 years (2010-11, 2012-13, 2014-15). There was less than 1,150 mm of rainfall in three years (2013-14, 2017-18, 2018-19), and moderate rainfall in the other four years. The lowest annual rainfall recorded during the decade was 1,051 mm.

Effective rainfall. Of the total rainfall, the amount crops effectively deplete from the root zone is called effective rainfall. This is the part of rainfall that is available for *in situ* evapotranspiration by crops. It is also called rainfall consumptive water use (RFCWU). The United States Department of Agriculture-Soil Conservation Service (USDA-SCS) method (Equation [1]) estimates the effective rainfall (ERF) or RFCWU in the WIZ.

Canal water supply. The HWT scheme has a rotational irrigation delivery schedule—generally of 10 days, though it can vary depending on the weather (Berundharshani and Munasinghe 2015). Irrigation Department records show that a considerable portion of the seasonal water supply is used for land preparation for paddy cultivation with continuous water issues lasting up to two weeks.

The water management committee decides on water issues for land preparation after considering the rainfall received until then. Therefore, the volume of water released for land preparation in the *maha* season (September to March) is lower. A part of this water evaporates, and another part recharges groundwater. Similarly, water diversions to paddy include deep-percolation requirements, which mainly recharge groundwater. Aggregate water diversions (Table 1) from the left bank and right bank canals range from 53 million cubic meters (Mm^3) to 91 Mm^3. Due to inadequate storage in the reservoir, there were few or no *yala* season canal water releases in three years (2013-14, 2016-17, 2017-18) during the past decade.

Tank Water Spread Area

On the basis of Sentinel-1 SAR satellite data, we calculated the change in the HWT's water spread area using the Google Earth Engine (GEE) platform. Threshold-based image classification was used for extraction and calculation of the water surface area.

Groundwater. Groundwater recharge takes place from three sources: rainfall, reservoir storage and canal irrigation supply. The main aquifer system underneath the Dry Zone of Sri Lanka is hard rock (Panabokke 2007). It is acknowledged that groundwater in a hard rock region is found both in the weathered rock zone (regolith) of 2-10 m thickness, and in the deeper fracture zone of basement rock located more than 30-40 m deeper (Panabokke and Perera 2005). Shallow regolith aquifers in hard rock regions occur in association with small tank cascade systems (Panabokke 2007). The large number of small tanks found across the undulating landscape of the Dry Zone are not randomly located; rather, they occur in the form of distinct cascades that are positioned within well-defined small watersheds or meso-catchment basins (Panabokke 2007). Crystalline hard-rock aquifer systems in the Huruluwewa WIZ have low recharge capacity (De Silva et al. 1999). We assume that only 10% of the total rainfall recharges the aquifers underneath the Huruluwewa WIZ. This percentage is the benchmark recommended by India's Central Ground Water Board for similar hard-rock aquifers in that country (GoI 2017).

Data on recharge from reservoir storage was not available for this analysis. Farmers observe that open wells have a water depth of 3-4 m even without canal water releases. De Silva et al. (1999) reported that most agro-wells (or open wells) have a depth of 6–10 m. The groundwater level rises quickly during the northeast monsoon (October to January) and slowly falls during the dry season from March to September. Groundwater levels are at their lowest from late August to September in the Huruluwewa command area. This shows the groundwater irrigation potential in the *yala* (dry) season from April-May to July-August.

$$ERF = RFCWU = \begin{cases} RF\,(125 - 0.2 \times RF) / 125 \;\; if\; RF \leq 250 \text{ mm} \\ 125 + 0.1 \times RF \;\; if\; RF > 250 \text{ mm} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

[2] https://www.iwmi.cgiar.org/what-we-do/projects/show-projects/?C=1099 (accessed on October 20, 2021).

De Silva et al. (1999) reported that a substantial number of agro-wells existed even in the 1990s. However, the situation has drastically changed since then. Our analysis used Google Maps of December 2017 to assess groundwater pumping locations in the WIZ. With the aid of Google Earth Pro, we manually identified small open water bodies and validated them with ground data collection. Even then, the number of open wells identified by this method is likely an underestimate. At some places, thick tree canopies hindered identification of wells underneath.

These open wells withdraw groundwater from pumps located in the head reaches, which benefit from recharge from all three sources: rainfall, canal irrigation and reservoir storage. Generally, the influence of recharge from reservoir storage diminishes from head reach to tail reach. However, there is no groundwater monitoring information to test this hypothesis in the HWT command area. The small-scale automatic groundwater monitoring network being implemented in the Mahaweli 'H' canal command in the Dry Zone shows groundwater levels closer to the surface in the presence of canal irrigation.[2] The large number of open wells downstream indicates intensive groundwater use for crop cultivation (Figure 6).

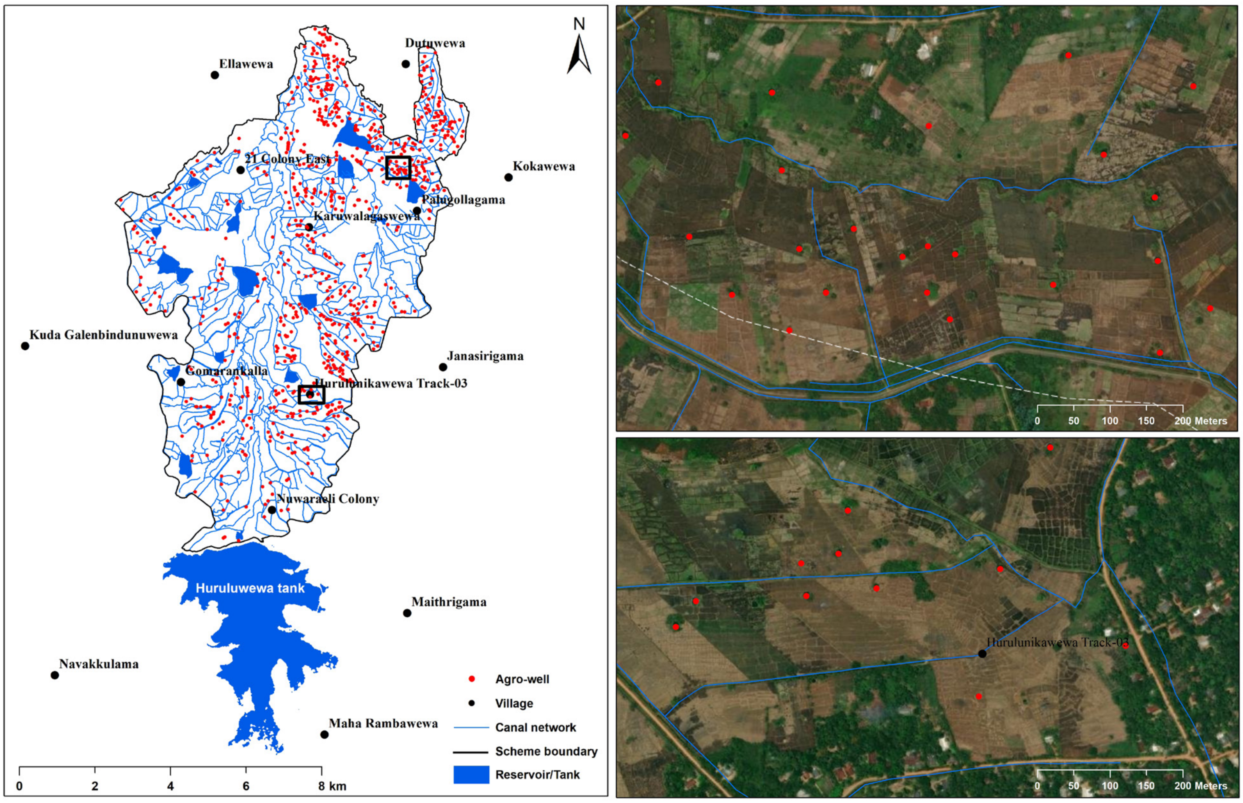

Figure 6. Map of the command area of the Huruluwewa Irrigation System and two high-resolution zoom areas showing open wells and DEM background (gray color).

Water Depletion

Water depletion has three components: Process beneficial depletion, non-process beneficial depletion, and non-process non-beneficial depletion.

Process beneficial depletion. This occurs on ccount of the total consumptive water use (TCWU) by crops in the CCA. TCWU is the evapotranspiration (ETa) from the crop area during different growth periods. The TCWU of a crop is estimated as shown in Equation (2).

$$TCWU = \sum_{j \in crops} TCWU_j = \sum_{j \in crops} \sum_{k=1}^{4} C_{jk} \times \sum_{i \in months} ETP_{ik} \times d_{ijk} \quad \text{..........................(2)}$$

Where: C_{jk} is the crop coefficient of the j^{th} crop in k^{th} growth period; ETP_{ik} is the daily potential evapotranspiration of the i^{th} month; and d_{ijk} is the number of days of the k^{th} growing period in the i^{th} month.

Water accounting assesses the TCWU and its components. RFCWU is essentially the effective rainfall (Equation [1]) over the crop area. The share of TCWU from irrigation (IRCWU) is the difference between TCWU (Equation [2]) and RFCWU.

Non-process beneficial depletion. This is TCWU from crops outside the CCA, i.e., ETa from the buffer zone and catchment.

Non-process non-beneficial depletion. This is evaporation from fallow and non-agricultural lands and the reservoir surface and open canals.

Our analysis uses the reference evaporation (ETo) and potential evapotranspiration (ETp), estimated from the weather data recorded at the Mahaillupallma research station, which is located 10-15 km from HWT and the command area. These estimates are available in various editions of the *Hydrological Annual* (1999-2018) published by the Irrigation Department of Sri Lanka.[3]

Performance Indicators

This analysis mainly focuses on four indicators of water supply performance. They are useful for intra- and inter-system or interannual comparison. These indicators are explained below:

- Irrigation supply per unit area (m^3/ha): the ratio of total irrigation supply to total cropped area. Irrigators call this quantity the "water duty" and it is usually expressed in meters, and is estimated by dividing the irrigation supply per unit area by 10,000.

- Irrigation WUE: the ratio of irrigation CWU to irrigation supply.

- Consumptive fraction (CF): the ratio of TCWU to available water supply (effective rainfall + canal water supply + natural groundwater recharge).

- Economic water productivity (EWP): the value of agricultural production per unit of water use (USD/m^3). The water use can be total irrigation supply (a popular measure among irrigation managers), or irrigation CWU (popular among irrigation planners, policymakers and researchers), or total water use, which also includes rainfall CWU. The latter indicates how effective rainfall is for crop cultivation.

Additionally, we estimated the physical water productivity (PWP) of individual crops to assess the potential for increasing the productive use of water for increasing crop evapotranspiration and crop yield.

The value of crop production is expressed in USD at 2015 constant value. Crop prices are producer prices collected from the FAOSTAT database (FAO 2020). The exchange rates and the GDP deflators for converting the values to constant USD prices are also from the FAOSTAT prices website (FAO 2020).

Results

Land-use Patterns

For most years of the past decade, official statistics show full utilization of the Huruluwewa command area in both *maha* and *yala* seasons (Figure 4). In fact, cropping intensity since 2015 has reached more than 200%. Cropping patterns in the *yala* season include a substantial NPC area sown with soybean, maize, pulses (cowpea, black gram, green gram, mung bean), vegetables (tomatoes), chili and big onion. Soybean has had the largest share of cropped area in the *yala* season since 2015. Being a drought-tolerant crop, its financial returns are relatively fixed due to forward sales agreements.

As can be seen in Table 2, there are differences between crop areas as per official statistics and remote sensing (RS) and GIS estimates (Figure 7).

In 2015-2016:

- Satellite data-derived total seasonal cropped area was 12% lower than the official figure in the *maha* season and 6% lower in the *yala* season.

- Satellite-derived soybean area in the *yala* season was 9% more than the official figure. However, this higher estimate was not at the expense of paddy area, which was about 22-25% of the total cropped area.

[3] https://www.irrigation.gov.lk/index.php?option=com_content&view=article&id=299&Itemid=206&lang=en (accessed on October 20, 2021).

Table 2. Land-use patterns in the water influence zone based on RS/GIS estimates.

Year	Crop area (ha)	Official statistics		RS/GIS estimates					
		CCA		CCA		Buffer zone		Reservoir catchment	
		Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
2015-2016	Paddy[a]	92	22	93	25	73	21	60	24
	Maize[a]	2	9	2	6	16	3	30	2
	Soybean[a]	3	59	4	68	8	73	8	71
	Other crops[a]	2	10	1	1	3	2	2	3
	Total cropped area	4,837	4,598	4,308	4,307	1,465	1,295	244	229
	Orchards/trees/non-agricultural area			2,373	2,263	3,425	3,317	1,400	1,389
	Water spread area			237	233	288	285	876	874
	Total land cover			6,920	6,920	5,180	5,180	2,521	2,521
2018-2019	Paddy[a]	87	33	90	50	67	38	51	26
	Maize[a]	3	11	2	6	16	26	21	35
	Soybean[a]	4	44	3	22	12	29	19	32
	Other crops[a]	6	13	5	22	4	7	10	7
	Total cropped area	4,608	4,588	4,362	4,398	1,515	1,317	251	220
	Orchards/trees/non-agricultural area			2,322	2,270	3,376	3,321	1,394	1,387
	Water spread area			235	233	286	284	875	875
	Total land area			6,920	6,920	5,180	5,180	2,521	2,521

Source: Authors' estimates.

Note: [a] Area as a percentage of total cropped area.

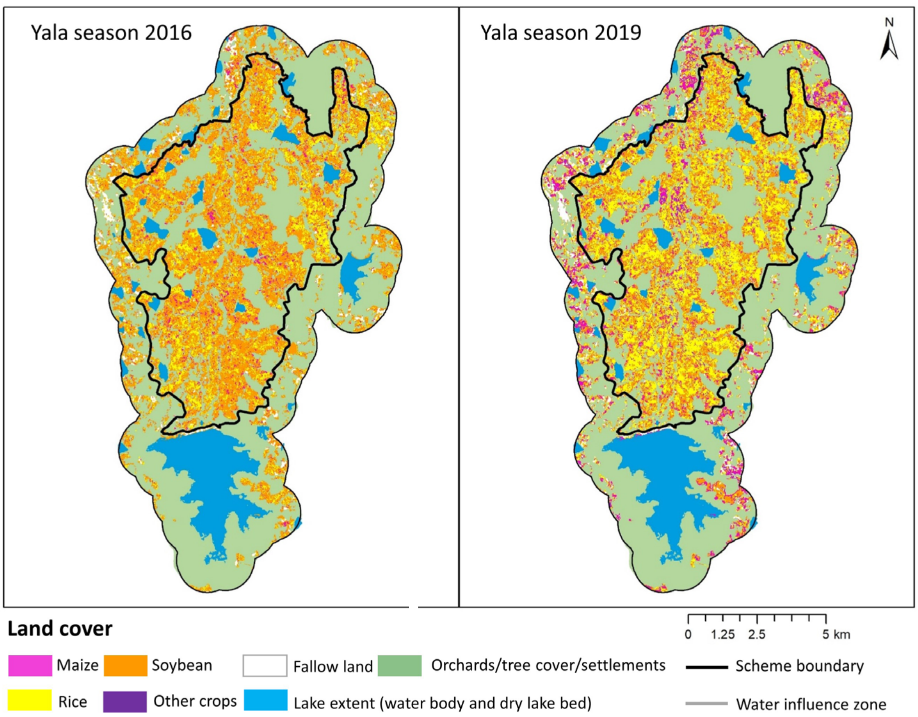

Figure 7. Land-use pattern of the WIZ of HWT derived from satellite data.

Source: Authors' estimates.

In 2018-2019:

- Official statistics and satellite data-based estimates were not significantly different in terms of the total cropped area.

- However, the *yala* season paddy area in the official records was 15% lower than the RS/GIS-based estimate. The increased soybean area explains the difference between the two estimates.

Although not significant, the above differences indicate that official statistics tend to report higher crop diversification. As per RS/GIS estimates, there is substantial rice cultivation even in the *yala* season.

Tree cover, including orchards, and settlements are a significant part of land cover in the WIZ: 37% in the CCA, 66% in the buffer zone, and 55% in the catchment area (Figure 4). These are mostly in the highland areas. Although the RS/GIS analysis did not separate orchards from other trees in the highland areas, ground observations and interviews conducted with farmers showed that orchards occupy a substantial part of this land-use category.

The orchard crops include plantain/banana, lime, orange, mango, papaya, etc., and plantation crops such as coconut. All of them are perennial crops. In the highlands, orchard crops deplete a substantial volume of water and generate income, a fact that often goes unnoticed in CCA-centric land- and water-use and productivity assessments. Molden et al. (2001) illustrated this in Huruluwewa as well as the Kirindi Oya irrigation system in southern Sri Lanka.

Moreover, according to farmers, most of these annual orchard crops emerged with the filling of the reservoir and release of canal water for irrigation. The orchard and other tree crops in the highlands also have substantial evapotranspiration, and this evapotranspiration would only be possible by extracting groundwater, which is recharged by the reservoir and canals. We will illustrate this later in the discussion on water depletion estimation in the section *Crop Consumptive Water Use*.

Within the WIZ, the buffer zone and catchment area have smaller cropped areas: one-third of the CCA in the buffer zone and less than 5% in the catchment area. The catchment of the HWT has the largest water spread area. The CCA and buffer zone have about 25% of the water spread area (or small water bodies) of the catchment. The tanks that store rainfall in the rainy season also capture drainage water resulting from canal irrigation in the command area. They, in turn, have multiple benefits, including irrigation.

Water Supply

Rainfall is the primary source of water for the Huruluwewa reservoir. There is also a provision of water diversion to the HWT system through a feeder canal, but Irrigation Department records show that external transfers that reach the reservoir, if any do, are only a small proportion compared to inflows from rainfall.

Rainfall, irrigation water supply and cropped area data indicate the influence of climate variability, its impacts and the adaptation strategies followed in the Huruluwewa CCA (Table 3). There was no *yala* season irrigation supply in three of the past 10 years (Table 1). Of these three years, no cultivation was possible in 2013-2014. However, in the other two drought years (2016-2017 and 2017-2018), farmers managed to irrigate more area in the *yala* season, which was even more than the CCA. What made that possible was the farmers' adaptation strategy against drought: efficient use of rainfall and groundwater, and NPC cultivation. This is evident in the green cover seen in the WIZ (CCA and buffer zone) (Figure 8). There are at least 248, 369 and 396 agro-wells withdrawing groundwater in the upper, middle and lower reaches of the Huruluwewa command area, respectively.

Table 3. Irrigation supply and cropping intensity in the Huruluwewa Irrigation System.

Factor	Season	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019
Irrigation supply (m^3/ha)	*Maha*	7,875	5,343	NA	2,376	9,084	6,668	5,424	4,404	6,324	6,345
	Yala	13,602	15,499	NA	10,849	0	12,487	7,508	0	0	8,754
	Total	9,380	10,421	NA	6,789	9,502	9,581	6,466	2,258	3,169	7,529
Cropping intensity (%)[a]	*Maha*	95	97	97	89	95	107	109	109	104	103
	Yala	34	97	97	97	0	108	109	103	103	100
	Total	129	194	194	186	95	215	218	212	207	203

Source: Authors' estimation.

Note: [a] Cropping intensity is the ratio of cropped area to CCA (4,445 ha).

NA = Not available

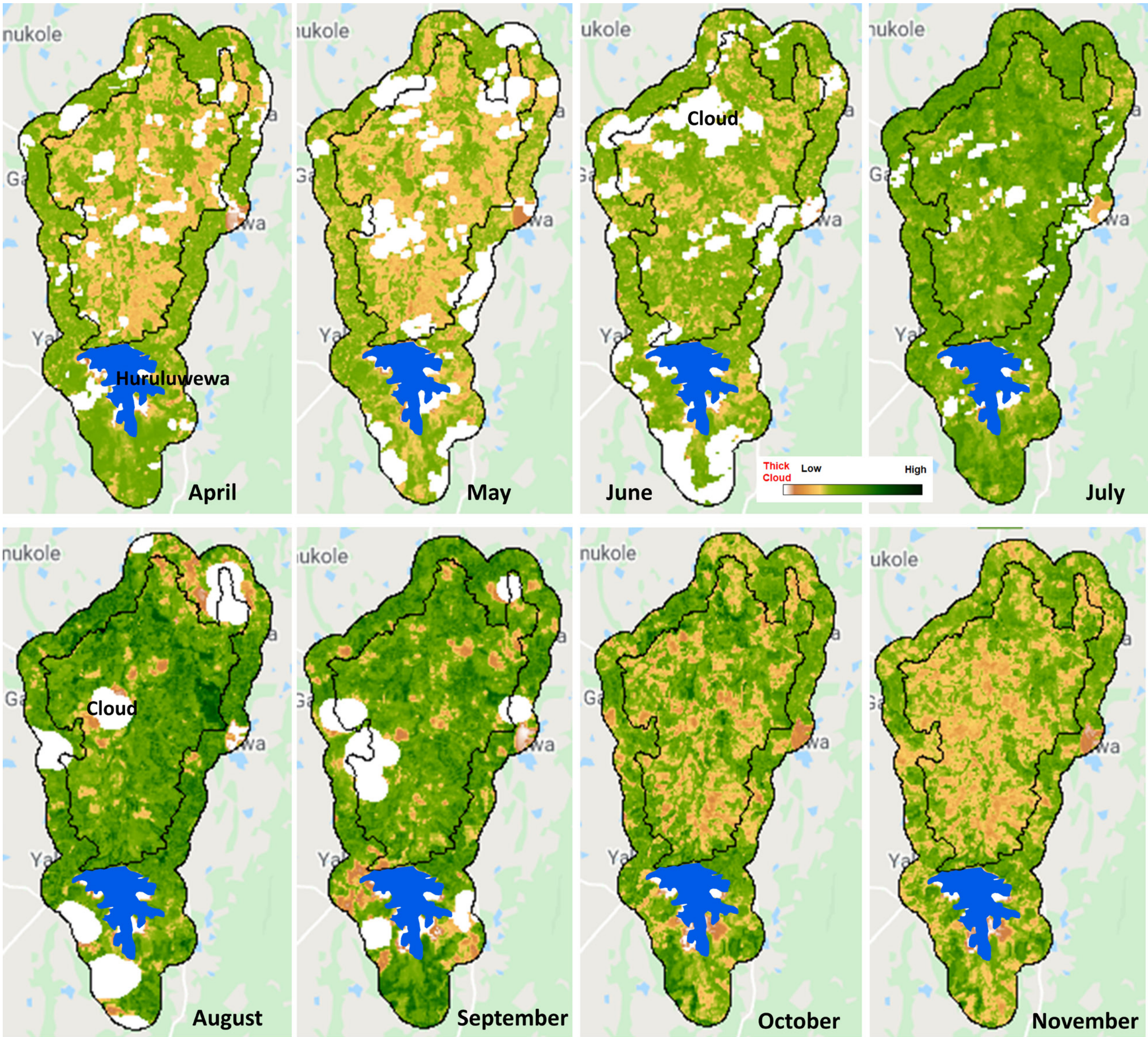

Figure 8. Monthly NDVI in the Huruluwewa crop command area in 2017.
Source: Authors' estimates.

The NDVI shows the green cover on the ground. In the 2017 *yala* season, farmers started growing crops in May-June, which normally would have happened in April had there been irrigation supply. The harvest was completed by October. In fact, the water spread area and storage of the reservoir were very low early in the *yala* season. Low storage continued through the 2017-18 *maha* and 2018 *yala* seasons. Nevertheless, even with substantially lower water storage, the Huruluwewa scheme cultivated 100% of the area during the two seasons (Figure 9).

Achieving 100% cropping intensity over three consecutive seasons despite low reservoir storage shows the remarkable ability of farmers as well as irrigation managers to adapt to weather variability. In fact, better management of rainfall in those three years allowed the management to reduce water releases for land preparation (Table 4). Water supply for land preparation was significantly (at 0.005 probability level) reduced from more than 50% of total water supply before 2015 to less than 20% after 2015. The only exceptional year was 2016-2017, when there was deficient rainfall at the start of the season. Short-duration rice varieties must have also helped farmers in achieving high cropping intensity over those three water-scarce seasons.

Crop Consumptive Water Use

The IRCWU relative to irrigation supply is very low in the CCA (Table 5). Hence the irrigation WUEs are very low in both *maha* and *yala* seasons, primarily due to deep percolation. Moreover, the consumptive fractions indicate that the WUE of the total water supply (rainfall, canal water and groundwater) in the command area is also low. Even with over 200% cropping intensity, the total water supply since 2015 was substantially higher than the seasonal crop water requirement.

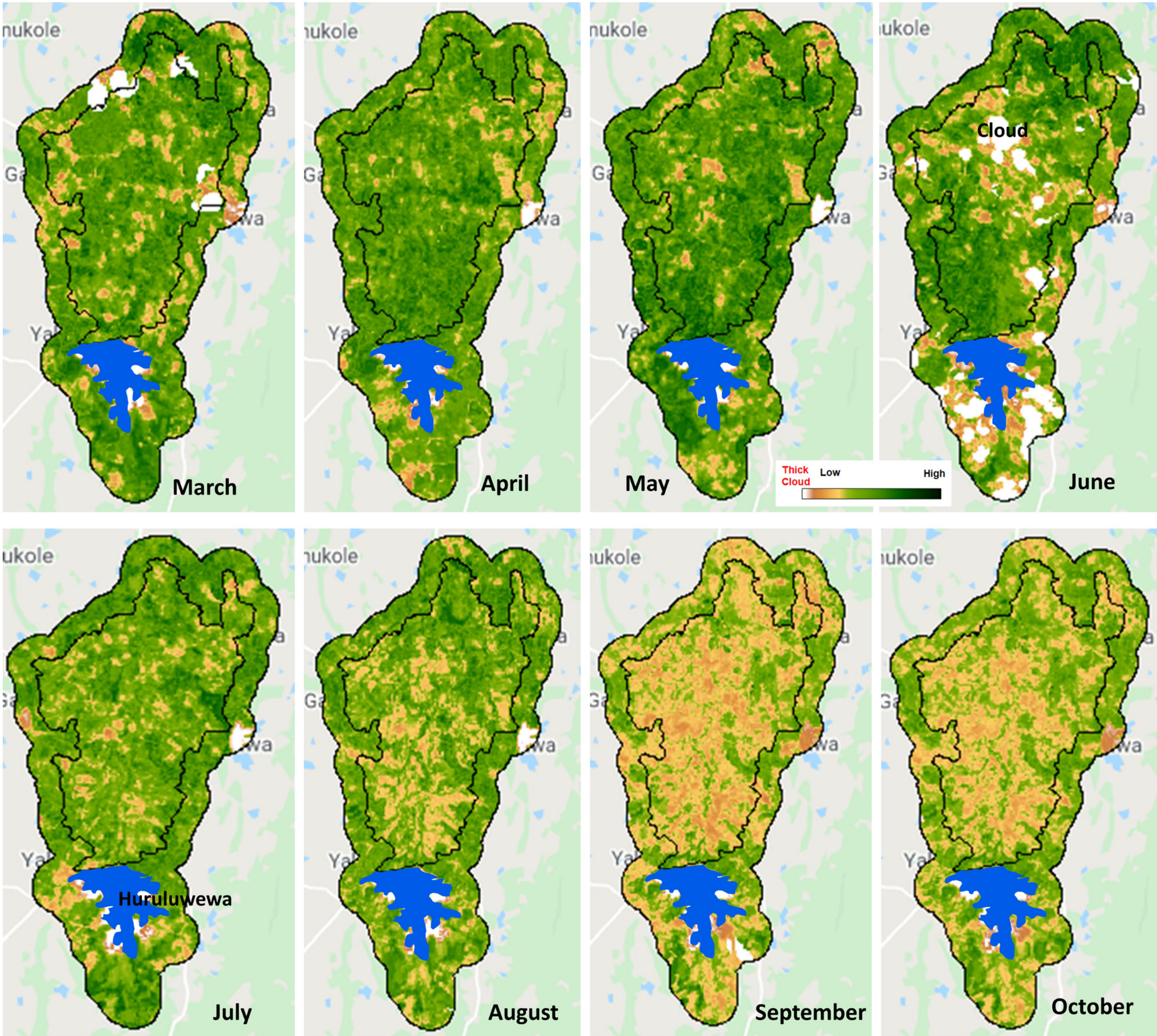

Figure 9. Monthly NDVI in the Huruluwewa crop command area in 2018.
Source: Authors' estimates.

Probing further, water use over the years highlights the following:

- Irrigation WUE in the 2010-2011 *maha* season was zero, because the effective rainfall in that season was more than sufficient for the crop water requirement. The CF confirms this: effective rainfall and natural recharge are more than the crop CWU. Yet, 23 Mm^3 of water was released for irrigation in the 2010-2011 *maha* season.

- WUEs for the 2013-2014, 2016-2017 and 2017-2018 *maha* seasons were less than 20%. Due to inadequate storage, no canal irrigation supply had been released in the *yala* season. However, farmers used rainfall and groundwater irrigation to cultivate the entire command area. In fact, the annual IRCWU in the latter two years was only about half of the irrigation supply in the *maha* season.

The analysis above shows substantial return flows due to canal irrigation in the HWT system. However, not all return flows (water supply minus irrigation CWU) were lost from the WIZ. The orchard crops in the highlands deplete water too. We estimated the total CWU of highland orchard crops with the assumption that 80% of the RS/GIS-based land area outside the CCA was under orchard crops.

Based on RS/GIS crop area estimates, the total effective rainfall for the highland orchards was only half of the CWU. Thus, groundwater would have contributed to a part of the other half of water needs, without which the extended dry period could not have been endured. Deep-rooted orchard crops can extract and deplete a substantial volume of groundwater

Table 4. Irrigation supply for land preparation.

Year	Starting date of water supply		Irrigation supply for land preparation (% of total)			
			Left bank canal		Right bank canal	
	Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
2009-2010	Nov 12 - Dec 22	Apr 24 - Jun 03	27	35	34	46
2010-2011	Oct 20 - Nov 19	Mar 26 - Apr 20	62	25	76	23
2011-2012[a]	-	-	-	-	-	-
2012-2013	Nov 30 - Dec 14	May 04 - July 06	51	53	75	57
2013-2014	Oct 22 - Nov 18	No releases	51	-	52	-
2014-2015	Dec 01 - Dec 06	Apr 27 - May 24	12	20	10	20
2015-2016	Nov 09 - Nov 29	May 02 - May 05	17	4	16	3
2016-2017	Nov 06 - Dec 09	No releases	35	-	34	-
2017-2018	Jan 08 - Jan 13	No releases	7	-	2	-
2018-2019	Oct 18 - Oct 26	Apr 25 - May 09	19	32	16	19

Source: Project Management Office, Huruluwewa, Sri Lanka.

Note: [a] Data for 2011-2012 are not available.

Table 5. Total and irrigation consumptive water use (TCWU and IRCWU) and irrigation WUE in the CCA.

Factor	Season	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018 2019-
IRCWU (Mm^3)	*Maha*	12.7	0.0	8.5	1.0	2.0	7.4	7.4	3.8	2.5	3.7
	Yala	3.1	17.1	14.7	7.9	0.0	10.7	10.2	8.5	10.2	13.1
	Total	15.8	17.1	23.2	8.9	2.0	18.1	17.6	12.3	12.7	16.8
TCWU (Mm^3)	*Maha*	20.8	15.4	17.8	13.2	16.2	19.7	16.2	17.2	13.7	15.6
	Yala	6.3	20.9	16.9	14.5	0.0	18.8	18.5	16.3	17.3	17.2
	Total	27.1	36.3	34.7	27.7	16.2	38.5	34.7	33.5	31.0	32.8
Irrigation WUE (%)	*Maha*	38	0	NA	11	5	24	28	18	9	13
	Yala	15	34	NA	17	0	18	28	0	0	34
	Total	29	23	NA	16	5	20	28	57	43	25
Total water supply (TWS) (Mm^3)	*Maha*	47	50	NA	34	57	54	42	40	44	46
	Yala	28	71	NA	56	4	72	48	12	10	45
	Total	74	121	NA	90	61	126	90	52	54	91
Consumptive fraction (%)	Total	36	30	NA	31	26	31	38	64	57	36

Source: Authors' estimates.

Note: NA = Not available.

resources. With the inclusion of orchard crops, the RS/GIS-based CWU estimates have a higher total CWU (Table 6).

Water Productivity

Our study found that water productivity based on official data was very low (Figure 10), in particular the following:

- Although PWP (kg/m³ of TCWU) of the dominant crop, paddy, was increasing over the past decade, the highest EWP in the *maha* season was about USD 0.50/m³ of TCWU.

- EWP and PWP showed similar trends in the *yala* season except after 2015. Crop diversification in the *yala* season may have contributed to higher EWP after 2015. There were no *yala* season irrigation releases in 2016-2017 and 2017-2018, and farmers chose a cropping pattern based on rainfall and available groundwater for irrigation. Such cropping patterns contributed to higher EWP in those two years.

However, a comparison with EWP estimates derived from RS/GIS-based data suggests a different picture (Table 6).

- With the inclusion of crop production benefits from return flows, EWP in the WIZ is substantially more than that based on official statistics reported only for the CCA. EWP per unit of CWU in the CCA based on official data was 33% higher in 2015-2016 and 29% higher in 2018-2019.

- EWP with respect to total water supply—which includes canal irrigation, effective rainfall and groundwater recharge—is substantially lower, only USD 0.13/m³ in 2018-2019.

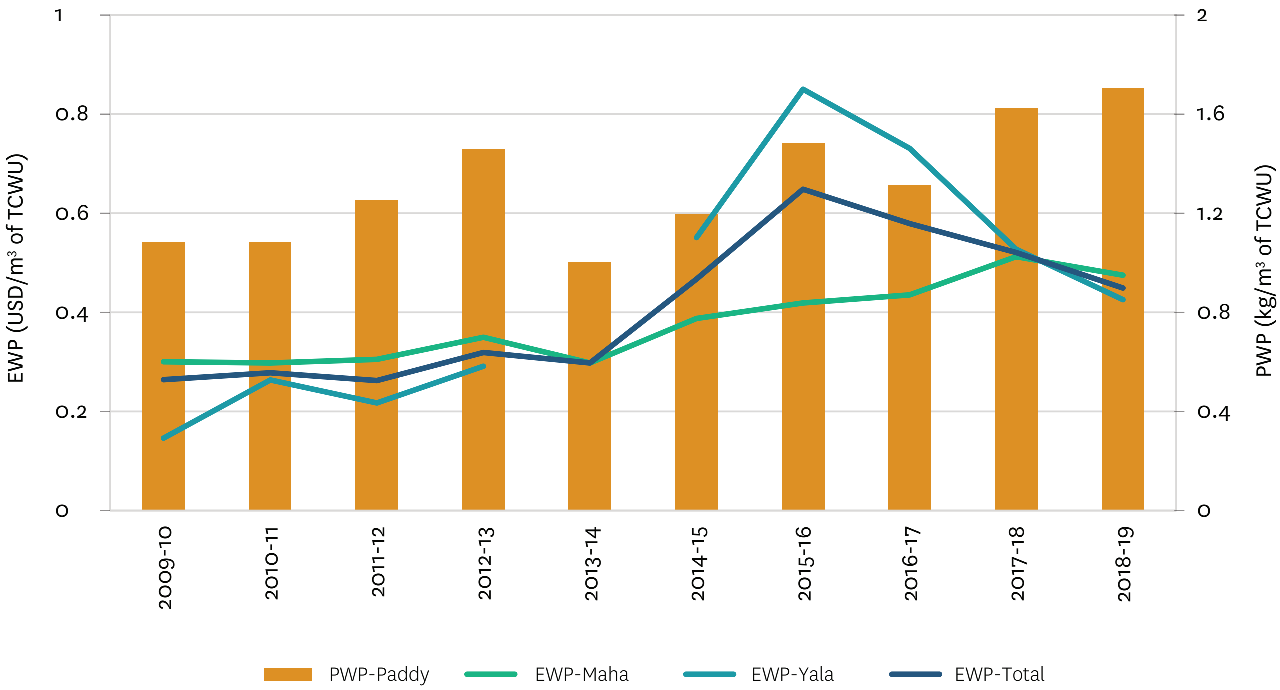

Figure 10. PWP of paddy and EWP of all crops in the *yala* and *maha* seasons.

Opportunities for Increasing Economic Water Productivity

Process depletion in the Huruluwewa Irrigation System, i.e., CWU in the CCA, was only a fraction of the available water resources. Water depletion outside the CCA increased the CF to about 60% in years with low (2018-2019) to moderate (2015-2016) rainfall. In high rainfall years, it is likely that only 50% of the water supply was used even after reuse in the WIZ. The fact is that rainfall and HWT storage are more than sufficient for 200% cropping intensity.

The primary reason for the low CF is the large irrigated paddy area. Almost the entire command area in the *maha* season and a part of it in the *yala* season raise a paddy crop. Due to the high water requirement for land preparation and deep percolation, paddy has a very low irrigation WUE, which contributes to the low CF. However, paddy contributes to the food security

Table 6. Consumptive water use (CWU), economic water productivity (EWP) and consumptive fractions (CF) derived from official and RS/GIS-based estimates in 2015-2016 and 2018-2019.

	Variable	Official data	RS/GIS-based estimates[a]		
		CCA	CCA	CCA + buffer zone	CCA + buffer zone + catchment
2015-2016	Total water supply (Mm^3)	90.3	85.6	92.9	94.1
	Cropped area (1,000 ha)	9.4	9.6	15.1	16.7
	Total CWU (Mm^3)	34.7	40.1	49.4	56.4
	Consumptive fraction (%)	38	47	53	60
	Total value[b] (USD millions)	22.5	18.8	32.8	37.5
	EWP (USD/m^3 of TCWU)	0.65	0.60	0.81	0.89
	EWP (USD/m^3 of TWS)	0.25	0.22	0.35	0.40
2018-2019	Total water supply (Mm^3)	91.0	88.1	94.7	95.7
	Cropped area (1,000 ha)	9.0	8.8	11.6	12.1
	Total CWU (Mm^3)	32.8	43.4	53.1	59.5
	Consumptive fraction (%)	36	49	56	62
	Total value (USD millions)	14.7	16.0	29.3	33.9
	EWP (USD/m^3 of TCWU)	0.45	0.50	0.70	0.78
	EWP (USD/m^3 of TWS)	0.16	0.18	0.31	0.35

Source: Authors' estimates.
Notes: [a] RS/GIS estimates include orchard area in the highlands.
[b] Value of production and EWP are in USD at constant 2015 value.

of households in the Huruluwewa scheme and beyond. Therefore, it is unlikely that a major shift from paddy cultivation will occur in the *maha* season except in very low rainfall years.

However, much of the return flow from substantial paddy irrigation in the *maha* season recharges groundwater, which becomes a potential source of irrigation for the *yala* season. Groundwater combined with rainfall and canal supply, if available, can mitigate the risks of water scarcity and support high-value crops. The present cropping patterns in the *yala* season, however, do not capitalize on this opportunity.

Soybean is a major part of the *yala* season cropping pattern, but it has one of the lowest EWP among the non-paddy crops (Table 7). Moreover, it has the lowest land productivity next to maize, which has an even lower EWP.

The land and water productivity values of crops show that further crop diversification in the *yala* season can increase farmers' incomes. Crop diversification with correct crop choices can also reduce the risk of crop failure in years with low water supply. Of course, crop diversification depends on many other factors: profits, access to markets, cultural practices, etc. Nevertheless, root crops (onions), vegetables, fruits and chili are potential high EWP alternatives to soybean and maize.

However, there are two major constraints to diversification to higher-value crops such as chili and onions: labor shortage and the challenge of getting an assured price for produce. However, diversification to fruits, which does not require as much labor as chili or vegetables, or as much water as paddy, can generate substantial income for farmers. For example, a 10% reduction in paddy or other low-EWP crops such as soybean and replacing these with fruits can be a major income booster for farmers in this irrigation system. A 10% reduction in the paddy area requires only an 11% increase in paddy yield to have the same output with higher EWP.

Table 7. Economic water productivity and land productivity of crops in Huruluwewa.

Crop	Economic water productivity (USD[a]/m³)		Land productivity (USD/ha)	
	Maha	*Yala*	*Maha*	*Yala*
Paddy	0.46	0.33	1,538	1,520
Maize	0.34	0.29	847	962
Soybean	0.35	0.29	796	977
Big onions	3.23	4.08	6,310	11,902
Vegetables (tomato)	1.00	0.69	3,437	3,372
Fruits (plantain)	0.45	-	4,101	-
Chili	2.09	1.50	6,480	6,081

Source: Authors' estimates.
Note: [a] Values are in USD at 2015 constant value.

Comparison with the Sina Irrigation System

The Sina irrigation project in Maharashtra, India, is described as a water-scarce irrigation system. In 2010-2011, which was one of the wettest years, the Sina command area received about 875 mm of annual rainfall (Table 8). On the other hand, Huruluwewa, also perceived to be water-scarce, received more than 1,150 mm of rainfall in 2018-2019, one of the driest years in the past decade. We selected these two years for comparison of the performance of the two irrigation systems.

The reservoir storage of Sina is slightly higher, but the annual water supply in Huruluwewa—from canal releases, effective rainfall and groundwater recharge—is substantially higher. This is mainly due to differences in effective rainfall: Sina receives almost no precipitation during the dry season.

The CCA of Sina is substantially higher than that of Huruluwewa, although the total cropped areas of the two systems are similar. That is due to the 200% irrigation cropping intensity achieved in Huruluwewa compared to 100% in Sina (in fact, a part of the command area in Sina was cultivated in the monsoon season too but it was not included in this comparative analysis).

Given the high irrigated area, irrigation WUE in Sina is close to 100%, while in Huruluwewa it is substantially lower. Sina uses almost all its water supply beneficially in the WIZ. This is mainly due to diversified cropping patterns. While paddy dominates the cropping patterns in Huruluwewa, sorghum is dominant in Sina.

The EWP in the CCA is similar too. However, the value of production is substantially higher in the Huruluwewa scheme. To increase income and climate resilience, Sina has to diversify to high-value, less water-intensive crops to meet the challenge of water scarcity. Climate risks have heightened in Sina. On the other hand, Huruluwewa has many options for increasing farmers' resilience. It can maintain low-EWP paddy irrigation in the *maha* season and change cropping patterns in the *yala* season to increase the output value. Groundwater acts as insurance against crop failure. Alternatively, Huruluwewa can reduce its paddy area slightly while increasing yield to maintain the same level of food grain production. Also, replacing paddy or other low-EWP crops with fruits can generate substantial income.

The tale of these two irrigation systems shows the opportunities available to supposedly water-scarce irrigation systems in Sri Lanka. In Sina, only a small cropped area is under high-value fruit crops such as pomegranate, orange, etc., at present. By increasing the fruit area by a small percentage, the system can generate some agricultural output even in deficient rainfall years with no canal irrigation supply. Perennial crops can increase economic productivity and farmers' incomes in good rainfall years. Some farmers have two or three milch cows and grow green fodder (lucerne) to feed them. Fruits and lucerne are drought-tolerant crops. Also, these crops act as insurance and enhance farmers' resilience against low rainfall years (Amarasinghe et al. 2021b).

Farmers in Huruluwewa can also consider more diversification of cropping patterns in the *yala* season. Given the existing rainfall patterns in Huruluwewa, fruits and fodder crops can better survive in low rainfall years and enhance income significantly. However, what makes farmers reluctant to grow high-value crops is a matter that needs further analysis.

Table 8. Comparison of the irrigation performance of Huruluwewa with the Sina irrigation system in Maharashtra, India.

Variable	Huruluwewa irrigation system (2018-2019[a])		Sina irrigation system (2010-2011[a])	
	CCA	WIZ	CCA	WIZ
Annual rainfall (mm)	1,151 (low rainfall year)		875 (high rainfall year)	
Main monsoon rainfall (mm)	891	261	870	5
Reservoir capacity (Mm^3)	67.65		67.95	
Water supply (Mm^3)	88.1	97.7	38.8	72.6
Cultivable land area (ha)	6,984	13,520	7,946	18,568
Cropped area (ha)	8,800	21,000	8,400	21,000
Consumptive fraction (%)		49		100
EWP (USD/m^3 TCWU)	0.50	0.78	0.47	0.29
EWP (USD/m^3 Total water supply)	0.18	0.35	0.19	0.31

Source: Data for Sina irrigation system are from Amarasinghe et al. 2021a.
Note: [a] The period 2018-2019 was one of the lowest rainfall years in Huruluwewa, and 2010-2011 was one of the highest rainfall years in the Sina irrigation system.

Conclusions

The Huruluwewa Irrigation System has many adaptation opportunities for enhancing EWP that would increase farmers' resilience against meteorological and agricultural droughts, which are more common today than several decades ago.

In the Huruluwewa WIZ, water depletion accounts for only half of the available water from rainfall, reservoir storage and groundwater. Farmers in Huruluwewa should consider diversifying away from rice to high-value crops—at least in the *yala* season. The dominant non-paddy crops that are grown at present have low EWP. The major non-paddy crops currently grown, such as maize and soybean, have even lower EWP. Crop diversification in the CCA will help farmers within the CCA as well as those in the buffer zone outside the CCA. Farmers in the buffer zone can use a substantial part of the recharged groundwater to increase their agricultural output.

Comparison of Huruluwewa with the Sina irrigation system in India shows stark differences in the irrigation performance of the two water-scarce irrigation systems. In Sina, policy interventions need not consider increasing irrigation WUE because there is hardly any water available for increasing crop CWU even in good rainfall years. In Huruluwewa, policy interventions in the command area should not consider increasing WUE, not because there is less water but because there is ample supply even in low rainfall years. The Huruluwewa Irrigation System and its farmers should consider diversifying to high-value crops. The available water is more than sufficient to meet the assured water needs of high-value crops.

However, this paper has not addressed some critical issues: Why is diversification not happening in the system now when there are no real water shortages? Do the perceived water and labor shortages, lack of information on prices of produce and the absence of value chains available to farmers hinder diversification to high-value crops? Diversification targets need to be discussed in seasonal meetings with all stakeholders, FOs, and the irrigation and agriculture departments. Diversification would also require policy, institutional and investment support.

Moreover, farmers should have access to monthly aquifer groundwater storage information, which they can use in planning assured water supply to high-value crops. The Irrigation Department should consider the conjunctive use of surface water and groundwater to increase EWP to enhance the resilience of farmers within the canal command area but also beyond it. The water storage in the reservoir meets the water needs wthin and outside the CCA.

Other interventions, which we have not looked at in this paper, but are currently being pilot tested as a bundled solution (crop insurance, flood/drought-tolerant seeds, weather and agronomic advisories), should also be required to support adaptation decisions. Short-term weather forecasting is necessary to enhance adaptation decisions in the irrigation system, which both system managers and farmers value during field observations. Preliminary observations from farmers in several parts of the country show the value of such information. Also, system managers also appreciate such information for proper irrigation scheduling. This will help risk-averse farmers to diversify to high-value crops. To complement these changes, it is imperative to also reduce post-harvest and market risks. Proper access to post-harvest storage and marketing information can boost farmers' incomes. Properly designed rainfall index-based insurance schemes can also reduce farmers' losses.

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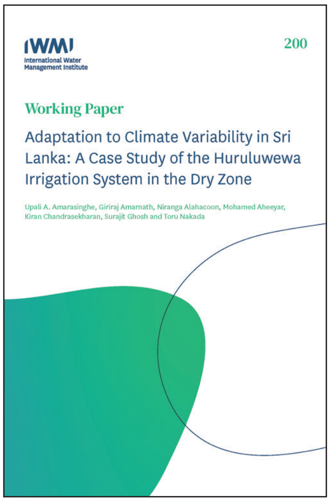

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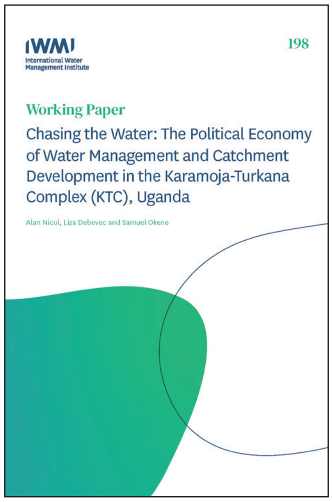

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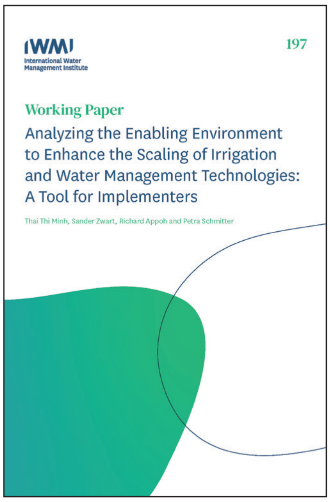

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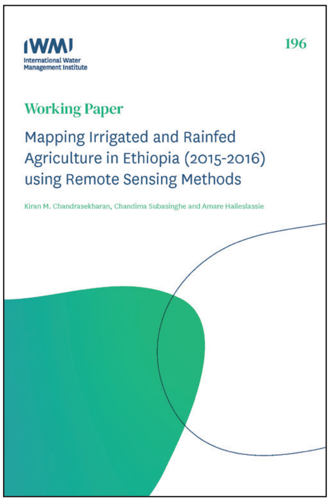

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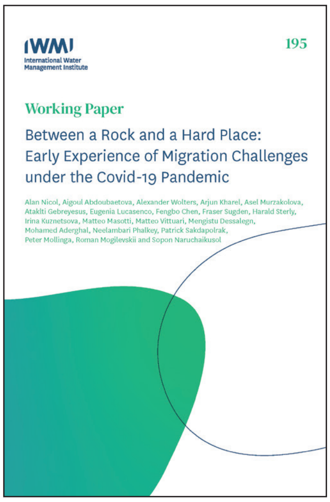

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IWMI is a CGIAR Research Center

ISSN 2012-5763
e-ISSN 2478-1134
ISBN 978-92-9090-931-6