*Tropical Agricultural Research (2022) 33(3): 247-259*

Contents available at: Sri Lanka Journals Online

Tropical Agricultural Research

Journal Home Page: https://tar.sljol.info


# Variation of Water Productivity in Paddy Cultivation Within a Tank Cascade: A Case Study in *Ulagalla*, Sri Lanka

K.K.P.N. Kahathuduwa[1*] and D.V.P. Prasada[2]

[1]*Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.*
[2]*Department of Agricultural Economics and Business Management, Faculty of Agriculture, University of Peradeniya, Sri Lanka.*

ARTICLE INFO

***Article history:***
Received: 30 June 2021
Revised version received: 20 October 2021
Accepted: 15 June 2022
Available online: 1 July 2022

***Keywords:***
Small tank cascade systems
Upstream
Downstream
Water productivity
Paddy cultivation

**Citation:**
Kahathuduwa, K. K. P. N. and Prasada, D. V. P. (2022). Variation of Water Productivity in Paddy Cultivation Within a Tank Cascade: A Case Study in Ulagalla, Sri Lanka. Tropical Agricultural Research, 33(3): 247-259.

DOI: http://doi.org/10.4038/tar.v33i3.8569

Kahathuduwa, K. K. P. N.
https://orcid.org/0000-0002-8948-2602



**ABSTRACT**

The village tank cascade systems are identified as an important invention of the hydraulic civilization of Sri Lanka. Water productivity is a widely used indicator to measure the performance of these types of systems. A combination of agronomic and socioeconomic factors acts as key elements influencing water productivity in paddy cultivation and its variation. The current study focused on variations and determinants of the upstream and downstream water productivity of a cascade. The study was carried out as a comparative study investigating how the factors affect upstream and downstream water productivity in paddy cultivation separately in the Ulagalla tank cascade system in dry zone Sri Lanka during the *Maha* and *Yala* seasons over the years 2019-2021. The study revealed water productivity in paddy cultivation of the upstream and the downstream Ulagalla tank cascade was at satisfactory levels with reference to global standards. Wildlife conflicts, previous crop losses due to natural disasters, and length of the field canal displayed significant, negative relationships with paddy water productivity. Farm size, command area, activities of farmer organization, water head, and availability of lining in the field canal displayed significant, positive relationships with water productivity in paddy cultivation.

[*]Corresponding author: piyumikahathuduwa327@gmail.com

## INTRODUCTION

Growing paddy has been a key part of the culture in most Asian countries including Sri Lanka. Rice is not only a staple food but also an integral part of Sri Lankan culture (Rijsberman, 2004). Throughout the island for about 1.8 million farm families, paddy cultivation is their main livelihood. Currently, as a country, Sri Lanka annually produces 2.7 million tons of rough rice, and it satisfies 95% of the domestic requirement (DOA, 2020). Despite the fact that dry zone agriculture is highly vulnerable due to a prolonged drought season and diminishing precipitation, it contributes to 70% of national paddy cultivation (Withanachchi *et al*., 2014).

It is a well-established fact that drought is one of the main constraints (Tuong & Bouman, 2003), and water is the limiting factor (Panabokke *et al.,* 2002*)* in the dry zone paddy cultivation. To triumph over these constraints by retaining more water in the dry zone, village tank cascade systems were invented by the ancient hydraulic civilization of Sri Lanka (Bandara, 1985; Dharmasena, 2012). The origin of village tank systems dates back to the 4th century B.C. or before (Witharana, 2004), which means the village tank cascade system possesses a history of more than 2000 years (Dharmasena, 2004). These human-made small reservoirs can be commonly observed in the peneplain land surface of the dry zone (Dharmasena, 1991). Through acclimatization to nature, the village tank cascade systems have become a constituent of the rural ecosystem (Witharana, 2004). Although anciently these human-made ecological constructions were sustainable systems that enabled high agricultural production along with water, soil, and biodiversity conservation, currently these valuable systems have been undergoing many problems.

The main reasons for these problems are the chronological changes in economic, socio-cultural, and institutional factors. These changes have resulted in the abandonment of 3062 small village tanks in the dry zone (Witharana, 2004), while the island-wide number is 7753 tanks (Panabokke *et al*., 2002). In addition to the complete abandonment of small village tanks, essential land components of these tanks were lost or reduced due to intensive cultivation and colonization. Since around 90% of small village tanks are clustered into cascade systems located all around the island, the abandonment of small tanks could cause complete or partial abandonment of cascades (Bandara, 1985; Panabokke, 2004).

Water productivity is considered a vital indicator of how efficiently and sustainably the water resource is used for agricultural practices. Currently, in agriculture, water productivity has acquired important attention as it underlines the importance of water conservation in agricultural production. There are irrigation-related, land, climate, and farmer-based factors that directly and indirectly affect water productivity which is important in improving water productivity and implementing water management practices (Barker *et al*., 1999). Before focusing on the methodology adopted, the following section discusses different definitions and applications of water productivity in paddy cultivation.

Water productivity is enumerated with reference to water use in various production sectors as the amount of output per unit of water used (Pourgholam-Amiji *et al*., 2021). According to Molden *et al*. (2003), water productivity is a performance indicator generally defined as the physical quantity or economic value derived from the use of a unit of water.

Thus, for paddy cultivation, it is the paddy yield obtained based on the water volume used in production (Cao *et al*., 2015). López-López *et al.* (2018) have pointed out that water productivity in paddy cultivation is the weight of the paddy over cumulative water input (irrigation plus rainfall). Therefore, in rain-fed systems like tank cascades, the cumulative water input for paddy cultivation can be identified as the total height of the water used by the farmer for flooding purposes in the field at different growth stages of the paddy crop.

Even a minor improvement in water productivity has a large impact on water budgeting, food security, raising farm-level income, and alleviation of poverty & inequality (Giordano *et al*., 2017). Hence, it is important to identify the factors affecting water productivity in paddy cultivation and their relationships in order to improve it. A combination of agronomic and socio-economic constraints acts as key elements of water productivity in paddy cultivation and its variations. (Daléus *et al*., 1989). But the factors affecting water productivity will vary according to location, even within the same system (Barker *et al*., 1999). There are studies that have focused on reasons for the variability of water productivity within the same site (Daléus *et al*., 1988; Daléus *et al*., 1989).

Thus, the main objective of this research was to investigate how the upstream water productivity in paddy cultivation differs from the downstream water productivity in paddy cultivation of a cascade and to identify how the factors affect differently upstream and downstream water productivity of a cascade, taking *Ulagalla* cascade as the study site.

## METHODOLOGY

### Site selection

The selected site for the study was the *Ulagall tank* cascade system located in *Thirappane* and *Kakirawa* Divisional Secretariats, Sri Lanka, adjacent to *Thirappane* and *Mahakanumulla* tank cascades. *Ulagalla* tank cascade is categorized as a large, long & straight, broad & wavy, undulating cascade having valleys at the head and middle with a moderately sloping axis (Sakthivadivel *et al.*, 1994), while the form index (the ratio between length to width) of the cascade is 2.08 (Sakthivadivel *et al*., 1996). The cascade covers around 51 km$^2$ of land area in the low country dry zone (DL1b), originally with 19 completely rain-fed tanks (*i.e.* without any connection to a major irrigation system) (Kumari *et al*., 2018). Of these, only nine tanks function as irrigational tanks at the moment (Figure 1).

### Data collection

Both primary and secondary data were collected for the study through field surveys and household surveys. Field surveys were conducted to explore the research site. During the field surveys, tanks were identified for the study according to their current function. Then the water spread area, catchment area, command area, and homestead area under each selected tank were estimated.

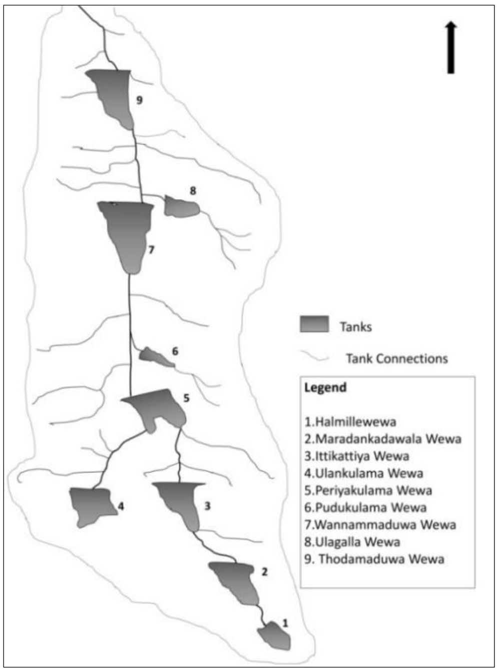


**Figure 1: Schematic representation of the *Ulagalla* cascade (Recreated based on Sakthivadivel *et al.*, 1994).**

## RESULTS AND DISCUSSION

Spatial mapping was conducted to identify and compare the changes in land use patterns in the *Ulagalla* cascade. The map data for the current land use patterns were obtained from Google Earthpro software. The demarcations of the structures were verified by field visits. The satellite images from Google Earth Pro software were used for this estimation. The 1:40 000 scaled satellite images of the water spread area, command area, feeding area, and homestead area of each tank were pasted into a $6.35*10^{-3}$ m * $6.35*10^{-3}$ m grid. Therefore, each square of the grid represents 0.0625 $km^2$ of the actual site. Then the squares covering each demarcated part of the cascade were counted manually and converted into $km^2$. The demarcation of each area was verified during the field observations and key informant surveys. The water spread areas of the tanks are taken at the full supply stage of the tanks.

A household survey was carried out from February to March 2020, representing 25% of farmer households registered under the Farmer Organizations in *Ulagalla* cascade. Accordingly, randomly selected 170 individuals were interviewed using a pretested, structured questionnaire. Secondary data such as farmer registration lists, farmer organization registration lists, and fertilizer subsidy registration lists were collected from Divisional Secretariats, Agrarian Service Centres, and *Grama Seva* Officers.

### Data analysis

As stated earlier, the study was carried out as a comparative study. The upstream and the downstream paddy water productivities and determinates of them were studied to identify the variations between the upstream and the downstream. The data of the *Yala* 2019, *Maha* 2019/2020, and Maha 2020/21 seasons in upstream and downstream tanks were analyzed separately to identify the variations of water productivity in paddy between the upstream downstream and *Yala* - *Maha*. The boundary of the upstream and the downstream of the cascade was demarcated at the point where the cumulated water surface areas of upstream and downstream tanks were approximately equal (Figure 1).

The literature referred to for the selection of variables for the empirical model is discussed below. Daléus *et al*. (1989) has conducted a study to investigate the relationship between water availability/ water coverage and agricultural water productivity; Wijayaratna (1993); Vermillion (1997) emphasis the relationship between the Farmer Organization activities and agricultural water productivity; Ashraf *et al*. (2010) have found that the relationship between command area and agricultural water productivity is positive, while the same study showed a negative relationship between individual farm size and agricultural water productivity; studies done by Zwart and Bastiaanssen 2004; Rockström 2003 prove fertilizer usage has a positive relationship with agricultural water productivity; According to Dharmasena, (2004) construction of agro wells for upland crop cultivation may affect the available water level in the tanks; Barker *et al*. (1999); Van-dam and Malik (2003); Van-dam *et al*. (2006) have found that the agricultural water productivity can be increased by lining distribution and field canals.

Previous studies showed that climatic factors, crop scheduling, and crop varieties have significant impacts on water productivity (Modlen *et al.,* 2003; Mdemu *et al.,* 2013). According to the farmer organization members, farmers, and agrarian officials, the decisions on paddy varieties that are going to be cultivated (during the research period BG 350 and 352 were used in the study site) and the time of cultivation are taken by the Farmer Organizations as collective decisions. Tennakoon (1986), also stated that these decisions are taken as collective decisions through farmer organizations in the village-tank systems. As the climatic factors were the same for the site since the whole cascade spread only an area of 51$km^2$. Hence those factors are not taken as independent variables considering those factors as constants for the site throughout the period that study was carried out. Accordingly, the conceptual framework for the study is shown in Figure 2.

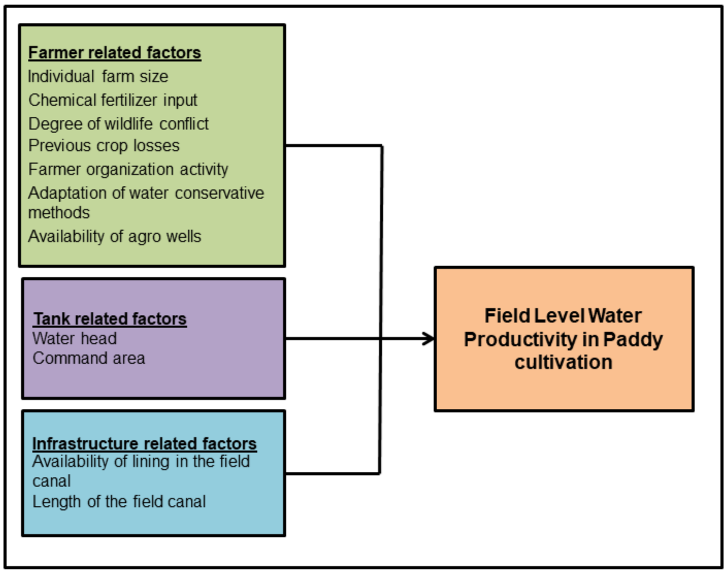


**Figure 2: Conceptual framework for the study.**

Water productivity in paddy cultivation was taken as the dependent variable for the study. Field level water productivity was calculated using the following equation (Eq.01).

$$WP = Y/V \qquad \text{(Eq.01)}$$

Where, WP is the water productivity at farmer field level, Y is the paddy yield, and V is the volume of water used for paddy cultivation (Van-dam & Malik, 2003; Giordano *et al*., 2017).

The cumulative water input for paddy cultivation is taken as the total height of the water used by the farmer for flooding purposes in the field at different growth stages of the paddy crop.

The independent variables were categorized into three types as farmer-related factors, tank-related factors, and infrastructure-related factors (Figure 2). Under farmer related factors Individual farm size (ha), Chemical fertilizer input (kg/ha), *Degree of human-wildlife conflicts†, Index for previous crop losses due to natural disasters‡ , Farmer organization activity (index)§, Adaptation of water conservative methods (dummy), and Availability of agro wells (index) **were taken. Under tank-related factors, Water head (m)††, and Command area (ha) under respective tank were taken while under infrastructure-related factors, Availability of lining in the field canal (index), ‡‡and Length of the field canal (km) were taken.

The empirical model estimated is given in the equation 02.

$$Y= \beta_0+ \beta_i V_i + U \qquad \text{(Eq: 02)}$$

Where, $Y$ Field level water productivity in paddy, $V_1$ - Iindividual farm size, $V_2$ -Chemical fertilizer input, $V_3$ - Degree of wildlife conflict, $V_4$ - Previous crop losses, $V_5$ - Farmer organization activity , $V_6$ - Adaptation of

* Chemical fertilizer input: the amount of main chemical fertilizers (*i.e.* Urea, MOP and TSP) to the paddy field in kg/ha

† Degree of human-wildlife conflicts: (1-very low, 2- low, 3-moderate, 4- high, 5-very high)

‡ Index for previous crop losses due to natural disasters: frequency of occurrence of the crop losses due to natural disasters, rupee value of the crop losses due to natural disasters taken into the account

§ Index for farmer organization activity: the respondents were asked to rank the services of the Famer Organizations such as maintenance of tank parts, distribution of water, distribution of fertilizer subsidy and decision making on cultivation process (1-very low, 2- low, - moderate, 4- good, 5- very good)

** Index for agro wells: the availability of the agro wells, the distance of the agro well to the tank and the paddy field are taken into consideration

†† Water head: the available water head of the tank at the beginning of the season

‡‡ Index for availability of lining in the field canal: the availability of lining in the field canals, if available the length of the lining, and the current condition of the lining (1-poor, 2-moderate, 3-good) taken into the consideration

water conservative methods, $V_7$ - Availability of agro wells, $V_8$ - Water head, $V_9$ - Command area, $V_{10}$ - Availability of lining in the field canal, $V_{11}$-Length of the field canal, and $U$- Error term. $V_7$ - Availability of agro wells, $V_8$ - Water head, $V_9$ - Command area, $V_{10}$ - Availability of lining in the field canal, $V_{11}$-Length of the field canal, and $U$- Error term.

## RESULTS AND DISCUSSION

Altogether 170 respondents participated in the household survey, where 70% (119) of the sample were male, and 30% (51) were female. The average age of the respondents was 45.90 years. The average number of years of schooling (*i.e.* years of formal education) was 10.5 years. Though all the respondents were engaged in paddy farming, 36.25% of them were government employees, and 22.94% and 24.71% were private-sector employees and engaged in business ventures respectively. The remaining 21.88% of the respondents were engaged in paddy farming as their sole livelihood. Further, 68.24% of the sample were commercial paddy farmers, and 31.76 % were subsistence paddy farmers.

### Hydrological status of the cascade

The hydrological linkages such as the upstream and downstream water flows, and the hydrological endowment are also important parameters for identifying cascades' functions and performances. The hydrological endowment is an indication of the adequacy or the inadequacy of water for feeding the existing feeding area (Gunarathna & Kumari, 2014; Witharana, 2004). It). The ratio of the total catchment area of the cascade (CAA) to the total water spread area of all tanks located within the cascade (WA), and the ratio of the total command area under all the small tanks (COA) to the total water spread area (WA) are two quantitative parameters, which can be used to express the hydrological endowment of a cascade (Jothi and Panabokke, 2001). Where CAA to WA ratio should be higher than eight (8) and COA to WA ratio should be less than 1 to have adequacy of water for feeding the exiting feeding area. In the *Ulagalla* tank cascade, the CAA to WA value was measured to be 8.74 and COA to WA value as 0.97.

Technically, according to the above values, the cascade is in a state where it can feed its command area for both *Yala* and *Maha* seasons. However, the depths of the tanks have decreased significantly. Dharmasena (1991) stated that the storage capacities of the village tanks decline at the same rate as the depth reduction due to sedimentation. Almost all the tanks in the cascade are silted hence, the water holding capacity of the *Ulagalla* cascade has reduced approximately by half of its initial capacity. Figure 3 illustrates how the depths of the corresponding tanks have changed over 20 years.

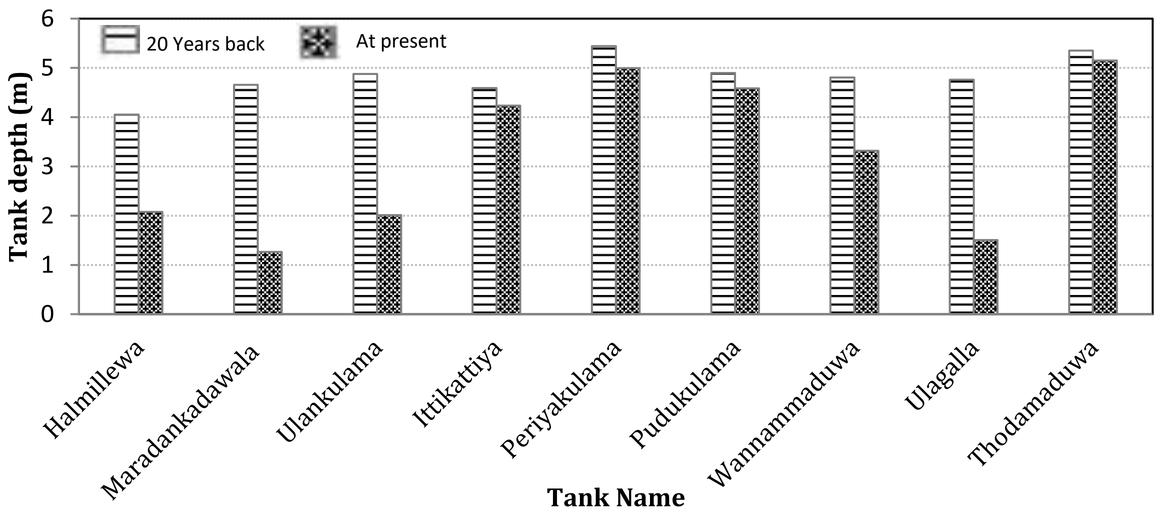


**Figure 3: Average effective depth of the tanks 20 years back vs. present**

The gradual reduction of cultivable extend under respective tanks results from the reduction of storage capacities. Further, the non-availability of water in the tank during the dry season for the cultivation purposes can be resulted (Dharmasena, 1991).

**Descriptive statistics of variables measured**

In the current study, the water productivities in paddy cultivation upstream areas are reported to be higher than downstream in both the *Yala* (2019) and *the Maha* (2019/2020) seasons. Compared with the global range, the values for upstream and downstream in both the *Yala* (2019) and the *Maha* (2019/2020) seasons were at a satisfactory level. In the upstream, the *Yala* and *Maha* values were reported as 0.72 kg/m$^3$ and 1.07 kg/m$^3$ respectively, while in the downstream the respective values were 0.47 kg/m$^3$ and 0.83 kg/m$^3$). The global value for water productivity in paddy cultivation ranges from 0.5 kg/m$^3$ to 1.1 kg/m$^3$ (FAO, 2021).

The average upstream paddy yield in *Yala* (2019) and *Maha* (2019/2020) season s were 2948.61 kg/ha and 3728.12 kg/ha respectively, whereas, the respective values in the downstream were 2686.45 kg/ha and 3364.45 kg/ha. The average paddy yield value for rain-fed systems in the Anuradhapura district for the respective *Yala* season was 3870 kg/ha (DCS, 2019), and for *the Maha* season, it was 4716 kg/ha (DCS, 2020). Although in both seasons, the average paddy yield in the upstream and downstream was recorded as lower than the district's average values upstream values were higher than downstream values in both seasons.

Upstream, the average individual farm size was higher than that of downstream in both seasons (see Table 1). In the *Yala* (2019) season, the cultivated area was considerably lower than *Maha* (2019/2020) both upstream and downstream. The farmers are reluctant to cultivate the paddy lands in the *Yala* season since the occurrence and the amount of rainfall are uncertain (Aheeyar, 2001). The findings of the present study can be supported by the above statement by Aheeyar (2001). As farmers were reluctant to cultivate during the *Yala* season since they were not certain about the adequacy and the occurrence of rainfall.

The amount of average fertilizer usage across the cascade was higher than the chemical fertilizer subsidy (289.6 kg/ha) by the government. The farmers believe that the given amount of fertilizer as the subsidy was not sufficient for them to get better yields, which was reported as the main reason for them to use fertilizer than the subsidy. The previous crop losses due to natural disasters downstream were higher than that upstream (see Table 1). The downstream paddy fields were been affected by the floods soon after cultivation was started, especially during *the Maha* season of the surveying year can be given as the possible reason for this situation. According to Tennakoon (2004), the regulated storage of water in upstream tanks in a cascade, reduces the risk of overflowing the downstream tanks during the seasons of above-average rainfalls. However, as mentioned above, the tank depths have reduced in significant values hence (see Figure 3), the water-holding of the tanks both upstream and downstream of the cascade was reduced. Therefore, the crops downstream were highly damaged because the overflowing water would be logged into the downstream paddy lands.

Upstream tanks act as buffer reservoirs to supply water to the downstream tanks when they are deficient in water to save crops (Dharmasena, 2004). However, in the current situation, the upstream tanks are not able to supply water for the downstream tanks since they are also lacking in water during the dry season.

In both upstream and downstream, the number of farmers using water conservative methods was higher in *the Yala* season (Table 1) as in the *Yala* season available amount of water for cultivation is limited. The water head in the tank was higher upstream for both seasons. In *Maha,* a higher water head was maintained in the tanks because of the onset of *the Maha* season, and during the *Maha* season, northeast monsoons are being activated. Usually, the northeast monsoon contributes more precipitation than the southwest monsoon in *Yala*. Most of the land preparations and early stages of cultivation are practiced using rainwater during *Maha*, which will save the stored water in the tank (Shakthivadevel *et al.,* 1994; Tennakoon, 1980). Since some stages of cultivation can be carried out with direct rainwater and the stored water in the tank is available for the latter stages of the cultivation, the farmers tend to cultivate more area of land in the *Maha* season than in the *Yala* season. The command area under each tank in *Maha* was higher compared to the *Yala* season (Table 1).

**Table 1: Descriptive analysis of the variables for 2019- *Yala* and 2019/2020- *Maha.***

| Variable | Upstream | | Downstream | |
|---|---|---|---|---|
| | ***Yala* season** | ***Maha* season** | ***Yala* Season** | ***Maha* Season** |
| | **Mean (Sd*)** | **Mean (Sd)** | **Mean (Sd)** | **Mean (Sd)** |
| Paddy water productivity (kg/m$^3$) | 0.72 (0.41) | 1.07 (0.08) | 0.47 (0.23) | 0.83 (0.11) |
| Individual farm size (ha) | 0.46 (0.21) | 0.68 (0.04) | 0.25 (0.19) | 0.57 (0.17) |
| Chemical fertilizer input (kg/ha) | 391.23 (55.38) | 388.72 (58.47) | 371.13 (44.15) | 366.28 (49.89) |
| Degree of human-wildlife conflicts (1-very low, 2- low, 3- moderate, 4- high, 5-very high) | 2.11 (1.19) | 2.58 (1.14) | 4.32 (1.33) | 3.14 (0.98) |
| Index for previous crop losses due to natural disasters | 3.14 (1.21) | 4.03 (1.43) | 4.51 (2.12) | 4.63 (1.98) |
| Index for farmer organization activity | 3.38 (1.18) | 2.81 (1.02) | 2.92 (3.32) | 1.94 (1.52) |
| Dummy variable adaptation of water conservative methods (:1-uses water conservation methods, 0- does not use water conservation methods) | 0.61 (1.22) | 0.11 (1.03) | 0.43 (0.12) | 0.18 (0.14) |
| Index for availability of agro wells | 2.14 (4.22) | 3.40 (2.12) | 2.67 (1.07) | 4.07 (1.34) |
| Water head (m) | 1.91 (0.78) | 2.39 (1.89) | 1.42 (1.27) | 2.19 (3.40) |
| Command area (ha) | 24.42 (17.12) | 50.59 (32.18) | 14.57 (6.7) | 48.52 (34.06) |
| Index for the availability of lining in the field canal | 2.08 (2.42) | 1.48 (1.28) | 2.11 (1.11) | 1.67 (2.56) |
| Length of the field canal (km) | 0.41 (0.07) | 0.72 (0.21) | 0.35 (0.42) | 0.81 (1.04) |

*Sd: Standard Deviation

### Results of the regression analysis

Individual farm size was having a significant positive relationship with water productivity in paddy cultivation, in the *Yala* (2019*)* seasons upstream and in the *Yala* (2019) and *Maha* (2019/2020) seasons downstream. This result can be supported by the findings of Ashraf *et al.* (2010), who found a positive relationship between individual farm size and water productivity in paddy cultivation. The possible reason in this particular scenario could be that when a single farmer has a larger area of paddy lands s/he is able to have a cumulatively larger amount of water compared to farmers with a lesser amount of paddy lands. They can reuse that water amount within their paddy lands by flooding different sets of paddy plots at different times.

Human-wildlife conflicts were found to have a significant, negative relationship with water productivity in paddy cultivation in both seasons upstream as well as in the *Yala* season downstream. Wild animals such as peacocks damage the crop throughout the cultivation period starting from broadcasting. The downstream elephants were reported as the main source of crop damage. In the *Yala* season, when food and water are scarce in the forests, elephants tend to come to villages looking for food and water.

The previous crop losses due to natural disasters have a significant negative relationship with water productivity in paddy cultivation, in the *Yala* season upstream and in both the *Yala* and *Maha* seasons downstream. The possible reasons for the above finding can be the occurrence of drought conditions in the *Yala* seasons and the high-water logging conditions downstream in the *Maha* seasons. According to Aheeyar (2001), the uncertainties about expected rainfall generate reluctance in farmers to cultivate in the *Yala* seasons. This scenario is applicable to the current research site as well. Additionally, even though farmers cultivate in the *Yala* seasons, they have less attention on their paddy lands because over 55% of them engage in daily waged jobs. Therefore, they do paddy farming at a subsistence level or as their part-time livelihood.

Activities of farmer organizations happen to show a significant, positive relationship with water productivity in paddy production in both *Yala* and *Maha* seasons upstream and downstream (see Table 2). It is evident in the literature that transferring the operational and management rights on the irrigation water to the farmer organizations has positive effects on yields, water productivity, and income (Wijayaratna, 1993; Vermillion, 1997). In these cascade systems, crop scheduling, irrigation management, and minor level maintenance are done by the farmer organizations with the collaboration of government agents (Tennakoon, 1986). The opening and closing of sluice gates on time, and minimizing wastage of tank water through fixing minor level malfunctions of tank infrastructure are some main duties of farmer organization with importance to water productivity in paddy water cultivation. A person selected by the farmer organization members named *Vel Vidhane* is responsible for the water distribution, and he is responsible for giving all the farmers equal and adequate water supply. Thus, the proper operationalization of the farmer organizations could be the reason for the significant positive relationship between the activities of farmer organizations and water productivity in paddy cultivation.

Water head was found to be having a significant, positive relationship with water productivity in paddy cultivation both upstream and downstream in *Yala* (2019) and *Maha* (2019/2020) season s. The water head (*i.e.* water availability or water allocation) of irrigation water is a factor determining the water productivity in paddy cultivation (Daléus *et al*., 1988). Having a higher level of water head causes better water supply at the lower-level fields, which will increase water productivity.

According to Barker *et al.* (1999), canal lining is a general strategy for increasing water productivity. The results of this study also show that there was a significant, positive relationship between the availability of lining in the field canal and the water productivity in paddy cultivation. When there is lining in the field canal, the water wastage through seepage and percolation can be minimized and the crops will get an adequate amount of water for the production, reaching the expected yield. Accordingly, when the water has to convey through a non-lined canal for a longer distance, water loss through seepage, percolation, and evaporation is increased.

This study also reveals that the length of the field canal has a significant negative relationship with water productivity in paddy cultivation upstream in the *Yala* (2019) season and downstream in both *Yala* (2019) and *Maha* (2019/2020) seasons. Downstream during the *Yala* season, wastage through field canals may further reduce the water use efficiency in paddy cultivation furthermore. Chemical fertilizer input, the adaptation of water conservative methods, and the availability of agro wells did not show significant relationships with water productivity in paddy cultivation.

**Table 2: The factors affecting water productivity in paddy cultivation.**

| Variable | **Upstream** | | **Downstream** | |
|---|---|---|---|---|
| | ***Yala* season** | ***Maha* season** | ***Yala* season** | ***Maha* season** |
| | **Co-efficient (Standard error)** | **Co-efficient (Standard error)** | **Co-efficient (Standard error)** | **Co-efficient (Standard error)** |
| Individual farm size (ha) | 0.001$^{**}$<br>(0.001) | 0.004<br>(0.022) | 0.004$^{**}$<br>(0.003) | 0.072$^{*}$<br>(0.006) |
| Chemical fertilizer input (kg/ha) | 0.000<br>(0.100) | 0.000<br>(0.050) | 0.000<br>(0.420) | 0.000<br>(0.000) |
| Degree of human-wildlife conflicts (1- very low, 2- low, 3-moderate, 4-high, 5- very high) | -0.013$^{**}$<br>(0.004) | -0.044$^{**}$<br>(0.005) | -0.004$^{**}$<br>(0.006) | -0.011<br>(0.105) |
| Index for previous crop losses due to natural disasters | -0.001$^{**}$<br>(0.003) | -0.019<br>(0.040) | -0.013$^{**}$<br>(0.002) | -0.073$^{*}$<br>(0.005) |
| Index for farmer organization activity | 0.018$^{**}$<br>(0.005) | 0.010$^{**}$<br>(0.003) | 0.004$^{*}$<br>(0.002) | 0.004$^{*}$<br>(0.009) |
| Adaptation of water conservative methods (1- uses water conservative methods, 0-Does not uses water conservative methods) | 0.081<br>(0.100) | 0.100<br>(0.073) | 0.103<br>(0.109) | 0.014<br>(0.139) |
| Index for availability of agro wells | 0.012<br>(0.103) | 0.107<br>(0.023) | 0.024<br>(0.044) | 0.141<br>(0.110) |
| Water head (m) | 0.002$^{**}$<br>(0.003) | 0.011$^{**}$<br>(0.001) | 0.000$^{**}$<br>(0.000) | 0.000$^{**}$<br>(0.000) |
| Command area (ha) | 0.004$^{**}$<br>(0.005) | 0.005$^{**}$<br>(0.001) | 0.001$^{**}$<br>(0.004) | 0.010$^{*}$<br>(0.003) |
| Index for availability of lining in the field canal | 0.063$^{**}$<br>(0.001) | 0.006$^{**}$<br>(0.002) | 0.003$^{*}$<br>(0.007) | 0.007$^{**}$<br>(0.002) |
| Length of the field canal (m) | -0.070$^{*}$<br>(0.003) | -0.017$^{*}$<br>(0.003) | -0.007$^{**}$<br>(0.006) | -0.006$^{*}$<br>(0.005) |
| Intercept | -0.195$^{**}$<br>(0.003) | 1.561$^{**}$<br>(0.002) | 1.380$^{**}$<br>(0.408) | 1.497$^{*}$<br>(0.016) |
| $R^2$ | 0.633<br>(n = 84) | 0.717<br>(n = 84) | 0.698<br>(n = 86) | 0.499<br>(n = 86) |

$^{**}$Statistically significant at 5% level
Statistically significant at 10 %level

## CONCLUSION

Although the values for the hydrological endowment of the cascade are at a satisfactory level, the water holding capacity of the cascade as a whole was observed to have reduced by approximately half of its initial capacity due to the siltation of tanks. The water productivity in paddy cultivation of the upstream and the downstream *Ulagalla* tank cascade was at satisfactory levels (with reference to global standards). Policy reforms of tank cascade systems, in terms of tank infrastructure enhancement, farmer knowledge, and management of wildlife threats were found to be critical determinants for sustainable production of the system.

**ACKNOWLEDGEMENTS**

Authors acknowledge the support from the AHEAD/DOR/52 project.

**REFERENCES**

Aheeyar, M. M. M. (2001). Socioeconomic and Institutional Aspects of Small Tank Systems in Relation to Food Security. In Panabokke, C. R., Tennakoon, M. U. A., & Ariyabandu, R. D. S. (Ed), Proceedings of the Workshop on Food Security and Small Tank Systems in Sri Lanka (pp. 64-78).

Ashraf, M., Nasir, A., & Saeed, M. M. (2010). Evaluation of the existing water productivity in the lower Bari Doab Canal (LBDC) command-A case study. *Pakistan Journal of Agricultural Science, 47*(4), 389-397.

Bandara, C. M. (1985). Catchment ecosystems and village Tank Cascades in the dry zone of Sri Lanka a time-tested system of land and water resource management. In Strategies for river basin management (pp. 99-113). Springer, Dordrecht.

Barker, R., Dawe, D., Tuong, T. P., Bhuiyan, S. I., & Guerra, L. C. (1999). The outlook for water resources in the year 2020: challenges for research on water management in rice production. Southeast Asia, 1, 1-5.

Cao, X., Wang, Y., Wu, P., & Zhao, X. (2015). Water productivity evaluation for grain crops in irrigated regions of China. *Ecological indicators*, *55*, 107-117.

Daléus, E., Palm, O., & Lundqvist, J. (1989). Water allocation, land tenure, and yield in a purana village, Sri Lanka. *International Journal of Water Resources Development*, *5*(1), 25-37.

Daleus, E., Palm, O., Sandell, K., Jayawardena, S. N., & Siripala, G. D. (1988). Management and environmental constraints to rice yield within a village irrigation system—a case study from Sri Lanka. *GeoJournal, 17*(3), 401-412.

DCS, (2019). Paddy Statistics: 2019 *Yala* Season, Annual report of the Department of Census and Statistics, Sri Lanka. [Online]. [Accessed on 27.05.2021]. [http://www.statistics.gov.lk/Agriculture/StaticalInformation/PaddyStatistics/MetricUnits/IncludingMahaweli/2019*Yala*]

DCS, (2020). Paddy Statistics: 2019/2020 *Maha* Season, Annual report of the Department of Census and Statistics, Sri Lanka. [Online]. [Accessed on 27.05.2021]. [http://www.statistics.gov.lk/Agriculture/StaticalInformation/PaddyStatistics/MetricUnits/IncludingMahaweli/2019-2020Maha]

Dharmasena, P. B. (1991). Present use of land and water resources in village tank farming: a case study in Maha Kanumulla cascade. J Soil Sci Soc Sri Lanka, 7, 1-17.

Dharmasena, P. B. (2004). Small tank heritage and current problems. In: (Aheeyar, M. M. (Ed), Small Tank Settlements in Sri Lanka, Proceedings of a Symposium, Hector Kobbekaduwa Agrarian Research and Training Institute Colombo.8.

Dharmasena, P. B. (2012). Watershed-based Governance in Ancient Sri Lanka. Department of Agriculture, Sri Lanka.

DOA (2020). Rice. Retrieved from: https://www.doa.gov.lk/rrdi/index.php/en/crop/42-crop-rice-cultivation, vol. 2020, Department of Agriculture, Sri Lanka.

FAO, (2021). Why agricultural water productivity is important for the global water challenge [Online]. [Accessed on 27.05.2021]. [http://www.fao.org/3/y4525e/y4525e06.htm]

Giordano, M., Turral, H., Scheierling, S. M., Tréguer, D. O., & McCornick, P. G. (2017). 9789290908487: Beyond "More Crop per Drop": evolving thinking on agricultural water productivity (Vol. 169). Colombo, Sri Lanka: International Water Management Institute (IWMI) Washington, DC, USA: The World Bank.

Gunarathna, M. H. J., & Kumari, M. K. N. (2014). Sustainable management of Malwathu Oya Cascade-I: Present status and future needs. *GSTF Journal on Agricultural Engineering (JAE), 1*(1).

Kumari, M. K. N., Sakai, K., Kimura, S., Nakamura, S., Yuge, K., Gunarathna, M. H. J. P., ... & Duminda, D. M. S. (2018). Interpolation methods for groundwater quality assessment in tank cascade landscape: a study of ulagalla cascade, Sri Lanka. *Applied Ecology and Environmental Research, 16*(5), 5359-5380.

López-López, R., Jiménez-Chong, J. A., Hernández-Aragón, L., & Inzunza Ibarra, M. A. (2018). Water productivity of rice genotypes with irrigation and drainage. *Irrigation and Drainage*, *67*(4), 508-515.

Mdemu, M. V., Francis, T., & Wurbs, R. (2013). Productivity of water in large rice (paddy) irrigation schemes in the upper catchment of the Great Ruaha River Basin, Tanzania. *Water resources planning, development and management*, 117-142.

Molden, D., Murray-Rust, H., Sakthivadivel, R., & Makin, I. (2003). A water-productivity framework for understanding and action. *Water productivity in agriculture: Limits and opportunities for improvement*, (1).

Jothi, V. and Panabokke, C.R. (2001). The nature and properties of small tank systems of the dry zone and their sustainable production thresholds. In: Proceedings of the workshop on food security and small tank systems in Sri Lanka. National Science Foundation, Sri Lanka, Colombo, 33–47.

Panabokke, C. R., Sakthivadivel, R., & Weerasinghe, A. D. (2002). Evolution, present status and issues concerning small tank systems in Sri Lanka (No. H036586). Colombo: International Water Management Institute.

Panabokke, V. J. D. C. (2004). Small Tank Settlements in Sri Lanka. Small Tank Settlements. In: Aheeyar, M.M. (Ed), Small Tank Settlements in Sri Lanka, Proceedings of a Symposium, Hector Kobbekaduwa Agrarian Research and Training Institute Colombo.8.

Pourgholam-Amiji, M., Liaghat, A., Khoshravesh, M., & Azamathulla, H. M. (2021). Improving rice water productivity using alternative irrigation (case study: north of Iran). *Water Supply*, *21*(3), 1216-1227.

Rijsberman, F. (2004) Growing more rice with less water. *Paddy and Water Environmental Research, 2,* 181-183.

Rockström, J. (2003). Water for food and nature in drought–prone tropics: vapour shift in rain–fed agriculture. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 358(1440), 1997-2009.

Sakthivadivel, R., Fernando, N., Panabokke, C.R. and Wijayaratna, C.M. (1996). Nature of small tank cascade systems and a framework for rehabilitation of tanks within them. Sri Lanka. Country Paper no.13. Colombo, Sri Lanka: International Irrigation Management Institute.

Sakthivadivel, R., C.R. Panabokke, N. Fernando and C.M. Wijayarathna, (1994). Guidance package for water development component of small tank cascade systems, Initial Environmental Evaluation Report, Sri Lanka field operations of IIMI

Tennakoon, M. U. A. (1980). Desertification in the dry zone of Sri Lanka. *Perception of Desertification*, *190*, 4.

Tennekoon, M.U.A (1986) Drought Hazard and Rural Development, Central Bank, Colombo.

Tennakoon, M. U. A. (2004). Tanks are not Mono Functional: They are Multi-

Functional. . In: Aheeyar, M.M. (Ed), Small Tank Settlements in Sri Lanka, Proceedings of a Symposium, Hector Kobbekaduwa Agrarian Research and Training Institute Colombo.8

Tuong, T. P., & Bouman, B. A. M. (2003). Rice production in water-scarce environments. Water productivity in agriculture: Limits and opportunities for improvement, 1, 13-42.

Van Dam, J. C., & Malik, R. S. (2003). Water productivity of irrigated crops in Sirsa district, India: Integration of remote sensing, crop and soil models and geographical information systems.

Van Dam, J. C., Singh, R., Bessembinder, J. J. E., Leffelaar, P. A., Bastiaanssen, W. G. M., Jhorar, R. K., ... & Droogers, P. (2006). Assessing options to increase water productivity in irrigated river basins using remote sensing and modelling tools. *Water resources development, 22*(1), 115-133.

Vermillion, D. L. (1997). Impacts of irrigation management transfer: A review of the evidence.

Wijayaratna, C. M. (1993). Irrigation turnover and self-management: The Philippine experience. Colombo. International Irrigation Management Institute.

Withanachchi, S. S., Köpke, S., Withanachchi, C. R., Pathiranage, R., & Ploeger, A. (2014). Water resource management in dry zonal paddy cultivation in Mahaweli River Basin, Sri Lanka: An analysis of spatial and temporal climate change impacts and traditional knowledge. *Climate, 2*(4), 329-354.

Witharana, D. D. P. (2004). Village tank categorization. In: (Aheeyar, M.M. (Ed), Small Tank Settlements in Sri Lanka, Proceedings of a Symposium, Hector Kobbekaduwa Agrarian Research and Training Institute Colombo.8

Zwart, S. J., & Bastiaanssen, W. G. (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. *Agricultural water management, 69*(2), 115-133.