



Water Productivity in Tank Cascade Systems: A Case Study in Mahakanumulla Cascade, Sri Lanka

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ABSTRACT

This study was conducted to assess the agricultural water productivity and its determinants in the Mahakanumulla tank cascade system located in the dry zone of Sri Lanka. The data collection for the study was carried out in the form of a survey, where 250 farmer households representing 17 tanks within the cascade were surveyed. The productivity assessment was conducted for the upstream and the downstream of the cascade separately. A regression model was used to identify the determinants of the agricultural water productivity in the Mahakanumulla cascade. The average agricultural water productivity in the upstream was 1.48kg/m³ and in the downstream it was 1.62 48kg/m³. The extent of command area and climate-related crop losses were the critical determinants of the agricultural water productivity both upstream and downstream. In the upstream, the tank capacity was a determinant of the field water productivity and, in the downstream, degree of wildlife damage remained significant in determining water productivity.

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INTRODUCTION

Paddy has a significant economic importance as the staple food of the Sri Lankans. According to the distribution of the rainfall, paddy is cultivated in both wet (mean annual rainfall over 2500 mm) and dry (mean annual rainfall less than 1750 mm) zones while dry zone has a larger cultivated area (Adhikarinayake, 2005).

There are two main paddy cultivating seasons in the dry zone Sri Lanka from October to January ('Maha' season) and April to May ('Yala' season). The expected rainfall in *maha* season is about 650mm and in *yala* season it is 150mm (Shakthivadivel *et al.*, 1996). Depending on the water supply to the paddy cultivation, there are three main paddy cultivation regimes in Sri Lanka namely major irrigation (tanks with a command area larger than 80 hectares), minor irrigation (tanks with command areas less than 80 hectares) and rain fed irrigation (Adhikarinayake, 2005).

Among the factors affecting paddy cultivation in the dry zone, water is considered as the limiting factor (Panabokke *et al.*, 2002). Due to the limited and highly seasonal rainfall in the dry zone, water retention is crucial for paddy cultivation. In order to retain the limited water resources in the dry zone, tank cascade systems have been constructed during the era of ancient hydraulic civilization in Sri Lanka (Bandara, 1984). These systems are considered as sustainable agricultural systems that support high agricultural production along with the conservation of the environment.

Tank cascade system in Sri Lanka

According to Bandara (1984), the tank cascade system in Sri Lanka is a connected series of tanks organized within a micro-(or meso-) catchment of the dry zone landscape for storing, conveying and utilizing water from an ephemeral rivulet (Figure 1). Under this layout, water is continuously recycled. Surplus water from the upstream tank and return flows from rice irrigation are captured in downstream tanks, and are thus used again in the command area of the second tank (Shah *et al.*, 2013). The major reason for the formation of tank cascade systems in the dry zone is the temporal and spatial disparities of the annual rainfall (Geekiyanaage and Pushpakumara, 2013). The average rainfall in the dry zone is approximately 1250mm and the rate of annual evaporation is around 1700mm – 1900mm. This indicates a

significant water stress in the area (Panabokke *et al.*, 2002). The dry zone landscape consists of gently undulating to undulating land surface with an impervious underlying basement rock which is ideal for constructing reservoirs or small tanks. Apart from the village tanks, the tank cascade system involves land components which are important to maintain the system balance. These components include protected forest in the catchment (*Gas gommanna*), *Gangoda* (hamlet or high elevation household area), *Kattakaduwa* (interceptor), *Iswetiya* (soil ridge), *Perahana* (filter) and *Godawala* (water hole) (Dharmasena, 2010).

The major use of most of the small village tanks in cascade systems is supplying irrigational water (Perera *et al.*, 2005). As a significant amount of rainfall is received only in 'Maha' season, the collection of water in small tank cascade system is crucial for the paddy farming during the 'Yala' season.

In the ancient hydraulic civilization, tank cascade systems consisted of sustainable production systems namely lowland paddy cultivation, chena cultivation, home gardens and animal farming systems. According to Jothi and Panabokke (2001), there had been a self-sufficient subsistence equilibrium of these cultivation systems within the tank cascade system supporting the usage of tank water under subsistence agriculture in all four farming systems sustainably. But the ancient tank cascade system has faced temporal and social changes with time. Since the abolishment of the ancient tank management system known as the '*Rajakariya* system' by the British rule, the management of the tank cascade system has been unsuccessful (Bandara, 2009). Also with time the essential land components of cascade systems have been lost or reduced as a result of intensive cultivation and encroachment.

Currently 1162 tank cascade systems are identified in Sri Lanka (Adhikarinayake, 2005). There is a timely need to identify the current function and the sustainability of the cascade systems as an important component in paddy production of Sri Lanka. As most of the tank cascade systems are mainly used for irrigation purposes 'agricultural water productivity' can be considered as an important indicator of how efficiently and sustainably the water resource is used for agricultural practices in tank cascade systems.

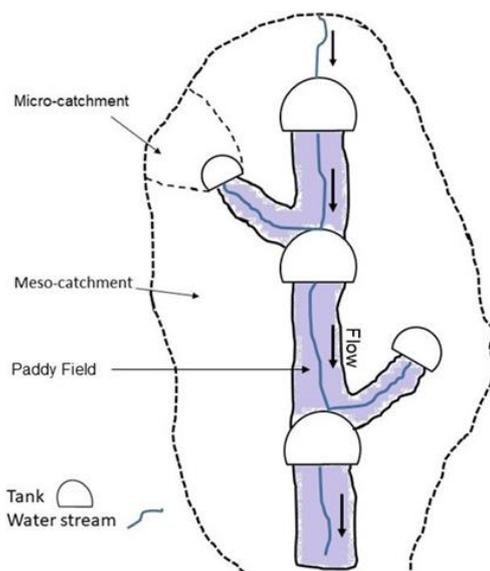


Figure 1. Schematic representation of a small Tank Cascade System

The Agricultural water productivity

According to Van dam and Malik (2003), the water productivity concept is based on “more crop per drop” or “producing more food from the same water resources” or “producing the same amount of food from less water resources”. Therefore generally it is defined as the output produced per unit of water involved in the production, or the value added to water in a given circumstance (Ali and Talukder, 2008). In agriculture, it is expressed as the net consumptive use efficiency in terms of yield per unit depth of water consumed per unit area of cultivation thus called the agricultural water productivity (Palanisami *et al.*, 2009). This is also called the “water use efficiency” in agriculture (Van dam and Malik, 2003).

Water productivity is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management (Ali and Talukder, 2008). In agriculture, large amount of water is used in the production process. Given that, it is a widely held perception that water use in agriculture is relatively inefficient and even small improvements in agricultural water productivity could have large implications for local and global water budgets. Therefore, such improvements would allow higher agricultural production with the same amount of water, or the same amount of agricultural production with less water (Scheierling *et al.*, 2014).

According to Scheierling *et al.* (2014), factors in several disciplines such as hydrology and hydrogeology, civil and irrigation engineering,

agronomy and crop physiology, and economics affect the agricultural water productivity. Also the impact of these factors can be different site to site. There are several studies carried out on the factors affecting the agricultural water productivity around the world focusing on different types of agricultural crops. The impact of climatic factors such as rainfall, evapotranspiration, humidity and seasonality on the agricultural water productivity has been explained in many studies (Kang *et al.*, 2009; Zwart and Bastiaanssen, 2004; Bouman, 2007 and Bastiaanssen *et al.*, 2003). The impact of irrigational water allocation has been studied by Hussain *et al.* (2014) and Bekchanov *et al.* (2012) who find that there is a positive relationship between the water allocation and water productivity.

The relationship between the agricultural land size and water productivity has been studied by Ashraf *et al.* (2010) and Barker *et al.* (2003) who emphasize a positive impact of land size on water productivity. The fertilizer usage has a positive relationship with the agricultural water productivity (Zwart and Bastiaanssen, 2004; Hussain *et al.*, 2014, Rockström *et al.*, 2003). Also, the cropping intensity shows a positive relationship with the water productivity (Fanadzo *et al.*, 2010).

Study Objectives

Only a few quantitative analyses have been carried out on the agricultural water productivity in local tank cascades so far. Therefore, the function and productivity of the existing tank cascade systems

are not well documented. The current study is designed to estimate the agricultural water productivity in the tank cascade systems and to identify the factors affecting water productivity by taking *Mahakanumulla* tank cascade as the study site.

METHODOLOGY

Site selection

The site selected for the research is *Mahakanumulla* tank cascade system located in *Thirappane* and *Kekirawa* Divisional Secretariats,

Sri Lanka (Figure 2). *Mahakanumulla* cascade is a completely rainfed cascade composed of 27 tanks (Panabokke *et al.*, 2002; Wijesundara *et al.*, 2014). *Mahakanumulla* cascade can be classified as a branched cascade type with a form index (ratio of length to width) of 2.8. Of the 27 tanks within the *Mahakanumulla* cascade, 5 are located along the main valley and the rest are located along the side or branch valleys (Panabokke *et al.*, 2002).

Mahakanumulla tank is the largest storage tank in the cascade. The tank cascade finally connects to the *Nachchaduwa* major tank along with the adjacent *Thirappane* and *Ulagalla* cascades. In the current study 17 tanks in the cascade belonging to *Thirappane* Divisional Secretariat were studied in *maha* season of 2019.

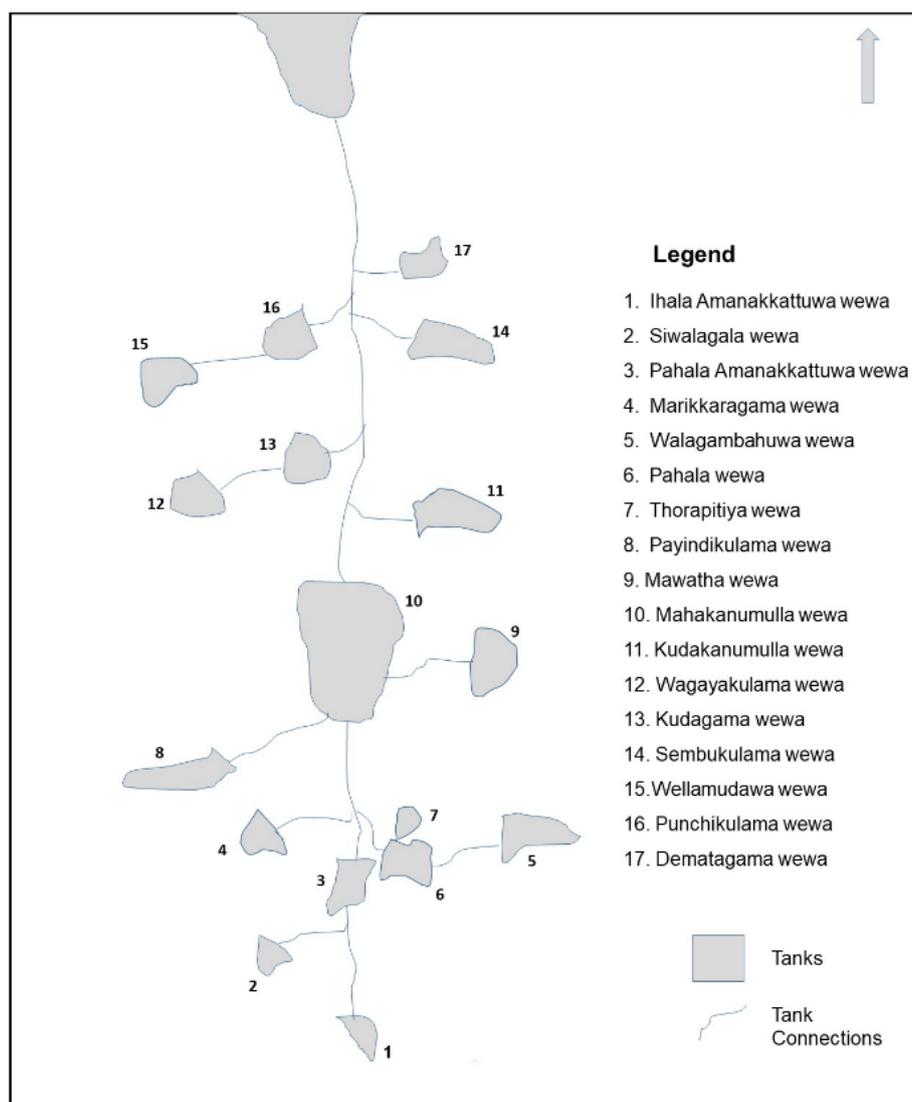


Figure 2. Schematic representation of the *Mahakanumulla* cascade

Data collection

The site location, road map and the land use were studied at the beginning of the research using Google Earth Pro (version 2019) application. Then a preliminary field survey was conducted in *Mahakanumulla* to collect both primary and secondary data on the socio economic and ecological environment of the cascade. In the preliminary field visit, the 17 tanks for the study were identified depending on the function and usage. Secondary data were collected from the Divisional Secretariat office of *Thirappane* and Agrarian Service Center of *Thirappane*. A household survey was conducted in 25% of the all farmer households in *Mahakanumulla* cascade with a systematic random sampling method using a survey questionnaire from December 2019 to January 2020. The data for the water productivity study was collected through this survey.

Data analysis

The data of the upstream and downstream tanks was analyzed separately in order to identify the variation between the upstream and the downstream. The largest storage tank in the cascade, *Mahakanumulla* tank was taken as the boundary of the upstream and the downstream.

The water productivity was calculated using the equation,

$$WP = Y/V$$

Where; WP is field level water productivity, Y is output of the farm, and V is volume of water used in a farm per season.

The water productivity analysis was carried out to estimate the impact of factors affecting water productivity in order to assess their relative importance to paddy productivity. The productivity function is a formal representation of the identified production factors that influence productivity and their effects on productivity that are of varying magnitude (Hussain *et al.*, 2014). The following productivity function was used in the present study to analyse the relationship of the independent variables with the agricultural water productivity.

$$Y_w = \beta_0 + \beta_1V_1 + \beta_2V_2 + \beta_3V_3 + \beta_4V_4 + \beta_5V_5 + \beta_6V_6 + U$$

Where; Y_w is agricultural water productivity (kg/m^3), V_1 is tank capacity (m^3), V_2 is command area (ha), V_3 is Individual farm size (ha), V_4 is fertilizer input (kg), V_5 is degree of wildlife damage,

V_6 is a dummy for the crop losses from climatic related disasters, and U is the error term.

The independent variables were selected based on the literature and the site-specific considerations. The tank capacity was calculated using the mid area method (Sawunyama *et al.*, 2006) Even though the climatic factors, water losses and time of cultivation have shown significant impact on water productivity in the previous studies, those factors were not considered as there is no significant variation in these factors among individual tanks as they are located in the same area. The impact of minor crops was not considered as the tank water was only used for paddy cultivation in *Mahakanumulla* cascade. The only recorded paddy varieties that are cultivated in the *Mahakanumulla* cascade are BG 350 and BG 352. The harvesting period of both varieties is 3.5 months and the potential yield is 7 tons/ha (Dhanapala, 2007). Because of the similar characteristics of both the varieties, the impact of the paddy variety on water productivity is not considered in the current study.

RESULTS AND DISCUSSION

Even though there are 27 tanks in the *Mahakanumulla* cascade according to the literature, 9 tanks were excluded in this study as the farming data in these tanks were insufficient for a statistical study due to the low number of farmers per tank. The tanks in *Mahakanumulla* cascade are mainly used for irrigation for paddy cultivation. For the water requirement for home garden and *chena* cultivation, agro-wells are used. The *chena* cultivation has become very restricted in the area as the larger forest area has become a reserve and the remaining area is found in sloppy ridges in watershed boundary (Dharmasena, 1991). Among the respondents who participated the household survey, 53% were men and 47% were women with an average education level of 9 years of schooling. 95% of them were original residents of the village and 5% were migrants. The main income of the majority was farming (68%) and the rest were engaged in fisheries, government service, occupations in private sector and business along with farming. 74% of the farmers interviewed were commercial farmers while 26% were subsistence farmers.

Descriptive statistics

The descriptive statistics of the dependent and independent variables are shown in Table 1. The water productivity of the cascade upstream is slightly lower than the water productivity in the

downstream. As mentioned in Ashraf *et al.* (2010), the larger command areas results in high water productivity values. The larger command area and individual farm size in the downstream compared to the upstream could be the reason for this difference. According to Kijne (2003), the global average of the water productivity values for paddy ranges between 0.6 kg per m³ to 1.1 kg per m³. The water productivity value in the *Mahakanumulla* cascade shows higher value than global average range. The average annual paddy yields of the cascade is less than the average annual paddy yield of Sri Lanka, 4448.76 kg/ha (DCS, 2018). The average annual paddy yield in the upstream is 2926.14 kg/ha while it is lower in the downstream (2577.5 kg/ha).

The average chemical fertilizer input in the upstream is higher than the downstream and both the values are higher than the recommended chemical fertilizer amount (270 kg/ha) in Sri Lanka as mentioned in Chandrajith *et al.* (2010). The farmers' tendency to use more chemical fertilizers apart from the amount of fertilizers received from the government fertilizer subsidy has been the reason for the high usage. This high usage could have a potential negative impact on the sustainability of the *Mahakanumulla* cascade in the future.

The index for elephant conflict is constructed considering the degree of the crop damage, property damage and life risk caused by the wild elephants. The impact on the upstream seems to be slightly lower than the downstream. According to the observations of the villagers, the reason could be the proximity of the downstream tanks to the *Nachchaduwa* tank which is a natural roaming ground of elephants and the topographic features that makes the area easily accessible to the elephants.

Regression analysis

The results of the regression analysis are shown in the Table 2. The tank capacity shows a significant positive relationship with the water productivity in the upstream. This emphasizes that the water productivity is likely to increase with tank capacity. But the tank capacity variable is insignificant in the downstream. The command area represents a positive relationship with the field water

productivity in both upstream and downstream. This finding agrees with the study by Ashraf *et al.* (2010) which says that when the cultivated area is increasing, the water productivity also increases. In this study, the individual farm size and the chemical fertilizer input shows insignificant impact on the water productivity. The index for the elephant conflict shows a negative impact on water productivity in the downstream although it is insignificant in the upstream. This shows that the farmers in the downstream are highly affected by elephant conflicts compared to the upstream. The crop losses from the climate related disasters show a significant negative impact on the water productivity. This demonstrates the frequent crop losses faced by the farmers mainly due to the prevailing dry seasons and short and intensive rainfall. In summary, the independent variables affecting the water productivity in upstream are found to be tank capacity, command area and the crop loss while the command area, index for elephant conflict and climate driven crop loss affect the water productivity in the downstream.

Although the water productivity values are high for the *maha* season, the survey has shown that the cultivation in *yala* season is low in the *Mahakanumulla* cascade due to the scarcity of water and the uncertainty of the rainfall. The cropping intensity of *maha* season for both upstream and downstream was 100% while the values for *yala* season were 28.3% and 17.3% respectively for the year 2018-2019. The reason is the reduced water retention in tanks making the paddy farming in *yala* uncertain. According to the interviews carried out, the majority of farmers do not consider paddy farming as a profitable activity as it is almost confined for only one season of the year. Also the losses incurred by elephant conflicts are significant in the cascade and a long term solution for the elephant conflict such as effective electric fences and translocation of aggressive animals are needed (Shaffer *et al.*, 2019). If year round paddy cultivation is possible, it would make the production under tank cascade systems an important contributor to the supply of rice. Therefore, more attention to the productivity and maintenance of tank cascade systems is necessary for the economy of the country as well as the conservation of tank cascade systems.

Table 1: Descriptive analysis of the variables for the year 2019

Variables	Upstream		Downstream	
	Mean	Standard Deviation	Mean	Standard Deviation
Water productivity (kg/m ³)	1.48	0.39	1.62	0.35
Tank capacity (m ³)	650.91	852.19	385.21	250.11
Command area (ha)	201.06	130.37	215.52	105.67
Individual farm size (ha)	5.62	4.03	6.39	5.30
Average annual yield (kg/ha)	2926.14	1061.9	2577.5	905.99
Fertilizer input (kg)	154.71	20.44	134.79	80.24
Index of elephant conflict	1.77	0.62	1.92	1.05

Table 2. Regression analysis representing the factors affecting agricultural water productivity

Variable	Parameter	Upstream regression model		Downstream regression model	
		Co-efficient	Standard error	Co-efficient	Standard error
β_0	Intercept	2.010	0.120	1.421	0.150
β_1	Tank capacity	0.001**	0.000	0.001	0.000
β_2	Command area	0.02**	0.001	0.02**	0.001
β_3	Individual farm size	-0.130	0.180	0.0110	0.660
β_4	Chemical fertilizer input	-0.001	0.000	-0.001	0.000
β_5	Index for elephant conflict	-0.130	0.050	-0.127**	0.380
β_6	Dummy variable for crop losses from climate related disasters	-0.180**	0.650	-0.165**	0.240
R ²	0.496			0.502	

**Statistically significant at 5% level of probability

CONCLUSION

The results of the study show that the water productivity of the *Mahakanumulla* cascade is at a satisfactory level at present. However, the upstream water productivity was found to be lower than the downstream water productivity. The extent of command area displays a significant positive impact on the field water productivity while the climate related crop losses have a negative impact. The tank water capacity is found to have a significant impact on field water productivity in the upstream and the elephant

encroachment showed a significant impact on the water productivity in the downstream.

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