Annals of Sri Lanka Department of Agriculture 2013. 15: 25-36

IRRIGATION EFFICIENCY AND WATER QUALITY OF MADURUOYA IRRIGATION SCHEME

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ABSTRACT

Irrigation efficiency, which is an indicator of effective water resources management, varies in different irrigation schemes in Sri Lanka, but is low in general. An experiment was conducted in Maduruoya irrigation scheme in *maha* and *yala* seasons of 2008/09 to evaluate the efficiency of main canal, distributory canals, sub distributory canals, field canals and head, middle and tail ends of the farmer fields and water quality of Maduruoya irrigation scheme. During the study, water inflow to the system (rainfall and irrigation) and outflows (evaporation, seepage, percolation and runoff) were measured. In addition, water quality of the Maduruoya scheme was also measured. Results revealed that higher conveyance efficiencies in the lined canals of main canal to distributor canals (88.2 %), distributory to sub distributory canals (73.9 %), but low in sub distributory to field canals (59.3 %). The overall Maduruoya system efficiency was recorded as 29.1 %. The application efficiency of the middle paddy fields (78.9 %) was highest while tail end fields recorded the lowest (25.2 %). Water quality analysis revealed that, the quality of water in Maduruoya irrigation scheme is ideal for irrigation.

KEYWORDS: Distribution canal, Irrigation efficiency, Maduruoya, Water quality.

INTRODUCTION

The Mahaweli Ganga Power and Irrigation Project is one of the largest multipurpose projects in Sri Lanka. The project included construction of five multipurpose reservoirs namely, Kothmale, Victoria, Randenigala, Rantambe and Maduruoya. Among these, Maduruoya irrigation scheme is located in the eastern dry zone of Sri Lanka and belongs to the Mahaweli system B. The catchment area of the reservoir is about 453 km^2 and the gross storage capacity is about 483,470 acre feet. There are 44,581 ha of paddy lands and 491 ha of other field crops in the command area of the Maduruoya reservoir (Anonymous, 1980).

In the traditional system of Maduruoya scheme, mainly poorly drained soils were used for paddy cultivation and the distributory systems and the distribution of water was practiced down the slope from field to field. This system was operated only as community venture and not as independent operations of individual farmers. Individual irrigation and drainage outlets to the farmers were not provided. If the community decided on the dates and pattern of irrigation, individuals in the community had no other option. Provision of individual irrigation and drainage outlets in farm plots based on the continuous supply of irrigation water was the next stage of the development in designing of irrigation systems. Therefore, the community participation was not required for the operation of the irrigation system. But, the tail-enders of canals had a disadvantage due to the unlimited supply of irrigation water to the head-enders resulting tail-enders to receive meagre amount. Irrigation water should be provided such a way that paddy plant does not suffer from over irrigation. Head enders maintain standing water in the fields to reduces the weed problems, but were not concerned about the extent of their water consumption (Sree Ramulu, (1998).

In 1970s, a tertiary distribution system was adopted based on field canals of uniform capacity serving more or less similar number of farmers facilitating practice of a rotational system of irrigation under the Mahaweli Project. It was expected to alleviate the tail-enders problems of the earlier models by this system. But the efficiency and equity in the distribution of water depended on total cooperation of the farmers in each field canal area. This, however, has not eliminated the problems of the tail-enders. Irrigation efficiency, which is an indicator of effective water resources management, varies in different irrigation schemes in Sri Lanka, but is low in general. These low efficiencies lead to water shortages within the command area of irrigation schemes particularly in the dry season or dry spells during the rainy season. Improvements in irrigation efficiency leads to improved equity in water distribution and minimize the gap between potential crop water requirement and actual water use.

One of the effective approaches to achieve these improvements is the good guidance of irrigation facilities, operation in institutional, managerial and technical aspects. This guidance will benefit farmers and other water users and persons/organizations in charge of water management (i.e. water users groups, water management authorities, etc.) directly. If efficient and equitable water use is realized, it makes positive impact on water resources management from sub-basin, basin to national levels. Therefore, the main objective of the present study was to evaluate the irrigation efficiency and water quality of the Maduruoya irrigation system at different conveying levels. Specific objectives were to estimate the application efficiency of irrigation water using water balance study and distribution efficiency to measure the differences of water application efficiency at the head, middle and tail end of the fields that is fed from a single field canal and also to determine quality of irrigation water.

METHODOLOGY

The study was carried out from *maha* 2008/09 to *yala* 2009 seasons in Mahaweli system B area of Polonnaruwa District in the Low Country Dry zone, ($DL2_b$) agro-ecological region of Sri Lanka (7.76 N, 81.18 E). The study area was under paddy cultivation during the study period. The conveyance and application efficiencies of irrigation water from Maduruoya reservoir to the farmer fields were estimated during land preparation, sowing to tillering, tillering to flowering and flowering to full maturity stages. The water issue data from Maduruoya reservoir up to the field canals (reservoir to main canal, main canal to distributory canal, distributory canal to sub-distributory canal, sub-distributory canal to field canal) were obtained from the Mahaweli authority of Sri Lanka. The water issue data were measured in end of each canal by the Mahaweli authority of Sri Lanka. Water delivered to the farmer field from field canal and the different sections of the farmer field was measured using partial flumes. Water delivered to the farmer field was at the inlet of the farmer field and water delivered to the different section of paddy field was measured at the outlet of the each field. Measurements were taken in 2 days interval in different stage of crop growth.

Conveyance efficiency

Conveyance efficiency at each diversion from the reservoir up to farmer field was measured using the equation:

$$\text{Conveyance efficiency} = \frac{W_{df} \times 100}{W_{dl}} \qquad \text{eq. 1}$$

Where;

Wdf=amount of water delivered to the field/next canal

Wdl=amount of water diverted from the reservoir/previous canal

Water balance

Water balance study was conducted in the farmer fields, 2 km away from the Regional Agricultural Research and Development Centre, Aralaganwila. Soil type of the farmer fields were Non Calcic Brown and finely levelled fields were located in a cascading system. All the inflow and outflow measurements were collected daily. Water balance of the system was estimated using the following equation:

$$\text{Inflow} = \text{Outflow} + \text{Change of Storage} \qquad \text{eq. 2}$$

Where;

Inflow=Rainfall, Irrigation;

Outflow=Evapotranspiration, Seepage, Percolation, Surface runoff.

Measurement of inflows

The amount of rainfall was measured from the meteorological centre at Regional Agricultural Research and Development Centre, Aralaganwila and the amount of irrigation water delivered to the head, middle and tail end of the field was measured using partial flumes installed at each point.

Measurement of outflows and irrigation efficiency

The amount of evapotranspiration was measured by using evaporation pan installed at Regional Agricultural Research and Development Centre, Aralaganwila and by multiplying the evaporation values by crop coefficient value (K_c). Minute changes of surface water levels due to seepage and percolation in paddy fields were measured by using sloping gauge. The total loss of water from the paddy fields was measured from the graduated inclined base of the sloping gauge. Three triangles were installed at same elevation as replicates.

Water loss was measured by placing a capillary tube and a scale on the inclined surface of the hypotenuse of the triangle in a 1.14 m x 1.14 m mini plot constructed in the centre of the representative field to avoid the turbulence of water in the field to get accurate measurement. However, small openings were made in the bund of mini plot to keep the equal level of water in the mini plot and actual field. To get the actual water loss, the readings were divided by 5 due to 1:5 ratio of vertical side to hypotenuse. Difference of the total loss of water as seepage and percolation (S and P) and evapotranspiration (ET_c) and the addition of water as rainfall (RF) at head, middle and tail end fields were recorded and averaged as the difference of direct water height by using the 1:5 ratio of the sloping gauge daily. Five centimetre water level in the field was maintained throughout the period of water measurements. By deducting the measured evaporation from this loss, the amount of water loss by seepage and percolation was calculated. Surface runoff was measured by measuring the outflow water using the partial flumes installed at outlets of head, middle and tail end of the field. The storage amount of water in each plot of the field was measured by using water balance equation.

$$\text{Storage} = \text{Inflow} - \text{Outflow} \qquad \text{eq. 3.}$$

Irrigation efficiency was calculated using the following equation:

$$\left.\begin{array}{r}\text{Irrigation Application}\\ \text{Efficiency}\end{array}\right\} \frac{\text{amount of water utilized in the field} \times 100}{\text{amount of water delivered to the field}} \quad \text{...eq. 4.}$$

Where;

Amount of water utilized in the field = Change of water storage in the field + Crop evapo-transpiration

Amount of water delivered to the field = Rainfall + Irrigation

System efficiency (Es)

System efficiency was calculated by using following equation;

$$E_s = 100\ (E_c / 100 \times E_a / 100) \qquad \text{eq. } 5.$$

Where,

E_s is the irrigation system efficiency,
E_c is the conveyance efficiency of the system and
E_a is the application efficiency of the system.

Measurement of water quality

Water samples for chemical analysis were taken from the different sections of the Maduruoya irrigation system, and drainage canal at the end of the cropping season. In the main canal water samples were collected at the beginning, 1 km away from the reservoir, 2 km away from the reservoir and at the end of main canal. Water samples were collected at the beginning of distributory, sub distributory and field canals. All the samples were collected at the end of cropping season. Electrical conductivity of water was measured using a conductivity meter at 28 ^{0}C. The pH of the water samples were measured using a pH meter at 28 ^{0}C. These procedures were repeated three times for each water sample. Phosphate concentrations in water samples were determined using colorimetric method. The water samples (10 ml) were mixed with phosphate colorimetric reagent. The color intensity was measured after 2 minutes using multi-parameter bench photometer. Nitrogen concentration of irrigation water was determined using UV absorption spectroscopy (SLS, 1983) and the total potassium was determined using flame photometer method (Jackson, 1979)

RESULTS AND DISCUSSION

The climate of the area which is fed from Maduruoya irrigation system is characterized by high temperature (>27 ^{0}C) throughout the year with some cool nights (18-20 ^{0}C) in December and January. The average rainfall of this area is about 1,100 mm, of which 80 % is received during *maha* season (Panabokke, 1996). The major soil groups in system B area are the Reddish Brown Earths (Rhodustalfs), Non-Calcic Brown Soils (Haplustalfs), Low Humic Glay Soils (Tropaqualfs), and Tropaquent. The catenary sequence is typically on slopes of 0.5 to 1 %, rarely up to 4 %. Underline, impervious basement rock, often within three meters of the surface and sometimes within one meter, groundwater rapidly rises in the bottom lands and lower slopes during the wet season. Seepage and percolation have been recorded in the range 5, poor to imperfect that permits rice cultivation. With good management and when irrigation water is not limited paddy yields on these soils are high, i.e., 4.5 to 6 t/ha (De Alwis and Panabokke, 1972).

Conveyance Efficiency (E_c)

Conveyance efficiency of the Maduruoya irrigation scheme showed a wide range of variation from main sluice to the tail end field at each conveying level (Table 1). Water conveyance efficiency was affected by water losses through evaporation/ evapotranspiration, seepage and leakage through water control structures in the conveying system. Majumdar (2002) reported that the losses may vary from 25 to 60 % of the water diverted for irrigation from main canal to the paddy fields. However, present study revealed that the efficiencies may vary from outside of this range possibly due to the lined canals (higher side) and the Non Calcic Brown soil of sandy nature (lower side).

Table 1. Efficiency of Maduruoya irrigation system at each conveying level.

Conveying level	*Conveyance efficiency*
LB-L_2 main canal to distributor (D_2) canal	88.2
Distributory (D_2) to sub distributry canal (SD_7)	73.9
Field canal 44 (FC_{44}) to head, middle and tail end fields	38.6

The efficiency (E_c) values from Main sluice (MS) to left bank (LB-L_2) and distributory (D_2) and from LB-L_2 and D_2 to sub distributor (SD_7) were in higher compared to others due to the lining surface of the main, sub-main and D canals. Though these canals were lined, the losses of water from lined surfaces are evident because of the poor maintenance, cracks of the lined surfaces and evaporation losses. De Silva (1990) reported that the conveyance losses from distributory canals were 9-12 % in head end, 17-36 % in middle end and 15 % in tail end section in *yala* season which was in general comparable to the results of the present study.

Conveyance efficiency (E_c) values from SD_7 to fields were in a lower range due to unlined surfaces, high seepage and percolation losses from Non Calcic Brown soils in these areas and evaporation losses. There are some sediment deposition and aquatic weed growth in field canals which leads to the overflow of water from field canals resulting lower conveyance efficiencies. The overall system efficiency of the Maduruoya irrigation system was recorded as low as 29.1 %. Majumdar (2002) also reported that the improper land levelling and grading, faulty choice of irrigation methods, application of excess water, frequent irrigation, very small or very large stream sizes, improper attentions during irrigation by the irrigator and faulty design of fields are the principal factors that cause low irrigation efficiencies. Illegal taping of irrigation from different section of canals by farmers for the irrigation of upland crops and paddy fields especially during the *yala* season also might lead to the lower overall conveyance efficiency in Maduruoya irrigation scheme.

Application Efficiency (E_a)

The water application efficiency may be defined as the percentage ratio of the amount of water stored in the crop root zone to the amount of water delivered to the fields. This efficiency is mainly used to design the irrigation practices in a farm. It account for loss of water by seepage in the supply channel, deep percolation and occasionally run-off occurring in fields (Majumdar, 2002). Results of the sloping gauges at head, middle and tail end fields in different stages of the cultivation were used to calculate the seepage and percolation (S and P) losses at each field and given in Table 2.

Table 2. Seepage and percolation losses in different stages of the cultivation at head, middle and tail end fields.

		Land preparation to Sowing	*Sowing to Tillering*	*Tillering to Flowering*	*Flowering to Maturity*
RF + ET_c (cm)		0.73	0.24	0.38	0.18
Difference of water level (cm)	Head	2.19	2.19	2.14	1.98
	Middle	0.75	0.78	0.78	0.75
	Tail	3.62	3.62	3.61	3.57
S and P rate between two irrigation (cm)	Head	1.46	1.95	1.76	1.81
	Middle	0.02	0.55	0.40	0.57
	Tail	2.89	3.39	3.24	3.39
Number of irrigated days	Head	5	5	8	5
	Middle	4	4	8	5
	Tail	5	4	8	5
Total S and P loss (cm)	Head	7.32	9.76	14.10	9.03
	Middle	0.07	2.18	3.18	2.86
	Tail	14.45	13.54	25.89	16.94

Highest water balance in the field was recorded in tillering to flowering stage of the crop both in head and tail section of the field due to the high amount of rainfall received during that period (Table 3). However, this phenomenon was not observed in the tail section of the paddy fields. Amount of water stored during that period was comparatively low even with high amount of rainfall. This was due to the higher seepage and percolation losses possibly due to the activation capillary action of soil and rill formation in sub soil resulting water loss from open lower bank of the paddy field because the drainage canal was flowing in lower elevation compared to the paddy fields.

Table 3. Results of the water balance study.

Inflows	*Land preparation-Sowing*	*Sowing to Tillering*	*Tillering to Flowering*	*Flowering to maturity*
		Head end		
Rainfall (cm)	12.6	11.6	26.5	14.9
Irrigation (cm)	10.5	15.3	11.2	13.1
Total	23.1	26.9	37.7	28.0
Outflows				
Seepage and Percolation(cm)	7.3	9.8	14.1	9.0
Evapotranspiration(cm)	1.8	2.1	3.6	1.3
Runoff (cm)	0.0	0.2	0.7	2.5
Total	9.1	12.0	18.4	12.8
Storage ΔS(cm)	14.0	14.9	19.3	15.2
		Middle end		
Rainfall (cm)	12.6	11.6	26.5	14.9
Irrigation (cm)	7.0	13.6	7.4	10.2
Total	19.6	25.2	33.9	25.1
Outflows				
Seepage and Percolation(cm)	0.1	2.2	3.2	2.9
Evapotranspiration(cm)	1.8	2.1	3.6	1.3
Runoff (cm)	2.1	6.9	1.2	3.2
Total	3.9	11.2	7.9	7.3
Storage ΔS(cm)	15.7	14.0	26.0	17.8
		Tail end		
Rainfall (cm)	12.6	11.6	26.5	14.9
Irrigation (cm)	6.1	11.0	5.8	8.9
Total	18.7	22.6	32.3	23.8
Outflows				
Seepage and Percolation(cm)	14.5	13.5	25.8	16.9
Evapotranspiration(cm)	1.8	2.1	3.6	1.3
Runoff (cm)	0.0	2.3	0.0	0.1
Total	16.2	17.9	29.5	18.3
Storage ΔS(cm)	2.5	4.7	2.9	5.5

Amount of water delivered to the field

The amount of water delivered to fields at head, middle and tail ends were shown in Table 5, which was calculated by using the amount of water delivered to each field (W_{df}) and RF. The calculation of application efficiency (E_a) at head, middle and tail end fields in different stages of the cultivation were summarized in Table 6.

Table 4. Amount of water utilized in 1.14 m x 1.14 m mini plot ($\Delta S+ET_c$).

ΔS (m^3)	*Land preparation-Sowing*	*Sowing to Tillering*	*Tillering to Flowering*	*Flowering to maturity*
Head	0.18	0.19	0.25	0.20
Middle	0.20	0.18	0.34	0.23
Tail	0.03	0.06	0.04	0.07
ET_c (m^3)				
Middle	0.02	0.03	0.05	0.02
$\Delta S + ET_c$(m^3)				
Head	0.21	0.22	0.30	0.21
Middle	0.23	0.21	0.38	0.25
Tail	0.06	0.09	0.08	0.09

Table 5. Amount of water delivered 1.14 m x 1.14 m mini plot (W_{df} + RF).

Delivered water amount (W_{df}) (m^3)	*Land preparation-Sowing*	*Sowing to Tillering*	*Tillering to Flowering*	*Flowering to maturity*
Head	0.14	0.20	0.15	0.17
Middle	0.09	0.18	0.10	0.13
Tail	0.08	0.14	0.08	0.12
RF (m^3)				
Head	0.16	0.15	0.34	0.19
W_{df} + RF (m^3)				
Head	0.30	0.35	0.49	0.36
Middle	0.25	0.33	0.44	0.33
Tail	0.24	0.29	0.42	0.31

Table 6. Application efficiencies of head, middle and tail end fields in different stages of the cultivation.

Field Location	*Land preparation-Sowing*	*Sowing to Tillering*	*Tillering to Flowering*	*Flowering to maturity*	*Average E_a*
Head end field	68.18	62.98	60.70	58.89	62.70
Middle end field	88.94	63.93	87.11	75.78	78.90
Tail end field	22.73	29.91	19.87	28.40	25.20

In the middle field, the application efficiency was relatively higher than the other two fields may be due to poor drainage of the soil present in the middle field. This may probably due to the restricted seepage and percolation losses of irrigation water in middle fields which was surrounded by the head end fields and tail end fields. The lower application efficiency of the tail end field may be due to the well drained NCB soils present in the tail end fields compared to the LHG soils present in the head end and middle end fields (Amarasiri, 1987). The drainage canal in the study area was situated in the lower elevation and it might have further enhanced the seepage and percolation losses from the tail end fields. The horizontal movement of water in soil from head end fields to tail end fields was also very low due to the lower elevation difference of the cascading system of the irrigation in these fields. But the horizontal movement of water in the soil from field canal to drainage canal in each field was high due to the greater slope gradient from the field canal end to the drainage canal of the study area. De Silva (1990) also reported the lower application efficiencies at tail end farmer fields in non cascading irrigation fields.

Water quality study

Water quality parameters of Maduruoya irrigation system are given in Table 7. There was a slight increasing trend of pH levels of water flowing from Maduruoya reservoir to the farmer fields (Table 7). There might be an anaerobic oxidation in still water in the reservoir and it might generate some organic acids in the reservoir. In contrast turbulent flow of the canal system might have lead to the oxidation of dissolved solids in the irrigation water leading to raise the pH level of irrigation water. However, the pH values of Maduruoya irrigation schemes are within the range of 6-8.5 which is the Sri Lankan standard for irrigation water (SLS, 1985).

Table 7. Water quality parameters of Maduruoya irrigation system.

Place	pH	EC (dS/m)	NH_4^+-N(ppm)	NO_3^--N (ppm)	K (ppm)	P (ppm)
Reservoir	6.99	0.11	0.56	1.36	1.61	0.0055
Main canal beginning	7.12	0.09	0.34	1.15	1.078	0.0047
Main canal 1 km away	7.53	0.11	0.26	1.17	1.078	0.0030
Main canal 2 km away	7.47	0.11	0.24	1.14	1.078	0.0042
End of main canal	7.24	0.08	0.25	1.34	1.078	0.0047
Sub distributory canal	7.51	0.11	0.26	1.35	1.078	0.0046
Distributory canal	7.49	0.08	0.26	1.31	1.078	0.0042
Field canal 1	7.46	0.09	0.26	1.18	1.078	0.0055
Field canal 2	7.47	0.09	0.20	1.31	1.078	0.0066
Drainage canal	7.67	0.14	0.22	1.26		0.0053

Slightly higher NH_4^+- N, $NO3^-$ - N and K levels in the reservoir water may be due to the addition of animal manures and leaf litter closer to the banks of the reservoir since water samples were drawn from the reservoir closer to the banks due to the inaccessibility to the centre of the reservoir. NH_4^+- N values ranged from 0.20-0.56 ppm in Maduruoya irrigation scheme however, there were no upper limit of NH_4^+- N for irrigation water in Sri Lanka according to the Sri Lanka Standards (SLS, 1980). $NO3^-$ - N concentration of the Maduruoya irrigation system varies from 1.14-1.36 ppm which is far below than the 5 ppm that was the Sri Lankan Standards for irrigation water. Considerable increase of P, K and EC in drainage canal water was not observed (Sri Lanka Standard Upper Limit EC = 0.7dS/m, P = 0.1 ppm, K = no upper limit) since the water samples were collected for chemical analysis in off season (SLS, 1980).

CONCLUSIONS

Results of the study revealed that the conveyance efficiency from main sluice (MS) to distributory (D) canal (88.15 %) is comparatively higher than the D to sub-distributory (SD) canal (73.92 %) although both are lined. The lower value of the conveyance efficiency from SD to field canal (FC) that resulted as 59.31 % was due to the unlined surface of the SD canal. From FC to fields the lowest conveyance efficiency was reported in the system as an average of 30.81 %. Average application efficiency of the middle paddy field was reported as the highest value (78.9 %). In the head end field it was reported as the 62.7 % which is lower than the middle field but higher than the tail end field (25.2 %). The lowest average application efficiency of the tail end field is due to the presence of well drained NCB soils. Because of that the seepage and percolation losses are high. Also the high gradient of slope towards the drainage canal from the field canal rather than along the field canal from head end to tail end loss the water by horizontal movement from field canal to drainage canal without facilitating a cascading irrigation. Overall system efficiency of the Maduru oya Irrigation Scheme was 29.1 %. Lower efficiency of the system was a result of losses of water from the cracks of the lined canals and unlined canal surfaces. Water quality study revealed that the quality of the irrigation water of the Maduruoya scheme is ideal for the irrigation.

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