Investigation of the Effectiveness of Proportioning Water-division Devices in Farmer-Managed Irrigation Systems. A Case Study of Njoro ya Goa Scheme in Tanzania

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Abstract

Proportioning water-division device is a simple irrigation water control structure which divides irrigation water in a canal into two or more parts equitably. Performance of proportioning water-division device in a farmer-managed irrigation system (FMIS) was assessed using Njoro ya Goa scheme as a case study. Njoro ya Goa scheme has four secondary canals namely; Goa 1, Goa 2, Goa 3 and Goa 4. Goa 1 and Goa 2 canals were selected for the study. Proportioning water-division devices were installed in 9 stations along Goa 1 canal while Goa 2 canal stations were left as a control. Mean hydraulic sensitivity for tertiaries along Goa 1 and downstream of the Goa 1 canal at the same station was equal to 0.25. The mean hydraulic flexibility for both the tertiaries and the Goa 1 canal was equal to 1.00. In Goa 2 canal, the mean hydraulic sensitivity for the tertiaries and downstream Goa 2 canal at the same station were different and they were 0.035 and 0.015 respectively. The hydraulic flexibility for the respective canals were 1.9 and 1.6. The crop yield for the January to April, 1996 season which was under the study was 4 ton/ha and 2.9 ton/ha for Goa 1 and Goa 2 respectively. The results show that there was an equitable irrigation water distribution along Goa 1 canal but not along Goa 2 canal. It can therefore, be concluded from the present study that proportioning water-division devices should be used as water control structures in farmer-managed irrigation systems in Tanzania and other parts of Africa as they are simple to construct, farmers can afford and they do not need high technological and educational background.

Keywords: Proportioning water-division devices, Equity, Tanzania

Introduction

Proportioning water division device is a simple irrigation water control structure which is usually placed in a canal perpendicular to the direction of flow. In some cases, it may be placed along or at an angle to the direction of flow depending on the topography (Parajuli, 1995). This structure divides irrigation water in a canal into two or more parts equitably that corresponds to the water shares due to each farmer or a group of farmers served by branching canals (Ambler, 1990). Parajuli (1995) reported that these structures are usually made of timber with rectangular notches although cement made proportioning weirs can also be used.

The basic concept of proportional distribution is that the irrigation water supply is proportionally distributed at each off-take of a common supply system. This means that the quantity of water flowing in a parent canal and off-take canals are equally affected by variation of water level in the parent canal. Parajuli (1995) indicated that in order to judge the proportionality of water division structures, hydraulic sensitivity and hydraulic flexibility are to be considered.

The allocation of irrigation water among

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sub-areas of a system should meet crop water needs and be equitable (Bellekens, 1995). According to Yoder (1995) the primary objective in designing water distribution structures, is to provide a mechanism for controlling irrigation water distribution to accommodate the varying flow in a canal and distribute it as accurately as possible according to planned water allocation below that point. In other words, the concept of equity should be taken into consideration during the design and construction process, to allow fair water distribution among the water users. Hence, equity ought to be one of the principle aims of managers of any farmer-managed irrigation systems (FMIS).

Equity of water distribution among water users is a function of both technical and social factors (Abernethy, 1986). To solve the technical part of the problem, the design capacity needs the introduction of flow measuring structures. These would facilitate in distributing irrigation water to water users on the basis of equity. Unfortunately, the already existing FMIS in Tanzania do not have flow measuring devices because of their being expensive to install and due to lack of technological capability on the part of the water users to operate, maintain and manage them. Hence guess- work normally dominates during water distribution process (Tarimo, 1994).

In Tanzania, the existing developed farmer managed irrigation systems normally use water control structures such as turnouts, steel gates and others to distribute irrigation water among the farmers. These structures are complex to the farmers in terms of their operation, maintenance and management. They have also one distinct disadvantage, that is, they need to be regulated now and then. This phenomena normally brings about conflict among water users. Ambler (1995) reported that when these conflicts are not attended, they may result into damages of both irrigation systems and property. It is therefore, important to use a technical approach that uses simple technology that may be easily understood and practised by the water users. It is from this background, that a study on the effectiveness of proportioning water division weirs for enhancing a fair water distribution among water users was conducted. The objective of the study being to investigate the performance of proportioning water division device for equitable water distribution in a FMIS in Tanzania.

Materials and Methods

Description of the study area

The research was conducted at an indigenous FMIS called Njoro ya Goa located near Moshi town in Kilimanjaro Region in the North of Tanzania. The scheme is located approximately at latitudes 3° S and longitude 37.5° E and about 5 km South - East of Moshi town. It consists of a relatively narrow strip of land developed on an alluvial plain. This is a small scheme developed by water users themselves without government/donor agency interventions with the exception of the intake.

The Njoro ya Goa area is characterized by three seasons; a long rain season from March to May, a dry season from June to October and short rain season from November to February. Annual rainfall averages 590 mm of which about 370 mm (63 %) falls in the long rainy season, 60 mm (10 %) in the dry season and 160 mm (27 %) in the short rainy season (URT/JICA, 1988).

The study area receives its irrigation water from Njoro ya Goa spring. The spring supplies irrigation water to the area through Goa 1, Goa 2, Goa 3 and Goa 4 secondary canals. The study area was conducted in Goa 1 and Goa 2 canals with a total area of about 98.5 ha and with about 300 farmers each owning plots of different sizes. The main crop grown is paddy. The Njoro ya Goa spring average discharge is estimated to be 129 l/s. However, its flow is relatively constant throughout the year with a minimum discharge of 100 l/s in March and a maximum of about 140 l/s in May (KADP, 1993).

Methodology

The scheme has a main canal and four secondary canals. The first two canals (Goa 1 and Goa 2) as shown in Fig. 1 were purposely selected for the study because all the four canals were similarly constructed in the sense that they were not lined, had laterals taken only

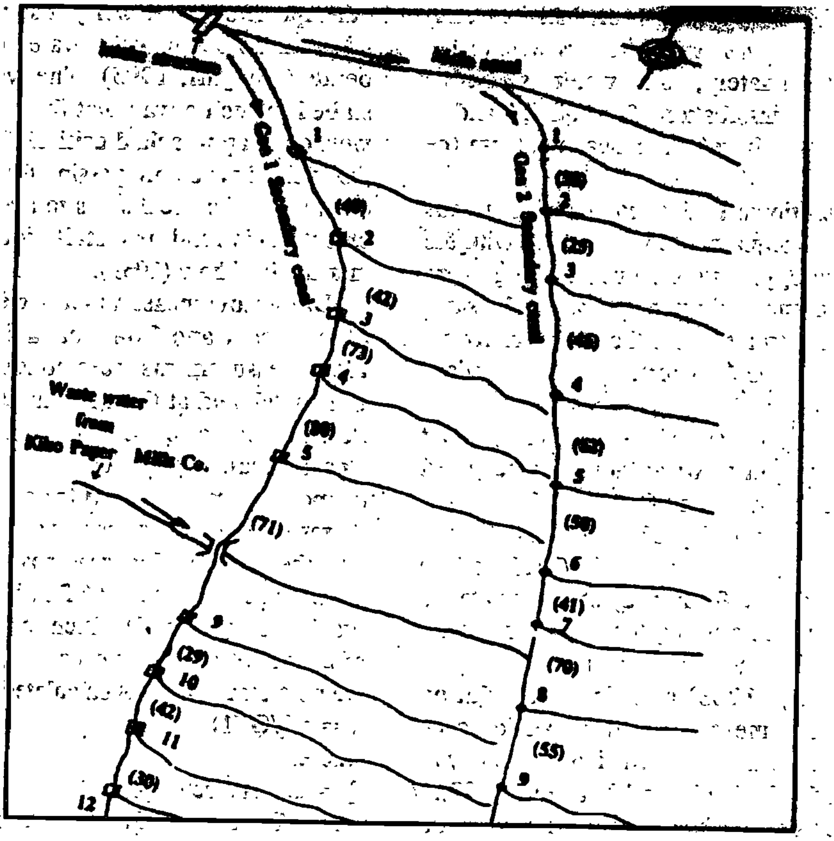

Figure 1: Njoro ya Goa scheme flow measuring stations

from the left hand-side as one moves downstream and that they did not have any water control structures. The two selected canals are therefore, representative of the rest.

The research was conducted along Goa 1 canal with an area of about 63.7 ha and Goa 2 canal with an area of about 34.8 ha. Goa 1 canal had 12 tertiaries while Goa 2 canal had 9 tertiaries. Each of the 12 tertiary canals along Goa 1 was selected as a station to be installed with proportioning water - division weir while the 9 tertiary canals along Goa 2 were selected as control station because they do not have any water control structures. The proportioning weirs were made out of hard wood timber with two openings as there was only one tertiary canal for each station.

The design of the width of the opening depended on the area of land to be served by it. The sill level of each opening in a particular weir was kept equal as suggested by Yoder et al. (1987). This means that only the width of the opening was varied to define the proportion of water that would pass thorough it. The total length of the weir and the accompanied width of their opening (notches) depended on the measured width of the canal at a station.

The concept of area was used during the design work. For example: For station 1 at Goa 1, the area to be served by tertiary canal was noted as being approximately 2.8 ha while the downstream command area was 60.9 ha. This meant that the total command area was 63.7 ha. Now, dividing 2.8 by 63.7 we get 0.044 or 4.4 %, meaning that 4.4 % of the available length in the weir will be used to allocate the tertiary water at station 1. The remainder (95.6 %) would serve the Goa 1 canal downstream the weir.

From the canal width measurements taken, the available length of the weir for station 1 was 140 cm. Hence, 4.44 % of the 140 cm gave 6.216 cm which was approximated to 6 cm for the tertiary opening as the design width. The rest (134 cm) would serve the Goa 1 canal for the command area downstream. This procedure was followed for the twelve-stations and; thus, the design was completed as shown in Table 1. Unfortunately, some water users tempered with the installation of station 6, 7 and 8, and they were therefore, discarded from the study.

An operational trial period of 30 days was necessary to acquaint the water users with the new technology. This involved visiting every farmer or group of farmers served by the same tertiary canal to introduce the device as irrigation water was being diverted into their tertiary canals automatically.

However, the water users complained about the small amount of water flow they received from the tertiaries. The flow into the tertiary canals were visually observed by the researchers and the water users. The width of the weir notches were further adjusted to relate the amount of water passing through it to the respective command sub-area as recommended by Leliavsky (1983) and Ford Foundation (1995). Adjustments were also made on each opening for the sake of maintaining harmony as recommended by Yoder and Thurston (1989).

Estimates of discharge were based on visual inspection (Ambler, 1995) and not on direct physical measurements. This was done in collaboration with the respective water users for each tertiary canal so as to reach a consensus on slot widths of the proportioning water division devices throughout the stations. To reach the consensus, the slot widths were repeatedly timber-nail-adjusted until an agreed width in each station were reached. This exercise took about one month before the actual data collection work started for 48 days. The dimensions of the adjusted slot width are shown in Table 2.

Given that there were no water division structures along Goa 2 canal, the widths of the tertiary canal and the secondary canal and the areas commanded by each canal at a station were used to calculate the proportion of water that has to pass through them as shown in Table 3. The calculated ratios were later used to calculate the expected flow rates at each station.

The set up of the proportioning water-division weirs was such that all possible positions where the main canal seemed to be bending were avoided so as to minimize problems of superimposition of velocity distribution. This problem do occur when water flow through bends (Parajuli, 1995). The weirs were installed in such a way that the flow above the weir crest approached critical depth and that the initial flow before passing through the weir crest was subcritical so as to avoid backwater effect. This kind of installation was recommended by Chow (1959).

Daily flow measurements were conducted along Goa 1 and Goa 2 canals for 48 days. Flow measurements were conducted for each weir notch and at the same time the expected flow rate was calculated for each station along Goa 1 canal. Along Goa 2 canal, flow measurements were conducted for each tertiary and its respective downstream water. At the same time the expected flow rate was calculated.

Using the methods of Parajuli (1995), hydraulic sensitivity (S) which measures the rate of change of discharge caused by a unit rise of the upstream head was calculated as follows:

$S = dQ/Q$ (1)

where:

Q = Canal discharge (l/s)

dQ = Change of discharge caused by a unit rise of the upstream head (l/s)

While hydraulic flexibility (F) which measures the rate of change of discharge of an off-take canal to the rate of change of discharge of the parent canal was calculated as:

$F = (dq/q)/(dQ/Q) = S_o/S_p$ (2)

where:

q = Off-take canal discharge (l/s)

dq = Change of discharge in the off-take canal caused by a unit rise of the upstream head (l/s)

S_o = Hydraulic sensitivity of the off-take canal

S_p = Hydraulic sensitivity of the parent canal

Apart from the flow measurements, secondary data related to socio-economic was collected. The data includes: sources of conflicts based on irrigation water distribution, acceptability of the technology and crop yield. A request was made to the Njoro ya Goa Irrigators Association to measure all the harvested paddy in all the area commanded by Goa 1 and Goa 2 canals respectively because the association did not have records on yield from their scheme.

Table 1: Designed notch width of the installed proportioning weirs at Goa 1 canal stations

Station number	A (ha)	B (ha)	C	D	W (cm)	W1 (cm)	W2 (cm)
1	63.7	2.83	0.044	0.596	140	6	134
2	60.9	2.22	0.036	0.964	100	4	96
3	58.7	1.82	0.031	0.969	160	5	155
4	56.9	6.10	0.107	0.893	110	12	98
5	50.8	1.21	0.024	0.976	90	2	88
9	27.6	0.81	0.029	0.971	70	2	68
10	26.8	1.82	0.068	0.932	60	4	56
11	25.0	0.40	0.016	0.984	60	1	59
12	24.6	2.83	0.115	0.885	60	7	53

Ky:
A = Area commanded by Goal 1 canal
B = Commanded area irrigated by a tertiary canal
C = Proportion of irrigation water to pass through tertiary canal notch
D = Proportion of irrigation water to pass through main (Goa 1) canal notch
W = Available notch length in the device to be proportioned
W_1 = Design notch width for water supply to the tertiary canal
W_2 = Design widith for water supply to the main canal down-stream the device

Table 2: Final notch width of the installed proportioning weirs at Goa 1 canal stations

Station number	W (cm)	W3 (cm)	W4 (cm)	E	F
1	140	131.0	9.0	0.936	0.064
2	100	96.0	4.0	0.960	0.04
3	160	154.0	6.0	0.963	0.037
4	110	97.5	12.5	0.886	0.114
5	90	85.0	5.0	0.994	0.056
9	70	65.5	4.5	0.936	0.064
10	60	54	6.0	0.900	0.100
11	60	57.5	2.5	0.958	0.04
12	60	52.0	8.0	0.867	0.133

Key:
E = Proportion of irrigation water to pass through main (Goa 1) canal notch
F = Proportion of irrigation water to pass through tertiary canal notch
W = Available notch length in the device to be proportioned
W3 = Design notch widith for supply to the main canal down-stream the device
W4 = Design notch widith for water supply to the tertiary canal

Results and Discussion

Irrigation water distribution along Goa 1 and Goa 2 canals

The mean discharge measurements for both canals are presented in Table 4. Observed discharge of the tertiaries along Goal 1 secondary canal are greater than expected. The main reason for the increase is because: first, the notch widths of the proportional water division weirs that led to the tertiaries were adjusted to suit the interest of the water users and secondly, some minor errors may have arose due to some effect of canal bend which tended to supply more water to the tertiaries as the secondary canal was slightly sinuous.

On the other hand, in Goa 2 secondary ca-

Table 3: Proportional water distribution ratios for Goa 2 canal stations

Station number	Area commended by tertiary canal (ha)	Area commended by Goa 2 secondary canal (ha)	Proportional irrigation water to pass through tertiary canals and Goa 2 canal: Tertiary canal	Goa 2 canal
1	1.62	34.80	0.047	0.953
2	3.64	33.18	0.110	0.890
3	4.05	29.54	0.137	0.863
4	2.43	25.49	0.095	0.905
5	3.24	23.06	0.140	0.860
6	3.24	19.82	0.163	0.837
7	2.83	16.58	0.171	0.829
8	1.62	13.75	0.118	0.882
9	2.43	12.13	0.200	0.800

nal, farmers felt that the flow released from the head work was not enough. To counter their feeling about the availability of irrigation water, they used drainage water from Goa 1 secondary canal which drains some of its water into Goa 2 secondary canal. As in Goa 1 secondary canal, more water was diverted to the tertiaries than the expected as shown in Table 4 simply because most of the tertiaries were not located on slight bends along the Goa 2 secondary canal.

Goa 1 secondary canal was also receiving drainage water in between stations. But between station number 5 and 6 waste water canal from Kibo Paper Mills Company drained into this canal as well. Some of the water is taken out by a drainage canal between station number 9 and 10.

Student's t - test analysis showed that the observed and expected discharge values were not different at 5% significant level in Goa 1 secondary canal. In Goa 2 secondary canal, there was a difference between the observed and expected discharge at 1% and 5% significant levels respectively.

Hydraulic sensitivity and flexibility of irrigation water along Goa 1 and Goa 2 canals

Mean hydraulic sensitivity and hydraulic flexibility results for Goa 1 and Goa 2 canals are shown in Table 5. For the water division to be proportional, the hydraulic flexibility should be equal to a unity and the hydraulic sensitivity of the off-take canal and the parent canal should be the same (Parajuli, 1995). The results for Goa 1 were excellent because the mean value of the hydraulic sensitivity for the tertiaries and the secondary canal downstream of the proportioning weirs were the same and its value was 0.25. Mean value of hydraulic flexibility for both the tertiaries and the secondary canal downstream the proportioning weirs was found to be equal to a unity. Therefore, there was an equity of irrigation water distribution along Goa 1 canal.

The case was different in Goa 2 secondary canal. The mean value of hydraulic sensitivity of the tertiaries was 0.035 and that of the secondary canal down stream the proportioning weir was 0.015 while, the hydraulic flexibility was 1.9 and 1.6 respectively (Table 5). This implies that the irrigation water was not proportionally distributed and hence there was no equity in irrigation water distribution. This may have been the main reason behind the dominating conflicts that were observed to erupt continuously among Goa 2 irrigators.

Flow through a channel junction

Flow through a channel junction is a phenomena that involves numerous variables such as the number of branching of canals, angle of intersection, shape and slope of the canals, discharge and corner rounding. Basically, the division of flow will depend upon backwater effects of the two or more branch canal and the dynamic conditions existing at the junction (Chow, 1959). Such a situation was avoided in the study by setting the device in such a way that the flow above the weir crest approached

Table 4: Mean observed and expected discharge in both Goa 1 and Goa 2 secondary canals and their respective tertiaries

Station number	Flow into tertiary canals		Flow into the secondary canal downstream the station	
	Observed (l/s)	Expected (l/s)	Observed (l/s)	Expected (l/s)
Observed and expected discharge along Goa 1 and its tertiaries				
1	4.30	4.25	65.35	62.66
2	3.64	2.07	45.56	51.22
3	2.00	1.14	27.30	28.72
4	3.14	3.43	27.75	26.74
5	3.03	1.70	28.27	28.98
9	5.46	2.91	41.02	42.5
10	1.60	1.82	13.83	13.76
11	4.20	0.82	16.95	18.64
12	2.67	1.59	10.02	10.30
Observed and expected discharge along Goa 2 secondary canal and its tertiaries				
1	1.98	0.19	1.39	3.96
2	0.56	0.36	2.46	2.86
3	1.08	0.66	2.75	4.04
4	1.22	0.30	1.20	2.78
5	1.20	0.52	1.69	3.12
6	1.26	0.74	2.49	3.39
7	1.34	0.68	1.89	3.38
8	1.13	0.51	2.09	3.55
9	1.16	0.70	1.74	2.79

critical depth, and that the initial flow before passing the weir crest was subcritical as suggested by Chow (1959). Apart from the backwater effect, Parajuli (1995) explained that there exists superimposition of velocity distribution of an approach canal across the direction of flow just upstream of the weir axis and the location of notches of a proportioning water-division weir. Thus, the coefficient of velocity for both weir notches may not be the same. IIMI (1995) indicated that the coefficient of velocity of the bigger notch is significantly greater than that of the small notch if the flow was perpendicular to the weir device. This characteristic may have led less water than the designed value to pass through the tertiary notch whenever the weir was placed perpendicular to direction of flow. This phenomena may have probably led to the need of making continuous adjustments of the notch widths so that the intended quantity of water could pass through the weir crest in the present study.

The set up of water divisors in the present study was such that all possible positions where the main canal seem to be bending are avoided. The purpose behind this is to avoid angular resolutions when computing the discharges which may complicate the work. Henderson, (1966) cautioned that if the weir devices are not well set to avoid bends, it can lead to one notch extracting more water than expected.

Although the weir structures were installed in fairly straight reaches of the channel, one could visualize that they had been installed in a straight stretch of the secondary canal and the device was perpendicular to the directions of flow, whereas, when the canal was viewed from a distance, the case did not hold typically true to every station. This situation, may have affected the water distribution at weir structures by a notch extracting more water than expected.

Acceptability of the proportioning water-division device by the water users

It was observed that there was no conflict on water distributions along Goa 1 canal farm blocks which may testify the equity of water

Table 5: Mean values of hydraulic sensitivity and hydraulic flexibility for each station along Goa 1 and Goa 2 canals

Station	ST	SS	FT	FS
GOA 1 CANAL				
1	0.017	0.020	1.1	1.3
2	0.021	0.025	1.0	1.1
3	0.023	0.028	0.8	1.0
4	0.017	0.017	0.6	0.6
5	0.025	0.018	1.1	0.8
9	0.013	0.014	0.7	0.8
10	0.058	0.035	1.8	1.1
11	0.031	0.029	1.1	0.9
12	0.019	0.038	0.7	1.3
Mean	0.025	0.025	1.0	1.0
GOA 2 CANAL				
1	0.024	0.012	2.1	1.8
2	0.030	0.015	1.8	1.5
3	0.032	0.017	1.6	1.4
4	0.024	0.010	1.1	2.3
5	0.035	0.011	2.1	1.1
6	0.018	0.008	1.6	1.1
7	0.081	0.021	3.5	1.7
8	0.043	0.018	1.9	1.3
9	0.027	0.023	1.6	1.9
Mean	0.035	0.015	1.9	1.6

Key:
ST = Mean hydraulic sensitivity of a tertiary canal downstream the proportioning weir
SS = Mean hydraulic sensitivity of a secondary canal downstream the proportioning weir
FT = Mean hydraulic flexibility of a tertiary canal downstream the proportioning weir
FS = Mean hydraulic flexibility of a secondary canal downstream the proportioning weir

distribution. The fact that water users were involved from the beginning in enhancing the use of these proportioning weirs led the researchers to conduct an interview on 78 randomly sampled farmers along Goa 1 secondary canal according to age, gender and responsibility on the acceptance of the technology and the results are shown in Table 6. Men of above 35 years of age accepted the technology slightly more than the young one probably because they had experienced more problems of water distribution than them. Similarly, men of below 35 years of age accepted the technology slightly more than women probably because they had experienced more problems of water distribution than them. It is possible that the men in general do the water distribution work while the women concentrates mainly in farm work which does not give them the exposure on how difficult it is to distribute irrigation water. However, from the results, it can be concluded that the technology was accepted by the water users. The main reason given by the water users was that they could visually verify the amount of irrigation water diverted into a tertiary canal.

Crop yield

The crop yield for Goa 1 and Goa 2 tertiary canal blocks are shown in Table 7. The trend in paddy yield shown in Table 7 indicates more or less uniform yield for Goa 1 farm blocks while those of Goa 2 were more or less non-uniform. The mean crop yield for Goa 1 and Goa 2 was 4.0 tons/ha and 2.9 tons/ha with a standard deviation of 0.16 and 0.52 tons/ha respectively. Everything else being equal, the irrigation water supply may have caused the difference.

Table 6: Water users' perception of the technology along the Goa 1 canal

Class of Water Users	Number of Water Users	Acceptance of the Technology		Rejection of the Technology	
		Number	Percentage	Number	Percentage
Men above 35 years of age	34	30	88.2	4	11.8
Men below 35 years of age	16	14	87.5	2	12.5
Women of mixed age group	22	19	86.4	3	13.6
Water allocation committee members	6	6	100	0	0
Total	78	69	88.5	9	11.5

Table 7: Actual crop yield of paddy for the cropping season under the study

Block commanded by tertiary canal station along Goa 1 canal	Crop yield from the blocks (tons/ha)	Block commanded by tertiary canal station along Goa 2 canal	Crop yield from the blocks (tons/ha)
1	4.15	1	3.18
2	3.90	2	2.95
3	3.68	3	2.74
4	3.82	4	3.11
5	3.85	5	3.89
9	3.97	6	2.58
10	4.12	7	2.09
11	4.20	8	2.17
12	4.07	9	2.96
Mean	4.00	Mean	2.90
Standard deviation	0.16	Standard deviation	0.52

Conclusion

The case study indicates that proportioning water-division weirs can distribute irrigation water according to an area served by a canal system equitably. This was shown by the equitable water distribution along Goa 1 secondary canal. In addition, in irrigation water scarcity condition, farmers can visualize their share of irrigation water thus minimizing conflicts.

The equity of irrigation water distribution and the crop yield observed in Goa 1 and Goa 2 canals indicates that proportioning water division devices automatically distribute irrigation water equitably and in return may have led to a higher crop production. These weirs may provide an extra advantage on the part of managers of irrigation schemes because they can easily charge irrigation water fees based on land size owned by individual water users.

The weirs in the present study were made of timber. It would be of interest to study the use of other construction materials such as bricks and concrete blocks which last longer while taking into account affordability by the farmers.

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