Performance Evaluation of Pressurized Irrigation System (A Case of Kobo Girana Irrigation System, Ethiopia)

Kassa Abera[1(✉)] and Michael Mehari[2]

[1] Department of Hydraulic Engineering, Wollo University, KioT, Kombolcha, Ethiopia
[2] Ministry of Water, Irrigation and Electricity, Addis Ababa, Ethiopia

Abstract. There are some pressurized irrigation projects launched in Ethiopia. Yet, there are no more research works on the performance evaluation of pressurized irrigation systems because of researchers believe that pressurized system has good performance. But practically, it is not true especially in developing countries such as Ethiopia, which has poor water resource management system. So to fill this gap, this research was studied on performance evaluation of Hormat Golina–4 drip irrigation systems in Kobo Girana Valley. The objective of this study was to evaluate the performance of Kobo Girana pressurized irrigation, specifically Hormat Golina-4 drip irrigation. The emitter discharge and soil moisture content were collected from seven experimental plots fields. The emitter flow was collected by using a total of 63 catch cans, 9 catch can per plot area and measured by using graduated cylinder. Hydraulic performance indicators such as application efficiency (Ea), irrigation adequacy (Pa), equity performance (PE), dependability performance (PD), delivery performance ratio (DPR) and distribution uniformity characteristics; percent of clogged emitters (Pc), emission uniformity (EU), emitter flow rate variation (qvar), coefficient of variation (Cv) and uniformity coefficient (Uc) were evaluated accordingly. The average values of the above discussed parameters in the scheme were found that Ea (61.41%), Pa (41.52%), PE (0.33), PD (0.23), DPR (2.21), Pclog (33.33%), EU (47.71%), pvar (71.03%), CV (45.31%) and UC (53.42%), respectively. Results showed that the overall performance level of Hormat Golina – 4 drip irrigation systems is low and poor.

Keywords: Performance · Evaluation · Pressurized irrigation · Drip system · Kobo Girana · Hormat Golina –4

1 Introduction

Ethiopia is one of the developing county which is highly dependent on rainfed agriculture. But due to high climate change variability and degradation of natural resources such as land and water potential, poverty and food insecurity increased from decade to decade. Therefore, one of the best solution to improve rainfed agriculture is development of different irrigation systems [1]. There is no consistent and reliable inventory and well

M. A. Delele et al. (Eds.): ICAST 2020, LNICST 385, pp. 85–97, 2021.
https://doi.org/10.1007/978-3-030-80618-7_6

– studied documented with regards to water and irrigation potential in Ethiopia [2]. Although, the Ministry of Water, Irrigation and Electric city (MoWIE) was indicated 560 irrigation potential sites on different major river basins in the region [3], the total area of irrigable land by twelve major river basins in the region is predicted as nearest to 3.7 million hectares which is based on the suitability of the topography [3]. However, only five percent of this area is irrigated with low performance [4]. Even though, Ethiopia has good rainfall distribution and ample water resources potential, still the agricultural system does not entirely benefit from the technologies and know-how of water resource management and irrigation development system [5].

Beside to major river basins in general and some of the planed irrigation plant in particular has been irrigated by pressurized irrigation system by extracting ground water like Kobo Girana pressurized irrigation system [6]. In Kobo Girana pressurized irrigation development program, 563 ha was irrigated by pressurized (drip and sprinkler) irrigation system but now only 439 ha is irrigated due to well yield reduction and lateral and emitter clogging problem. Performance evaluation and assessment of pressurize irrigation system is one of a technical analysis and classification of water resource management in irrigation and drainage schemes to assure that the input of resources (water and land), operational timetables, anticipated outputs and essential actions proceed as the intended. Solving the performance level of irrigation system using several techniques and planning is deliberated a key issue for addressing the requirement for increasing productivity of irrigated scheme under stress on water resources availability. Many irrigation schemes in developing countries such as Ethiopia, are highly characterized by poor performance level. The main reason for low performance is related to poor institutional structures and non-flexibility of the schemes arrangements [7].

In Ethiopia, irrigation development is still in infant stage due to many challenges, especially, pressurized irrigation system is not well adopted due to its high initial cost and requirement of skilled man power [2]. Adoption of innovated technologies by landholders is a dynamic learning process in developing countries such as Ethiopia. Because, adaptation of innovative technology is highly dependent on different conditions of the society such as, social, cultural and economic aspects, and also characteristics of the technology transformation methods. Therefore, adoption will arise after the landowner recognizes that the technology boosts the individual goals related to their income. The variety of goals is dependent among landowners, including socio-economic, and environmental objectives. Technology is more likely to be adapted when there is a high relative improvement and when they are easily trainable, simple to test and acquire about preceding to implementation.

Kobo Girana Valley Development Program implements large scale pressurized irrigation Project over the region with combination of Surface and Pressurized irrigation system and the source of irrigation water is from ground water. This sub basin has good ground water potential. The main problem of irrigation development in Hormat Golina-4 is inappropriate management of the innovated technology. This is principally due to lack of responsible skilled man power and inadequate institutional setup that are equipped with sufficient capacity [6]. Therefore, it requires a proper operation and watering of the field crop based on the design requirement to increase crop production and to improve water management problems for the sustainability of the system. So to check the effective functionality of each auxiliary structures of the system, performance evaluation of this project is necessary. With this background and justification, this study have been conducted to evaluate the performance of Kobo Girana pressurized irrigation scheme a case of Hormat – Golina 4 Drip irrigation system, with the objectives of assessing the current operation rules and recommending another possibilities for more effective usage of water, sustainability of the system, to improve crop productivity of the irrigable land and to duplicate the technology from government oriented system to small holder farmers by introducing the advantage and the productivity of pressurized irrigation system over surface irrigation system.

2 Methods and Materials

2.1 Study Area Description

Kobo Valley sub-basin pressurized and surface irrigation project is topographically located between 12°18′ to 11°56′ N and 39°23′ to 39°47′ E of latitude and longitude respectively. Kobo Girana Irrigation Development Project is located in North Wollo Zone Administration in Amhara region which is found at a distance of 50 km from Woldia Town and 410 km from Bahir Dar Town. The total area of Kobo Valley sub-basin is assessed, 1439 km^2 from which 29% is flat plain and the remaining area is dominated by large mountainous and undulating hilly. The project area is bounded by from North Southern Tigray Zone, from Soth Alawha sub-basin, from West Lasta Mountain and from East Zoble Mountain (Fig. 1).

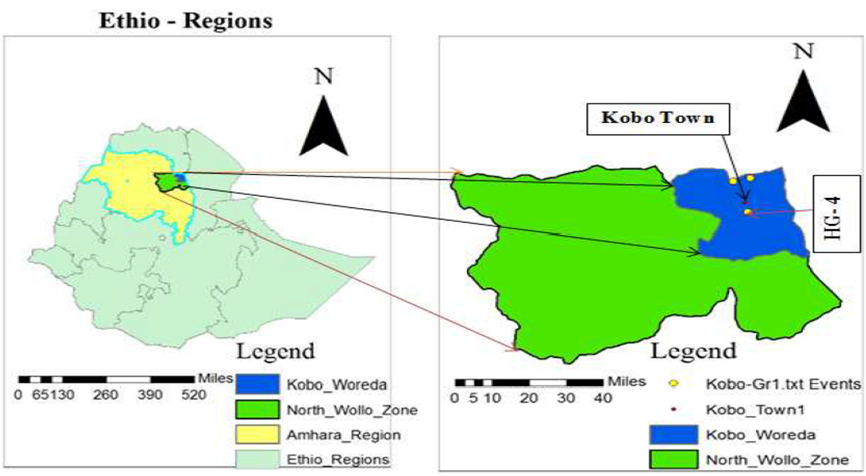


Fig. 1. Kobo Girana Valley, Hormat Golina – 4 Location

There are fourteen pressurized irrigation systems; three partially drip and partially sprinkler, eleven drip and forty surface irrigation sites in Kobo Girana Valley Development Program. There is a total of 563 ha irrigable land by drip irrigation system, but now only 439 ha is irrigated. From these Hormat Golina number four (HG-4) is one of a drip irrigation system which is located 3 km from the Kobo Town to south direction and it has a total irrigable area of 50ha and the total number of beneficiaries in this system are 695. Generally, there are 25 head controls and 200 valves to irrigate a total area of 50ha in HG – 4. The manifold has a length of 100 m in which the laterals connected by three – way connectors with a lateral length of 25 m. Each connector has a spacing of 3 m. The lateral and emitter spacing is 1 m and 0.3 m respectively. The width of the lateral is restricted by the operating valve. One head control can irrigate 2 ha at the same time and it contains eight valves each irrigated 0.25 ha (Fig. 2).

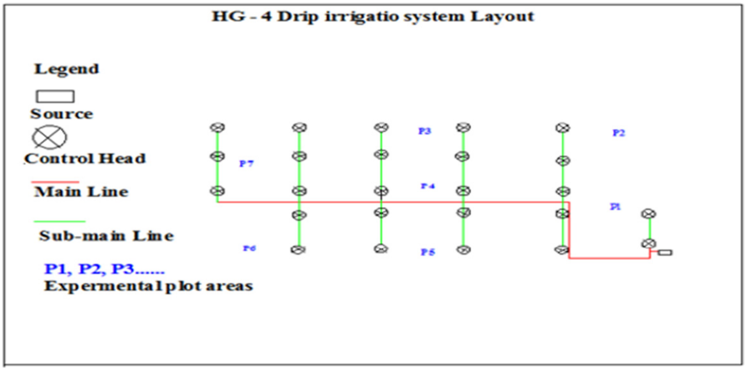
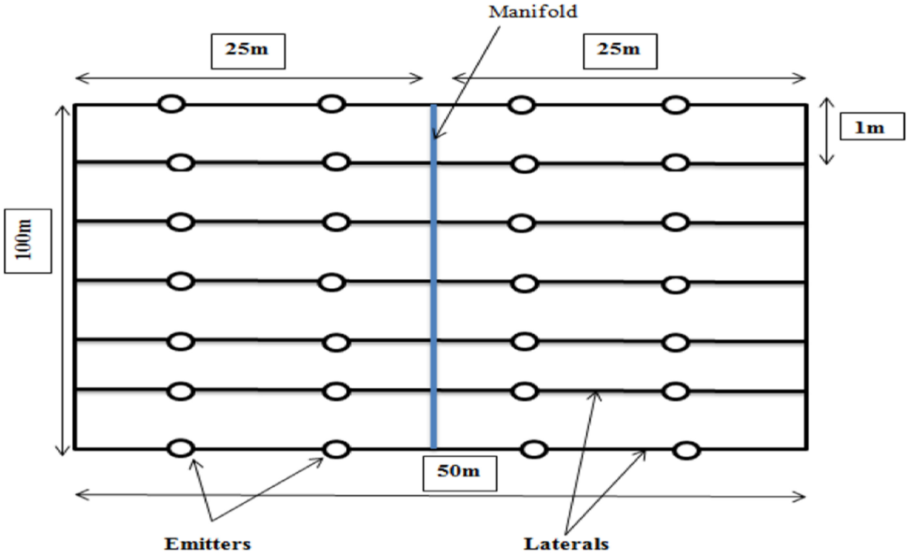


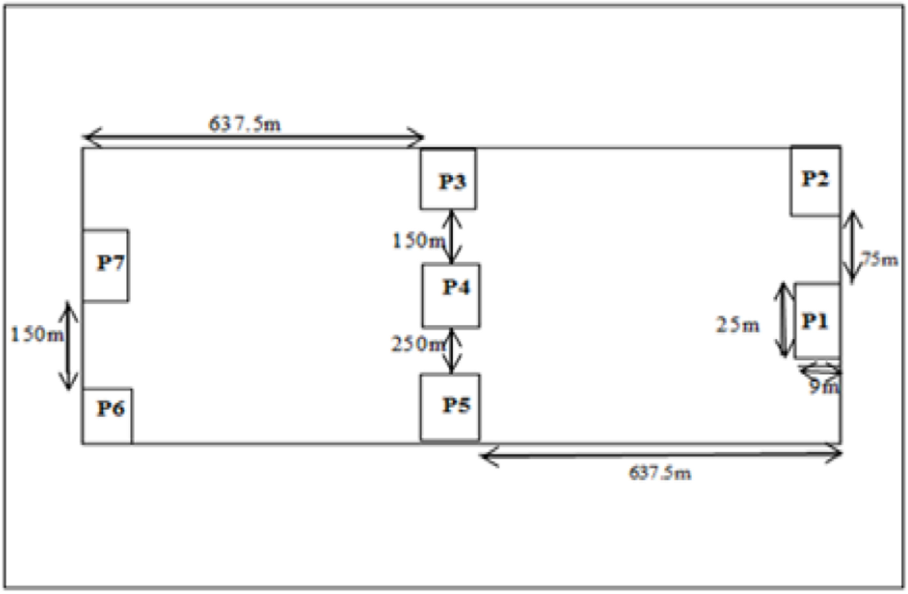
Fig. 2. Hormant - Golina – 4 Drip Irrigation System Layouts

The data were collected directly by measuring different hydraulic parameters on the field. Seven plot areas were designed for this specific study, two from the head, three from the middle and two from the tail respectively. Each plot has a total area of 0.0225 ha. To measure the emitter discharge 63 catch cans were distributed; nine catch cans in each plot. Three catch cans at the head of the lateral, three catch cans at 12.5 m from the head of the lateral and three catch cans at tail of the lateral length were installed.

Soil samples were also collected to determine the soil moisture content one sample before irrigation and three samples after irrigation by collecting 84 soil samples from seven plots with an interval of 0–20, 20–40 and 40–60 cm depth. It is assumed that, the effective root zone for the irrigated vegetable crop is not more than this depth. According to Allen, the maximum effective root zone depth of onion is no longer than 60 cm [8]. The moisture content of collected soil samples was determined using gravimetric method. The soil sample data have been collected from the field by using soil auger and plastic bag. Finally, to determine moisture content, collected soil sample was applied to oven dry at 105 °C for 24 h using a catch can (Fig. 3).



a) Lateral and emitter distribution layout of HG – 4



b) Soil sample location in the experiment plot area

Fig. 3. Experimental Plot Areas Layout of Hormat – Golina 4

2.2 Data Analysis Methods

Hydraulic Performance Indicators

Irrigation Application Efficiency

Irrigation application efficiency is an indicator of losses which occurred depending on the input and output conditions of the system. It is expressed in terms of percentage by dividing the water stored in the root zone to the delivered water to the farm. Generally, irrigation application efficiency can be defined as bellow.

$$\mathrm{E_a} = \frac{\text{water stored in the root zone}}{\text{water delivered to the farm}} * 100 \tag{1}$$

Where: $\mathrm{E_a}$ = application efficiency.

Adequacy of Irrigation

The quality and quantity of crop production depends on the adequacy of water supplied to the irrigation field. Therefore, adequacy of irrigation is the percentage of area replenished by water to the total area of the field to be irrigated. In case of drip irrigation system, the total irrigable area is not wetted and only the root zone area is replenished by water. During the field work the replenished area within the root zone for each experimental plot were measured. Then, adequacy of Hormat Goliina – 4 drip irrigation system is estimated as shown below.

$$\mathrm{P_a} = \left(\frac{a_{rz}}{A_T}\right) * 100 \tag{2}$$

Where: $\mathrm{P_a}$ = adequacy of Irrigation, $\mathrm{A_T}$ = total irrigable area, $\mathrm{a_{rz}}$ = area with root zone replenished by water.

Equity

Equity is the distribution of water fairly to the users throughout the whole system (head, middle and tail). Equitable water distribution will be attained when the ratio of water delivery to head users to the delivery at the tail users equal to one. Equity indicates the ability of a system to uniformly delivery water to the users. The measure is given by:

$$\mathrm{PE} = \frac{1}{T}\sum_{T} C_{VR}\left(\frac{Q_d}{Q_T}\right) \tag{3}$$

Where: PE = Equity, T = time (week, month, season); for this study, week, R = region (plots, reaches, sections); for this study, plots, $\mathrm{C_{VR}}$ = spatial coefficient of variation which is the ratio of delivery water to intended water to the region R, (Qd/Qr) where $\mathrm{Q_d}$ and $\mathrm{Q_r}$ are the delivered discharge measured on the experiment plot area and the required discharge in the designed emitter respectively.

Dependability

Dependability is the degree of temporal variability in the ratio of delivered water to the required water over the region. The dependability parameter is defined as:

$$\mathrm{PD} = \frac{1}{R}\sum_{R} C_{VT}\left(\frac{Q_d}{Q_r}\right) \tag{4}$$

Table 1. Water delivery performance indicators Range

Parameters	Range		
	Poor	Fair	Good
PD	>0.20	0.11–0.20	0.00–0.10
PA	<0.80	0.80–0.89	0.90–1.0
PE	>0.25	0.11–0.25	0.00–0.1

Source: Molden and Gate (1990)

Where: PD = dependability, T and R were defined before, C_{VT} is temporal coefficient of variation at discrete location in a region R and a time span T.

Delivery Performance Ratio (DPR)
The most important and simple performance indicator in irrigation field is delivery performance ratio, which is the ratio of actual delivered discharge to designed discharge. [9]. The average monthly measured discharge for each emitter should be compared with intended (design) discharge by the form of Eq. (5) to get the DPR.

$$\text{Delivery Performance Ratio} = \frac{Q_{act}}{Q_{des}} \tag{5}$$

Where: Qact is the actual measured discharge in each emitter; Qdes is the intended design discharge.

On the actual field, all the emitters were not fully functional and then the total number of completely clogged emitters has been determined using [10] by Eq. (6).

$$P_{NC} = \left(\frac{Nc}{N}\right) * 100 \tag{6}$$

Where: PNc = number of clogged emitters in percent, Nc = number of clogged emitters in the plot, N = total number of emitters in the experiment plot. Drip irrigation is commonly limited to a small area coverage that gradually and commonly delivers water directly to the crop root zone in a droplet manner. Emitter clogging has often been accepted as inconvenient and one of the most significant worries for drip irrigation system projects, it causes to decreased system performance level and increased water pressure between irrigated and non-irrigated crops in the field [11].

Uniformity Characteristics
Uniformity refers to the extent of available water distribution over the delineated irrigation area.it is highly affected by water pressure distribution, pipe network arrangement, water quality, source of energy to boost water from the source, status of lateral and hydraulics nature of emitters [12].

Distribution Uniformity (DU)
The first one is distribution uniformity (DU) or emitter uniformity (Eu) which will be calculated by using [13] Eq. (7).

$$D_U = 100 * \left(\frac{q_{\min}}{q_{aver}}\right) \tag{7}$$

Where: DU = Field distribution uniformity (%); qmin = minimum discharge rate obtained from measurement (l/h) and, qaver = average emitter discharge rates of the given plot (l/h).

Emitter Flow Variation (qvar)
Emitter flow variation is the important uniformity characteristics used to check the flow variation between emitters within the latera and it is calculated using equation of [14].

$$q_{var} = \left(\frac{q_{max} - q_{min}}{q_{max}} \right) \quad (8)$$

Where: q_{var} = emitter flow variation, qmax = maximum flow rate in the emitter (l/h), qmin = minimum flow rate in the emitter (l/h).

Coefficient of Variation
Another uniformity parameter is coefficient of variation which is the variation of emitter flow rate from the mean. It is the ratio of standard deviation to mean as shown below by using Equation of [14].

$$Cv = \frac{Sd}{qav} \quad (9)$$

Where: Sd = standard deviation of emitter flow rates (l/h) and, q_{av} = average emitter flow rate (l/h).

Uniformity Coefficient
Coefficient of uniformity (Uc) is defined as the coefficient of variation and expressed as the ratio of standard deviation to mean and it is determined using Eq. (10) as described below [15].

$$U_C = \left(1 - \frac{S_d}{q_{av}} \right) * 100 \quad (10)$$

Where: U_C = coefficient of uniformity (%); Sd = average standard deviation of all emitters flow (l/h), q_{av} = average emitter flow rate (l/h).

3 Result and Discussion

3.1 Irrigation Application Efficiency

The average irrigation application efficiency of HG- 4 was obtained (using Eq. 1) 61.41%. According to Adapted from Irrigation Association, the current efficiency status of the scheme is poor. It is obvious that the application efficiency for drip irrigation is about 90–95%. But, this low efficiency was resulted due to the long service time of the lateral (above ten year), 33.33% of the emitters were completely clogged and 47.62% were discharging over the intended design discharge which is resulted from illegal penetration of the clogged emitters by the users using awl and nail (Table 2). The over discharging, 47.62% (Table 2) was resulted by modifying the manufactured emitter diameter by farmers when the emitter clogged by dust material or fertilizer. This increases the loss of water in the system.

Table 2. Irrigation Efficiency analysis and result

Plot	Emitter discharge (L/hr) Along the lateral			Average discharge		Area	SMD(mm)	Wd(mm)	Ea(%)
	Head	Middle	Tail	Qaver(L/hr)	V(m^3)	A(m^2)			
P1	2.60	3.13	0	1.91	21.65	225	50.76	96.21	52.76
P2	2.33	0.42	1.64	1.46	17.05	225	48.74	75.78	64.32
P3	0.94	0.64	0	0.53	13.06	225	48.77	58.06	84.00
P4	0.27	1.76	0	0.68	13.67	225	49.34	60.74	81.23
P5	1.90	2.58	0.33	1.61	18.71	225	34.10	83.15	41.01
P6	1.34	3.23	2.17	2.25	26.18	225	47.98	116.35	41.24
P7	2.32	1.74	0	1.35	15.78	225	50.98	70.14	72.68
Average application efficiency in each reaches (%)						Overall Ea (%)			
Reach			Head	Middle	Tail	61.41			
Average efficiency Ea (%)			58.54	68.75	56.96				

Table 3. Current Emitter status of HG – 4 on the selected plot areas

Emitter status	No	Percent (%)
Normal discharging emitters	12	19.05
Over discharging emitters	30	47.62
Completely clogged emitters	21	33.33
Total	63	100.00

3.2 Irrigation Adequacy

In Hormat – Golina 4 the maximum averaged replenished width at the root zone was 0.74 m which is 74% of the intended design width (1 m). Using Eq. 2, the adequacy of this scheme has been obtained 41.52%. This inadequate water is resulted due to clogging of emitters (33.33%) and improper penetration of emitters which reduces the water distribution from lateral head to tail (end) and the water availability reduced from head to tail reach. This implies that more water was loss at head reach and the pressure is reduced at the tail reach (Fig. 4).

3.3 Equity

Average overall equity of the delivery system of Hormat – Golina 4 is found to be 0.33 (Table 3). Therefore, based on the general criteria given in (Table 1), [9], (0.33 > 0.25), the overall result implies that the scheme equity is poor.

3.4 Dependability

The average dependability of this scheme was obtained 0.23 which is unsatisfactory, based on criteria's given in (Table 1) [9], (0.23 > 0.2) (Table 4).

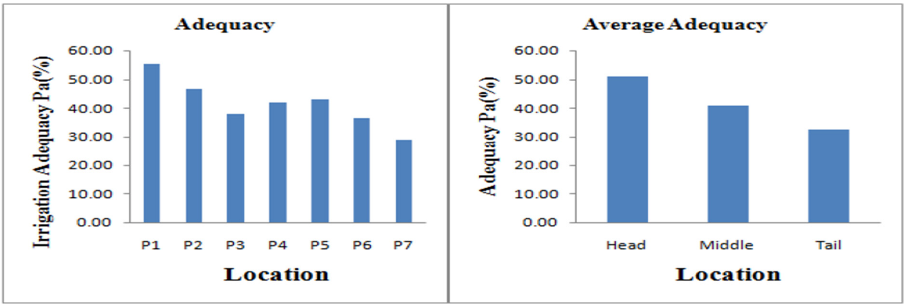


Fig. 4. Irrigation adequacy in each experiment plots and Reaches

Table 4. Equity and dependability result

Parameter	Reaches			Average
	Head	Middle	Tail	
PD	0.23	0.25	0.22	0.23
PE	0.21	0.46	0.32	0.33

Where: PD = dependability performance and PE = equity performance.

3.5 Delivery Performance Ratio (DPR)

Delivery performance ratio is used to check the delivered quantity of water to crop in line with the intended designed emitter discharge. Accordingly, delivery performance ratio (DPR) of Hormat – Golina 4 was obtained 2.21. This value is greater than unity which is due to the farmers simply puncturing the clogged emitters without considering the standard emitter spacing and diameter which resulted high water loss (Fig. 5).

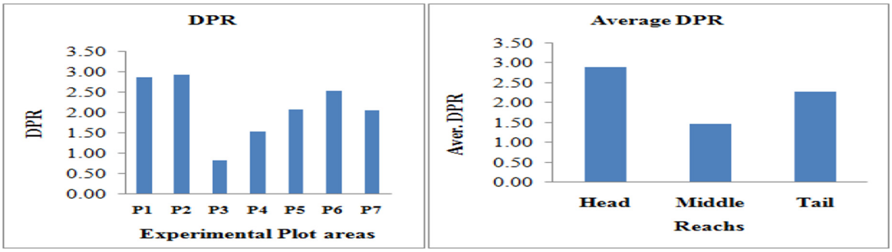


Fig. 5. Delivery Performance Ratio of experimental plots and reaches

3.6 Emitter Distribution Uniformity

Distribution Uniformity (EU)
Average distribution uniformity of Hormat Golina – 4 was 47.71% and which is classified as poor distribution uniformity (<70 for drip system) [15].

Emitter Flow Variation (qvar)
The overall flow rate variation of this scheme was found 71.03% which is unacceptable according to [16]. This unacceptable flow variation may come from the long period service of the lateral (ten years in case of HG – 4), poor water quality due to addition of fertilizer, temperature of the area, emitter manufacturing variation and emitter clogging as explained by [17] (Fig. 6).

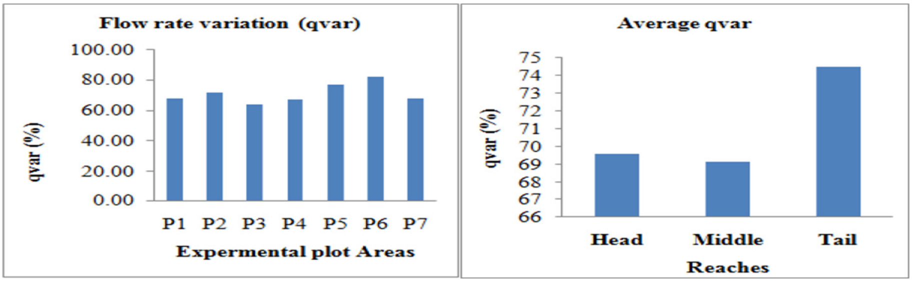


Fig. 6. Flow rate variations for experimental plot areas and reaches

Coefficient of Variation (Cv)
Average coefficient of variation at head, middle and tail respectively were obtained 35.76%, 50.79% and 49.38% respectively and the overall average coefficient of variation was 45.31% according to [15], which is unacceptable value.

Uniformity Coefficient (Uc)
The overall uniformity of the scheme has been found 53.42% and According to [18], this result felts to unacceptable. At the head reach the water pressure is high and as the head increased from head reaches to tail reach, the water pressure becomes low and it cannot be easily pass through the clogged emitters. Uniformity coefficient has inverse proportion with flow rate variation. This implies that as flow rate variation decreased, coefficient of uniformity will have increased.

4 Conclusion and Recommendation

4.1 Conclusion

This study was conducted in Kobo Girana Valley Development program, to evaluate the performance level of Hormat Golina – 4 drip irrigation systems with the objective of assessing hydraulic performance indicators and uniformity characteristics analysis. The result showed that the overall irrigation application efficiency of the system and emission uniformity of the emitters was 61.41and 47.71% respectively. This implies that the performance of the scheme is poor.

The major problems observed during the study were emitter clogging, water sharing problem with users at the head and at the tail, illegal penetration of clogged emitters by the users and luck of maintenance and improper collection of laterals after irrigation has completed. In this situation the scheme will not serve very well in the future unless the laterals changed.

4.2 Recommendation

For water scared areas, drip irrigation system is one of a vital method for both water saving and good crop production. But improper management of the system will result high investment cost. Mostly newly innovated technologies are directly copied and transferred from developed countries to developing countries without adequate training. As a result, the direct users of the technology simply practiced in traditional experience and which leads to low performance of the system. The system by itself may not be performed low, but due to poor management and maintenance practice the overall performance of the system will be low. This kind of problems was observed in Hormat Golina – 4 drip irrigation system. So, the concerned institutions are expected to give due emphasis for these innovated technologies, not only transferring it but adequate training must be given to the users. In a case of Hormat Golina – 4 drip irrigation system; 33.33% of the emitters were clogged and most of the laterals are highly damaged. So to increase the productivity of the scheme, the laterals need replacement unless it is difficult to continue by this condition and set a ground rule and penalty for users when they illegally penetrate the laterals.

References

1. Awulachew, S.B., Merrey, D.J., Kamara, A.B., Koppen, B.V., Vries, F.P.D. Boelee, E.: Experiences and opportunities for promoting small– scale/micro irrigation and rainwater harvesting for food security in Ethiopia. Working paper 98 (IWMI): Colombo, Sri Lanka (2005)
2. Haile, G.G.: Irrigation in Ethiopia, a review. J. Environ. Earth Sci. **3**, 264–269 (2015). https://doi.org/10.15413/ajar.2015.0141
3. Awulachew, S.B., Yilma, A.D., Loulseged, M., Loiskandl, W., Ayana, M., Alamirew, T.: Wp123, Water Resource and Irrigation Development in Ethiopia (2007)
4. Ekwe, A.C., Onu, N.N., Onuoha, K.M.: Technical and Institutional Evaluation of Geray Irrigation Scheme in West Gojjam Zone, Amhara Region Ethiopia. J. Spat. Hydrol. **6**, 1–14 (2006)
5. Awulachew, S.B., Erkossa, T., Namara, R.E.: Irrigation potential in Ethiopia 59 (2010)
6. Tadesse, N., Nedaw, D., Woldearegay, K., Gebreyohannes, T., Steenbergen, F.V.: Groundwater management for irrigation in the raya and kobo valleys, Northern Ethiopia. Int. J. Earth Sci. Eng. **8**, 1104–1114 (2015)
7. Dejen, Z.A.: Hydraulic and operational performance of irrigation schemes in view of water saving and sustainability (2015)

8. Allen, R., Pereira, L., Raes, D., Smith, M.: Crop Evapotranspiration: - Guidelines for Computing Crop Water Requirements. Irrigation and Drainage Paper, 56. FAO, Rome (1998)
9. Molden, D.J., Gates, T.L.: Performance measure of irrigation water delivery systems. J. Irrig. Drain. Eng. **116**(6), 804–823 (1990)
10. Liu, H., Huang, G.: Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. Agric. Water Manag. **96**, 745–756 (2009)
11. Zamaniyan, M., Fatahi, R., Boroomand-nasab, S.: Evaluation of emitters and water quality in trickle irrigation systems under Iranian conditions (2013)
12. Smajstrla, A.G., Boman, B.J., Pitts, D.J. Zueta, F.S.: Field evaluation of micro irrigation water application uniformity. Fla. Coop. Ext. Ser. Bul. 265. Univ. of Fla (2002)
13. Kruse, E.G.: Describing irrigation efficiency and uniformity. J. Irrig. Drain Div. ASCE **104**(IR1), 35–41 (1978)
14. Wu, I.P.: A Unit-plot for drip irrigation lateral and sub-main design. ASAE Paper, St. Joseph, MI 49085. No. 83-1595 (1983)
15. ASAE: Design, installation and performance of trickle irrigation systems. ASAE standards. Transactions of American Society of Agricultural Engineering. Ep 405, St. Joseph, Michigan, pp. 507–510 (1985)
16. Bralts, V.F.: Operational principles-field performance and evaluation. In: Trickle Irrigation for Crop Production, pp. 216–240. Elsevier, Amsterdam (1986)
17. Jensen, M.E.: Design and operation of farm irrigation systems. An ASAE Monograph No. 3. ASAE 2950 Niles Road. St. Joseph, Michigan 49085, USA (1983)
18. ASAE: Field evaluation of micro irrigation systems. EP458, pp. 760−765 (2003)