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ASSESSMENT OF HYDRAULIC PERFORMANCE OF A LOW- COST DRIP IRRIGATION SYSTEM FOR CLIMATE CHANGE ADAPTATION

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Abstract.

Experiment was conducted in a greenhouse at the Students Research and Demonstration farm of the Federal College of Land Resources Technology, Owerri, Nigeria during the periods, September to October, 2023 and December, 2023 to March, 2024. The experiment was to assess the hydraulic performance of a low-cost drip irrigation system developed for climate change adaptation. The experiment was laid out in a randomized block design with 3 replications of plots measuring 4 m x 0.5 m each. Volumetric method was used to determine discharge from each emitter. The coefficient of variation (CV), emitter flow variation (FV), emission uniformity (EU), design emission uniformity (EU_k), statistical uniformity (U_s) and uniformity coefficient (CU) were determined using the Christiansen's method and Merriam and Keller's method, and assessed using the America Society of Agricultural Engineers (ASAE, 1996, ASAE, 1999. ASAE, 2003) performance rating. The results showed that the mean and standard deviation of the emitter discharges were 0.86 and 0.027 l/h respectively and no emitter clogging was observed. The values of CV, FV, EU, EU_k, Us and CU of 3.15 %, 10.3 %, 91.45 %, 83.62 %, 96.85 % and 95 % respectively recorded with the drip irrigation system show that the system was well designed and highly efficient. Therefore, the system can enhance crop production, improve farmers income and reduce poverty in developing countries of the world.

Keywords: Coefficient of variation, emitter flow variation, emission uniformity, design emission uniformity, statistical uniformity, uniformity coefficient.

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I. INTRODUCTION

Water is regarded as the most essential natural resource on the planet earth and an indispensable component for agricultural production. About 70% of the global water is utilized for agricultural activities and about 80% of the water is being utilized in the developing economies of the world [1]. Water used for crop production is increasingly becoming scarce in all agro-ecological zones worldwide. This has been aggravated by climate change and the resultant rainfall variability that has been reported to have severe impact on agricultural production systems, particularly in Sub-Saharan Africa (SSA). With the changes in the climate regime, SSA is expected to experience drier climate that will severely affect the rain-fed agricultural production system widely practiced in the region [2]. [3] reported that climate change will also cause increased variability of water resources which will result in surface water scarcity and groundwater depletion and which will in turn limit irrigation practice and threaten food security in the region.

The above scenario underscores the need to adopt production systems in Sub-Saharan African countries which will produce more yields per drop of water used in order to adapt to the menace of climate change. In order to solve the problem of water shortage in agriculture due to climate change, it has become increasingly critical to reconsider the traditional methods, with the use of modern systems and technologies in irrigation that achieve an increase in productivity of water per unit volume by reducing the water gates during irrigation process [4]. This can be achieved through micro-irrigation system particularly drip irrigation system. Drip irrigation method is the only method adjudged to hold so many prospects for dry season production of high value crops including vegetables [5]. Drip irrigation systems play an important role in addressing the high rainfall variability in the region [6]; [7] and increasing cycle of crop production [8]; [9] amid water scarcity and limited available water. Irrigation development in SSA is limited to technologies with higher water use efficiency as water scarcity is a perennial and temporal challenge in most parts of the region.

Drip irrigation has been reported as the most efficient method of applying water to crops [3]. Compared with the sprinkler systems that are 75-85% efficient, drip systems are more than 90% efficient [10]. Two factors are responsible for the high efficiencies of drip irrigation systems, first is that water infiltrates into the soil before it can evaporate or run off and second is because water is applied directly to crop's root zone where it is needed.

Drip irrigation is commonly adopted in small scale production areas where there is water scarcity. There are to main types of drip irrigation system – high pressure system that requires a pumping unit to push water to the system, a pressure regulator to prevent blowout and leaks, a device that prevents backflow and high pressure withstanding tubing and a low head (gravity fed) system that eliminates the need for these costly components which makes it cost effective amid simplicity and ease of installation.

Performance of any drip irrigation system is influenced by the physical and hydraulic characteristics of the drip tubing [11]. Ascertainment of the actual performance of a localised drip system at the field level is a prerequisite to convincing farmers of its adoption. To this effect, some studies have been conducted which evaluated a drip irrigation system's performance based on water distribution uniformity and variation [12], [13], [14] while considering manufacturing variations [15], emitter clogging [16]; [17] and pressure losses [18]. [19] reported local related studies on the evaluation of gravity fed drip irrigation system in crop production and performance evaluation as influenced by water heads and lateral lengths. However, there have not been studies to evaluate hydraulic performance of an expandable locally developed low cost gravity fed drip irrigation system under constant head condition for climate change adaptation. Therefore, this study was conducted to accomplish the above as its objective.

II. MATERIALS AND METHODS

A. Description of study area

The study was conducted in a greenhouse at students Research and Demonstration Farm of Federal College of Land Resources Technology, Owerri located at Oforola, Imo State, Nigeria. The area (Figure 1) lies between Latitude 5^{o}24'N and Longitude 6^{o}54'E and occupies an elevation of 60 m above mean sea level. It can be accessed from Port Harcourt road through Avu road or through Obinze –Oforola road and through Avu – Obosima road, It covers an area of about 1.05 km^2 and lies at a distance of about 7 km from Owerri, the Imo State Capital.

The area lies within humid tropical climate having strong effect of the Continental Air Mass. The annual rainfall ranges from 2000 mm – 2500 mm while the temperature ranges from 27^{o} – 31^{o}C. The average minimum and maximum temperatures are 17.19 and 34.27 ℃ respectively. It is characterised by two seasons; rainy season that runs from April to October with a break of dryness popularly referred to as August break and dry season that spans from November to March. The relative humidity is generally high (97 %) especially during rainy season [20]. Average monthly evapotranspiration varies from 3.3 – 4.6 mm/da. Many smallholder farmers in the area grow vegetables with a hand-held watering system [21].

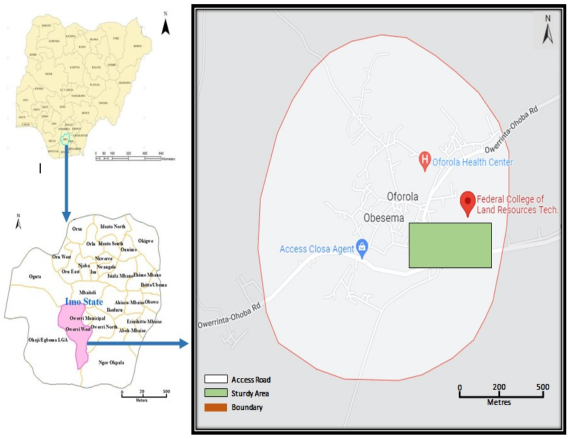

Figure 1: Map of Imo State showing the study area

B. Materials and Equipment used for the Study

i. A 200-litre water distribution PVC tank with a hole at 5 cm .to receive the tap
ii. A 1.5 m simple support for the tank
iii. Water outlet fitting and filter to keep out sand and silt from blocking the emitters
iv. A flexible pipe of diameter 20 mm and length 2.5 as mainline
v. A 25 m long LLDPE pipe of 20 mm as header tape
vi. 12 PVC pipes of a diameter of 16 mm and 1 m as sub-main
vii. A standard water tap of diameter 20 mm fitted at the base of the 1000 litre PVC tank to release water into the system
viii. 36 LLDPE pipe of diameter 12 mm and length 4 m as laterals. 3 laterals are attached to each sub-main. The laterals supply water to the in-line emitters
ix. 250 ml graduated cylinders to catch water from the emitters
x. Stop watch to record time of water collection from emitters

C. System Layout

With reference to the system layout (Figure 2), the components of the low - cost drip irrigation system were assembled together accordingly. The 20 mm standard water tap was screwed through a drilled hole at the base of the 200-litre capacity PVC tank. One end of the 20 mm diameter flexible hose mainline is connected to the standard tap and the other end is connected to a tee located at the mid-section of the header tape. The sub-mains are connected to the header tape using valved tee connectors. The laterals are connected to the sub-mains by means of elbows and tees. The mainline tee joints and the header tape valved tee connectors were made water tight using adhesive material. However, the lateral tee and elbow joints were made force-fit to facilitate disassembling from the tees and elbows whenever the need arises. The whole system was assembled and set up in the field for testing and technical evaluation of its technical performance characteristics.

Figure 2: Assembling of system components in the greenhouse

Figure 3: Layout of the drip irrigation system in the greenhouse

D. Evaluation Procedure

The method proposed by [22] and applied by [23] and [24] was used to collect data for determining the technical performance parameters of the low-cost drip irrigation system under evaluation. The system has 36 laterals. Each lateral has 12 in-line emitters. For each lateral, 4 emitters were selected thus; first emitter point close to the inlet, two in the middle at the one-third (4^{th}) and two-thirds (8^{th}) positions and one at the far end (12^{th}) and had their discharges measured. The gate valve at the exit of the distribution tank placed at 1.5 m above the ground surface was open full to supply water to the sub-mains and thereafter the gate valve at each sub-main pipe was opened full and water was allowed to drop from each of the selected emitter into a graduated cylinder placed under it (Figure 4). The drops from each emitter were run for 5 minutes using a stopwatch. The volumes of water collected from each emitter were collected three times and recorded. Using the volumetric method, emitter discharge for each run was determined. The average of these three discharge values for each emitter was found and recorded. In all, 108 emitters had their discharges measured.

Figure 4: Flow measurement of emitter discharge at pressure head of 1.5 m

1. **Emitter discharge**

The average emitter discharge rate (qa) of the system was computed according to the equation of [24]

$$q_a = \frac{1}{n}\sum_{i=1}^{n} q_i \quad (1)$$

Where:

q_a = average emitter discharge rate (l/h);

q_i = flow rate of emitter (l/h);

n = total number of emitters

2. **Water Distribution Parameters**

The following water distribution parameters were determined and used as indices for evaluating the system's performance.

2.1. **Coefficient of Emitter Flow Variation (CV)**

The coefficient of emitter flow variation was computed according to [14] and [16] as follows:

The coefficient of emitter flow (Cv):

$$Cv = \frac{s_d}{q_a} \quad (2)$$

Where:

Cv = emitter coefficient of manufacturing variation;

q_a = average discharge rate of the emitters sampled (l/h);

s_d = standard deviation of the discharge rates in the sample

The evaluated system was rated according to [25] Cv values as shown in Table 1.

Table 1: Recommended classification of manufacturer's coefficient of variation (Cv) for point source and line source emitters for design purposes [25]

Emitter Type	CV range	CV (%) range	Classification
Point source	< 0.05	< 5	Excellent
	0.05-0.07	5-7	Average
	0.07-0.11	7-11	Marginal
	0.11-0.15	11-15	Poor
	>0.05	> 15	Unacceptable
Line Source	< 0.10		Good
	0.10-0.20		Average
	< 0.02		Marginal-Uacceptable

2.2**Emitter flow variation:**

The emitter flow variation was computed using the equation applied by [26]as follows:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \quad (3)$$

Where:

q_{max} and q_{min} = maximum and minimum emitter flow variation along the line respectively.

Table 2: Classification of emitter flow variation (q_{var}) [27]

Classification	q_{var} %
Desirable	< 10
Acceptable	10-20
Unacceptable	>25

2.3**Statistical uniformity (Us)**

The statistical uniformity of the drip system was computed by the following equation [15] which was used by [16] and [28] for the performance evaluation of drip irrigation system.

$$Us = 100(1-\frac{S_d}{q_a}) = 1-C_v \quad (4)$$

Where:

Us = statistical uniformity of the emitter discharge rate;

C_v = coefficient of variation

S_d and q_a as defined previously

Table 3: Recommended classification of statistical uniformity (Us) values for design purpose [27]

Classification	Us (%)
Excellent	100-95
Good	90-95
Fair	80-75
Poor	70-65
Unacceptable	<60

2.4**Application efficiency (Ea)/uniformity coefficient (CU)**

The application efficiency of the low cost drip irrigation system was computed using the equation:

$$CU = (1 - \frac{\sum |x|}{m \times n}) \times 100 \quad (5)$$

Where:

CU = uniformity coefficient (%);

x = absolute deviation of the individual observation from the mean discharge (l/h);

m = mean of all observations (l/h);

n = number of observations.

Table 4: Recommended classification of uniformity coefficient (CU) values purpose [27]

Classification	CU (%)
Excellent	≤ 90
Very good	80-90
Fair	70-80
Poor	60-70
Unacceptable	< 60

2.5**Field emission uniformity (EU)**

The field emission uniformity of the low -cost drip irrigation system was computed according to [29] equation used by [13] and [30]:

$$EU = \frac{q_n}{q_a} \times 100 \quad (6)$$

Where:

EU = emission uniformity;

q_n = average lowest ¼ of emitter flow rate (l/h);

q_a = average emitter flow rate (l/h).

The evaluated system was classified according to the EU values following [31]; [32]; [33] as shown in Table 5.

Table 5: Recommended classification of emission uniformity

[31], [33]	[32]	EU (%)
Poor	Low	< 66
Poor	Mean	66-70
Acceptable		70-79
Good		80-84
Good	High	84-90
Excellent		> 90

2.6**Design Emission Uniformity (EU_k)**

The design emission uniformity was computed according to the equation proposed by [34] and used by [35] and classified using Table 6.

$$EU_k = 100\left[1 - 1.27\frac{C_v}{\sqrt{n}}\right]\frac{q_{min}}{q_a} \quad 7)$$

Where:

EU_k = design uniformity (%);

C_v = manufacturing coefficient of variation for point or line-source emitters;

n = number of emitter per plant or value is 1 for line source emitters;

q_{min} = minimum emitter discharge rate at minimum pressure in the section (l/h);

q_a= average or design emitter discharge rate (l/h).

Table 6: Recommended classification of emission uniformity (EU_k) for design purpose [34]

Classification	EU_k(%)
Excellent	90-100
Good	81-84
Acceptable	68-75
Poor	56-62
Unacceptable	< 50

III.RESULTS AND DISCUSSION

A. Hydraulic Performance of Drip Irrigation System

The hydraulic performance of the low-cost drip irrigation system is discussed under the average

discharge rates from the laterals and hydraulic parameters of the system.

1. The average discharge rates of emitters from the laterals.

The variation of average discharge rates of the emitters across laterals is presented in **Figure 5.** The minimum and maximum discharge rates of the emitter are 0.758 and 0.934 l/h respectively. The mean and standard deviation are 0.86 and 0.027 //h respectively. It shows a slight variation of the average discharge rates indicating that the system can supply water to plants almost uniformly. **Table 7** shows the system's performance parameters. The system 's pressure variation of 9 % is below the standard of 40% recommended by [36] The low value of 0.000326 m obtained for total energy drop in the system explains the nearly uniformly rates of the emitters. The low energy drop is due to the smoothness of the wetted surfaces of the laterals, sub-mains and mainline, and the tightness of the joints.

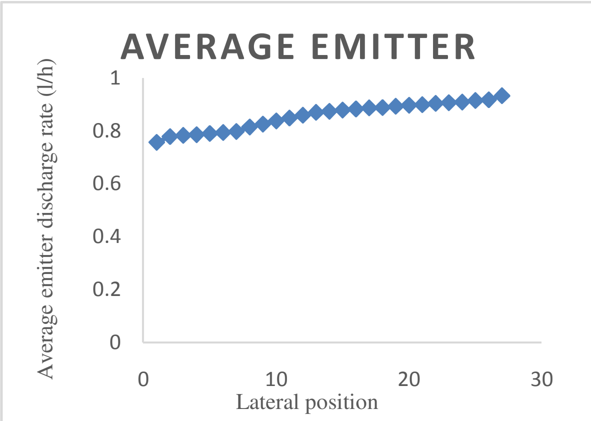

Figure 5: Variation of emitter discharge rates across laterals of the system

Table 7: System's performance parameters

Q (l/h)	H_v (%)	D_H (m)	CV	FV	EU	EU_k	U_S	CU
0.86	9	0.000326	3	19	92	84	97	9

2) **Hydraulic parameters of the low-drip irrigation system and their ratings**

The performance of emission devices plays an important role for the success of a drip irrigation system. It is therefore essential to evaluate the different hydraulic characteristics required to assess the suitability of a drip irrigation system for a specific requirement and also rate the system design. The parameters of coefficient of variation (CV), emitter flow variation (FV), emission uniformity (EU), design emission uniformity (EU_k), statistical uniformity (U_s) and uniformity coefficient (CU) were assessed. **Table 8** shows the classification of the low – cost drip irrigation system with respect to the computed values for the above-mentioned water distribution uniformities.

The coefficient of variation of emitter flow (CV) computed for the system was 3.15 % and was considered good which conforms to the report of [23] that for inline emitters, values less than 5 % are good. The flow variation of the system was calculated at 10.3 % and was considered as acceptable and consistent with the report of [27] that emitter flow variation of less than 10 % are generally considered acceptable.

The EU value of the system was estimated as 91.45 % and was rated as excellent which agrees with the report of [31] and findings of [33] that drip irrigations operating with emission uniformities greater than 90 % are classified as excellent. The system achieved an EUk of 83.62 % and was assessed as good in accordance with [34] report that micro irrigation systems with design emission uniformity ranging from 81 – 84% are classified as good.

The Us of the system was evaluated at 96.85 % and was rated excellent based on the report of [27]that micro-irrigation system that operate with Us values between 100-95%) are classified as excellent. Similarly, a 95 % CU was obtained with system and showed that the system's performance was excellent according to ASAE standards for drip irrigation systems (EP 405).

Table 8: The values and rating of the hydraulic parameters of the low-cost drip irrigation system based on [25]; [27]; [31]; [33]; [34]

Parameter	Calculated Value (%)	Rating
CV	3.15	Good
FV	10.3	Good
EU	91.45	Excellent
EU_k	83.62	Good
U_s	96.62	Excellent
CU	95	Excellent

IV. Conclusion

Small scale farmers who constitute 80 % of the farming population need micro-irrigation systems that are simple, affordable and highly efficient. They need it in order to substantially raise productivity and increase income while managing their irrigation systems independently.

The values of CV, FV, EU, EU_k, Us and CU of 3.15%, 10.3%, 91.45%, 83.62%, 96.85% and 95% respectively recorded when the low-cost drip irrigation system was evaluated show that the system is well designed and highly efficient.

In view of the above, the system can enhance crop production, improve farmer's income and reduce poverty in the rural communities in developing countries. For this reason, governments through extension workers are strongly urged to promote it among rural farmers.

References

[1] Amoo, M.O., Ademiju, T., Adesigbin, A. and Ali, G. (2010). Performance Evaluation of Drip Irrigation Systems on Production of Okra (*Hibscusescalentus*) in South Western Nigeria. *Journal of Engineering Research and Reports*, 1 – 10.

[2] IPCC (2014). Climate Charge 2014: Impacts Adaptation and Vulnerability. Contributions of the working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, UK and New York, USA

[3] Sobowale, A., Omotayo, A.M., Olobashola, J.O., Abdulsalaan – Sahir, P., Elemo, K., Badu-Apraku, B., Oladopo, M. and Omonayajo, L. (2015) low Cost Constant – Head Drip Irrigation Emitter for Climate Change Adaption in Nigeria: Engineering Design and Calibration. *Nigerian Journal of Technology, (NTO TECH),* Vol. 34 No. 4, pp. 898 – 906. ISSB: 0331-8443.

[4] Ismail, S.M. (2010). Influence of deficit irrigation on water use efficiency and bell pepper production (*capsicum annum L*). *Env. and Arid Land Agric. Sci*., 21(2):29-43.

[5] Riza, A.N., Akhter, T., Akhter, F and Khair, M.A. (2016). Evaluation and improvement of a low-head drip irrigation system to be used by small scale farmers in Bangladesh. *Journal of Science, Technology and Environment Informatics* 04 (01): 251-259.

[6] Ngigi, S, Thome, J., Waweru, D. and Blank, H. (20evier01). Low-cost Irrigation for Poverty Reduction. *An Evaluation of Low-Head Drip Irrigation Technologies in Kenya*; Annual Report 2000-2001; International Water Management Institute (IWMI): Colombo, Sri Lanka; Pp. 23 – 29.

[7] Assefa, T., Jha, M. Reyes, M., Srinivasan, R. and Worglul, A.W. (2018) Assessment of Suitable Areas for Home Gardens for irrigation Potential, water availability and Water-Lifting Technologies. *Water*, 10, 495

[8] Matson, P.A., Parton, W.J., Power A. and Swift, M. (1997). Agricultural intensification and ecosystem properties. *Science*, 277; 504 – 509. [9] Burney, J.A. Naylor, R.L. and Postel, S.L. (2013). The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proc. Watt Acad. Sc.* USA, 110:12513-12517.

[10] Polak, P., Nanes, B., and Adhikari, D. (1997). Low Cost Drip Irrigation. System for Small Farmers in Developing Countries. *Journal of the American Water Resources Association* ,33, No. 1: 119 – 124.

11] Kumar, S. and Singh, P. (2004). Evaluation of Hydraulic Performance of Drip Irrigation System. *Journal of Agricultural Engineering*. Pp. 44.

[12] Ella, V.B. Reyes, M. R. and Yoder, R. (2008). *Effect of hydraulic head and slope on water distribution uniformity of a low cost drip irrigation system*. Office of International Research Educators and Development (ORED), Virginia

[13] Barragan, J. Bralts V. and Wu, I.P. (2005). Assessment of emission uniformity for micro-irrigation design. *Biosystems Engineering,* 93 (1): 89-97. Available online at www.sciencedirect.com. Accessed 28 Sept. 2022.

[14] Kirnak, H., Dogan, E., Demir, S., and Yalcin, S. (2004). Determination of hydraulic performance of trickle irrigation emitters used in irrigation systems in the Harran Plain. *Turkish Journal of Agriculture and Forestry,* 28 (4):223-230.

[15]Bralts, V.F., and Kesner, C.D. (1983). Drip irrigation field uniformity estimation. *Transactions of the ASAE*, 26 (5), 13369 – 1374

[16] Yavuz, M.J. Demirel, K., Erken, O., Bahar, E. and Deveciler, M. (2010). Emitter clogging and effects on drip irrigation systems performances. *African Journal of Agricultural Research*, 5 (7):532-538.

[17] Zhang, G., Shen D., Ning B., Xie R., Jin X., Liu, C., Hon. P., Xue J., Chen, J., Zhang W., Liu, W., Wang K. and Li, S. (2019). Using irrigation interval to optimize water use efficiency and maize yield in Xinjiang, Northwest China. *Crop Journal*, Vol. 7, No. 3, pp. 322 – 334.

[18] Almajeed, A and Alabas, M. (2013). Evaluating the hydraulic performance of drip irrigation system with multi cases. *Glob. J. Eng. Res*. 13 (2-J) ASAE (2003). *Design and Installation of Micro Irrigation Systems*. American Society of Agricultural Engineers, ASAE EP 405. 1, pp. 6.

[19] Martinez, C. G., Wu C.L.R, Fajardo and Ella, V.B (2021). *IOP Conf. Ser.; Earth and Environ Sci.*1038 012005

[20] Igbojionu, D.O, Obineche C.I and Igbojionu, J.N (2021). Design, Development and Evaluation of a Bucket Drip Irrigation System for Dry Season Vegetable Production in South-Eastern Nigeria. *Turkish Journal of Agricultural Engineering Research (TURKAGER),* 2(1): 183-192

[21] Obineche, C.I. and Ahaneku, E.I. (2008). Effect of deficit irrigation on growth, yield and water use of Okra in Owerri, Imo State, Nigeria. Master Thesis, unpublished

[22]Nayakama, F.S. and Bucks D.A. (1986). *Trickle Irrigation for Crop Production: Design, Operation and Management,*Elsvier

[23] Raphael, O.D., Amodu, M.F., Okunade, D.A., Elemile, O.O. and Gbadamosi, A.A. (2018). Field Evaluation of Gravity -Fed Surface Drip Irrigation Systems ina Sloped Greenhouse. *International Journal of Civil Engineering and Technology (IJCIET)*, 9, 536-548

[24] `Zamaniyan, M., Fatahi, R. and Boroomand-Nasab, S. (2014). Field Performance Evaluation of Micr Irrigation Systems in Iran. 0*Soil and Water Research*, 9, 135-142. https://doi.org/10.17221/8/2013-SWR

[25] ASAE (2003). *Design and Installation of Micro Irrigation Systems*. American Society of Agricultural Engineers, ASAE EP 405. 1, pp. 6.

[[26] Mansour, H.A. (2012). Design considerations for closed circuits of drip irrigation system. Doctoral dissertation, Faculty of Agriculture, Agric., Ain Shams University, Egypt.

[27] ASAE (1999). Field Evaluation of Micro Irrigation Systems. American Society of Agricultural Engineers (ASAE). St. Joseph, Mich., USA

[28] Mistry, P., Akil, M., Suryanarayana, T.M.V. and Parek, F.P. (2017). Evaluation of drip irrigation system for different operating resources. In Internal *Journal of Advance Engineeringand Research Development*. Natural Conference & Application of Nano Technology (pp. 2348-6406).

[29] Keller, J. and Bliesner, R.D. (1990). *Sprinkler and Trickle Irrigation*, Van Westland Reinhold, New York, ISBN 0442-24645-5.

[30] Popale, P.G., Bombale, V.T and Magar, A.P. (2011). Hydraulic performance of drip irrigation system. *Engineering and Technology in India*, 2 (1 & 2): 24 – 28.

[31] Merriam and Keller (1978). *Irrigation System Evaluation: A Guide for Management* 3rd ed. (Logan, Utah: Agricultural and Irrigation Engineering Department, Utah State University.

[32] Capra, A. and Scicolone, B. (1998). Water quality and distribution uniformity in drip/trickle irrigation systems. *Journal of Agricultural Engineering Research*, 70:355- 365

[33] Kumari, C.P., Bhagat, E.I.B and Neeraj, K. (2018). Emission Uniformity Evaluation of Installed Drip Irrigation System. Internal Journal of Chemical Studies, 6,1651-1654

[34] ASAE (1996). Field evaluation of microirrigation systems. America Society of Agricultural Engineers (ASAE) Standards, 43 Edition, ASAE, St. Joseph, 756-761

[35] Noori, J.S. and Al. Thamiry, H.A. (2012). Hydraulic and Statistical Analysis of Design Emission Uniformity of Trickle Irrigation Systems. *Journal of Irrigation and Drainage Engineering*, 138 (9): 791-798.

[36] Rajput T. B. S. (1985). Design of a drip irrigation system proceedings of short course on Sprinkler and Drip irrigation, 25th-26th March, Trg. Unit, WAPCOS, (India) Ltd, New Delhi, pp 309-340

