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Performance of Direct Coupled Kijito Wind Pump Drip-Irrigation System

P. A. Kabok[1*], D. M. Nyaanga[2], M. C. Chemelil[2]

1. Lake Basin Development Authority, P. O. Box 1516-40100, Kisumu, and.

2. Department of Agricultural Engineering, EgertonUniversity, P.O. Box 536-20115, Egerton, Kenya.

Abstract

A horizontal axis wind pump was directly - coupled to a drip-irrigation system at Rusinga Island, Kenya and its field performance established through a total of 39 test runs repeated at fixed time every day for a period of 20 days. The choice of time of test-runs captured the approximate difference in the wind speed pattern of the area, three times daily for the period of the tests. The power source, for a 900m^2 drip-irrigation unit with pressure compensating emitters, was the Kijito wind pump manufactured in Kenya. The unit, designed for mature passion fruits had emitter spacing of 0.9m x 2m limited by market availability, but could be used by trellising. Potential evapotranspiration in the design procedure was by Pan Evaporation method. The other normal irrigation parameters related to climate and soils were calculated or estimated. The aim was to establish use of a wind pump for drip irrigation and its field performance. It was established that wind pump coupled to drip-irrigation system with pressure compensating emitters was technically feasible. Drip-irrigation efficiencies E_U and E_{Ua} were acceptable and varied between 93% in the morning to 94% in the afternoon for the 39 test-runs. Wind regime at site, knowledge of wind pump performance characteristics and type of emitter discharge were the critical parameters for the system design and development. Subsequently the design (technology) was considered realistic, replicable and applicable and would be useful in arid and semi-arid areas or areas faced with weather vagaries but have favourable wind regimes

Key words: Wind Regime, Field performance, Test runs, Pressure compensating Emitters, Irrigation Efficiencies

1. Introduction

The Lake Victoria shore (LS) is a narrow band along the Winam Gulf covering Busia, Siaya, Kisumu, Homa Bay and Migori counties, parts of former Western and Nyanza provinces in Kenya. Itis delineated by a 1200 m topographical height above sea level or about 60-km distance off the Kenyan gulf of Lake Victoria shoreline This is bounded by Latitudes 0° 00'00" Equator, 1° 05' 00"S and Longitude 34° 59' 00"E. It has a mild climate, low rainfall with seasons that are distinguishable as dry period (Dec-March), wet or long rains (April-July) and short rains (August-Nov) as described by [22]. The average annual rainfall is less than 1,000 mm and increases towards the highlands to 2000mm per year. The rainfall is bimodal with most occurring during the wet season, the remainder is spread between June and

November. Evaporation exceeds rainfall in most months except April/May [42].The LS therefore requires supplementaryirrigation in most parts of the year [24].

It is observed that energy is a critical component in any irrigation undertaking in the region. But energy sources particularly petroleum have problems of high capital costs, operational and maintenance costs, environmental concern, technical know-how and availability. Utilization of renewable energy sources (wind, hydro and solar) do offer attractive options when viable in an area to the small-scale farmer individually or in groups for irrigated agriculture. In this respect, the government of Kenya has in place plans to implement within the region multipurpose hydro-power projects. These will not be adequate for the whole region and particularly parts of the Lake shore. Solar and wind energy though require specific technologies for their exploitation but solar energy in terms of irradiances has high potential. In the case of wind energy potential it is established within the LS[20] that it increases with proximity to the Lake Victoria shore. As such, there are sites within the LS which have existing water pumping windmills and many others where wind speeds are considered favourable for water pumping.

The wind energy potential can therefore be utilized for water supply and for irrigation. Wind pumps though have capacity limits to pumping that need to be used judiciously especially when under taking irrigation. Drip irrigation among the methods is recognized to have great potential for high irrigation efficiencies [11] [32] but may be affected by standard of the system management and design. It then becomes the best choice for use with the wind pumps for the crop production. In Kenya though, drip-irrigation is in its early stages and mostly limited to backyard activities of horticulture by individual efforts. The system parameters on the other hand need to be designed with the knowledge of the effects of (i) physical factors and (ii) the hydraulic factors to allow (i) sound operation and (ii) for checking of the specifications as diagnostic tools for maintenance [2].

Wind energy conversion systems (WECs) and drip-irrigation technologies as in this case, developed separately in the different parts of the world [41] for diverse purposes. The WECs are used in agriculture, water supply, and other industrial applications, but vary on the basis of the state of wind technology, institutional framework and macro-economic factors in place [6]. In agriculture WECs are often mainly used for surface irrigation [35] [33] [38]. In Kenya the Global Wind Pump Evaluation Programme [16] [23], describes the potential of WECs in agriculture and particularly could be directed for drip-irrigation.

Wind energy over the past years however has sometimes been viewed negatively, often associated only with destruction of the environment - buildings, crops, evaporation from reservoirs and soil erosion. Only until recently when characterization studies in various parts of the world by among others: [5][8][7][17][15][36][34][10][18][19][19][37][29][4] enhanced its application methodology as also recorded in [40][41][25][26][14] [9]and[43].The above literature is prerequisite reading for the planning and modeling of the wind pump - drip-irrigation. In Kenya use of WECs in this respect is unknown.

In recognition of such positive views towards application of wind energy in enhancement of energy needs and developments, this study presents a wind pump drip-irrigation system mainly with respect to: - (i) a field test-run of a direct coupled wind pump driven drip-irrigation system along the shores of Lake Victoria and (ii) to evaluate the performance of the developed wind pump drip-irrigation system with respect to changing wind speeds and discharges.

2.Materials and Methods

The design, installation operation and monitoring of the performance of a wind pump drip-irrigation system require the knowledge of wind regime, wind pump operating characteristics and the crop water requirement (CWR). The system discharge hence should be compatible with the wind pump, the wind regime and cop water requirement. The study aspects thus included system discharge and the performance test run of the drip irrigation system. These are captured in the form of the location, the crop water requirement, the wind speeds, the test run evaluation and the system and the discharge.

2.1. Location

The study was conducted at Tom Mboya High School, Rusinga Island which lies between latitude 00° 30'S and longitude 34° 15'E in Kenya. The wind pump was already installed on a hand dug well located at a site 10m off the Lake Victoria shore. Westward of the site was a long stretch of lake water towards Tanzania and Uganda. Eastward, northward and southward there was an interruption of wind flow by the Rusinga Island ridges that surround the pump site in form of figure C curvature. Approximately 290m away from the wind pump within the school, the designed pilot irrigation unit branched off into a drip-irrigation head control unit (Figure 1), supplied by a 50 mm galvanized iron main pipe.

2.2. Water Requirement

The water requirement for passion fruit at Rusinga was determined according to [39][12] [13] as illustrated in Table 2. The evapotranspiration values were calculated based on E_{Pan}valuesderived from data of a nearby Rusinga historical data. This was used to derive IR_g and IR_n valuestogether with the other parameters as in the Table 2, which were estimated with regard to the prevailing weather and soil conditions of the site. The Pan Method results (Table 1) as opposed to Radiation, Blarney Criddle and Penman (modified) 1948, was selected for computation of water requirements. The ET_o values based on Epan were considered average compared to the other methods, thus used to avoid over irrigation or under irrigation. Also that in the LS region, the equipment and data for the Pan methodismore easily available. The maximum ET_o of 5.5 mm/day (Table 1) was determined for the month of March with average gross irrigation water requirement of 4.6mm/day (Table 2). The maximum irrigation interval based on soil and ET_{crop} parameters was thus calculated (12 days), for the required emitter and system discharge.

Table 1: Mean daily potential evapotranspiration, Rusinga data: (1972 – 1981)

	MONTHS											
METHOD	1	2	3	4	5	6	7	8	9	10	11	12
Blaney-Criddle	5.3	5	4.1	3.9	3.9	3.8	3.7	3.8	4	4.4	4.2	4.8
Pan Evaporation	5.2	5.3	5.5	4.4	4.1	4	4.3	4.6	5	5.2	4.6	4.9
Pen Man (1948) –Modified	6.4	6.6	6.2	5.5	5.1	5	5.2	5.5	5.9	6.2	5.8	6.1
Radiation	6.6	6.4	6.2	5.9	5.7	5.4	5.3	5.7	6	6.6	6.1	6.2

Table 2: Seasonal water requirement of passion fruit at RusingaIsland

	MONTH OF THE YEAR											
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
ET_O Pan Evap. mm/day.	5	5.2	4.6	4.9	5.2	5.3	5.5	4.4	4.1	4	4.3	4.6
K_c	0.85	0.85	0.85	0.85	0.9	0.9	0.85	0.85	0.85	0.85	0.85	0.85
K_r	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.6	0.6	0.6	0.6	0.6
ET_{crop} mm/day	3.7	3.9	3.4	3.7	4.1	4.2	4.1	2.2	2.1	2.0	2.2	2.3
K_s	1	1	1	1	1	1	1	1	1	1	1	1
E_u	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
IR_g mm /day	4.1	4.3	3.8	4.1	4.6	4.7	4.6	2.4	2.3	2.2	2.4	2.6
IR_g L/day/Plant	36.9	38.7	34.2	36.9	41.4	42.3	41.4	21.6	20.7	19.8	21.6	23.4

NB: Irrigation interval = 5 days, hours per day of irrigation = 12, Area per plant = 1.8 m^2.

Where: E_a = irrigation efficiency, K_c = crop coefficient, E_u = design emission uniformity, K_r = takes care of non-beneficial evaporation which occur in the conventional irrigation methods, K_s = water storage efficiency, ET_o = potential evapotranspiration and ET_{crop} = crop evapotranspiration.

The parameters of crop water requirement as a factor in the design are summarized in Table 2 and the following equations.

$$IR_n = ET_{crop} . K_r - R + L_r \ldots\ldots\ldots\ldots\ldots (1)$$

$$IR_g = (F_c - W_p) d_m . R_z \times {}^{P}/_{100} . \gamma_b \ldots\ldots\ldots\ldots\ldots (2)$$

Or

$$IR_g = ET_{crop} . K_r . E_a + L_r - R \ldots\ldots\ldots\ldots\ldots (3)$$

$$E_a = K_s E_u \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: IR_n = net irrigation water requirement, L_r = extra water needed for leaching, R = water received by the plant from other sources other than irrigation, IR_g = maximum amount or depth of water to be applied taking into account suitable reduction as all the soil is not wetted. F_c = Volume moisture at field capacity (%), d_m = moisture depletion allowed or desired (%), R_z = soil depth or root zone to be considered in meters, P = volume of the soil wetted as a percentage of the total volume, and γ_b = bulk density of the soil(others as defined in Table 2).

2.3. Wind Speeds

In order to determine discharge for the wind pump, the wind speed historical data was obtained from the Rusinga weather station as in Table 3. The station was within a distance of one kilometer. It wasnot in use but the 2m height wind speed data coarsely indicated the wind regime to be between 2 m/s to 3m/s. The initial wind pump site preliminary wind measurements however showed the range to be within the 3m/s to 4m/s. This was later confirmed from the observed data taken from October to December season. The same time period was used for evaluation of the designed and installed wind pump drip irrigation system. Ordinarily, the established wind speed range from such data wouldbe used to select a wind pump rotor diameter for a system to be established. In this case, the wind pump was installed hence the data together with the Kijito Wind pump performance Table 4 was used for determining the possible discharge from the wind pump. The table is always obtained from the particular wind pump manufacturer.

Table 3: Mean monthly wind speeds (m/s)

Month	N	Missing	Mean	SD
Jan	341	0	2.94	0.57
Feb	311	30	3.08	0.65
Mar	341	0	2.99	0.60
Apr	330	11	2.60	0.52
May	341	0	2.28	0.43
Jun	330	11	2.32	0.38
Jul	341	0	2.45	0.45
Aug	340	1	2.56	0.43
Sep	330	11	2.62	0.41
Oct	341	0	2.63	0.52
Nov	330	11	2.61	0.66
Dec	340	1	2.78	0.47
Annual Avg	335.67	6.3	2.65	0.508

2.4.System and discharge

Since the main line wasinstalledfor purposes of water supply to a school/hospital, the drip-irrigation system was however designed, checked for hydraulic characteristics and installed. The Hazen William's equation together with Christiansen's (1942) modifying factor (F) in [31] and the system discharge(equations 5 and 6) were thus used for the design of the hydraulic system, the manifold and the laterals. The 20% rule by [3] was used in the design process to help achieve the maximum allowable range of uniformity coefficient (C_u) for the drip irrigation.

The irrigation interval (I_i) and system discharge (Q_s) were calculated based on CWR equations 5 and 6 and by specifying the other parameters as listed in Table 5.

When using the wind pump performance table, they characteristically show the pump head (H_s) in meters, diameter of the rotor, wind speed range (m/s) and the corresponding discharge. Table 4 shows the characteristic arrangement of the wind pump operating conditions by the manufacturer. This was however modified in the top row by putting wind speed instead of discharge and adding in columns below; the percent head loss (J) and head loss (H) within the pipeline. The Table 4 of the J, H and Q values is specific to the main line of 50 mm diameter and length of 290m. If the size is changed then the J, H and Q values will vary. The H_s values given include head (m) due to mainline.

Table 4: Calculated J & H Values - Based on theKijito wind pump table.

	Wind Speed (m/s)								
Head (H_s) (m)	**2 – 3**			**3 – 4**			**4 – 5**		
10	J	Q	H	J	Q	H	J	Q	H
20	0.64	0.79	1.86	4.3	2.21	12.6	18	4.71	51
40	0.2	0.42	0.58	1.25	1.13	3.6	5	2.38	14.4
80	0.12	0.21	0.16	0.32	0.54	0.92	1.3	1.17	3.9
120	-	-	-	0.17	0.38	0.48	0.6	0.79	1.86
160	-	-	-	0.1	0.29	0.29	0.4	0.58	1.05
200	-	-	-	0.06	0.21	0.17	0.2	0.46	0.69
240	-	-	-	-	-	-	0.2	0.38	0.48

(J) =The percent head loss (H)=head loss andQ= System discharge

Table 5: Micro-irrigation System Parameters

	I	II	III	IV	V
q_d (L/hr.)	3.5	18.4	3.5	3.5	3.5
Q_s (m³/hr.)	0.86	4.6	1.7	0.79	0.86
I_i (days)	3	12	5	3	3
I_h (hours)	16	12	12	7	16
P_e (m)	10	10	10	10	10
A_P (m²)	2 x 2	2 X 2	0.9 X 2	0.9 X 2	2 x 2
A_t (ha)	0.1	0.1	0.09	0.04	0.1

Where: (q_d)= suitable emitter discharge, Qs =system discharge, I_i=irrigation interval (I_h) = irrigation hours and (A_t) =irrigation area P_e is the pump elevation

A total head (22.15 m) based on Fig.1 inclusive of H value was used to read out by interpolation the expected main line discharge for the wind regime (3 to 4 m/s).The system total head (drip-irrigation unit, manifold, main line/others) once determined (H_s); the expected discharge was read from the wind pump operating characteristics (Table 4) and compared to the calculated water requirement regime to specify the system discharge (Q_s). These would correspond only after varying some of the limiting factors given in Table 5. Instinctively, the wind pump output should be greater than or equal to the calculated crop water requirement. All together, the size or length of the pipe can be varied, new values obtained and the discharge corresponded to the water requirement for the system.

A choice however was made for a suitable emitter discharge (q_d), system discharge (Q_s), irrigation interval (I_i), irrigation hours (I_h) and irrigation area (A_t) with regard to Table 5 but pegged on values of q_d and Q_s. Emitter discharge choice was based on crop spacing and the type available. Change of any of the variables of equations (5 and 6) also adjusted the Q_s and q_d. In Table 5, only and P_e were reasonably held constant among the five option choices, signifying specific emitter and wind pump. The guideline was to design an option with parameters that complied with 3.5 l/hr. emitter size, wind pump/wind regime capacity of 3-4 m/s or water available, crop water requirement and system discharge (Q_s) of 1.7 m^3/hr restricted by the wind pump.

$$Q_s = q_d \,.\, I_i \,.\, {}^{A_t}\!/_{A_p} \,.\, 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

From

$$q_d = IR_g . A_p / I_h \text{ and } Q_s = I_i . A_t . IR_g . 10 / I_h \ldots . \quad (6)$$

The proposed five system optional operational conditions were developed as in Table 5. Option V was selected at preliminary design stage and this changed at installation stage because first, one lateral was damaged and secondly, the largest emitter spacing obtained in the market was 0.9m. Trial option III indicted that the wind pump was able to provide 1.7m³/hr, as opposed to what was expected from the Rusinga historical wind data and Kijito wind pump performance. This meant that for maximum crop water requirement, irrigation was possible for 0.45 ha per season, on 12 hour day irrigation, 5 days interval and system discharge of 1.7m³/sec.

2.5. Drip-irrigation field evaluation

This aspect of drip-irrigation system evaluated is expressed in the following equations.

$$E_a = K_s E_u \text{ or } 100{,}000 / K_s E_u \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7).$$

Where; E_a, K_s, and E_u are explained under Table 2. The other aspects of drip-irrigation evaluation that could be considered are monitoring of the soil brought into active exchange with the water/ the nutrients, the percentage-wetted soil (p). Both the K_s (Table 2) and p (35%) were however estimated.A horizontal axis wind pump was directly - coupled to a drip-irrigation system at Rusinga Island and its field performance established by 39 test runs for a period of 20 days and 10 minutes each. The choice of time of test-runs was such that it captured the difference in the wind speed pattern of the area, three times daily for the period of the tests (10.30, 12.30 and 15.30hrs). The Kijito wind pump was the main power source for the 900m^2 drip-irrigation unit with pressure compensating emitters. The unit was designed for mature passion fruits and had emitter spacing of 0.9m x 2m limited by market availability. The Potential evapotranspiration was determined by Pan Evaporation method. The other irrigation parameters related to climate (effective rainfall, ET crop and soils (Leaching Lr) were either calculated or estimated.

The study used the procedures proposed by [2][39][1] to determine the uniformity of distribution (E_u and E_{ua})as given in equations 8 and 9. During the test runs, an interval of ten minutes was selected for turn on and off of inflow to the irrigation unit. Pressure readings were only taken at the head control unit because of lack of pressure gauges and proper attachment equipments. A sample field test-run (Table 6) together with field layout (Fig. 1) shows the other necessary test-run details. Plate 1 shows how emitter discharges were done in the field.

$$E_u = \frac{Minimum\ \ rate\ \ of disc\,harge\ \ per\ \ plant}{Average\ \ rate\ \ of disc\,harge\ \ per\ \ plant} \ldots\ldots\ldots\ldots \quad (8)$$

$$E_{UA} = \frac{100}{2}\left[\frac{q_{min}}{q_{avg}} + \frac{q_{avg}}{q_x}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where E_u = field emission uniformity as a percentage, q_{min} = minimum discharge rate computed from average of the smallest four readings per test run, q_{avg} = average of all the field data emitter discharge rates, E_u= design emission uniformity [21][30], E_{ua}= absolute uniformity as a percentage and q_x = average of the highest one-eighth emitter flow rates

Table 6: Sample field micro-irrigation test run (3.20 - 3.30 pm)

Distribution Location on the Lateral		**LOCATION OF LATERAL ON SUBMAIN**			
		Inlet End Discharge (l/hr.)	$^1/_3$ Down Discharge (l/hr.)	$^2/_3$ Down Discharge (l/hr.)	Far End Discharge (l/hr.)
Inlet End	A	3.6	3.7	3.5	3.4
	B	3.5	3.6	3.4	3.5
	Time (Min)	10	10	10	10
	Aver.	3.6	3.7	3.5	3.5
1/3 Down	A	3.3	3.3	3.5	3.4
	B	3.4	3.4	3.4	3.3
	Time (Min)	10	10	10	
	Aver.	3.4	3.4	3.4	3.4
2/3 Down	A	3.5	3.3	3.3	3.4
	B	3.5	3.3	3.4	3
	Time (Min)	10	10	10	
	Aver.	3.5	3.3	3.4	3.2
Far End	A	2.9	3	3.1	3.1
	B	3.1	3.3	3.4	3.4
	Time (min)	10	10	10	10
	Aver.	3	3.2	3.3	3.3

3. Results and Discussions

3.1. System Discharge and Design

The design process/approach is a two-sided concept [20] that must relate system discharge and the crop water requirements (CWR) for the balancing of parameters in equations 5 and 6.Headloss (H_s) for the system in Fig. 1 (22.15m) included: P_e = 10m, topographical head (6m), system frictional head loss (1.6m), mainline losses (7.7m) and 1.45m for the other losses due to additional equipment added to the system (filter, water meter etc.). Table 3as a first guide to wind speed characteristics of the area, showed that mean monthly wind speeds varied between 2.32 m/s in June to 3.1 m/s in February. Deviations below the mean lower than 2m/s were in the months of May, June and November. It was observed that supplementary irrigation within the lakeshore would be most necessary between August toMarch, when water deficit exists Monthly mean wind speed range, considering yearly average and monthly standard deviations is observed to be between 2-3 m/s (Table 3).

From the wind speed range (2-3m/s), wind pump discharge size (Q_s) and using Table 4, the system discharge was determined by interpolation as 0.62m^3/hr. for a total head of 22.15m lying between 20m and 40m total head. This however, could not be sustained by any of the options in Table 5. Test runs at site indicated that wind speeds were actually in the range of 3 - 4m/s (Table 6). Option III (Table 5) was therefore selected for the operation because the system discharge of wind pump was 1.7m^3/hr. based on the water requirement.

3.2 Field Efficiency Tests

A total of 39 test runs were carried out three times daily in the month of November. The choice of time of test-runs captured the approximate difference in the wind speed pattern of the area, three times daily for the period of tests.

Results of the average discharge of the test runs, the amount of water passing to the irrigation unit, pressure at the control head and the calculated emission uniformity (E_u%) are given in Table 7. Table8presents the calculated minimum discharge for the test runs, coefficient of variation (CV) of discharge of test runs, average wind speeds of the one hour measurement period that covered test run interval, and the absolute emission uniformity of the test runs calculated using equation (9). Sample result of a test run and calculations are given in Table 6

The efficiencies given in Tables 7 and 8 are the result of equations 8 and 9. Average discharges in the respective tables were the result of sample test-runs, example given in Table 7. The sample test-run shows location of laterals on the manifold and the distribution points on the lateral. The average of two adjacent discharge points denoted by letter A and B was taken as a single discharge point and resulted into sixteen discharge points within the micro-irrigation unit. The averages of the discharge points for each test-run time were then tabulated as in Table 7. The minimum discharge expressed as the average of the four lowest readings within the test-run unit was in turn tabulated as in Table 8. The average and minimum discharge of the two forms of efficiencies, for each day of the test-run irrespective of time of the day is further shown in Figures 3 and 4. Time system of emitter discharge and uniformity coefficients with regard to the time of the day are illustrated in Figure 5.

Table 7: Emission uniformity coefficient micro-irrigation test runs – RusingaIsland

Date	Average Discharge ml/10 min/emitter			Average Discharge at Control Head m^3/10min			Pressure at Control Head (bar)			E_U%		
Time	10	12.3	3.2	10	12.3	3.2	10	12.3	3.2	10	12.3	3.2
3	496	570	533	0.34	-	-				90	91	95
4	528	536	549	0.32	0.21	0.34				94	94	93
5	551	577	535	0.22	0.34	0.47				93	93	95
6	493	531	538	0.31	0.21	0.31				94	95	96
9	570	534	560	0.23	0.47	0.43				95	90	93
10	557	533	561	0.23	0.33	0..39				91	95	91
11	534	553	550	0.23	0.34	0..33	> 0.8	> 1	> 1.2	91	95	97
12	538	534	552	0.33	0.43	0.25	> 0.8	>1	>1.8	94	94	92
13	531	535	562	0.43	0.33	0.24	0.4 -0.6	1-1.6	>1.6>	94	94	94
14	509	519	530	0.31	0.43	0.31	>0.4	1.2 -1.8	1-1.8	94	95	95
16	565	517	570	0.37	0.3	0.24	0.8-14	0.4	1.4-2	94	95	96
18	545	556	558	0.23	0..34	0.44	0.8-1.6	0.6	1-2.4	96	95	94
19	524	543	600	0.32	0.26	0.45	0.6	2-Jan	-	94	96	97
Aver.	534	541	553	0.3	0.33	0.35	-	-	-	93	94	94

Table 8: Absolute emission uniformity coefficient, micro-irrigation test runs –RusingaIsland.

Date	Av. Min. discharge ml/10 min/emitter			Coefficient of variation (CV)			Test Run Average Wind Speed			E_{UA}		
Time	10	12	3.2	10	12.3	3.2	10	12.3	3.2	10	12.3	3.2
3	448	518	1015	8.1	6.6	4.3	3.2	4.1	9.4	90	91	95
4	495	502	513	5.1	5.1	5.8	3.2	2.2	3.2	93	93	93
5	511	549	506	5.8	3.7	5	4.2	3.9	3.6	93	95	93
6	465	502	516	4.2	4.2	4.1	2.8	2.8	3.9	94	95	95
9	543	479	521	3.8	8.1	4.9	4.5	3.9	6.2	94	91	94
10	505	527	511	6.4	3.9	7	4.5	3.5	-	91	95	92
11	487	486	533	6.4	5.7	3.1	2.4	5	-	91	92	96
12	504	504	509	5.3	4.6	6.1	2.6	3.9	3.1	93	93	91
13	497	502	530	6.1	4.3	4.3	1.7	3.8	4.1	92	94	94
14	479	493	505	4.3	4	4	2.1	3.5	4.6	94	94	94
16	533	491	547	4	4.6	4.2	3.7	3	3.6	94	94	94
18	521	526	525	4	4.6	4.5	2.4	2.9	4.3	95	95	94
19	492	522	579	4.9	3.1	3	1.9	3.6	2.9	94	96	97
Aver	498	508	523	5.3	4.8	4.6	3	3.5	4.4	93	94	94

Table 9 summarizes the analysis of variance for time of tests of 10.30a.m, 12.30pm and 3.20pm. A one-way analysis of variance was used to check on the difference that could occur in the average emitter discharges. The computed F-value of 2.93 and tabulated was 3.27 and the probability (P-value) at 5% significance level was 0.661. This result shows that the difference in average discharge was not significant. This study therefore concludes that the discharge averages were constant at head control unit irrespective of pressure developed by the wind pump at different wind speeds. This confirms consistency in performance of the system.

Subtracting minimum discharges in Table 9 from average discharges in Table 8 shows that the closer the difference to the standard deviation 21, Table 9, the higher was the uniformity coefficient achieved in percent. This is exhibited in Figures 3 and 4. Any difference that was lower than two standard deviations showed uniformity coefficient lower than 93%. Increase or decrease in system discharge cannot be perfectly matched to the efficiency coefficients. This could be attributed to wind speed, the pressure compensating nature of the emitters and the water held in the pipe line which could be pushed to the unit at minimal wind speed. Owing to the large interval of wind speed (1hr) measurements and the small test-run interval, this effect could not be explicit. But it is evident that the system efficiency did not follow wind speeds, it depended on the difference between the minimum and the average discharge with regard to the standard deviation. The coefficient of variation (Cv) was therefore also influenced by this phenomenon.

Table 9: Analysis of variance of mean emitter discharges

Time	Mean	Sample Size	Group Std Deviation
10.30 am	533.92	13	24.336
12.00 pm	546	13	19.425
3.20 pm	553.69	13	18.741
Total	544.54	39	20.983

	Degrees of Freedom	Sum of Squares	Mean Square	F	P
Time	2	2582	1291	2.93	0.0661
Error	36	15849	440.27		
Total	38	18431.7			

$F_{0.05}$, 2, 36 = 2.93, Cases included = 39, missing cases = 0

Water supply at control head varied between1.8 m^3/hr. to 2.1m^3/hr. (3.4%) This meant that an average of 1.8m^3/hr. minimum water was available from the wind pump. It supported the system design discharge choice of 1.7m^3/hr. (Table 4). A one-hour average wind speed was between 3.0m/s to 4.4 m/s, suggesting that 2- 3 m/s annual wind regime chosen earlier had to be revised to a regime of 3-4m/s. Pressure at the head control unit varied by up to 75% but was observed as non-significant (Table 9) for the emitter discharge. This was confirmed by the insignificant variations by the test runs average discharge and test run minimum discharge, which increased from 534 to 553 and 498 to 523 milliliters respectively. These varied with time (Fig. 5) and day of test (Figures 3 and 4) but showed in Table 8, the efficiencies, which remained constant at 93% in the morning and 94% in the afternoon. This is attributed to the temporal variations.

The average test run coefficient of variation (Cv) decreased from 5.3% to 4.6%, showing some improvement though small. This pointed out that increased average wind speeds in the morning meant improved average emitter discharges (Fig. 5) with time of the day, which corresponded with increased wind speed within the day. The variations of system discharges, efficiencies, and wind speed were consistent as shown in Figures 3 to 4 and Tables 8 and 9. Wind regime therefore, as the prime mover was consistent. The design approach and approaches used can be upheld and replicated as the pressure and discharge variations were well regulated by the pressure compensating emitters. However, seasonality could affect results because of change of wind regime as is exhibited in the day variations.

It was found by [39] that values of $E_u$andE_{ua} determined in the field were ranging from 85% to 95%. [2] on the other hand suggests "the general criteria for $E_u$andE_{ua} values as; 90% or greater, excellent; 80 to 90%, good; 70 to 80%, fair; and less than 70%, poor". It can be deduced from the foregoing that the drip-irrigation unit performance was good based on trends above in spite of pressure variation due to wind speeds. The performance could also be attributed to the kind of emitter used (self-compensating) with an exponent value of nearly zero, screens that were at the head control unit at the 50 mm, Arad water meter at the foot of the wind pump, and the water meter at the head control unit that reduced the emitter blockage.

3.3. Design Challenges

The design process required that parameters were either accurately determined or estimated dependent on the conditions for implementation of the wind pump drip-irrigation system. Primarily the parameters are: location of the system, type of crop, soil type and the calculation thereof for the gross water requirement (IR_g). Though the hydraulic calculations are routine process, challenges are occasioned mostly because of the spatial and temporal variations. ET_o in itself requires an established method for a region (e.g. PenMan Equation, Radiation, Pan Evaporation and Blaney-Criddle Methods) that accurately estimates it in a local area. The Ground cover and crop coefficient (K_c) also need knowledge of the crop in terms of its development stages within a management and the climatic conditions. Others include the percentage-wetted portion of the total soil volume (W_P) and the factor K_r that take care of the non-beneficial evaporation, which occur in the conventional irrigation methods. In order to account for these, research is necessary for every locality of the region. Economic conditions often do not allow for this more so in the developing world. This is coupled with the wind regime, because it should be synchronized to only a particular design of a wind pump.

Equivalently, there are various approaches to the characterization of wind regime, problems with data availability, choice and use of predicting equations, density and sustenance of measurement facilities especially in the developing countries. Hence before embarking on the design process adequate understanding of the conditions of the drip-irrigation, wind, wind pump and their performance need a thorough situational review. Figure 2 may also serve to explain this. It also symbolizes a sprinkler design where emitter is the sprinkler head, motorized pump becomes the wind pump (WP) and wind regime (WR) serves to illustrate the horsepower of the pump, which may be varied for the same environment. The challenges may be quite specific but the design process illustrates the approach and key parameters required. Another factor was the water availability and quality, availability defined by crop water requirements and wind pump operating output at the available wind regime (Q_s). Water quality for the system was taken care of by the preliminary assessment and the introduced appropriate filters.

4. Conclusion

This study has demonstrated that a wind pump directly coupled to a drip-irrigation system is feasible. The approach of synchronizing water requirement with respect to the plant for an irrigation unit area (system discharge), wind pump output based on its characteristics and wind regime and the emitter discharge is considered a new development for the use of the two otherwise separate systems.

The emission uniformity coefficient (E_u) and the absolute emission uniformity coefficient (E_{ua}) obtained in this evaluation were higher than 90% and confirmed that use of wind pump with pressure compensating emitters performed acceptably equally well and gave equally comparable (E_u and E_{ua}) values. Morning or afternoon wind speed variation resulted into a one percent difference of 93% to 94%. This meant that the choice of wind pumps performance range; design criteria and the efficiency of irrigation achieved were acceptable for use in a drip-irrigation system.

Wind speeds at the study site and period concentrated between 3–4 m/s and slightly greater for the 10m level anemometer observations. Application oftheKijito wind pump was therefore feasible considering its rated performance range (3 to 4m/s) as it was sustained. Drip-irrigation system parameters were however observed to relate or affect one another iteratively.

Drip-irrigation uniformity coefficient achieved with use of pressure compensating emitters was reasonable and within acceptable range. Applications with different wind pump rotor diameters; will need adjustment of irrigation area because each rotor diameter performs differently in the same wind regime. The behaviour of non-pressure compensating emitters forms another important test area, particularly to see the effect of wind speed variation with discharge along the laterals. Wind tunnel test runs or other method of test would also be of interest in this regard.

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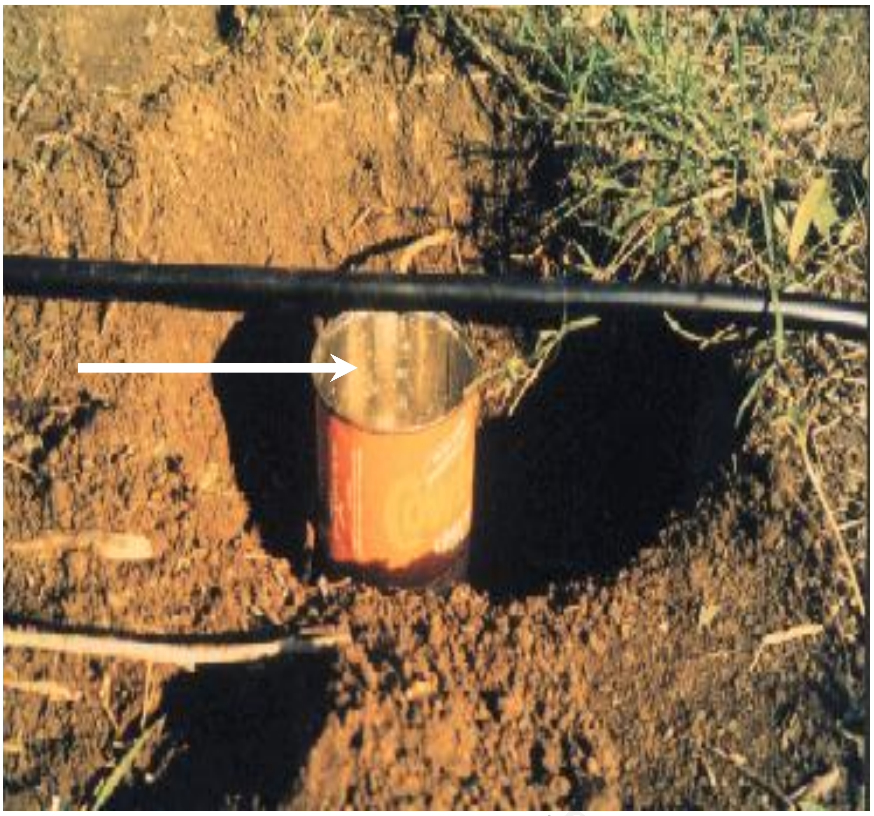

Plate 1: Water from Emitters

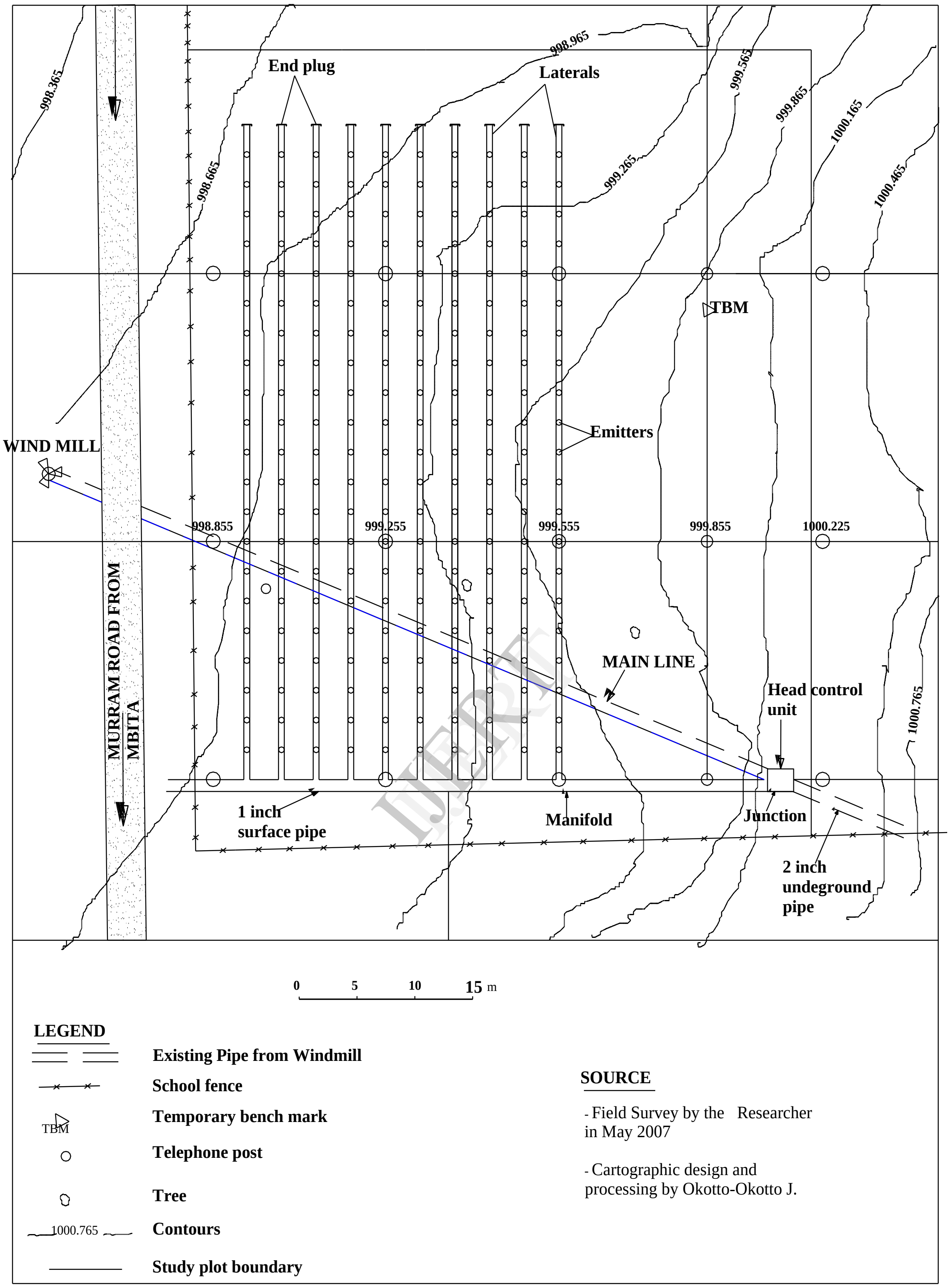

Fig. 1: Demonstration Plot for Drip-irrigation System at Tom Mboya Sec. School

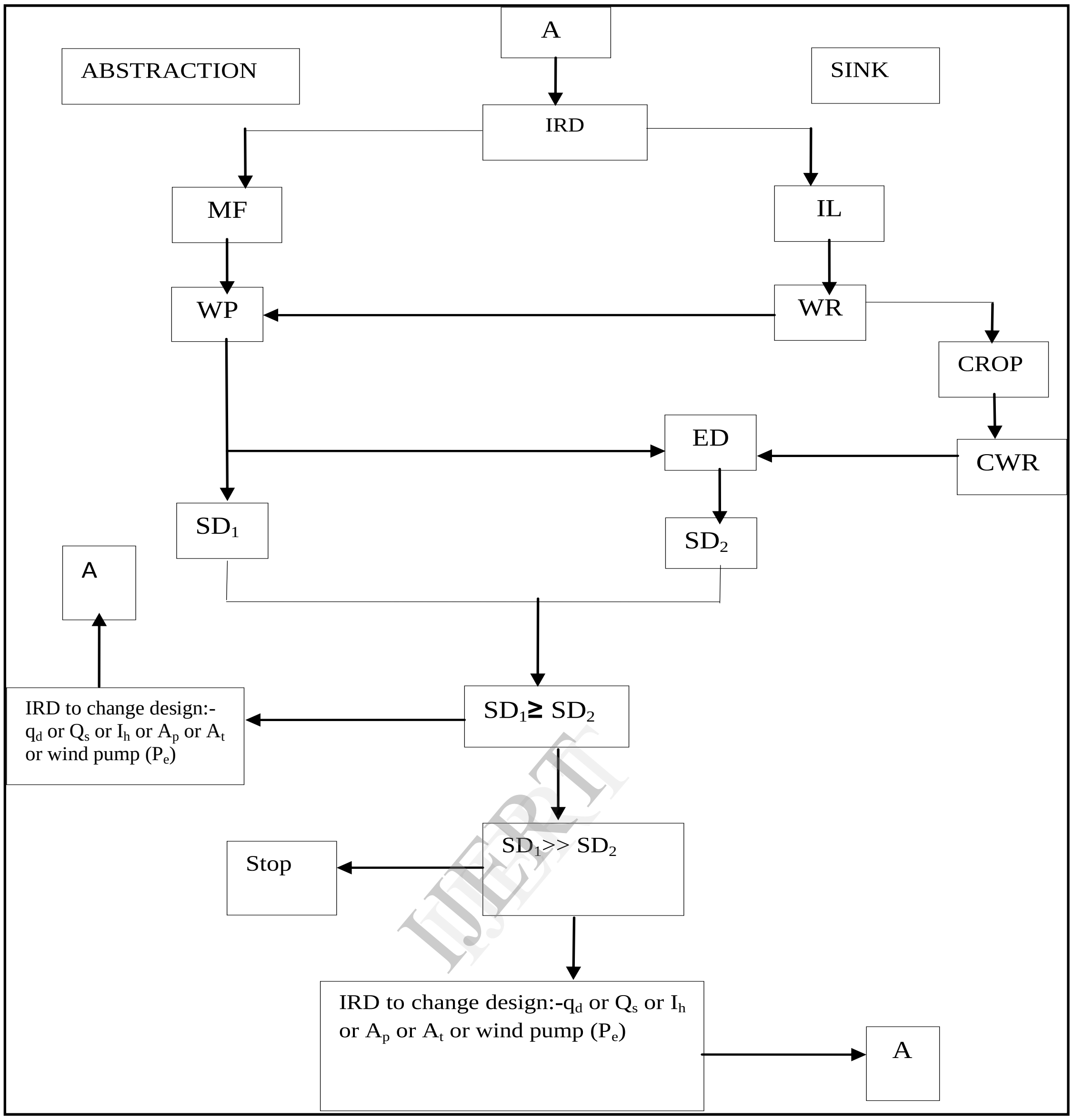

Figure 2: Wind Micro-irrigation Design Illustration Chart

Where IL = irrigation location, MF = Manufacturer, WP = wind pump, WR = wind regime, CWR = crop water requirement, ED = Emitter discharge, SD_1 = Wind pump rated discharge, SD_2 = Discharge based on crop water requirement, IRD = Irrigation Designer.

(i) WP on the INPUT (Abstraction) side corresponds to CWR on the SINK side.

(ii) SD_1 should be just greater or equal to SD_2 dependent on design efficiency.

(iii) The chart (Fig. 1) can be applied elsewhere for the design of a sprinkler irrigation but developed for a wind pump (horizontal axis) micro-irrigation

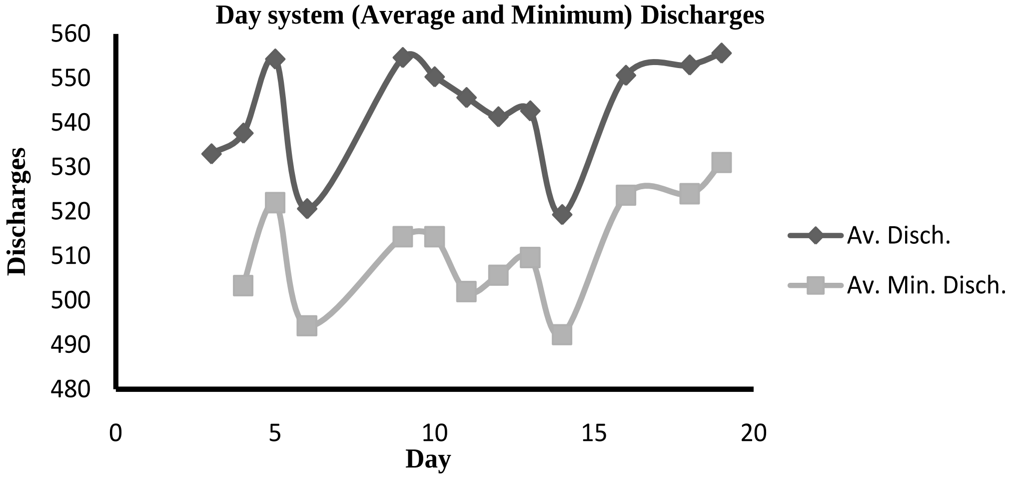

Fig. 3: Day System (Average and Minimum) Emitter Discharges

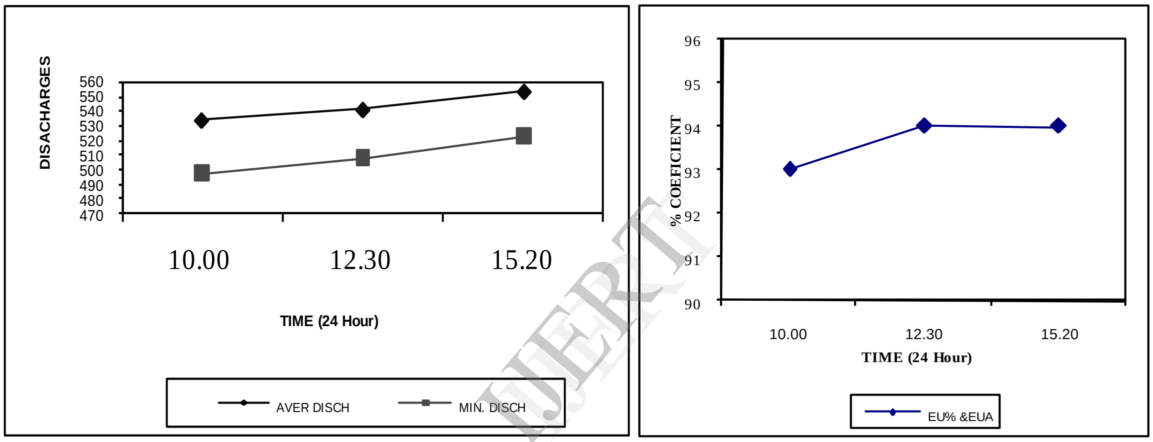

Fig. 4: Day System (EU% and EUA) Uniformity Coefficients.

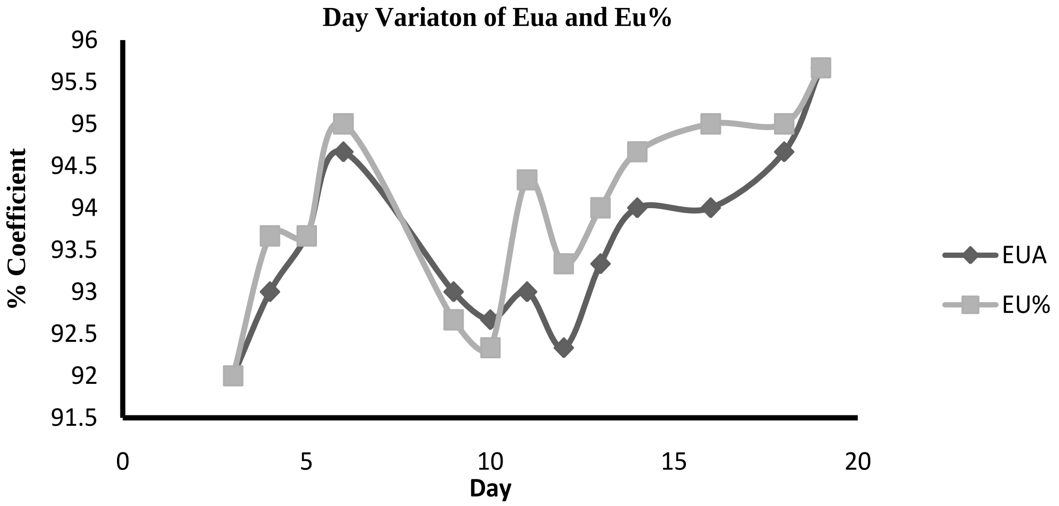

Fig. 5: Time System of Emitter Discharges and Uniformity Coefficients