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Prediction of Wind Pump Water Discharges for Drip Irrigation at the Shores of Lake Victoria-Kenya

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ABSTRACT

Wind pump discharge has traditionally been estimated from the manufacturer's tables. However for wind pump drip irrigation (WPDI) system there is need to relate the discharge to hydraulics in the pipeline, emitter discharges and weather/soil. The relations in the form of governing equations comprise of the instantaneous discharge, pipe, emitter and resource equations (ET_o, area and duration of irrigation). The objective was to predict from the wind speeds the expected discharge and relate it to the governing equations. The actual wind speed and wind pump discharge data from Rusinga was initially used to compare the performance of the existing instantaneous wind pump discharge equations. The Kisumu 10 m wind speeds assisted in developing the percent availability instantaneous wind pump discharge equation($Q = K(\sum V_i R_i)$which was used to estimate the irrigation depth and area by relating to known irrigation equations. The results showed that the irrigation duration could be predicted from the developed wind speed interval percent availability tables. The discharge equation (model) developed based on availability was in agreement with the results from the existing instantaneous wind pump discharge equations. The accuracy of the equations to predict discharge improved with the length of the hourly wind speed, short time step of measurements, the startup pump rotation speed and the measuring equipment. It was possible to estimate wind pump discharge from hourly wind speeds, wind strength limits thus irrigation area, depth and duration.

Keywords: *Instantaneous Discharge Equations, Governing Equations, Resource Equations, Percent Wind Speed Availability, Irrigation duration.*

LITERATURE REVIEW

1. INTRODUCTION

The discharge from the horizontal axis wind pumps is often presented in graphs or charts such as Table 1. A number of model equations 1 to 5 by LE Gouriêrês (1982), Lysen (1982), Kabok and Chemelil (2001) are in use. Lysen (1982) matches windmills to the wind regimes using the graphical, computational and the estimation methods. Continued research in wind pump discharge relationships however is still necessary due to variations in locations on earth surface and types of wind mills and pumps. Drip irrigation is an added relationship to the horizontal axis wind pumps, the wind speeds, and even the modern state of art low solidity wind mills. Previous works in drip irrigation and wind power are found in Kabok (2001), Mike (2002), Kabok and Chemelil, (2005), Ale and Pradhan (2006). They noted that wind energy can be used to drive drip irrigation systems.

Table 1: Amount of Water Delivered per Day (m^3) by Kijito Wind Pump Models

Model	**3.66 m**			**4.86 m**			**6.10 m**			**7.32 m**			**7.20 m**		
Wind (m/s) Head (m)	**Light 2-3**	**Med 3-4**	**Strong 4 -5**	**Light 2-3**	**Med 3-4**	**Strong 4-5**	**Light 2-3**	**Med 3-4**	**Strong 4-5**	**Light 2-3**	**Med 3-4**	**Strong 4 -5**	**Light 2-3**	**Med 3-4**	**Strong 4 -5**
10	10	28	59	21	71	150	39	107	227	61	167	354	70	192	407
20	5	14	29	10	35	75	19	53	113	30	83	177	35	95	204
40			15	5	18	37	10	27	57	15	42	89	17	48	102
60		7	11	4	14	28	7	20	43	11	31	66	13	36	76
80		5	7	3	9	19	5	13	28	8	21	44	9	24	51
100		3	6		7	16	4	10	24	7	18	36	8	21	41
120		2	5		6	12	3	9	19	5	14	29	6	16	33
150			4		4	9		7	14	4	10	22	5	13	28

a) Water Pumping Windmill

The water-pumping windmill (WPWM) is a horizontal axis type with a rotor pivoted freely on the tower for proper orientation to the wind and multi-blade coupled to a reciprocating piston pump. The design incorporates the rotor on the tripod coupled to the pump and it includes a safety mechanism. The system is for water delivery. The basic principles of the wind rotor design have been outlined by Wilson *et al* (1976), Nick Van De Yen (1979), Lysen (1982), Ainsworth (2004), Berges (2007) and Van Dam (2010). The WPWM may be taken as a black box with wind as input and water as the output.

Wind mills and turbines should be designed to maximize the use of the slowest wind speeds and controlled to operate at the rated wind speed or power output (Van Dam, 2010). Wind energy utilization by Wind Energy converters (WECs) should operate over a rising limb from zero speed to the design rated speed until the WEC is furled out (Ahmet, 1995).

The rotor blades operate in an air stream and experience lift (perpendicular to the direction of undisturbed air stream) and drag (in the direction of undisturbed air flow) forces which can be described by dimensionless quantities. Factors that affect the Betz's power coefficient (theoretical maximum power fraction of extracted wind power) are the rotation of the wake behind the rotor, due to the extra kinetic energy losses, the finite number of blades, air mixing at the tip (lip losses) and the drag and lift coefficients ratio (C_d/C_L) which does not go to zero. Radius (R) of the rotor for the water pumping windmill is chosen based on the required energy output (E) as: $E = 0.1R^2{V_d}^3T$ where; V_d is design wind speed, T is time length in hours in which average wind speed was taken. R is the radius of the rotor. The use of the average wind speed is an assumption since variation of wind speeds cannot be ignored. The other methods for estimating the energy are described by Lysen (1982); such as graphical, computational and estimation approaches. These are not adequate for planning a wind pump drip Irrigation (WPDI) system, due to the need for an assessment of wind speed availability in duration and strength.

b) Wind Pump Drip Irrigation (WPDI) Discharge Estimate

Wind pump discharge for any turbine or pump is normally provided by the manufacturers as in Table 1, it shows performance in terms of the head of water for different wind pump rotor diameters, for the model, for varied wind speeds and the discharges as the output. This approach assumes magnitudes of length, strength and duration of wind speeds at a location. The effect of wind speed variation with time in the day and seasons is not taken care of (masked). It emphasizes variation of discharge with distance at a location much more. This needs investigation. A worthy assumption with regard to this is that the recorded data points over a particular hour (9 am or 10 am) for a long period can be representative of what happens in every second within the hour; presumably to depict the fluctuation of the wind speeds within the hour. Thus, this was the basis of percent discharge model development. Ale and Pradhan (2006), provides an insight into use of wind pumps for irrigation but does not fully and directly show how WPDI is used with the variations of wind speeds. It is possible to use a horizontal axis wind pump for drip-irrigation as long as key aspects are determined or taken care of in the design process (Kabok 2001; Kabok and Chemelil, 2005). These include identification and quantification of performance characteristics of the wind pump (expected discharge versus the head), wind regime at the proposed site and the type of emitter to be used. In addition, the normal irrigation design parameters of evapotranspiration, soil and water characteristics referred to as the climate resources (Ogindo, 2003), should be determined for the design process. WPDI technology can be applicable to arid and semi-arid areas (ASAL) and other areas faced with harsh dry weather conditions but have favorable wind regimes for crop production.

c) Hydraulic Equations

The hydraulic equations 4.1 to 4.5 are herein grouped into categories as; Emitter and Hazen Williams equation, Instantaneous Discharge Equations and climate resource equations as shown below. Although they were developed separately, they require to be linked for the better understanding of wind pump irrigation. Apart from the development of linkage frame work, the instantaneous discharge equations need review and assessment due to variation of location of wind pump models/sizes and wind speeds.

Group A: Emitter and Hazen Williams equation; could be crosschecked by Darcys or Scobeys equations and are stated as;

$$q_e = K_e H^x \text{ ....(1)}$$

$$\mathrm{J} = \frac{\Delta \mathrm{H}}{\mathrm{L}} \times 100 = 1.13 \times 10^{11} \frac{\mathrm{Q}^{1.85}}{\mathrm{C}} \mathrm{D}^{4.87} \mathrm{F} \text{.........(2)}$$

Group B: The Instantaneous Discharge Equations

$$Q_s = \frac{0.1AV^3}{\rho H} \quad \text{(Lysen, 1982) ....(3)}$$

$$Q_s = \frac{0.1D^2V^3}{H} \text{ \{LE Gourieres, 1982); ....4)}$$

$$Q_s = KV_{\textit{(Foot of wind pump)}} \text{ (Kabok and Chemelil, 2001)............ (5)}$$

Where $K = {}^{A}/_{\rho}$, A = Rotor area; ρ is air density for equation 5

Group C; The emitter and climate resource equations, to be related to the best of equations 4.3 - 4.5, are as below:

Design emitter discharge: $q_d = \frac{I_{Rg} \times A_p}{I_h}$ ……………………(6)

System discharge: $Q_s = \frac{I_i \times A_t \times I_{Rg} \times 10}{I_h}$……………..... (7)

$$I_{Rg} = E_{TCROP}.K_r.E_a + L_r - R \text{.........................}(8)$$

And

$$I_{Rg} = \left(F_e - w_p\right) \times dm(C_v) \times R_z \times \frac{P}{100} \times \gamma_b \text{..........} (9)$$

Where; Q_s and Q = System Discharge, q_e= Emitter Discharge; J = Head Loss in Percent of Pipe; V = Wind Speed Velocity; H = Pressure Head of Operation; D = Pipe Diameter in (mm);

ρ = Density in kg/m^3; F = Pipe Frictional Factor; K, x, K_r &K_e= Constants; L = Length in meters; C = Pipe Friction Coefficient; ΔH = Head Loss in Pipe; q_d = Design Emitter Discharge; I_i =Irrigation Interval; I_h = Irrigation Hours; A_p= Plant Irrigated Area; A_t = Total Area of Irrigation within the Interval; 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; Wp=wilting point; Ea=system efficiency and ET crop=crop evapotranspiration.

Any of equations 4.3 and 4.5 above multiplied by time equals to total volume of water-applied i.e. $\sum Q_s t$ = system discharge; equivalent to equation 10 below formulated from equation 7.

$$Q_s I_h = I_t \times A_t \times I_{RG} \times 10 \text{..................................} (10)$$

This implies,

$$\sum Q_{st} = I_i \times A_t \times I_{RG} \times 10 \text{..........................} (11)$$

$$R_z = \frac{\sum Q_{st}}{I_i} \times A_t \times \left(F_c - W_p\right) \times 0.1_p \times d_m$$

Equivalent to;

$$R_z = \frac{\sum Q_{st}}{I_i} \times A_t \times S_f \text{..} (12)$$

The manipulation can be done to 6 to relate it to emitter discharge. WPDI mode can hence be evaluated from depth of irrigation and emitter discharge.

2. MATERIALS AND METHODS

To use wind to pump water for irrigation requires the study of adequacy of wind speeds, discharges, the soil and the crop related weather systems. These are affected by wind temporal and spatial variations. Some of the constituting (wind speeds, ETo, Hydraulic equations and discharge) factors and equations as above are developed for determination of irrigation depth, area and duration.

2.1 Wind Pump Drip Irrigation System (WPDI)

The wind pump drip irrigation (WPDI) system requires the analysis of wind energy, the water-pumping windmill (WPWM) and the production resources (land, crops and soil ET_o). The idealized system is as shown in Fig 1 for design of Wind Pump Drip Irrigation (WPDI) System. The transformation of the variable wind speed (wind characteristics or spectrum) into energy to deliver water through pipes and to plants through direct coupling of the system is not well known. The development concept is to use the existing equations such as Hazen Williams, wind pump instantaneous wind pump discharge equations 3 to 5 and the resource (Ogindo, 2003) equations 6 to 9 as the governing equations for delivery of water from the wind pump to the plant. The WPDI system relates to the wind speed capability to discharge by use of the equations 3 to 5.An equation other than 3 - 5 was also developed and compared to the equations relating wind speeds to discharges. The design and evaluation of the WPDI irrigation system involves using the hydraulic equations in section 1c and the tested methods of irrigation evaluation (Soccol *et al* 2002) keeping in mind future maintenance of the system. In the design, installation, operation and evaluation of the wind pump drip irrigation (WPDI) system, a conceptual frame work (Fig 1) with three components is first developed. The key steps are; 1) determination of most probable wind regime for daily, seasonal and annual wind speeds 2) Selection of suitable wind pump. 3) Application of the hydraulic equations (emitter and pipe) together with resource (crop and soil) to design or evaluate the irrigation system.

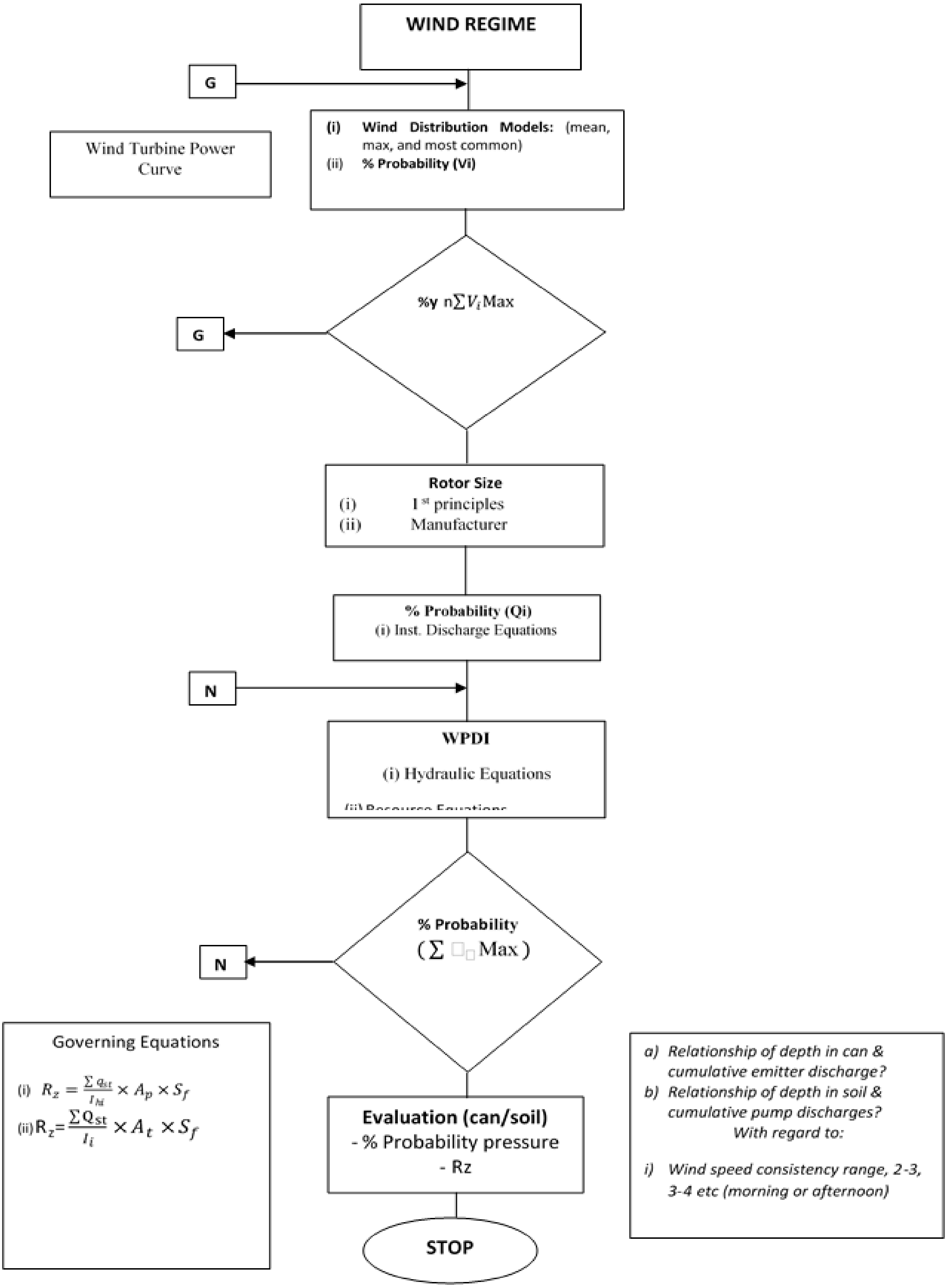

Fig.1: Flow Chart for Design of Wind Pump Drip Irrigation (WPDI) System

2.2 Estimating Hourly Percentage Wind Speeds

Kisumu data was used since the existing other five (Muhuru bay, Kibos cotton, Kadenge, Ahero and Rusinga) stations of the Lake Victoria shore (LS) in Kenya lacked the hourly measured wind speeds records. The hourly wind speeds obtained were measured at 10 m height from the year 1996 to 2011 on a 24 hour day basis using a data logger. Table 2 gives the average daily wind speeds and months as shown for Kisumu for the years 2006 to 2011.

Table 2: Average Daily Wind Speeds (m/s) for Kisumu from 2006 to 2011

Day	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	5.78	6.16	6.69	5.28	3.56	4.10	4.67	3.92	4.63	4.70	4.09	5.52
2	5.36	6.30	6.26	4.49	3.83	4.51	4.39	3.38	4.56	5.89	5.08	4.65
3	5.63	6.47	6.67	5.43	4.95	3.60	4.57	4.66	5.08	4.76	4.32	5.06
4	5.23	6.28	6.08	6.36	4.29	4.83	4.11	4.38	5.03	5.14	5.07	5.15
5	5.22	6.51	6.63	5.57	4.44	4.47	5.16	3.89	5.96	4.79	4.35	5.73
6	6.13	6.19	6.31	5.13	4.31	4.31	3.32	4.57	5.03	5.28	4.38	5.48
7	5.68	6.77	6.83	4.19	3.81	4.04	4.04	3.85	5.52	4.98	4.38	5.35
8	6.51	6.65	5.07	5.59	5.01	5.11	4.42	3.97	4.94	5.08	4.42	6.10
9	5.93	6.67	5.32	5.06	4.46	4.40	4.33	4.76	4.21	4.97	4.95	5.92
10	5.47	5.97	5.81	4.94	4.76	5.39	4.06	4.96	5.07	4.60	5.08	5.38
11	5.81	5.48	5.42	5.08	4.06	3.88	3.53	4.25	5.08	5.81	4.38	4.69
12	5.36	5.66	5.84	4.49	3.92	4.89	3.98	4.12	4.78	5.24	5.01	4.69
13	5.03	5.54	6.53	5.17	3.98	4.35	4.44	4.39	5.79	5.13	4.97	4.69
14	6.44	5.46	5.98	5.10	4.38	4.36	3.54	4.33	4.39	4.12	4.53	4.69
15	6.63	5.96	6.48	5.73	4.09	4.26	4.10	3.91	5.10	4.32	4.38	4.69
16	6.31	5.63	5.76	4.75	3.58	4.53	4.40	4.08	5.70	5.61	4.62	4.69
17	5.70	6.73	5.58	4.76	3.62	3.85	4.22	4.83	5.06	5.03	5.54	4.69
18	5.09	6.32	5.90	4.99	4.24	4.00	4.64	4.38	5.14	5.28	5.41	4.69
19	6.42	5.47	5.17	5.22	3.83	4.06	3.99	3.58	5.42	4.88	4.33	4.69
20	4.94	6.06	5.50	5.16	4.45	4.50	4.15	3.75	5.56	4.84	4.30	4.69
21	5.70	6.02	5.85	5.09	4.11	4.27	5.07	2.61	6.15	5.51	3.83	4.69
22	5.16	6.03	5.66	4.72	4.42	4.44	4.76	5.28	5.23	4.46	4.45	4.69
23	5.21	6.44	5.00	4.24	4.25	4.06	4.14	4.56	6.18	5.43	4.49	4.69
24	5.74	6.36	5.78	4.44	4.26	3.46	3.79	4.38	5.56	5.32	4.78	4.69
25	5.75	6.76	5.47	4.67	4.83	4.72	4.26	4.23	5.66	4.74	4.76	4.69
26	5.76	6.56	5.90	4.59	4.53	4.26	4.28	4.14	5.15	4.67	4.83	4.69
27	5.14	7.08	5.65	4.26	4.03	4.17	4.31	4.22	5.07	4.99	4.22	4.69
28	5.59	8.23	5.23	4.13	4.60	4.25	4.40	4.54	5.48	5.63	4.94	4.69
29	6.07		5.86	4.42	3.44	4.16	4.57	4.84	4.90	4.81	4.06	4.69
30	6.11		5.63	4.05	3.67	4.42	3.83	4.35	5.07	4.57	4.41	4.69
31	6.81		5.80		4.09		3.99	4.26		4.68		4.69
Avg	**5.73**	**6.28**	**5.86**	**4.90**	**4.19**	**4.32**	**4.24**	**4.24**	**5.22**	**5.01**	**4.61**	**4.93**
Avg=average.												

The frequency distribution of hourly wind speeds recorded over the period of 5 years (1996 to 2011) for Kisumu was used to identify the percent effective wind speed useful for driving the wind pump. The wind speed was segregated (interval) with the specific minimum percent contribution to discharge estimates in mind. The speeds were arranged in columns each containing a particular hour (9 a.m., 10 a.m.) for the 24 hour wind speed day spectrum. These were further categorized into seasons of four months each; Dec-March (dry period), April-July (wet or long rains) and August-Nov (Short Rains). The frequency of the wind speeds ranges of 1m/s intervals was determined by counts within wind spectrum. The seasonal spectrum or block was further analyzed for each hour for the 24 hour period. This was done by dividing the counts of each wind speed designated intervals by the total number of observations within the particular hour. This was taken as the percentage availability ratio or frequency of each wind speed range within that particular hour. Particularly this was to depict the time periods of similar magnitude, that is time of the day with consistent strength or magnitude of wind speeds (Low, high and Moderate) when wind pumps were to be operational to carry out irrigation (8 hrs, 10 hrs, 18 hrs). The ratios as in Tables A6 and A7 allowed observing, detecting and isolation of wind speed ranges with similar magnitudes.

The percent sector spectrum that is responsible for discharge (start rotating speed to design rated speed) needs to be isolated to determine the performance of a wind pump. The continuous pen recorded wind speed data (showing variation within the hour) forms the basic assumption in determining the ratio or percent of the wind speeds spectrum of the hour that actually contributes to the wind mills mode of operation (Ahmet 1995) and thus the wind pump discharge. The wind speed range just before the cut in speed of rotation and cut out speed of the wind pump will register zero discharge.

The percent wind speeds contributing to discharge were determined based on seasons (the dry, long rains, short rains) and on annual basis Table A6. This was further grouped based on time period of equal magnitude within the day for the 24 hour period, by choosing time period with similar ratio of wind speed magnitude. The column cell relating to the wind speed intervals were calculated based on the counts divided by the total observations until the values diminished to zero; meaning the ratios could vary depending on the wind speed intervals selected. These ratios showed the strength and magnitude for irrigation with time.

2.3 Predicting Discharge from Wind Speeds

Measuring wind speed and discharge simultaneously from a wind pump at a point of interest is the sure way of determining the relationship and thus the periodic discharge. The manufacturers often give estimate tables of the performance characteristics of windmills or wind pumps which are often exaggerated and may not be site specific. The approach here is to estimate discharge from a wind pump by use of measured hourly wind speeds and the existing instantaneous discharge equations as illustrated in section 1b to c.

The amount of water pumped by a wind pump on a daily basis can be estimated based on time of day, season or period of interest. The time with similar ratio or percent wind speed magnitude Table A6 to A7 was used with the instantaneous wind pump discharge equations as is proposed in section 1c. For seasons (dry period, wet or long rains or short rains 24 hour), there will hence only be a season's average ratio per wind speed interval per time period of the day selected. The wind pump equations as proposed in section 1c are only instantaneous. The day's cumulative wind pump discharge was estimated by selecting a wind speed mean (Vi) from each day's wind speed range or interval. This was substituted into the chosen instantaneous equation as the first step. It was then multiplied by a season's average ratio (R_i) for the hour or the selected hours of the irrigation as the second step. All were then sequentially added from least contributing wind speed range to the maximum and multiplied by the time period of irrigation or hours of need for the day. This gave the total volume of water required for irrigation at that particular time. Taking equation 5 in section 1c, the expected discharge per seasons average wind speed, based on the selected time period of irrigation, takes the form as below;

$$V_{QT\,=}\ KV_{foot\ of\ wind\ pump} \times 360 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(13)}$$

Where;

$$V_{QT} = V_{Q1} + V_{Q2} + V_{Q3} \ldots\ldots\ldots V_{Qn}$$

$$T = 1, 2, 3, \ldots\ldots 24 \text{ (no of hours)}$$

This implies

$$V_{QT} = 3600K \left(\sum V_i R_i\right) \times T$$

$$Q = K'(\sum V_i R_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(14)}$$

Where K'=3600KT

Where V_{QT} is the volume of water discharged by the wind pump, T is the number of hours or time period of irrigation, represented by 1 to n for the 24 hour period, V_i is the selected wind velocity average within the count range, K is a constant; K in equation 13 is from the instantaneous equation 5.; this can also take the form of Q in equations 3 and 4. R_i is the ratio of the range count within the hour.

In order to use equation 14 from wind speed data, the percent availability Table A6 and A7 is first developed. An appropriate instantaneous discharge equation is then selected that should relate to discharge of a particular wind pump. This can be achieved through field or wind tunnel tests just as for the instantaneous equations in section 1c. Once the constant K as in equation 5 is developed, it can then be used with equation 14.

2.4 Performance of the Kijito wind pump

Actual wind speeds and discharge from a 6.1m diameter wind pump were taken. The wind pump discharges were measured by an anemometer and an Arad 50 mm discharge meter for a period of 90 days (August to November). The relationship of the wind speeds by using instantaneous equation 5 and results compared with the measured discharges for Kijito wind pump at Rusinga (Tom Mboya School). This was then regressed and a fitted line plot using excel and Minitab software (2000).

The Kisumu hourly 10 m wind speed data were also used to estimate discharges based on the equations 3(Q_1), 4(Q_3), actual discharge 5(Q_4) and 14(Q_5). The best performing equation compared to Q_4 was selected. Q_5 was developed as in section 1.2.3. The discharge constant K (0.1) for equation 13 was adopted from equation 4 and as was confirmed during the development of equation 5.

2.5 Area and Depth of Irrigation

Drip irrigation depth and area is a function of the water supply and other irrigation resources (land, crops, soil and ET_O). The maximum amount or depth of water to be applied (the gross irrigation water requirement IR_g) can then be calculated from Equation 8 in section 1c which derives its parameters from weather. ET_O was calculated to facilitate the use of equation 6 and 7 in section1c for determination of the emitter discharge and system discharge. The ET_O influences area and depth of irrigation but its determination faces challenges since it has not been established for the Lake Shore.

The system discharge was calculated by varying iteratively the parameters of equation7 until pump discharge and irrigation balances was ascertained compared to the wind pump discharge. That is;

System discharge (q_s) equation 6………..... $q_d = \frac{I_{Rg} \times A_p}{I_h}$

Or equation 7………………………… $q_s = \frac{I_i \times A_t \times I_{Rg} \times 10}{I_h}$

Where; $Q_s = q_s = I_t \times A_t \times I_{RG} \times 10$ ……..………..(15)

This implies,

$$A_t = \frac{Q_s}{I_i \times I_{RG} \times 10} \quad ………..…………………….(16)$$

And

$$I_{RG} = ET_{CROP}.K_r.E_a + L_r - R \; or \; \left(F_c - w_p\right) \times d(C_v)m \times R_z \times \frac{P}{100} \times \gamma_b$$

Hence WPDI mode is determined from either system discharge or emitter discharge as related to the weather. The soil parameters in the Lake Shore can be measured or determined and estimated from published data (Andriesse and Van der Pouw, 1982**)** as in Table 3 below or parameters as in equation 9.

Table 3: Typical Moisture Values for Various Soil Types

	Percentage of Dry Weight of Soil			
Soil Type	**Field Capacity**	**Wetting Point**	**Available Water**	**Density (Kg/m^3)**
Sand	5	2	3	1500
Sandy Loam	12	5	7	1400
Loam	18	10	8	1350
Silt Loam	24	15	9	1300
Clay Loam	30	19	11	1300
Clay	40	24	16	1200

Source: Linsley (1979)

The key drip irrigation parameters apart from discharge are ETo with other parameters implied in the gross water requirement (IR_g). The IR_g was calculated from the weather equation 8 or alternatively from soil based equation 9. The estimated or determined discharge was then used to balance the parameters of equation 1 to 9.

3. RESULTS AND DISCUSSION

The Kisumu station had, a cumulative 1800 data points captured at 10 m height for the 5 year time period (1996 to 2011) of which 600 data points are for each of the three seasons (dry, long rains and short rains). A table (A6 & A7) was developed to show wind speed intervals (0 to1, 1.01 to 2, 2.01 to 3, 3.01 to 4), in column one and row one starting from columns 2 to the 25th for each hour of the day (1 to 24 hours). The rest of cell values (row two, column two onwards) apart from the first column were ratios of frequency to the total counts of a wind speed intervals within the hour for the data showing the frequency of wind speeds on the designated wind speed ranges. The developed tables comprised the wind speed intervals. These were then summarized to constitute Table A6 and A7 that showed hourly average ratios (cell values) for the wind speed interval variation on annual basis and the seasons (Dec-March, April-July, and August-Nov). This was considered equivalent to frequency as could be derived from a continuously pen recorded data from the particular hour for the wind speed intervals.

However, it is observed that the accuracy of the estimated discharge improved with the length of the hourly measured data, the wind speed range step interval and the accuracy of the measuring equipment. The essence of determination of the ratios as in Table 4 indicates that estimate calculations can be for the daily discharge on a 24 hour period or can be varied with regard to Tables A6 and A7to be specific to the desired time period of irrigation or a season.

3.1 Percent Wind Speeds from Hourly Wind Speeds

Based on the ratios of the percent wind speeds calculated as in section 1.2.2, the Table 4 (extracted from table A6 and A7) below in the first column indicates that the hourly wind speeds of the Kisumu data starts from a wind speed of zero to a maximum of 12 m/s. The rows 1 and 2 in column 1 (.0 to 1 m/s and 1.01 to 2 m/s for example) comprise the wind speed range, which shows that 37% (30+7), 45%, 43% and 41% represents wind speeds availability during the dry, long rains, short rains and annual averages respectively.

The rest of the wind speeds are distributed from 2m/s to 12 m/s, with the usable interval for a wind pump concentrated between 2m/s to 8 m/s. The wind speeds above 8m/s though available are low in frequency. Figure 2 below represents graphically the spectrum of magnitude of wind for the Kisumu station and the percentage available wind speed per interval.

Table 4: Percent Wind Speed interval Availability Index – Kisumu

WS-interval m/s	Dec-March	April-July	Aug.-Nov	Annual
1	0.30	0.37	0.36	**0.34**
2	0.07	0.08	0.07	**0.07**
3	0.17	0.18	0.17	**0.17**
4	0.16	0.10	0.10	**0.12**
5	0.11	0.08	0.08	**0.09**
6	0.08	0.08	0.09	**0.09**
7	0.04	0.05	0.06	**0.05**
8	0.03	0.03	0.03	**0.03**
9	0.01	0.01	0.01	**0.01**
10	0.01	0.01	0.01	**0.01**
11	0.00	0.00	0.01	**0.01**
12	**0.00**	**0.00**	**0.00**	**0.00**

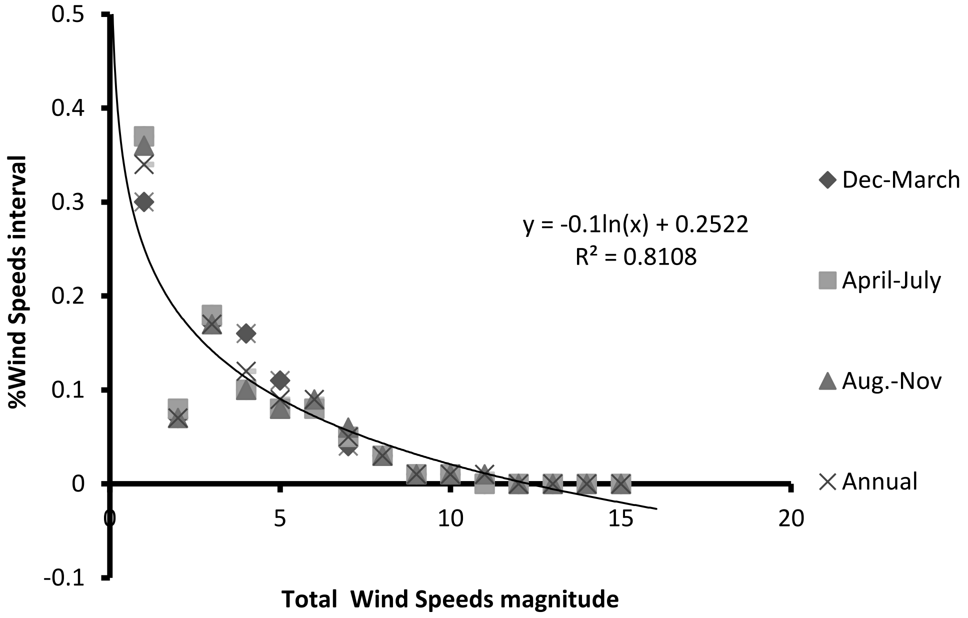

Fig. 2: Graphical Percent Wind Speed Range Availability

The Table 4 shows the annual upper and the lower limit of the wind speed ratio as varying from 0.01 to 0.34. The upper limit ratio (higher wind speeds, 8 -12 m/s) is constant while the lower limit varies with seasons. The wind speeds are higher in the dry season (ratio of 0.3) compared to the long and the short rain periods (respectively 0.37 and 0.36) of the year. This is an indicator of the minimum and maximum wind speeds available in an area at a particular height, and for calculating the wind pump discharges in a season or time period as desired for irrigation (equation 13). The 10 m height hourly frequency distribution (Table 4) confirms wind speed variation at Kisumu. The variations are twofold; the percent availability of the wind speed within a season and with the seasons. There is a relationship between the percent of wind speeds within an interval and magnitudes within the season. The relationship is logarithmic having trend line equations implying that:

% of a wind speeds in each interval; available
(Dec-March) $= -0.1\ln(x) + 0.25, R^2 = 0.81$
(April-July) $= -0.1\ln(x) + 0.28, R^2 = 0.81$
(Aug-Nov) $= -0.1 ln\ (x) + 0.27, R^2 = 0.79$
(Annual) $= -0.1\ ln\ (x) + 0.26, R^2 = 0.81$

This approach of percent wind speed interval availability (Table 4) is more informative in comparison with Table 1 which is often used by manufacturers in presenting wind pumps' discharges. From table 4 ,the logarithmic relationship shows that during the dry seasons the available wind speeds potential are higher, in that the lower the constants the higher the upper wind speed range availability. These relationships show clearly the temperature effects signified by seasons. The Table A6 and A7 summarized in Table 4 allows the use of equation 14 $(Q = K(\sum V_i R_i)$ developed from instantaneous equation 5 to calculate discharges from wind speed intervals though equations 3 and 4 can also be tested in a similar way. Cumulative discharges per each hour of the day can be calculated as desired from equation 4.

3.2 Predicting Discharge from Wind Speeds

The actual and predicted data were compared as shown in Fig 4 and from among the three instantaneous equations. Fig 4 is an illustration of the work of Kabok and Chemelil (2005), Q_3 whose equation compared well with the actual discharge Q_4, though slightly higher and to the Lysens equation (1982) Q_2. This is further represented in Fig 3 for the fit indicating regression equation $(\text{Actual} = 0.79808\,\text{Predict} + 0.00007183$ together with the other regression parameters. The LE Gourieres equation was multiplied by a factor of 0.001 to make the figure smaller to enable it fit in a graph with the other equations. However lysens equation bares similarity to the actual, Q_4. The Le Gouireres 1982 equation compared well at the beginning, but it diverged upwards, showing wind speeds continually increases with discharges. This may not be true because of the rated wind speed and also limit due to capacity and nature of the reciprocating pump.

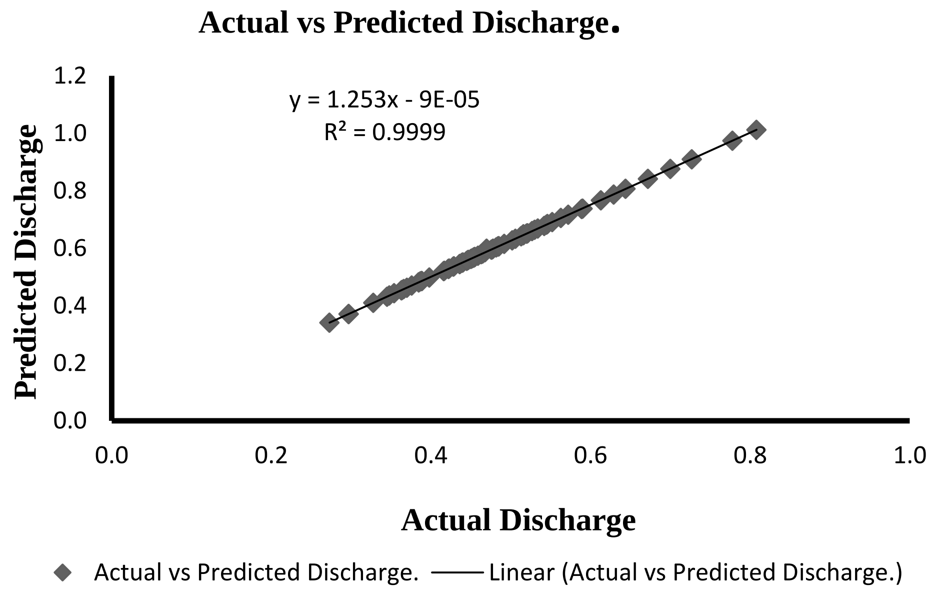

Fig. 3: Actual Rusinga Vs. Predicted Q_3 Discharge

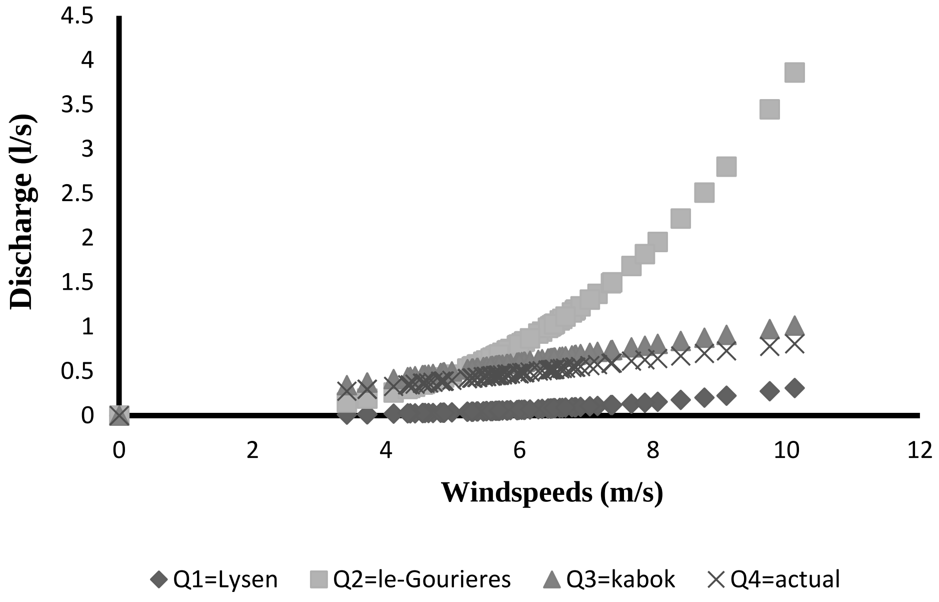

Fig. 4 Predicted discharge Vs. Wind speeds

In order to use the hourly wind range frequency percentages for determination of discharge of a wind pump, the performance of the equations .3 to 5 in Fig .4 were first determined as in 1.3.2 above. Since Kisumu did not have the measured discharge, values were hence predicted using all the equations as shown in Fig 4 with the actual wind speed data in Table .2. The seasons wind speed averages (Table .2) were then used to determine the expected discharge, including (14) Q_5, the percent availability discharge equation.

When Q_3 (Kabok and Chemelil; 2001, 2005) and Q_5 are compared, the seasons estimate discharge is lower by 40% (Q_3 to Q_5) and 25% of the calculated actual discharge (Q_4 to Q_5. These translate respectively to discharge of $0.72m^3/hr$ and $0.36m^3/hr$ lower. The Kabok and Chemelil (2001, 2005) equation according to Table 5 show that the discharge estimate averages $1.78m^3/hr$; while the new developed equation 14 based on the percent availability approach shows discharges averaging $1.1m^3/hr$ per season. This is attributed to Q_5 taking into consideration only the usable wind speeds range.

This is reasonable since Fig 4 shows that Q_2 is slightly higher than actual discharge Q_4. This though may highly depend on the range of wind speed chosen and the wind pump starting speed selected. The approach indicates that output is comparable as long as the amount of data is large enough (> 5 years) and wind pump starting speed is correctly determined from field tests. Hence the method can be used as a first estimate of the expected discharge.

Table 5: Estimated Seasonal Discharge

Season	WS	Q1	Q2	Q3	Q4	Q5
Dec-March	5.68	0.06	0.69	0.57	0.45	0.30
April- July	4.40	0.03	0.32	0.44	0.35	0.28
Aug- Nov	4.76	0.03	0.40	0.48	0.38	0.30
Annual	4.95	0.04	0.45	0.49	0.40	0.30

Where: WS = seasons average wind speed

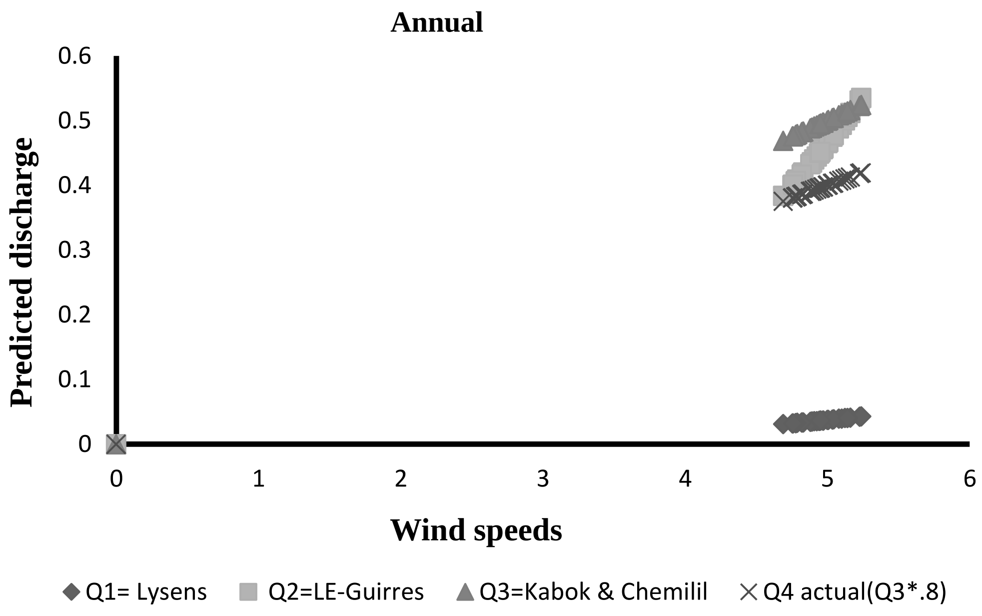

Fig. 4: Predicted Discharge for Kisumu

This study shows that it is possible to use the hourly recorded wind speed data and the instantaneous discharge equations to estimate the days discharge based on seasons. The data in Table 2 is based on the daily average; a smaller time step table can be obtained from Tables A6 & A7 of 8hrs, 10 hrs or 12hrs, which can be developed for the exact irrigation duration. Daily average wind speed data may also be assumed to exhibit the percent wind speed availability within numerical selected ranges.

The same procedure with daily recorded data is not practical for specific time measurements daily, monthly for a number of years. An approach similar as above based on daily average data was attempted. It was noted that daily measured average wind speed data do hide more variability's as compared to the hourly data. Hourly records or smaller time steps are hence preferred. This is because daily data are average and will need a large amount of data (3600*24*30 *12) to cover for hourly variations. Inherently therefore it can be less accurate with few data points as this will need years of record to obtain the most approximate wind speed for each day of the month. Deciding on the duration of wind speed strengths within the 24 hours of the day will also be difficult. The hourly wind speeds allows decision on the time step of irrigation or duration and the wind speed strength available.

This approach developed is to be used together with drip irrigation, especially the instantaneous wind pump discharge equations, the hydraulic and resource equations. The developed procedure and equations, where appropriate may be used to estimate the irrigation duration discharge from measured wind speeds and thus irrigation area and depth as in section 1.2.5.

4. CONCLUSION AND RECOMMENDATIONS

Based on shorter time step and length of wind speeds measurements and the instantaneous discharge equations, the discharge for wind pump drip irrigation can be determined. In addition by use of the design chart (soil parameters, ET_O, the hydraulic equations, wind speeds and instantaneous discharge equations) wind pump drip irrigation can be evaluated for performance. The time and period of irrigation can also be determined with accuracy. It is therefore possible to:

- Use hourly as opposed to daily wind speeds measurements and shorter time steps to estimate the percentage available wind speeds for predetermined wind speed ranges. The longer the duration of wind speed measurement the more informative it is, as it integrates the spatial and temporal variations of wind speeds on the earth's surface. The hourly wind speeds or other shorter time step of measurements can be blocked into time of the day, seasons and annual basis to single out the duration of interest such as for wind pump drip irrigation.
- Predict or estimate wind pump discharges by using the instantaneous wind pump discharge equations whose field performance may differ with type of wind pump and the wind speeds. In this case, the Kabok and Chemelil (2005) equation fitted well better than the other equations. It also compared well to the developed percent wind speed based discharge equation 14

  The discharge equation ($Q = K(\sum V_i R_i)$ shows time and seasons variation much more clearly than the tables proposed by the manufacturers. Table A6 and A7 is used in this text and is here developed for the purpose.
- In the design, installation, operation and evaluation of the wind pump drip irrigation (WPDI) system a chart (conceptual frame work) was developed. It shows that discharge is the key link to the resource equation parameters particularly ETo, irrigation depth and area. The irrigation depth and area hence is easily determined from the frame work.

But;

- ETo, irrigation depth and area relationship may need further field investigation for as many sites. This will be to ascertain the constant for the discharge for the instantaneous equations which may differ with the wind pump rotor diameters, type of the wind pump and even the percent wind speed range extent.

There is need to employ GIS for wind speed measurements which is more accurate in terms of duration and locations of sites. Low solidity windmills need to be studied in this regard and especially in relation to wind speeds percent availability and discharge, both for electrical and rotor wind pump.

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