International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Household Level Wastewater Management: A Pilot Case Study For Hawassa Town, Ethiopia

Mihret Dananto Ulsido
Hawassa University, Institute of Technology
School of Biosystems and Environmental Engineering, Ethiopia

Abstract

In many developing countries urbanization takes more land from agriculture for the construction of infrastructures. In return it generates a continuous solid and liquid waste that further claim additional land from the sector. To compensate the shortage in production due to the stolen land, urban farming with partially treated wastewater could be a feasible option. However, the major challenge in the area of wastewater reuse for irrigation is minimization or aversion of the direct contact between irrigators, crops and the wastewater. To overcome this challenge and to fulfill the "crop per drop" strategy of FAO, urban farming with efficient irrigation techniques like drip irrigation with household wastewater could be an attractive intervention. This article shows the viability of an interlinked intervention to manage urban wastes for agricultural production and diversifying income of households in Hawassa town using irrigation water from household wastewater collection chambers.

Key words: crop-per-drop, drip irrigation, urban farming, wastewater

1 - Introduction

The history of drip irrigation is some what clouded. There are almost as many versions of its origins as there are people to tell it. Suffice to say, however, that drip irrigation really got off the ground with the development of the plastic industry and the availability of economical, reliable and chemical resistant plastic. At any rate, drip irrigation is now a well-accepted vehicle for watering many types of crops even with wastewater. So well accepted that, in the past two decades, an entire industry devoted for designing, manufacturing, and installing drip irrigation has opened a new gate in the area of wastewater application in irrigated fields.

Drip irrigation is classically defined as a slow watering process intended to deliver water and nutrients to the root area of a plant [3]. The objective is to maintain the water content of the soil close to field capacity, so that the roots have a constant supply of moisture with adequate aeration.

A drip irrigation system with wastewater usually consists of a collection, treatment and control station, pipe net work, lateral distribution system and emitters (figure 1). Assuming that water is available under pressure, the control station should contain a filtration, disinfection and pressure regulating system, a back flow preventer and air relief valve. The station that collects the sewer consists of a series of septic tanks used as a settling and an overflow collection chamber. To make the system more energy independent; the distribution system is pressurized with treadle pump and the system is designed in such a way that gravity shall govern the flow (figure 1). A typical example of wastewater reuse with drip irrigation technique is the system at the Sam Lords Castle Hotel in Barbados [10]. Effluent consisting of kitchen, laundry, and domestic sewage ("gray water") is collected in a septic tank, from which it is pumped to an aeration chamber.

The most common system of disinfection in this area is chlorination [8]. Chlorine tablets, liquid, powder, and gas are widely used. Chlorination of water supplies on an emergency basis was practiced in the region as early as about 1850 [8]. At present, chlorination of both water supplies and wastewater is widespread. Chlorination for disinfection is used to prevent the spread of waterborne diseases and to control algal growth and odors. Economics, ease of operation, and convenience are the main factors used to evaluate disinfection processes.

According to Jess [6], an effective and reliable filtration (figure 1) is the heart of drip irrigation system. The schematic in figure 1 actually shows a process that gives high quality irrigation water. However, as a function of capital, a simplified option can also be adopted.

With drip irrigation, the part of the field between plants normally remains dry so that water is not lost in these areas by deep percolation. Further, since there is no surface buildup of water, losses are minimized by evaporation and run-off. Approximated system efficiency with fresh water reaches up to 90% (5). However with the use of wastewater with a suspended solids content greater than 78 mg/l and a BOD5 greater than 25 mg/l of O2, did not permit optimal efficiency (≥90%) to be achieved: a maximum coefficient of 77% was measured in labyrinth emitters protected by an Arkal disk filter (2). Drip irrigation system is well known for its water saving mechanism and minimized contact between the wastewater, the operator as well as the crop to be irrigated. Just how much water can be saved depends on many parameters such as, type of soil, size and type of plant, topography. With drip irrigation, the volume of the soil wetted is much less than by other irrigation methods. It may vary 5% to 10% of the soil around young trees.

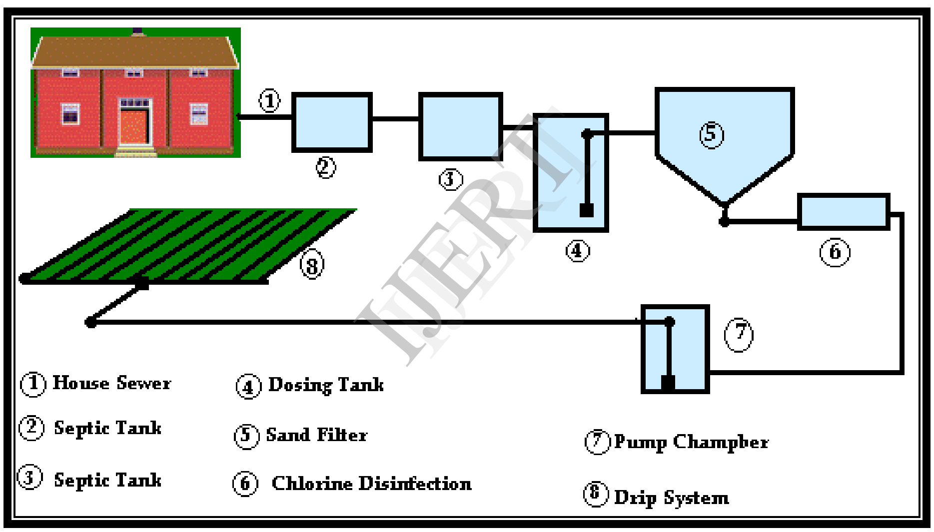

Figure 1- Schematic of a Typical Residential Drip Irrigation System.

Many experiments have been conducted that illustrate greater yield and quality of product associated with drip irrigation with wastewater. This is probably due to variety of reasons acting in concern. For example, plant protection from disease and insects is improved by avoiding the wetting of plant stem and leaves. Reducing the wetted areas also limits weed growth and restricts population of potential pest hosts. Many farmers in developed and developing countries who have used drip irrigation have given glowing testimonies. Due to this reasons, this paper will try to asses the feasibility of this method of wastewater application together with treadle pumps in Hawassa town, Southern Ethiopia for urban farming as a means to supplement family food budget through better use of household wastewater.

2 - Methods

The best way to design, install and maintain a drip irrigation system that uses wastewater is a complicated science by itself and is a topic of discussion in the next section. However, when designing a drip irrigation system, some of the factors, which must be considered include: the topography of the site, plot sizes, soil type, crop water requirements, capacity and pressure out put of the water source and water quality [6].

To decide up on the different characteristics of a feasible drip irrigation system, friction losses have been determined using standard Hazen Williams's equation along the pipe net works and laterals. The CROPWAT program that uses FAO-Penman Monteith equation is employed to determine crop water requirement of the crop selected. To determine the drip system required, different manufacturers and suppliers specifications have been used.

3 - Result and Discussions

Cabbage and pepper are the common vegetables grown in the backyard. Hence they are considered as design crop. The maximum reference evpotranspiration (ET_O) in Hawassa is about 5 (4.3) mm per day (table 1) in January. Using the crop factor (K_c) for the aforementioned vegetables (Cabbage and Green pepper) the crop Water Requirement (CWR) is computed (Table 1).

Table 1- Crop Water Requirement (CWR) in Hawassa

Date	ETo (mm/10 days)	Kc	CWR (mm/10 days)	Eff. Rainfall (mm/10 days)	IR (mm/10 days)
1/10	34.98	0.7	24.49	3.68	20.81
11/10	35.85	0.7	25.09	2.26	22.83
21/10	36.78	0.71	26.3	2.36	23.94
31/10	37.75	0.81	30.4	1.47	28.93
10/11	38.72	0.9	35.05	9.25	25.8
20/11	39.64	1	39.85	5.59	34.26
30/11	40.5	1.05	42.53	2.62	39.91
10/12	41.26	1.05	43.33	0	43.33
20/12	41.89	1.04	43.57	1.97	41.6
30/12	43.24	0.98	42.37	5.92	36.45
Total	390.63		352.97	105.24	247.73

Hence 4.3mm/day is the maximum daily CWR for the peak month December. Deducting the effective rainfall from the CWR, 4,33mm/day will be the maximum daily irrigation requirement of the crops selected (table 1). The depth of water applied per irrigation is computed using the equation:

$$AD = AW\ (mm/\ m) * Depletion\ factor\ (D_f) * soil\ depth\ (m)$$

Where

$$AD = Alowable\ Deplition (mm)$$

$$AW = \text{Re}adily\ Available\ water\ per\ unit\ depth\ of\ soil\ (mm/m)$$

$$DF = Depletion\ factor (\ from\ Table\ 2\ and\ 3)$$

Table 2-Depletion factor (D_f) for different crop groups (Source; Larry, 1988).

Group	**CWR(mm/day)**								
	2	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.5	0.425	0.35	0.3	0.25	0.225	0.2	0.2	0.175
2	0.675	0.575	0.475	0.4	0.35	0.325	0.275	0.25	0.225
3	0.8	0.7	0.6	0.5	0.45	0.425	0.375	0.35	0.3
4	0.875	0.8	0.7	0.6	0.55	0.5	0.45	0.425	0.4

Based on the type of vegetables selected, the following information is considered for designing purpose:

- spacing between emission device, S, = 30cm
- lateral spacing, L, = 70cm
- in line drippers (commonly available on market)
- Flow pattern – turbulent

Considering cabbage as our design crop; the maximum D_f value of 0.4 is taken for 4.33 mm/day CWR (table 2). Taking AW value of 40mm/m [4] (soil in the project area is sandy having a soil depth of 50cm):

$$AD = 40mm/m * 0.4*0.5m$$
$$= 8mm$$

Table 3-Crop group according to soil water depletion (Source: Larry, 1988).

Group	**Crops**
1	Onion, Pepper , Potato
2	Banana, Cabbage, Grape, Pea, Tomato
3	Bean, Citrus, Ground Nut, Pineapple, Sunflower, Water Melon
4	Cotton, Maize, Olive, Safflower, Sorghum, Soybean, Sugar Beat

The designed daily water uptake (D_a) is calculated from the maximum irrigation requirement (IR) of the area and drip irrigation efficiency (E_a) with wastewater (0.77),

$$D_a = \frac{IR}{E_a} = \frac{4.3\, mm/day}{0.77} = 5.8mm/day$$

Hence Irrigation interval (I) in days is computed as:

$$I = \frac{AD}{D_a} = \frac{8mm}{5.8mm/day} \approx 2\ days$$

The area irrigated by an emission device depends on the types of emitter used. The wetting patterns of in line dripper available on market as a function of different soil types (table 4) are used for the determination of dripper's capacity and wetted area.

Table 4-Wetting Pattern of inline Drip Emitter in Different Soils (source: Jess, 2006)

Soil type	*Dripper flow rates (l/h)*	**Wetted area (sq. m)**
Sandy	2	0.40
Loam	2	0.70
Clay	2	0.50

The number of drippers required for irrigation is then computed as:

$$Number\ of\ Drippers\ per\ plant = \frac{Plant\ area}{Dripper\ wetted\ area}$$

$$Dripper\ wetted\ area - from\ Table\ 4$$

Therefore, the number of drippers per single plant is computed as:

The hydraulic design of the drip system is made in two steps, first for the main line followed by laterals. The main line is designed to carry the maximum discharge required for total number of plants in the plot. Taking an average garden of 6m × 6m area, 172 plants can be accommodated for a plant spacing of 0.3m× 0.7m.

$$Number\ of\ Drippers\ per\ plant = \frac{Plant\ area}{Dripper\ wetted\ area} = \frac{0.7m*0.3m}{0.4} \approx 1$$

Hence one emitter per plant having a capacity of 2li/hr is enough to irrigate a single plant for a running time of

$$Runtime/every\ 2\ days = \frac{D_a(lit/day)}{Flowrate(lit/hr)[Table\ 4]*Number\ of\ drippers\ per\ plant}$$
$$= \frac{0.0048*0.4\ *1000\ l/day}{2l/hr*1}$$
$$= 1hr$$

Therefore the users are advised to irrigate effective one hour every two days.

Hydraulic System Design

$$Maximum\ discharge\ required = No.of\ plants \times peak\ discharge\ per\ plant$$
$$= 172x\ 2\ L.hr^{-1} = 344\ L.h^{-1} \approx 0.5\ L.S^{-1}$$

A friction head loss in the main line is determined considering an average home garden having a length and width of 6m.

$$\begin{aligned} Number\ of\ connectors\ required &= Total\ width\ /\ width\ between\ two\ Laterals \\ &= 6m/\ 0.7m \\ &= 9 \end{aligned}$$

Equivalent length of nine standard-flow-through-branch tees, one-standard-flow-through-run and two 90^0 regular elbows equals:

$$L_{eq} = \frac{KD}{f} = \frac{9*1.8*.025m}{0.02} + \frac{0.6*0.025m}{0.02} + \frac{0.25*0.025m}{0.02} = 20m$$

$Where: L_{eq} is\ the\ equivalent\ length\ in\ meter,\ f\ is\ the\ moody\ friction\ factor\ = 0.02, D\ is\ pipe$
$internal\ diameter\ = 25mm\ (the\ next\ least\ size available\ on\ market), K\ is\ local\ loss\ coefficient$
$(= 0.25\ for\ elbow, 1.8\ for\ through\ branch\ tee\ and\ 0.6\ for\ through\ run\ tee)$

$$Therefore\ total\ length\ = actual\ length\ (6m) + the\ equivalent\ length\ (20m) = 26m$$

For a discharge of about 0.5l/s through a pipe of 25mm diameter, the friction loss would be 5.5 m per 100m lengths or 1.43m for 26 m length (table 5).

Table 5-Friction Losses for Flow of Water (m/100m) in smooth Pipes(c=140) (Source, NABARAD)

Peak Discharge(l/s)	Pipe diameter in mm									
	20	25	32	40	50	65	80	100	125	150
0.5	16.4	5.5	1.6	0.6	-	-	-	-	-	-
1	-	10.0	6.0	2.0	0.7	-	-	-	-	-
2	-	-	16.0	7.3	2.5	0.7	0.3	-	-	-

For other type of pipes (such as smooth new plastic pipes) the above value needs to be corrected by a correction factor [9], 0.86 for our case.

$$Friction\ head\ loss\ = 1.41m\ x\ 0.86\ = 1.3m$$

As the proposed system have nine outlets along its six meter width, the previous friction head loss value is corrected by a reduction coefficient of 0.42 [9] for a multiple outlet.

Therefore the total head loss in the main line is

$$Friction\ head\ loss\ main\ = 1.3\ x\ 0.42\ = 0.5m$$

Similarly the head losses in the laterals are determined from an average size home garden mentioned above. A lateral is selected that the pressure differences from the proximate end to the last emitter do not exceed 10% of the normal operating head which in the present case is 1.5m.

$$Number\ of\ laterals = Total\ length\ /\ Lateral\ spacing = 6m/\ 0.7m\ = 9$$
$$Number\ of\ emitter\ per\ plant\ = 1$$
$$Number\ of\ emitter\ per\ lateral\ = Total\ width\ /\ emitter\ spacing = 6m\ /\ 0.3m\ = 20$$

The maximum permissible variation in friction loss in the pipe is 1.5x10/100 which is 0.09m for a lateral of 6 m length. For average land slope of 0.05 m/ 10m, thus the maximum allowable total friction loss in a single lateral is 0.09m + 0.05m ≅ 0.2 m. In addition to 6 m length of the lateral, there is additional loss due to connectors. The equivalent length of an emitter is about 0.6m. Therefore the equivalent length of 20 emitters would 20x0.6 = 12 m. Thus, the total length for calculation of friction loss in laterals would be 18 m (6m+12m). The total flow in laterals is 38 l/h i.e. $344\ l.h \div 9$. Smaller diameter pipe (e.g. 9.2mm) can accommodate the flow with smaller value of friction losses. Hence the friction head loss in the laterals can be estimated by Hazen-Williams formula as:

$$h_L = 863\, L\, \left(\frac{100}{C}\right)^{1.85} (q)^{1.85} / (d_h)^{4.8655}$$

Where, h_L *is head loss in a single lateral* (m), L *is pipe or tube length* (m), C *= design coefficient determined for the type of pipe or tube* (140 *for PVC*), q *= flow rate* $(lit/\min)$ *and* d_h *= hydraulic diameter* (mm). *Therefore;* $h_L = 863 \times 18m\ (100\ /\ 140)^{1.85} \times (0.63 lit/\min)^{1.85} / (9.2mm)^{4.8655} = 0.073m$

For nine laterals the total head loss can be (9*0.073m) 0.6m.Assuming the total head loss in the control head is 0.4m (higher loss for this section); the pressure head required upstream is 0.4 +0.5+ 0.6≅ 1.5m.

Pump Capacity and Cost Analysis

The horsepower (HP) of pump set required is based upon design discharge and total operating head. The total head is the sum of total static head (table 6) and friction losses (table 6) in the system that was determined in the previous section.

Table 6-Total static head (m).

Static Head	*Depth to water*	**3 m (average depth of septic tank)**
	Draw down	0.5 m (assumed)
	Height of Delivery pipe	0.25m
	Friction loss in pipes, bends, foot valves etc.	1.0 m
Total static head (A)		4.75m
Friction loss	Friction loss in main pipe	0.5 m
	Friction loss in laterals	0.6 m
	Minimum head required over control head	0.4 m
Total friction loss (B)		1.5m
Total head(A) + (B)		6.25

The required HP of the pump has been calculated as:

$$Hp\ of\ pump\ set\ = \frac{Q \times H}{75 \times \eta} = 0.5 \times 6.25 \big/ 75 \times 0.39 = 0.1\ or\ \frac{1}{10^{th}} of\ a\ HP$$

Where; Q is *discharge* (l/s), H is *Head* (m), and $\eta =$ *Pumping efficiency* (39 *to* 52%).

0.1 *HP is a small power that can be easily generated by a young man*

The 20% internal rate of return (IRR) computed for only ten years of the project life showed the project as a promising one (table 7). Further more all the volume of wastewater recycled within the household where more than 90% of the waste is water, increases the significance of the project.

Table 7-The unit cost in Ethiopian Currency (1/10th of euro) of the drip irrigation system for 36m^2 garden.

Years	0	1	2	3	4	5	6	7	8	9	10
Cost of cultivation	10	11	12	13	14	15	16	17	19	20	22
Cost of Installation	600	-	-	-	-	-	-	-	-	-	-
Operating /Maintenance	0	10	12	12	13	14	14	15	16	16	16
Income	0	150	150	153	153	165	178	193	208	225	243
Net Benefit	-610	129	126.2	128	126.3	136.4	149	161	174	189	205
NPV(at 8%Interest rate)	-610	-485	-377	-275	-182	-90	4	98	192	286	381

Internal Rate of Return (IRR) (%):20%, Total Invested (outflows): 905.00 birr, and Total Return (inflows):1818.0 birr

5. Conclusion

In many developing countries like India and Ghana, wastewater is an opportunity than a problem. The main challenge is how to manage this resource than dumping somewhere else where it becomes a problem. This study paper tried to illustrate a feasibility of one of the many alternatives that gives a solution in the area of wastewater management challenges. Drip irrigation is a better alternative that minimizes the contact between waste water, the crop to be irrigated and the operator that manages the system. Here drip irrigation is considered not only as a technique to minimize irrigation water consumption but as a means that minimizes a possible spread of disease causing organisms in irrigated fields. The above technical and economical analysis showed that drip irrigation for urban farming in Hawassa town is a cost effective and technologically feasible practice. Integrating drip irrigation with treadle pump made the system more energy independent and also found to be a wise and labour intensive option. Finally; to bring this thought in to practice, understanding the nature of the wastewater available in the household and possible size of a plot in the backyard is very essential. For better management and handling of wastewater the writer advise a-priori waste separation before the first septic thank.

Reference:

1. Capra A. and Scicolone B., Emitter and filter tests for wastewater reuse by drip Irrigation, Agricultural Water Management, Volume 68, Issue 2, 1 August 2004, Pages 135-149.
2. DIG – Irrigation Products. Drip Irrigation Design Manual. *Available at* *http://www.digcorp.com/comm/tec006.htm*
3. FAO, 1988. Irrigation water management, Training manuals - 5. Rome, Italy. *Available at* *http://www.fao.org/docrep/S8684E/s8684e00.HTM*
4. Hanson R. B., Fipps G., and Martin C.E., 2000. Drip Irrigation of Row Crops: What is the State of the Art? *Available at* *http://www.oznet.ksu.edu/sdi/Abstracts/DripIrrigationofRowCrops.htm*
5. Jess Stryker's, 2006. Drip Irrigation Design Guidelines. *Available at* *http://www.irrigationtutorials.com/dripguide.htm*
6. Larry G. James, 1988. Principles of Farm Irrigation System Design. (John Wiley and Sons, Inc, Washington: USA).
7. Michael A. Rowan, 2004.The Utility of Drip Irrigation for the Distribution of On-Site Wastewater Effluent. The Ohio State University, Columbus.
8. NABARD- India's National Bank of Agriculture and Rural Development. Drip Irrigation. *Available at* *http://www.nabard.org/roles/ms/mi/drip.htm.*
9. UNEP, 1997. Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. Washington, D.C., USA.