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Evaluating the performance of localized irrigation system outlets using treated wastewater

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A R T I C L E I N F O

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A B S T R A C T

The study was carried out to evaluate the performance of the outlets of a localized irrigation system (drip and bubbler) with discharges (up to 108 L/h) using treated wastewater. The study was conducted at three locations: Cairo, Beni Suef and Luxor, during the years 2021 and 2022, using pressure compensating (PC) (Cairo and Beni Suef) and non-pressure compensating (NPC) (Luxor) outlets. The actual performance of the outlets was studied by measuring emission uniformity (EU) and clogging percent (CP). Readings were recorded every 32 hours and for a running duration according to the site's conditions. The main results showed that: (A) At Cairo site: EU and CP for PC outlets at flow rates (3.5 - 54 – 108L/h) were (76.2 –56.7%), (78.2 –33.7%), (81.6 –16.2%) respectively after 96 operating hours by using treated wastewater. (B) At Beni Suef site: EU and CP for PC outlet at flow rate 24L/h was (72.7 – 47.6%) respectively after 192 operating hours by using treated wastewater. (C) At Luxor site: EU and CP for NPC outlet at flow rate 70L/h was (59.4 – 76.3%) respectively after 192 operating hours by using treated wastewater. The study concluded that the use of treated wastewater for the localized irrigation system with low or high discharge outlets leads to clogging of the outlets with increased operating time, which leads to a decrease in application uniformity. Therefore, the study recommends the use of PC outlets with a discharge rate of no less than 108 L/h in cases of necessity.

1. Introduction

Scarcity and high cost of clear water in most recent projects leads to increase the demand of using treated wastewater to irrigate more landscape areas.

Mohamedand Ibrahem (2022) mentioned that reuse of treated wastewater is one of the main alternative options to expand water resources, especially in dry areas, because it represents another source of renewable water.

Hashem and Qi (2021) showed that irrigation with treated wastewater became a valuable resource and an attractive choice to manipulate water lack, especially since the wastewater amount is huge in several countries. Using this huge wastewater as an irrigation source after appropriate treatment has economic and environmental benefits since it could conserve a huge quantity of freshwater, besides decrease or even eliminate the need to supply expensive chemical fertilizers to the soil.

Also, reuse of wastewater is one of the most important non-congenital water sources in Egypt, as it represents about 65% of the non-traditional water resources and about 17% of the total available Egyptian water resources during the period 2015-2019 (CAPMAS, 2020).

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Eldeep et al. (2020) proposed that water reuse is an economical alternative in developing water resources because it can save more than half the cost of producing desalinated water and treated wastewater is considered a good irrigation source for both arid and semi-arid areas.

Abdel Moula et al. (2021) concluded that irrigation with reclaimed water is a widespread solution to coping with water scarcity, especially in the Middle East and North Africa (MENA) region. Also in Egypt, the resulting price of a cubic meter of treated wastewater, used in irrigation, ranged from 2.5 to 4 Egyptian pounds.

Massoud and Elfadel, (2002) mentioned that treated wastewater effluents may be reused for different purposes such as landscape irrigation (parks, green areas, golf courses, etc…,), recreational activities, firefighting and groundwater recharge.

Guidelines for the safe use of treated wastewater (TWW)) were published by World Health Organization (WHO, 2006).

Elbana et al. (2014) and Shetta (2016) showed that use of treated wastewater provides a reliable alternative source for irrigation in arid and semi-arid regions.

studies as (Qadir and Aziz, 2021; Aboamera et al., 2017; Ismail et al., 2013; Rashad et al., 2012), explained that the CP ranged from 12.24 to 80.61% by using treated wastewater and different outlets types with flow rate ranged from 1.6 to 8 L/h after181operating hours.

El-Berry et al. (2006) showed that CP of high flow rate outlets and EU were (12, 43, 82, 89%) and (90, 90, 77, 83%) for outlets flow rate, (180, 120, 40, 4L/h) respectively after 200 hours of operation.

Due to the lack for sufficient studies on the performance of the outlets of localized irrigation systems, especially with high flow rate using treated wastewater, the research aims to evaluate the performance of some high flow rate outlets of localized irrigation system using treated wastewater by measuring the actual performance of outlets in three locations (Cairo – Beni Suef - Luxor).

2. Materials and methods

Field measurements were carried out at three locations in (Cairo, Beni Suef and Luxor) with treated wastewater for outlets flow rates (3.5 - 54 - 108-24-70 L/h) according to the field and operational conditions of each site in order to assess the performance of those outlets. The following are the specifications of the sites, outlets and water used for each site and the equations used.

2.1. Materials

2.1.1. Studied sites

Table 1

Data of sites.

Site name	Coordinates	Area (m^2)	Dimensions (m)
Cairo	N = 30° 04' 48.1", E = 31° 40' 26.3"	170400	Av.= 800×213
Beni Suef	N = 29° 05' 24.8", E = 31° 11' 00.7"	5940	90×66
Luxor	N = 25°37' 16.8", E = 32° 42' 48.0"	28188	261×108

2.1.2. Measurement Devices

The following devices were used during experimental work**:**

1. Calibrated cylinder for measuring water volume.
2. Stopwatch for measuring the times.
3. Pressure gauges with sensitivity 0.1 bar.
4. Catch can**:** Plastic collectors were used for measuring water volume collected.

Three collected samples of treated wastewater were taken analyzed in land lab of the Faculty of Agriculture of Azhar University - Assiut branch.

2.1.3. Wastewater analysis:

Chemical characteristics for treated wastewater were represented in Tables 2 and 3.

The operating pressure of all evaluated outlets was one bar with automatic filter cleaning. Outlet discharges were recorded at the beginning and each 32:64 up to 192 operating hours according to site conditions. Table 4 show engineering and hydraulic criteria for tested outlets.

2.2. Methods

2.2.1. Performance of outlets

Performance for different outlets, which PC and NPC outlets at flow rates 3.5, 54, 108 and 24 L/h for PC and 70 L/h for NPC was measured and calculated by using the following equations:

2.2.1.1. The flow rate

The flow rate was measured using the following equation (Melvyn, 1983).

$$Q = \frac{V}{T} \quad \text{... [1]}$$

where:

Q = The flow rate (L/h),
V = Water volume (L), and
T = Time of collecting water (h).

Table 2

Analysis of the total cations and anions and phosphorus in treated wastewater samples.

Parameter	Cairo tertiary treatments	Beni Suef secondary treatment	Luxor secondary treatment	None	Slight to moderate	Severe
pH	7.15	7.47	8.05	—	6.5 – 8.4	—
Electrical conductivity (EC), dS/m	0.919	3.96	3.15	< 0.7	0.7 - 3.0	> 3.0
Total dissolved solids (TDS), mg/L	558.16	2534.4	2016	< 450	450 - 2000	> 2000
Total suspended solids (TSS), mg/L	9.85	50.23	87.88	—	—	—
$Co3^-$, mg/L	0.00	0.00	0.00	–	–	–
$Hco3^-$, mg/L	179.95	488.00	421.20	< 91.50	91.50 – 518.50	>518.50
Cl^-, mg/L	152.31	834.25	633.50	< 106.50	106.50 - 350.00	> 350.00
$So4^-$, mg/L	93.60	388.80	295.80	—	—	—
Ca^{2+}, mg/L	63.60	184.00	118.30	—	—	—
Mg^{2+}, mg/L	25.20	84.00	95.00	—	—	—
Na^+, mg/L	81.20	526.01	512.90	< 69.00	69.00 – 207.00	> 207.00
K+, mg/L	15.32	20.72	32.70	–	–	–
p, mg/L	1.341	3.123	5.031	–	–	–

Table 3

Analysis of heavy metals in treated wastewater.

Parameter	Tertiary treatments	Beni Suef secondary treatment	Luxor secondary treatment	Max. Allowed Heavy Metals Mg/L
Al, mg/L	0.048	0.301	0.531	5.00
B, mg/L	0.062	0.082	0.055	-
Cr, mg/L	0.000	0.000	0.001	0.10
Fe, mg/L	0.137	0.219	0.226	5.00
Mn, mg/L	0.046	0.102	0.112	0.20
Ni, mg/L	0.024	0.051	0.034	0.20
Pb, mg/L	0.022	0.175	0.213	5.00
Zn, mg/L	0.013	0.181	0.142	2.00
Cu, mg/L	0.011	0.015	0.021	0.20
Co, mg/L	0.004	0.013	0.011	0.05
Cd, mg/L	0.000	0.001	0.003	0.01

Table 4

Engineering and hydraulic criteria for tested outlets

outlets type	Specifications
Pressure-compensating In-line outlet	Discharge rate 3.5 L/h, (0.5- 4 bar), self-flushing, area cross-section and 0.5 m spacing between the Outlets
Pressure-compensating On-line outlet	Discharge rate24 L/h, (0.5 - 4 bar), self-flushing, area cross-section
Local online outlet	Discharge rate about70 L/h, (1 - 3 bar), multi- outlets
High flow rate pressure-compensating outlet	Discharge rate about (0.9 L/m); (54 L/h); full circle, trickle pattern, (1.5- 6 bar) self-compensating
High flow rate pressure-compensating outlet	Discharge rate about (1.8 L/m); (108 L/h); full circle, trickle pattern, (1.5- 6 bar) self-compensating

2.2.1.2. *Average Outlet discharge* (Q_{avg})

$$Q_{avg} = \frac{\sum_{i=1}^{n} q_i}{N} \quad ... [2]$$

where: $\sum q_i$= the sum of the individual discharge in each lateral line, and
N= the number of outlets.

2.2.1.3. *Emission uniformity* (EU)

Emission uniformity is used to indicate performance for outlets. Values were calculated according to the following equation (Keller and Karmeli, 1974).

$$EU = 100\left(\frac{q_{min\ 1/4}}{\bar{q}}\right) \quad ... [3]$$

where: $q_{min\ 1/4}$= the mean rate of discharge of the lowest quarter of the field data of outlet discharge (L/h), and
$\bar{q}$ = the mean of all outlet discharge (L/h).

Table 5 describes the limits of EU for the different drip irrigation outlets (IA, 2005), AENRI-LOFTI-MASE (2002) and (El-Basha et al., 2019).

Table 5

Rating of EU for drip irrigation zones.

Type of zone	Excellent (%)	Very Good (%)	Good (%)	Fair (%)	Poor (%)
Micro Spray	80	70	60	50	40
Drip-standard	80	70	65	55	50
Pressure drip compen-sating	95	90	85	80	70

(IA, 2005), AENRI-LOFTI-MASE (2002) and (El-Basha et al., 2019).

2.2.1.4. *Clogging percent* (CP)

CP was calculated using equation (El-Berry et al., 2006)

$$CP = (1 - E) \times 100 \quad ... [4]$$

where: CP = Outlets clogging percent (%), and
E = Outlets efficiency (%).

2.2.1.5. *Outlet Efficiency* (E)

$$E = \left(\frac{q_u}{q_n}\right) \times 100 \quad ... [5]$$

where: E = outlet efficiency (%),
q_u= outlet discharge (L/h), and
qn = new outlet discharge.

2.2.1.6. *Coefficient of correlation* (R^2)

Correlation between measured and calculated data according to the following equation (Ellithy, 2002).

$$\text{Coefficient of correlation } (R^2) = \frac{\sum(x-\bar{x})(y-\bar{y})}{n.\sigma_x.\sigma_y} \quad ... [6]$$

where: R^2 = coefficient of correlation between two groups of data,
x = data number in the first group,
$\bar{x}, \bar{y}$ = average,
y = data number in the second group,
σ_x, σ_y = standard deviation, and
n = number of data.

3. Results and discussions

3.1. *At Cairo site*

3.1.1. *Outlets clogging percent* (CP)

Fig. 1 represents the effect of operating time on outlets CP using treated wastewater (tertiary treatment) in Cairo site. The results show that CP increases with operating time. The highest CP was 56.7% at a flow rate of 3.5 L/h and the lowest CP was 16.2% at a flow rate of 108 L/h after 96 operating hours. These results may be due to the fact that sedimentation increases inside narrow-slotted outlets.

3.1.2. *Outlets emission uniformity* (EU)

Fig. 2 illustrates the effect of operating time on outlets EU using treated wastewater (tertiary treatment) in Cairo site. The results show that EU decreases with operating time. The highest EU was 86.3% at a flow rate of 108 L/h and the lowest EU was 76.2% at a flow rate of 3.5 L/h after 96 operating hours. These results may be due to the increased CP with lower flow rate.

3.2. *At Beni Suef site*

Fig. 3 clarifies the effect of operating time on outlet CP and EU using treated wastewater (secondary treatment) in Beni Suef site. The results show that when outlet CP reached to 47.6% was EU 72.7% for localized irrigation system using PC outlets at flow rate 24 L/h after 192 operating hours, which is poor for EU according to IA (2005) rating, AENRI-LOFTI-MASE (2002) and El-Basha et al. (2019).

3.3. *At Luxor site*

Fig. 4 shows the effect of operating time on outlet CP and EU using treated wastewater (secondary treatment) in Luxor site. The results show that when outlet CP reached to 76.3% was EU 59.4% for localized irrigation system using NPC outlets at flow rate 70 L/h after 192 operating hours, which is fair for EU according to IA (2005) rating, AENRI-LOFTI-MASE (2002) and El-Basha et al. (2019).

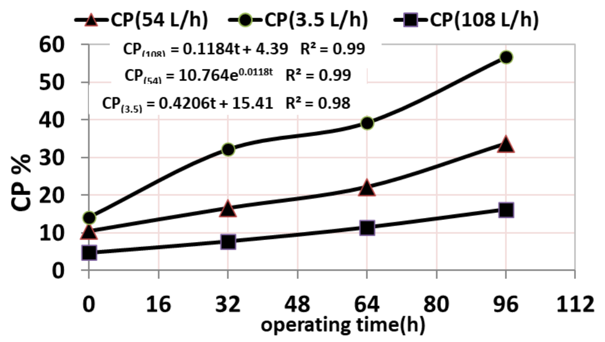

Fig. 1. Effect of operating time on CP of outlets at Cairo site.

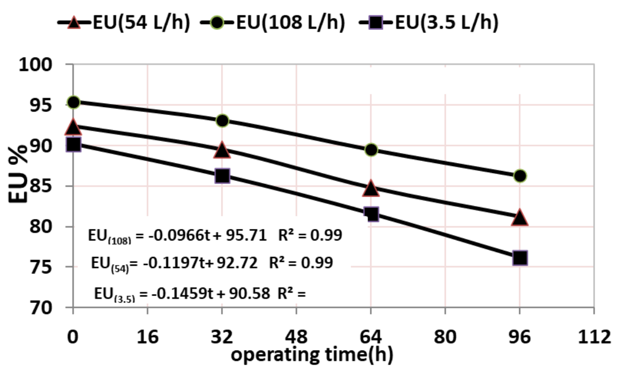

Fig. 2: Effect of operating time on EU of outlets at Cairo site.

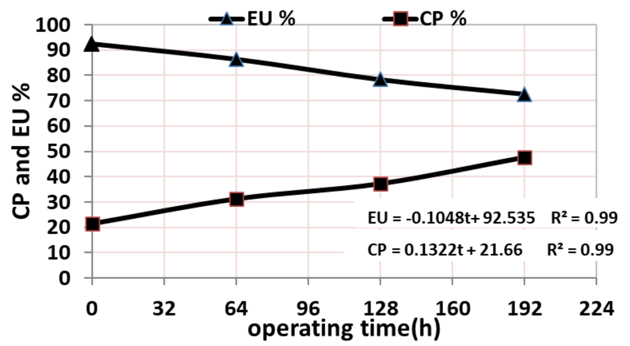

Fig. 3: Effect of operating time on high flow rate of outlet CP and EU at Beni Suef site.

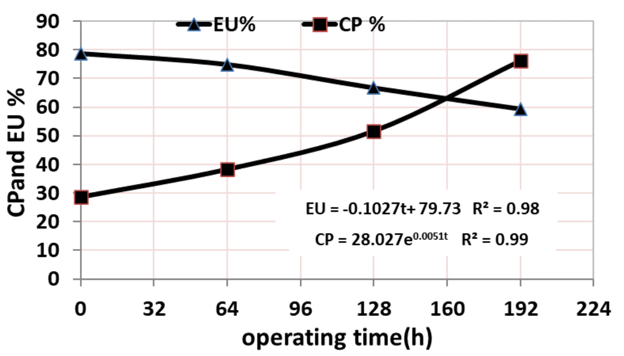

Fig. 4: Effect of operating time on high flow rate of outlet CP and EU at Luxor site.

3.4. Summarize the results of tested outlets at three sits (Cairo, Beni suef, Luxor) for localized irrigation system

Fig. 5 illustrate and summarize the results of tested outlets at three sits (Cairo, Beni Suef, Luxor) after operating time ranged from 96 to 192 operating hours according to site conditions using different treated wastewater (tertiaryand secondary treatment).

It is clear that the maximum of EU is 86.3% was recorded with the minimum of CP is 16.2% using outlet flow rate is 108 L/h after 96 operating hours at Cairo site, which is good according to IA (2005) rating, AENRI-LOFTI-MASE (2002) and El-Basha et al. (2019). That may be due to using treated wastewater (tertiary treatment) and high outlet flow rate.

Whereas it is clear that the maximum of CP is 76.3 % was recorded with the minimum of EU 59.4 % using outlet flow rate is 70 L/h after 192 operating hour at Luxor site, which is fair according to IA (2005) rating, AENRI-LOFTI-MASE (2002) and El-Basha et al. (2019). That may be due to low water treatment quality and filtration efficiency.

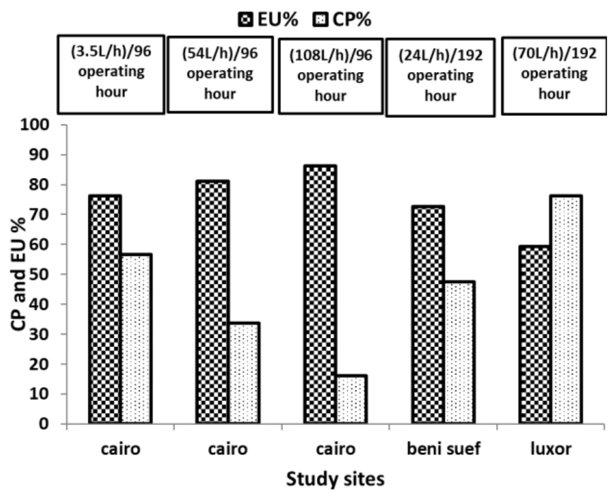

Fig. 5: Effect of using treated wastewater in different sites on outlets EU and CP.

4. Conclusions

The performance of the outlets of the localized irrigation system with treated wastewater for the Cairo, Beni Suef and Luxor sites was evaluated by measuring the application uniformity and the clogging percent according to the conditions of each site.

- At the Cairo site (tertiary treatment and PC outlets) decrease CP and increase EU at increasing the flow rate, so it is recommended to use a high-flow bubbler irrigation system or sprinkler irrigation.

- At the Beni Suef and Luxor sites (secondary treatments and PC and NPC respectively) the type of outlets had the greatest and most effective effect since the flow rate 70 L/h at Luxor, while it 24 L/h at Luxor, however CP is much higher than at Beni Suef.

Therefore, it is recommended to use PC outlets in the localized irrigation system, as well as continuous maintenance of the filters.

- The study recommended to avoid using treated wastewater with drip irrigation system with treated wastewater, due to increase CP with advanced operating time that affect directly on EU and irrigation efficiency to unacceptable rating.

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آداء مخارج نظام الري الموضعي بمياه الصرف المعالج

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الملخص العربي

نفذت الدراسة لتقييم آداء مخارج نظام ري موضعي (تنقيط وفوار) بتصرفات (تصل إلى ١٠٨ لتر/س) باستخدام مياه الصرف المعالج. تمت الدراسة فى ثلاثة مواقع وهى القاهرة وبنى سويف والأقصر خلال عامي ٢٠٢١م و ٢٠٢٢م باستخدام مخارج منظمة للضغط (القاهرة وبنى سويف) وغير منظمة للضغط (الأقصر). تم دراسة الآداء الفعلى للمخارج عن طريق قياس الانتظامية ونسبة الانسداد. **وأظهرت النتائج ما يلي:**

- **فى موقع القاهرة**

النسبة المئوية للانتظامية والانسداد كانت (٧٦,٢ – ٥٦,٧ %) و (٧٨,٢ – ٣٣,٧ %) و(٨١,٦ – ١٦,٢ %) لمعدل تصرفات مخارج منظمة للضغط (٣,٥ – ٥٦ – ١٠٨ لتر/س) على الترتيب بعد زمن تشغيل ٩٦ ساعة باستخدام مياه الصرف المعالج.

- **في موقع بني سويف**

النسبة المئوية للإتظامية والانسداد كانت (٧٢,٧ – ٤٧,٦ %) لمعدل تصرف مخرج منظم للضغط (٧٠ لتر/س) بعد زمن تشغيل ١٩٢ ساعة باستخدام مياه الصرف المعالج.

- **في موقع الأقصر**

النسبة المئوية للانتظامية والانسداد كانت (٥٩,٤ – ٧٦,٣ %) لمعدل تصرف مخرج غير منظم للضغط (٧٠ لتر/س) بعد زمن تشغيل ١٩٢ ساعة باستخدام مياه الصرف المعالج.

خلصت الدراسة إلى أن استخدام مياه الصرف المعالج لنظام الري الموضعي بمخارج منخفضة أو عالية التصرف يؤدي إلى انسداد المخارج مع زيادة زمن التشغيل مما يؤدي إلى انخفاض انتظامية الإضافة، لذا توصى الدراسة باستخدام مخارج منظمة للضغط بمعدل تصرف لا يقل عن ١٠٨ لتر/س فى حالات الضرورة.