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Effect of Long Term Irrigation with Primary-Treated Wastewater on some Soil Proprieties

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ABSTRACT

Irrigation of Abu-Rawash area, Giza, Egypt with primary-treated wastewater for 50 years caused accumulation of heavy metals. The area was divided into the following 5 different categories according to the duration period of irrigation 0, 10, 20, 25 and 50 years. Analysis of available N, P, K, Cu, Zn, Fe and Mn nutrients and Pb, Ni, Mo, Cd, and B heavy metals were done on soil samples from layers of 0-30, 30-50 and 50-100-cm. Salinity was highest in the uncultivated soil than in the cultivated ones. With increase of years of cultivation, the contents of nutrients and elements were greater. The contents of nutrients and elements in the surface exceeded those of the subsurface. Ranges of available contents of elements (mg kg^{-1}) in the top soil layer were 8 – 456.7(N), 5.5 - 138(P), 88 - 1190(K), 1.5 -16(Cu), 4 - 18(Zn), 4.7 – 80.6(Fe), 0.08-0.54(B), and 2 - 30(Mn). Respective ranges in the deepest layer were 1.6 – 16.9(N), 2.9 – 46.52(P), 27 – 83.6(K), 0.7 – 1.3(Cu), 1.3 -5.5(Zn), 1.9 – 18.24(Fe), 0.05-0. 08(B) and 0.9 – 4.8(Mn). After 50 years of irrigation with wastewater heavy metals of Pb, Ni, Mo, and Cd in the top layer showed a descending order with values of 10.81>2.22>0.23>0.16 respectively. In the deepest layers the contents were 0.29>0.05.> 0.00=0.00, respectively.

Keywords: irrigation - wastewater – soil heavy metals – macro and micronutrients.

INTRODUCTION

World population is expected to reach eight Billion by 2030 (Morrison *et al*., 2009). Rapid industrial and agriculture development is required to cope with such population growth, which indicates more water for irrigation since agriculture is largest water consumer using 70% of it (Van-der-Hook *et al*., ., 2002, FAO, 2013). Scarcity of water particularly in arid and semi-arid regions is attributed to one or more of the followings: climate change, ground water depletion, improvement of living standards and ill distribution of surface water and rain (Shiklomanov, 1993; Konikow and Eloise, 2005; FAO, 2012). As a result, some un-conventional water resources such as wastewaters are used for irrigation (Scott *et al*., 2004; Pedrero *et al*., 2010; Yao *et al*., 2013; Jeong *et al*., 2016). About 10 % of world population use waste waters for irrigation (WHO, 2006; Kauser, 2007). Such waters may be refuses of industrial, commercial and domestic sources (Eriksson *et al*.,2002 and Becerra-Castro *et al*., 2015). Treating wastewaters can be done by one or more of the following treatments: primary, secondary and tertiary (advanced). Wastewaters may be used without pre-treatments or after partial or full pre-treatments depending on the cost and the degree of pollution (Abegunrin *et al*., 2016; Zhang *et al*., 2016). Wastewaters are reused either directly for irrigation without mixing with fresh water, or indirectly after mixing with fresh water, most waste waters are discharged to water streams (Jeong *et al*., 2016).

Due to their contents of useful substances including plant nutrients, wastewaters can improve soil fertility when used for irrigation, with positive results and increased crop yields (Ensink *et al*., 2004; Mohammad and Ayadi, 2004; Abegunrin *et al*., 2016). On the other hand, they may contain hazardous materials which render them potential pollutant sources. Hazardous materials and substances in wastewaters include pathogens and heavy metals, which pollute and degrade arable lands (Ensink *et al*., 2004; Shuvillin *et al*., 2010; Christou *et al*., 2014). Pollution of soil with heavy metals due to irrigation with wastewaters depends on their contents of hazardous substances and the duration of their use. Petousi *et al*., (2015) reported that irrigating soil with wastewaters for less than 3 years had little negative effects on soil quality although some accumulation of heavy metals in soil may occur; however, their use for 10 years can cause marked heavy metal accumulation. Rusan *et al*., (2007) noted that the soil was not polluted with Cd and Pb despite being irrigated for a long time with wastewaters having low content of such metals. On the other hand, Klay *et al*., (2010) reported accumulation of Pb to hazardous levels in soil following 14 years of irrigation with wastewater of high Pb content.

In many areas of Egypt, wastewaters are totally or occasionally used for irrigation. The aim of the current study is to assess the effect of irrigation with primary-treated wastewater for different periods of years on some soil properties.

MATERIALS AND METHODS

Area of study:

The Abou-Rawash wastewater-treatment plant (Giza governorate, Egypt; 30^o 07´N, 31 ^{o}08´E) discharges 1.2 Mm^3 day^{-1} of primary-treated wastewater The water is transferred to the Barakat drain then to the Nile River. Climate of the area is hot dry arid in summer and humid cold with very few rainfalls (< 10 mm $year^{-1}$) in winter (El-Ramady *et al*., 2013). The area chosen for the study is a land having a soil having a "sand texture" (95.3 % sand, 3.4%silt, and 1.3%clay), divided into the following 5 different categories according to the duration period of primary-treated wastewater irrigation: 0, 10, 20, 25 and 50 years. Soil profile ditches were dug in each category. The zero duration period (un-irrigated) category consisted of a barren uncultivated land, while the other irrigated categories are lands of timber woods (i.e. under timber trees).

Soil and water analysis:

Soil samples were taken from the 3 layers of 0-30, 30-50, and 50-100 cm in each profile, air-dried then sieved through a 2-mm sieve and kept for analyses. For each soil layer, 3 sub-samples were taken then mixed to one sample. Electrical conductivity (EC), pH and soluble ions were measured in the irrigation water as well as in the soil paste extract. Available N, P, K, Fe, Mn, Cu, Zn, B, and Mo in soil were determined (Page *et al*., 1982) in the soil. Heavy metals were extracted from soil by 0.005 M DTPA (Lindsay and Norvell 1978). Measurement of micronutrients and heavy metals was done using

Inductively Coupled Plasma Optical Emission Spectrometer (Teledyne Leeman ICP-OES model, USA). Samples of wastewater were taken each three months during the year for analysis (four samples). Properties the wastewater is shown in Table 1.

Weighted Mean(WM):

A mean where some values, like nutrient content in different layers, contribute more than others.

$$WM = \sum WX / \sum W$$

where: X represents the values (nutrient content for example) and W represents weight of the value (layer thickness for example).

which means:

$$WM= \frac{W1X1+W2X2+\cdots+WnXn}{W1+W2+\cdots+Wn}$$

Table 1. Salinity, pH, soluble ions and soluble elements in the AboRawash primary-treated wastewater used for irrigation of the soil.

EC (dS m^{-1})	pH	Soluble ions mml$_c$ L^{-1}									
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}			
0.98	7.55	3.2	3.0	3.1	0.43	5.5	3.0	1.23			
Soluble elements (mg L^{-1})*											
N	P	K	Zn	Mn	Cu	Fe	B	Pb	Ni	Mo	Cd
mg L^{-1}											
29.6	2.50	16.8	nd	nd	nd	0.255	0.317	0.016	0.004	0.019	0.003

nd: not detected

RESULTS AND DISCUSSION

Soil salinity:

Soil salinity was highest in soil of 0 irrigation “represented by a barren soil in the area” (Table 3), with weighed mean of EC within the 100-cm soil depth of 4.57 dS m^{-1} (Table 3). The EC value for the irrigated soils ranged between 0.66 and 1.17 dS m^{-1} (Table3). Thus the decrease in soil salinity occurred due to irrigation ranging from 74.4 to 85.5% indicating a direct positive effect due to irrigation. The highest decrease occurred following 10 years of irrigation, and the lowest was in soils irrigated for 25 to 50 years. The comparatively greater decrease in the 10-year cultivated soil than the 25 to 50-year ones may indicate a comparatively intensive irrigation of the former soil than the latter. Herrero and Pérez-Coveta, (2005) stated that increasing time of irrigation (period of 24 years) soil salinity decreased. The pattern of change with depth (Table 2) shows an increase with depth in the barren soil, but a decrease with depth in the irrigated ones. Although the overall high salinity of the barren uncultivated soil is a manifestation of the aridity of the region (El-Ramady *et al*., 2013); the little rainfall falling on it may have translocated some soluble salts to its deeper layers causing increased salinity with depth. In the irrigated soil the decrease with depth is most probably a result of upward translocation of salinity which must have occurred in between spells of irrigation. In all soils, nearly all soluble ions followed a pattern of increase with depth, rather similar to that of salinity. Only soluble SO_4^{2-} showed a decrease with depth exhibiting more SO_4^{2-} ions on the surface than in the subsurface. This may indicate formation of $CaSO_4$ in the upper soil layers than the lower ones. Soluble ion contents (weighed means) along the 100-cm depth, shows a general pattern of decrease with the increase of years of irrigation notably after 10 years. In some cases, there was an increase in ion contents.Examples are: Ca, K, HCO_3, and Cl following 20 years of irrigation; Ca, Mg, Na, K, and SO_4 following 25 years of irrigation and Na, K, HCO_3, and Cl following 50 years of irrigation. For the 20-year irrigation period, the percentage decrease in contents of the above-mentioned ions amounted to 78.1, 71.9, and 89.6 % for Ca, K, and Cl, respectively, as for HCO_3 the contents increased by 61.1%. For the 25-year irrigation, the percentage decrease was 72.7, 46.1, 91.7, 69.6, and 20.3% for Ca, Mg, Na, K, and SO_4, respectively. For the 50-year irrigation, the percentage decrease was 87.6, 60.7, and 86.8% for Na, K, and Cl, respectively, HCO_3 the contents increased by 132.9 %. Though the increase in HCO_3 ions ranged between 61 to 133% the concentration was very low. The increased irrigation had a very slight effect on soil pH; it ranged between 6.30 to 6.76.

Table 2. Effect of irrigation with wastewaters (primary-treated) on pH and salinity of the soil.

Years of irrigation	Depth (cm.)	pH	EC (dS m^{-1})	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{--}
				mmol$_c$ / L						
0	0-30	6.83	2.27	17.98	5.33	1.65	o.87	1.67	1.67	22.50
	30-50	6.76	4.18	21.51	8.64	16.38	1.34	2.46	32.48	12.93
	50-100	6.72	6.10	25.31	12.65	31.20	1.64	2.33	65.16	3.31
10	0-30	6.49	0.92	3.66	4.33	1.57	0.33	1.99	2.66	5.24
	30-50	6.59	0.84	5.00	4.33	1.13	0.31	2.00	7.33	1.44
	50-100	6.73	0.43	1.66	1.33	1.04	0.18	0.99	3.00	0.23
20	0-30	6.40	1.12	6.00	3.3	1.7	0.54	6.15	3.00	2.39
	30-50	6.70	0.64	3.00	2.90	0.78	0.24	2.30	3.00	1.62
	50-100	6.89	0.86	5.00	2.35	0.945	0.345	2.35	5.2	1.09
25	0-30	6.16	1.86	10.32	8.66	1.87	0.44	1.67	3.66	15.96
	30-50	6.52	0.97	5.00	4.66	1.65	0.51	1.33	2.66	7.83
	50-100	6.60	0.84	4.00	3.33	1.43	0.36	1.67	2.66	4.79
50	0-30	5.67	1.40	5.70	6.30	2.20	0.69	7.60	3.70	3.59
	30-50	6.26	1.30	3.30	5.00	4.20	0.54	3.00	10.00	0.04
	50-100	6.69	0.92	3.70	3.30	1.80	0.42	4.30	4.30	0.62

Table 3. Effect of irrigation with wastewaters (primary-treated) on pH and salinity of soil (weighed means).

Years of irrigation	pH	EC ($dS\ m^{-1}$)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	SO_4^{--}
			mmol$_c$ L^{-1}						
0	6.76	4.57	22.35	9.65	19.37	1.35	2.16	39.58	10.99
10	6.63	0.66	2.93	2.83	1.22	0.25	1.49	3.76	1.98
20	6.71	0.89	4.90	2.75	1.139	0.38	3.48	4.10	1.59
25	6.45	1.17	6.10	5.20	1.61	0.41	1.60	2.96	8.75
50	6.30	1.14	4.22	4.54	2.40	0.53	5.03	5.26	1.40

Available N, P and K nutrients:

All available macro nutrients (weighed means) increased with the increase in years of irrigation (Table 4). The ranges of increase were 1.8 to 37.7 folds for N, 0.2 to 7.3 folds for K, and 1.9 to 18.5 folds for P. Simmons *et al.*, (2010) reported that Soil N and P increased with irrigation with waste water. The contents showed progressive decrease with depth. The surface layer contained the highest contents of nutrients whereas the deepest layer contained the lowest contents. Values of percentage decrease between the surface layer and the ones beneath, middle layer and the bottom one, were as follows for the 0-year irrigation (the barren soil) 61.3 and 76.3% for N, 10.9 and 63.6 for P, and 37.5 and 63.6 for K. Corresponding percentages for the 10-year irrigation were 44.6 and 54.3% for N, 41.4 and 72.4 for P, and 45.2 and 56.7 for K. Corresponding percentages for the 20-year irrigation decreases were 83.5 and 91.3 for N, 46.7 and 67.6 for P, and 65.3 and 70.3 for K. Decreases for the 25-year irrigation were 58.4 and 93.6 for N, 70.7 and 79.3 for P, and 74.1 and 81.3 for K and those for the 50-year irrigation were 92.8 and 95.5 for N, 3.9 and 71.0 for P, and 86.3 and 91.4 for K. The magnitudes of decrease with years of irrigation was more marked regarding N and K. Accumulation of nutrients in the top layer demonstrates the direct effect of irrigation with water containing high contents of elements including plant nutrients of NPK.

Table 4. Contents ($mg\ kg^{-1}$) of available N, P, and K in soil* as affected by irrigation with primary-treated wastewater.

Years of irrigation	Depth (cm)	N		P		K	
		content	WM**	content	WM**	content	WM**
0	0-30	8.0	4.0	5.5	4.5	88	53
	30-50	3.1		4.9		55	
	50-100	1.9		3.8		32	
10	0-30	17.5	11.2	29.0	16.1	104	65
	30-50	9.7		17.0		57	
	50-100	8.0		8.0		45	
20	0-30	49.6	18.7	22.5	12.8	202	104
	30-50	8.2		12.0		70	
	50-100	4.3		7.3		60	
25	0-30	84.1	35.0	92.0	42.5	320	143
	30-50	35.0		27.0		83	
	50-100	5.5		19.0		60	
50	0-30	456.7	153.9	138.0	87.9	1190	441
	30-50	32.8		132.6		163	
	50-100	20.7		40.0		102	

*: extraction solutions KCl for N, Na-bicarbonate for P and NH4-acetate for K. **WM: weighed mean along the 100-cm depth

Available micro nutrients:

In most cases, available micro nutrients (weighed means) increased with the increase in years of irrigation (Table 5). There was a decrease in Mn and Zn (11.9 and 31.0 % respectively) after 25 years of irrigation and in Fe (18.8%) after 50 years of irrigation. Ranges of increase were 2.6 to 9.8 folds for Fe, 3.1 to 6.7 folds for Mn, 0.5 to 31.9 folds for Zn and 0.5 to 4.7 folds for Cu. There was a progressive decrease with depth in all treatments, with the exception of two cases Mn in the 0-year irrigation and Cu in the 10-year irrigation where the contents in the surface and middle layers were similar. Values of percent decrease between the surface layer and both middle layer and the bottom layer were as follows: 21.3 and 48.9% for Fe, nil and 50.0 for Mn, 37.5 and 62.5 for Zn and 33.3 and 60.0 for Cu in the 0-year irrigation (the barren) soil. after 10 years of irrigation decrease was 6.9 and 12.2 for Fe, 20.0 and 70.0 for Mn, 46.1 and 69.2 for Zn and 0.0 and 50.0 for Cu; 58.3 and 80.4 for Fe, 25.0 and 50.0 for Mn, 16.7 and 41.7 for Zn and 60.0 and 80.0 for Cu after 20 years of irrigation; 50.2 and 60.8 for Fe, 50.0 and 87.5 for Mn, 33.3 and 83.3 for Zn and 50.0 and 87.5 for Cu after 25 years of irrigation; 15.3 and 91.8 for Fe, 73.3 and 93.3 for Mn, 61.1 and 77.8 for Zn and 87.5 and 93.8 for Cu after 50 years of irrigation. Considerable accumulation of nutrients in the top layer demonstrates the direct effect of irrigation with water containing high contents of elements. Singh *et al.*, (2012) reported that extractable Fe, Mn, Zn, Cu, Pb, Ni, and Cd increased due to irrigation with waste water.

Table 5. Contents (mg kg^{-1}) of available Zn, Mn, Cu, and Fe in soil as affected by irrigation with primary-treated wastewater.

Years of irrigation	Depth (cm)	Fe content	Fe WM**	Mn content	Mn WM**	Zn content	Zn WM**	Cu content	Cu WM**
0	0-30	4.7	3.4	2	1.5	4.0	2.5	2	1.3
	30-50	3.7		2		2.5		1	
	50-100	2.4		1		1.5		1	
10	0-30	13.1	12.1	10	6.1	6.5	3.7	2	1.5
	30-50	12.2		8		3.5		2	
	50-100	11.5		3		2.0		1	
20	0-30	33.6	16.2	12	8.4	12.0	9.1	5	2.4
	30-50	14.0		9		10.0		2	
	50-100	6.6		6		7.0		1	
25	0-30	61.7	36.8	16	7.4	12	6.2	8	3.7
	30-50	30.7		8		8		4	
	50-100	24.2		2		2		1	
50	0-30	80.6	29.9	30	11.6	18	8.8	16	5.7
	30-50	12.3		8		7		2	
	50-100	6.6		2		4		1	

Extractable (Available) Heavy metals and Boron:

Contents of Pb, Ni, Mo, Cd, and B were below the permissible limits. Extractable Pb and Ni (weighted means) increased with the increase in years of irrigation (Table 6). The ranges of increase were 0.9 to 21.1 folds for Pb, 29.3 to 236.3 folds for Ni. The increase in Mo occurred after 20 years of irrigation and the increase after 50 years of irrigation was 10.5 folds. The first 20 years of irrigation had nearly no effect on available Cd and B then increased with time of irrigation reaching 15 folds for Cd and 2.3 folds for B after 50 years of irrigation. The contents showed a progressive decrease with depth in Pb and Ni. Percent decrease between the surface layer and both the middle one and bottom layer were as follows: in the barren soil decrease was 36.0 and 56.0 for Pb. There was no Ni in the middle and bottom layers in the barren soil. In the 10-year irrigation soil decreases were 9.3 and 53.4 for Pb, 66.7 and 72.2 for Ni. In the 20-years irrigation decreases were 90.4 and 92.3 for Pb, and 87.8 and 95.1 for Ni. In the 25-year irrigation decreases were 88.1 and 91.0 for Pb, and 51.0 and 86.5 for Ni. In the 50-year irrigation decrease were 94.9 and 96.7 for Pb, and 91.9 and 99.1 for Ni. As regards changes in Mo with depth, there was no available Mo in all soil layers for the 0 and 10-year irrigation soil. For the 20-year and the 50-year irrigation, there were traces only in the surface layer and none in the sub-layers. Concerning Cd there were traces in the top layer and none in the underlying layers for soils irrigated up to 20 years, but for the 25- and 50-year irrigation, both of the two upper layers contained traces of Cd (slightly relatively more in the 50-year).Available boron slightly increases with the increase in years of irrigation. There was a tendency to decrease with depth.

The increase in contents of extractable Mo, Cd, Pb, and B in the soil which occurred with the increase in years of irrigation with waste water. This indicates pollution resulting from the use of such water. However, the relatively lower available contents of such elements than their permissible limits may indicate conversion into insoluble forms. Petousi *et al*., (2015) stated that irrigating soil with wastewaters for 10 years may lead to heavy metal accumulation.

Table 6. Available Pb, Ni, Mo, Cd, and B in soil irrigated by primary-treated wastewater (mg kg^{-1}) related to permissible limits

Years of irrigation	MP limit*	Pb 17.183		Ni 12.252		Mo n.i**		Cd 2.250		B 8.000	
	Contents (mg kg^{-1})										
	Depth (cm)	content	(WM)	content	(WM)	content	(WM)	content	(WM)	content	(WM)
0	0-30	0.25	0.16	0.01	0.003	0.00	0	0.01	0.003	0.09	0.076
	30-50	0.16		0.00		0.00		0.00		0.07	
	50-100	0.11		0.00		0.00		0.00		0.07	
10	0-30	0.43	0.31	0.18	0.091	0.00	0	0.01	0.003	0.09	0.08
	30-50	0.39		0.06		0.00		0.00		0.09	
	50-100	0.20		0.05		0.00		0.00		0.07	
20	0-30	2.71	0.97	0.41	0.143	0.02	0.006	0.01	0.003	0.08	0.073
	30-50	0.27		0.05		0.00		0.00		0.07	
	50-100	0.21		0.02		0.00		0.00		0.07	
25	0-30	3.35	1.24	1.04	0.484	0.10	0.033	0.02	0.008	0.11	0.096
	30-50	0.40		0.51		0.00		0.01		0.09	
	50-100	0.30		0.14		0.00		0.00		0.09	
50	0-30	10.81	3.53	2.22	0.712	0.23	0.069	0.16	0.048	0.54	0.240
	30-50	0.55		0.18		0.00		0.00		0.14	
	50-100	0.36		0.02		0.00		0.00		0.10	

*** Maximum permissible limit for heavy metals (mg kg^{-1}) using NH_4-acetate, pH 4.8 (Grubinger and Ross 2011); Severson and Gough (1983) for boron. ** not identified. WM: weighed mean.**

CONCLUSION

The effect of irrigation with wastewater on soil properties depends on its contents either inorganic (nutrients and heavy metals) or organic, longer irrigation time leads to accumulation of nutrients, salts, and heavy metals. When using such waters, it is recommended to test both waste water and soil regularly, also taking in consideration the type of grown plant

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تاثير الرى لفترة طويلة بمياة الصرف المعالجة اوليا على بعض خواص التربة.

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الرى في منطقة ابورواش ، محافظة الجيزة، مصر بمياه الصرف المعالجة اوليا لمدة خمسون عاما أدى لتجمع للعناصر الثقيلة. تم تقسيم منطقة الدراسة الى خمس قطاعات على حسب الرى بمياة الصرف المعالجة الى صفر (ارض بور غير مروية) ،10،20،25،50 عاما. قدرت الصورة الميسرة من العناصر المغذية التالية N, P, K, Cu, Zn, Fe, Mn, B و من العناصر الثقيلة Pb, Ni, Mo, Cd في عينات تربة من طبقات تربة : صفر-30 سم ، 30-50 سم ، 50-100 سم. كانت الملوحة اعلى ما يكون فى الأرض غير المزروعة (المروية) مقارنة مع الاراضى المزروعة (المروية) مع زيادة أعوام الزراعة (الرى) زاد المحتوى من العناصر (المغذية و الثقيلة). المحتوى من العناصر (مغذية وثقيلة) زاد في سطح التربة عنة في الطبقات التحت سطحية. محتوى العناصر الميسر (مليجرام/كجم) في الطبقة السطحية للتربة كان 456.7-8 (N)، 138-5.5 (P)، 1190-88 (K)، 16-1.5 (Cu)، 18-4 (Zn)، 80.6-4.7 (Fe)، 0.54-0.08 (B)، 30-2 (Mn). القيم المماثلة في الطبقات التحت سطحية كانت 16.9-1.6 (N)، 46.5-29 (P)، 83.6-27 (K)، 1.3-0.7 (Cu)، 5.5-1.3 (Zn)، 18.2-1.9 (Fe)، 0.08-0.05 (B)، 4.8-0.9 (Mn). بعد 50 عام من الرى بمياة الصرف المعالجة كان ترتيب العناصر الثقيلة مرتبة تنازليا كما يلى Pb>Ni>Mo>Cd في الطبقة السطحية و التحت سطحية و كانت التركيزات (مليجرام/كجم) كما يلى : 10.81>2.22>0.23>0.16 في الطبقة السطحية، 0.29>0.05>0.00=0.00 في الطبقة التحت سطحية.