Egypt. J. Soil Sci. 47, No.4, pp. 335 - 346 (2007)

Bioremediation of Contaminated Water with Heavy Metals

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THE CURRENT study represents a trial towards ameliorating waters polluted with some heavy metals (Ni, Co and Cd) due to human & industrial activities. To achieve this target, an experimental lab medium was conducted on two wastewater samples collected from the sewage effluent of El-Gabal El-Asfar station and the industrial wastewater at El-Saff area. These wastewater samples were inoculated with different algae species, *i.e.*, *Scenedesmus obliquus* , *Chlorella vulgaris* and *Spirulina plantensis* algae at 28 ± $2C^0$ under light of 4000 lux intensity (14 hr light followed by 10 hr darkness) for various periods of 7, 15 and 21 days.

The obtained results could be summarized in the following:-

- Bioremediation with algae significantly reduced Ni, Co and Cd concentrations in the studied wastewaters.
- The tested algae species could be arranged according to their mean values of removal efficiency of Ni in the following descending order: *Scenedesmus* > *Chlorella* > *Spirulina,* while the corresponding sequence for Co and Cd was: *Chlorella* > *Scenedesmus* > *Spirulina.*
- * The efficiency index of algae regardless of its species on removing Ni from the studied wastewaters was usefulness as compared to Co and Cd.

Keywords: Bioremediation, Algae, Heavy metals, Wastewaters.

Various synthetic and natural pollutants such as pesticides, polyaromatic hydrocarbons have caused imbalance in the natural functioning of the ecosystem. Among these materials, heavy metals cause severe damage for the living systems at various levels. On the other hand, algae have been proved to play an important role in purification and removal of metals from wastewater. The presence of heavy metals in the environment is partially due to natural processes, but is mostly the result of industrial waste (Mansour & Sidky, 2002).

The Main sources of heavy metal contamination are: 1) Urban industrial aerosols, created by combustion of fuels, metal ore, refining and other industrial processes, 2) Liquid and solid wastes generated from animals and humans, 3) Mining activities and 4) Industrial and agricultural chemicals.

Recently, the research for heavy metals removal has focused on new technologies rather than traditional methods such as ion exchange, chemical

precipitation, membrane process and solvent extraction, which are expensive and inefficient .These draw backs of traditional metal removal techniques have lead researchers to the investigation of the use of microbial biomass as biosorbents for heavy metals. In related studies, metal removal abilities of live cells of various species of bacteria, algae, fungi and yeast have been investigated with a great interest on the nature and mechanisms of metal microorganisms interaction of metal removal (Khodair , 1998). Since a few years tremendous growth in the field of "Biotechnology" is overruling chemical technologies used for pollution abatement. As alternatives, slowly, biological tools are being substituted in pollution abatement programs. This new technology has been loosely grouped together under the term "Bioremediation".

Bioremediation refers to the use of microorganisms in removal of hazardous toxic pollutants from soil and wastewaters. One of these is algae which can use for water purification and remove heavy metals (Norberg & Persson, 1984). Algae have been proved to play an important role in purification and removal of trace elements from wastewater. Biological decontamination of heavy metals in wastewater and in soils is a new branch of science which helps us to solve pollution problems without adding new problems or new pollutants. Biological decontamination of heavy metals in wastewater and in soils is a new branch of science which helps us to solve pollution problems without adding new problems or new pollutants. The use of microorganisms in removal of hazardous toxic pollutants from soil and ground water is a good way. So that, many authors found valuable to study the role of microbial biomass to remove these heavy metals. Microorganisms can accumulate heavy metals from external environment (Brierley, 1990 and Avery *et al.*,1991).

The response of algae cells to metal exposure is essential to determining the viability of biological treatment (Terry & Stone, 2002). Algae have a principal role in the disappearance and degradation of environmental contaminants , where they are a fundamental component in the aquatic ecosystem (Rachlin *et al.*, 1983). Also the algae have a vital role for transforming sewage and wastewater into valuable bio-mass and treated water can be used for irrigation. They remove elements from the wastewater which can be reused (Shelef *et al.*,1978 and 1980).

Microorganisms can accumulate heavy metals from external environment (Brierley, 1990 and Avery *et al* .,1991). Mahfouz (1989) mentioned that the problems of heavy metals in waste-water, particularly from certain industries , could be solved by growing species algae on such waste-water. Moreover, heavy metals are concentrated in the algae cells, after harvesting the biomass, the resulted water has the permissible limits of heavy metals for irrigation or any suitable domestic use.

In aquatic environment , algae play an important role as removes of some polluting agents such as zinc, copper, cadmium and lead (Fayed *et al.*,1983). Sonose (1997) showed that heavy metals removal percentages after incubation

period were 73.9 % for Fe, 100% for Mn , 32.5% for Zn, 44.3% for Ni and 10% for Co in case of *Chlorella ellipsodea"*, but in case of *Scenedesmus dimorphus* the removal percentages were 68.8% for Fe, 69.65 for Mn, 71.45 for Zn , 44.3% for Ni and 33.8% for Co. Shafik (1998) reported that *Scenedesmus obliquus and Chlorella vulgaris* were more effective to remove Cd, Mn and Pb and decrease Ni from effluent than *Spirulina platensis* or a mixture of them. Ali (2005) showed that *Scenedesmus obliquus* and *Chlorella vulgaris* were more effective than *Spirulina platensis* or a mixture of them, for natural purification of wastewater from heavy metals.

There are five major mechanisms by which the micro-organisms may interact with metals as follows: 1) The metal is bound to the surface of the organism, 2) The metal may be taken up into the cell, 3) An oxidation-reduction which may cause solubilization and /or precipitation of metal, 4) The metal may be complexed and kept in a soluble or transferred across the cell membrane and 5) Certain metals are biochemically transformed by cell which keeps the toxic elements at low level (Olsen & Kelly, 1986).

The current study deals with identifying the effect of different algae species on removing some metal ions from two kinds of wastewater, *i.e.,* sewage effluent and industrial wastewater.

Material and Methods

Material

Two pure strains of green algae (*i.e., Scenedesmus obliquus* and *Chlorella vulgaris*) as well as one pure strain of blue green algae (*i.e., Spirulina platensis*) were obtained from Agric. Microbial Dept., Soils, Water and Environ. Res. Inst., ARC. On the other hand, wastewater samples were collected from sewage effluent at El-Gabal El-Asfar station and industrial wastewater at El-Saff, filtered and pasteurized by heating to 60°C and cooled to 4°C and heated again to 60°C to avoid any break of any matter . The experiment was carried out on 500 ml Erlenmyer flasks , each containing 250 ml wastewater sample inoculated with either one or the three selected algae strains. The inoculated Erlenmyer flasks as well as the control ones were incubated at 28-30°C under light of 4000 lux intensity from fluorescent tubes at light cycle of 14 hr light followed by 10 hr darkness.

The inoculated wastewater samples beside of the control were induplicated and divided into three groups. Incubation periods of these groups were 7, 15 and 21 days. Heavy metals (Cd, Ni and Co) were determined before and after inoculation by Atomic Absorption Spectro-photometer Perkin Elmer (Model, 2380) (Table1).

Chemical analysis

- Water pH was determined by using a glass electrode according to the procedure described by Page *et al.* (1982).

- Electrical conductivity (EC_{iw}) and soluble ions were determined according to the methods outlined by Jackson (1973).
- Heavy metals Ni, Co and Cd were measured with an Atomic Absorption Spectrophotometer, Perkin Elmer (Model 2380).

TABLE 1. Some chemical properties of the investigated wastewaters.

Water characteristics	El-Gabal El-Asfar	El-Saff
pH	6.78	7.8
EC (dS /m)	1.3	1.1
Soluble cations ($mmol_c\ L^{-1}$)		
Ca^{2+}	4.71	4.48
Mg^{2+}	0.91	0.87
Na^{+}	6.92	4.48
K^{+}	0.46	0.37
Soluble anions ($mmol_c\ L^{-1}$)		
CO_3^{2-}	----	---
HCO^{-}_3	3.60	2.58
Cl^{-}	5.97	5.25
SO_4^{2-}	3.43	2.37
SAR	4.13	2.74
Adj. SAR	9.08	5.48
RSC	-	-
B ($mg\ L^{-1}$)	0.345	0.090
Heavy metals ($mg\ L^{-1}$)		
Cd	0.086	0.043
Co	0.235	0.191
Ni	0.350	0.218

Results and Disscusion

Effect of applied algae species on removing Cd, Co and Ni metals

The accumulation of heavy metals by algae in laboratory medium has been in the focus of numerous studies.

Cadmium

Cadmium (Cd) is a toxic heavy metal, and it represents a contaminant mainly of aquatic ecosystems. It has many industrial uses such as in Cd batteries, anti-corrosive coating of metals, pigments, and stabilizers for plastic (Stoeppler, 1991).

Data in Tables 2 & 3 show the values of residual content (RC), removed amount (RA) of heavy metals (µg /L) and removal percentage of metals (RP) of wastewater of El-Gabal El-Asfar and El-Saff treated with algae during different incubation periods. The removed amounts percentages of Cd by algae during the studied different incubation periods , *i.e.,* 7, 15 and 21 days were 27.00, 95.00 and 85.00 % for *Chlorella* ; 29.00, 94.00 and 83.00 % for *Scenedesmus* and 18.00, 85.00 and 80.00% for *Spirulina*, respectively. The corresponding amounts percentage of El-Saff wastewater were 25.00, 91.80 and 79.00 % for Chlorella, 23.00, 90.00 and 81.00 % for *Scenedesmus* and 22.00, 87.00 and 80.00 % for *Spirulina*, respectively. These findings are emphasized by Ross (1980) who reported that algae spices can be used for removal of heavy metals from industrial- waste solutions. It is worthy to mention that the minimum removed value of Cd from water media (15.48 µg/L) was recorded at the first period by *Spirulina*, while the maximum one (81.7 µg/L) was recorded by *Chlorella* at the second incubation period for El-Gabal El-Asfar wastewater . This means that the efficiencies of *Chlorella vulgaris* and *Scenedesmus oblique* for removing cadmium from water media were more higher than that of *Spirulina platensis.* These results are in agreement with those found by Shafik (1998) .

The means of removed amounts (RA) of Cd along the incubation periods were 59.34 µg/L for *Chlorella vulgaris*, 59.05 µg/L for *Scenedesmus obliquus* and 52.67 µg/L for *Spirulina platensis,* for El Gabal El Asfar sewage effluent *vs* 65.27, 64.67 and 62 .23 µg/L ,respectively for El-Saff wastewater.

The mean values of the removal percentage of cadmium along the different incubation periods were 69.00, 67.00 and 53.67 % for *Chlorella*, *Scenedesmus* and *Spirulina*, respectively. In other words the used algae species could be arranged according to their efficiency in decreasing Cd concentration in El-Gabal El-Asfar wastewater in the following descending order: *Chlorella* > *Scenedesmus*> *Spirulina.* These results are in agreement with those obtained by Filip *et al.* (1979) who found that, *Scenedesmus obliquus* and *Chlorella vulgaris* were more effective for removing Cd from sewage effluent than *Spirulina platensis.* Similar trend was obtained in case of El-Saff wastewater.

The obtained results showed that the 15-days incubation period was the most suitable incubation period for the studied algae to reduce Cd content in the studied two wastewaters. The results show that within this period, *Chlorella vulgaris. Scenedesmus obliquus* and *Spirulina plantensis* could remove 91.8, 90.0 & 87.0 % for El-Saff and 95, 94 & 85 % for El-Gabal El-Asfar wastewaters from the initial concentration of Cd. These results are in agreement with those obtained by Filip *et al.* (1979), who demonstrated that the algal flora native could remove 70-90 % of the Cd from the wastewater. A similar trend was noticed for the behavior of heavy metals removing by using algae species in the aquatic media of El-Saff with different values for the tested heavy metals.

The aforementioned results reveal that *Scenedesmus obliquus* and *Chlorella vulgaris* were more effective for removing Cd from wastewater of El–Gabal El–Asfar (pH 6.78) than El–Saff wastewater (pH 7.8). These findings are emphasized by Todorova & Koleva (1973) who mentioned that the highest growth of Chlorella vulgaris was detected at pH 7. Also, Lee & Tay (1991) reported that the best pH for Chlorella pyreyoidosa growth media is 7.0.

Also , it is noticed that *Spirulina* was more effective for removing Cd from El–Saff wastewater than El-Gabal El-Asfar wastewater ; this may be due to the ability of *Spirulina* to grow better at the relatively higher pH values. This finding stands in well agreement with those of Torzillo *et al.* (1991) and Wilde *et al.* (1993) who reported that *Spirulina* grow best at the relatively high pH media.

TABLE 2. Effect of applied algae species on removing Cd, Co and Ni metals from El-Gabal El-Asfar wastewater.

Periods (day)	Status	El-Gabal E-Asfar wastewater experiment								
		Chlorella			Scenedesmus			Spirulina		
		Cd	Co	Ni	Cd	Co	Ni	Cd	Co	Ni
0	(IC) µg/L	86.0	235.0	350.0	86.0	235.0	350.0	86.0	235.0	350.0
7	(RC) µg/L	62.8	157.5	266.0	61.1	162.2	276.5	70.5	195.1	259.0
	(RA) µg/L	23.2	77.6	84.0	24.9	72.9	73.5	15.5	40.0	91.0
	(RP) %	27.0	33.0	24.0	29.0	31.0	21.0	18.0	17.0	26.0
15	(RC) µg/L	4.3	10.1	98.0	5.2	14.3	87.5	12.9	36.9	126.0
	(RA) µg/L	81.7	224.9	252.0	80.8	220.7	262.5	73.1	198.1	224.0
	(RP) %	95.0	95.7	72.0	94.0	93.9	75.0	85.0	84.3	64.0
21	(RC) µg/L	12.9	21.2	105.0	14.6	16.5	98.0	17.2	49.4	129.5
	(RA) µg/L	73.1	213.9	245.0	71.4	218.6	252.0	68.8	185.7	220.5
	(RP) %	85.0	91.0	70.0	83.0	93.0	72.0	80.0	79.0	63.0
Mean	(RA) µg/L	59.3	172.1	193.7	59.1	170.7	196.0	52.5	141.2	178.5
	(RP) %	69.0	73.2	55.3	67.0	72.6	56.0	53.7	60.1	51.0

TABLE 3. Effect of applied algae species on removing Cd, Co and Ni metals from El-Saff wastewater.

Periods (day)	Status	El-Saff wastewater experiment								
		Chlorella			Scenedesmus			Spirulina		
		Cd	Co	Ni	Cd	Co	Ni	Cd	Co	Ni
0	(IC) µg/L	43.0	191.0	218.0	43.0	191.0	218.0	43.0	191.0	218.0
7	(RC) µg/L	32.3	135.6	167.9	33.1	132.6	170.0	34.4	139.4	157.0
	(RA) µg/L	10.8	55.4	50.1	9.9	58.4	48.0	8.6	51.6	61.0
	(RP) %	25.0	29.0	23.0	23.0	30.6	22.0	20.0	27.0	28.0
15	(RC) µg/L	3.5	13.2	64.3	4.3	18.0	57.3	5.6	22.7	69.5
	(RA) µg/L	39.5	177.8	153.7	38.7	173.0	160.7	37.4	168.3	148.5
	(RP) %	91.8	93.1	70.5	90.0	90.6	73.7	87.0	88.1	68.1
21	(RC) µg/L	9.0	18.7	67.6	8.2	19.1	73.0	8.6	34.4	48.0
	(RA) µg/L	34.0	172.3	150.4	34.8	171.9	145.0	34.4	156.6	170.0
	(RP) %	79.0	90.2	69.0	81.0	90.0	66.5	80.0	82.0	78.0
Mean	(RA) µg/L	28.1	135.2	118.1	27.8	134.5	117.9	26.8	125.5	126.5
	(RP) %	65.3	70.8	54.2	64.7	70.4	54.1	62.3	65.7	58.0

Cobalt

The results presented in Tables 2 & 3 show the residual content (RC), removed amount (RA) of Cobalt (µg /L) and removal percentage of Co (RP) from El-Gabal El-Asfar and El-Saff wastewaters treated with algae species during different incubation periods.

Data in Tables 2 & 3 reveal the removed amounts of Co from El-Gabal Al-Asfar wastewater by algae species during the different incubation periods , *i.e.*, 7, 15 and 21 days were 77.55, 244.90 and 213.85 (µg /L) for *Chlorella vulgaris*, 72.85, 220.67 and 218.55 (µg /L) for *Scenedesmus obliquus* and 39.25, 198.11 and 185.65 (µg /L) for *Spirulina platensis* , respectively .

The corresponding removal percentages of Co at the same previously mentioned periods of incubation were 33.00, 95.00 and 91.00 % for Chlorella, 31.00, 93.90 and 93 % for *Scenedesmus* and 17.00, 84.30 and 79.00 % for *Spirulina* , respectively.

The removed amounts of Co at all the incubation periods were relatively higher for *Chlorella vulgaris* and *Scenedesmus obliquus* than for *Spirulina plantensis*. From these results, it can be deduced that *Chlorella vulgaris* and *Scenedesmus obliquus* were more efficient in removing cobalt from media than *Spirulina platensis*. The highest removed percentages attained due to the studied algae species were shown at the second incubation period, *i.e.*, 15 days .

The minimum value of removed Co from media (39.95 µg/l) was associated with *Spirulina* in the first incubation period, while the maximum removed value of Co (224.90 µg/l) was obtained by *Chlorella* in the second incubation period of 15 days .

The mean values of the removal percentages of Co along the different incubation periods were 73.23, 72.63 and 60.10% for *Chlorella, Scenedesmus* and *Spirulina*, respectively. In other words, the studied algae species could be arranged according to their efficiencies in removing Co from El-Gabal El-Asfar waste-water in the following descending order: *Chlorella* (172.10 µg/L) > *Scenedesmus* (170.69 µg/L) > *Spirulina* (141.24 µg/L).

In El-Saff wastewater experiment, the amounts of Co removed by algae species during the incubation periods were 55.39, 177.82 and 172.28 µg/L for *Chlorella,* 58.45, 173.05 and 171.9 µg/L for *Scenedesmus*. The corresponding removed amounts with *Spirulina* were 51.57, 168.27 and 156.62 µg/L as compared to the initial concentration of Co (191.00 µg/L) .

The obtained results also showed that the 15-days incubation period was the more suitable period for *Chlorella* and *Scenedesmus* than the 7 and 21days. Data show that *Scenedesmus obliquus* and *Chlorella vulgaris* could remove 93.1 and 90.6 % from the initial concentrations of Co (191.00 µg/L) at the 15 days incubation period, while at the same period of incubation , *Spirulina platensis* could remove only 88.10 % of Cd from media.

It is worthy to note that the used algae species could be arranged according to their efficiencies in removing Co from El-Saff wastewater to the following descending order: *Chlorella* > *Scenedesmus* > *Spirulina*. This sequence seemed to be similar, to great extent, to that achieved for El-Gabal El-Asfar wastewater.

Nickel

The residual content (RC), removed amount (RA) of nickel (µg/L) and its removal percentage from wastewater of El-Gabal El-Asfar due to incubation experiment with algae species under different incubation periods are presented in Tables 2 & 3.

The residual amounts of Ni at the first, second and third periods of incubation were 266.00, 98.0 and 105.5 µg/L for *Chlorella vulgaris* 276.5, 87.5 , 98.0 µg/l for *Scenedesmus obliquus* and 259.00, 126.0, 129.5 µg/l for *Spirulina platensis*, respectively .

The amounts of Ni removed by algae during the different incubation periods of 7, 15 and 21 days were 84.0, 252.00 and 245.000 µg/L for *Chlorella vulgaris*, 73.5, 262.50 and 252.00 µg/L for *Scenedesmus obliquus* and 91.0, 224.00 and 220.5 µg/L for *Spirulina platensis*, respectively.

The corresponding values of the removal percentages of Ni at the same times of incubation were 24.0 , 72.0 and 70.0 % for *Chlorella*, 21.0 , 75.0 and 72.0 % for *Scenedesmus* and 26.0, 64.0 and 63.0 % for *Spirulina*, respectively ,

The minimum value of removed Ni (73.5µg/L) was recorded by *Scenedesmus* in the first incubation period; while the maximum value of removed Ni (262.5 µg/L) was recorded by the same algae species in the second incubation period (*i.e.*, 15 days).

The used algae species could be arranged according to the mean values of the removal percentage of Ni in the following descending order: *Scenedesmus* > *Chlorella* > *Spirulina*. In the second and third periods, *Scenedesmus obliquus* was more effective for removing Ni element (75.0 and 72.o %) from media than *Chlorella vulgaris* (72.0 and 70.0 %) and *Spirulina platensis* (64.0 and 63.0), respectively.

Concerning the effect of different algae species on nickel content in El-Saff wastewater under the different studied incubation periods, data in Table 3 reveal that the residual of nickel, the removed amount and the corresponding removal percentages. The residual amounts of nickel in incubated algae media under the different three incubation periods are presented in Table 2.

The residual amounts of nickel in El-Saff wastewater after being treated by algae species during the three incubation periods of 7, 15 and 21 days ranged from 64.31 to 167.86 µg/L, from 57.33 to 170.04 µg/L and 47.96 to 156.96 µg/L for *Chlorella, Scenedesmus and Spirulina,* respectively. The minimum and maximum values of the residual Ni were recorded by *Spirulin* at the third period and *Scenedesmus* at the first period of incubation, respectively.

The amounts of Ni removed by algae species during the different incubation periods from the initial concentration, *i.e.*, 218.0 µg/L were 50.14, 153.69 and 150.42 µg/L for *Chlorella* 47.96, 160.67 and 144.97 µg/L for *Scenedesmus*. The corresponding removed amounts with *Spirulina* were 61.04, 148.46 and 170.04 µg/L, respectively.

The obtained results showed that the 15-days incubation period was more suitable than the 21days period for *Chlorella* and *Scenedesmus*, while the 21 days was more suitable for *Spirulina*. Data show that *Scenedesmus obliquus* and *Chlorella vulgaris* could remove 73.7 and 70.5 % from the initial concentrations of Ni (218.0 µg/L). On the other hand, *Spirulina platensis* could achieve its highest effect at the third period of incubation (21 days), where it could remove 78.0 % of Ni.

Comparing the effect of the studied algae species on removing Ni from wastewaters of El-Gabal El-Asfar and El-Saff, data reveal that the efficiency of fungus regardless of its species on removing Ni from both the two wastewaters was lower than the corresponding efficiencies of algae in removing Cd or Co.

Tables 2 & 3 reveal that the removal percentages of Cd and Co were 69.00, 67.00 % and 65.27, 64.67 % in El–Gabal El–Asfar and El–Saff wastewaters, respectively. The corresponding removal percentages for Ni were 53.67 and 62.33%, respectively.

Spirulina spp. was more effective in removing Cd, Co and Ni elements from El-Saff than El-Gabal El-Asfar wastewater, probably due to ability of *Spirulina* to grow best at high pH.(Table 20). Torzillo *et al.* (1991) and Wilde *et al.* (1993) gave an almost similar trend. On the other hand, *Chlorella* and *Scenedesmus* species seemed to be more efficient for removing Cd, Co and Ni from El-Gabal El-Asfar wastewater than El-Saff wastewater.

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(Received 11/2007;
accepted 12/2007)

المعالجة الحيوية لمياه ملوثة بالعناصر الثقيلة

حسن حمزة عباس* ، **إبراهيم محمد عبدالعزيز حجازى** ، **أحمد أبو الوفا خليل**
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* كلية الزراعة بمشتهر – جامعة بنها و معهد بحوث الأراضى والمياه والبيئة – مركز البحوث الزراعية – القاهرة – مصر .

يهدف البحث إلى علاج المياه الملوثة بالعناصر الثقيلة ، حيث أجريت تجربة لمعالجة عينتان من المياه الملوثة بالعناصر الثقيلة مأخوذتان من محطة معالجة المياه في الجبل الأصفربالقاهرة ومياه الصرف الصناعي بمنطقة الصف بالجيزة ، حيث تم تحضين عينتي المياه مع الطحالب التالية كل على حدة :
Scenedesmus obliquus, Chlorella vulgaris or *Spirulina plantensis* *وذلك* على درجة حرارة ٢٨ ± ٢° سليزيوس في ظل شدة إضاءة ٤٠٠٠ لاكس (١٤ ساعة إضاءة يعقبها ١٠ ساعات إظلام) وذلك لفترات ٧ ، ١٥ ، ٢١ يوما وبعد كل منها يتم تقدير محتوى المياه من المتبقي من أيونات معادن النيكل والكوبالت والكادميوم.

ويمكن تلخيص أهم النتائج التى تم الحصول عليها فيما يلى :-
- أدت المعالجة بأجناس الطحالب إلى انخفاض تركيز كل من النيكل والكوبالت والكادميوم في المياه الملوثة موضع الدراسة.
- أمكن ترتيب أجناس الطحالب المستخدمة تنازليا على حسب متوسط النسب المئوية لإزالة النيكل كما يلى: - *Scenedesmus* > *Chlorella* > *Spirulina*
أما الترتيب المقابل على حسب متوسط قيم النسب المئوية لإزالة كل من الكوبالت والكادميوم فكان تنازلياً كالتالي: *Spirulina* > *Scenedesmus* > *Chlorella*.
- كانت كفاءة الطحالب على إزالة النيكل من المياه الملوثة موضع الدراسة اقل من الكوبالت والكادميوم بغض النظر عن جنس الطحلب المستخدم.