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POTENTIAL USE OF SOME NATURAL MATERIALS FOR REMEDIATING POLLUTED WATER

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ABSTRACT: In the light of water scarcity and high population growth of Egypt, there is an urgent need to exploit and reuse every drop of water. Remediation of the available marginal water resources such as drainage water for irrigation purposes became mandatory. A laboratory experiment was conducted at Soil Science Department Laboratory, Faculty of Agriculture, Zagazig University during 2021 to find effective and low-cost ways of wastewater remediation to be easily available. For that, the water samples were synthetically contaminated with two heavy metals, namely nickel and lead which were added in concentrations of 10 mg/l and 0.5 mg/l, respectively. Four natural materials *i.e*, moringa seeds cake (M), rice straw biochar (B), sugarcane bagasse biochar (S) and zeolite (Z) were used in this investigation to study their potentiality on removing lead and nickel from polluted water. All materials were used at two rates of 10 and 20g/l. Four different particle diameters were used for each of rice straw biochar, bagasse biochar and zeolite as follows: < 0.125 mm, 0.125 – 0.212 mm, 0.212 – 0.250 mm and > 0.250 mm. All materials used gave considerable efficiencies in removing lead and nickel ions from polluted water showing an inverse proportional efficiency with particle diameters. The rate of 20g/l surpassed the rate of 10 g/l for all treatments under the same diameter. The most efficient treatment for removing lead was sugarcane bagasse biochar at rate of 20 g/l and particles diameter less than 0.125 mm with a removal efficiency of 90.39 % whereas the most efficient treatment for removing nickel was rice straw biochar at rate of 20g/l and diameter of particles less than 0.125mm with removal efficiency of 81.6%. The removal efficiency of lead for the investigated natural materials could follow the order: sugarcane biochar> rice straw biochar> moringa seeds cake> zeolites while the order was rice straw biochar> sugarcane bagasse biochar> moringa seeds cake> zeolites for nickel.

Key words: Polluted water, heavy metals, biochar, zeolite, moringa.

INTRODUCTION

The main source of irrigation water in Egypt is Nile water which provides a quantity of 55.5 billion cubic meters per year being used for agriculture, industry and domestic purposes. The agricultural sector is the main consumer of Nile water, about 86% (**FAO, 2016**). However, this quantity is not enough especially with the increasing population and increasing demand of water for reclamation projects adopted by Egypt vision 2030. The per capita share of renewable water resources in Egypt has been reduced from about 2500 m^3/capita/year in 1950's, to about 700 m^3/capita/year in 2015 and it is expected to reach 250 m^3/capita/year in 2050. To overcome this problem there are some suggested scenarios to decrease the gap between the required amount of water and the available resources **Amer *et al.* (2017)**. These are water reuse, use of non-renewable groundwater and treating marginal water such as desalinization, treating of wastewater for the purpose of agricultural use.

According to **Zidan and Dawoud (2013)** there are three major types of marginal-quality water in Egypt: these are wastewater from urban and peri-urban areas, saline and sodic agricultural drainage water, and brackish groundwater. Around cities, farmers use wastewater from residential,

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commercial, and industrial sources, sometimes diluted but often without treatment. Sometimes farmers in deltaic areas and tail end sections of large-scale irrigation schemes irrigate with a blend of canal water, saline drainage water, and wastewater. Others irrigate with saline or sodic groundwater, either exclusively or in conjunction with higher quality surface water. Many of those farmers cannot control the volume or quality of water they receive.

There are simple and effective ways for treating wastewater to be used as irrigation water. These ways include the use of Moringa seeds as a natural coagulant that heavy metals from the polluted water (**Suhartini *et al.*, 2013; Shan *et al.*, 2017; Swelam *et al.*, 2019**). Moringa seed cake was used to filter water using flocculation to produce potable water for animal or human consumption (**Ndabigengesere *et al.*, 1995; Hellsing *et al.*, 2013**). Moringa seeds contain dimeric cationic proteins (**Ghebremichael *et al.*, 2005**) which absorb and neutralize colloidal charges in turbid water, causing the colloidal particles to clump together, making the suspended particles easier to remove as sludge by either settling or filtration. Moringa seed cake removes most impurities from water.

They also include the use of biochar produced from different plant sources (**Kobya *et al.*, 2005; Han *et al.*, 2013; Alhashimi and Aktas, 2017**) such as rice straw, bagasse, etc. Biochar can be prepared by performing what so called pyrolysis which is one of the main thermal processes used for converting organic wastes into carbonaceous materials that can be used for wastewater depollution **(Selmi *et al.*, 2018).** During pyrolysis, lignin, cellulose, hemicellulose, and fat in the feedstock are thermally broken down in oxygen-free conditions to enrich the carbon content of the starting material by eliminating non-carbon species such as oxygen and hydrogen. Carbonization temperature, heating rate, nitrogen flow rate, and carbonization time are the main factors controlling the process of pyrolysis and profoundly determine the nature and the distribution of carbonization products: biochar (solid fraction), bio-oil (small quantities of condensable liquid), and non-condensable gases (syngas) *e.g.*, CO, CO_2, CH_4, and H_2 (**Ahmad *et al.*, 2012; Suliman *et al.*, 2016**). The removal of different elements (carbon, hydrogen, oxygen) in the form of gases and volatiles results in a decrease in O/C and H/C atomic ratios and correspondingly an increase in aromaticity and carbon content, which enhances the biochar stability (**Brewer, 2012; Windeatt *et al.*, 2014**). This tendency becomes more pronounced as the pyrolysis temperature increases. Increasing pyrolysis temperature (>500 °C) results also in greater hydrophobicity and higher surface area and micropore volume (**Keiluweit *et al.*, 2010)**, which make of the produced biochar highly amenable for the removal of organic pollutants. Lower pyrolysis temperature (<500 °C), however, allowed for a biochar with smaller pore size, lower surface area, and higher oxygen-containing functional groups, which was more suitable for the removal of inorganic pollutants. The increase in pyrolysis temperature also increases the pH of biochar due to the enrichment of ash content (**Brewer *et al.*, 2012; Gul *et al.*, 2015**). The heating rate is also an important factor that must be controlled during the process of carbonization. A high heating rate promotes the release of gases and the decrease in the solid yield.

Natural zeolite has been known as a useful adsorbent for polluted water. Natural zeolite is a kind of porous material with large specific surface area but with limited adsorption capacity. Many researches were carried out to study the effect of natural zeolites in removing metal ions from wastewater (**Turan and Ergun, 2009; BAO *et al.*, 2013; Sočo and Kalembkiewicz, 2013; Pandová *et al.*, 2018**).

The main aim of the present study is to evaluate the potential use of some natural materials for removing some heavy metals from polluted water to be used in irrigation purposes as a low cost and readily way for wastewater remediation.

MATERIALS AND METHODS

The primary field survey of water samples taken from several non-point sources pollution for local drains led to the fact that their contents of heavy metals were within the permissible limits according to **FAO (1992).** Due to the difficulty of obtaining polluted wastewater from their point-source pollution outlets, a laboratory experiment was conducted at the laboratory of Soil Science department, Faculty of Agriculture, Zagazig University during the year of 2021. Contaminated water samples with two heavy metals, namely nickel and lead, were synthetically prepared. The procedures and methods used in this study are described in the following sections.

Synthetic Polluted Water

According to **FAO (1992)** the recommended maximum heavy metal contents of lead and nickel in irrigation water are 5 mg/l and 0.2 mg/l, respectively. Therefore, synthetic polluted water by lead and nickel were prepared with quasi two folds of the permissible limits. The polluted water of both elements was prepared using the AAS standard solution after dilution to reach a final concentration of 10 and 0.5 mg/l of lead and nickel, respectively.

Natural Materials

Four natural materials were used to study their effectiveness in removing heavy metals from polluted water. These are rice straw biochar, sugarcane bagasse biochar, zeolite, and moringa seeds cake. Biochar of rice straw and sugarcane bagasse were produced by pyrolyzing air-dried samples at 400C- 600C under oxygen-limited conditions in a muffle furnace. The temperature was gradually increased to the target pyrolysis temperature, where it was held for 2 h. Once cool the biochar of rice straw and sugarcane bagasse as well as zeolite were ground and passed through series of sieves of 0.25 mm, 0.212, mm, and 0.125 mm.

Four separate groups with different diameters of each material were obtained, and these were as follows: < 0.125 mm, 0.125 – 0.212 mm, 0.212–0.250 mm and >0.250 mm. The chemical characteristics of these materials are presented in Table 1.

Experimental Setup and Procedures

Two different rates of each material were used for both synthetic polluted waters of lead and nickel. Two rates of each group (10 g/l and 20 g/l) were weighted and then added to one liter glass Erlenmeyer flask with stopper containing the synthetic polluted water for lead and nickel. The experiment was carried out at room temperature of 25℃ under atmospheric pressure with three replicates. The flasks were shaken for two hours and then were filtered using Whatman No.42 filter papers. The filtrates were collected and subjected to lead and nickel analysis. Atomic absorption spectrometer AA analyst 200 Perkin Elmer Instrument, (Shelton, Connecticut, USA) was used for determining Pb and Ni contents in the filtrates. pH was measured at (1:10) water suspension using a glass electrode while, EC was measured at (1:10) water extract using EC meter. CEC was determined according to the barium chloride (pH 8.2) method (Jackson, 1973). The removal amount of each metal was calculated by subtracting the final concentration from the initial one. The products were used to calculate the removal efficiency for the materials under investigation.

Statistical Analysis

Analysis of variance (ANOVA) was carried out to compare the means of different treatments under a complete randomized design calculating the least significant difference (LSD, $p < 0.05$) using the CoStat software version 6.303, Monetery, USA (**Fisher, 1936**).

RESULTS AND DISCUSSION

Effect of Treatments on Lead and Nickel Removal

The ANOVA test was performed to compare the investigated materials with different rates and diameters to allow the selection of the most efficient treatment for removing lead and nickel with statistically significant difference. Table 2 presents the output data for the inspected treatments and their significances.

Moringa

Moringa had a considerable positive effect on lead removal showing an efficiency of 84.60 and 86.00% at rates of 10 g/l and 20 g/l, respectively. Adding moringa seeds cake resulted in reducing lead concentration from 10 mg/l to 1.54 and 1.40 mg/l at rates of 10 g/l and 20 g/l, respectively (Table 3). Based on LSD value (0.530) no significant difference between the two rates is found and then it is suggested to use the first rate (10 g/l). This positive effect may be

Table 1. Some chemical properties of the investigated natural materials

Material	pH, in H_2O	EC, dSm^{-1}	CEC, cmol kg^{-1}	Total C, %	Ash content, %
Rice straw biochar	6.7	2.85	48.6	38.2	39.5
Sugarcane bagasse biochar	7.2	0.62	88.5	69.3	8.6
Moringa seeds cake	6.3	0.35	79.4	57.8	9.4
Zeolite	6.8	1.20	34.7	-	-

pH in (1:10) water suspension; EC in (1:10) water extract.

Table 2. Analysis of variance (ANOVA) results of lead and nickel for investigated materials

Treatment code	Pb^{2+} mean value (mg/l)	Ni^{2+} mean value (mg/l)
M R1	1.54 ^{jkl}	0.137 ^{mn}
M R2	1.40 ^{klm}	0.123 ^{no}
B R1 D1	1.29 ^{klm}	0.109 ^{op}
B R1 D2	2.06 ^{ij}	0.124 ^{n}
B R1 D3	3.23 ^{h}	0.156 ^{kl}
B R1 D4	4.11 ^{g}	0.188 ^{hi}
B R2 D1	1.06 ^{lm}	0.092 ^{q}
B R2 D2	1.15 ^{lm}	0.103 ^{pq}
B R2 D3	2.08 ^{i}	0.127 ^{mn}
B R2 D4	3.29 ^{h}	0.163 ^{jk}
S R1 D1	1.21 ^{klm}	0.104 ^{pq}
S R1 D2	1.69 ^{ijk}	0.142 ^{lm}
S R1 D3	4.87 ^{ef}	0.162 ^{jk}
S R1 D4	5.34 ^{de}	0.177 ^{ij}
S R2 D1	0.96 ^{m}	0.099 ^{pq}
S R2 D2	1.28 ^{klm}	0.134 ^{mn}
S R2 D3	4.07 ^{g}	0.154 ^{kl}
S R2 D4	4.66 ^{f}	0.161 ^{k}
Z R1 D1	6.54 ^{b}	0.225 ^{g}
Z R1 D2	7.36 ^{a}	0.312 ^{e}
Z R1 D3	7.70 ^{a}	0.352 ^{c}
Z R1 D4	7.76 ^{a}	0.397 ^{a}
Z R2 D1	5.61 ^{cd}	0.202 ^{h}
Z R2 D2	6.08 ^{bc}	0.280 ^{f}
Z R2 D3	6.42 ^{b}	0.329 ^{d}
Z R2 D4	7.45 ^{a}	0.375 ^{b}
LSD at 0.05	**0.530**	**0.014**

M: moringa seeds cake, B: rice straw biochar, S: sugarcane bagasse biochar, Z: zeolite, R1: rate of 10g/l, R2: rate of 20g/l, D1: diameter < 0.125 mm, D2: diameter 0.125 – 0.212 mm, D3: diameter 0.212 – 0.250 mm, D4: diameter > 0.250 mm.

Table 3. Lead and nickel concentrations in polluted water after moringa seeds cake treatment

Concentration after treatment (mg/l)	Treatment	
	M R1	**M R2**
Lead (Pb^{2+})	1.54	1.40
Efficiency (%)	**84.60**	**86.00**
Nickel (Ni^{2+})	0.137	0.123
Efficiency (%)	**72.60**	**75.40**

M: Moringa seeds cake, R1: rate of 10g/l, R2: rate of 20g/l

attributed to the coagulation effect of moringa seeds (**Ndabigengesere *et al.*, 1995; Hellsing *et al.*, 2013**). Moringa seeds contain dimeric cationic proteins which absorb and neutralize colloidal charges in turbid water (**Ghebremichael *et al.*, 2005).**

Comparing the two rates of moringa seeds cake on nickel removal, the rate of 20g/l gave higher efficiency of 75.40% compared with the rate of 10 g/l which gave a removal efficiency of 72.60% (Table 3). However, the rate of 10g/l should be used since no significant difference between both rates is found (Table 2).

Rice Straw Biochar

Table 4 shows the effect of rice straw biochar on lead removal where it can be seen that at both rates of 10 and 20 g/l, the removal efficiencies decreased with increasing particulates diameter indicating that the smaller the particle size the higher surface area, adsorption capacity and removal efficiency. Rice straw is the most abundant agricultural wastes in many countries. Converting these low cost, high carbon and abundant residuals into biochar can act as a kind of efficient and cost-effective sorbent which is capable of removing organic or inorganic pollutants from aqueous environments (**Tan *et al.*, 2015**). However, removal efficiency of the second rate (20g/l) surpassed the first rate (10g/l) for all particles diameters. This may be attributed to the presence of more quantity of rice straw biochar and hence more surface area for lead adsorption. Particulate size and resulting total surface area available for adsorption are both important factors in metal adsorption processes (**Luoma, 1989**). Small particles with large surface-area-to-mass ratios allow more adsorption than an equivalent mass of large particles with small surface-area-to-mass ratios.

The most effective treatment regardless of the different particles diameters and addition rates was B R2 D1 (Table 2) with a removal efficiency of 89.36% followed by B R1 D1 (87.07%). However, it is suggested to use the treatment B R1 D1 although no significant difference between the two application rates. Table 4 shows the effect of rice straw biochar on nickel removal which followed the same trend of Pb. The adsorption of Ni^{2+} to biochars reached equilibrium rapidly which may be due to the small particle size of the biochars and the buffing effect of the biochars (**Shen *et al.*, 2017**). However, the efficiency of the second rate (20 g/l) surpassed the first rate (10g/l) for all diameters. The most effective treatment regardless the different diameters and rates was B R1 D2 showing a removal efficiency of 81.6% followed by B R1 D4 (79.4%).

Sugarcane Bagasse Biochar

Table 5 shows the effect of sugarcane bagasse biochar on lead and nickel removal. At rates of 10 and 20 g/l, the efficiencies of lead and nickel removal decreased with increasing in diameter indicating that the smaller the particle size the higher the removal efficiency. Particle diameters can strongly influence the ability of adsorbent materials to bind metal contaminants. Fine particles are more reactive and have a higher surface area than coarser material (**Gerber *et al.*, 1991**). Biochar made from sugarcane bagasse

Table 4. Lead concentrations in polluted water containing after rice straw biochar treatment

Treatment	Diameter (mm)	Pb^{2+} concentration after treatment (mg/l)	Pb^{2+} removal efficiency (%)	Ni^{2+} concentration after treatment (mg/l)	Ni^{2+} removal efficiency (%)
B R1 D1	< 0.125	1.29	87.07	0.109	78.20
B R1 D2	0.125 – 0.212	2.06	79.45	0.124	75.20
B R1 D3	0.212 – 0.250	3.23	67.75	0.156	68.80
B R1 D4	> 0.250	4.11	58.89	0.188	62.40
B R2 D1	< 0.125	1.06	89.36	0.092	81.60
B R2 D2	0.125 – 0.212	1.15	88.49	0.103	79.40
B R2 D3	0.212 – 0.250	2.08	79.16	0.127	74.60
B R2 D4	> 0.250	3.29	67.13	0.163	67.40

B: rice straw biochar, R1: rate of 10g/l, R2: rate of 20g/l, D1: diameter < 0.125 mm, D2: diameter 0.125 – 0.212 mm, D3: diameter 0.212 – 0.250 mm, D4: diameter > 0.250 mm.

Table 5. Lead and nickel concentrations in polluted water containing of Ni after sugarcane bagasse biochar treatment

Treatment	Diameter mm	Pb^{2+} concentration after treatment (mg/l)	Pb^{2+} removal efficiency %	Ni^{2+} concentration after treatment (mg/l)	Ni^{2+} removal efficiency %
S R1 D1	< 0.125	1.21	87.89	0.104	79.20
S R1 D2	0.125 – 0.212	1.69	83.09	0.142	71.60
S R1 D3	0.212 – 0.250	4.87	51.25	0.162	67.60
S R1 D4	> 0.250	5.34	46.59	0.177	64.60
S R2 D1	< 0.125	0.96	90.39	0.099	80.20
S R2 D2	0.125 – 0.212	1.28	87.20	0.134	73.20
S R2 D3	0.212 – 0.250	4.07	59.35	0.154	69.20
S R2 D4	> 0.250	4.66	53.36	0.161	67.80

S: sugarcane bagasse biochar, R1: rate of 10g/l, R2: rate of 20g/l, D1: diameter < 0.125 mm, D2: diameter 0.125 – 0.212 mm, D3: diameter 0.212 – 0.250 mm, D4: diameter > 0.250 mm.

and other agricultural residues may be effective alternative, low-cost environmental sorbents of lead or other metals (**Inyang *et al.*, 2011**). However, efficiencies of the second rate (20g/l) surpassed the first rate (10g/l) for all diameters. This may be ascribed to the presence of more quantity of sugarcane bagasse biochar and then higher surface area for lead and nickel adsorption.

The most effective treatment regardless the different diameters and rates was S R2 D1 showing a removal efficiency of 90.39% followed by S R1 D1 treatment (87.89%) for Pb. The same trend was found for Ni showing a removal efficiency of 80.2 and 79.2%, respectively. However, it is suggested to use the treatment S R1 D1 because no significant difference (Table 2) between both treatments is found for Pb and Ni and then low cost.

Zeolite

Table 6 shows the effect of zeolite on lead removal where it can be seen that the efficiencies of removal decreased with increasing in diameter indicating that the smaller the particle size the higher removal efficiency it is for both rates of 10 and 20 g/l. However, efficiencies of the second rate (20g/l) surpassed the first rate (10g/l) for all diameters under study. This may be due to the presence of more quantity of zeolite and then higher surface area for lead adsorption.

The most effective treatment regardless the different diameters and rates was Z R2 D1 showing a removal efficiency of 43.91% followed by Z R2 D2 (39.24%) for Pb as well as ZR2D1 followed by ZR1D1 treatment giving a removal efficiency of 59.6 and 55.0%, respectively for Ni. This indicates that for Ni the rate of 20g/l at diameter of particles less than 0.125mm (ZR2D1 treatment) should be used since there is a statistically significant difference between both treatments.

Modified zeolites can be recommended for wastewater treatment and control of environmental pollution **(Panneerselvam *et al.*, 2009).**

Conclusion

Remediation of polluted water can be achieved using natural materials such as *Moringa oleifera* seeds cake, biochar produced from rice straw and sugarcane bagasse and zeolite. All treatments gave a considerable ability and efficiency in removing the two heavy metals elements under study (Pb and Ni). Biochar produced from sugarcane bagasse was the most efficient substance in removing lead whereas rice straw biochar was the most efficient substance in removing nickel from the aqueous solution. It is worth to mention that zeolite treatment at rate of 10g/l with particles diameter greater than 0.250mm gave the least removing efficiency for Pb and Ni elements. These results indicate that the natural materials of moringa seeds cake, biochar of plant residues and zeolites could act as effective and low-cost adsorbent substances for the removal of heavy metal ions from wastewater to be suitable for irrigation purposes.

Table 6. Lead and nickel concentrations in polluted water after zeolite treatment

Treatment	Diameter, mm	Pb^{2+} concentration after treatment (mg/l)	Pb^{2+} Removal efficiency %	Ni^{2+} concentration after treatment (mg/l)	Ni^{2+} Removal efficiency %
Z R1 D1	< 0.125	6.54	34.61	0.225	55.00
Z R1 D2	0.125 – 0.212	7.36	26.39	0.312	37.60
Z R1 D3	0.212 – 0.250	7.70	23.01	0.352	29.60
Z R1 D4	> 0.250	7.76	22.40	0.397	20.60
Z R2 D1	< 0.125	5.61	43.91	0.202	59.60
Z R2 D2	0.125 – 0.212	6.08	39.24	0.280	44.00
Z R2 D3	0.212 – 0.250	6.42	35.76	0.329	34.20
Z R2 D4	> 0.250	7.45	25.53	0.375	25.00

Z: zeolite, R1: rate of 10g/l, R2: rate of 20g/l, D1: diameter < 0.125 mm, D2: diameter 0.125 – 0.212 mm, D3: diameter 0.212 – 0.250 mm, D4: diameter > 0.250 mm.

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الاستغلال المحتمل لبعض المواد الطبيعية في معالجة المياه الملوثة

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نظرا لندرة المياه العذبة في البلدان الواقعة في المناطق الجافة وشبه الجافة ، و في ظل ندرة المياه وارتفاع عدد السكان في مصر التى تعتبر واحدة من تلك البلدان، هناك حاجة ملحة لاستغلال وإعادة استخدام كل قطرة ماء، لذلك أصبح من الضرورى معالجة موارد المياه الهامشية المتاحة مثل مياه الصرف المتنوعة لاستخدامها لأغراض الري. يوجد العديد من المواد الطبيعية المتنوعة التي يمكن استخدامها لمعالجة المياه الملوثة مثل بذور المورينجا، والفحم الحيوي الناتج من المخلفات النباتية، ومعادن الزيوليت الطبيعي، حيث يمكن لهذه المواد أن تساعد في إزالة الملوثات من المياه الملوثة ومن ثم يمكن استخدامها في الري. ان الهدف الرئيسي من هذه الدراسة هو إيجاد طرق سهلة و فعالة ومنخفضة التكلفة ومتاحة للجميع، لمعالجة مياه الصرف الملوثة بالعناصر الثقيلة. في هذا البحث تم تناول أربعة مواد طبيعية لدراسة مدى قدرتها على إزالة عنصرى الرصاص والنيكل من المياه الملوثة. هذه المواد هي مسحوق بذور المورينغا، الفحم الحيوى لقش الأرز، الفحم الحيوى لتفل قصب السكر واخيرا الزيوليت. تم استخدام جميع المواد بمعدلين 10 و 20 جم/لتر، وتم استخدام أربعة أقطار مختلفة لحبيبات كل من الفحم الحيوي لقش الأرز ، والفحم الحيوى لتفل قصب السكر ، والزيوليت. أظهرت النتائج أن جميع المواد المستخدمة أعطت كفاءة كبيرة في إزالة أيونات الرصاص والنيكل من المياه الملوثة، كما أن هذه الكفاءة تناقصت بزيادة أقطار الحبيبات. من المهم أيضًا الإشارة إلى أن معدل 20 جم/لتر أعطى كفاءة ازالة أكبر من معدل 10 جم/لتر وذلك لجميع المعاملات تحت نفس القطر من الحبيبات. كانت المعاملة الأكثر كفاءة لإزالة الرصاص هي الفحم الحيوي لتفل قصب السكر بمعدل 20 جم/لتر وقطر حبيبات أقل من 0.125 مم، حيث بلغت كفاءة الازالة 90.39%، بينما كانت المعاملة الأقل كفاءة هي الزيوليت بمعدل 10 جم/لتر وأقطار حبيبات أكبر من 0.250 مم بكفاءة إزالة 22.40%. فيما يتعلق بإزالة النيكل ، كانت المعاملة الأكثر كفاءة هي الفحم الحيوي لقش الأرز بمعدل 20 جم/لتر وقطر حبيبات أقل من 0.125 مم بكفاءة إزالة بلغت 81.6%، بينما كانت أقل معاملة هي الزيوليت بمعدل 10 جم/لتر وأقطار حبيبات أكبر من 0.250 مم. وعموما، اظهرت النتائج ان كفاءة إزالة كل من أيونات الرصاص والنيكل من المياه الملوثة صناعيا بواسطة المواد الطبيعية التي تم دراستها يمكن أن تتبع الترتيب التالى: الفحم الحيوي لتفل قصب السكر > مسحوق بذور المورينجا> الفحم الحيوى لقش الأرز> الزيوليتات.

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