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# Removal of Heavy Metals in Water by Biosorption Method Using Three Different Bacillus sp-derived Biosorbents

Mehmet Fırat BARAN[1], Zahir DÜZ[2], Ayşe BARAN[3], Cumali KESKİN[4], Necmettin AKTEPE[5]

[1]Medical Laboratory Techniques, Vocational Higher School of Healthcare Studies, Mardin Artuklu, [2]Science Faculty, Chemistry Department, Dicle University, Diyarbakir, Turkey, [3]Mardin Artuklu University, Institute of Science, Mardin, Turkey, [4]Mardin Artuklu University, Department of Medical Services and Techniques, Mardin, Turkey, [5]Department of Nursing, Mardin Artuklu University School of Health, Mardin, Turkey

[1]https://orcid.org/ 0000-0001-8133-6670, [2]https://orcid.org/0000-0002-3642-4206, [3]https://orcid.org/0000-0002-2317-0489
[4]https://orcid.org/ 0000-0003-3758-0654, [5]https://orcid.org/ 0000-0001-6503-6686

✉: m.firatbaran@gmail.com

## ABSTRACT

Water is an important part of the ecosystem for life. With industrialization, pollution in water resources has reached a worrying level. Water pollution due to heavy metals and their increasing concentrations have caused researchers to increase their interest in the subject due to the damage they cause to water ecosystems. It requires serious cost and time to eliminate the pollution caused by heavy metals in water. In recent years, the use of biosorption method using bacteria to remove heavy metals in water has become widespread. The main reason why this method is preferred is that gram-positive bacteria have a thick peptidoglycan layer on the cell wall and increases the adsorption capacity. In this study, in drinking, waste, river water and artificially prepared samples, batch method of heavy metal biosorption and biosorption competition in multiple prepared heavy metal solutions were investigated. For these processes, *Bacillus licheniformis sp. Bacillus subtilis sp.* and *Bacillus subtilis (ATCC 6051)* strains were used as a biosorbent. Biosorbtion of Cd (II), Cu (II), Pb (II), Fe (II), Ni (II) and Zn (II) metals from waters with these biosorbents at different pHs at 25 ° C with 0.25 mg $L^{-1}$ It was investigated. Surface morphological structures of biosorbents were evaluated using SEM images and element compositions were evaluated using EDAX profile. Element content was determined using ICP-OES. It was found that heavy metal ions were removed up to 98% with maximum biosorption at pH 6.0.

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# Farklı Biyosorbentler Kullanarak Su Ortamında Ağır Metallerin Biyosorbsiyon Metodu ile Giderilmesi

## ÖZET

Su canlılar için ekosistemin önemli parçasıdır. Endüstrileşme ile birlikte su kaynaklarındaki kirlenme endişe edilir boyutlara ulaşmıştır. Ağır metallere bağlı su kirliliği ve bunların artan konsantrasyonları su ekosistemlerine zarar verdiğinden araştırmacıların konuya olan ilgisinin artmasına sebep olmuştur. Ağır metallerin sularda oluşturduğu kirliliği gidermek ciddi maliyet ve zaman gerektirmektedir. Son yıllarda suda bulunan ağır metallerin uzaklaştırılması için bakteriler aracılığıyla biyosorbsiyon yönteminin kullanılması yaygınlaşmıştır. Bu yöntemin tercih edilmesinin temel sebebi gram pozitif bakterilerin hücre duvarında kalın bir peptidoglikan tabakasına sahip olması ile adsorbsiyon kapasitesini artırmasıdır. Bu çalışmada içme, atık, nehir suları ve suni olarak hazırlanan numunelerde çalkalamalı metod kullanarak ağır metal biyosorbsiyonu ile birlikte çoklu hazırlanmış ağır metal çözeltilerinde biyosorbsiyon rekabeti incelenmiştir. Bu işlemler için Dicle nehri bölgesine ait topraklardan izole edilen *Bacillus licheniformis sp. Bacillus subtilis sp.* ve *Bacillus*

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**Anahtar Kelimeler**
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*Bacillus licheniformis sp.*
Biyosorpsiyon
ICP-OES
Atık su

*subtilis (ATCC 6051)* suşları ile sulu çözeltiden Cd (II), Cu (II), Pb (II), Fe (II), Ni (II) ve Zn (II) metallerinin biyosorbsiyonu değerlendirildi. *B. subtilis* suşları ve *B.licheniformis sp.* organizmalarının yüzey morfoljik yapıları SEM görüntüleri, element kompozisyonları EDAX verileri ile incelendi. ICP-OES kullanılarak element içeriği tespit edildi. Sulu çözeltideki Cd (II), Cu (II), Pb (II), Fe (II), Ni (II) ve Zn (II) metal iyonları farklı pH'larda 25 °C de 0,25 mg $L^{-1}$ biomass ile biyosorbsiyon gerçekleştirildi. pH 6.0 da maksimum biyosorbsiyon ile metal iyonlarının % 98 varan oranda giderildiği belirlendi.

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## INTRODUCTION

Heavy metal pollution is a worrying global problem as a result of rapid industrialization (Yahiaoui et al., 2020). High concentrations of the heavy metals pose a toxic threat to all life forms (Wu et al., 2020; Morcali and Baysal, 2019). Heavy metal-containing wastewater from metal coating facilities, mining activities, fertilizer industry, battery and paper industries are directly or indirectly discharged into water sources. Heavy metals are not biodegradable in water, soil or atmosphere. Biologically accumulating heavy metals cause toxic and carcinogenic effects for many organisms (Kucukcongar et al., 2020; Lieswito et al., 2019).

Various methods are used to remove heavy metals from water and wastewater (Qin et al., 2020). Ion exchange (Zendehdel et al., 2019), chemical precipitation (Eltarahony et al., 2020), coplexing (Eggermont et al., 2020), membrane filtration (El-yazeed et al., 2020), adsorption (Subramani et al., 2019), biosorption (Sabri et al., 2018) methods are some of them. Biosorption is a favorite technique for heavy metals removal. Being environmentally friendly and not requiring high energy increases the interest in this field by making the method economical. In biosorption applications, heavy metal adsorbing sources are considered as biosorbents (Kouli et al., 2020; Halimahtussaddiyah, 2017; Nasab et al., 2020). Biosorbent sources such as bacteria (Abedinzadeh et al., 2020), fungi (Qin et al., 2020; Verma et al., 2013) yeasts (Yasmin et al., 2020), algae (Liu et al., 2018), shellfish ( (Keshvardoostchokami et al., 2017), plants (Parthasarathy and Narayanan, 2014) are used in biosorption applications. Biosorbtion studies performed with biologically sourced adsorbents are in a very interesting position in terms of easy application stages, low cost, high biosorption efficiency, reuse of the adsorbent and not containing toxic chemicals that will harm health (Qin et al., 2020; Shokoohi et al., 2020; Khameneh and Moharreri, 2020).

In studies using bacteria as adsorbents, it has been observed that gram positive bacteria exhibit better character than gram negative bacteria in terms of biosorption efficiency. Gram-positive bacteria have a thick cell wall, which increases biosorption (Baran and Duz, 2019; Biswas et al., 2020).

In this study, the removal of Cd (II), Cu (II), Pb (II), Fe (II), Ni (II), Zn (II) heavy metals were investigated at appropriate pH values with different biomasses using the batch biosorption technique, and it was also aimed to examine the biosorption competition in the solution.

## MATERIAL and METHOD

### Isolation of Bacterial Strains

1 g soil sample was taken for each strain to be used in the isolation of the strains from the soils of the Tigris river coastal region. The samples were mixed with 4.5 mL of sterile distilled water. The homogenized samples were kept at 80 °C for 10 minutes (Lennete et al., 1985). Samples were diluted using sterile water to obtain colonies. It was incubated at 37 °C by inoculation on nutrient agar medium containing 10 % NaCl. At the end of the period, the colonies grown in the medium were evaluated according to their morphology. Colonies with Bacillus morphology were seeded on nutrient agar medium and incubated at 37°C for 1 night (Sneath et al., 1986). Taxonomic descriptions of *Bacillus licheniformis sp. (B. licheniformis sp.)* and *Bacillus subtilis sp.* (*B. subtilis sp.*) were carried out by Dr. Hüsamettin Aygün of Dicle University.

### Equipment and Chemicals

Metal salts of analytical purity $Cd(NO_3)_2.4H_2O$, $Pb(NO_3)_2$, $Cu(NO_3)_2.3H_2O$, $Zn(NO_3)_2.4H_2O$, $Fe(SO_4).7H_2O$ and $Ni(NO_3)_2.7H_2O$ were used. Stock solutions and pH adjustment (NaOH, HCl and $HNO_3$) were used as acid and base in experimental studies.

Stock solutions of iron, lead, copper, nickel, zinc and cadmium were prepared as 1000 mg/L from these metal salts.

Perkin-Elmer OPTİMA 5300 Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), HANNA HI-2211 7000 seven multi brand pH meters, ALC-4235 A brand model centrifuge devices, as well as EVO 40 LEQ model SEM-EDAX devices for biosorbent characterization were utilized.

### Biosorbent Preparation Process

Isolated from the soils on the banks of the Tigris river *B.licheniformis sp.* and *B. subtilis* wild strains as well as the *Bacillus subtilis ATCC 6051* (*B. Subtilis* ) strain were used for biosorption as a biosorbent. Nutrient agar, nutrient broth solid media forms were used to the cultivate bacteria.

The microorganisms used are gram positive bacilli and have a thick peptidoglycan layer. The structure of this layer is a large polymer formed by cross-linking peptide chains with N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM) pentapeptide chains (Reith and Mayer, 2011; Tocheva et al., 2013).

Inoculation was performed on nutrient agar medium. It was left to incubate at 37 $^{o}$C for 24 hours. Then the microorganisms grown were transferred from solid media to 1.0 liter nutrient broth media. The bacteria were left in a shaker at 37 $^{o}$C for 24 hours to grow. The media content obtained after growth was subjected to centrifugation at 7,000 rpm for 15 minutes. The bottom pellet was washed several times with sterile distilled water. Then it was left to dry. The dried pellet was passed through a 180 µm sieve. *B. licheniformis sp.* (Fl), *B. subtilis sp.* (Fs) and *B. subtilis* (B1) biosorbent naming was done. Biosorbents have been made ready for the biosorption process.

### Heavy Metal Biosorption with Batch Method

Biosorbtion processes with biosorbents were performed using the physical adsorption batch method (Ali et al., 2020). This method is based on the removal of heavy metals from the aqueous solution by stirring (Mwandira et al., 2020; Nazmara et al., 2020). Different pH biosorption trials were carried out and the pH values in which the metals showed the best activity among these studies were selected for the biosorption application. In the studies conducted with the batch method, the removal of heavy metals at different pH's and low concentrations in water was investigated. (Shokoohi et al., 2020; Tengxia et al., 2020).

### Biosorption at Low Concentration

From the stock solutions of 1000 ppm containing metal salts, dilutions were made for each metal (Cd, Cu, Fe, Ni, Pb and Zn) and the solutions were prepared with an initial concentration of 1.5 ppm. The pH of the solutions of Cd, Cu, Fe, Ni, Pb and Zn was adjusted as 5, 4.5, 6, 6, 5.5 and 6.5, respectively. Then, B1, Fl and Fs biosorbents were weighed 0.25 mg and left to the 1000 mL flasks. Metal solutions were added and agitation was carried out at 25 $^{o}$C. After the samples were taken and centrifuged, readings were made with ICP-OES. After the equilibrium concentrations were determined, the percentage metal removal capacities of B1, Fs and F1 biosorbents for each metal were evaluated. Percent metal removal was calculated using the equation stated below (Baran and Duz, 2019).

$$\%A=((Co-Cd))/Co \times 100 \quad (1)$$

Co = Initial metal concentration,

Cd = Refers to the concentration of metal at equilibrium.

### Low Concentration Biosorption Competition

A mixture of metal ions Ni (II), Cd (II), Pb (II), Cu (II), Fe (II) and Zn (II) with an initial concentration of 1.5 ppm was prepared from the stock solutions. The proper pH was adjusted. The biosorbents (F1, Fs and B1) were weighed 0.25 mg and each was placed in a separate 1000 mL flask. The prepared metal mixture solution was added on them. It was left to stir during equilibrium at 25 ° C. Samples were centrifuged and readings for metal contents were made with the ICP-OES device. Then percent recovery was calculated with the equation shown in formula (1).

### Biosorption Competition in Drinking, River and Wastewater

B1 biosorbent with the best biosorbent ability was selected in the applications. This stage, which is the last stage of biosorption applications, was evaluated for its applicability to drinking, waste and river waters. Samples were taken from different stations (Table 5-6). The initial concentrations of the water samples taken were determined via the ICP-OES device. 0.25 mg L-1 of B1 biosorbent was weighed and put into the flasks and water samples taken from different points were added on them. Samples were left in a shaking water bath for one hour. The samples taken at different times were centrifuged and the Equilibrium concentration was determined. Percent metal removal was calculated by the equation defined in formula (1).

## RESULTS and DISCUSSION

### Biosorbent Characterization

#### SEM-EDAX micrographs

Morphological appearances and element compositions of Fs, F1 and B1 biosorbents before and after biosorption were evaluated by the SEM analysis. The bacterial cell is morphologically rod-shaped and has a smooth surface. However, its morphology changed after metal biosorption (Figure 1-3) (Pugazhendhi et al., 2018; Dahaghin et al., 2017).

In the EDAX profile, a decrease was observed in B1 biosorbent after biosorbtion in Potassium (K) ions. In the study conducted with the *Bacillus gibsonii s-2* strain, it is reported that the biosorbent absorbs lead ions as a result of the biosorption of the lead metal. In the EDAX analysis, it was stated that the effective decrease in $Na^+$ ions, one of the ions in the bacterial profile after biosorption, was based on the ion exchange between Pb-Na (Zhang et al., 2013). The decrease in $K^+$ in the EDAX profile indicates that biosorption occurs by ion exchange in similarly between K-Pb, K-Fe and K-Cd. In addition, heavy metals adsorbed after biosorption are also reflected in the EDAX profile (Figure 4). Similar findings of SEM-EDX micrographs were presented in recent biosorption studies (Ayucitra et al., 2017; Zendehdel et al., 2019; Kucukcongar et al., 2020; Su et al., 2020).

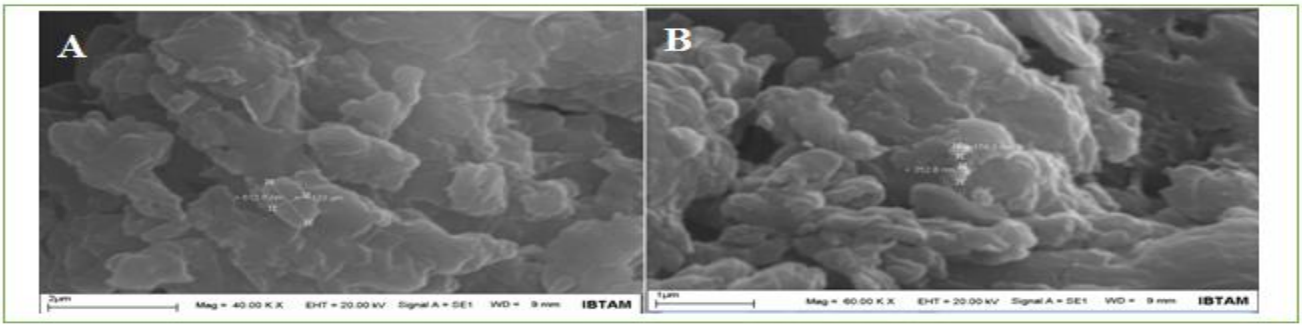


Figure 1. SEM images of the B1 biosorbent (A) before and (B) after metal interactions.
*Şekil 1. B1 Biyosorbentinin metal etkileşiminden önceki (A) ve metal ile etkileştikten sonraki SEM görüntüleri. (B)*

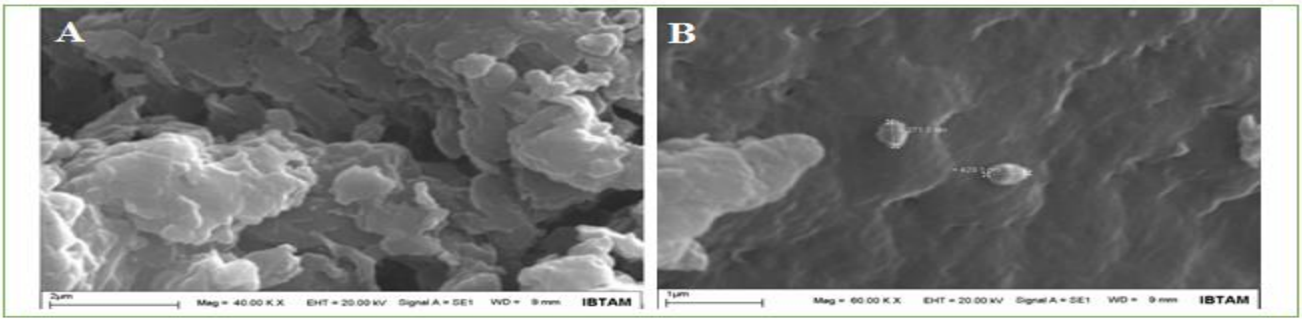


Figure 2. SEM images of the F1 biosorbent (A) before and (B) after metal interactions.
*Şekil 2. F1 Biyosorbentinin (A) metal etkileşiminden önceki ve (B) metal ile etkileştikten sonraki SEM görüntüleri.*

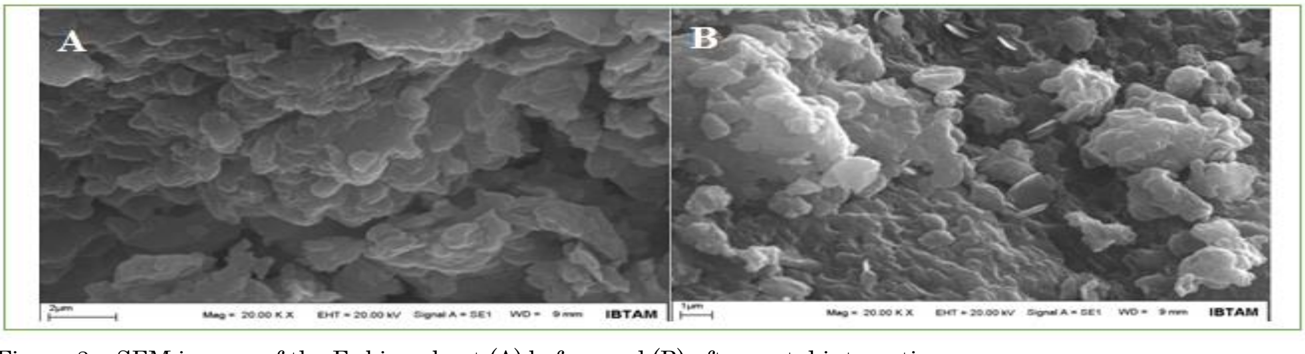


Figure 3. SEM images of the Fs biosorbent (A) before and (B) after metal interactions.
*Şekil 3. Fs Biyosorbentinin (A) metal etkileşiminden önceki ve (B) metal ile etkileştikten sonraki SEM görüntüleri.*

## Biosorption Studies

Cd, Cu, Fe, Ni, Pb and Zn 1.5 ppm solutions were evaluated by biosorption at pH 5, 4.5, 6, 6, 5.5 and 6.5, respectively. Equilibrium concentrations and metal removal percentages were calculated using the equation in formula (1).

When Table 1 and figure 5 data were examined and compared for biosorbtion at low concentrations, it is seen that the metals that F1, Fs and B1 biosorbents adsorb best were Cd and Pb. It is seen that the biosorbent that provides the best Cd and Pb removal in biosorbents is B1 with % 98.13 and % 97.53 removal rates, respectively. It has been reported in the biosorption studies that Cd and Pb ions are largely adsorbed (Abedinzadeh et al., 2020; Mwandira et al., 2020). It has been stated in studies that bacteria are more resistant to Pb and Cd stress (Su et al., 2020; Borralho et al., 2020).

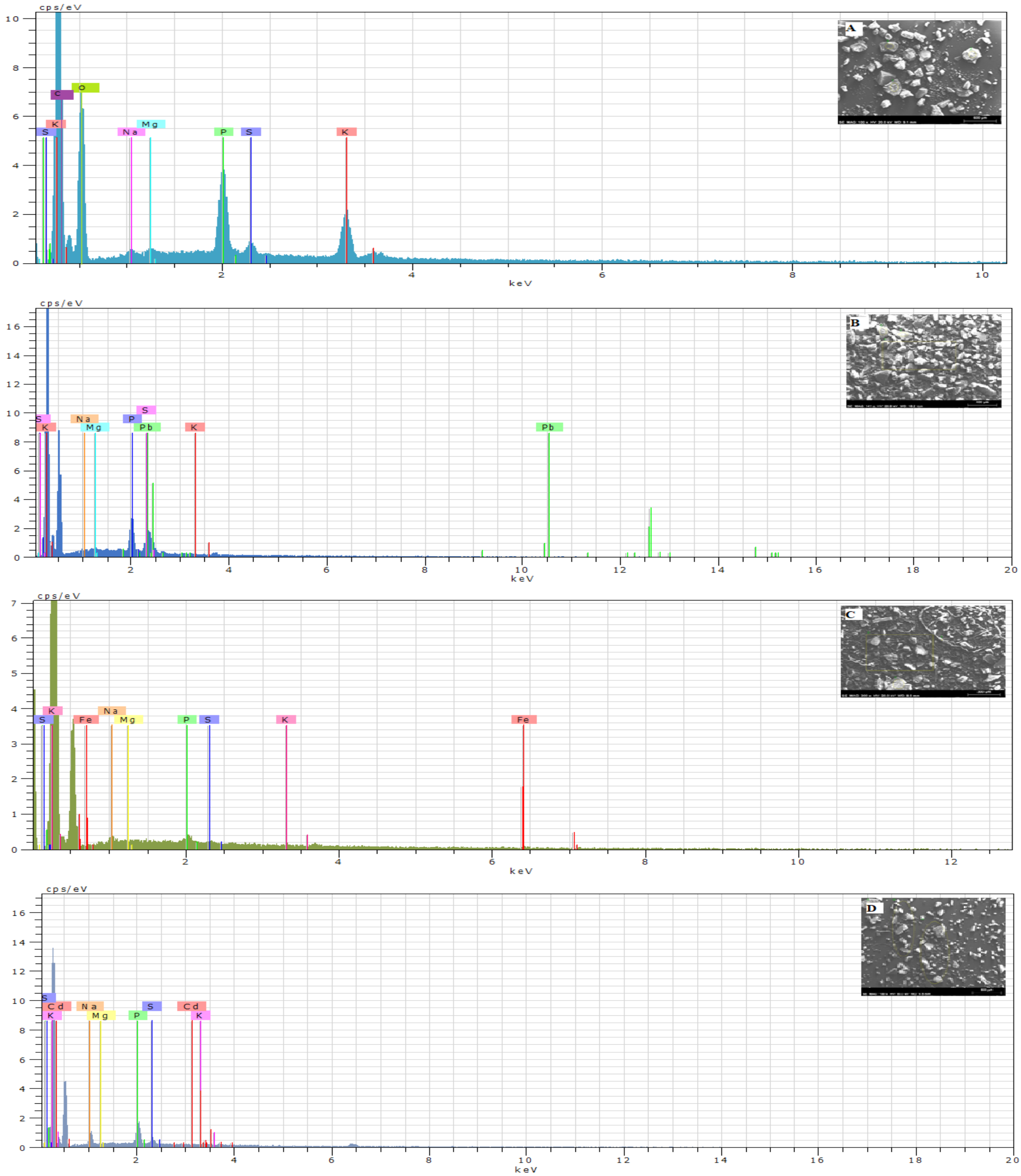


Figure 4. EDAX data of B1 biosorbent (A), after interaction with B1-Pb (B), after interaction with B1-Fe (C), after interaction with B1-Cd (D).

*Şekil 4. B1 biyosorbentine ait EDAX verileri (A), B1-Pb ile etkileşme sonrası (B), B1-Fe ile etkileşme sonrası (C), B1-Cd ile etkileşme sonrası (D)*

Table 1. Low concentration metal ion equilibrium concentrations and % recovery data of biosorbents (F1, B1 and Fs)

*Çizelge 1. Biyosorbentlerin (F1, B1 ve Fs) düşük konsantrasyonda metal iyonu denge konsantrasyonları ve % kazanım verileri*

| Metal Ions | pH | $C_{o(ppm)}$ | B1 $C_{e(ppm)}$ | B1 Recovery% | FI $C_{e}$ (ppm) | FI Recovery% | Fs $C_{e}$ (ppm) | Fs Recovery% |
|---|---|---|---|---|---|---|---|---|
| **Cd** | 5 | 1.5 | 0.028±0.0008 | 98.13 | 0.054±0.0007 | 96.13 | 0.083±0.0008 | 94.46 |
| **Cu** | 4.5 | 1.5 | 0.178±0.0043 | 88.13 | 0.312±0.0032 | 79.20 | 0.472±0.0066 | 68.53 |
| **Fe** | 6 | 1.5 | 0.116±0.0038 | 92.26 | 0.161±0.0020 | 89.25 | 0.375±0.0015 | 75.00 |
| **Ni** | 6 | 1.5 | 0.311±0.0034 | 79.26 | 0.339±0.0127 | 77.40 | 0.635±0.0052 | 57.66 |
| **Pb** | 5.5 | 1.5 | 0.037±0.0016 | 97.53 | 0.059±0.0021 | 96.06 | 0.114±0.0017 | 92.40 |
| **Zn** | 6.5 | 1.5 | 0.099±0.0023 | 93.40 | 0.135±0.0038 | 91.00 | 0.236±0.0055 | 84.26 |

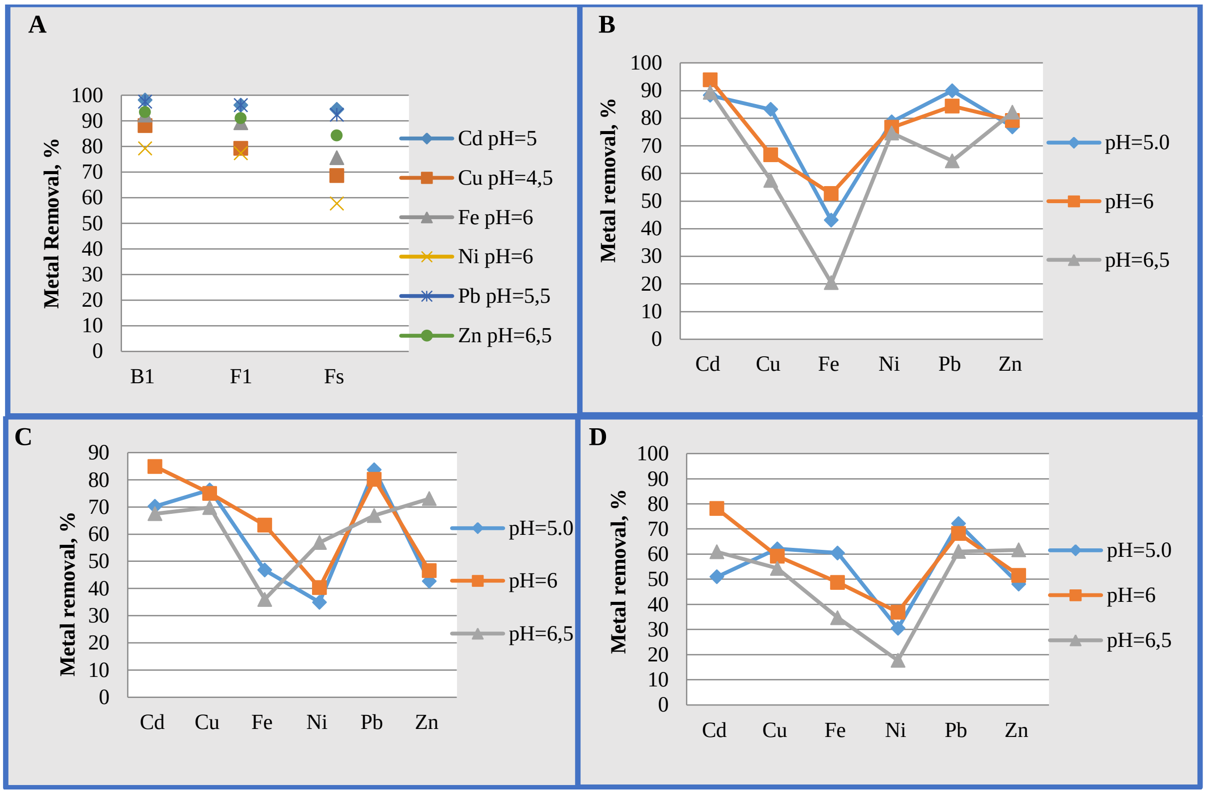


Figure 5. A. Low concentration metal ion biosorption Table, B. The graph of the biosorbent competition with the pH effect of the B1 biosorbent in the medium containing all metals, C. The biosorbent competition graph with the pH effect of the F1 biosorbent in the medium containing all metals, D. Graph of biosorbtion competition with pH effect of Fs biosorbent in media containing all metals.

*Şekil 5. A. Düşük konsantrasyonda metal iyonu biyosorbsiyon grafiği, B. biyosorbentinin metallerin tümünü içeren ortamda pH etkisi ile biyosorbsiyon rekabeti grafiği, C. F1 biyosorbentinin metallerin tümünü içeren ortamda pH etkisi ile biyosorbsiyon rekabeti grafiği, D. Fs biyosorbentinin metallerin tümünü içeren ortamda pH etkisi ile biyosorbsiyon rekabeti grafiği.*

Biosorbtion competitions of B1, F1 and Fs biosorbents at different pH values in a mixture solution of Cd (II), Cu (II), Fe (II), Ni (II), Pb (II) and Zn (II) metal ions were investigated. When Figure 5 and Table 2-4 are examined, it is observed that the biosorption capacity of some metals increases and some decreases with the increase of pH. This reveals the importance of pH in biosorbent metal adsorption. Studies have indicated that pH changes affect the biosorption capacity (Pratush, 2018; Zhao et al., 2019).

When we evaluated the results of biosorption application in drinking, river and wastewater, values were found below the biosorption capacity efficiency obtained in experimental studies. The presence of different metal contents in this type of water and their participation in biosorption may have affected this situation. The highest biosorption efficiency was obtained with % 81.09 removal of Pb and % 75 of Cd in the sample taken before the Dicle river facility (Table 5-6).

Biosorbtion studies performed with different biosorbents are shown in Table 7.

## CONCLUSION

 

Depletion of water resources and exposure to toxic pollution with heavy metals is a major problem. Finding ways to deal with them is a serious issue that every segment should focus on. Various methods are used to remove toxic contaminated water resources from heavy metals or to protect them from such

Table 2. Results of biosorbent competition of B1 biosorbent in different pH solutions containing a mixture of metals

*Çizelge 2. B1 biyosorbentinin metallerin tümünü içeren farklı pH da ortamlarında biyosorbsiyon rekabetinin incelenmesi*

| | **pH=5** | | **pH=6** | | **pH=6.5** | |
|---|---|---|---|---|---|---|
| **Metal Ions** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** |
| **Cd** | 0.176±0.0012 | 88.26 | 0.093±0.0009 | 93.80 | 0.160±0.0003 | 89.33 |
| **Cu** | 0.253±0.0039 | 83.13 | 0.500±0.0028 | 66.66 | 0.639±0.0060 | 57.40 |
| **Fe** | 0.854±0.0066 | 43.00 | 0.510±0.0038 | 52.66 | 1.194±0.0030 | 20.40 |
| **Ni** | 0.320±0.0111 | 78.66 | 0.350±0.0040 | 76.67 | 0.381±0.0096 | 74.60 |
| **Pb** | 0.151±0.0011 | 89.93 | 0.235±0.0027 | 84.33 | 0.532±0.0014 | 64.53 |
| **Zn** | 0.348±0.0061 | 76.80 | 0.313±0.0039 | 79.13 | 0.268±0.0063 | 82.13 |

Table 3. Results of biosorbent competition of F1 biosorbent in different pH solutions containing a mixture of metals

*Çizelge 3. F1 biyosorbentinin metallerin tümünü içeren farklı pH da ortamlarında biyosorbsiyon rekabetinin incelenmesi*

| | **pH=5** | | **pH=6** | | **pH=6.5** | |
|---|---|---|---|---|---|---|
| **Metal Ions** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** |
| **Cd** | 0.446±0.0856 | 70.26 | 0.229±0.0036 | 84.93 | 0.487±0.0028 | 67.53 |
| **Cu** | 0.355±0.0054 | 76.33 | 0.375±0.0052 | 75.00 | 0.453±0.0040 | 69.8 |
| **Fe** | 0.798±0.0028 | 46.80 | 0.550±0.0088 | 63.33 | 0.960±0.047 | 36.00 |
| **Ni** | 0.976±0.0297 | 34.93 | 0.895±0.0185 | 40.33 | 0.646±0.0090 | 56.93 |
| **Pb** | 0.246±0.0021 | 83.66 | 0.297±0.0015 | 80.20 | 0.497±0.0057 | 66.86 |
| **Zn** | 0.857±0.0059 | 42.86 | 0.802±0.0057 | 46.53 | 0.404±0.0008 | 73.06 |

Table 4. Results of biosorbent competition of Fs biosorbent in different pH solutions containing a mixture of metals

*Çizelge 4. Fs biyosorbentinin metallerin tümünü içeren farklı pH da ortamlarında biyosorbsiyon rekabetinin incelenmesi*

| | **pH=5** | | **pH=6** | | **pH=6.5** | |
|---|---|---|---|---|---|---|
| **Metal Ions** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** | **$C_e$ (ppm)** | **Recovery %** |
| **Cd** | 0.735±0.0458 | 51.00 | 0.328±0.0033 | 78.13 | 0.586±0.0145 | 60.93 |
| **Cu** | 0.568±0.0066 | 62.13 | 0.612±0.0050 | 59.2 | 0.685±0.0012 | 54.33 |
| **Fe** | 0.983±0.0104 | 60.46 | 0.769±0.0021 | 48.73 | 0.979±0.0021 | 34.72 |
| **Ni** | 1.043±0.0729 | 30.46 | 0.947±0.0229 | 36.86 | 1.234±0.0069 | 17.73 |
| **Pb** | 0.418±0.0043 | 72.13 | 0.476±0.0015 | 68.26 | 0.586±0.0074 | 61.06 |
| **Zn** | 0.775±0.0062 | 48.33 | 0.727±0.0096 | 51.53 | 0.574±0.0055 | 61.70 |

Table 5. Biosorption efficiency values of Cu, Cd and Pb metals in drinking water and wastewater samples were taken from different stations.

*Çizelge 5. Farklı bölgelerden alınan içme ve atık su örneklerinde Cu, Cd ve Pb metlallerine ait biyosorbsiyon verimi değerleri*

| **Sampling Point** | Cu | | | Cd | | | Pb | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Co ppb** | **Ceppb** | **% recovery** | **Co ppb** | **Ce ppb** | **% recovery** | **Co ppb** | **Ce ppb** | **% recovery** |
| **DI** | 15.62±1.8 | 8.128±0.6 | 48.07 | 0.97±0,001 | 0.44±0.02 | 54.63 | 0.66±0.008 | 0.13±0.005 | 71.73 |
| **DNO** | 106.6±0.35 | 37.6±0.02 | 66.03 | 9.48±0.09 | 2.37±0.03 | 75.05 | 2.75±0.3 | 0.52±0.8 | 81.09 |
| **DAG** | 24.04±0.81 | 11.04±1.34 | 54.16 | <LOD | <LOD | - | 1.13±0.30 | 0.29±0.004 | 74.36 |
| **DAC** | 14.25±0.5 | 7.03±0.11 | 51.84 | <LOD | <LOD | - | 0.96±0.005 | <LOD | - |
| **DNS** | 113.7±0.25 | 113.7±0.25 | 60.17 | 13.37±0.06 | 4.71±0.04 | 63.16 | 5.16±0.98 | 1.29±0.007 | 75.00 |
| **MI** | 99.74±2.95 | 99.74±2.75 | 57.98 | 2.26±0.08 | 1.03±0.06 | 54.42 | 2.34±0.36 | 0.67±0.009 | 68.34 |

Table 6. Biosorption efficiency values of Ni, Zn and Fe metals in drinking water and wastewater samples taken from

different stations

*Çizelge 6. Farklı bölgelerden alınan içme ve atık su örneklerinde Ni, Zn ve Fe metlallerine ait biyosorbsiyon verimi değerleri.*

| | Ni | | | Zn | | | Fe | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sampling Point** | **Co ppb** | **Ce ppb** | **Recovey %** | **Co ppb** | **Ce ppb** | **Recovey %** | **Co ppb** | **Ce ppb** | **Recovey %** |
| **DI** | 15.80±08 | 0.08±0.6 | 61.56 | 101.0±9.1 | 42.57±3.02 | 57.90 | 8.1±0.21 | 2.26±0.06 | 72.09 |
| **DNO** | 11.54±0.75 | 3.57±0.21 | 68.12 | 52.28±1.08 | 17.3±1.48 | 67.01 | 162.1±3.4 | 58.32±1.55 | 67.09 |
| **DAG** | 30.16±2.2 | 9.6±1.22 | 69.00 | 110.34±9.6 | 48.6±1.43 | 56.48 | 10.8±1.12 | 3.91±0.07 | 68.76 |
| **DAC** | 14.9±0.86 | 4.46±0.07 | 71.04 | 51.48±1.28 | 19.5±0.04 | 61.64 | 7.17±0.05 | 2.63±0.04 | 63.00 |
| **DNS** | 22.3±1.45 | 8.17±0.42 | 63.33 | 79.13±2.9 | 34.3±1.48 | 56.96 | 213±1.95 | 79.38±0.38 | 62.91 |
| **MI** | 9.76±0.95 | 3.51±0.61 | 64.98 | 257.7±4.8 | 90.73±1.6 | 62.96 | 71.5±1.36 | 27.16±1.09 | 62.31 |

**DI:** Diyarbakir Drinking Water, **DNO:** Tigris River Before Installation, **DAG:** Introduction to Dicle Treatment Plant, **DAC:** Leaving Dicle Treatment Plant, **DNS:** Tigris River After Facility and **MI:** MI: named as Mardin Drinking Water samples. ***Dİ:****Diyarbakır İçme suyu,* ***DNO:*** *Dicle Nehr i Tesis Öncesi,* ***DAG:*** *Dicle Arıtma Tesisine Giriş,* ***DAÇ:*** *Dicle Arıtma Tesisinden Çıkış,* ***DNS:*** *Dicle Nehri Tesis Sonrası,* ***MI:*** *Mardin İçme Su numuneleri olarak adlandırılmıştır.*

Table 7. Results of biosorption studies for heavy metal removal
*Çizelge 7. Ağır metal adsorbsiyonu için yapılan çalışmalar*

| Biosorbent | Metals | pH | Temperature °C | Removal % | References |
|---|---|---|---|---|---|
| Chitosan / oxide nanocomposite | Ni(II), Cd(II), Pb (II) | 3 | 22 | 98 | (Keshvardoostchokami, et al., 2017) |
| Algae | Cu(II) | 4 | 25-45 | 96.4 | (N A Lieswito, 2019) |
| *Pseudomonas sp* | Cd(II) | 7 | - | 92 | (Xu et al., 2020) |
| *Bacillus subtilis* | Zn(II) | 7.6-8.4 | 30 | 89.5 | (Sun et al., 2020) |
| *Bacillus gibsonii S-2* | Pb (II) | 4 | 40 | - | (Zhang et al., 2013) |
| *Talaromyces islandicus* | Pb (II) | 5 | 30 | 90 | (Sharma et al., 2020) |
| *Eucalyptus camaldulensis* | Pb (II) | 7 | 25 | 85 | (Sabri et al., 2018) |
| *Algae (Mixed culture)* | Pb (II) | 6 | 30 | 95.43 | (Mousavi et al., 2019) |
| *Ralstonia solanacearum* | Pb (II) | 6 | 35 | 90 | (Pugazhendhi et al., 2018) |
| *Sargassum muticum* | Pb (II) | 5 | 20 | 96 | (Hannachi and Hafidh, 2020) |
| *B. licheniformis* | Pb (II) | 6 | 30 | 98 | (Wen et al., 2018) |

situations. Using biosorbent, heavy metal removal with biosorption has advantages over physical and chemical applications. Some of these advantages are the ease of the application process, the absence of toxic chemicals in the process stages, and the economical nature of the biosorbent after the process. When choosing a biosorbent for biosorbent, qualities such as its applicability to drinking and wastewater at low concentrations, high biosorption capacity, cheap cost and no risk of being a pathogen for human health should be considered. Considering these criteria, soil bacilli resistant to extreme conditions, which do not carry pathogenicity risk, were used as biosorbents. As a result of the experiments carried out at different pH values at 25 °C, the maximum adsorption capacity at pH 6.0 was determined. The morphological change of biosorption in biomass and its element composition were also revealed ~~by~~ via the SEM and EDAX micrographs. It was determined that the highest adsorption capacities were about % 98 of Pb (II) and Cd (II) metals. As a result, heavy metal removal up to 98 % was achieved with the high metal binding capacity of bacteria. Considering the widespread presence of many biosorbents in nature, the biosorption method will provide significant benefits for heavy metal removal in water.

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The contribution of the authors is equal.

### Statement of Conflict of Interest

Authors have declared no conflict of interest.

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