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ORIGINAL PAPER

Removal of metals and metalloids from acidic mining lake (AML) using olive oil solid waste (OSW)

R. İlay[1] · A. Baba[2] · Y. Kavdır[1]

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Abstract
The acidic mining lakes have low pH values and high metal and metalloid concentrations. In this study, the ability of low-cost olive oil solid waste (OSW) to remove Al, As, Cd, Fe, B and Ti ions from aqueous solutions in short term has been evaluated. Adsorption capacities (mg g^{-1}) of OSW (1:5–1:10 w/v) were 764.06–411.75 for Al, 0.26 for As, 0.07–0.14 for Cd, 2181.5–2406.5 for Fe, 23.70–82.50 for B and 0.12–0.0.34 for Ti. OSW addition increased acidic mine water (AMW) pH from 2.41 to 3.2 with 1:5 and from 2.41 to 2.7 to 1:10 mixing ratio, respectively, after 10 min. The best gradual decrease has been observed with different ratio of OSW applications on B and Ti concentrations. OSW adsorbs 32.41% and 62.68% of B at the ratio of 1:5 and 1:10 and 55.29% and 83.04% of Ti at the ratio of 1:5 and 1:10 (OSW:AMW) mixtures, respectively. The results show that OSW has great potential for metal removal from acidic mine water.

Keywords Adsorption · Olive oil solid waste · Heavy metal/metalloid · Acidic mine lake

Introduction

It is known that oxidation of sulfur bearing minerals is responsible for the formation of low pH waters. This event is typically observed in mining activities, which results in the formation of acid mine drainage (AMD) from underground galleries to surface waters or in the creation of acidic mining lakes (AML) within the surface depressions of abandoned open-pit mines. AMLs are commonly observed in the open-pit coal mining sites in Central Europe and Northern America where lignite reserves are found close to ground surface. Hundreds of such AMLs are found in the Lusatia region of Germany (Friese et al. 1998; Yucel et al. 2014; Wisotzky and Obermann 2001; Karakas et al. 2003; Yucel and Baba 2013), and numerous researches have been conducted on their formations and characteristics (Blodau 2006; Evangelou 1998). AMLs have low pH values and high metal and metalloid concentrations (Gunduz et al. 2007; Yucel et al. 2016). It has been previously reported that pH values ranged from 2 to 4 and electrical conductivity values reach up to 5000 μS^{-1} cm (Yucel et al. 2014; Blodau 2006; Evangelou 1998). These low pH values cause elevated concentrations of metals/metalloids and toxic elements such as Cr, Al, Cd, Mn, As, Zn and Ni. Drainage water from AMLs can destruct downstream aquatic life. Besides degraded water quality, acidic mining lakes are also responsible for landslides by dissolving carbonate minerals in soil (Geller et al. 1998; Schultze and Geller 1996). There are number of AMLs in the Çan Coal District in Çanakkale, Turkey (Fig. 1). The area is rich in lignite, which is currently being utilized in a 2 × 160 MW capacity thermal power plant and in domestic heating of the surrounding residential areas. There are also numerous small-scale private companies that extract coal from a number of sites in the region. When the depression cones of these open pits are filled with surface and subsurface drainage, numerous AMLs with variable sizes are formed (Baba et al. 2009; Yucel et al. 2014). pH of these lakes are generally lower than 4 and accumulate metals such as Al, Fe, Mn. The limnological and hydrogeochemical characteristics of AML (Gunduz and Baba 2008; Gunduz et al. 2007; Yucel and Baba 2013; Yucel et al. 2014) were studied in detail. Yucel and Baba (2016) reported that if sulfur content of a

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✉ R. İlay
rilay@comu.edu.tr

[1] Soil Science and Plant Nutrition Department, Agricultural Faculty, Çanakkale Onsekiz Mart University, 17020 Çanakkale, Turkey

[2] İzmir Institute of Technology, Geothermal Energy Research and Application Center, 35430 Gülbahçe, Urla, İzmir, Turkey

Fig. 1 Acidic mine lake in Biga Peninsula

rock > 0.3%, it oxidizes rapidly and may produce AMD. The paste pH of the mine wastes was between 2.3 and 3.8, which were similar to pH value of AML water in the region.

Acidic mine lakes have brown reddish color caused by dissolution of iron hydroxides. If such lakes are not rehabilitated, they lead to contamination of surface and groundwater resources (Gunduz and Baba 2008). Reclamations of such lakes with current treatment technologies are expensive; therefore, there is an urge to find out other materials. Many technologies, including reverse osmosis and ion-exchange resin, have been used to remove heavy metals and harmful metalloids from aqueous solution. The most commonly used technology for active treatment is chemical neutralization. Liming is a common and effective treatment practice to neutralize acidity and precipitate heavy metals. However, this method of treatment becomes expensive due to the extensive period during which treatment is required (MEND 1994). The adsorbents can be mineral, organic, zeolites, industrial and agricultural by-products and wastes (Kurniawan et al. 2006). The lists of some materials that can be used as low-cost absorbents for metal and metalloid removal from aqueous solutions are summarized in Table 1.

Treatment of AMD by passive methods is grouped in four categories: anoxic limestone drain, neutralization, biosorption, bioreactors and wetland treatment. There are some criteria to select the best biosorption materials such as the treatment of AMD should not create environmental problems, materials used for AMD treatment should be renewable, materials should be readily available and material should be economic (Bechard 1993). Several ways to accumulate and bind pollutants by organic materials have been reported by Veglio and Beolchini (1997).

Turkey is an important olive producer and production of olive for oil extraction in 2015 was 1.3×10^6 tons in Turkey (TUİK 2015). Approximately 75% of trees were grown for olive oil production and 25% for table olive production in Turkey (TUIK 2015). About 26% of Turkey's total olive production is produced from Marmara region (study area). Olive oil solid waste (OSW) is a by-product which can also cause storage problems. Little amounts of OSW are used as organic fertilizer (İlay et al. 2013), fodder, and additive in animal food. OSW can also be used as a low-cost adsorbent.

The use of agricultural and organic by-products in bioremediation of heavy metals is known as biosorption (Gupta et al. 1998, 2012a; Gupta and Saleh 2013). Biosorption of metals and metalloids by agricultural and industrial wastes is used in water treatment. Red mud (Nadaroglu et al. 2010) is largely produced from the alumina industry. De-oiled soya was used as an adsorbent for removal of toxic dyes from wastewater (Mittal et al. 2009, 2010). Hasan et al. (2000) reported that rubber-wood ash was good adsorbent for the Ni(II) cation from dilute solution. The maximum adsorption for nickel was 0.492 mmol g^{-1} at pH 5 and 30 °C. Balarak et al. (2015) used canola residues to remove methylene blue from aqueous solution, and the maximum dye removal was obtained to be 97.5%. Photocatalytic treatment can be used to reduce water pollution caused by dyes (Saravanan et al. 2013a, b). The photocatalytic activity of ZnO modified with CdO successfully degraded methylene blue under visible light (Saravanan et al. 2011, 2015). Martínez et al. (2006) used by-product of wine production for sorption of lead and cadmium from aqueous solutions. They reported that, at pH 5.5, maximum sorption capacities of grape stalk was 0.241 and 0.248 mmol g^{-1} for Pb(II) and Cd(II), respectively. HCl or EDTA solutions were successful to desorb lead from the grape stalks.

Amin et al. (2006) used rice husk to desorb arsenic from aqueous solution. Six grams of rice husk was mixed with 100 µg L^{-1} As containing solution at a pH range of 6.5–6.0. About 71–96% desorption was observed with KOH-treated rice husk. Besides modified cellulose materials, walnut hull was also good absorbent (Wang et al. 2009) for chromium

Table 1 Metal/metalloids adsorption capacities for some low-cost adsorbents

Material	Metal/metalloid	Adsorption capacities (mg g^{-1})	References
Fly ash	B	20.9	Oztürk and Kavak (2005)
Montmorillonite	Cu(II)	3.0	Abollino et al. (2003)
Cocoa shells	Pb(II)	6.2	Meunier et al. (2003)
Cork wastes	Pb(II)	13.46	López-mesas et al. (2011)
Organophilic bentonite	Cd(II)	2.8	Andini et al. (2006)
Hazelnut shell	Ni(II)	10.1	Demirbas et al. (2002)
Tobacco dust	Zn(II)	25.1	Qi and Aldrich (2008)
Peanut hulls	Cu(II)	65.6	Periasamy and Namasivayam (1996)
Orange peel (citrus reticulate)	Ni(II)	80.0	Ajmal et al. (2000)
Grape stalk waste	Ni(II)	10.6	Villaescusa et al. (2004)
	Cu(II)	10.1	
	Cd(II)	0.24 *	Martinez et al. (2006)
Coffee beans	Cd(II)	0.058*	Kaikake et al. (2007)
Grape stalk	Cu(II)	42.92	Escudero et al. (2008)
	Ni(II)	38.31	
Apple residues	Cd(II)	0.158	Lee et al. (1998)
Tobacco (dust cultural waste)	Pb(II)	39.6	Qi and Aldrich (2008)
Sugar beet pulp	Pb(II)	73.8	Reddad et al. (2003)
Olive pomace	Cd(II)	0.030	Martín-Lara et al. (2008)
Tree bark	Cu(II)	21.6	Gaballah and Kilbertus (1998)
Banana peel	Cu(II)	0.075	Kurniawan et al. (2006)
Olive cake	Cd(II)	65.35	Al-Anber and Matouq (2008)
Tea factory waste	Cr(VI)	54.65	Malkoc and Nuhoglu (2007)
Grape bagasse	Cd(II)	0.479	Farinella et al. (2007)
Palm tree leaves	Zn(II)	14.7	Abu Al-Rub (2006)
Rubber-wood		0.492*	Hasan et al. (2000)
Cotton cellulose	B(III)	11.3	Liu et al. (2007)
Apple residue	Cu(II)	0.170	Lee et al. (1998)
Rice bran	Zn(II)	14.17	Wang et al. 2006
Brewery waste	Pb(II)	33.1-1656	Can and Jianlong (2008)
	Ag(I)	17.3-864	
Carrot residue	Cu(II)	0.515	Nasernejad et al. (2005)
Crab shell	Cu(II)	243.9	Vijayaraghavan et al. (2006)
	Co(II)	322.6	
Maize cob and husk	Zn(II)	495.9	Iqwe et al. (2005)
	Pb(II)	456.7	
	Cd(II)	493.7	
Olive pomace	Cu(II)	0.180*	Martín-Lara et al. (2008)
Active carbon from oat hulls	As	1.57–3.09	Chuang et al. (2005)
Olive solid waste (OSW)	Al(III)	764.05–411.75	This study
	As	0.26	
	Cd(II)	0.079–0.142	
	Fe	2181.5–3406.5	
	B	23.70–82.50	
	Ti	0.128–0.348	

*mmol g^{-1}

(VI). Optimum pH for removal was 1.0, while chromium (VI) removal was 97.3% (Wang et al. 2009). The removal increased with adsorbent concentration and the decrease in adsorbate concentration. Gharaibeh et al. (1998) reported that olive oil by-products were efficient for zinc and lead removal from aqueous solutions. Removal of heavy metals and metalloids from contaminated water is very important for environmental health (Weng and Huang 2004). Conventional technologies for the removal of heavy metal such as chemical precipitation, membrane separation, reverse osmosis, adsorption and emulsion per traction technology (Zhou et al. 1993; Naiya et al. 2009; Ali 2010, 2012; Ali et al. 2012; Gupta et al. 2011, 2012b, 2013). Saravanan et al. (2016) suggested that PANI/ZnO nanocomposite can be used for environmental remediation. Many methods have been studied to develop much more cheaper and effective technique for removal of metals and metalloids from wastewater and adsorption was the most effective method for removal of heavy metal if combined with appropriate regeneration steps (Naiya et al. 2009; Khan et al. 2011; Ali et al. 2016, 2017).

The aim of this study is to investigate the possible use of olive oil solid waste (OSW) as a low-cost and reachable adsorbent for the removal of toxic metals and metalloids from acidic mine lakes which can be seen in different part of world such as Biga Peninsula.

Materials and methods

Study area

The Çan Coal District is located in Biga Peninsula in North Western Turkey. It is located about 100 km away from Çanakkale. The Çan Coal District has been in operation since 1980s, and lignites are being extracted in the region. Acidic lakes can be seen around this region where agriculture especially olive and olive oil productions are an important part of economy. As a result, high amount of olive oil waste are generated that can cause storage problems. Paleozoic-aged metamorphic rocks are the basement of the study area. Volcanic rocks are altered and fractured due to the effects of active faults in the region (Fig. 2). Many industrial metals and some precious metals have been detected in the altered volcanic rocks (Baba and Gunduz 2010; Baba et al. 2009).

Methods

100 mL sample was taken from AML water for heavy metals and metalloids analysis. AML samples were filtered through 0.45-µm filter paper and stored in refrigerator at 4 °C. 0.5 N HNO_3 was added to samples to reduce sample pH below 2 and analyzed by inductively coupled plasma-mass spectroscopy technique (Agilent 7500ce Octopole Reaction System (ORS) ICP-MS). Some chemical analysis results of AMW are shown in Table 2. Olive oil solid waste (OSW) has been obtained from olive oil factory in Çanakkale, and some analysis results of OSW (İlay et al. 2013) are presented in Table 3. Total carbon and nitrogen contents of OSW were determined by Leco CN elemental analyzer (Kirsten 1983). Dry ashing technique was used to determine macro- and micro-element contents of OSW and analyzed by ICP-OES (Wolf et al. 2003). Total phenolic compounds (TPC) of OSW was determined by using the Folin–Ciocalteu reagent and expressed as gallic acid equivalents (Lesage-Meessen et al. 2001). EC and pH of OSW was determined in 1:5 OSW: water mixtures using EC and pH meter. OSW samples were sieved through 4-mm screen opening, subsamples were taken and mixed with acidic mine water (AMW) at rates of 1:5 (20 g OSW:100 ml AMW) and 1:10 w/v (20 g OSW:200 ml AMW) with five replicates. pH of OSW and OSW–AMW mixture was determined using an Orion 420A pH meter. Samples were mixed with glass stirrer, and initial pH was determined after 10 min. The tops of the beakers were covered with parafilm to prevent evaporation of water from samples then shaked for 19.5 h at 100 rpm with rotational shaker (Heidolph-unimax). Samples were removed from shaker and pH readings were repeated (1st reading). Samples were shaked at 100 rpm, and pH readings were repeated every hour for 5 times (2, 3, 4, 5, 6. readings). Before ICP analysis, samples were filtered through Whatman No: 2 filter paper and stored at cooler at 4 °C. Results of pH values after shakings are presented in Fig. 3. All these measurements were conducted at 25 °C laboratory temperature.

Surface area measurements were performed on Quantachrome Quadrasorb SI surface area analyzer. The samples were out-gassed for 3 h under nitrogen prior to adsorption measurement. The specific surface area of OSW was determined by applying the BET method. OSW was ground with grinder, and sieved to 0.5 mm particle size and sample weight was 0.34 g.

Heavy metals and metalloid absorptions of OSW at 1:5 and 1:10 AMW have been calculated according to Eq. (1)

$$q = \left[\left(C_i - C_f\right) * V\right] / W \quad (1)$$

where $q =$ (amount of adsorbate, adsorbed in mg)/(amount of adsorbent used for adsorption in g). C_i is the initial concentration of heavy metals and metalloid (mg L^{-1}); C_f is final heavy metals and metalloid concentrations of solution (mg L^{-1}); V is final total volume in the reactor (L); W is the amount of OSW used for biosorption test (g) (*density of OSW was 0.8 g cm^{-3}).

SPSS 17 package program has been used for statistical analysis. Differences among treatments were determined by ANOVA; comparisons were made by Post Hoc Test.

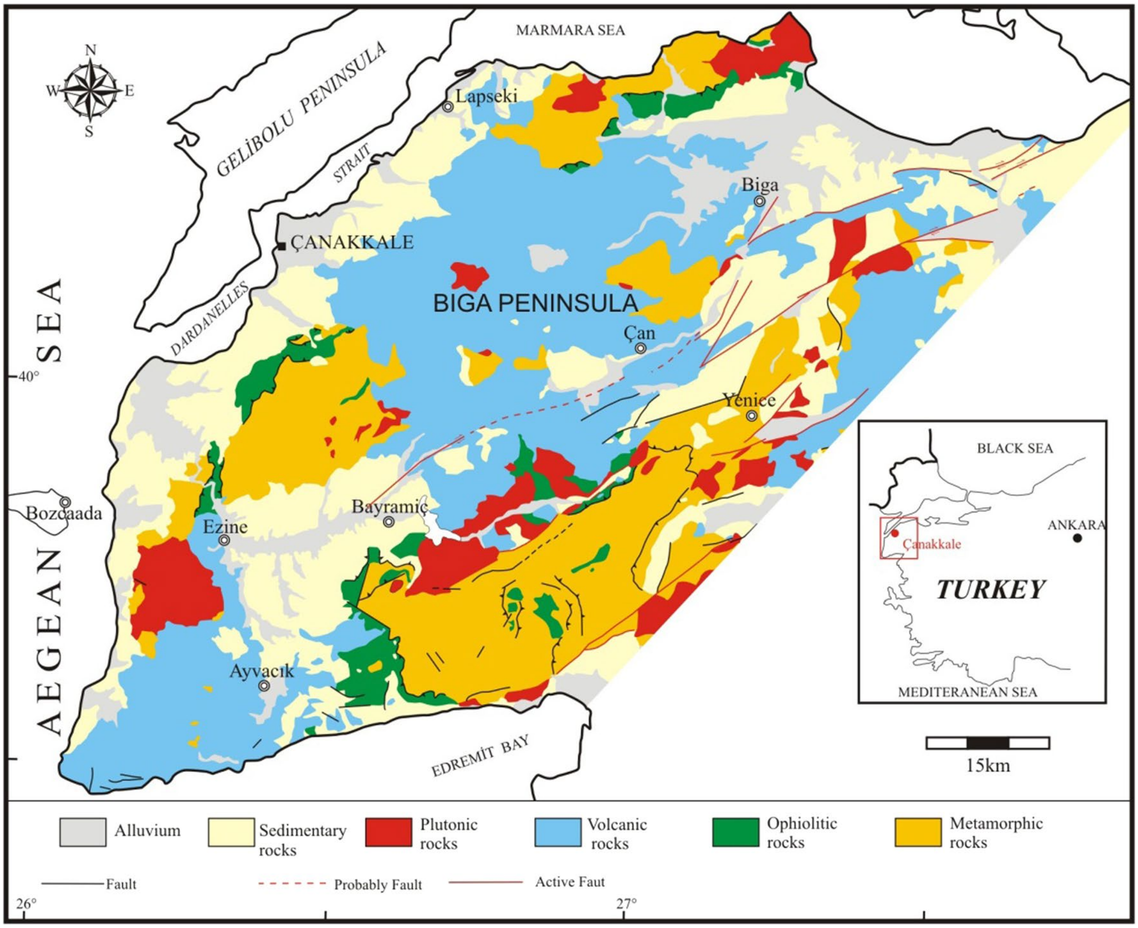

Fig. 2 Geological map of Biga Peninsula (Baba and Gunduz 2010, modified from General Directorate of Mineral Research, Exploration 2002)

Results and discussion

OSW has low pH (5.7), high Fe (1243.91 mg kg^{-1}) content and surface area of OSW was 0.545 m^2 g^{-1} (Table 3). Descriptive statistical results are presented in Tables 4 and 5. The results of heavy metals and metalloids concentrations after treatment of AMW are presented in Figs. 4, 5 and 6. AMLs have low pH values and high metal and metalloid concentrations (Gunduz et al. 2007; Yucel et al. 2016).

Addition of OSW to AMW increased pH from 2.41 to 3.2 with 1:5 and from 2.41 to 2.7 with 1:10 mixing ratio, respectively, after 10 min (Fig. 3). The increase in pH can be caused by either adsorption of acidic metals by OSW or release of basic elements from OSW. OSW applications reduced Al, As, Cd, Fe, B and Ti concentrations in AMW which resulted with the increase in mixture pH. Increasing pH in AMW:OSW mixtures reduced most of the metals and metalloid concentrations except As. Al and Fe concentration reduced with 1:5 OSW which had higher solution pH. B, Ti and Cd concentrations reduced in AMW:OSW mixtures compared to AMW alone (pH:2.41, Fig. 3).

Heavy metals and metalloid adsorption capacities of OSW are presented in Table 6. Except Al, all cations were effectively adsorbed by 1:10 (OSW:AMW) mixture. Al concentration of AMW reduced from 273 to 150.75 mg L^{-1} when it was mixed with 1:5 (OSW:AMW) mixture (Fig. 4a). OSW: AMW (1:5) treatment reduced Al concentration of AMW about 45%, while 1:10 (OSW:AMW) treatment reduced 13% (Fig. 4a).

On the other hand, 1:5 (OSW:AMW) mixture had no significant effect on As reduction from AMW (Table 4 and Fig. 4b). 1:10 (OSW:AMW) mixture application reduced As concentration of AMW about 22% compared to initial value ($p < 0.05$).

OSW application dramatically reduced Fe concentrations of AMW (Fig. 5a). Average initial Fe concentration was 411 mg L^{-1}, and it reduced to 61.95 mg L^{-1} with OSW addition (1:5). OSW treatments reduced Fe concentrations 84.92% and 73.67% with 1:5 and 1:10 (OSW:AMW) mixtures, respectively (Fig. 5a). Iron content of OSW was originally higher than those of AMW (Tables 2 and 3). When AMW amount increased from 1:5 to 1:10 (OSW:AMW)

Table 2 Chemical properties of AMW

Properties	Value
pH	2.41
Li*	0.599
B	11.7
Na	210
Mg	160
Al	273
K	1100
Ca	65.5
Cr	0.0167
Mn	57.7
Fe	409
Co	2.37
Ni	1.12
Cu	0.144
Zn	10.6
Ga	0.019
As	0.103
Sr	2.55
Cd	0.0329
Ba	0.102
Ti	0.0373
Pb	0.0134

*Concentrations of all metal and metalloids are given in mg L^{-1} unit

Table 3 Chemical properties of the OSW (İlay et al. 2013)

Parameters	Value
pH	5.7 ± 0.04
EC (μS cm^{-1})	822 ± 2
N (%)	1.12 ± 0.06
P (%)	0.04 ± 0.00
K (%)	0.57 ± 0.00
Ca (%)	0.5 ± 0.02
Mg (%)	0.06 ± 0.00
B (mg kg^{-1})	16.9 ± 0.55
Fe (mg kg^{-1})	1243.91 ± 75.61
Mn (mg kg^{-1})	32.75 ± 1.99
Zn (mg kg^{-1})	17.34 ± 3.15
C (%)	49.1 ± 0.75
TPC (mg kg^{-1})	1.20 ± 0.01
C/N	43.8 ± 1.86
BET surface area (m^2 g^{-1})	0.545

TPC total phenolic compounds

mixture, soluble Fe of OSW released into the water. As a result 1:10 (OSW:AMW) mixture has higher Fe content compared to 1:5 (Fig. 5a).

OSW treatments reduced Cd contents significantly ($p < 0.05$) by 38.67% and 38.48% with 1:5 and 1:10 (OSW:AMW) mixtures, respectively (Table 5 and Fig. 5b). Gupta et al. (2006) used an industrial solid waste of sugar industry called "The bagasse fly ash" and removed 90% of Cd and Ni in 60 and 80 min, respectively, under the batch test conditions. Gupta et al. (2006) also studied influences of solution pH, adsorbent dose, adsorbate concentration, temperature, particle size, etc., on the removal of Cd and Ni. Maximum adsorption of Cd and Ni observed when concentrations were 14 and 12 mg L^{-1} and at a pH value of 6.0 and 6.5. Martín-Lara et al. (2008) reported that Cd absorption capacity of OSW was 0.030 mmol g^{-1}. In this study, Cd absorption capacity of OSW was 0.07 and 0.14 mg g^{-1} for 1:5 and 1:10 (OSW:AMW) mixtures, respectively. There were statistical differences ($p < 0.05$) of Cd contents among OSW treated and untreated AMW; however, no significant differences have been observed between ratios (Table 5 and Fig. 5b).

Agricultural by-products bind heavy metals by adsorption, chelation and ion exchange (Gardea-Torresdey et al. 1996; Sun and Shi, 1998). Iqwe et al. (2005), investigated that the adsorption of Pb^{2+}, Cd^{2+} and Zn^{2+} ions from solutions by unmodified and modified maize cob and husk. Maximum adsorption occurred at 495.9, 456.7 and 493.7 mg g^{-1} for Zn^{2+}, Pb^{2+} and Cd^{2+} ion, respectively, without modification.

B and Ti concentrations were lower in 1:10 (OSW:AMW) mixture than those in 1:5 ratio (Fig. 6a, b). Liu et al. (2007) reported that with higher pH, there was lower removal of boron by cotton cellulose. Therefore, increasing AMW resulted in lower solution pH and lower B and Ti removal. Instead of increasing sorbent amount, perhaps solution pH can be increased to enhance removal capacity of OSW.

The best gradual decrease has been observed with different ratio of OSW applications on B and Ti concentrations (Fig. 6b). OSW adsorbs 32.41% and 62.68% of B at the ratio of 1:5 and 1:10, respectively. OSW adsorbs 55.29% and 83.04% of Ti at the ratio of 1:5 and 1:10 (OSW:AMW) mixtures, respectively (Fig. 6b).

Several organic materials used to treat AMW according to local availability such as composts produced from cow manure, sawdust, straw (Vile and Wieder 1993). They reported that AMW quality in compost wetlands is improved by filtration of colloidal materials and adsorption of metals by the organic matrix. In general, biologically mediated Fe(II) reduction occurred and caused alkalinity (Vile and Wieder 1993).

Agricultural waste and other agricultural by-products have been used to remove heavy metals from aqueous medium (Kelly-Vargas et al. 2012; Hegazi 2013; Kadirvelu et al. 2001; Hamza et al. 2013). Carrot residues were

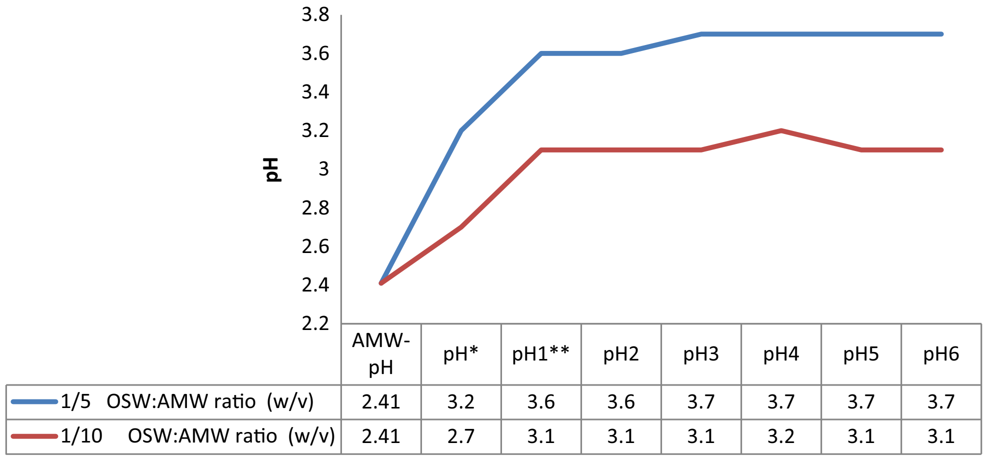

Fig. 3 Changes of pH as a function of time during the experiments (OSW:AMW mixture of 1 g/5 ml and 1 g/10 ml) with starting pH of 2.41. *10 min. after mixing, **19.5 h after mixing of OSW and AMW, interval among other pH readings were 1 h (last pH reading (pH6) was done 24.5 h after first reading)

Table 4 Descriptive statistics of metal/metalloids concentrations (mg L^{-1}) in AMW:OSW mixtures

Metals and metalloids	Applications	*N*	Mean	Std. error	Minimum	Maximum	Significant
Al	AMW	4	272.950	0.484	271	274	$p<0.05$
	AMW:OSW (1:5)	4	150.750	21.800	112	210	
	AMW:OSW (1:10)	5	236.400	3.326	229	248	
As	AMW	4	0.103	0.001	0.100	0.100	$p<0.05$
	AMW:OSW (1:5)	4	0.104	0.006	0.090	0.110	
	AMW:OSW (1:10)	5	0.080	0.006	0.060	0.090	
Fe	AMW	4	411.000	1.225	408.000	414.000	$p<0.05$
	AMW:OSW (1:5)	4	61.950	6.989	50.900	80.200	
	AMW:OSW (1:10)	5	108.200	2.709	102.000	115.000	
Cd	AMW	4	0.033	0.000	0.030	0.030	$p<0.05$
	AMW:OSW (1:5)	4	0.020	0.003	0.020	0.030	
	AMW:OSW (1:10)	5	0.020	0.001	0.020	0.020	
B	AMW	4	11.700	0.108	11.400	11.900	$p<0.05$
	AMW:OSW (1:5)	4	7.908	0.646	6.660	9.640	
	AMW:OSW (1:10)	5	4.366	0.049	4.200	4.490	
Ti	AMW	4	0.037	0.001	0.040	0.040	$p<0.05$
	AMW:OSW (1:5)	4	0.017	0.002	0.010	0.020	
	AMW:OSW (1:10)	5	0.006	0.000	0.010	0.010	

used as a biosorbent for heavy metal removal. Carboxylic and phenolic functional groups were responsible for the cation exchange capacity of carrot residue (Nasernejad et al. 2005). Pagnanelli et al. (2003) used olive solid waste biosorption of Cu, Pb and Cd. They concluded that carboxylic and phenolic groups were responsible for metal removal by a surface complexation mechanism. Therefore, OSW can be a promising, economic and easily available waste to clean AMW from metals and metalloids.

Conclusion

AMW-containing metals and metalloids have been sampled from Biga Peninsula, Çanakkale. Such water poses risk to the environment since they contain elevated concentrations of metals and metalloids. Evaluation of OSW for the metal and metalloid removal from AMW was studied. The results showed that it is possible for reclamation of AMW using olive solid waste. Results indicated that

Table 5 Statistical data of multiple comparisons between groups

Heavy metals and metalloids	(I) 1 (AMW) 2 (1:5) 3 (1:10)	(J) 1 (AMW) 2 (1:5) 3 (1:10)	Mean difference (I–J)	Std. error	Sig.
Al	1.00	2.00	122.20000*	17.214	0.000
		3.00	36.550	16.331	0.147
	2.00	1.00	−122.20000*	17.214	0.000
		3.00	−85.65000*	16.331	0.001
	3.00	1.00	−36.550	16.331	0.147
		2.00	85.65000*	16.331	0.001
As	1.00	2.00	−0.001	0.008	1.000
		3.00	0.02322*	0.007	0.028
	2.00	1.00	0.001	0.008	1.000
		3.00	0.02416*	0.007	0.023
	3.00	1.00	−0.02322*	0.007	0.028
		2.00	−.02416*	0.007	0.023
Fe	1.00	2.00	349.05000*	6.128	0.000
		3.00	302.80000*	5.813	0.000
	2.00	1.00	−349.05000*	6.128	0.000
		3.00	−46.25000*	5.813	0.000
	3.00	1.00	−302.80000*	5.813	0.000
		2.00	46.25000*	5.813	0.000
Cd	1.00	2.00	0.01267*	0.003	0.002
		3.00	0.01261*	0.002	0.001
	2.00	1.00	−0.01267*	0.003	0.002
		3.00	0.000	0.002	1.000
	3.00	1.00	−0.01261*	0.002	0.001
		2.00	0.000	0.002	1.000
B	1.00	2.00	3.79250*	0.509	0.000
		3.00	7.33400*	0.483	0.000
	2.00	1.00	−3.79250*	0.509	0.000
		3.00	3.54150*	0.483	0.000
	3.00	1.00	−7.33400*	0.483	0.000
		2.00	−3.54150*	0.483	0.000
Ti	1.00	2.00	0.02033*	0.002	0.000
		3.00	0.03067*	0.002	0.000
	2.00	1.00	−0.02033*	0.002	0.000
		3.00	0.01035*	0.002	0.001
	3.00	1.00	−0.03067*	0.002	0.000
		2.00	−0.01035*	0.002	0.001

*The mean difference is significant at the 0.05 level

mixing OSW with AMW at different rates reduced Al, As, Cd, Fe, Ti and B concentrations of water. Results suggested that OSW can remove maximum of 764 mg g^{-1} of Al, 0.14 mg g^{-1} Cd, 3406.5 mg g^{-1} Fe, 82.5 mg g^{-1} B and 0.35 mg g^{-1} Ti from AMW. OSW removed Fe more efficiently than other cations with a removal percentage approximately equal to 85%. Using raw OSW is an alternative method to remove metals and metalloids from AMW. OSW is easily reachable and inexpensive waste material in the Region. Therefore, it can be used easily and quickly in need.

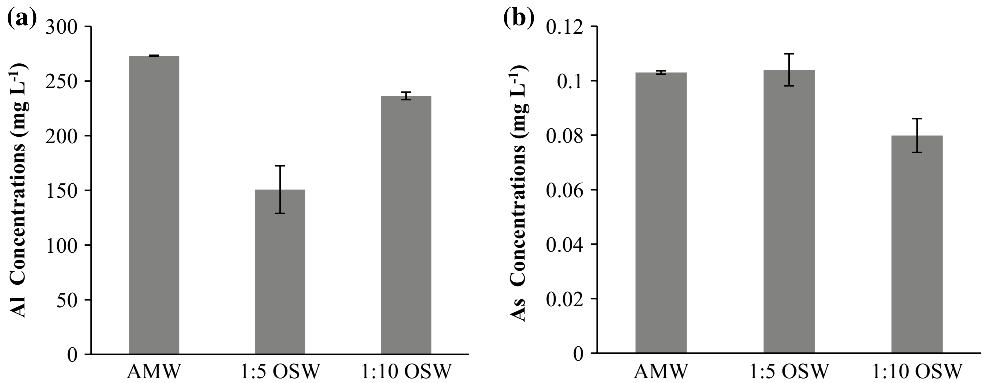

Fig. 4 **a**, **b** Al and As concentrations of AMW after OSW treatment

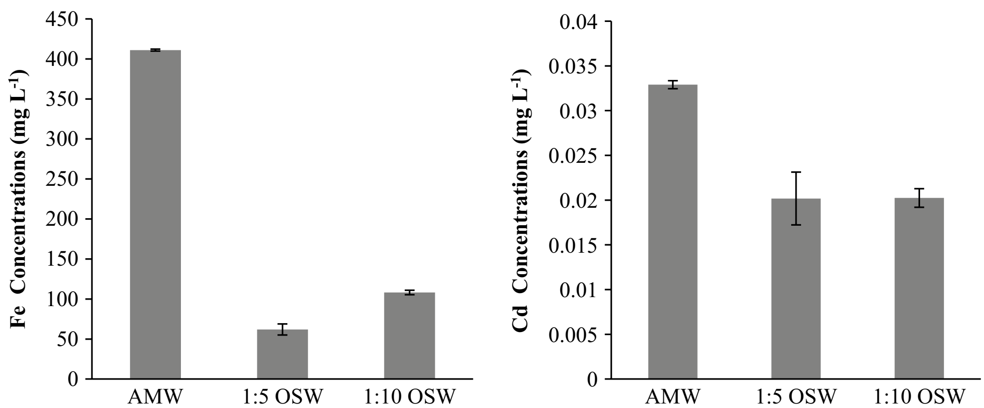

Fig. 5 **a**, **b** Fe and Cd concentrations of AMW before and after OSW treatment

Fig. 6 **a**, **b** B and Ti concentrations of AMW after OSW treatment

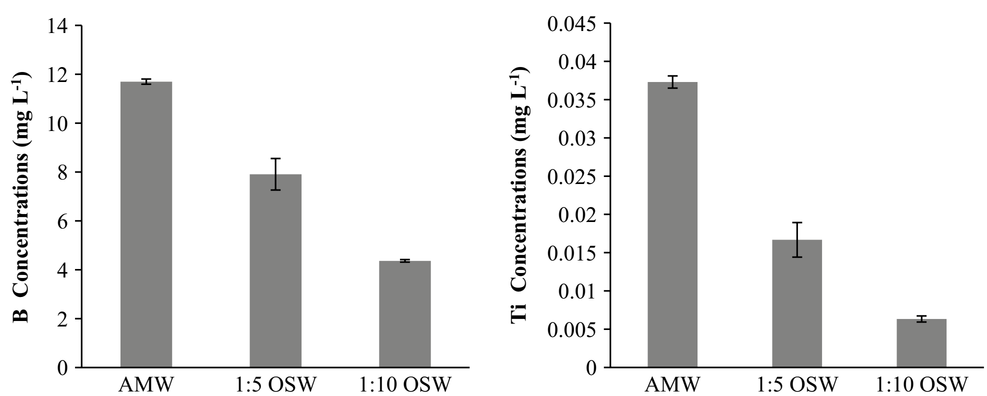

Table 6 Heavy metals and metalloids adsorption capacities (mg g^{-1}) of OSW

OSW:AMW ratio (w/v)	Al	As	Cd	Fe	B	Ti
1:5	764.06	–	0.079	2181.56	23.703	0.128
1:10	411.75	0.260	0.142	3406.5	82.507	0.348

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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