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Heavy Metal Pollution from Dental Clinics–Part 1:Annual Emissions Assessment

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ABSTRACT: This study aimed to evaluate the concentration of heavy metals in liquid effluents and to quantify the mercury content in dental amalgam waste generated by dental clinics. Three neighbouring cities in Northeast Algeria were considered in this study (Constantine, Skikda, and Annaba). Heavy metals, such as Hg, Cu, Zn, Fe, Ni, Mn, Cr, Cd, and Pb, were analysed in wastewater and then compared with acceptable standard values. Special attention was given to mercurybecause of its dangerous effects. The results collected indicated the presence of heavy metal contamination in dental wastewater. Heavy metal concentrations were significantly high for all heavy metals and exceeded the allowed concentrations. However, Pb and Cr were shown to have acceptable concentrations. This study highlights the possible contamination of the environment by mercury and heavy metals generated by dental clinics. This study also demonstrates an order of magnitude of the concentration of these heavy metal in a large agglomeration with a population of 2.5 million people.

Keywords: mercury, heavy metals, dental amalgam, waste, environmental risks.

INTRODUCTION

Today, environmental protection is one of the most important concerns for the international community. This interest is due to the derangement of the balance of the biosphere by massive industrial and domestic discharges of heavy metals, which affect soil and water.Heavy metals cause critical problems because of their non-degradable pollutants(Gao et al., Khan et al., 2013) and they are recognized as harmful for both the environment and human health because of their harmful toxicity effects (Alomary et al., 2007, Cherfi et al., 2015, Rahmanian et al., 2015). These elements can bio-accumulate in plants, animals, and humans via the food chain(Mahmood et al., 2014).

Dental amalgam containing mercury and silver is currently used as a metallic restorative. In fact, this restorative method have been used for the treatment of various lesions of tooth for 150 years(AFSSAPS. 2005). Amalgam alloy is composed of 50 w/w% mercury, while the other 50 w/w % is composed of silver (20–34w/w %), copper (1–15 w/w %),and tin (8–15 w/w %). Other heavy metals, such as zinc, indium, or palladium, can be added to the

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amalgam in minor proportions (0–5 w/w %)(Drummond et al., 2003).

The safety of dental amalgam has been a controversial subject given its high content of mercury(Hylander et al., 2006a, Megly 2007, Bates 2011, Tibau et al., 2019). This does not exclude silver, tin, and copper from being considered negative because of their effects on the environment. Minamata Convention is an important universal acknowledgment of the potential damages of utilizing mercury dental amalgam on humans and the environment(Mackey et al., 2014).

Dental practices generate significant levels of heavy metals in their liquid effluents.It was demonstrated that a high concentration of mercury (31.3 mg/L) was found in dental wastewater tests when the amalgam separator was not associated with the dental chair(Adegbembo et al., 2002). Some authors point out that mercury emissions from dental clinics can be decreased by the installation of amalgam separators.Additionally, it has been reported that mercury removal efficiency depends on the type of amalgam separator(Hylander et al., 2006b). In literature, it was found that in addition to mercury, other heavy metals have also been detected in liquid effluent, with hazardous (Shraim et al., 2011).

Mercury, can be generated from dental clinics in the form of amalgam waste,which is collected with household and municipal waste, and could be released into the environment and contaminate water, soil, and air(Adegbembo et al., 2002). A study in Nigeria revealed that soil and water samples collected near an amalgam waste dump contained very high levels of lead, chromium, mercury, cadmium, and manganese(Adedigba et al., 2004).Research work has shown that dental amalgam solid waste generates mercury vapour. It was also found that the quantity of mercury vapour is influenced by temperature and the type of solution (Dalla Costa et al., 2008).However, it was assessed that the dental clinics in the state of Illinois can generate up to 947kg/year of non-contact mercury in the form of dental amalgam waste(Drummond et al., 2003).Other research has estimated that the amount of amalgam waste rejected by dental offices in the prefecture of Xanthi (Greece) is 25.8 kg/day (Kizlary et al., 2005).

The objective of this work was to quantify the emission of different heavy metls and give an order of magnitude of the concentration of these heavy metal in dental clinics effluents, mercury in particular, that can be found in the large agglomeration of NortheastAfrica with a population of 2.5 million people.The daily and annual amount of mercury released into the environment was evaluated. This study can be very usefull for life cycle analysis (LCA) of heavy metals and mercury in particulary.

MATERIALS AND METHODS

Wastewater and dental amalgam waste wascollected from forty dental clinics in the following areas: 8 dental clinics in Constantine, 16 in Annaba, and 16 in Skikda. Dental clinic samples and wastewas collected for 90 days (from January to March).

A flame atomic absorption spectrophotometer (ICE 3000 series,Thermo Scientific) was used to analyse metals in wastewater samples. All Hg analyses of wastewater were performed using a cold vapour generation system (VP Thermo Scientific) connected to an atomic absorption spectrophotometer (ICE 3000 series, Thermo Scientific) under a continuous flow of argon.

All samples of wastewater discharged from the dental clinics were collected in plastic bottles. Samples were preserved with HNO_3 to a pH of 2 at the time of collection and then refrigerated in at 4°C. According to previous work, particular

care was given to laboratory equipment used to avoid any contamination(Rodier et al., 2009).

Wastewater samples were analysed for the following 9 heavy metals using different experimental conditions based on appropriate American Society for Testing and MaterialsASTM: Hg, Cu, Zn, Ni, Mn, Fe, Cr, Pb, and Cd.The appropriate ASTM methods were used for the analysis of ionic concentrations according to the following: ASTM D 3223 was applied in the determination of mercury,ASTM D1691 was used for ionic concentrations of zinc,ASTM D3557 was used for cadmium,ASTM D3559 was used for lead,ASTM D1688 was used for cooper,ASTM D1068 was used for iron,ASTM D1886 was used for nickel,ASTM D1687 was used for chromiumand ASTM D858 was used for manganese(ASTM).

To calibrate the system, standards solution were prepared daily for each tested element using a manual standard addition procedure. The reagents and blanks were monitored for each fraction after each series of samples during the analysis. The blank test was analysed during each measurement seriesand the concentration of the element found in the blank should be less than 0.5 times the lowest calibration standard.

The assessment focused on evaluating and comparingmercury discharged to landfills. Samples were collected from the following 16 dental clinics: 4 from Constantine, 8 from Annaba, and 4 from Skikda. To evaluate the amount of dental amalgam waste, the samples were taken from each clinic at the end of the day for a period of 3 months (January to March). When the sampling was finished, it was found that the quantity of dental amalgam waste generated depends of the activities conducted with dental amalgam on patients. Dentists commonly triturate excess amalgam during each procedure to ensure a sufficient filling for the tooth.

Excess dental amalgam not used was collected and weighted. Also, the old dental amalgam fillings removed when replacing them with composite or ceramic were also weighed. In addition, all extracted teeth with amalgam fillings were collected and placed in a sodium hypochlorite solution to be disinfected. The amalgam fillings were then removed from the teeth and weighed(Kizlary et al., 2005).By using data from dental clinics, a 50% by weight, mercury content in amalgam. The amount mercury discharge in each area per year can be calculated as follows:

$$\text{number of the dental clinics} \times \text{average mass of the dental amalgam per day} \times \text{number of working day per year} \times 50\% \text{ mercury in amalgam}$$

The mean, maximum, minimum values and standard deviations were computed and recorded. All statistical analyses were computed by usingStatistical Package for Social Science (SPSS) version 21. One-way analysis of variance (ANOVA) was used to discuss the differences in heavy metal concentration and mercury concentration in dental amalgam waste between areas. The difference by regions was considered to be significant when a probability threshold (p) was less than 5% ($p<0.05$).Student's test was used to compare means of concentrations of different heavy metals with local permissible limits. Principal component analysis (PCA) is a multivariate analysis method used in environmental research. PCA was used to represent the association between different metals in different areas and to identify different pollutant sources.

RESULTS AND DISCUSSION

The measured concentrationsof heavy metals in wastewater from dental clinics in the three areas revealed the presence of heavy metals (Figure 1a–1j). The statistical descriptions of all heavy metals, including Hg, Cu, Zn, Mn, Ni, Fe, Cd, Cr, and Pb, and the ANOVA tests are given in Table1.

Table 1.Comparison of heavy metal concentrations (mg/L) in wastewater from dental clinics in different cities

Metals	Area	Mean ± SD (mg/L)	Min (mg/L)	Max(mg/L)	LPM **(mg/L)	One way ANOVA	
						F	p
Hg	Constantine	289 .4± 237.2*	28.71	1238.2	0.01	6.56	0.002
	Skikda	425.7 ±408.6*	12.5	1630.3			
	Annaba	234.1 ±222.3*	3.45	553.56			
Cu	Constantine	241.4 ± 41,1*	0	750.9	1	1.99	0.14
	Skikda	144.1 ± 209.4*	0	899.5			
	Annaba	207.4 ± 282.6*	0	953.7			
Zn	Constantine	52.8 ± 18.4*	0	859.6	2	1.54	0.21
	Skikda	23.2 ± 52.2*	0	271.7			
	Annaba	59.4 ± 185.7*	0	997.3			
Mn	Constantine	38.4 ± 12.1*	0	400.3	1	5.55	0.005
	Skikda	4.7 ± 4.7*	0	21.4			
	Annaba	10.2 ± 84.1*	0	402.2			
Fe	Constantine	22.2 ± 4.1*	0	125	1	12.57	0.000
	Skikda	4.4 ± 5.0*	0	17.4			
	Annaba	20.2± 29.3*	0	120.1			
Ni	Constantine	2.6 ± 0.5	0	21.5	2	7.68	0.001
	Skikda	6.1 ± 8.4*	0	34.6			
	Annaba	3.98 ± 4.71	0	19.5			
Cd	Constantine	0.51 ± 0.09*	0	2.1	0.1	4.76	0.01
	Skikda	0.21± 0.52	0	1.9			
	Annaba	0.79 ± 1.77*	0	9.8			
Cr	Constantine	0.19 ± 0.05*	0	1.5	2	2.79	0.06
	Skikda	ND	ND	ND			
	Annaba	0.17± 0.35*	0	1.4			
Pb	Constantine	0.44±0.19	0	6.1	0.5	1.24	0.29
	Skikda	ND	ND	ND			
	Annaba	0.46±1.3	0	5.9			

SD: refer to Standard Deviation of heavy metals concentration
F: refer to Friedman values of one away ANOVA
ND: Refer to not defined
p: refer to significant of ANOVA
* Significant differences from local permissible limits (P<0.05 of Student's test) are marked with asterisks.
** LPM: Local permissible limits **(**Official Journal of the Algerian Republic. 2006, 2009).

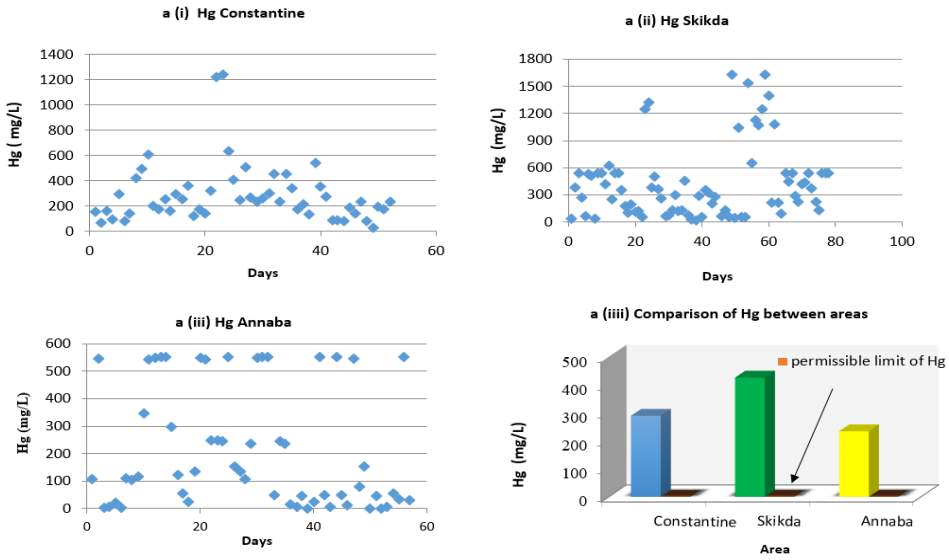

Fig. 1a. Concentration of mercury (mg/L).

Figure 1a (i)shows the concentration levels of Hg in the dental clinics in the Constantine region, with a total sample population of 52.The mean concentration of Hg during this period was found to be 289.4 mg/L with a maximum of 1238.2 mg/L and a minimum of 28.7mg/L. The standard deviation in this case was found to be 237.26 mg/L. Figure 1a (ii)shows the concentration of Hg in the dental clinics in the Skikda region in the same period with a total sample population of 77.The average concentration and concentration range were found to be 425.7 mg/L and 12.5–1630.3 mg/L, respectively.Figure 1a (iii)shows the concentration of Hg in the dental clinics in the Annaba region with a total sample population of 57.The concentration varied between 3.44 and 553.5 mg/L, with a mean concentration of234.1 mg/L and a maximum standard deviation of 222.3 mg/L.

More interestingly, at some clinics, dental amalgam was only used during the extraction of old fillings and was replaced by composite materials or ceramic. These clinics produced more Hg (1238.2mg/L for Constantine and 1630.3 mg/L for Annaba). However, the mercurial pollution persisted as long as patients had old fillings.

From Table 1, it is clear that in the three areas there were significant differences between Hg levels in the different areas.Figure 1a (iiii) shows the mean concentration of Hg measured in the three studied areas. The highest Hg mean concentration was registered at Skikda (425.7 mg/L). This is the outcome of the numerous daily activities related to dental amalgam (placement or extraction of amalgam, scaling and polishing, number of patients treated, and the amount of amalgam debris in the wastewater).The one-way ANOVA analysis revealed the existence of a significant difference in Hg concentration among the different sites (ANOVA, $F=6.56$, $p<0.05$)simply because the activities related to dental amalgam differ from one dental office to another.

Figure 1b (i)shows the concentration level of Cu in the dental offices in Constantine. The mean concentration was to be 241.4 mg/L with a maximum of 750.6 mg/L.The measured concentrations of Cu in the samples of dental clinics from Skikda are shown inFigure 1b (ii). From Table 1,it can be observed that the mean concentration was 144.1 mg/L with a maximum of 899.9 mg/L.Figure 1b (iii)summarizes the Cu concentration recovered from dental clinics in the Annaba region. The mean concentration was found to be 207.4 mg/L with a maximum of 953.7 mg/L.For Constantine, Skikda, and Annaba, Cu levels were different and higher than permissible limits (1 mg/L).The one-way ANOVA analysis revealed that there was no significant difference in Cu concentrations in the study sites (ANOVA, $F=1.996$, $p=0.14$).The highest mean Cu levels were found in Constantine with 241.4 mg/L(Figure 1b(iiii)).

Figure 1c (i)shows the concentration level of Zn in the dental clinics in Constantine.The mean Zn mean concentration was52.8 mg/L with a range of 0–859.6 mg/L.The measured Zn concentrations in samples recovered from the dental clinics in Skikda are shown in Figure 1c(ii). The average concentration and concentration range were 23.2 mg/L and 0–27.7 mg/L, respectively.Figure 1c (iii)summarizes the concentration level of Zn recovered from dental clinics in the Annaba region. The mean concentration was 59.4 mg/L with a maximum of 997.3mg/L.The mean Zn concentrations in the areas were significantly different and higher than the permissible limit (2 mg/L).However, results showed no significant difference in Zn concentration (Figure 1c (iiii)) between the three areas (ANOVA, $F=1.54$, $p=0.21$). The higher mean concentration of Zn (59.4 mg/L) was found in Annaba (Figure 1c(iiii)).

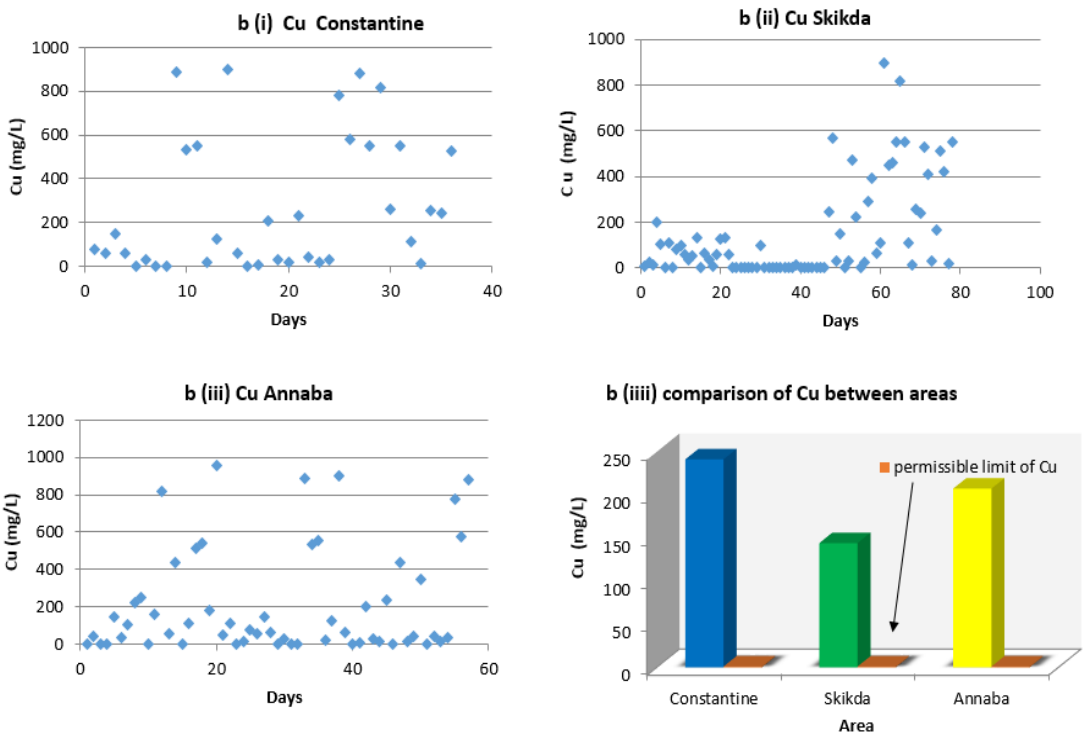

Fig. 1b. Concentration of cooper (mg/L).

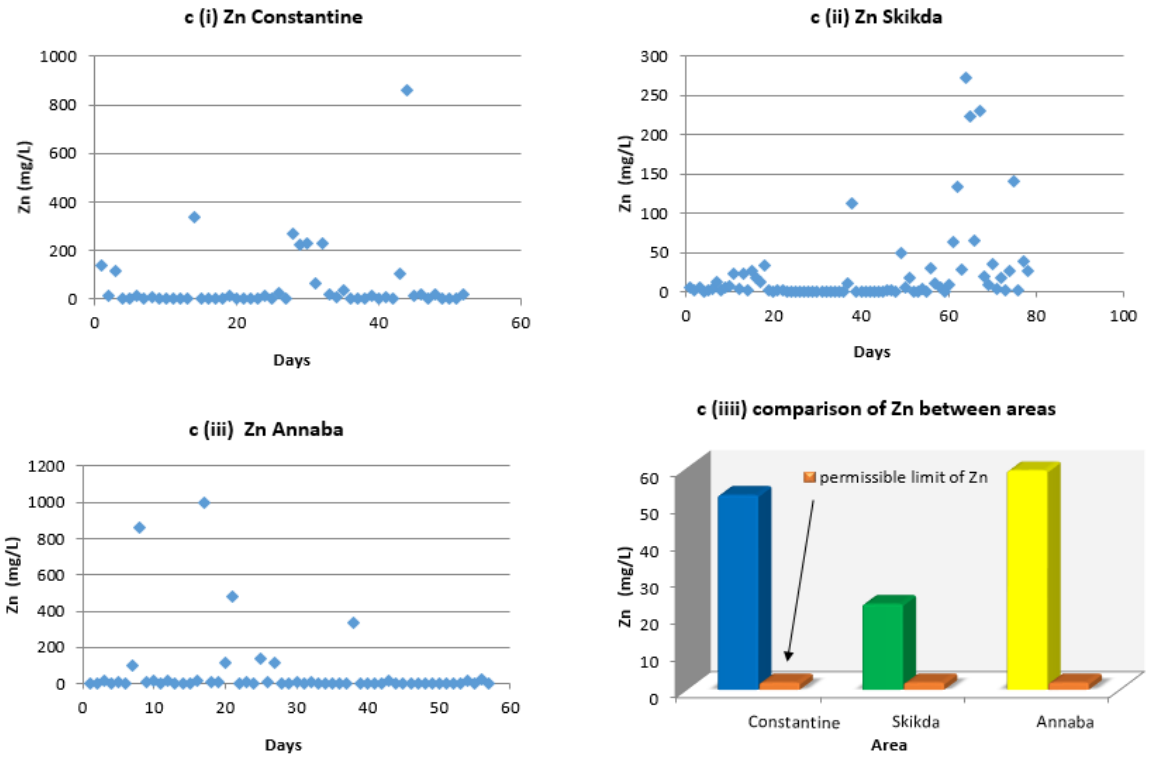

Fig. 1c. Concentration of zinc (mg/L).

Figure 1d (i)shows the concentration levels of Mn in dental clinics in Constantine where the mean concentration was 38.4 mg/L and the maximum concentration was 400.3 mg/L.The measured concentrations of Mn in dental clinic samples in Skikda are shown in Figure 1d (ii). The average concentration and concentration range were 4.7 mg/L and 0–21.4mg/L, respectively.Figure 1d (iii)summarizes the concentration levels of Mn in the dental clinics in Annaba. The mean concentration was 10.2 mg/L with a maximum of 402.5 mg/L.The results of the Student's test indicated that Mn concentrations were significantly different and higher than the permisible standard limits, as shown in Table 1 and Figure1d (iiii).Results revealed significant differences in Mn concentrations between Constantine, Annaba, and Skikda. This is due to the different activities in dental clinics (ANOVA, F=5.55, p<0.01). It can be concluded fromFigure 1d(iii) that the highest mean concentration of Mn was detected in Constantine with 38.4 mg/L.

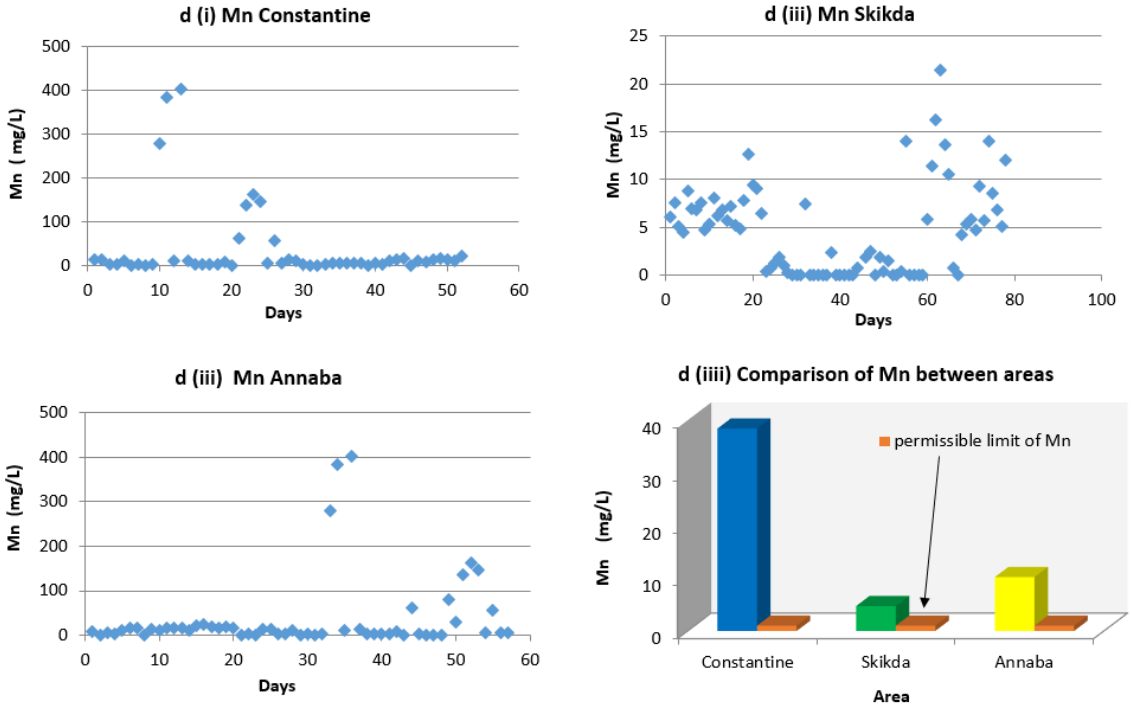

Fig. 1d. Concentration of manganese (mg/L).

Figure 1e (i)shows the concentration levels of Fe in the dental clinics in Constantine. The mean concentration was 22.2 mg/L with a maximum concentration of 125 mg/L. The measured concentrations of Fe in dental clinic samples from Skikda are shown in Figure 1e (ii). The average concentration and concentration range were 4.4 mg/L and 0–17.4 mg/L, respectively.Figure 1e (iii)summarizes the concentration levels of Fe in the dental clinics from Annaba. The mean concentration was 20.2 mg/L with a maximum of 120.1 mg/L.As shown in Table 1, the Student's test of Fe revealed that the mean concentrations in the regions studied were remarkably different and high compared to the limit threshold value. A comparison of Fe concentrationsbetween the studied areas showed significant differences (Figure 1e (iiii))(ANOVA, F=12.57, p<0.0001). The highest mean concentration of iron was detected in Constantine (22.2 mg/L).

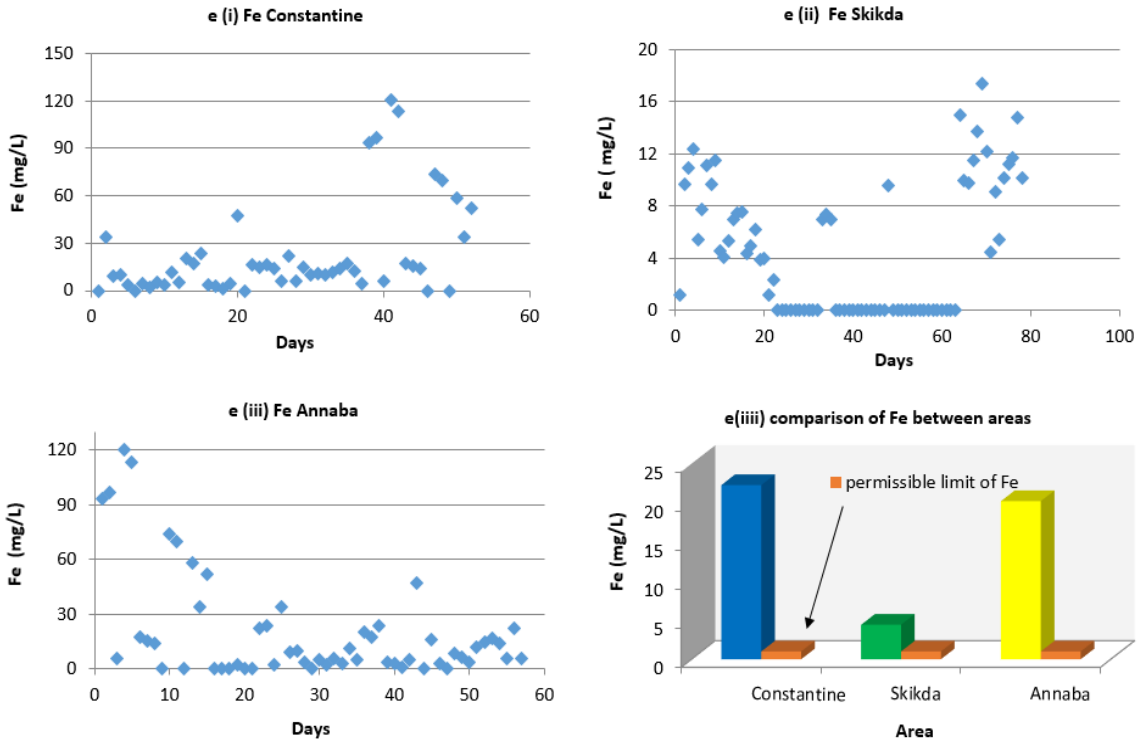

Fig. 1e. Concentration of iron (mg/L).

Figure 1f (i)shows the concentration levels of Niin the dental clinics of Constantine. The mean concentration was 2.6 mg/L with a maximum of 21.5 mg/L. The measured concentrations of Ni in dental clinicsamples of Skikda are given inFigure 1f (ii). The average concentration and concentration range were 6.1 mg/L and 0–34.6 mg/L, respectively.Figure 1f (iii)summarizes the concentration levels of Niin the dental clinics of Annaba. The mean concentration was 3.98 mg/L with a maximum of 4.7 mg/L.On the other hand, the levels of Ni from Skikda were greater than the permissible limit (2 mg/L) and were in the range of threshold values at Constantine and Annaba.Ni was found in all sampling sites (Figure 1f(iiii)), and the ANOVA test revealed significant differencesbetween the studied areas (ANOVA, $F=7.68$, $p<0.01$). The highest mean concentration of nickel was detected at Skikda with 6.1 mg/L.

Figure 1g (i)shows the levels of Cdin the dental clinics of Constantine. The mean concentration was 0.51 mg/L with a maximum of 2.07 mg/L. The measured concentrations of Cd in the dental clinicsamples of Skikda are given inFigure 1g (ii). The average concentration and concentration range were 0.21 mg/L and0–1.94 mg/L respectively.Figure 1c (iii)summarizes the concentration levels of Cdin the dental clinics of Annaba. The mean concentration was 0.79 mg/L with a maximum of 9.8 mg/L.The results in Table 1 show that there was a significant difference between Cd levels and the threshold value of 0.1 mg/L at Constantine and Annaba but not Skikda.For Cd, a one-way ANOVA test revealed differences between the three regions (Figure 1g (iiii))(ANOVA, $F=4.76$, $p<0.05$). The highest mean level of Cd was found at Annaba (0.79mg/L).

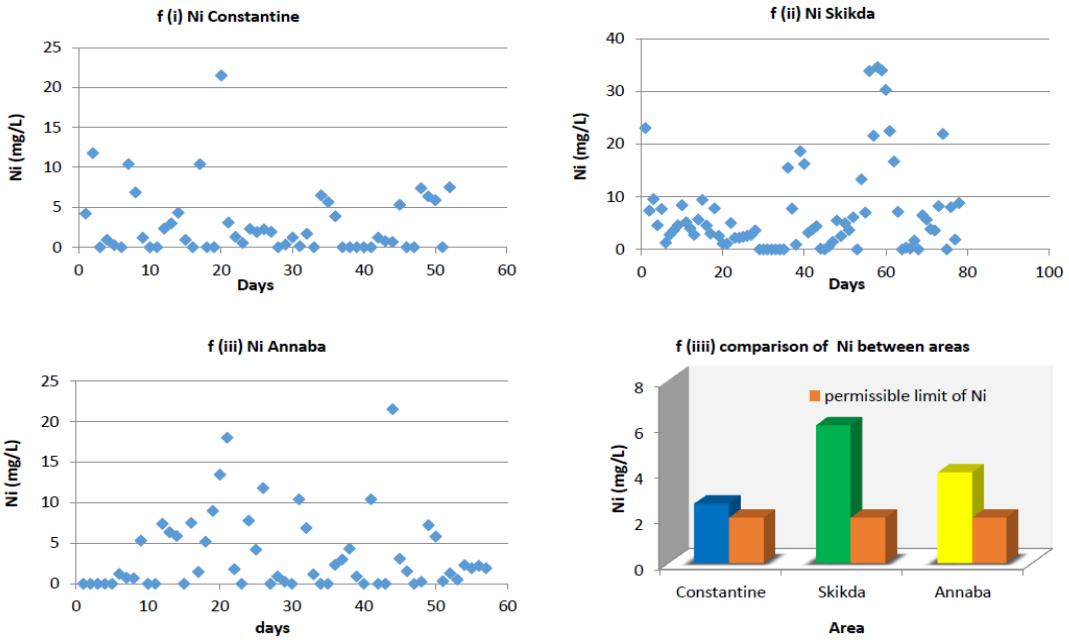

Fig. 1f. Concentration of nickel (mg/L).

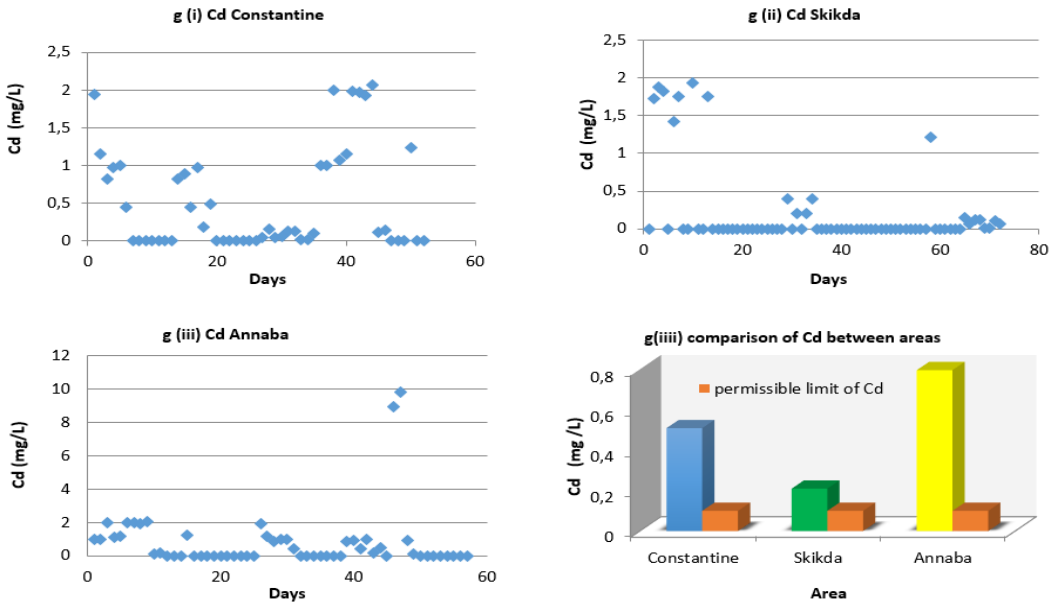

Fig. 1g. Concentration of cadmium (mg/L).

Figure 1h (i)shows the concentration levels of Crin the dental clinics of Constantine. The mean concentration was 0.19 mg/L with a maximum of 1.5 mg/L. Cr was not detected in the effluents of dental offices from Skikda.

The measured concentrations of Cr from dental clinic samples of Annaba are shown in Figure 1h (ii). The mean concentration was 0.17 mg/L with a maximum of 1.41 mg/L.The levels of Cr were significantly different than permissible limitsfor Constantine and Annaba. In the majority of samples analysed, there was no chromium, except for some samples. For these reasons,they were no differences between means of Cr (Figure 1h (iii)) (ANOVA,F=2.79, p=0.065). The highest mean level of Cr was recorded in Constantine of 0.19 mg/L.

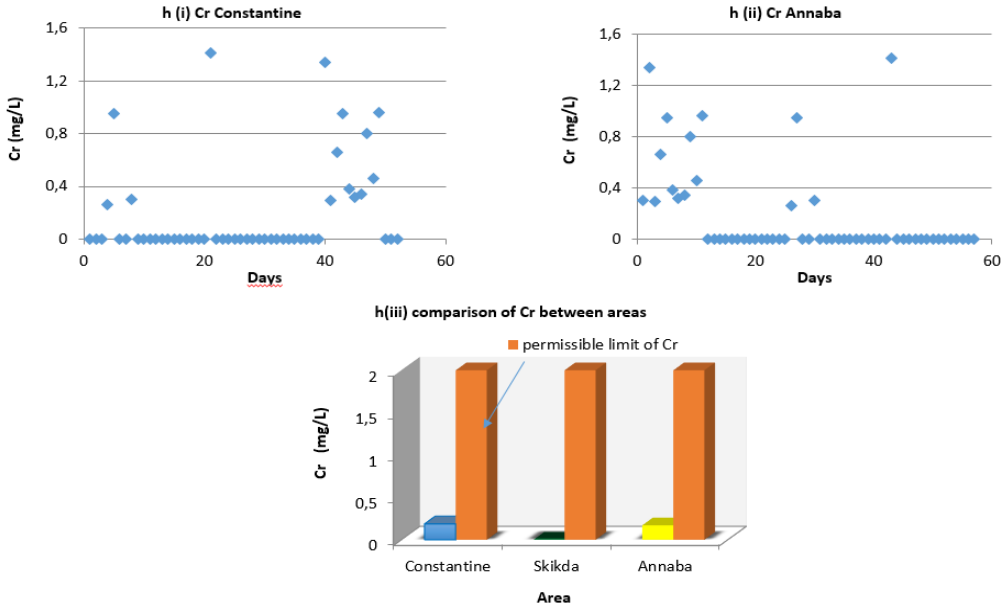

Fig. 1h. Concentration of chromium (mg/L).

Figure 1j (i)shows the concentration levels of Pb from dental clinics of Constantine. The mean concentration was 0.44 mg/L with a maximum of 6.1 mg/L. Pb was not detected in effluents of dental clinics of Skikda.The measured concentration of Pb in samples from dental clinics of Annaba is shown inFigure 1j (ii). The mean concentration was 0.46 mg/L with a maximum of 5.98 mg/L.The Pb levels in the three studied areas were lower than the permissible limits in wastewater (Figure 1j(iii)).As shown in Table 1, the Student's testof Pb revealed that the mean concentrations in the regions studied were not different in terms of Pb limits allowed. In the majority of samples analysed,there were no traces of lead. For these reasons,there were no differences between the means of Pb(Figure 1j (iii))(ANOVA, F=1.239, p=0.293) in the three areas.

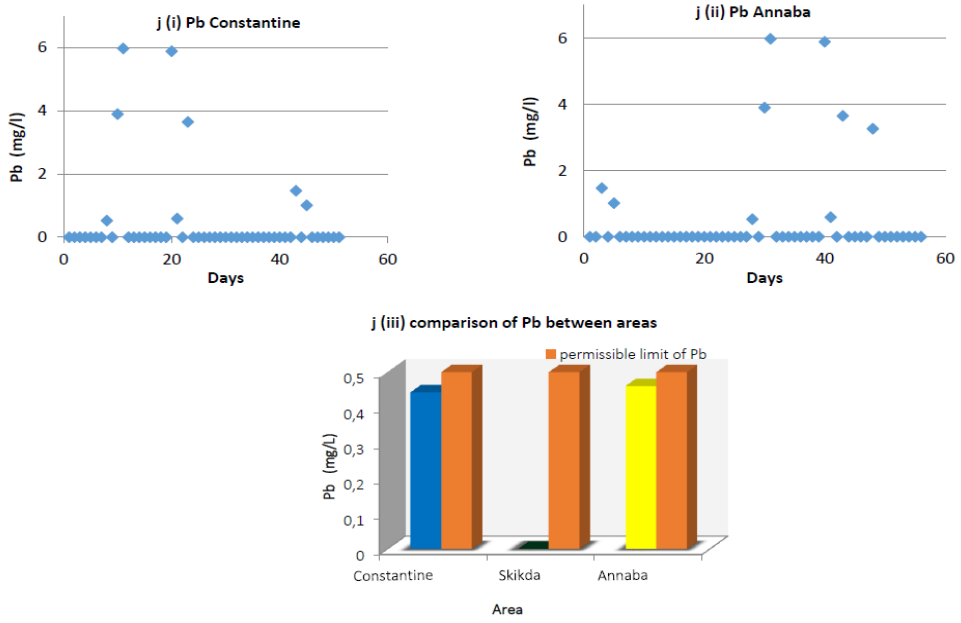

Fig. 1j. Concentration of lead (mg/L).

From Table 1, it can be concluded that wastewater recollected before dental amalgam activities (removal or placement of dental amalgam) contains the following heavy metals: Hg, Cu, Fe, Zn, Mn, Pb, Cd, Ni, and Cr. However, the differences in heavy metal levels among the sites can be attributed to the variety of operations dentists perform. In addition, results showed that the samples contained hazardous levels of heavy metals, especially the constituents of dental amalgam, which include Hg, Cu, and Zn. The presence of Hg, Cu, and Zn can be explained by the composition of dental amalgam.Whereas the presence of the other metals, such as Ni and Cr, can be explained by the existence of fixed prosthesis metal in the patient's mouth. These metals are usually used for the posterior teeth and are often nickel–chrome and chrome–cobalt (Palaskar et al., 2010).

For Fe, Cr, Mn, and Ni, their presence results in the use of instruments in dental operations. For example, tweezers for dental care and spatula, fouler, and dental mirror, which are made of stainless steel(Olefjord et al., 1985). Based on the concentration of heavy metals in all samples in this study, the trends in heavy metal concentrations in the different dental clinic samples were in the following order: Hg>Cu>Zn>Mn>Fe>Ni >Cd >Pb>Crwhich is in line with the overall trend in the literature of mercury in wastewater from dental clinics(Vandeven et al., 2005, Hylander et al., 2006b).Mercury released to the environment from dental clinics can be reduced by installing amalgam separators in the dental chair(Mutter et al., 2004, Hylander et al., 2006a, Hylander et al., 2006c).Overall, all measurements highlighted the necessity to take action to reduce the emission of heavy metals from dental clinics.

Principal Component Analysis (PCA) has been applied to study differences and correlations between the heavy metal concentrations to find the heavy metal distribution in studied areas. According to the results, heavy metal concentrations in effluents of dental clinics can be grouped into two principal components, described 95.51% and 4.33% of the variability observed in heavy metal levels produced in different study areas.

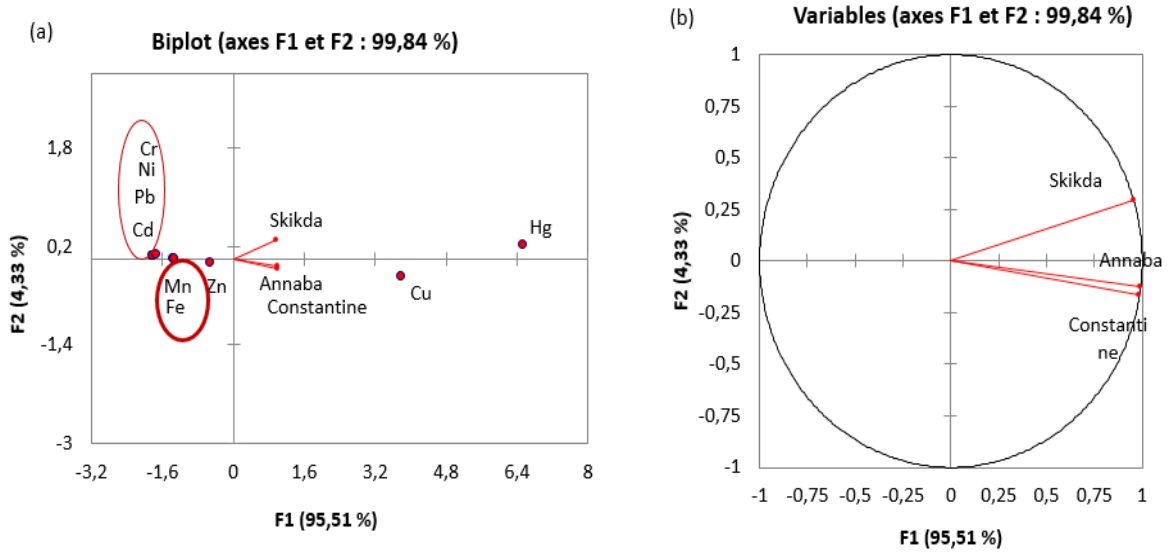

Fig. 2. (a): Loading plot of variables, (b): Score plot of samples areas.

From the loading plot inFigure 2 (b), it was observed that the concentration of heavy metals in Annaba and Constantine can be correlated more easy. The F1 axis is linked to Skikda, Constantine, and Annaba on the right side.It can be observed from Figure 2 (a) that the correlation between Hg and Cu was significant. These results imply that Hg and Cu may originate from a similar pollution source, which is dental amalgam. This could be proof that dental amalgam is a major source of pollution of Hg and Cu from dental clinic effluent.Comparing the two plots in Figure 2helped to identify the variations between areas and the different metals present in them. Looking at the two plots in Figure 2 (a) distinctive variety amongst regions was observed and the diverse metals introduced in them were also seen.Hence, it can be said that Annaba and Constantine are more polluted by Cu and Skikda is more polluted by Hg. Mercury was detected the most in Skikda, which may be explained by the high activity with dental amalgam in Skikda in comparison to Annaba and Constantine. According to the results, Zn did not follow the same trends as the rest of the constituents of dental amalgam (Hg and Cu). This may be due to the fact that dental amalgam has small proportions of Zn compared to Hg and Cu. Hence, the distribution maps showed that Pb, Cr, Cd, and Ni were significantly correlated and co-varied in the same manner. In our study, thesepollutants were detected with low concentrations and, sometimes, their concentrations were equal to zero.Another observation that can be noted is that Fe and Mn were positively correlated. The presence of Fe, Ni, and Mn could be due to the materials used by the dentist.

During the period from January to April, samples were collected daily. Mercury production from dental amalgam waste is given in Table 2.

Table 2.Mercury emission in the form of dental amalgam solid waste by dental clinics of the three areas in the study.

Areas		Constantine	Annaba	Skikda
Daily emission mean of Hg (g clinic $^{-1}$ day^{-1})		0.26 (87)	0.20 (68)	0.34 (52)
SD (g clinic^{-1} day^{-1})		0.16	0.14	0.23
Min (g clinic^{-1} day^{-1})		0.02	0.04	0.03
Max (g clinic^{-1} day^{-1})		0.67	0.77	1.39
95% Confidence Interval (CI)	Lower	0.22	0.16	0.27
	Upper	0.29	0.23	0.40
Estimation of daily emission of Hg in area (g clinic^{-1} day^{-1})		46.44	27.80	56.61
Estimation of annually emission of Hg in area (Kg year^{-1})		13.28	7.95	16.19

Number in parentheses: refer to number of sample in each area
SD: refers to Standard deviation of daily emission of Hg

On the basis of the results obtained from the selected dental clinics, the means and range of values of mercury emission from dental amalgam solid waste were as follows: 0.26 g clinic^{-1} day^{-1} and 0.02–0.67 g clinic^{-1} day^{-1} for Constantine, 0.2 g clinic^{-1} day^{-1} and 0.04–0.77 g clinic^{-1} day^{-1} for Annaba, and 0.34 g clinic^{-1} day^{-1} and 0.03–1.39 g clinic^{-1} day^{-1} for Skikda (Table 2,Figure 3). The highest weight of mercury in the daily dental waste (1.394 g clinic^{-1} day^{-1})was detected in Skikda.

According to the one-way ANOVA test, the Hg weight in the dental amalgam waste was significantly different in Constantine, Skikda, and Annaba (ANOVA, F=8.931, $p<0.0001$). Data showed that the difference was significant between the regions of Constantine and Annaba ($p<0.05$), Constantine and Skikda ($p<0.05$) and Annaba and Skikda ($p<0.0001$).

The weight of waste differs from clinic to clinic and for the same clinic on different days. Therefore, the total daily amalgam dental waste coming from clinics is related to the number of patients and the cavity volume of the tooth that has been filled. It is understandable that as the size of the restoration increases the amount of dental amalgam solid waste decreases.

The number of dental clinics in Constantine, Annaba, and Skikda were 180, 139, and 168, respectively. Based on the actual number of dentists in each region, the daily emission of Hg in Constantine, Annaba, and Skikda were 46.4 g/day of Hg, 27.8 g/day of Hg, and 56.5 g/day of Hg, respectively, in dental amalgam waste (Figure 4).

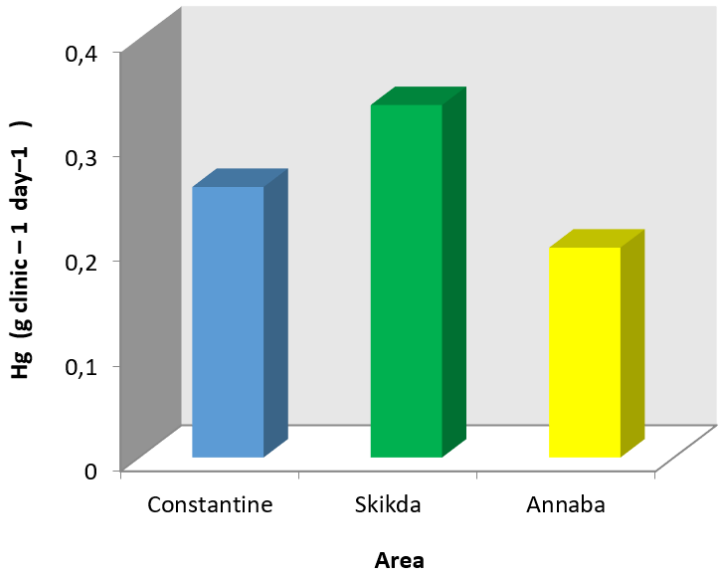

Fig. 3. Comparison of the daily production of Hg in dental clinics. amalgam solid waste.

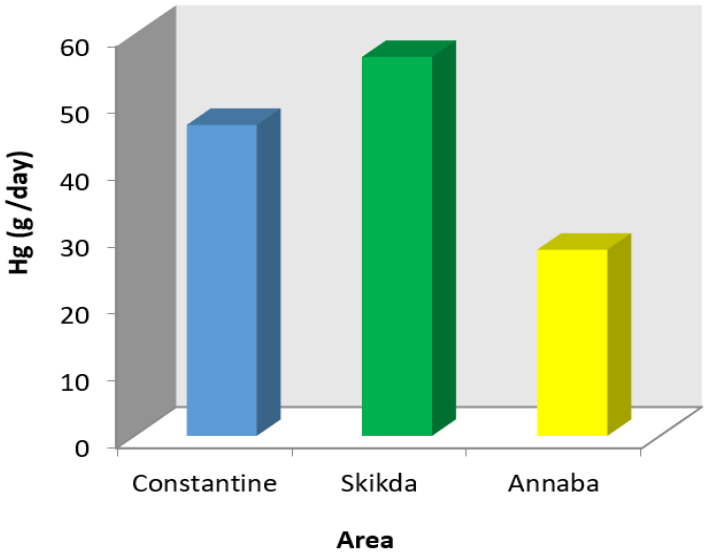

Fig. 4. Estimation of the daily production of Hg for all dentist of areas.

Based on the mean values of the daily production of Hg from dental amalgam solid waste and the total number of dental clinics in each area of the study, the dentists in Constantine, Annaba, and Skikda have the potential to generate (extrapolated for a year with 286 working days) 13.28 Kg/year of Hg, 7.95 Kg/year of Hg, and 16.19 Kg/year of Hg, respectively (Figure 5).

The reduction in the use of amalgam as a restorative material in dental clinics can be attributed to the decreasing usage of materials containing mercury. Mercury in the form of amalgam solid waste has the potential to migrate into the environment, and to reduce the risk of Hg non-contact dental amalgam can be recycled.

Discharge mercury in the form of amalgam at landfills, which is incinerated or conducted to the public dump, and this can cause an increase in mercury concentration in the environment. To reduce the risk of dental amalgam waste, it must be separated from the other waste from the dental clinic and it has to be stored in specific containers (Berglund et al., 2001, Drummond et al., 2003, Stone et al., 2003).

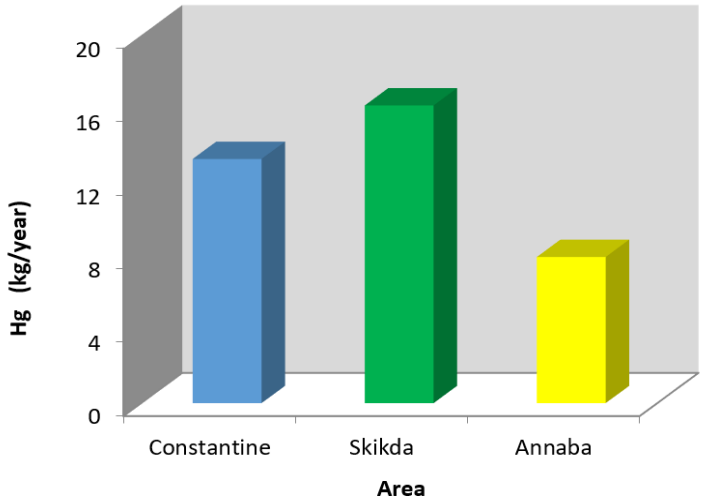

Fig. 5. Estimation of the annuallyproduction of Hg for all dentist of areas.

CONCLUSION

This study dealt with the behaviour of different heavy metals released into the environment from dental clinics in Algeria. This study clearly demonstrates the high levels of heavy metals in liquid effluents of dental clinics and the importance of mercury released in dental amalgam solid waste. Data also revealed that the concentration of heavy metals, such us Hg, Cu, Zn, Fe, Ni, Mn, and Cd, in the effluent of dental clinicsexceeds the allowed threshold in limits in the different regions considered in this study. The concentrations of Cr and Pb were lower than permissible limits. Therefore, dental offices are considered a significant source of mercury, cooper, and other heavy metals. Based on the concentrations of heavy metals in all samples of this study, the trend in heavy metal concentrations in the different dental clinic samples was the following:

Hg>Cu>Zn>Mn>Fe>Ni>Cd>Pb>Cr.

Mercury in the form of amalgam waste was also measured and found to be hazardous to the environment. Relying on the resultsobtained in this study and other studies of the storage of the amalgam residues (waste), it is necessary to establish a plan of management and organization for the collection of dental amalgam waste and treatment to reduce environmental risk. This work provides relevant information

regarding pollution generated by dental clinics in the different studied areas. This study demonstrates the danger of the effluents of dental clinics and their impact on the environment. The results presented show that dental clinics are potential sources of mercury in wastewater and in solid waste. As a continuation of this study, life cycle analysis (LCA) will be done on heavy metals and mercury in particulary coming from dental clinics.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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