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STUDY OF HIGH LEVELS INDOOR AIR MERCURY CONTAMINATION FROM MERCURY AMALGAM USE IN DENTISTRY

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Abstract

In 2005, United Nations Environment Programme (UNEP) estimated that 362 tonnes of dental mercury are consumed annually worldwide. Dental mercury amalgams also called silver fillings and amalgam fillings are widely done. These fillings gave off mercury vapours. Estimated average absorbed concentrations of mercury vapours from dental fillings vary from 3,000 to 17,000 ng Hg. Mercury (Hg) also known as “quick silver” is an essential constituent of dental amalgam. It is a toxic substance of global concern. A persistent pollutant, mercury is not limited to its source but it travels, on time thousands of kilometers away from the source. Scientific evidence, including, UNEP Global Mercury report, establishes mercury as an extremely toxic substance, which is a major threat to wildlife, ecosystem and human health, at a global scale. Children are more at risk from mercury poisoning which affects their neurological development and brain. Mercury poisoning diminishes memory, attention, thinking and sight.

In the past, a number of studies at dental sites in many countries have been carried out and reported which have been reviewed and briefly described. This paper describes and discusses the recent investigations, regarding mercury vapours level in air, carried out at 18 dental sites in Pakistan and other countries. It is evident from the data of 42 dental sites in 17 countries, including, selected dental sites in five main cities of Pakistan, described and discussed in this paper that at most dental sites in many countries including Pakistan, the indoor mercury vapours levels exceed far above the permissible limit, recommended for safe physical and mental health. At these sites, public, in general, and the medical, paramedical staff and vulnerable population, in particular, are at most serious risk to health resulting from exposure to toxic and hazardous mercury.

Key words: Air, Amalgam, Dentistry, Mercury, Pollution.

Introduction

Mercury has been used in dental amalgams for over 160 years. These amalgams contain approximately elementary mercury 50%, silver 30% and 20% other metals, such as, tin, copper and Zinc (Hardy, 1998; SDPI, 2013), Dental amalgams, also called silver fillings and amalgam fillings, are widely done because it is inexpensive, ease to use and best settling material. Most importantly it is resin free which make it less allergic than composite fillings. In 2005, United Nations Environment Programme (UNEP) estimated that 362 tonnes of dental mercury are consumed annually worldwide. These fillings give off mercury vapours and their amount depends upon cavity size, tooth characteristics, composition, age of amalgam, time taken for filling, the number of fillings, temperature of ingested food/drinking liquids and the activities, such as, chewing and grinding of teeth (VACMP, 1998; BIO Intelligence Service, 2012). The daily intake of the vapours of mercury, from ambient air and dental fillings, through absorption into the blood-stream of adults is about 32 ng Hg/2 ngm^{-3} (of background air) in rural areas and about 160 ng Hg/10 ngm^{-3} (of background air) in urban areas. Estimated average absorbed concentrations of mercury vapours from dental fillings vary from 3,000 to 17,000 ng Hg (Clarkson et al., 1988; Skare and Engqvist. (1994). Mercury vapours are taken up via lungs and 80% of them is absorbed.

Mercury (Hg), the essential constituent of dental amalgam, is also known as quick silver, is a toxic substance of global concern. A persistent pollutant, mercury is not limited to its source but it travels, on time thousands of kilometers away from the source. Scientific evidence, including, UNEP global mercury report, establishes mercury as an extremely toxic substance, which is a major threat to wildlife, ecosystem and human health at a global scale (Arvidson et al., 1994). It is also a major threat to fish that constitutes an all-important nutritious component of human diet. Children are more at risk from mercury poisoning, which affects their neurological development and brain. Mercury

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poisoning diminishes memory, attention, thinking and sight. Mercuric ion reacts immediately with intracellular molecules or structures (e.g., enzymes, glutathione, tubulin, ion channels, or transporters), inhibiting their activities and interfering with normal cellular function. Mercury vapours can cause damages to central nervous system, thyroid, kidneys, lungs, immune system, eyes, gums and skin. Neurological and behavioural disorders include tremors, insomnia, memory and vision problems, neuromuscular effects and headaches. Fetuses and young children are more vulnerable to the mercury vapours **(**Kirby et al., 2012; Pamphlett and Coote, 1998; Stortebecker, 1989).

Mercury poses risks to environment and human health, especially the health of children, which has been subject of recent reviews (Gibb and O'Leary 2014; UNEP, 2013b) and studies (Visalli et al., 2013; Geier et al., 2013). In September, 2012, International Union for Conservation of Nature (IUCN) World Conservation Congress (WCC-2012) adopted Sustainable Development Policy Institute (SDPI) Motion (M-169) and called upon government representatives of Intergovernmental Negotiating Committee (INC) to support a legally binding treaty on mercury with an objective to protect human health and the environment from hazardous and toxic mercury (UNEP, 2013a). In January, 2013, 140 countries in Geneva adopted a ground-breaking, world's first legally binding treaty on mercury, now called "Minamata Convention on Mercury," limiting the use and emission of health-hazardous mercury. To-date, the convention has already been signed by 94 countries (Minamata, 2013).

In the past, a number of studies at dental sites in many countries have been carried out and reported. Only very specific data reported in these studies (24 dental sites in 10 countries), regarding indoor mercury vapours levels has been included (Annex. 1) and discussed. The research work described in this paper is continuation of our early work on air quality and health impacts due to hazardous chemicals contaminations of air (Khwaja et al., 2012; Khwaja and Glavin, 2006; Khwaja, 2005). The main objective of the present investigations was to monitor indoor/outdoor mercury vapours contamination in air of 18 selected dental sites in i.e., five main cities in Pakistan. The selected dental sites were private and public sectors dental teaching hospitals, teaching dental colleges, dental clinics and general hospitals. Sampling points were air (i) within operative dentistry sections/wards/rooms, (ii) adjacent corridors and (iii) open air. USA EPA reference concentration in air, 300 nanogram per meter cube (ng/m^3), has been referred to.

Material and Method

Mercury was monitored in air with the help of the instrument, Lumex Mercury Analyzer RA-915+ (Mercury Analyzer). Operational and maintenance guidelines, as described in the Lumex User's Manual were followed throughout the fieldwork. For quality assurance, Lumex test cell was run, using the internal check standard cell prior to each measurement. Annual calibration of the instrument was done and certified by Lumex, Inc. All measurements at a visited site were recorded on especially designed/formatted data sheets.

Workplace "Exposure Standards" were subjected to an exposure time duration (8 working hours) and were expected to be higher than the environmental exposure standards. It is to be noted that the observed mercury contamination in air at the visited sites and reported in the present study are only snap values (with maximum exposure time of 10 minutes) at the time of measurements. For discussion of the results, therefore, USA EPA reference concentration in air. 300 nanogram per meter cube (ng/m^3) has been referred to. This level, because of its safety factors, is considered to cover vulnerable population such as children. At 300 ng/m^3 mercury in air, a person should be able to breathe the air for 24 hours, 365 days a year for 70 years, without adverse effect on health (ATSDR, 2012; TEMPR, 2013).

Results and Discussion

Literature survey was carried out with the sole objective to gather very specific reported data about mercury levels in air, at as many dental sites of as many countries as possible. The same has been described in Annex 1, Tables 1 and 2 and Figs. 1 and 2. Since different investigators employed different units of mercury vapours measurements, for uniformity, these have been converted to ng/m^3 (Tables 1 and 2, and Figs. 1 and 2). The number of sampling sites and sampling points in the literature varied but for this report only 1 to 4 sites/points have been included for comparative mercury vapours levels observed at different sites in the countries. Except for Iran sites 1 and 4, all other sites showed mercury levels in air at dental sites higher than the USA EPA reference 300 ng/m^3 (Fig. 1). The highest mercury levels in air at some dental sites have been observed and reported for Puerto rico, Norway and UK (Fig. 1). In this study reports, most of these sites have been identified to be dental teaching institutions, whereas several students received training on operative dentistry using mercury/mercury amalgam (Annex. 1).

In addition to the data of indoor mercury vapours levels in nine countries (Table 1), during literature survey mercury data in air at ten sites in USA (Annex. 1) has also been identified and is shown in Table 2 and Fig. 2).

Table 1. Indoor reported mercury levels (ng/m^3) at dental sites in nine countries.

Country	Reported Level		
	Site A	Site B	Site C
Canada	13 ug/m^3 (13000)*	11 ug/m^3 (11000)*	12 ug/m^3 (12000)*
Colombia	2206 ng/m^3	4435 ng/m^3	2116 ng/m^3
Iran	8.39 ng/m^3	Nil	Nil
Iran-2	3.35 mg/m^3 (3350000)	Nil	Nil
Iran-3	0.009 mg/m^3 (9000)	0.014 mg/m^3 (14000)	Nil
Iran-4	0.011 ng/m^3	Nil	Nil
India	2.44 ug/m^3 (2440)	3.11 ug/m^3 (3110)	3.78 ug/m^3 (3780)
India-2	1.23 ug/m^3 (1230)	1.98 ug/m^3 (1980)	2.77 ug/m^3 (2770)
Norway	0.38 mg/m^3 (380000)	Nil	Nil
Puerto Rico	3.3 mg/m^3 (3300000)	102.7 ug/m^3 (102700)	Nil
Scotland	28.9 ug/m^3 (28900)	37.8 ug/m^3 (37800)	6.5 ug/m^3 (6500)
Turkey	27 ug/m^3 (27000)	25 ug/m^3 (25000)	48 ug/m^3 (48000)
UK	250 ug/m^3 (250000)	Nil	Nil
UK-2	1.05 mg/m^3 (1050000)	0.1 mg/m^3 (100000)	1.07 mg/m^3 (1070000)

Values in brackets are converted values in ng/m^3
(Source: Annex. 1)

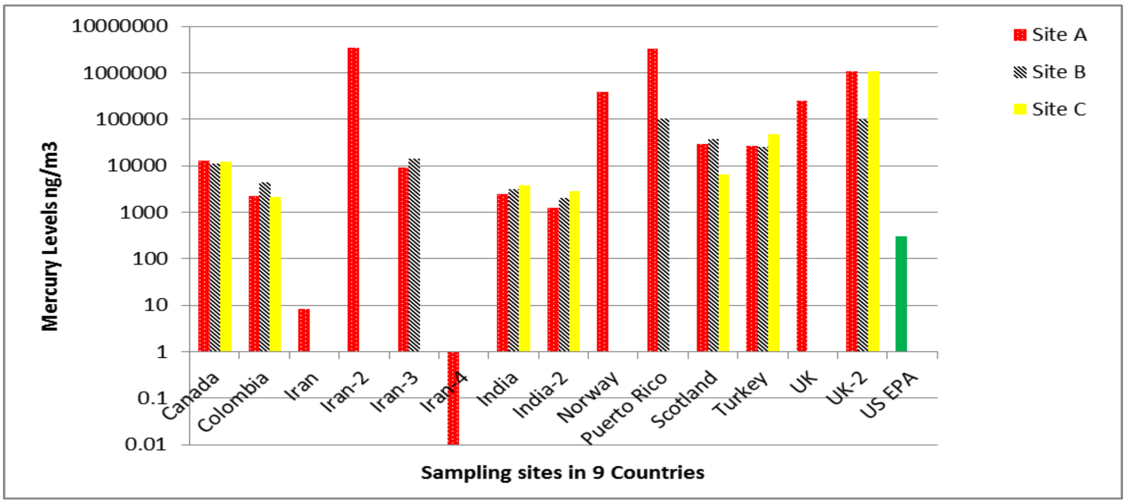

Fig. 1. Indoor mercury levels (ng/m^3) at dental sites in nine countries.
Source: Annex. 1.

Table 2. Reported indoor mercury levels (ng/m^3) at USA dental sites.

Dental site	Reported levels		
	Site A	Site B	Site C
USA	46526 ng/m^3	72211 ng/m^3	36895 ng/m^3
USA-2	18 mg/m^3 (18000000)	18 mg/m^3(18000000)	0.03 mg/m^3(30000)
USA-3	0.237 mg/m^3(237000)	0.168 mg/m^3(168000)	0.126 mg/m^3(126000)
USA-4	0.199 mg/m^3(199000)	0.006 mg/m^3(6000)	0.004 mg/m^3(4000)
USA-5	0.199 mg/m^3(199000)	0.017 mg/m^3(17000)	Nil
USA-6	Nil	Nil	0.03 mg/m^3(30000)
USA-7	500 ng/m^3	Nil	Nil
USA-8	0.03 ng/m^3	65 ng/m^3	0.05 ng/m^3
USA-9	0.13 mg/m^3(130000)	0.28 mg/m^3 (280000)	0.10 mg/m^3(100000)
USA-10	3 ng/m^3	110 ng/m^3	180 ng/m^3

Values in brackets are those converted to ng/m^3
Source: Annex. 1

As can be seen from Fig. 2, except USA sites 8 and 10, all the other eight dental sites have mercury levels higher than the USA EPA reference concentration in air (300 ng/m^3). According to the information, provided in the report, at USA dental site 10, only mercury filling removals have been carried and no mercury filling has been done for 20 years (CDC, 2012). The highest mercury levels in air (many times greater than the USA reference concentration) were observed at USA sites 2A and 2B. Enough information about this site is not given in the referred report to help to explain these extremely high indoor mercury levels observed (Gronka et al., 1970).

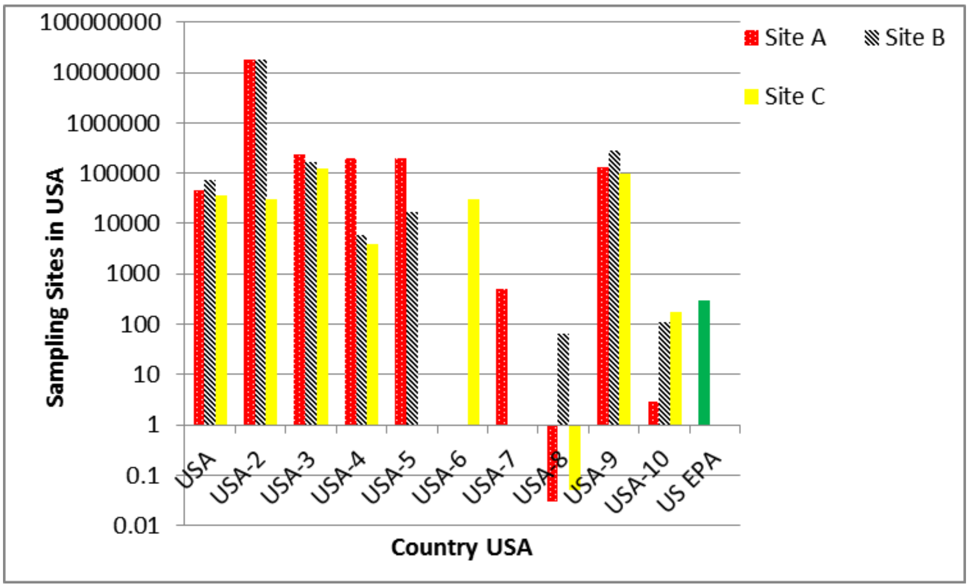

Fig. 2. Indoor air reported mercury levels (ng/m^3) at USA dental sites.
Source: Annex. 1.

Air monitoring of mercury vapour level at dental sites in Pakistan

According to preliminary reported data in 2009, the estimated maximum and minimum emission and transfer of mercury in Pakistan is about 36,900 and 10,800 kg per year, respectively. At present, there is no mercury specific legislation in the country. However, development of a mercury management national action plan is in the making (GoP and UNEP, 2009). In 2010, a study in Pakistan, evaluating the amalgam use by dentists in the country and its waste management, has indicated that 92% dentists used amalgam often/always, whereas 56% of the study samples did not agree that amalgam should be phased out and replaced with non-mercury fillings. 92% dentists of the selected samples perceived amalgam a health risk, whereas 46% considered it an environmental hazard (Rubina et al., 2010). A similar study carried out in Karachi indicated 94% of dentists performed dental amalgam restoration, 57% using hand mixing for dispensing and 55% disposing of mercury waste in the sink. (Iqbal et al., 2011).

In the present study mercury monitoring in air was carried out at selected dental sites in five main cities of Pakistan. At each site, sampling points were operative dentistry ward/section, adjacent corridor and open air. Among all thirty four (34) visited/monitored dental sites in Lahore, Peshawar, Abbottabad, Rawalpindi and Islamabad, eleven (11) sites were most contaminated with mercury level in air many times higher than the recommended limit of 300ng/m^3. Mercury level in air of operative dentistry (OPD) at 15 out of 17 dental teaching institutions was found to be higher than the recommended limit, whereas, similar higher mercury levels were observed in 5 out of 7 general hospitals and all the 10 private clinics visited (Table 4). The highest mercury levels in OPD air at teaching institutions, general hospitals and private clinics were found to be 44,067, 17,172 and 1,800 ng/m^3 and the lowest values at these sites were 109, 174 and 333 ng/m^3, respectively (Table 4). Among dental sites mercury contamination of air was found to be generally in the increasing order operative section > corridor > open air and at teaching institutions > general hospitals > private clinics (SDPI and ZMWG, 2013).

Table 4. Mercury levels at visited sites in Lahore, Peshawar, Abbottabad, Rawalpindi and Islamabad.

Sr. No.	Sample	No of samples (n)	Mercury levels in air ng/m^3		Above standard *(300ng/m^3) No (%)
			Max.	Mini.	
1	Dental teaching institutions	17	44067	109	15 (88)
2	General hospitals	7	17172	174	5 (71)
3	Dental clinics (Private)	9	1800	333	9 (100)

Source: SDPI and ZMWG, (2013); *ATSDR, (2012).

During 2011 – 2013, as a part of ZMWG global mercury project, indoor mercury vapours monitoring with lumex mercury analyser at dental sites has been carried out by ZMWG partner organisations in Armenia, Cote D'Ivoir, Lebanon, Morocco, Philippines and Tanzania (Annex. 1, Table 3 and Fig. 3). For comparison with monitoring results in Pakistan in order to assess the gravity of the indoor air mercury contamination in the country, these are very briefly summarised below:

Armenia lacks information and data on the current status of mercury contamination and possible environmental and health hazards related to mercury, in the country. Mercury levels in air, of patients' rooms, at three dental clinics, were found to be (04.00 to 14.20 ng/m^3) far below the USA EPA reference concentration of 300ng/m^3. However, most of the observed indoor mercury levels were many times above the observed mercury levels (02.20 ng/m3) of open air at dental clinic entrances (Annex. 1). For many years, in Armenia, mercury/mercury amalgam has not been in use for operative dentistry and there is no import of it, in the country, since it is not at all demanded (AWHHE and ZMWG, 2012).

Three dental clinics sites in Cote D'Ivore were monitored for indoor and outdoor mercury levels with Lumex mercury analyser (JVPE and ZMWG, 2012). Results of measurements are given in Annex. 1, Fig. 3 and Table 3. Site 1 (Bouake) and site 3 (Korhogo) showed the highest (6759 ng/m^3) and the lowest (337 ng/^{3}) mercury levels of indoor air of dental clinics, respectively. At site 2 (Abidjan), the air adjacent to the teaching hospitals was also observed to be highly polluted showing mercury vapours of levels much higher than the USA EPA reference concentration.

Like Armenia, in Lebanon also mercury/ mercury amalgam has not been in use for many years (IndyAct and ZMWG, 2011). If used, the capsulated mercury amalgam and mechanical mixing have been employed, which substantially reduce mercury emissions and release to the environment. The visited dental clinics indicated mercury vapours level of indoor air between 10.3 – 787 ng/m^3. The highest level was observed at Saida (site 2, Annex. 1), which was above the USA EPA reference level. The lowest level of 10.3 ng/m3 was observed at Dahiyeh (site 1), whereas generally, mercury amalgam has not been in use (IndyAct and ZMWG, 2011).

Table 3. Indoor mercury levels (ng/m^3) in different countries monitored by ZMWG.

Country	Reported levels		
	Site A	Site B	Site C
Armenia	**12**	**10**	**14**
Armenia-2	**4.4**	**Nil**	**Nil**
Armenia-3	**4**	**Nil**	**Nil**
Cote D'Ivoire	**6759**	**Nil**	**Nil**
Cote D'Ivoire -2	**806**	**Nil**	**Nil**
Cote D'Ivoire-3	**337**	**Nil**	**Nil**
Lebanon	**163**	**10.3**	**Nil**
Lebanon-2	**787.8**	**797.1**	**134.8**
Lebanon-3	**291.4**	**46.5**	**Nil**
Morocco	**131.6**	**170.4**	**25.4**
Morocco-2	**104.2**	**31-Jan**	
Pakistan	**8627**	**2453**	**791**
Pakistan-2	**3930**	**333**	**714**
Pakistan-3	**2798**	**9003**	**1800**
Pakistan-4	**2631**	**179**	**Nil**
Philippines	**20**	**6760.9**	**Nil**
Tanzania	**615**	**986**	**4588**

Source: Annex. 1.

In Morocco, lower levels of indoor mercury vapours at the visited dental sites were observed, as compared to Lebanon, the highest value being 170.4 ng/m^{3}at Rabat Faculty of Dental Medicines (IndyAct and ZMWG, 2011). At Tangier site (Annex. 1), mercury levels of indoor air in the clinics were in the range 31.4 to 104.2 ng/m^3. Little use of mercury amalgam has been reported in the country and the capsulated and mechanical mixing methodologies are employed for the same (IndyAct and ZMWG, 2011).

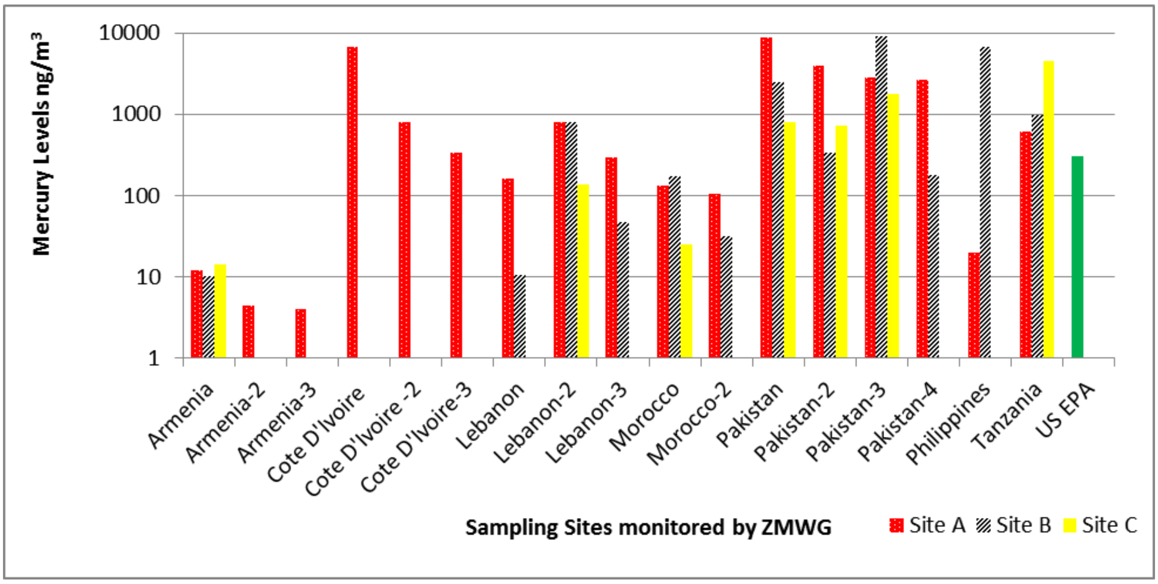

Fig. 3. Indoor mercury levels (ng/m^3) at dental monitored by ZMWG in different countries.

Source: Annex. 1.

In Philippines at three sampling points of site 1(hospital), indoor mercury vapours levels were observed to be 6,760 to 20.0 ng/m^3 (Annex. 1). However, at the entrance of the two hospitals, mercury vapours levels of open air were below USA EPA reference level of 300 ng/m^3 (BT and ZMWG, 2011). Mercury levels in air at dental section in 3 visited hospitals of Dar-es-Salam (Tanzania) were observed to be 615 – 4,588 ng/m^3, higher than the USA EPA reference level 300 ng/m^3 (Table 3, Annex. 1), thought to be due to lack of ventilation and no mercury recovery system (AGENDA and ZMWG, 2013).

Monitoring data at 17 dental teaching institutions of 5 main cities in Pakistan is shown in Fig. 4 (SDPI and ZMWG, 2013). 88% of the sites indicated mercury vapours indoor mercury levels above the USA EPA reference level of 300 ng/m^3. Comparatively higher mercury vapours levels were observed at dental teaching institutions in different countries (Figs. 1 and 2) and also observed during mercury monitoring by ZMWG (Fig. 3). Similarly, very high mercury levels in air have been observed for nearly all visited teaching institutions in the country (Fig. 4). At some sites, the mercury vapours contamination, even in the adjacent corridors and the surrounding air, were higher than the US reference concentration (Fig. 4). Most likely these, very high mercury vapours levels in air were due to the use of liquid mercury and non-mechanical mixing for mercury amalgam making.

The study also showed general unawareness regarding appropriate handling of mercury/mercury amalgam, mercury containing wastes, improper and inadequate ventilation system and lack of awareness regarding health hazards of mercury to human health and its impact on the environment. A recent report on mercury vapour exposure during dental students' training in amalgam removal has indicated the highest mercury vapours release, if water spray and suction were not used during the amalgam removal process (Warwick et al., 2013). At some of the visited sites in Pakistan, the main reasons for the observed elevated levels of mercury in air at OPD, adjacent corridors and the surrounding air was the careless use of mercury/mercury amalgam and inappropriate mercury/mercury amalgam waste management (SDPI and ZMWG, 2013).

Conclusion and recommendations

It is evident from the earlier reported data (Tables 1 and 2), the data collected by ZMWG (Table 3) and data collected in the present study at thirty four (34) sites in Pakistan that at most dental sites in many countries (including, Pakistan) the indoor mercury vapours levels at these sites exceed far above the permissible limit, recommended for safe physical and mental health. At these sites, public in general and the medical, paramedical staff and vulnerable population in particular, are at most serious health risk, resulting from exposure to toxic and hazardous mercury.

In order to reduce the risk of mercury exposure to public health, we strongly recommend that the use of hazardous mercury be banned for operative dentistry and other uses, through signing and ratifying the Minamata Convention on mercury (2013) by the national governments of the world at the earliest time possible. We also recommend that,

- Following the best preventive approach -"Waste Reduction at Source", mercury emission/release streams be identified within dental sites by carrying out environmental waste audit, so that

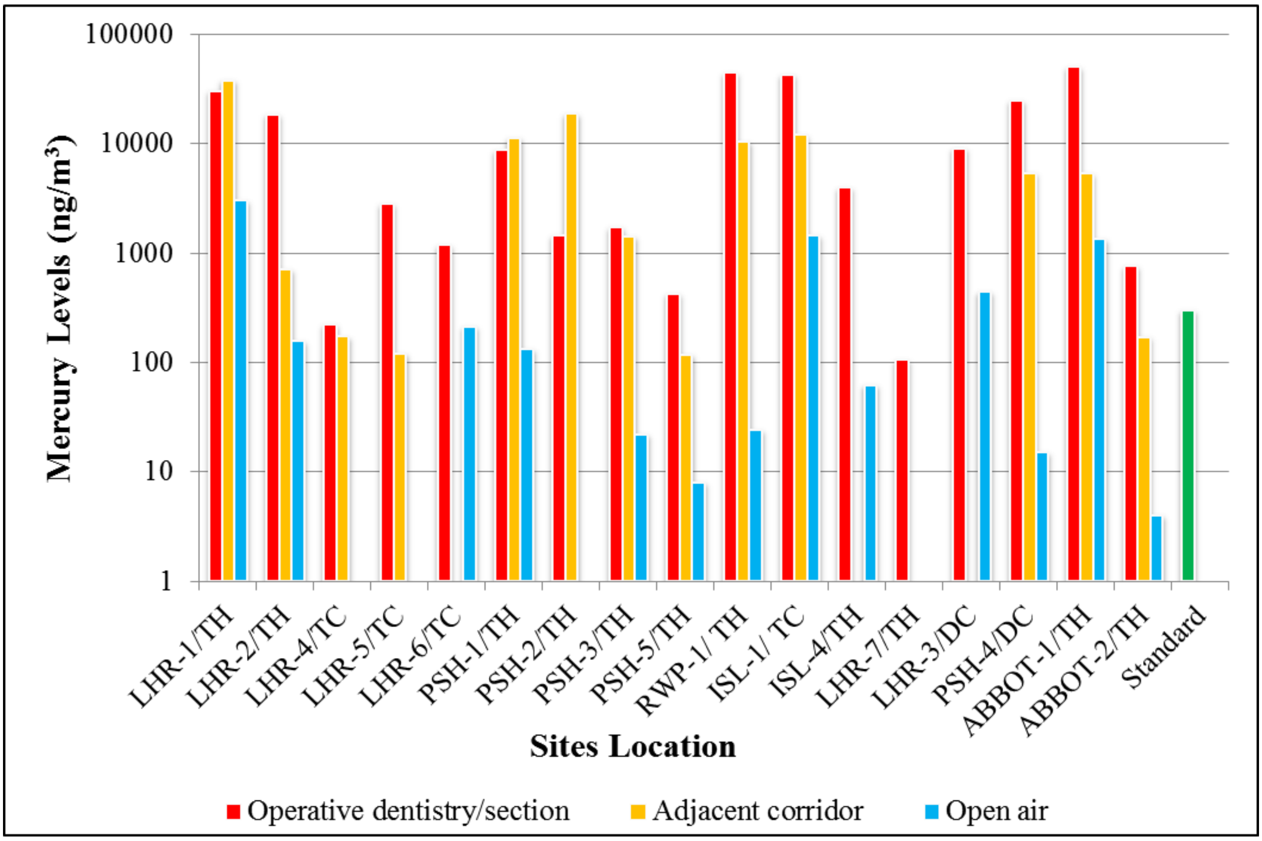

Fig. 4. Mercury levels at teaching hospitals and dental colleges in Pakistan. Source: SDPI and ZMWG, 2013.

accordingly, control measures at sites be designed and implemented at the earliest.

- Non-mercury dental fillings be advised to patients by dentists.
- Best in-house environmental practices (cross ventilation, exhaust fans) and use of best environment friendly technologies be encouraged. Standard operating procedures (SOPs) for mercury handling collection, transport and use be developed and implemented at all dental sites.
- An institutional mercury waste management plan be put in place at all mercury operated sites and the same be periodically monitored and evaluated by the management.
- Capsulated mercury amalgam use and mechanised mixing be promoted and encouraged in operative dentistry, as evident from the reported studies that effectively and substantially reduce mercury waste and its release/emission to the environment.
- At the identified highly polluted dental sites described in the present study (evident from the reported data of snap/spot measurements of mercury vapours in air, at the time of measurements), a follow up comprehensive survey and monitoring programme, including measurement of mercury levels for 8 hours exposure period, be developed and implemented at the earliest, to further validate the risks resulting from mercury exposure to public health in general and visitor/medical staff in particular.
- Mercury specific legislation, including national emissions/releases standards, standard minimum mercury amount in products and protocols for permits/license be developed and implemented for private clinics/teaching institutions.
- The current curriculum at dental colleges and teaching institutions be reviewed and revised to include mercury toxicity and hazards, mercury specific occupational and health safety, mercury releases and emissions control, environmentally sound mercury waste management, non-mercury dental fillings and alternate material and capsulated mercury amalgam and mechanised mixing technologies.

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Annex. 1

Study of indoor mercury vapours pollution at dental teaching institutions, hospitals and clinics resulting from mercury amalgam use in dentistry.

Country	Site	Sampling points			Mercury vapours levels (mean value with standard deviation and number of observations			Referred standard	Reference number with full reference below the table	Remarks/ Comments
		A	B	C	A	B	C			
Armenia	**Abovyan, Kotayk/ Dental Clinic**	**Patient room**	**Surgical room**	**Corridor**	**12.00**	**10.60**	**14.20**	**US EPA Rfc 300 ng/m³**	**AWHHE and ZMWG (2012)**	**Open air/near entrance 02.20 ng/m³**
Armenia-2	**Yerevan, Kotayk/ Dental Clinic**	**Patient room**	**-**	**-**	**4.4**	**-**	**-**	**US EPA Rfc 300 ng/m³**	**AWHHE and ZMWG (2012)**	**Open air/near entrance 02.20 ng/m³**
Armenia-3	**Haybusak University, Yerevan/ Dental Clinic**	**Patient room**	**-**	**-**	**4.0**	**-**	**-**	**US EPA Rfc 300 ng/m³**	**AWHHE and ZMWG (2012)**	**Open air/near entrance 02.20 ng/m*3***
Canada	**Dental Offices, Vanacouver, BC**	**Operatory/ Garbage area**	**Laborator y**	**Laboratory Sinks**	**13 ug/m³**	**11 ug/m³**	**12 ug/m³**	**-**	**Roydhouse et al., 1985**	**Mean values**
Colombia	**64 clinics/ Cartagena**	**Air**	**Spittoons**	**Bench**	**2,206 ng/m³**	**4,435 ng/m³**	**2,116 ng/m³**	**USA EPA 300ng/m³**	**Maria, (2011)**	**Six months samples**
Cote D'Ivoire	**Bouake**	**Dental Clinic**	**Teaching hospital**	**-**	**6759 Air Within clinic**	**18 Adjacent outdoor air**	**-**	**US EPA Rfc 300 ng/m³**	**JVPIE and ZMWG (2012)**	**Reported maximum Hg levels**
Cote D'Ivoire 2	**Abidjan**	**Dental Clinic**	**Teaching hospital 1 Treich-ville**	**Teaching hospital 2 Cocody**	**806 Air Within clinic**	**850 Adjacent outdoor air**	**1295 Adjacent outdoor air**	**US EPA Rfc 300 ng/m³**	**JVPIE/ZMWG (2012)**	**Reported maximum Hg levels**
Cote D'Ivoire 3	**Korhogo**	**Dental Clinic**	**Hospital**	**-**	**337 Air Within clinic**	**22 Adjacent outdoor air**	**-**	**US EPA Rfc 300 ng/m³**	**JVPIE/ZMWG (2012)**	**Reported maximum Hg levels**

Iran	**Tehran/sites not specified**	**211 dental clinics**	**-**	**-**	**8.39 +/- 9.68 mg/m^3**	**-**	**-**	**-**	**Hasani , (2007)**	**Mean value**
Iran - 2	**Shiraz City/ public and private clinics**	**-**	**-**	**-**	**3.35 mg/m^3**	**-**	**-**	**WHO and ACGIH TLV 25 ug/m^3**	**Masoud,et al., 2011.**	**0.4 – 7.7 mg/m^3 (range)**
Iran - 3	**Clinics in Tehran / sites not specified**	**Govt. clinics**	**Non-governme nt clinics**	**-**	**0.009mg/ m^3**	**0.014 mg/m^3**	**-**	**OSHA 100,000; NIOSH 50,000 and ACGIH 25,000 ng/m^3**	**Mousavi, et al., 2009.**	**Data also indicates increasing mercury levels in air with increasing number of patients treated**
Iran - 4	**Tehran/sites not specified**	**Dental Offices**	**-**	**-**	**0.011 +/- 0.002 ng/m^3 (n=305)**	**-**	**-**	**NIOSH 0.05; ACGIH 0.02 mg/m^3**	**Hassan, et al., 2009.**	
India	**Hospital/Delhi**	**Calibration room**	**Dental Wing**	**Storage room**	**2.44 ug/m^3**	**3.11 ug/m^3**	**3.78 ug/m^3**	**OSHA (PEL)100; NIOSH (REL) 50 ; ACGIH (TLV) 25; ASTDR (MRL) 0.2; and EPA (Rfc) 0.3 ug/m^3**	**Pastore, et al., 2007.**	**-**
India - 2	**Hospital/Delhi**	**General ward**	**Nursing room**	**Maintenance room**	**1.23 ug/m^3**	**1.98 ug/m^3**	**2.77 ug/m^3**	**Same as above**	**Pastore et al., 2007.**	**-**
Lebanon	**Dahiyeh**	**Dental Clinic 1**	**Dental Clinic 2**	**-**	**163.1**	**10.3**	**-**	**US EPA Rfc 300 ng/m^3**	**IndyAct and ZMWG (2011)**	**Mercury amalgam not used**
Lebanon 2	**Saida**	**Dental Clinic 1**	**Dental Clinic 2**	**Dental Clinic 3**	**787.8**	**797.1**	**134.8**	**US EPA Rfc 300 ng/m^3**	**IndyAct and ZMWG (2011)**	**Clinic 1 and 2 use packaged amalgam filling. Clinic 3 Hg amalgam not used**
Lebanon 3	**Beirut**	**Dental Clinic 1**	**Dental Clinic 2**	**-**	**291.4**	**46.5**	**-**	**US EPA Rfc 300 ng/m^3**	**IndyAct and ZMWG (2011)**	**Air within dental clinics**
Morocco	**Rabat, Faculty of Dental Medicines**	**Site 1/ Child care**	**Site 2/ Pedodonti cs Cabinet**	**Site 3/Waiting room**	**131.6**	**170.4**	**25.4**	**US EPA Rfc 300 ng/m^3**	**IndyAct and ZMWG (2011)**	**Hg amalgam not used**
Morocco 2	**Tangier**	**Site 1/ OPD room**	**Site 2/Waiting room**	**-**	**104.2**	**31.4**	**-**	**US EPA Rfc 300 ng/m^3**	**IndyAct and ZMWG (2011)**	**Reported maximum Hg levels**
Norway	**Oslo/Scandinav ian Institute of dental material**	**Dental laboratory**	**-**	**-**	**0.38 mg/m^3**	**-**	**-**	**TWA 0.05mg/m^3**	**Brune, and Beltesbrekke (1978)**	**Maximum value**
Pakistan	**Peshawar**	**OPD/ Dental teaching hospital**	**OPD/Dent al teaching college**	**Dental clinic**	**8,627**	**2,453**	**791**	**US EPA Rfc 300 ng/m^3**	**SDPI and ZMWG (2013)**	**Lower Hg levels in adjacent corridor and open air**
Pakistan 2	**Islamabad**	**OPD/ Dental Teaching hospital**	**OPD/Dent al clinic 1**	**OPD/ Dental clinic 2**	**3930**	**333**	**714**	**US EPA Rfc 300 ng/m^3**	**SDPI and ZMWG (2013)**	**Lower Hg levels in adjacent corridor and open air**
Pakistan 3	**Lahore**	**Dental Teaching college 1**	**Dental teaching college 2**	**Dental clinic**	**2798**	**9003**	**1800**	**US EPA Rfc 300 ng/m^3**	**SDPI and ZMWG (2013)**	**Lower Hg levels in adjacent**

										corridor and open air
Pakistan 4	**Rawalpindi**	**OPD/ Hospital 1**	**OPD hospital 2**	**-**	**2,631**	**179**	**-**	**US EPA Rfc 300 ng/m^3**	**SDPI and ZMWG (2013)**	**Lower Hg levels in adjacent corridor and open air**
Philippines	**Hospital A/ Location not to be disclosed**	**Site 1/ OPD room**	**Site 2/ Storage Cabinet open**	**Site 3/ Entrance hall way**	**20.0**	**6,760.9**	**274**	**US EPA Rfc 300 ng/m^3**	**BT and ZMWG (2011)**	**Reported maximum level**
Philippines 2	**Hospital B/Location not to be disclosed**	**Open air/outside door**	**-**	**-**	**9.6**	**-**	**-**	**US EPA Rfc 300 ng/m^3**	**BT and ZMWG (2011)**	**Reported maximum level**
Puerto Rico	**School of Dentistry, University of Puerto Rico**	**Dental Simulation Laboratory (DSL)**	**Dental Clinic (DC)**	**-**	**1.1 - 3.3 mg/m^3**	**13.6 - 102.7 microgram (ug)/m^3**	**-**	**OSHA (Permissible Exposure Limit) = 100 ug/m^3**	**Adriana et al., 2007.**	
Scotland	**180 dental surgeries/site not specified**	**Chair**	**Mixing Device**	**Air**	**28.9 ug/m^3**	**37.8 ug/m^3**	**6.5 ug/m^3**	**OES 25 ug m^3 8hrs/day**	**Ritchie et al., 2004**	**Mean values**
Tanzania	**Dar es Salaam**	**Site 1/ Hospital, Dental Section**	**Site 2/Hospital, Dental Section**	**Site 3/Dental Clinic**	**615**	**986**	**4,588**	**US EPA Rfc 300 ng/m^3**	**AGENDA and ZMWG (2013)**	**Indoor air during filling process**
Turkey	**Izmir/Dental School of Ege University**	**Student laboratory**	**Clinic 1 and 2**	**Clinic 3**	**27 ug/m^3**	**25 ug/m^3**	**48 ug/m^3**	**WHO 25 ug/m^3**	**Tezel et al. (2011)**	**Annual averages of daily air mercury levels**
UK	**Laboratory/sites not specified**	**-**	**-**	**-**	**250 ug/m^3**	**-**	**-**	**UK Health and Safety Executive = 25 ug/m^3**	**Stonehouse and Newman (2011)**	**-**
UK - 2	**Dental Practice/Site not specified**	**Surgery A/ Chair side**	**Surgery B/ Chair Side**	**Surgery C/ Chair Side**	**1.05 mg/m^3**	**0.1 mg/m^3**	**1.07 mg/m^3**	**Health and Safety Executive TLV TWA 0.05 mg/m^3**	**Stanley and Ingram (1989)**	**Floor level**
USA	**Great Lakes II**	**Clinic 1 (110 chairs)**	**Clinic 2 (30 chairs)**	**Clinic 3 (2 chairs)**	**46,526 +/- 19,912 ng/m^3 (n= 19)**	**72,211 +/- 10,850 ng/m^3 (n=19)**	**36,895 +/- 7,894 ng/m^3(n=19)**	**USA Federal OSHA 100,000 ng/m^3; NIOSH 50,000 ng/m^3; ACGIH 25,000 ng/m^3**	**Stone et al., 2007.**	**1.Ambient air (1000 feet away) 13.2 +/- 13.5 ng/m^3 (n=89)**
USA - 2	**59 dental offices/site not specified**	**Pertinent locations**	**Breathing zones of dental workers**	**home**	**18mg/m^3**	**18 mg/m^3**	**0.03 mg/m^3**	**ACGIH TLV 0.1 mg/m^3**	**Gronka, et al., 1970.**	**Mercury carried home with shoes/ clothes**
USA - 3	**8 dental offices/sites not specified**	**Site 3**	**Site 5**	**Site 8**	**0.237 +/- 0.020 mg/m^3**	**0.168 +/- 0.023 mg/m^3**	**0.126 +/- 0.001 mg/m^3**	**OSHA 0.050 mg/m^3**	**Rubin and Paul (1996)**	**Average(n=8) 0.092 +/- 0.008 mg/m^3**
USA - 4	**Clinic/site not specified**	**Amalgam well**	**Breathing zone 2**	**Waste baskets**	**0.199 mg/m^3**	**0.006 mg/m^3**	**0.004 mg/m^3**	**USA EPA Rfc 300 ng/m^3**	**Janeth et al., 2003.**	**1 Dental clinic with 4 examining rooms**
USA - 5	**Clinic/University of Utah**	**Amalgam well**	**Breathing zone**	**-**	**0.199 mg/m^3**	**0.017 mg/m^3 (n=24)**	**-**	**OSHA PEL**	**Janeth et al., 2003.**	**Maximum values**
USA - 6	**University of Washington/site not specified**	**Background**	**-**	**-**	**0.003 mg/m^3**	**-**	**-**	**TLV 0.05 mg/m^3**	**Powell et al. (1994)**	**Average value**

USA - 7	**Minnesota Dental Offices/Site not specified**	**Air**	**-**	**-**	**300 – 500 ng/m^3**	**-**	**-**	**USA EPA 300 ng/m^3**	**MDEQ/MPCA and WDNR (2003)**	**Tests over sink traps and floor drains**
USA - 8	**Dental Clinics**	**Treatment room 1**	**Treatmen t room 2**	**Treatment room 3**	**0.02 – 0.03 ng/m^3**	**65 – 1 mg/m^3**	**0.03 – 0.05 ng/m^3**	**TLV 0.05 mg/m^3**	**Janeth, et al (2003)**	**Breathing level**
USA - 9	**69 dental clinics/Des Moines area**	**Office 3**	**Office 6**	**Office 11**	**0.13 mg/m^3**	**0.28 mg/m^3**	**0.10 mg/m^3**	**NIOSH TV 0.05 mg/m^3**	**Thomas et al. (1984)**	**Floor level**
USA - 10	**Dental Clinics/Site not specified**	**Open air**	**Operating room normal**	**Amalgam filling removal**	**3 – 2 ng/m^3**	**100 – 110 ng/m^3**	**140 – 180 ng/m^3**	**WHO 200 ng/m^3**	**CDC/EEB (2012)**	**No mercury filling since 20 years; only filling removal**