Available online at: www.mbai.org.in doi: 10.6024/jmbai.2012.54.2.01695-02

Mercury levels in hair of fish consumers along Ulhas River Estuary and Thane Creek, Maharashtra, India.

Jayashree Satheesh Menon* and Sarita Vishwas Mahajan[1]
Maharashtra College of Arts, Science and Commerce, Mumbai Central, Mumbai, India- 400008,
[1]B. N. Bandodkar College of Science, Chendani - Koliwada, Thane (W), Maharashtra.

*Correspondence e-mail: menonjayu72@gmail.com

Received: 10 Aug 2011, Accepted: 15 Nov 2012, Published: 10 Dec 2012

Original Article

Abstract

Waters and fish of Ulhas River Estuary (73⁰14'E, 19⁰14'N to 72⁰ 54'E, 19⁰17'N) and Thane creek (72⁰55' E, 19⁰N to 73⁰ E, 19⁰15'N) are contaminated with mercury, a potent neurotoxin causing health hazards in humans. The fish-consumers residing along the banks of these water bodies are therefore continuously exposed to mercury. A study to evaluate mercury exposure levels of these populations was carried out by analyzing mercury levels in their hair samples. Among the study areas, the population of reference site, Khadavli, showed values below the detection limit whereas Alimgarh and Diwe-Kewni populations had mean hair mercury of 8.87 μg/g and 9.017 μg/g respectively. Wehele, Vittawa and Airoli populations had comparatively lower levels of hair mercury with an average of 6.7 μg/g, 4.84 μg/g and 5.37 μg/g respectively. The proposed safety limit of 10 μg /g in hair was exceeded by 20.37%, 34.72% and 1.96% of the populations of Alimgarh, Diwe-Kewni and Wehele respectively. The entire populations of Vittawa and Airoli were within this safety limit. As 5-10 μg/g hair Hg levels has been associated with neurobehavioral disturbances and psychomotor defects in adults, percentage of such population was determined and the results indicated that continuous monitoring in these areas is required.

Keywords: *Mercury, Thane creek, Ulhas River Estuary, hair, fish, population, exposure assessment.*

Introduction

Mercury (Hg) is widely recognized as a potential threat to human health due to its capacity to cause systemic toxicity. Methyl-Hg, the organic form of Hg, is a known neurotoxic compound that bioaccumulates and biomagnifies along the food-chain resulting in very high levels in the top level organisms (UNEP, 2007). Fish, being at the apex of the aquatic food-chain becomes a dominant source of human exposure to Hg (Dorea *et al*., 2003). The toxicological risk associated with Hg intake through the consumption of contaminated fish, is enhanced in regular fish-eaters. Studies on Hg levels in a few estuaries and coastal regions of India reveal very high levels of Hg. In Hoogly estuary, an average of 280 ng/ml of Hg was detected in water (Agrawal *et al*., 2004) whereas Karwar coast showed a range of 1.5 and 50 ng/ml (Krishnakumar *et al*., 1990). On the other hand, lower levels of 0.0763 ng/ml and 0.116 ng/ml were reported by Rajathy (1997) in Ennore estuary and Kaladharan *et al*. (1999) in west coast of India respectively.

The area selected for the present study, Ulhas River Estuary (URE), 73⁰14'E, 19⁰14'N to 72⁰ 54'E, 19⁰17'N, is the downward-end stream of 54 kms stretch of the Ulhas River. There are six industrial zones located along the banks of riverine as well as estuarine parts of Ulhas River. The effluents from these zones, treated or partially treated find their final way to Ulhas River Estuary, directly or indirectly through the outlets, consequently affecting aquatic life in this area (Environmental Status Report of Kalyan region, 2004-05). The second study area, Thane Creek (TC), $72^{0}55'$E, 19^{0} N to 73^{0}E, $19^{0}15'$N, embanks Asia's largest industrial zone, Thane-Belapur industrial belt, on its east. The west bank has highly urbanized Mumbai and Thane regions burdened with a sizeable number of industries. Sewage water generated from the nearby cities is finally disposed in the creek along with industrial effluents leading to its deteriorating status and affecting the fishery of the creek. Hasan (1984) in his studies on the effluents of Kalyan-Bhiwandi area and Ulhas river estuary reported a concentration of mercury between 2.21 μg/l and 5.23 μg/l in water. Patil (1982) reported Hg concentration in Ulhas creek ranging from 0.1 to 5.4 μg/l. The main sources of Hg contamination in the aquatic environment of URE are the two major chlor-alkali plants situated on the banks of River Kalu (tributary of River Ulhas) at Mohane and at Shahad, which are located upstream of Ulhas River Estuary (Environmental Status Report of Kalyan region, MPCB, 2004-05). Similarly, along the bank of Thane Creek, a chlor-alkali plant is located at Ghansoli. There are also two thermal power plants (source which releases high amount of Hg in air) situated near the study areas, one at Dahanu and other at Chembur, Mumbai. Other sources include pulp & paper industries, fertilizer industries, cement industries, petroleum industries, drugs & pharmaceutical industries, paints & pigments industries, chemical industries, pesticide industries, synthetic resin & plastics industries, dyes & dye stuffs industries, solid waste, bio-medical waste and sewage (Mercury in India- Standards & Legislations, www.toxicslink.org,Environmental Status Report of Thane Region, MPCB, 2005, Environmental Status Report of Navi Mumbai Region, MPCB, 2005, Environmental Status Report of Mumbai Region, MPCB, 2005).

Menon (2009) have reported high Hg levels in fish from Thane Creek and URE (Table 1). The villagers residing along their banks depend on these mercury contaminated fish for daily sustenance (Menon, 2009) which may lead to deleterious state of health. Therefore, a study to evaluate the exposure levels of these populations to Hg was carried out by estimating Hg levels in their hair samples. Hair has the ability to incorporate toxic metals like Hg during its growth process (Hightower and Moore, 2003). The amount of Hg deposited in hair indicates the body-burden of Hg in the individual and the concentration of toxic metals in hair is reported as proportional to their concentration in other body tissues (Bidone *et al.*, 1997). WHO (1990) had reported that no health effect was observed with hair Hg levels below 50 μg/g for adults. However, recent studies on chronic low level methyl-Hg exposures in adults suggest that a guidance level of 50 μg/g in hair may not be protective (Yokoo *et al.*, 2003). Several other studies reveal that maternal hair Hg levels below 10 μg/g can also cause adverse effects in children (Mahaffey and Rice, 1998). In adults also, hair mercury concentrations below 50 μg/g have been associated with neurobehavioral disturbances (Lebel *et al.*, 1998). Most researchers have suggested a BMDL (Bench Mark dose Limit) of 10 μg/g of hair Hg for Amazonian populations (UNEP Chemicals, 2002). Therefore, the primary goal of this investigation was to determine the population distribution of hair Hg levels in the study areas, to identify the % of sub-population exceeding the safe limit of 10 μg/g and thereby assessing the risk of Hg exposure.

Material and methods

Study areas

The hair samples of the individuals were collected during a prospective survey of substantial fish-eating communities along Ulhas river estuary and Thane creek. Six villages were selected for the present study out of which one was the reference village named Khadavli. Out of the remaining five villages, three were located along Ulhas river estuary and the

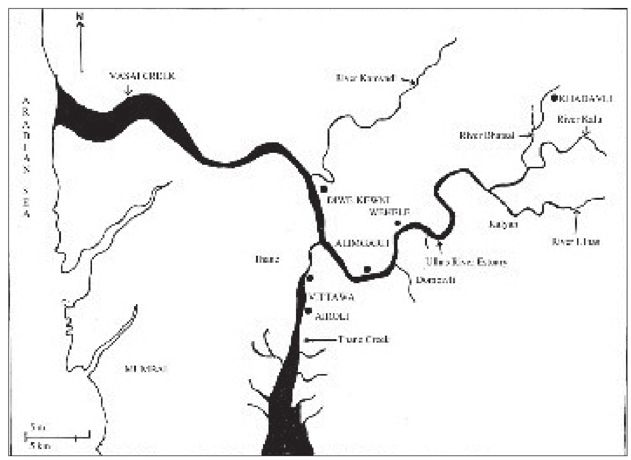

Fig. 1. Map of Ulhas River Estuary, Thane Creek and the study areas

remaining two along Thane creek (Fig 1). Brief description of villages covered for the study is presented in Table 1.

Questionnaire

The survey was conducted in the study areas during the period from March 2006 to August 2006, aided by a custom-made questionnaire which included the socio-demographic characters of the subjects, the details about the types and frequency of fish consumption. The fish consumption details of approximately past three months were recorded. This was necessary as 3 cms of the length of the hair strand from the root indicated past three months Hg exposure by the individual. During the survey it was noted that fish consumption was

Table 1. Details of the study villages

Village	Location details	Population details	Commonly consumed fishes	Status of contamination
Khadavli (latitude 19°21' N and longitude 73°13' E)	Located 15 kms upstream of the Ulhas river estuary on the southern bank of the River Bhatsai, a tributary of River Ulhas.	Population:1100. Occupation: Fishing, business & service, fish caught & sold locally	*Labeo* spp., *Tilapia* spp., eels, *Gobius* spp. and prawns	Non polluted water (Environmental Status Report of Kalyan Region, MPCB, 2004-05),Hg in water below detection limit (0.1 μg/lit)*, Hg in fish below detection limit**
Wehele (19° 14' N and 73° 03' E).	Located on the opposite bank of the densely populated and industrial zone of Dombivli. A socio-economically weak society.	Population:2400 Occupation: Fishing, sand-dredging, business.	*Mugil* spp., *Mystus* spp., *Tilapia* spp., Mudskippers, *Lates* spp., *Scylla serrata*, Prawns and *Arius* spp.	Polluted water (Athalye *et al.*, 2003),Hg in water: Average 8.7 ng/ml*, Hg in fish: Average 0.42 μg/g*
Alimgarh (19° 12' N and 73° 02'E)	Located at a distance of 12 kms from Thane city . It is located 7 kms downstream of the village Wehele and is equally polluted.	Population:1800 Occupation:Fishing Fishing communities living near the bank of Ulhas river estuary are totally devoted to their profession.	*Mugil* spp., *Mystus* spp., *Tilapia* spp., *Lates* spp., *Scylla serrata*, *Megalops* spp., *Therapon* spp., prawns and *Boleophthalmus* spp.	Polluted water (Athalye *et al.*,2003),Hg in water: Average 8.7 ng/ml*, Hg in fish: Average 0.6 μg/g **
Diwe-Kewni (19°16' N and 73° E).	The twin villages of Diwe-Kewni are situated along the northern bank of Ulhas river estuary. Located at a distance of 15 kms from Thane.	Population:2200 Occupation: Fishing. The population consisted of both middle class and lower class people.	*Mugil* spp. *Mystus* spp., *Tilapia* spp., *Arius* spp., *Scylla serrata*, *Boleophthalmus* spp., *Therapon* spp. and prawns.	Polluted water (Athalye *et al.*,2003),Hg in water: Average 2.6 ng/ml*, Hg in fish: Average 0.44 μg/g*
Vittawa (19° 11'N and 72° 59' E)	Located along on the eastern bank of Thane creek at a distance of only 3 kms from Thane city.	Population:2200. Only a few families are engaged in fishing. Other occupations: business, service The fishing communities are poverty-stricken.	*Mugil* spp., *Mystus* spp., *Tilapia* spp., *Megalops* spp., *Arius* spp.,Prawns and *Scylla serrata*.	Polluted water (Zingde and Desai,1981Sadasivan and Tripathi,2001, Mishra *et al.*,2007),Hg in water: Average 5.7 ng/ml*,Hg in fish: Average 0.69 μg/g*
Airoli (19°18' N and 72°59' E)	Located along the eastern bank of Thane creek at a distance of 8 kms from Thane city.	Population: 1400. The fishing population here is restricted to a small area known as Airoli Koliwada Most of them are engaged in other business or jobs in Mumbai.	*Mugil* spp., *Tilapia* spp., *Lates* spp., prawns and *Scylla serrata*.	Polluted water (Zingde and Desai, 1981, Mishra *et al.*,2007), Hg in water: Average 5.71 ng/ml *, Hg in fish: Average 0.7 μg/g*

* Menon & Mahajan,2010 ** Menon,2009

the only source of mercury exposure in these areas as the villagers were not in the practice of using mercury containing products like shampoos, dyes, hair waivers, bleaching creams etc. and also did not consume meat, chicken or eggs regularly nor do they have amalgamated teeth. Consumption of fish was recorded to be at par or even higher than rice or jowar and consumption of vegetables and fruits was negligible (Menon, 2009).

Collection, digestion and estimation of Hg in hair samples

Collection of hair samples was carried out by Lau and Ashmead method (1975). Hair samples from volunteered subjects were collected in duplicate by cutting the hair at the base from the occipital region of the head. The proximal end of the hair sample was tied with a thread and the hair samples were carefully placed in polythene bags of size 10 cms x 7.5 cms, sealed, labelled appropriately and brought to the laboratory for further processing. One bundle of hair sample approximately contained 300 to 350 strands of hair. Thereafter, 3 cms hair sample was cut from the proximal end, which would reflect Hg exposure for the past three months. The hair sample was transferred to a 100ml pre-cleaned, sterilized beaker, and was washed with a mild detergent and cleaned with acetone two times. Then 1 gm of sample was accurately weighed and separated. It was then cut into pieces by using sterilized s.s scissors and then treated with chemicals for digestion as per 'Standard Method' (APHA, AWWA and WPCF, 1981) which included addition of concentrated sulphuric acid, nitric acid, potassium permanganate and potassium persulphate and then heating the sample on a water-bath at 70^{0}C to breakdown organic compounds and oxidize the released Hg to Hg^{2+}. NaCl-hydroxylamine was added to reduce the excess of oxidants. Hg concentration was then estimated on Mercury analyzer MA 5804 (AAS) with a detection limit of 0.1 μg/l at BARC, Mumbai by adding $SnCl_2$ which acted as a reducing agent to release Hg vapours from the sample.

Quality control

Accuracy of the analyses was assured using NRC, Canada Certified Standard Reference Material-DORM-3 which showed a recovery of 94.27%. In addition, sample duplicates and reagent blanks were also included. The reagent blanks showed values below the detection limit. The precision for duplicate analyses was good with a relative standard deviation of 0.061.

Study design/ Data analysis

A total of 306 hair samples were analysed from the study areas. The population distribution of hair Hg of men, women and children were determined separately to evaluate the % of population exceeding the safety limit of 10 μg/g (UNEP Chemicals, 2002). As 5-10 μg/g hair Hg levels have been associated with neurobehavioral disturbances and psychomotor defects in adults, percentage of such population was also determined.

Results and discussion

Fish meals per week in the population

Table 2 shows the number of fish meals per week in the study areas.

The result shows that the average number of fish meals in the study areas is high. A very high average of fish meals in Alimgarh and Diwe-Kewni in comparison to other villages showed the high reliability of these populations on estuarine fish.

Table 2. Number of fish meals per week in the study areas

Study Areas	N	Minimum	Maximum	Average	SD
Khadavli	48	1	5	2.583	1.02
Wehele	51	8	10	8.105	0.45
Alimgarh	54	8	21	11.276	5.36
Diwe-Kewni	72	5	21	12.136	4.11
Vittawa	59	3	10	6.178	1.56
Airoli	70	4	12	8.478	1.59

SD denotes standard deviation N= no. of individuals

Table 3. Hair mercury levels in the populations of the study areas in μg/g

Study Areas >	Wehele	Alimgarh	Diwe-Kewni	Vittawa	Airoli
N	51	54	72	59	70
Minimum	0.00	0.00	0.00	0.00	0.00
Maximum	31.03	19.32	21.54	8.15	9.00
Average	6.68	8.88	9.01	4.84	5.35
Std Deviation	4.77	5.57	5.39	2.31	2.31

Table 4. ANOVA-single factor results for Hair Hg levels in the study areas

Source of Variation	SS	df	MS	F	P-value	F crit
Between locations	964.6177	4	241.1544	13.18011	6.51E-10	2.401345
Error	5562.241	304	18.29685			
Total	6526.859	308				

Hair mercury levels in the populations of the study areas

Hair Hg levels of the reference site, Khadavli showed values below the detection limit. Therefore, population distribution of Hair Hg levels of the population of Khadavli could not be analysed. Thus, the risk of Hg poisoning is ruled out in Khadavli population. Table 3 shows hair mercury levels in the populations of the remaining five study areas.

The values were subjected to statistical evaluation by ANOVA-single factor method which showed a significant difference in location-wise Hair Hg levels as shown in Table 4.

Correlation between fish consumption and Hair mercury levels

Fig. 2 shows the correlation between the number of fish meals and the Hair Hg levels of the populations in the study areas. Statistical evaluation by regression analysis of this data came out with the best fit equation Y = 0.98 X - 1.832 with coefficient of determination R^2 = 0.965 (96% of the variability in the hair Hg concentration are attributable to the number of fish meals). Moreover, Kehrig *et al.* (1998) has also reported that the bacteria present in the sediments convert mercury to methyl-mercury, the most toxic mercury compound, in the aquatic environment only which is then bioaccumulated in fish. Therefore, fish is the major source of human exposure to methyl mercury (WHO, 1990).

Hair mercury levels in males, females and children in the study areas.

Table 5 shows the hair Hg levels in men, women, children and reproductive age-group of women of the study areas. Table 6 and Fig.3-7 show the population distribution of Hair Hg concentration in the study villages. In Wehele, out of the 51 hair samples analysed, excluding a woman subject with 31.03 μg/g, the range of hair Hg concentration was from 0 to 9.483 μg/g with a mean of 6.74 μg/g. 1.96% exceeded the

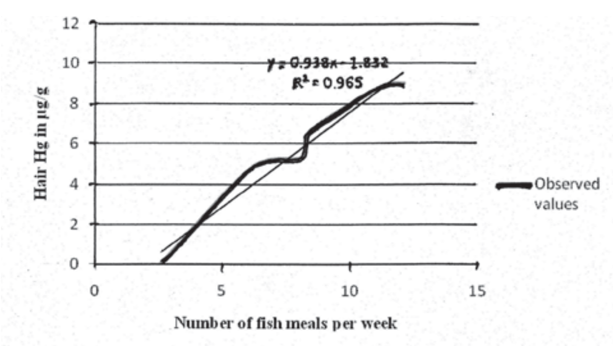

Fig. 2. Correlation between the number of fish meals and the Hair Hg levels of the populations in the study areas

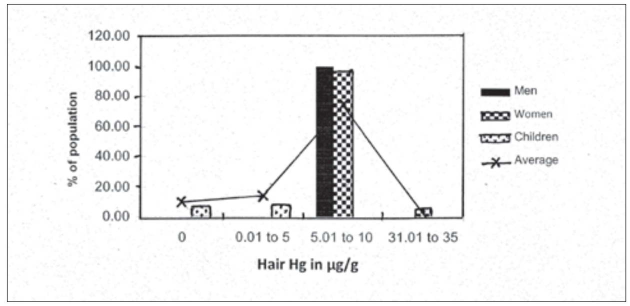

Fig. 3. Population distribution of Hair Hg levels in Wehele.

safety limit of 10 μg/g. 74.51% of the subjects had hair Hg levels in the range of 5.01 to 10 μg/g. All men and 95.24 % women were also in this range. The maximum Hair Hg levels in children was observed to be 1 μg/g. The reproductive group i.e. women between 21 to 40 yrs of age also had hair Hg level below 10 μg/g. The results show that the population of Wehele was at the threshold of risk to Hg exposure and therefore need to be continuously monitored.

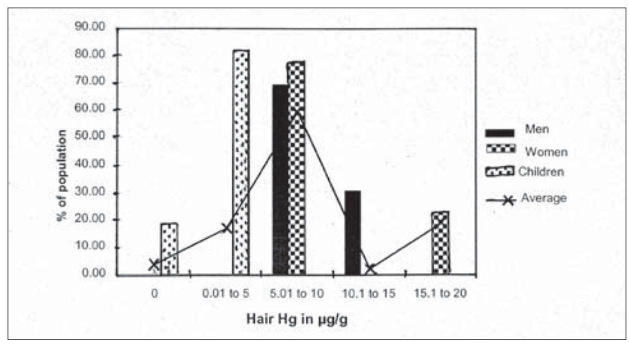

Fig. 4 Population distribution of Hair Hg levels in Alimgarh,

The mean hair Hg level of the populations of Alimgarh was 8.87 μg/g. The % exceeding 10 μg/g was 20.37%, out of which 8 were women from the reproductive group. In Alimgarh, except 2 subjects, which included children who exhibited hair Hg below the detection limit, all others fell in the range

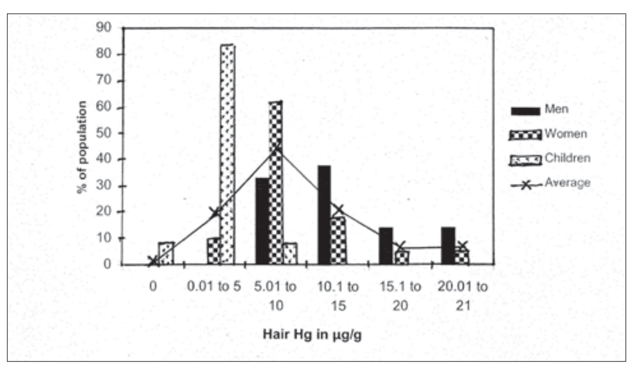

Fig. 5 Population distribution of Hair Hg levels in Diwe-Kewni.

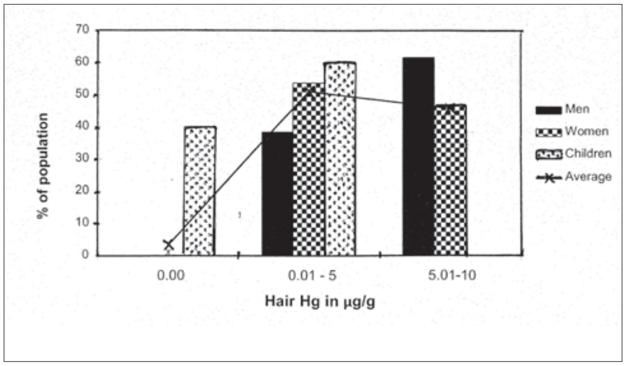

Fig. 6 Population distribution of Hair Hg levels in Vittawa.

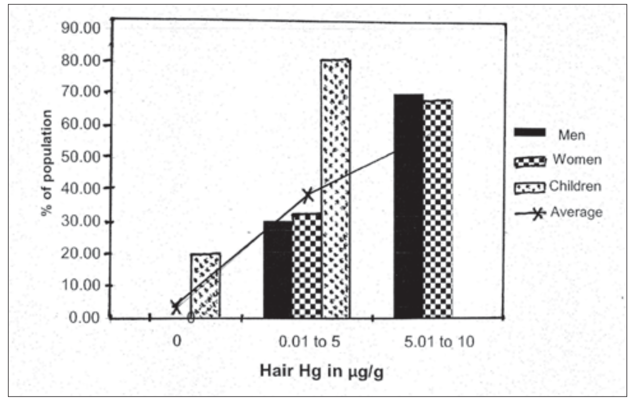

Fig. 7 Population distribution of Hair Hg levels in Airoli.

of 0.01 to 20 μg/g. The peak was obtained with 59.26 % falling in the range of 5.01 to 10 μg/g. 77.42% of women had hair Hg in the range of 5.01 to 10 μg/g and the remaining 22.58% in the range of 15.1 to 20 μg/g with a maximum of 19 μg/g. Similar range was observed in the fishing villages in the Tapajos river basin, Amazon population where sensory disturbance, tremor, failure in two-point discrimination, and slight balancing failure were diagnosed with mild Minamata disease (Harada *et al.*, 2001). Children showed a low hair Hg levels in this area with 81.82 % falling in the range of 0.01

Table 5 : Hair mercury levels in males, females and children from the study areas

Study Areas>	**Wehele**				**Alimgarh**			
	Males	Females	Children	Females of Repro. Grp	Males	Females	Children	Females of Repro. Grp
N	18	21	12	15	15	28	11	24
Minimum	7.59	6.72	0.00	6.72	7.48	8.00	0.00	8.00
Maximum	9.48	31.03	1.00	9.00	18.00	19.32	1.00	19.32
Average	9.56	8.82	0.80	7.31	12.48	11.50	0.82	10.15
Std.dev	0.59	6.34	0.53	0.83	2.87	3.80	0.40	3.60
Study Areas>	**Diwe-Kewni**				**Vittawa**			
	Males	Females	Children	Females of Repro. Grp	Males	Females	Children	Females of Repro. Grp
N	23	38	11	20	20	28	11	23
Minimum	8.85	4.07	0.00	7.70	2.50	2.50	0.00	4.00
Maximum	20.29	21.54	5.50	21.54	8.13	8.16	1.00	7.40
Average	14.02	11.50	1.73	11.07	5.76	7.85	0.40	5.54
Std.dev	4.09	4.10	0.95	4.03	1.83	2.19	0.42	2.13
Study Areas>	**Airoli**							
	Males	Females	Children	Females of Repro. Grp				
N	29	31	10	20				
Minimum	0.50	1.00	0.00	4.00				
Maximum	9.00	8.20	1.00	9.00				
Average	7.72	7.53	0.70	6.07				
Std.dev	1.92	1.95	0.42	1.27				

N=number of individuals

Table 6. Population distribution of Hair Mercury levels in the study areas

WEHELE				
Hair mercury in μg/g			Subjects	% of population
Range	Min	Max	N	
0	0	0	5	9.8
0.01 to 5	1	1	7	13.73
5.01 to 10.0	5.42	9.48	38	74.51
31.01 to 35.0	31.03	31.03	1	1.96
Mean	6.74		Total=51	
% exceeding 10 μg/g	1.96%			

VITTAWA				
Hair mercury in μg/g			Subjects	% of population
Range	Min	Max	N	
0	0	0	2	3.39
0.01 to 5	0.5	5	30	50.85
5.01 to 10	5.54	8.2	27	45.76
Mean	4.84		Total=59	
% exceeding 10 μg/g	0%			

ALIMGARH				
Hair mercury in μg/g			Subjects	% of population
Range	Min	Max	N	
0	0	0	2	3.7
0.01 to 5	1	1	9	16.67
5.01 to 10	7.48	9.48	32	59.26
10.1 to 15	13.1	13.1	1	1.85
15.1 to 20	15.8	19	10	18.52
Mean	8.87		Total=54	
% exceeding 10 μg/g	20.40%			

AIROLI				
Hair mercury in μg/g			Subjects	% of population
Range	Min	Max	N	
0	0	0	2	2.86
0.01 to 5	0.5	5	27	38.57
5.01 to 10	5.87	9	41	58.57
Mean		5.37	Total=70	
% exceeding 10 μg/g	0%			

DIWE-KEWNI				
Hair mercury in μg/g			Subjects	% of population
Range	Min	Max	N	
0	0	0	1	1.39
0.01 to 5	0.75	4.98	14	19.44
5.01 to 10	5.2	9.62	32	44.44
10.1 to 15	10.2	13.3	15	20.83
15.1 to 20	15.3	19.3	5	6.94
20.01 to 21	20.2	21.5	5	6.94
Mean	9.017		Total=72	
% exceeding 10 μg/g	34.70%			

N= number of subjects

to 5 μg/g. 24.24% of women from the reproductive group exceeded the 10 μg/g safe limit. Hair mercury levels of 6-18 mg/kg during pregnancy in the fish-eating population of New Zealand have indicated developmental delay in children (Kjellstrom *et al*., 1986). The overall study showed that the population of Alimgarh is highly vulnerable to Hg poisoning.

The mean hair Hg level of the populations of Diwe-Kewni was 9.017 μg/g. Eight women from the reproductive group exceeded 10 μg/g. In Diwe-Kewni too, 34.72% of the population exceeded the safety limit of 10 μg/g. A population of 44.44% fell in the range of 5 to 10 μg/g Hg in hair. 83.33% of children were in the range of 0.01 to 5 μg/g and 8.33% were in the range of 5.01 to 10 μg/g. Thus the overall scenario suggests the vulnerability of Diwe-Kewni population to Hg poisoning similar to Alimgarh.

The hair Hg level in the population of Vittawa depicted a mean of 4.84 μg/g. No individuals crossed 10 μg/g Hair Hg levels and even the reproductive group was well within this level. Two subjects had hair Hg levels below the detection limit. 45.76% had hair Hg levels in the range of 5.01 to 10 μg/g, out of which 61.54% were men and 46.34 % were women. On the contrary, children had a low Hair Hg with 40% having hair Hg below the detection limit and 60% in the range of 0.01 to 5 μg/g. Women of reproductive age had hair Hg within 9 μg/g. Thus the population of Vittawa is relatively on a safer side with respect to Hair Hg but the population distribution indicates that they need to be continuously monitored.

In the village of Airoli, the hair Hg level in the population showed a mean of 5.37 μg/g. Two subjects had hair Hg levels below the detection limit. Other subjects had the Hair Hg concentration in the range of 0.5 to 9 μg/g, with 58.57% population being in the range of 5.01 to 10 μg/g. 69.57% of men and 67.57% of women fell in the range of 5.01 to 10 μg/g. On the contrary, children had a low hair Hg with 20% having hair Hg below the detection limit and 80% in the range of 0.01 to 5 μg/g. The women in the reproductive group also had hair Hg levels well below the safe limit. Therefore this village was also not at a high risk of Hg poisoning but like Vittawa, the population distribution indicates that a continuous monitoring of neuro-psychological defects in these populations is mandatory.

It is evident from the results that 74.5% of the population of Wehele, 59.26% of the population of Alimgarh, 44.44 % of the population of Diwe-Kewni, 45.76% of the population of Vittawa and 68.57% of the population of Airoli consuming estuarine/creek fish in the study areas have hair Hg levels in the range of 5 to 10 μg/g. Adult population with hair Hg levels below 10 μg/g have also been reported to show minor sub-clinical symptoms (Morrisette *et al.*, 2004) and even neuro-psychological defects (Dolbec *et al.*, 2000). The Canadian recommendation of 6 μg/g for hair Hg (Kosatsky *et al.*, 2000) was exceeded by 52.94% (N=27) in Wehele, 59.26% (N=32) in Alimgarh, 27.78% (N=20) in Diwe-Kewni, 13.56% (N=8) in Vittawa and 17.14% (N=12) in Airoli. Therefore, these villagers are vulnerable to Hg poisoning and a continuous monitoring of Hg levels in these populations are mandatory.

The reason for the variation in hair Hg levels in the fish-eating communities in the villages along Ulhas river estuary and Thane creek has been accounted here. In the reference (control) site, the population of Khadavli had negligible hair Hg levels compared to other study areas located in the contaminated zones. Many studies have concluded that hair Hg concentration in the people residing near contaminated areas was higher than those living in non-contaminated areas (Santos *et al.*,2002).

The accessibility of the population to the estuarine/creek fish is an influential factor in causing variations in location-wise hair Hg levels. The populations of the remote villages of Diwe-Kewni and Alimgarh had higher hair Hg levels owing to their total dependence on fish for their dietary mainstay compared to populations of Wehele, Vittawa and Airoli which had accessibility to the nearby cities. Several workers have observed that the populations residing near the fishing sources consumed larger quantities of fish than the inland populations (Pallotti *et al.*,1979).

Diwe-Kewni was a comparatively less polluted site with respect to the Hg levels in water and fish of that area (Menon, 2009). But the frequency of fish consumption by these populations was very high reflecting their cultural background of high fish consumption (Table 2). This elevated the average hair Hg level of this area making it to be the location with the highest hair Hg levels. The weak socio-economic conditions of the villagers also compelled them to rely on the cheap and easily accessible estuarine fish. There are also studies which ascertain that the traditional and cultural background are responsible for high amounts of fish consumption in the populations of certain locations (Boischio and Henshel, 2000), thereby elevating their hair Hg levels. Thus location-wise differences in hair Hg levels can be accounted for the differences in the pollution status of the site, proximity and accessibility to the source of contamination as well as fish consumption pattern and life-style.

Finally, it can be concluded that hair mercury levels of the populations of Alimgarh and Diwe-Kewni are highly vulnerable to mercury contamination through fish consumption. The population of Wehele is at the threshold level of Hg contamination while the populations of Vittawa and Airoli are comparatively safe with respect to mercury exposure through fish consumption. The observed results in the present study indicate that application of psychological tests and studies on the learning abilities, I.Q levels, memory, concentration, judgment etc. in the populations should be undertaken, particularly in children, which can throw light on the mild neurological disorders caused due to Hg exposure. So also, steps must be taken to reduce Hg exposure of these populations by imparting awareness about Hg pollution, issuing recommendations on fish consumption and above all, reducing the sources of mercury pollution. This work is first of its kind reporting hair mercury levels of fish-eating populations of India; it provides a base-line data for assessing the risk of mercury exposure in fish-eating populations and can be used as a reference tool while framing fish advisories.

Acknowledgements

We are thankful to the villagers of Khadavli, Wehele, Alimgarh, Diwe-Kewni, Vittawa and Airoli for their co-operation.

References

Agrawal, A., R.Singh and M. Priti. 2004. Lurking Menace-mercury in the health care sector, Toxic Link, *www.noharm.org.*

APHA, AWWA and WPCF.1981. Part 303 F Mercury. In: *International Standard methods for the examination of water and waste water, 15th edition, American Public Health Association,* American Water Works Assessment and Water Pollution Control Federation, Washington, D.C.164 pp.

Athalye. R. P, N. N. Patil , M.U. Borkar, G. Quodros and V.U. Somani. 2003. MMR-ES Project, *Mumbai Metropolitan Region-Environmental Studies, Study of Flora ,Intertidal Macrobenthic Fauna and Fishery of Ulhas River Estuary and Thane Creek to assess the pollution status and decide mitigation strategy*-A project submitted to MMRDA.

Bidone, E. D., Z.C. Castilhos, T.M. Cid de Souza and L.D. Lacerda.1997.Fish Contamination and Human Exposure to Mercury in the Tapajós River Basin, Pará State, Amazon,Brazil: A Screening Approach.*Bull. Environ. Contam. Toxicol,* 59: 194-201.

Boischio, A. A. P. and D. Henshel. 2000. Fish Consumption, Fish Lore, and Mercury Pollution-Risk Communication for the Madeira River People. *Environ. Res.* 84: 108-126.

Dorea Jose, G., C. Antonio, Barbosa I´Ris Ferrari and R. Jurandir and De Souza. 2003. Mercury in hair and in fish consumed by Riparian women of the Rio Negro, Amazon, Brazil. *Int. J. Environ. Health Res.,* 13(3): 239 - 248.

Dolbec, J., Mergler D Souza., C.J. Passos and S.L.Sousa de Moraes. 2000. Methylmercury exposure affects motor performance in riverine population of the Tapajos river, Brazilian Amazon. *Int Arch Occup Environ Health*, 73: 195-203.

Environmental Status Report of Kalyan Region. 2004-05. *Maharashtra Pollution Control Board*: 1-44, http://mpcb.mah.nic.in

Environmental Status Report of Thane Region.2005. *Maharashtra Pollution Control Board*: 1-26. *http://mpcb.mah.nic.in*

Environmental Status Report of Navi Mumbai Region . 2005. *Maharashtra Pollution Control Board*: 1-26. *http://mpcb.mah.nic.in*

Environmental Status Report of Mumbai Region. 2005. *Maharashtra Pollution Control Board*: 1-26. *http://mpcb.mah.nic.in*

Harada, M. J. Nakanishi, E. Yasoda, M., M.C. Pinheiro, T. Oikawa, de Assis., G. Guimarâes, da Silva., B. Cardoso, T. Kizaki and H. Ohno. 2001. Mercury pollution in the Tapajos River basin, Amazon: mercury level of head hair and health effects. *Environ Int.*, 27(4): 285-90.

Hasan, Q.R.A.1984. Studies on Pollution in Ulhas creek with reference to effluents from MIDC Kalyan-Bhiwandi and their effects on *Mystus gulio. PhD Thesis*. University of Mumbai.

Hightower, J. M. and D. Moore, 2003. Mercury Level In High-End Consumers of Fish. *Environ. Health Perspect.*, 111 (4): 604-608.

Kaladharan,P., V. K. Pillai, A. Nandakumar and P.K. Krishnakumar.1999. Mercury in seawater along the west coast of India. *Indian.J. Mar. Sci*, 28: 338-340.

Kehrig,H.A., O. Malm, H. Akagi, J.R. Guimaraes and J.P. Torres.1998. Methyl mercury in fish and hair samples from the Balbina reservoir, Brazilian Amazon. *Environ. Res.* 77 (2): 84–90.

Kjellstrom, Ta., P. Kennedy, S.Wallis and C.U. Mante.1986. Physical and mental development of children with prenatal exposure to mercury from fish. Stage 1: Preliminary tests at age 4, *National Swedish Environmental Protection Board Report 3080, Solna, Sweden.*

Kosatsky, T., R. Przybysz and B. Armstrong. 2000. Mercury exposure in Montrealers who eat St. Lawrence River sportfish. *Environ. Res*, 84(1): 36-43.

Krishnakumar, P. K., V. K. Pillai and K. K. Valsala.1990. Bioaccumulation of trace metals by marine flora and fauna near a caustic soda plant (Karwar,India). *Indian.J.Fish*, 37 (2):129-137.

Lau ,H. K. Y. and H. Ashmead.1975. Trace Minerals in Human Hair by Atomic Absorption spectrophotometry- Recovery study. *Analytical letters*, 8(11): 825-829.

Lebel, J., D. Mergler, M. Lucotte, M. Amorim and J. Dolbec.1998. Neurotoxic effects of low-level methyl mercury contamination in the Amazonian Basin. *Environ. Res.*, 79 (A): 20-31.

Mahaffey, K .R. and G.E. Rice. 1998. Mercury Study Report to Congress. *Govt Environmental Protection Agency, Office of Air Quality Planning and Standards. Reports Announcements and Index (GRA and I), Issue 09, http:// www.epa.gov/oar/mercury.html.*

Mercury in India, Environmental Health Aspects. 2006. Chapter 2: p.1-48. *www.toxicslink.org*

Mercury in India,Usages and releases, *www.toxicslink.org*

Mercury in India, Environmental Health Aspects. 2006, p. 1-48. *www.toxicslink.org*

Menon, J. S. 2009. Bioaccumulation of Mercury and a Few Pesticides in Fish from Thane Creek and Ulhas River Estuary and its Relation to Dietary Intake and Contaminant Levels Among Fish Eaters. *Ph.D Thesis, University of Mumbai.*

Menon, J.S. and S.V.Mahajan. 2010. Site-wise Mercury Levels in Ulhas River Estuary and Thane Creek near Mumbai, India and its Relation to Water Parameters. *Our Nature* , 8: 170-179

Morrisette, J., L. G. Takser, A.St-Amour, J. Smargiassi Lafond and D. Mergler. 2004. Temporal variation of blood and hair mercury levels in pregnancy in relation to fish consumption history in a population living along the St. Lawrence River. *Environ.Res.*, 95: 363-374.

Mishra, S., S. Bhalke, V. Saradhi, B. Suseela, R. M. Tripathi, G. G. Pandit and V. D. Puranik. 2007. Trace metals and organometals in selected marine species and preliminary risk assessment to human beings in Thane Creek area, Mumbai. *Chemosphere*. 69: 972–978.

Pallotti, G., B. Bencivenga and T. Simonetti Ibtal. 1979. Mercury levels in whole blood, hair and fingernails for a population group from Rome and its surroundings. *Sci. Tot. Environ*, 11: 69-72.

Patil, A. R. 1982. Study of Heavy metals (Cu,Cd &Hg) in the Aquatic Environments of the Ulhas & Mulla-Mutta Rivers. *M.Sc.Thesis. University of Mumbai.*

Rajathy, S.1997. Mercury in water, sediment and in some estuarine organisms of the Ennore Estuary, Madras, Tamil Nadu. *J. Mar. Biol. Ass.India*, 39: 174-177.

Sadasivan,S. and R.M.Tripathi . 2001. Toxic and trace metals in Thane creek, *www.barc.ernet.in*

Santos, E.C.O., V.M. Câmara, M. Jesus, E.S. Brabo, E.C.B. Loureiro, A.F.S. Mascarenhas, K.F. Fayal, G.C. SáFilho, F.E.S. Sagica, M.O. Lima, H.Higuchi and I.M. Silveira.2002.A Contribution to the Establishment of Reference Values for Total Mercury Levels in Hair and Fish in Amazonia. *Environ. Res.* 90: 6-11.

UNEP Chemicals, Inter-Organisations Programme for the sound management of chemicals: In Global Mercury Assessment, Geneva, Switzerland : *UNEP Chemicals*, 2002.

UNEP Chemicals and WHO Geneva, Switzerland. 2007. Guidance for Estimating Exposure to Mercury to Identify Populations at Risks, *www.chem.unep.ch*: p.1-181.

WHO (World Health Organisation).1990. IPCS. *Environmental Health Criteria*, Methylmercury. WHO, Geneva.Vol.101

Yokoo, E. M., G.V. Joaquim, L.Grattan, S.L. Schmidt, I. Platt and E.K.Silbergeld.2003. Low level methyl mercury exposure affects neuro psychological function in adults, *Environmental Health: A Global Access Science Source*, p. 2-8, www.ehjournal.net

Zingde, M.D. and B.N.Desai.1981. Mercury in Thana Creek, Bombay Harbour, *Mar. Pollut. Bull.*,12(7): 237-241.