Mercury Pollution in Sonbhadra District of Uttar Pradesh and its Health Impacts

INVESTIGATORS

Mr. Ramakant Sahu

Ms. Poornima Saxena

Dr. Sapna Johnson

Ms. Soundaram Ramanathan

Ms. Sugandh Juneja

ADVISORS

Prof. (Dr.) H. B. Mathur

Prof. (Dr.) H. C. Agarwal

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CENTRE FOR SCIENCE AND ENVIRONMENT
41, TUGHLAKABAD INSTITUTIONAL AREA, NEW DELHI –110062
TEL: 91-11-2995 6110/5124/6394/6399
FAX: 91-11-2995 5879 EMAIL: cse@cseindia.org
WEBSITE: www.cseindia.org

POLLUTION MONITORING LABORATORY
CORE-6A, FOURTH FLOOR, INDIA HABITAT CENTRE
LODHI ROAD, NEW DELHI – 110003

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1. POLLUTION MONITORING LABORATORY OF CSE

The Centre for Science and Environment (CSE), a non-governmental organization based in New Delhi, has set up the Pollution Monitoring Laboratory (PML) to monitor environmental pollution. PML is an ISO 9001:2008 certified laboratory accredited by SWISO, CH-5610, Wohlen, Switzerland, conducting Pollution Monitoring and Scientific Studies on Environmental Samples. The Laboratory has highly qualified and experienced staff that exercise Analytical Quality Control (AQC) and meticulously follow what is called Good Laboratory Practices (GLP). It is equipped with most sophisticated state-of-the-art equipments for monitoring and analysis of air, water and food contamination, including Gas Chromatograph with Mass Detector (GC-MS), Gas Chromatograph (GC) with ECD, NPD, FID and other detectors, High Performance Liquid Chromatograph (HPLC), Atomic Absorption Spectrometer (AAS), UV-VIS Spectrophotometer, Mercury Analyzer, Respirable Dust Sampler etc. Its main aim is to undertake scientific studies to generate public awareness about food, water and air contamination. It provides scientific services at nominal cost to communities that cannot obtain scientific evidence against polluters in their area. This is an effort to use science to achieve ecological security.

2. THE STUDY

The PML carried out a study on the heavy metal pollution in Singrauli area based on a community request. CSE carried out the study only in Sonbhadra and thus the report focuses only on this district specially the Myorepur block. Our study area coordinates are between longitude $82^0$39’ - $83^0$06’ E and latitude $24^0$05’ - $24^0$37’ N.

A significant number of residents reported adverse health conditions which may be linked with heavy metal especially mercury pollution. In view of these reports, PML investigated the health related problems of the residents of Sonbhadra district to see if there is any linkage with the pollution from heavy metals particularly mercury.

The methodology adopted for the study was a primary survey, sample collection from villages in the district and testing of these samples at the PML. Two CSE researchers visited the area for the primary survey in May 2012. Soil, water, cereals, fish and biological samples were collected. Another two CSE representatives visited the area in August 2012 to reconfirm the findings of the primary survey.

3. INTRODUCTION

The north eastern part of Madhya Pradesh which is the Singrauli district and the adjoining southern part of Sonbhadra district in Uttar Pradesh is together termed as the Singrauli region. The area remained unexploited until the construction of Rihand dam (or Govind Ballabh Pant Sagar - GBPS) in 1961. The dam was constructed on the river Rihand, which is a tributary of the Son river, at village Pipri (Sonbhadra) with 466 square kilometer (km^2) of submerged area at full capacity and 10.6 billion cubic meter (m^3) storage capacity[1].

Before construction of the dam the submerged area was the main populated area of the region. There are estimates that around 1,05,000 people were displaced when the dam was constructed[2]. Major part of the displaced population was rehabilitated on the forestland in the east, south east and north eastern area of GBPS particularly because of coal reserves on the western side of GBPS. With the discovery of rich coal deposits in 2,200 km^2 area the transformation of the region began[3]. As a result, people underwent multiple displacements from various projects within a span of 25 years; estimates of displaced persons varies between 2,00,000 and 3,00,000[4].

Today Singrauli's landscape hosts many thermal power stations and coal mines. The area also has aluminium smelting plant, chemical industry, cement industry and other industrial and commercial operations (see *Table 1: Industries present in Singrauli*). Coal-based thermal power capacity of the region stands at about 12,700 MW (10 thermal power plants) and the coal mining capacity is about 83 million tonnes per annum (MTPA) (14 mines). Most of the coal mines are present at the border of Uttar Pradesh and Madhya Pradesh.

In addition to these industries already operating in Singrauli, there are others which are coming up[5] (see *Table 2: Proposed Industries in Singrauli*). Another 9,200 MW of thermal power capacity is planned in the Singrauli region as is another 50 MTPA of coal mining projects.

[1] http://www.preservearticles.com/2012020122314/complete-information-on-rihand-dam-project.html as viewed on September 25, 2012

[2] S Chaurasia & SK Mishra, 2007, *Fluoride Contamination in Rain Water of Singrauli Region*, Indian Journal of Environmental Protection; **27 (10)**, 923-926

[3] ibid

[4] http://www.ieo.org/world-c3-p1.html as viewed on September 25, 2012

[5] Coming up projects are those which may have obtained an environmental clearance, ToRs or awaiting these

Table 1: Industries present in Singrauli

S.No.	Company	Capacity
	Madhya Pradesh (Singrauli)	
THERMAL POWER PLANTS		**(in MW)**
1	NTPC Limited - Vindhyachal STPS	3260
MINING		**(in MTPA)**
1	Northern Coal field Ltd. - Dudhichuwa	11
2	Northern Coal field Ltd. - Krishnashila Unit	2
3	Northern Coal field Ltd. - Nigahi Mine	15.5
4	Northern Coal field Ltd. - Singrauli Colliery Block B	4.375
5	Northern Coal field Ltd. - Jayant Mine	15
6	Northern Coal field Ltd. - Almori Mine	10
7	Northern Coal field Ltd. - Jhingurda Mine	5
8	Northern Coal field Ltd. - Bina Extension mine	2
9	Northern Coal field Ltd. - Khadia Extension Mine	1
	Uttar Pradesh (Sonebhadra)	
THERMAL POWER PLANTS		**(in MW)**
1	Hindalco Industries Power Division Renusagar	741.7
2	Kanoria Chemicals & Ind. (Power Division) Renukoot	50
3	N.T.P.C Rihand Nagar	2000
4	N.T.P.C Shakthi Nagar	2000
5	UPRVUNL - Obra thermal Power station U-A	550
6	UPRVUNL - Obra thermal Power station U-B	1250
7	UPRVUNL - Anpara thermal Power station, A	630
8	UPRVUNL - Anpara thermal Power station, B	1000
9	LANCO - Anpara Thermal Power Plant, C	1200
MINING		**(in MTPA)**
1	Northern Coal field Ltd. Dudhichuwa	4.037
2	Northern Coal field Ltd. Bina	4.05
3	Northern Coal field Ltd. Kakari	3
4	Northern Coal field Ltd. Khadia	4
5	Northern Coal field Ltd. Krishnashila	2
CHEMICAL INDUSTRY		**(in tonnes/month)**
1	Hindalco industries Ltd. Renukoot	32429.99
2	Hi - Tech Carbon Renukoot	5100
3	Aditya Birla Chemical Industries Limited	18333.3
CEMENT INDUSTRY		**(in tonnes/month)**
1	Dalla Cement, Dalla	66000
LIME STONE MINING		**(in tonnes/month)**
1	Dalla Cement (Bhalua,Jugul & Padarach mines)	266666
ABRASIVE INDUSTRY		**(in tonnes/day)**
1	Orient Micro Abrasives Ltd. Renukoot	16.66

Source: 1. Anon, 2011, *Action Plan for Improvement of Environmental Parameters in Critically Polluted Area – "Singrauli-MP"*, MP Pollution Control Board, Bhopal

2. Anon, 2012, Regional office, Uttar Pradesh Pollution Control Board, Robertsganj, Sonbhadra
3. http://www.uprvunl.org/anpara.htm as viewed on September 10, 2012
4. http://www.lancogroup.com/DynTestform.aspx?pageid=21 as viewed on September 10, 2012.

Table 2: Proposed Industries in Singrauli

S.No.	Company	Capacity
	Madhya Pradesh (Singrauli)	
THERMAL POWER PLANTS		**(in MW)**
1	Jaiprakash Power Ventures Limited	1320
2	Chitrangi Power Pvt. Ltd.	3960
3	DB Power Ltd.	600
4	NTPC – Singrauli Stage – 3	1000
MINING		**(in MTPA)**
1	NCL -Dudhichua Coal Mine Expansion	12.5
2	Moher and Moher Almori – Coal Mine Expansion	12
3	Chhatrsal Coal Mining Project of Sasan Power Ltd.	5
CEMENT PLANT		**(in MTPA)**
1	Jayapee Super Cement Plant	2.5
2	Kota Cement Plant of Jaiprakash Associates Ltd.	0.5
	Uttar Pradesh (Sonebhadra)	
THERMAL POWER PLANTS		**(in MW)**
1	NTPC – Rihandnagar Super Thermal Power Plant Stage – 3	1000
2	UPRVUNL - Anpara thermal Power station, D	1000
3	Hindalco Industries Power Plant Expansion	258
MINING		**(in MTPA)**
1	NCL - Kakri Coal Mine Expansion	4
2	NCL – Krishnashila Coal Mine Expansion	5
3	NCL- Khadia Coal Mine Expansion	10

Source: 1. http://environmentclearance.nic.in/ as viewed on September 12, 2012

2. Anon, 2011, *Action Plan for Improvement of Environmental Parameters in Critically Polluted Area – "Singrauli-MP"*, MP Pollution Control Board, Bhopal

3. Anon, 2012, Regional office, Uttar Pradesh Pollution Control Board, Robertsganj, Sonbhadra

3.1 Sonbhadra

In Uttar Pradesh, Sonbhadra district has eight divisions/blocks – Ghorawal, Robertsganj, Chatra, Nagwa, Chopan, Myorepur, Dudhi and Babhani[6]. The district has a population of 1,862,612 as per the 2011 census which houses close to one per cent of the state's population[7]. While the

[6] http://sonbhadra.nic.in/division.htm#3 as viewed on August 31, 2012

[7] Anon, 2011, *Provisional Population Tables, Uttar Pradesh series 10*, Census of India 2011, Directorate of Census Operations, Uttar Pradesh, pg. 32-33

population density (population per km^2 area) of Sonbhadra was 218 as per the 2001 census, it has increased to 270 according to the 2011 census[8]. The population density for the country is 382[9].

Hindalco Industries was the first factory to be established in the district followed by coal mining sites in 1963 and Kannoria Chemicals (which is now Aditya Birla Chemicals (India) Ltd.) in 1965 after which Renusagar thermal power plant came up in 1967 and Dalmia cements in 1971[10]. The district is an emerging energy hub of India due to availability of coal and water[11].

The installed capacity of the nine thermal power plants in Sonbhadra is about 9,500 MW (see *Table 1: Industries in Singrauli*). The state utility Uttar Pradesh Rajya Vidyut Utpadan Nigam Limited (UPRVUNL) is a major player in the power field in Sonbhadra. The company has four power plants operating in the district with a capacity of 3,430 MW. The district is set to get another 10,000 MW capacity of thermal power soon[12]. This would imply an installed capacity of about 20,000 MW which means 17% of the coal-based capacity in the country[13]. The existing coal mining capacity in the district is 17 MTPA. Northern Coalfields Limited (NCL) has five open cast coal mines in Sonbhadra – Dudhichua, Beena, Kakari, Khadia and Krishnashila. Another 19 MTPA coal mining capacity is planned in the district. There are also chemical, abrasive and cement industries in the district.

CPCB and MoEF released the Comprehensive Environment Pollution Index (CEPI) for 88 industrial clusters of the country in collaboration with the Indian Institute of Technology (IIT), Delhi in 2009. On the basis of this CEPI study, MoEF declared Singrauli area as a Critically Polluted Area (CPA). Singrauli was rated the 9th most CPA of India[14]. It was indexed 81.79 out of 100. As a result, in January 2010 a moratorium on any new projects including expansion projects was imposed in the area. The states were to submit an action plan to address the environmental concerns in these areas. Based on the action plans submitted by Madhya Pradesh and Uttar Pradesh Pollution Control Boards and CPCB's recommendation, MoEF lifted the moratorium in July 2011.

[8] ibid

[9] Anon, 2011, *Chapter 7: Density of Population*, Census of India 2011, pg. 138

[10] Anon, *Singrauli Shetra ka Vikas*, Banwasi Seva Ashram, Sonbhadra, pg.1

[11] Anon, 2011, *Action Plan for Improvement of Environmental Parameters in Critically Polluted Area – "Singrauli-MP"*, MP Pollution Control Board, Bhopal, pg. 2

[12] Conversation with District Magistrate of Sonbhadra on August 27, 2012

[13] Coal based installed capacity in India is 117283.4 MW according to Central Electricity Authority as of August 2012

[14] http://www.cpcb.nic.in/upload/NewItems/NewItem_152_Final-Book_2.pdf as viewed on May 10, 2012

3.2 Coal and Mercury

Mercury (Hg) occurs naturally in the environment in three forms – elemental, inorganic compounds (primarily mercuric chloride) and organic compounds (primarily methyl mercury). Mercury can be introduced into the environment by both natural and anthropogenic sources, including volcanic emissions, mining, industrial and agricultural activities[15]. All forms of Hg are quite toxic, and each form exhibits different health effects. Mercury is the only metal that can exist in both liquid and vapor form at ambient temperatures. Coal contains mercury as a natural component along with other elements in trace amounts. Mercury contained in the coal evaporates during combustion in boilers operating at temperatures above 1100^0C. Given the large quantity of coal burned in thermal power plants as well as in industrial, commercial and residential burners, considerable amounts of mercury are released into the environment. As the coal is combusted in the utility boiler, mercury is vaporized and released as a gas. Some of the mercury may cool and condense as it passes through the boiler and the air pollution control system.

Mercury content in coal varies in different mines depending upon the region. A technical paper at the Indo-European Seminar on Clean Coal Technology in 1997 estimated the concentration of mercury in Indian coals in the range of 0.01 to 1.1 ppm[16]. A study carried out by University of Roorkee showed mercury to be in the range of 0.8 – 11.4 ppm in coal[17]. The Central Pollution Control Board (CPCB) conducted a study on 'Mercury Balance in Thermal Power Plants'. CPCB analysed 11 coal samples and found mercury concentration in the range of 0.09 – 0.487 ppm[18]. A report by IL&FS for the MoEF states that Indian coal has an average mercury concentration of 0.53 ppm, based on measurements from a few selected power plants[19]. The coal in the Sonbhadra district is estimated to contain 0.26 ppm of Hg[20].

The mercury emanating from thermal power plant's stack is 58.05% gaseous and 2.4% in particulate form. About 32.5% retained in the ashes (fly ash and bottom ash). The remaining

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[15] T W Clarkson, 1993, *Mercury: Major Issues in Environmental Health*, Environmental Health Perspectives; **100**, 31-38

[16] P Agrawal, A Mittal, M Kumar, S K Tripathi; 2008, Mercury Exposure in Indian Environment due to Coal Fired Thermal Power Plants and Existing Legislations – A Review, Indian Journal of Forensic Medicine and Pathology; 1(2), 41-43

[17] ibid

[18] www.toxicslink.org/docs/06035_publications-1-33-2.pdf *as viewed on September 25, 2012*

[19] Nalini Bhat *et al*; 2010, *Technical EIA Guidance Manual for Thermal Power Plants*, IL&FS Ecosmart, Hyderabad, pg. 3-17

[20] Dr Ragini Kumari; 2010, *Emission Estimate of Passport-Free Heavy Metal Mercury from Indian Thermal Power Plants and Non-Ferrous Smelters*, Toxics Link, pg. 14

7.05% could not be accounted for[21]. Measurements at an NTPC power plant indicated that the concentration of mercury in the stack flue gas was about 2.8±0.5 μg/m^3 [22].

3.3 Arsenic in Coal

Arsenic is found naturally in the coal. Three dominant forms of Arsenic found in coal are sulfides, organic and arsenate forms but the most common form of occurrence in coal is sulfides[23]. Arsenic has a strong affinity to concentrate in sulfide minerals and its association with pyrite (FeS_2) in some coal is well-documented[24].

Average concentration of Arsenic at world level for bituminous and lignite coals are 9.0 and 7.4 ppm, respectively and maximum Arsenic concentrations are 50 and 49 ppm, respectively[25]. On the contrary, Arsenic content in Indian bituminous coal is 22.3 – 62.5 ppm[26]. Coal used in Indian thermal power plants is mainly bituminous and sub-bituminous which on combustion generate over 40% of fly ash[27].

On combustion, a large amount of Arsenic leaves the coal matrix and is distributed between the vapor and particulate phases in different proportions, depending on factors such as the initial concentration in the parent coal, the design and operating conditions of the combustion facility and the particulate control devices. Arsenic is initially volatilized at the temperature of coal combustion, but in the cooler portions of the flue gas stream it partitions between the vapor phase and fly ash particles. Compared to other trace elements in fly ash, Arsenic shows particularly strong enrichment (5–10 times) on the finest (<10 μm diameter) size fractions of highest surface area[28].

[21] Dr Ragini Kumari; 2010, *Emission Estimate of Passport-Free Heavy Metal Mercury from Indian Thermal Power Plants and Non-Ferrous Smelters,* Toxics Link, pg. 29

[22] Nalini Bhat *et al*; 2010, *Technical EIA Guidance Manual for Thermal Power Plants*, IL&FS Ecosmart, Hyderabad, Annexure-1

[23] VC Pandey, JS Singh, RP Singh, N Singh, M Yunus; 2011, *Arsenic hazards in coal fly ash and its fate in Indian scenario*; Resources, Conservation and Recycling; **55**, 819–835

[24] YE Yudovich, MP Ketris; 2005, *Arsenic in coal: A review*; International Journal of Coal Geology; **61**, 141–96

[25] ibid

[26] ibid

[27] ibid

[28] (a)DFS Natusch, JR Wallace, CA Evans; 1974, *Toxic trace elements: preferential concentration in Respirable particles*; Science; **183**, 202–4; (b) RD Smith; 1980, *The trace element chemistry of coal during combustion and the emissions from coal-based plants*; Progress in Energy and Combustion Science; **6**, 53–119

Arsenic is reported to be present in fly ash. Arsenic concentrations in fly ash generally range from 2 - 440 ppm, but depending on the concentration in the original coal and the combustion methods, it can be as high as 1000 ppm[29].

Arsenic contaminated the aquatic and terrestrial environments through leaching and erosion of fly ash pond. Arsenic concentration more than permissible limits have been reported in the soil, tube-well and surface water near thermal power plants[30].

4. REVIEW OF LITERATURE

4.1 Mercury Poisoning

Mercury is one of the most toxic elements and its neurotoxic effects in humans are well known[31]. Minamata disease is the first well studied and the most serious mercury poisoning which occurred due to consumption of fish and other seafood contaminated with mercury caught from coastal area in Minamata, Japan in which wastewater from an industrial plant was discharged[32].

After 1956's Minamata disaster another similar methyl mercury disaster happened in Niigata prefecture of Japan in May 1965. General medical survey of the Niigata Minamata reports 64 – 908 parts per billion (ppb) mercury in blood, 56.8 – 570 parts per million (ppm) mercury in hair and 92 – 915 µg per day mercury in urine[33]. A clear correlation was observed between the amount of river fish ingested and mercury content in hair.

Another case of Minamata disease happened in Ontario (Canada) during 1970. Illegal dumping of industrial chemical waste containing mercury into the river by Dryden Pulp and Paper Company was the reason behind the incident. It was calculated that there were at least seven tonnes of mercury released into the river system[34]. People affected were found to have more than 200 ppb of mercury accumulated in their blood in 1970s. Harada *et al* conducted a survey in 2010 and said

[29] LE Eary, D Rai, SV Mattigod, CC Anisworth; 1990, *Geochemical factors controlling the mobilization of inorganic constituents from fossil fuel combustion residues I: review of the major elements*; Journal of Environmental Quality; **19**, 202–214

[30] VC Pandey, JS Singh, RP Singh, N Singh, M Yunus; 2011, *Arsenic hazards in coal fly ash and its fate in Indian scenario*; Resources, Conservation and Recycling; **55**, 819–835

[31] (a) TW Clarkson, 1997, *The toxicology of Mercury*, Critical Reviews in Clinical Laboratory Sciences; **34**, 369-403 (b) L Magos, 1997, *Physiology and toxicology of mercury*, Metal Ions in Biological Systems; **34**, 321–370

[32] M Harada, 1995, *Minamata disease: methylmercury poisoning in Japan caused by environmental pollution,* Critical Reviews in Toxicology; **25**, 1–24

[33] http://www.eolss.net/sample-chapters/c09/e4-12-02-05.pdf as viewed on September 21, 2012

[34] http://en.wikipedia.org/wiki/Ontario_Minamata_disease as viewed on September 25, 2012

that "four decades later, the effects of that mercury are still present"[35]. Symptoms such as difficulty in walking in a straight line, visual disturbances, hearing impairment, headaches, insomnia, exhaustion, fatigue, etc. were observed in nearly one-third of the people surveyed in 2010[36].

In early 1970 Iraq imported “wonder wheat seeds” from Mexico. Methyl mercury was coated on the seeds. Methyl mercury was then used as a cost effective fungicide by many countries like Mexico, even though few countries banned it. The result was disastrous; the methyl mercury coated seeds resulted in severe mercury poisoning of Iraq[37]. Nearly 10,000 people died and 1,00,000 were severely and permanently brain damaged[38].

Hindustan Lever Limited (HLL) acquired a thermometer production unit in Kodaikanal town of Tamil Nadu in 1986[39]. The factory produced 163 million thermometers till 2001 using about 900 kg of mercury annually, which were exported to the US and Europe[40]. There are allegations that through course of time the company started dumping mercury into the open and it is estimated that more than 1000 workers of the factory were also exposed to mercury[41]. In March 2001, the thermometer factory was shut down due to the mounting public pressure and in early 2003, the company was forced to export 289 tonnes of mercury-contaminated material to a mercury recycling facility in United States[42]. It is reported that the workers and their family are still suffering mercury induced illness.

4.2 Mercury in Human Body

In humans for the manifestation of the toxicity symptoms of mercury it is essential that mercury enters the body and is retained at least for some time. There are two major pathways for this to happen, (1) with food through the gastrointestinal tract, and (2) as mercury vapour in the atmosphere through breathing as generally there is not much absorption through the skin.

1. **Mercury intake with food:** Elemental mercury is not absorbed in the gastrointestinal tract as it is not soluble in water. Organic mercury, mainly methyl mercury, is absorbed to the extent of

[35] http://www.cbc.ca/news/canada/story/2012/06/04/grassy-narrows-mercury.html as viewed on September 20, 2012

[36] http://freegrassy.org/wp-content/uploads/2012/06/Harada-et-al-2011-English.pdf as viewed on September 20, 2012

[37] http://www.project-syndicate.org/commentary/iraq-s-secret-environmental-disasters as viewed on September 21, 2012

[38] http://corrosion-doctors.org/Elements-Toxic/Mercury-Iraq-1.htm as viewed on September 21 ,2012

[39] http://www.sipcotcuddalore.com/Kodaikanal/background.htm as viewed on September 21, 2012

[40] ibid

[41] ibid

[42] ibid

about 95% in the gastrointestinal tract[43]. Most of the mercury present in fish and other sea food is in the form of methyl mercury and hence readily absorbed. Methyl mercury can accumulate up the food chain in aquatic ecosystems and lead to high concentrations of methyl mercury in predatory fish, which, when consumed by humans, can result in an increased risk of adverse effects in highly exposed or sensitive populations[44]. The major source of methyl mercury intake in humans is fish and seafood products, and are therefore the main target in monitoring aqueous system contamination for both environmental and public health purposes[45]. Methyl mercury is mostly found complexed with free cysteine and with proteins and peptides containing cysteine[46]. The methyl mercuric – cysteinyl complex is recognised by amino acid transporting proteins in the body as methionine, another essential amino acid[47]. Because of this mimicry, it is transported freely throughout the body including across the blood–brain barrier and across the placenta, where it is absorbed by the developing fetus. It strongly binds to proteins and is not readily eliminated.

2. Mercury intake while breathing: Burning of coal for power generation and use of mercury in industries is one of the major causes for release of mercury in the vapour form in the atmosphere. In such areas, population gets exposed to mercury vapour along with the inhaled air. More than 80% of this mercury is absorbed in the bronchial alveoli and is one of the major causes of pollution by mercury and uptake by humans[48].

In 2003, scientists in the United States with an aim to study blood mercury levels in American children carried out a study using the 1999-2000 National Health and Nutrition Examination Survey. Household interviews, physical examinations and blood mercury levels assessments were performed on 705 children and 1709 women. The geometric mean concentration of total blood mercury found was 0.34 ppb (95% confidence interval (CI), 0.30 - 0.39 ppb) in children and 1.02 ppb (95% CI, 0.85 - 1.20 ppb) in women.

The Canadian Health Measures Survey (CHMS) measured mercury and other environmental contaminants in the Canadian population from 2007 to 2009. Total mercury in blood was detected

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[43] TW Clarkson; 2002, *The modern faces of Mercury*; Environmental Health Perspectives; **110**, 11-13

[44] Anon; 2000, *Toxicological Effects of Methyl mercury*, Committee on the Toxicological Effects of Methyl mercury**,** Board on Environmental Studies and Toxicology, Commission on Life Sciences National Research Council, National Academy Press, Washington DC

[45] Anon; 1990, *Environmental Health Criteria 101: Methyl mercury*, IPCS, World Health Organization, Geneva

[46] LE Kerper, N Ballatori, TW Clarkson; 1992, *Methylmercury transport across the blood–brain barrier by an amino acid carrier*; American Journal of Physiology; **262(5)**, R761–R765

[47] ibid

[48] MG Cherian, TG Hursh, TW Clarkson; 1978, *Radioactive mercury distribution in human subjects after inhalation of mercury vapour*; Archives of Environmental Health; **33**, 190-214

in 88% of the Canadian population aged 6 – 79 years[49]. The geometric mean concentration across the population was 0.69 ppb[50]. Mercury concentrations were lower for children and teens aged 6 – 19 years than for adults. Children aged 6 – 11 years had a geometric mean concentration of 0.27 ppb, similar to that of teens aged 12 – 19 years (0.31 ppb)[51]. Geometric mean concentrations increased with age reaching 1.02 ppb for those aged 40 - 59, before decreasing to 0.87 ppb in the 60 – 79 years age group[52]. Geometric mean concentrations of mercury were similar for males and females across all age groups, with no significant differences between the two sexes.

Human hair has been considered as a useful bio-indicator of mercury[53]. According to a Japanese study on 765 people, one needs to ingest 0.3 mg mercury daily to reach a hair mercury concentration of 50 ppm for a 60 kg man[54]. In a study conducted by Agusa *et al.*, during 1999 - 2000, mercury levels in the hair of residents from Phnom Penh, Kien Svay and Tomnup Rolork of Cambodia were found to be 0.54 – 190 ppm[55]. The study also determined the mercury concentration in marine and freshwater fish to relate the mercury intake in Cambodian people with fish consumption. Mercury concentration in fish in the study area ranged from <0.01 – 0.96 ppm and it was suggested that fish was probably the main source of mercury for Cambodian people[56]. Northern Brazil's largest reservoir situated in Tucurui receives water from Tocantins river which comes from Serra Pellada gold mining area. According to a study carried out in Tucurui region, mercury concentration in human hair ranged from 0.9 – 240 ppm[57].

Industrial Toxicology Research Centre, Lucknow carried out an environmental epidemiological study involving over 1200 persons residing in the Singrauli area. Their exposure to mercury was assessed through analysis of hair and blood, along with local food and water samples collected from the area. The study found the mean mercury levels in blood (1055 subjects) significantly

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[49] http://www.statcan.gc.ca/pub/82-625-x/2010002/article/11329-eng.htm as viewed on September 21, 2012

[50] ibid

[51] ibid

[52] ibid

[53] (a) D Airey; 1985, *Mercury in human hair due to environment and diet: A review,* Environmental Health Perspectives; **52**, 303–316 (b) J Matsubara, & K Machida; 1985, *Significance of elemental analysis of hair as a means of detecting environmental pollution,* Environmental Research; **38**, 225–238

[54] (a) K Kojima, T Araka; 1972, *Normal mercury levels in food in Japan,* Stencil, Tokyo (b) T. Leino, & M. Lodenius; 1995, *Human hair mercury levels in Tucurui area, State of Para, Brazil*; Science of the Total Environment, **175**, 119-125

[55] T Agusa *et al*; 2005, *Mercury contamination in human hair and fish from Cambodia: levels, specific accumulation and risk assessment,* Environmental Pollution; **134**, 79–86

[56] ibid

[57] T Leino & M Lodenius; 1995, *Human hair mercury levels in Tucurui area, State of Para, Brazil,* Science of the Total Environment; **175**, 119-125

higher ($P<0.001$) in the subjects as compared to that in controls[58]. 66.3% subjects from Singrauli had more than 5 ppb of mercury in their blood as compared to 10.5% in controls[59]. Mean mercury in hair (1183 subjects) were also significantly higher ($p<0.001$) in subjects as compared to that in controls. 23% of vegetable samples (n=100) had mercury levels higher than the permissible limit[60]. 15% of drinking water samples had mercury more than the permissible limit of 1.0 ppb[61]. The mean mercury values in fish samples (n=30) collected from Singrauli region were significantly higher ($p<0.001$) than the mean values of fish collected from control areas[62]. According to the study, women (n=100) attending the gynaecology clinic revealed headache and still births, menstrual irregularities, sterility, numbness and tingling of the lower extremities. Hyper-pigmentation, anaemia, black line over gums, high B.P. and tremors were also seen in some of the cases.

4.3 Bio-accumulation of Mercury in Human Body

Inorganic mercury released into the environment from natural or anthropogenic sources is transformed to organic mercury (mainly methylated form) by bacteria[63] which is then accumulated in higher trophic animals through food chain[64]. Humans also accumulate mercury in their body through consumption of fish and other marine organisms[65]. Once mercury is absorbed in the body it complexes with blood and tissues before reacting with biologically important sites.

Half life of Hg in blood absorbed as vapour is 2 – 4 days and 90% is excreted via urine and faeces[66]. The second phase takes 15 – 30 days[67]. The residence time of elemental mercury in the atmosphere is 0.5 – 2.0 years[68]. In areas remote from industry, atmospheric levels of mercury are about 2 – 4 ng/m³ and in urban areas about 10 ng/m³ [69]. This means that the daily amount absorbed into the bloodstream from the atmosphere as a result of respiratory exposure is about 32

[58] RC Srivastava; *Guidance and Awareness Raising Materials under new UNEP Mercury Programs (Indian Scenario)*, Center for Environment Pollution Monitoring and Mitigation, Lucknow

[59] ibid

[60] ibid

[61] ibid

[62] ibid

[63] MK Hamdy & OR Noyes; 1975, *Formation of methyl mercury by bacteria*, App Microbiol; **30**, 424-432

[64] (a) A Boudou & F Ribeyre; 1997, *Mercury in the food web: accumulation and transfer mechanism*s, Metal Ions in Biological Systems; **34**, 289–319. (b) FM Morel *et al.*; 1998, *The chemical cycle and bioaccumulation of mercury*, Annual Review of Ecology and Systematics; **29**, 543–566

[65] (a) Anon; 1990, *Environmental Health Criteria 101: Methylmercury*, World Health Organization, Geneva. (b) TW Clarkson; 1997, *The toxicology of mercury*, Critical Reviews in Clinical Laboratory Sciences; **34**, 369–403

[66] Anon; 1991, *Environmental Health Criteria No. 118; Mercury inorganic*, IPSC, World Health Organisation, Geneva

[67] ibid

[68] WH Schroeder & J Munthe; 1998, *Atmospheric Mercury - An overview*, Atmospheric Environment; **32**, 809-822

[69] ibid

– 64 ng in remote areas and about 160 ng in urban areas[70]. Methyl mercury has a half-life in human blood of about 50 days. In the Minamata Bay incident waste mercury discharged into sea water was methylated and concentrated into fish 5,000 – 50,000 fold. An increase in ambient air levels of mercury results in an increase in deposition in natural bodies of water, possibly leading to elevated concentrations of methyl mercury in fish[71].

4.4 Standards for Mercury

World Health Organisation (WHO) estimated a tolerable concentration of 0.2 μg/m^3 for long-term inhalation exposure to elemental mercury vapour and a tolerable intake of total mercury of 2 μg/kg body weight per day[72]. In industrial environments where workers are subjected to long-term exposure to mercury vapour, the lowest-observed-adverse-effect-level (LOAEL) might be around 15 - 30 μg/m^3 [73].

According to USEPA, current Reference Dose (RfD) of mercury is 0.1 μg/kg body weight/day which is equivalent to 5.8 ppb blood mercury level[74]. Health Canada has issued the guidelines/ recommendations for mercury exposure which are as below:

Biological Materials	**Blood**	**Hair**
Normal Acceptable Range	<20 ppb	<6 ppm
Increasing Risk	20-100 ppb	6-30 ppm
At Risk	>100 ppb	>30 ppm

Source: **http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/mercur/q57-q72-eng.php** as viewed on September 26, 2012

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[70] Anon; 2000, *Air Quality Guidelines for Europe* 2nd Edition, World Health Organisation, European Series, No. 91

[71] WHO; 2000; Air Quality Guidelines for Europe 2nd Edition, WHO Regional Publications, European Series, No. 91

[72] IPCS; (2003) Concise International Chemical Assessment Document 50: *Elemental mercury and inorganic mercury compounds: human health aspects*. Geneva, World Health Organization, International Programme on Chemical Safety [Exposure to mercury_WHO]

[73] MM Veiga, RF Baker; 2004, *Global Mercury Project: Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners*, UNIDO, Vienna International Center, Austria

[74] http://www.epa.gov/hg/exposure.htm as viewed on September 25, 2012

5. HEALTH EFFECTS

5.1 Mercury

Mercury is extremely toxic and has no biological function to perform in the human body. The metal gets bio-concentrated and biomagnified within the food chain. Chronic exposure of mercury affects the nervous system, causing tremors, spasms and loss of memory, severe depression, and increased excitability, delirium, hallucination and personality changes. Renal damages have been observed in chronically exposed workers. The majority of reported toxic effects that can result from exposure to mercury affect the central nervous system (CNS)[75].

Sorensen *et al.* (1999) reported in a study of 1,000 children of 7 year-old Faroese children that diastolic and systolic blood pressures increased by 13.9 and 14.6 mm Hg, respectively, and 47% decrease in heart rate variability (an indication of cardiac autonomic control) as the cord-blood mercury increased from 1.0 to 10 ppb[76].

Salonen *et al.* (1995) reported effects in adults from a study of 1,833 Finnish men aged 42 - 60 years who were free of clinical chronic heart disease, stroke, claudication, and cancer. Over the 7 years observation period, men with hair mercury in the highest tertile (=>2 ppm) had a two times greater risk of acute myocardial infarction than the rest of the study population[77].

Mercury vapour exposure in chlor alkali workers for 8 - 9 years resulted in blood mercury level of 12 ppb and they tended to have increased number of electroencephalography (EEG) abnormalities[78]. In another study of chlor alkali workers an exposure for 5.5 years resulted in 10 ppb mercury in blood and the workers reported memory disturbances, sleep disorders and also anger, fatigue and confusion[79].

[75] K Brigden, D Santillo, R Stringer; 2002, *Hazardous emissions from Thai coal-fired power plants: Toxic and potentially toxic elements in fly ashes collected from the Mae Moh and Thai Petrochemical Industry coal-fired power plants in Thailand*, Greenpeace Research Laboratories, Department of Biological Sciences, University of Exeter, Exeter, UK

[76] N Sorensen, E Budtz-Jorgensen, P Weihe, P Grandjean; 1999, *Prenatal methylmercury exposure as a cardiovascular risk factor at seven years of age*, Epidemiology, **10(4)**, 370-375

[77] JT Salonen, K Seppänen, K Nyyssönen, H Korpela, J Kauhanen, M Kantola, J Tuomilehto, H Esterbauer, F Tatzber, R Salonen, 1995, *Intake of mercury from fish, lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular, and any death in eastern Finnish men*, Circulation, **91(3)**, 645-55

[78] L Piikivi, U Tolonen; 1989, *EEG findings in chlor-alkali workers subjected to low long term exposure to mercury vapour*; Br. J. Ind. Med.; **46,** 370-375

[79] L Piikivi, Hanninen; 1989, *Subjective symptoms and psychological performance of chlorine alkali workers*; Scand. J. Work Environ. Health, **15,** 69-74

5.2 Arsenic

Arsenic is a naturally occurring ubiquitous element with metalloid properties. Arsenic is highly mobilized element. Arsenic is widely present in soil, rocks, sediments, and metals ores in the form of oxyhydroxide or sulfide or compounds of various metals in the most parts of world[80]. Arsenic is also found in coal[81]. There are many arsenic compounds, both organic and inorganic, in the environment. Airborne concentrations of arsenic range from 1 ng/m^3 to 10 ng/m^3 in rural areas and from a few nano-grams per cubic metre to about 30 ng/m^3 in non contaminated urban areas. Near emission sources, such as nonferrous metal smelters and power plants burning arsenic-rich coal, concentrations of airborne arsenic can exceed 1 $\mu g/m^3$. At an air concentration of 1 $\mu g/m^3$, an estimate of lifetime risk is 1.5×10^{-3} [82]. A lethal dose of arsenic oxide is generally regarded as 100 mg[83].

Chronic ingestion of inorganic arsenic causes multi system adverse health effects. High dose of arsenic in drinking water causes characteristic skin manifestation, vascular disease including arteriosclerosis, renal disease, neurological effects, cardiovascular disease, chronic lung disease, cerebrovascular disease, reproductive effects and cancers of skin, lungs, liver, kidney and bladder. Increased exposure of arsenic is also associated with non insulin dependent diabetes mellitus[84]. High arsenic level in drinking water affected the visual perception of children but not the visual motor integration[85].

Arsenic is also associated with the growth retardation in children. The height of children might be affected by the arsenic in drinking water[86]. Arsenic contaminated drinking water is also responsible for spontaneous abortion, stillbirth and infant mortality[87].

[80] N Singh, D Kumar and A P Sahu; 2007, *Arsenic in the environment: Effects on human health and possible prevention*; Journal of Environmental Biology; **28(2)**, 359-365

[81] VC Pandey, JS Singh, RP Singh, N Singh, M Yunus; 2011, *Arsenic hazards in coal fly ash and its fate in Indian scenario*; Resources, Conservation and Recycling; **55**, 819–835

[82] WHO, 2000; *Air Quality Guidelines for Europe 2nd Edition*, WHO Regional Publications, European Series, No. 91. (http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf, viewed as on 28.08.2012)

[83] http://www.lenntech.com/periodic/elements/as.htm#Health%20effects%20of%20arsenic as viewed on September 28, 2012

[84] (a) MM Rahman, SA Tondel, Ahmad and O. Axelson; 1998, *Diabetes mellitus associated with arsenic exposure in Bangladesh*, Am. J. Epidemiology; **148**,198-203; (b) SE Wang, JM Chiou, CJ Chen, CH Tseng, WL Chou, CC Wang, TN Wu and LW Chang; 2003, *Prevalence of Non-Insulin-Dependent Diabetes Mellitus and related vascular disease in southwestern arseniasis-endemic and non endemic areas in Taiwan*, Environ. Hlth. Perspect.; **111**, 155-159

[85] N Singh, D Kumar and A P Sahu; 2007, *Arsenic in the environment: Effects on human health and possible prevention*; Journal of Environmental Biology; **28(2)**, 359-365

[86] ibid

[87] (a) A Aschengrau, S Zierler and A Cohen; 1989, *Quality of community drinking water and the occurrence of spontaneous abortion*, Arch. Environ. Hlth.; **44**, 283-290; (b) CH Rich, SR Browning, IH Picciotto, C Ferricco, C Peralta and H Gibb; 2000, *Chronic arsenic exposure and risk of Infant Mortality in two areas of Chile*, Environ. Hlth. Perspect; **108**, 667-673

Skin manifestation is the most common and initial sign of chronic arsenic exposure. Chronic ingestion of arsenic causes characteristic melanosis, keratosis, basal cell carcinoma and squamous cell carcinoma[88]. Presence of both melanosis and keratosis is the conformational sign of chronic arsenic toxicity. Melanosis includes diffuse melanosis (hyperpigmentation), spotted melanosis (spotted pigmentation), non melanoma (depigmentation) and leucomelanosis in which white and black spots are present side by side on the skin. Melanosis is found mainly on the trunk and extremities or on the whole body[89].

An effect of inorganic arsenic in the form of airborne particles (mostly arsenic trioxide) on respiratory system occurs mainly in industrial area. Initially, the lesions of mucous membrane of respiratory system including the irritation of nasal mucosa, larynx, bronchi and later perforation of nasal septum were observed[90]. Exposure of arsenic through other routes instead of inhalation can also affect the respiratory system and cause a high rate of chronic cough and bronchopulmonary disease[91].

Inorganic arsenic is indirect-genotoxic carcinogen of lungs, skin and several internal organs in the humans[92]. Inorganic arsenic is weak to induce gene mutation at specific loci. The biochemical action of inorganic arsenic carcinogenicity include inhibition of DNA repair enzyme (DNA Ligase enzyme), inhibit DNA methylation, interference with tubulin dynamics and mitosis, induction of oxidative stress, and promote cell clone immortalization[93].

The genotoxicity of inorganic arsenic includes both structural and numerical chromosomal abnormality, increase in sister chromatid, gene amplification, and cell transformation[94]. Thus arsenic is probably a promoter or progressor rather than a true carcinogen[95].

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[88] M Maloney,; 1996, *Arsenic in dermatology*, Dermatologic Surgery; **22**, 301-304

[89] DN Guha Mazumdar, AK Chakraborti and A Ghose; 1988, *Chronic arsenic toxicity from drinking tubewell water in rural West Bengal*, Bulletin of the World Health Organization; **66**, 499-506

[90] CH Hine, SS Pinto and KW Nelson; 1977, *Medical problems associated with arsenic exposure*, J. Occupational Medicine; **19**, 391-396

[91] JM Borgono, P Vicent, H Venturino and A Infante; 1977, *Arsenic in the drinking water of the city of Antofagasta: Epidemiological and clinical study before and after the installation of the treatment plant*, Environ. Hlth. Perspect.; **19**, 103-105

[92] IARC; 1987, International agency for research on cancer monographs on the evaluation of carcinogenic risk to humans: Overall evaluations of carcinogenicity, an updating of IARC monographs. Vols. 1-42 Suppl. 7, Lyon: IARC Publ. pp. 100-106

[93] N Singh, D Kumar and A P Sahu; 2007, *Arsenic in the environment: Effects on human health and possible prevention*; Journal of Environmental Biology; **28(2)**, 359-365

[94] (a) JK Waner, LE Moore, MT Smith, DA Kalman, E Fanning and AH Smith; 1994, *Increased micronuclei in exfoliated bladder cells of individuals who chronically ingest arsenic-contaminated water in Nevada,* Cancer Epidemiology, Biomarkers & Prevention; **3**, 583-590; (b) YH Hsu, SY Li, HY Chiou, PM Yeh, JC Liou and YM Hsueh; 1997, *Spontaneous and induced sister chromatid exchanges and delayed cell proliferation lymphocytes of Bowen's disease patients and matched controls of arseniasis-hyperendemic villages*, Mutation Research; **336**, 241-251

[95] IARC; 1987, International agency for research on cancer monographs on the evaluation of carcinogenic risk to humans: Overall evaluations of carcinogenicity, an updating of IARC monographs. Vols. 1-42 Suppl. 7, Lyon: IARC Publ. pp. 100-106

5.3 Fluoride

In India about 60 million people have been poisoned by well water contaminated with excessive fluoride dissolved from granite rocks[96]. Fluoride toxicity includes dental fluorosis, skeletal fluorosis, depressed activity of thyroid, disruption of activity of hormones such as melatonin-sleep hormone causing chronic insomnia. Ingestion of low doses of fluoride (0.2 – 0.3 ppm) causes gastrointestinal discomfort and interferes with bone formation and leads to increases in wrist and hip fractures. Chronic ingestion of excess fluoride (12 mg/day) may cause adverse effects on kidney[97]. Skeletal fluorosis is endemic and causes irritable bowel symptoms and joint pain[98].

6. OBJECTIVES OF THE STUDY

The main objective of this study was to assess the exposure of the people of Dhudhi subdivision of Sonbhadra district of Uttar Pradesh to heavy metal pollution especially mercury pollution as the area is believed to be heavily polluted due to the presence of many coal mines, coal based thermal power plants and many other polluting industries.

7. MATERIALS AND METHODS

7.1 Sampling

Water and soil samples were collected from this region and analyzed for the presence of certain heavy metals (Pb, Cd, Cr, As & Hg), Physico-chemical properties of water were also determined. A few samples of cereals grown in the area were also collected and analyzed for heavy metals. A few fish samples were collected and tested for methyl mercury. Blood, hair and nail samples of some of the local people showing adverse health conditions were also collected and analyzed for mercury.

[96] Pearce, Fred. 2006; *When the rivers run dry. Journeys into the heart of world's water crisis*. Toronto Key Porter (ISBN 978-1-55263-741-8)

[97] National Research Council, 2001, *fluoride in drinking water*. A scientific review of EPA's Standards. Washington, D. C. National Academies Press

[98] R Gupta, AN Kumar, S Bandhu, S Gupte; 2007, *Skletal fluorosis mimicking seronegative arthritis*; Scand. J. Rheumatol; **36,** 154-155

7.1.1 Water Samples

Twenty three samples of water were collected from different places in polypet bottles and stored at 4^0C away from direct sunlight and brought to the laboratory for analysis. Details of the samples are given in table 1A.

7.1.2 Soil Samples

Seven soil samples were taken at a depth of 20-30 cm below the surface. These were kept in transparent polythene bags and brought to the lab for analysis (Table 1B).

7.1.3 Cereal Samples

Five different samples of rice, wheat and mixed pulses about 100 gm, grown in the area were collected from the houses of the residents and transported to the lab for analysis (Table 1C).

7.1.4 Fish Samples

Three different samples of fish were collected from Rihand reservoir at three different locations and transported to lab in cold conditions for analysis (Table 2D).

7.1.5 Blood, hair and nail samples of local residents

19 persons having some health problems were selected at random and their health problems were recorded. Blood samples were collected in commercially available heparinised tubes. Hair and nail samples were also taken from the same persons and stored in polybags. All these samples were stored at -4^0C and brought to the lab for mercury analysis. Details of the persons sampled and their health conditions are given in Table 2E.

7.2 Equipments

- Atomic Absorption Spectrometer (Thermo) Solar M-6 Series (AAS)
- Gas Chromatograph (Thermoquest-Trace GC) with the ^{63}Ni selective electron-capture detector (ECD)
- GC Column: DB 1701 column (30m X 0.25mm X 0.25µm)
- Hot Plate
- 10 µL syringe from Hamilton Co
- Vortex
- Sonicator

- Centrifuge of Remi equipments
- Nitrogen evaporator
- Water bath

7.3 Chemicals

All the acids and reagents – nitric acid, hydrochloric acid, perchloric acid, potassium permanganate, hydroxyl ammonium chloride, sodium borohydride, sodium hydroxide, potassium persulfate etc. used for the analysis were of Analytical Grade and purchased from Merck. All the solvents viz. acetone, toluene used were HPLC grade (Merck). Ultrapure water was used from Elga USF Maxima Ultra Pure Analytical Grade DI Water System

7.4 Glassware

Beakers, volumetric flasks, conical flasks, funnels, pipettes, watch glasses and glass rods were obtained from Borosil. The volumetric flasks and pipettes were calibrated. All the glassware were cleaned with detergent and 10% nitric acid and rinsed thoroughly with distilled water before use. All the glassware used in the methyl mercury determination in fish - beaker, volumetric flask, conical flask, funnel, pipettes, sample tubes, centrifuge tubes etc were cleaned with detergent and rinsed thoroughly with hot tap water followed by distilled water. Then rinsed thrice each with acetone and toluene before use.

7.5 Standards

Standards for mercury, arsenic, lead, cadmium and chromium were purchased from Merck. Methyl mercury chloride (> 99% pure) standard was purchased from Sigma-Aldrich: Fluka. Calibration solutions of methyl mercury chloride prepared in toluene in the concentrations of 0.05 – 1.0 ppm were used. The experimental solution of hydrochloric acid was 1:1 solution (v/v).

7.6 Determination of Physico-chemical Properties of Water

Total dissolved solids, calcium, magnesium, total hardness, chloride and fluoride were determined by using the standard methods published jointly by American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF)[99].

[99] Standard methods for the examination of water and waste water 16th edition, Washington D. C.

7.7 Digestion and Analysis of Heavy Metals in Water by AAS

7.7.1 Mercury in Water

The samples were digested according to the EPA method 7470A and analyzed using flameless AAS using sodium borohydride as the reducing agent. The detection limit was 0.002 ppm.

7.7.2 Arsenic in Water

Water samples were digested according to the EPA method 7062 and analyzed in AAS using hydride generation technique and sodium borohydride as reductant. The detection limit was 0.002 ppm.

7.7.3 Lead, Cadmium and Chromium in Water

Samples were digested following the EPA method 3010A and analyzed in flame AAS. The detection limit for lead was 0.012 ppm, cadmium 0.007 ppm and chromium 0.017 ppm.

7.8 Heavy Metals in Soil

7.8.1 Mercury in Soil

Samples were digested according to the EPA method 7471B and analyzed by flameless AAS using sodium borohydride as the reducing agent. The detection limit was 0.01 ppm.

7.8.2 Arsenic in Soil

Soil samples were digested according to the EPA method 7062 and analyzed in AAS using hydride generation technique and sodium borohydride reductant. The detection limit was 0.004 ppm.

7.8.3 Lead, Cadmium and Chromium in Soil

Samples were digested following the EPA method 3050B for the determination of lead, cadmium and chromium and analyzed in flame AAS. The detection limit for lead was 0.016 ppm, cadmium 0.009 ppm and chromium 0.021 ppm.

7.9 Heavy Metals in Cereals

For the determination of lead, cadmium, chromium, arsenic and mercury the cereal samples were digested according to the procedure described by Lin *et al*[100].

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[100] HT Lin, SS Wong, GC Li; 2004, *Heavy Metal Content of Rice and Shellfish in Taiwan*; Journal of Food and Drug Analysis; **12 (2)**, 167-174

7.9.1 Mercury in Cereals

Approximately 0.5 g of cereal sample (rice, wheat and mixed pulses) was digested with 10 mL of conc. HNO_3 at 80˚C until the digest was clear. The amount of Hg was determined with flameless atomic absorption spectrometer using sodium borohydride as the reducing agent (Lin *et al*, 2004)[101]. The detection limit was 0.04 ppm.

7.9.2 Arsenic in Cereals

Approximately 0.5 g of each sample was refluxed in 10 mL of concentrated nitric-sulfuric-perchloric acid mixture (4:1:1, v:v:v) for one hour. Then 90% formic acid was added drop by drop until the evolution of red-brown gas disappeared. The volume of the digest was then made to 25 mL with distilled water. The resulting solution was analyzed in AAS by the hydride generation technique using $NaBH_4$ as reducing agent. (Lin *et al*, 2004)[102]. The detection limit was 0.03 ppm.

7.9.3 Lead, Cadmium and Chromium in Cereals

Approximately 0.5 g of each sample was refluxed in 5 mL of concentrated HNO_3 for one hour and then 5 mL of 70% perchloric acid was added. Refluxing was continued for another half an hour. The digests were analyzed in flame atomic absorption spectrometer (Lin *et al*, 2004)[103]. The detection limit for lead was 0.02 ppm, cadmium 0.01 ppm and chromium 0.02 ppm.

7.10 Methyl Mercury in Fish

7.10.1 Extraction method

The sample preparation was based on acidic digestion and extraction with toluene (AOAC 1992). Organic interferences were removed from homogenized fish by acetone wash followed by toluene wash. Protein bound methyl mercury is released by addition of HCl and extracted into toluene. Toluene extract is analyzed for CH_3HgCl by gas chromatograph using an Electron Capture detector.

Accurately weighed 2 g of macerated muscle tissue (just below the integument) of the fish into a 50 ml centrifugation test tube, 25 ml acetone was added and the solution was stirred vigorously for 15 seconds with a glass rod. After centrifugation (2000 rpm for 5 min), it was decanted carefully and acetone layer was discarded (repeated 3 times). Then 20 ml toluene was added;

[101] ibid
[102] ibid
[103] ibid

tightly capped and vigorously shaken for 30 second. Centrifuged for 5 minutes at 2000 rpm. Carefully decanted and discarded the toluene layer.

2.5 ml hydrochloric acid (1:1 dilution (v/v) with water) was added to the centrifuge tube and stirred with the glass rod. The tissues were broken up with glass rod, and methyl mercury chloride was extracted by adding 20 mL toluene and shaking gently for 2 min. It was centrifuged for 5 min at 2000 rpm. Carefully transferred the toluene phase to a stoppered test tube using a Pasteur pipette. Repeated the extraction step adding 20 mL toluene and shaking for 2 min each time. The combined extracts in graduated cylinder were diluted to 50 mL with toluene, stoppered and mixed well and added 10 g of anhydrous sodium sulphate, refrigerated and kept overnight for determination by a gas chromatograph.

7.10.2 Analysis

Methyl mercury was analyzed by Gas Chromatograph (Thermoquest-Trace GC) with the ^{63}Ni selective electron-capture detector (ECD). The samples were analyzed by injecting 2 µL of extract into GC equipped with a narrow-bore fused-silica capillary column (DB-1701; 30m X 0.25mm X 0.25µm). The external standard method was used for the calibration.

- Detector temperature: 300^0C.
- Injector Temperature: 240^0C,
- Oven Temperature: 70^0C (hold 1.00 minutes) to 160^0C at 10^0C /min (hold 2 minute).
- Carrier gas: Nitrogen @ 1mL/min
- Run time: 12.0 minutes

Peak identification was performed by the GC software (Chromcard-32 bit Ver 1.06 October 98) with calibration table set up with a relative retention time window of 0.65%. The samples were calibrated (retention time, area count) against standard mixture of known concentration. Retention time of methyl mercury chloride was 8.93 minutes. Identification of peak was performed by comparing the retention time (Rt) of the samples GC-peaks with the Rt of the methyl mercury chloride standards. Calculated methyl bound mercury content of the test sample and expressed as µg Hg/g (ppm Hg).

The calibration curves for methyl mercury chloride were linear (R2 ≥0.999) in the concentration range 0.05 - 1.0 ppm. Each sample was analyzed in triplicate and reproducibility of the results was more than 90% by the method. The recovery of methyl mercury chloride under the experimental conditions was more than 90%. The relative standard deviation (RSD) for the determination of methyl mercury chloride was within 10%. The detection limit for methyl mercury chloride was 0.03 ppm.

The reliability of the method (stability of the GC-retention time, calibration range, recovery, repeatability of determination, etc.) was checked for the present investigation, and was found to be satisfactory for the analysis. The GC retention times (RT) of methyl mercury chloride were stable throughout the study, with a maximum variation <1%.

7.11 Digestion and Analysis of Mercury in Human Blood, Hair and Nails

7.11.1 Mercury in Blood

For the determination of Mercury in blood, Agilent's Application Note-AA126: (Determination of Mercury in Blood and Urine by Cold Vapor AAS Using the VGA-77 by G. A. Hams, Pacific Laboratory Medicine Services, Royal North Shore Hospital, St Leonards NSW 2065, Australia) was used.

1.0 mL of whole blood was mixed with 3 mL of a 5:2:1 mixture of 70% (w/w) nitric acid, 70% (w/w) perchloric acid and 98% w/w sulfuric acid in a 10 mL test tube. The digestion mixture was warmed to 40°C for 60 minutes and then heated at 90°C for at least 60 minutes with frequent mixing until the brown fumes of oxides of nitrogen stopped evolving and the remaining liquid was golden yellow in color. Finally the volume was made to 5.0 mL with distilled water and the solution mixed thoroughly prior to determination. Blood determinations were calibrated by preparing a series of mercury solutions in 0.4% (w/w) nitric acid and 1% (w/w) sulfuric acid and perchloric acid.

7.11.2 Mercury in Hair

For the determination of mercury in hair, samples were digested according to the procedure described by Leino and Lodenius (1995)[104]. Before analysis samples were washed successively with acetone, distilled water and again with acetone and then dried at 40-45^{0}C. The dried samples were weighed and digested by adding 2.5 mL of 4:1 (H_2SO_4:HNO_3). The samples were left to stand for 3 hours and then heated at around 85^{0}C for one hour. After cooling, 4.0 mL of 5% $KMnO_4$ was added and left overnight. The excessive permanganate was reduced by adding 1.0 mL of Hydroxyl ammonium hydrochloride. These digested samples were then analyzed in flameless AAS by borohydride reduction. The detection limit was 0.02 ppm.

[104] T. Leino, M Lodenius; 1995, *Human hair mercury levels in Tucurui area, State of Para, Brazil*; Science of the Total Environment; **175**, 119-125

7.11.3 Mercury in Nails

To determine mercury in nails, samples were digested following the procedure described by *Pallotti et al*, 1979[105]. Approximately 0.1 g of nail sample was digested with a mixture of nitric and sulfuric acids (1:4) and 6.0 mg of vanadium pentoxide at 70^0C. The digested sample was then diluted to 25 ml with water and the total mercury determined by flameless atomic absorption spectrophotometer using sodium borohydride as the reducing agent. The detection limit was 0.02 ppm.

8. RESULTS AND DISCUSSION

In view of the presence of a large number of coal based power plants, chlor alkali and other industries in Singrauli region and many residents of the region showing adverse health conditions, other than normal sicknesses, an investigation of heavy metals, especially mercury in the environment as well as in human population was considered important and hence carried out. For this purpose a team of Scientists from PML went to Singrauli twice and surveyed the area and recorded the health condition of selected local residents and collected samples.

8.1 Drinking Water

A total of 15 drinking water samples were collected and analyzed for various physico-chemical parameters and heavy metals.

- More than 50% (8 of 15) samples had TDS in the range of 501- 1150 ppm which is higher than the desirable limit for drinking water (Table 2A). Sample numbers W20 and W23 collected from hand pumps at Dibulganj and Renukut had TDS 1150 and 1130 ppm respectively which is more than two times the desirable limit for drinking water.

- More than 86% samples (13 of 15) had calcium in the range of 80 – 224 ppm as against the desirable limit for drinking water of 75 ppm. Out of 15 drinking water samples 7 samples (46.7%) had calcium double the desirable limit for drinking water. Two samples (W04 and W23) had calcium almost three times the desirable limit for drinking water. More than 33% samples (5 of 15) had calcium even higher than the permissible limit of drinking water of 200 ppm.

[105] G. Pallotti, B. Bencivenga, T. Simonetti; 1979, *Total mercury levels in whole blood, hair and fingernails for a population group from Rome and its surroundings*; The Science of the Total Environment; **11**, 69-72

- Three samples (20%) were found to contain magnesium more than the desirable limit for drinking water of 30 ppm. Highest concentration of magnesium (51.24 ppm) was found in sample number W19 collected from hand pump at Chilika Daad village.
- 60% samples (9 of 15) exceeded the desirable limit of hardness for drinking water of 300 ppm. In these 9 samples hardness was found in the range of 320 – 650 ppm. Two samples even exceeded the permissible limit of hardness for drinking water of 600 ppm.
- Fluoride was detected in 80% (12 of 15) of the drinking water samples in the range of 0.1 – 2.1 ppm. The fluoride content of the samples W16 and W15 was 2.1 and 1.8 ppm, much higher than the desirable limit for drinking water of 1.0 ppm. Both the samples were from the same hand pump but W15 was filtered while W16 was unfiltered. These samples were collected from the fluoride affected area (Kusmaha village). In some of the hand pumps of this area Uttar Pradesh government fitted a filter in 2009 to remove the fluoride. This hand pump is one of them. The results show that the filter is not as effective as it should have been and is releasing the calcium into the water as a result of which total hardness and calcium (389 & 80 ppm respectively) is higher than the unfiltered water (335 & 48 ppm respectively). This could be attributed to the lack of maintenance of the filter. High concentrations of fluoride were reported from some village ponds in Singrauli region being upto 3.14 ppm and were considered to be due to burning of coal in power plants etc[106]. Residents of this area have lot of adverse health effects such as skeletal fluorosis indicating fluoride toxicity.
- Of these 15 drinking water samples 3 samples (20%) contained mercury ranging from 0.003 – 0.026 ppm of mercury. Sample number W01 which was collected from hand pump at Dibulganj contained 0.026 ppm of mercury which is 26 times higher than the desirable limit of mercury in drinking water (0.001 ppm). Similarly sample numbers W02 (dug well at Anpara) and W06 (hand pump at Chilika Daad) contained 0.008 and 0.003 ppm of mercury respectively (Table 2A) which is 8 and 3 times higher than the desirable limit of mercury in drinking water.
- The three villages – Anpara, Dibulganj and Chilika Daad are situated very near to thermal power plants. Chilika Daad is situated next to both thermal power plant and coal mine. Coal mine operated by Northern Coal Limited (NCL) is just 200-300 meters away from this

[106] S. Chaurasia, S. K. Mishra; 2007, *Fluoride Contamination in Rain Water of Singrauli Region*; Indian J. Environ. Prot.; **27 (10)**, 923-926

village. In rainy season the water from the mining areas where very high piles of loose soil are present, comes to this village along with the soil and floods the whole area.

- The most probable cause of the high concentration of mercury in the ground water of these villages is the burning of large amount of coal in the thermal power plants.
- Only one drinking water sample (W19) collected from hand pump at Chilika Daad was found to contain 0.002 ppm of Arsenic which is within the desirable limit of arsenic for drinking water. Lead, cadmium and Chromium were either not detected or were below detection limit in the drinking water samples.
- Sample numbers W03 (water supplied by Renusagar Power Project (NTPC) to Garbandha Village), W08 (water supplied by NTPC to Chilika Daad village) and W14 (water from tap supplied by UPID, near gate of VIP colony, Renukut) had good water quality. All the three samples were treated water supplied by either companies or government. Rest of the samples had one problem or other except one sample (W22) collected from hand pump at Malviya Nagar, Obra.

8.2 Surface Water

Three surface water samples were collected and analyzed for various physico-chemical parameters and heavy metals. Two samples W13 and W 17 collected from Rihand dam and Obra dam had 633 and 536 ppm of TDS respectively. Sample from Rihand dam (W13) also had 188 ppm of calcium and 500 ppm total hardness. Water from Obra dam (W17) contained 1.8 ppm of fluoride which is high (Table 2A).

Water of Rihand dam (W13) at Renukut – Pipri where Dongiya Nallah drains into Rihand dam, contained 0.01 ppm of mercury. The most probable cause of this high concentration of mercury in this sample is the Dongiya Nallah.

Two of three surface water samples were found to contain Arsenic with the maximum concentration of 0.019 ppm. In the water sample from Renuka river at Obra (W10), 0.008 ppm of Arsenic was found (Table 2A). Thermal power plants run by National Thermal Power Corporation (NTPC) at Obra discharge their effluents (slurry of fly ash) in to the Renuka river as they are situated very close to it. So, the probable causes of the high concentration of Arsenic in this river water are the fly ash discharged in to it and the burning of coal in the thermal power plants. Water from Obra dam where Murdhawa Nallah meets it was found to contain 0.019 ppm of Arsenic (Table 2A). The most probable cause of this high concentration of Arsenic is

Murdhawa Nallah which also had very high concentration (0.170 ppm) of Arsenic. It carries the effluents of Hindalco Industries Limited and discharges it into the Obra dam.

8.3 Effluent Water

A total of 5 effluent samples were collected and analyzed. Effluent of Aditya Birla Chemicals (India) Ltd. (ABCL) (W12) had a TDS of 4370 ppm which is more than double the standard (2100 ppm) prescribed for effluents. Two out of five effluent samples had fluoride. Water from Dongiya Nallah (W12) contained 4.5 ppm of fluoride which is more than double the amount permitted (2.0 ppm) in the effluent water. Dongiya Nallah carries the effluents of Aditya Birla Chemicals and discharges them in to Rihand Dam. Thus, it is contaminating the water of Rihand dam which people use for various purposes including drinking. Water sample of Murdhawa Nallah contained 1.9 ppm of fluoride which is at border line of the prescribed limit for effluent water of 2.0 ppm (Table 2A).

Water of Dongiya Nallah (W12) was found to contain 0.127 ppm of mercury which is 12.7 times higher than the prescribed limit (0.01 ppm) for effluent water. Dongiya Nallah carries the effluents of Aditya Birla Chemicals (India) Ltd. (ABCL) which produces the chlor alkali products. Mercury level in water near chlor alkali industry has been reported as high as 0.176 ± 0.0003 ppm in water[107].

Two samples (40%) contained Arsenic (Table 2A). Water samples from ash pond of Shakti Nagar thermal power plants run by NTPC (W05) had 0.020 ppm of arsenic which is well within the prescribed limit for effluents but the water from Murdhawa Nallah (W18) contained 0.170 ppm of arsenic which is at border line with the prescribed limit (0.20 ppm) for effluent water.

Lead was found in only one sample (W11) which was collected from Jharia Nallah at Obra which carries the municipal sewage as well as effluents of thermal power plants. 0.047 ppm of lead was contained in it which is well within the limit prescribed for effluent water (0.10 ppm). Most probably the lead in this sample came from municipal sewage. In rest of the samples lead was either not detected or was below detection limit. Cadmium and Chromium were either not detected or were below the detection limit (Table 2A).

Effluent of ABCIL had 4370 ppm TDS, 562 ppm calcium, 41.48 ppm magnesium, 1550 ppm total hardness, 1530 ppm chloride, 4.5 ppm fluoride and 0.127 ppm mercury. These results show that ABCIL is one of the major sources of pollution of water of Rihand dam.

[107] R. C. Srivastava; *Guidance and Awareness Raising Materials under new UNEP Mercury Programs (IndianScenario)*; Center for Environment Pollution Monitoring and Mitigation, Lucknow

8.4 Heavy Metals in Soil

8.4.1 Mercury

Mercury was found in all the seven samples (100%) analyzed in the range of 0.42 – 10.09 ppm (Table 2B). Highest concentration 10.09 ppm of mercury was found in the soil sample (S04) collected near Rihand dam where Dongiya Nallah meets at Renukut – Pipri. It is 1.53 times of the Canadian soil quality guidelines for agricultural and residential/parkland soil of 6.6 ppm. The most probable reason of the very high mercury content of this soil is Dongiya Nallah as its water contained very high amount of mercury (0.127 ppm) as it carries the effluent of chlor-alkali plant. The soil samples collected from Anpara, Chlilika Daad and Obra contained 1.64, 1.75 and 0.42 ppm of mercury respectively. A soil sample earlier collected and analysed in 2011 by CSE-PML from outside Anpara thermal power plant near fly ash pond also contained 0.71 ppm of mercury (a coal sample collected from Anpara thermal power plant at the same time was found to contain 0.15 ppm of mercury). Anpara, Chilika Daad and Obra are situated very near to thermal power plants. In rest of the three samples (S05, S06 and S07) mercury concentration was found in the range of 0.50 - 0.57 ppm. These results show that the entire stretch from Obra to Chilika Daad contained mercury because the thermal power plants present in this stretch release the mercury in to the environment and also because of coal mining activity.

8.4.2 Arsenic

Arsenic was also found in all the seven samples (100%) analyzed for it in the range of 0.52 – 7.67 ppm (Table 2B). Highest amount of Arsenic (7.67 ppm) was found in soil sample collected from Khairahi village (S06). According to Agency for Toxic Substances and Disease Registry (ATSDR) of the US, the mean level of arsenic permissible in soil is 7.2 ppm. The second highest concentration (6.36 ppm) of Arsenic was found in the soil sample collected near the Rihand dam where Dongiya Nallah meets it (S04). The third highest concentration 2.66 ppm of Arsenic was found in the soil sample collected from Obra (S03) – town which harbors one of India’s oldest thermal power plants. Soil samples S01 and S02 collected from the two villages (Anpara and Chilika Daad) situated near the thermal power plants were found to contain 1.58 and 1.76 ppm of Arsenic respectively. Rest of the two soil samples S05 and S07 collected from Kusmaha village and Renukut contained 0.67 and 0.52 ppm of Arsenic respectively. All the samples had arsenic within the Canadian soil quality guideline for the protection of environmental and human health which is 12 ppm for arsenic in all the four types of soils (Table 2B).

8.4.3 Lead

Lead was found in 86% of the samples (6 out of 7) ranging from 10.4 – 35.1 ppm (Table 2B). Highest concentration of lead 35.1 ppm was found in the soil sample S04 collected from the place where Dongiya Nallah drains into Rihand dam. The most probable reason of high concentration of lead here is the Dongiya Nallah which carries the effluent of ABCIL. Second highest concentration of lead (29.5 ppm) was found in the soil sample S06 collected from Khairahi village and could be because of the use of lead based paints, lead acid battery and trans boundary movement of lead from industrial area. In the soil samples S01 and S02 collected from Anpara and Chilika Daad village (situated close to thermal power plants) the lead concentrations were 10.9 and 25.9 ppm respectively. Rest of the soil samples S05 and S07 collected from Kusmaha village and Renukut had 13.1 and 10.4 ppm of lead. All the samples had lead within the Canadian soil quality guideline for the protection of environmental and human health which is 70 ppm for lead in agricultural soil and 140 ppm in residential/parkland soil.

8.4.4 Cadmium

Cadmium was either not detected or was below the detection limit.

8.4.5 Total Chromium

Chromium was found in all the samples (100%) in the range of 11.5 – 41.6 ppm (Table 2B). Highest concentration was found in the soil sample S07 collected from Ramlila Maidan at Renukut. Sample S01, S02 and S03 collected from Anpara, Chilika Daad and Obra (situated near thermal power plants) had 37.4, 39.9 and 23.1 ppm of Chromium. Sample S04 collected near Rihand dam where Dongiya Nallah meets it was found to contain 24 ppm of Chromium. Rest of the two samples S05 and S06 collected from Kusmaha and Khairahi village had 11.5 and 38.8 ppm of Chromium. All the samples had total chromium within the Canadian soil quality guideline for the protection of environmental and human health which is 64 ppm for total chromium in agricultural and residential/parkland soil (Table 2B).

8.5 Heavy Metals in cereal samples

Two samples of wheat, one sample each of rice, paddy and mixed pulses from that area were analyzed for the heavy metals Pb, Cd, Cr, As and Hg and the results are given in Table 2C.

8.5.1 Mercury

Mercury was either not detected or was present in very low amount.

8.5.2 Arsenic

Three out of five (60%) cereal samples were found to contain Arsenic in the range of 0.042 – 0.173 ppm. Highest amount of Arsenic was found in the rice sample being 0.173 ppm. Second highest concentration (0.120 ppm) of Arsenic was found in the paddy sample from Kirwani village. Mixed pulses sample collected from Obra had 0.042 ppm of Arsenic.

India has set the maximum permissible level of total Arsenic as 1.1 ppm for all food items not non-specified food including rice and rice based products[108]. Arsenic levels in all the three samples were well within the prescribed limit.

Rice can be contaminated with arsenic. Arsenic accumulates in a layer of the bran (aleurone layer) thus brown rice would have even higher levels of arsenic. Organic brown rice syrup has been identified as having high levels of arsenic. This means foods made with rice or rice syrup may have high levels of arsenic[109]. Arsenic is not evenly distributed in the bran, but accumulated in a small area on the surface of the grain. The area of Arsenic accumulation was located to the position of the ovular vascular trace[110]. It is reported that nutrients are transported to the endosperm through ovular vascular trace[111]. Probably Arsenic together with some other nutrients was transported into endosperm, but difficult to diffuse physiologically from the surface to inside or is accumulated preferentially in the protein-rich tissue (aleurone). Arsenic speciation in bran was confirmed that 95% of total arsenic in bran is inorganic Arsenic[112].

8.5.3 Lead, Cadmium and Chromium

Lead was either not detected or was below the detection limit. Cadmium was not detected in any of the samples. Chromium was found only in the paddy sample collected from Kirwani village being 1.6 ppm.

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[108] Discussion Paper on Arsenic In Rice: Joint FAO/WHO Food Standards Program, Codex Committee on Contaminants in Foods, 5th Session, The Hague, The Netherlands, 21 – 25 March 2011

[109] http://www.uoguelph.ca/foodsafetynetwork/arsenic-food, viewed as on 23.08.2012

[110] (a) E Lombi, KG Scheckel, J Pallon, AM Carey, YG Zhu, and AA Meharg; 2009, *Speciation and distribution of arsenic and localization of nutrients in rice grains*; New Phytologist; **184(1)**, 193-201; (b) AA Meharg, E Lombi, PN Williams, KG Scheckel, J Feldmann, A Raab, YG Zhu, R Islam; 2008, *Speciation and localization of arsenic in white and brown rice grains*; Environmental Science and Technology; **42**, 1051–1057

[111] S Krishnan, P Dayanandan; 2003, *Structural and histochemical studies on grain-filling in the caryopsis of rice (Oryza sativa L.);* Journal of bioscience; **28(4)**, 455-469

[112] Sun Guo-Xin, PN Williams, AM Carey, Zhu Yong-Guan, C Deacon, A Raab, J Feldmann, RM Islam, AA Meharg; 2008, *Inorganic arsenic in rice bran and its products are an order of magnitude higher than in bulk grain;* Environmental Science and Technology; **42**, 7542-7546

8.6 Methyl Mercury in Fish Samples

A total of 3 commonly available freshwater fish samples were fished from the Rihand reservoir. All the three fishes were fished from three different locations where effluents are discharged and were analyzed for methyl mercury content. The results (calculated as the element) are given in Table 2D. Of these three fishes two were Rohu (*Labeo rohita*) and one was Malli (*Wallago attu)*.

Of the three fish samples analyzed, methyl mercury was detected in two. Methyl mercury was found in both the Rohu fish samples while Malli had no methyl mercury in it. The highest concentration of methyl mercury (0.505 ppm calculated as the element) was found in the fish 1 (Rohu) collected from Shaktinagar, Near Baliya Nallah (NTPC effluent discharge) which is 2 times of the standard set by Food Safety and Standards Authority of India (FSSAI). While in another Rohu fish sample (Fish 3) fished near Dhungiya Nallah, Rihand Reservoir (Kannoria Chemicals effluent discharge) was found to contain 0.447 ppm of methyl mercury (calculated as the element) which is 1.8 times the standard set by FSSAI. In Fish 2 (Malli) fished from Belva Dah, Rihand Reservoir (near Anpara ash pond) methyl mercury was not detected.

From the above results it is confirmed that the fishes of Rihand reservoir are not suitable to eat and are one of the sources of mercury in local residents.

8.7 Mercury in Human Body

A significant number of residents of this region complained of many health problems not generally related to the common diseases. These varied from joint pain, body pain, skin discoloration, speaking difficulty, swelling in legs, blurred vision, burning sensation in extremities, muscular spasms, trembling of hands, etc many of which are also seen in mercury and arsenic poisoning.

Blood, hair and nail samples were collected from a total of 19 persons (12 female and 7 male) of age 08 – 63 years from Chilika Daad, Dibulganj, Khairahi-Kirwani and Obra. Of these 19 persons, 8 persons (5 female and 3 male) were from Chilika Daad, 5 (4 female and 1 male) from Dibulganj, 3 (2 female and 1 male) from Khairahi-Kirwani and 3 (1 female and 2 male) from Obra.

8.7.1 Mercury in Human Blood

The results of mercury in blood samples are given in Table 2E along with the details of the individual and their health conditions. The average concentration of mercury in blood was found to be 34.30 ppb. Out of 19 samples, 16 samples (84.2%) had more than USEPA's limit of mercury in blood (5.8 ppb). According to health Canada guidelines 12 out of 19 persons (63.1%) are in the category of increasing risk as they had blood mercury level between 20 – 100 ppb and one out of 19 persons is at risk as more than 100 ppb of mercury was found in his blood. All these persons were showing different adverse health conditions.

Highest concentration of mercury (113.48 ppb) was found in the blood sample of Kailash of Khairahi village. He has reported the problem of burning extremities, electrifying feeling, joint pain, and muscular spasm. He eats fish 2-3 days in a week. Second highest concentration of mercury (78.68 ppb) was found in the blood samples of Saraju Nisa of Chilika Daad village. She has abdominal pain, joint pain, skin discoloration, burning extremities, and electrifying feeling throughout the body.

Of the 19 persons sampled, 7 were males and 12 were females. All the males (100%) had mercury in their blood and were in the range of 26.23 – 113.48 ppb with average concentration of 44.66 ppb. All the males exceeded the USEPA’s safe level of mercury in blood of 5.8 ppb and they are in increasing risk category of health Canada guidelines as they had more than 20 ppb of mercury in their blood (Annexure 2).

75% females (8 of 12) had mercury in the range of 10.31 – 78.68 ppb which is higher than USEPA’s safe level of mercury in blood. The average concentration of mercury in blood of females was found to be 28.26 ppb (Annexure 2).

100% blood samples from Dibulganj, Khairahi-Kirwani and Obra contained mercury while 62.5% blood samples from Chilika Daad contained mercury.

8.7.2 Mercury in Human Hair

More than 57% (11 of 19) hair samples were detected with mercury in the range of 1.17 - 31.32 ppm and the average concentration was 7.39 ppm (Table 2E). Out of 19 persons 5 (26.3%) had mercury between 6 – 30 ppm means they are in increasing risk category of health Canada guidelines and 10.5% (2 of 19) are at risk category as they had more than 30 ppm of mercury in their hair.

Highest concentration of mercury (31.32 ppm) was found in hair sample of Abrania (Dibulganj) who has reported the problems of abdominal burning, tingling, muscular spasm and joint pain. Second highest concentration of mercury (30.65 ppm) was detected in the hair sample of Himanshu (Chilika Daad). He is suffering from diabetes since the age of 1.5 years. In the hair samples of Priyanka Bharati (Dibulganj) and Sushil (Dibulganj) had 26.50 ppm and 15.26 ppm of mercury respectively Priyanka Bharati has reported the problems of burning sensation through the body and Shushil has started stammering earlier he had no difficulty in speaking (Table 2E).

Concentration of mercury in hair more than 20 ppm may result in different symptoms such as vertigo and dizziness, headache, pain in limb extremities, reduction in vision, etc as found in people in three fishing villages in the Tapajos river basin, Amazon[113]. Some of these symptoms were also observed in some of the residents (Table 2E).

Of 7 males 4 (57.1%) had mercury in their hairs in the range of 1.17 – 30.65 ppm while of 12 females 7 (58.3%) were found to contain mercury in their hairs in the range of 1.57 – 31.32 ppm. The average concentration of mercury in hair of male and female were 7.27 and 7.45 ppm respectively (Annexure 2). The highest concentrations of mercury in hair samples among male and female persons were 30.65 and 31.32 ppm respectively.

100% hair samples from Khirahi-Kirwani and 80% samples from Dibulganj village had mercury while 66.7% samples from Obra were found to contain mercury. Only 25% samples from Chilika Daad village had mercury (Annexure 1).

8.7.3 Mercury in Human Nails

Mercury was detected in the 44% (8 of 18) nail samples in the range of 0.16 – 7.02 ppm and the average concentration was 0.83 ppm (Table 2E). Highest amount of mercury (7.02 ppm) was found in the sample from Lata Devi (Chilika Daad). Out of 18 samples only one sample (5.6%) had more than 5 ppm of mercury. Three other samples (16.7%) had more than 1 ppm of mercury. Rest of the 4 samples (22.2%) had mercury in the range of 0.16 – 0.90 ppm.

Of 7 males only 2 (28.6%) had mercury in their nails (1.44 & 0.08 ppm) and the average concentration of mercury in nail samples of male persons was 0.22 ppm. While 54.5% (6 of 11) females were found to contain mercury in their nails in the range of 0.16 – 7.02 ppm and the average concentration of mercury in their nail samples was 1.22 ppm (Annexure 2).

Mercury was detected in 62.5% nail samples from Chilika Daad village while 33.3% samples from both Khairahi-Kirwani and Obra were detected with mercury. Only 25% samples from Dibulganj village had mercury (Annexure 1).

[113] MJ Harada, Nakanishi et. al; 2001, *Mercury pollution in the Tapajos River basin, Amazon Mercury level of head hair and health effects;* Environment International; **27,** 285-290

9. CONCLUSIONS

Most of the drinking water samples were not found to be suitable for drinking. The treated water samples supplied by the companies or government were found to be good. The fluoride content of the samples from fluoride affected area was 2.1 times higher than the desirable limit of 1.0 ppm. The results show that the filter fitted to remove the fluoride is not as effective as it should have been. The fluoride content of the filtered water was 1.8 times higher than the desirable limit. Also the installed filter releases calcium as the value of calcium was higher in the filtered water than the unfiltered water. Residents of this area show adverse health effects such as skeletal fluorosis which is one of the fluoride toxicity symptoms.

Out of 23 samples 15 were ground water being used for drinking purpose and from these, 3 samples (20%) contained mercury higher than the permissible limit. Sample from hand pump at Dibulganj contained mercury 26 times higher than the permissible limit of 0.001 ppm. Similarly samples from Anpara (W02) and Chilika Daad (W06) contained mercury 8 and 3 times higher than the permissible limit respectively.

In soil the highest amount of mercury (10.09 ppm) and lead (35.12 ppm) were found in sample collected near Rihand dam (S04) and of Arsenic (7.67 ppm) and chromium (41.57 ppm) were found in sample from Khairahi village (S06) and Renukut (S07) respectively. All these samples except S04 were from residential areas. The cereals contained only a small amount of arsenic in 3 of the 5 samples. All were well within the prescribed limit of 1.1 ppm.

The two fish samples (Rohu) were found to contain methyl mercury. Both the fish samples had methyl mercury almost double the standard of methyl mercury in fish (0.25 ppm calculated as the element) set by FSSAI. The results of the water, soil and fish samples do indicate pollution due to mercury, arsenic and fluoride.

Average concentrations of mercury in human blood, hair and nail were 34.30 ppb, 7.39 ppm and 0.83 ppm respectively. More than 84% blood samples were found to contain mercury above the safe level (5.8 ppb) set by USEPA. All the male persons examined who were showing adverse health conditions, were detected with mercury in their blood with the average concentration of 44.66 ppb.

75% females were detected with mercury in their blood and the average concentration was 28.26 ppb. All the females detected with mercury in their blood had more than 5.8 ppb of mercury which is a safe level according to USEPA.

More than 57% of hair samples contained mercury. Of which 26.3% persons are at increasing risk category of health Canada guidelines and 10.5% are at risk category. 57.1% male and 58.3% female persons had mercury in their hair samples. The average concentrations of mercury found in the hair samples of male and female persons were 7.27 and 7.45 ppm respectively.

Mercury was detected in the 44% nail samples. Highest concentration of mercury found in nails was 7.02 ppm. 5.6% nail samples had more than 5 ppm of Hg.

Khairahi-Kirwani samples showed the maximum mercury levels in blood. The highest concentration of mercury found in blood is 19.5 times higher than the safe limit prescribed by USEPA (5.8 ppb). Here all the three persons sampled had mercury in blood and hair while only one had mercury in nails. All the three residents ate fish. The resident who had maximum mercury in blood (Kailash) also ate fish 2-3 times a week. The soil had 0.5 ppm mercury.

From Dibulganj where samples were collected from 5 persons, the maximum concentration of mercury found in blood is 10.6 times higher than the safe level. All of them had mercury in blood whereas 80% had it in hairs and 20% in nails. Well water and hand pump water in this village contained mercury 8 and 26 times higher than the permissible limit, respectively.

From Chilka Daad, samples of 8 persons were taken of which 62.5% had mercury in blood and nail while in hair only 25% had mercury. The maximum concentration found in blood is 13.6 times higher than the safe level. The water in the hand pump in this area had mercury 3 times higher than the permissible limit and the soil had 1.75 ppm mercury.

Three persons from Obra who showed adverse health conditions were sampled for blood, hair and nail. The maximum concentration found in blood is 5.1 times higher than the safe level. All three persons had mercury in blood, two in hair and only one had it in nails. The soil had 0.42 ppm mercury.

Many residents of this region exhibit adverse health conditions, other than normal diseases.

It is thus clear that the residents of the Singrauli region of Sonbhadra district of Uttar Pradesh who were examined and were showing adverse health conditions could be suffering from the effects of mercury poisoning as the region is heavily polluted by mercury. Likely cause of the mercury pollution in the area is burning of huge amount of coal for power generation.

10. RECOMMENDATIONS

1. Mercury standards must be set for coal-based thermal plants, coal washeries and mining
2. The moratorium must be reimposed on Singrauli to develop a future course of action.
3. Old plants that do not meet standards should be shut down.
4. The government should commission a cumulative regional impact assessment and carrying capacity study to assess how many coal-based power plants, coal mining and other industries this area can sustain depending on the assimilative capacity of the environment. This assessment must give primacy to water and mercury pollution.
5. All existing plants and upcoming plants must have state-of-the-art mercury control system.
6. A detailed ground water quality survey should be done in the region to understand mercury and arsenic contamination.
7. The system for regular mercury monitoring and advisory must also be put in place.
8. Monitoring of methyl mercury in fish should be done regularly and advisory for eating fish must be issued by the government.
9. Health advisory should be issued by the government.
10. Treated water must be provided to all hamlets, villages and towns in Singrauli, and the polluting companies must pay for it.
11. Health services to the affected people must be provided
12. The programme for decontamination of areas like reservoirs, ash pond of power plants and plants like the caustic soda plant of Aditya Birla group must be put into motion.

Table 1A: Details of Water and Effluent Water Samples Collected from Singrauli

S. No.	Sample Code	Location	Date of Collection	Latitude in degree	Longitude in degree
1	W01	Hand Pump at Dibulganj	28.05.2012	24.21008	82.807
2	W02	Well water from Kalika Singh's House, Anpara	28.05.2012	24.19406	82.7904
3	W03	Water supplied by Renusagar Power Project (NTPC) to Garbandha Village Area	28.05.2012	24.17688	82.79314
4	W04	Well Water, Garbandha Village	28.05.2012	24.17684	82.79237
5	W05	Water from Ash Pond of Shakti Nagar NTPC	28.05.2012	24.11169	82.75635
6	W06	Hand pump in Prahlad's House at Chilika Daad	28.05.2012	24.12538	82.70212
7	W07	Hand Pump at Chilika Daad Near Kashmir Valley School	28.05.2012	24.12372	82.7071
8	W08	Water supplied by NTPC to Chilika Daad	28.05.2012	24.12372	82.7071
9	W09	Water from Ballia Nallah	28.05.2012	24.09969	82.69992
10	W10	Water from Renuka River at Obra	29.05.2012	24.45124	82.96507
11	W11	Jharia Nallah at Obra near Shushil's House	29.05.2012	24.45	82.96844
12	W12	Dongiya Nallah at Renukut (Pipri) Effluent of Aaditya Birla Chemicals (India) Ltd (ABCL)	29.05.2012	24.19908	83.37667
13	W13	Rihand Dam where Dongiya Nallah meets to Rihand Dam (Renukut – Pipri)	29.05.2012	24.19829	83.04396
14	W14	Water from tap supplied by UPID, near gate of VIP colony, Renukut	29.05.2012	24.20371	83.02249
15	W15	Hand pump in front of Rambhajan's house at Kusmaha village – Filtered water	30.05.2012	24.16428	83.09614
16	W16	Hand pump in front of Rambhajan's house at Kusmaha village – Unfiltered water	30.05.2012	24.16428	83.09614
17	W17	Obra dam where Murdhawa Nallah (Ganda nala/Thad Pathar) meets	30.05.2012	24.25173	83.01267
18	W18	Murdhawa Nallah (Ganda nala/Thad Pathar)	30.05.2012	24.25082	83.01408
19	W19	Hand Pump at Chilika Daad	31.05.2012	24.12504	82.70011
20	W20	Hand Pump at Dibulganj in front of former Pradhan's house	31.05.2012	24.20993	82.80648
21	W21	Hand pump in front of govt. school at Kirwani village, in front of Kailash's house	01.06.2012	24.18035	83.06649
22	W22	Hand pump at Obra, Malviya Nagar	01.06.2012	24.4495	82.96837
23	W23	Hand pump at bus stand Renukut near Ramlila Maidan	02.06.2012	24.21838	82.96796

Note:

- For Heavy metal analysis water samples were preserved by acidifying with Nitric Acid to pH<2
- All samples were stored at 6^0C, and out of direct sunlight, from the time of collection till analysis.

Table 1B: Details of Soil Samples Collected from Singrauli

S. No.	Sample Code	Location	Date of Collection	Latitude in degree	Longitude in degree
1	S01	Soil from Anpara Village, beside Anpara Power Plant	28.05.2012	24.16428	82.79109
2	S02	Chilika Daad near Coal Depot	28.05.2012	24.12458	82.69596
3	S03	Sector 10 at Obra	29.05.2012	24.44509	82.98997
4	S04	Soil near Rihand dam and Dongiya Nallah (Renukut – Pipri)	29.05.2012	24.1985	83.0601
5	S05	Soil in front of Rambhajan's house at Kusmaha village	30.05.2012	24.16461	83.09622
6	S06	Soil in front of Kailash's house at Khairahi village	01.06.2012	24.18002	83.06664
7	S07	Soil from near Ramlila Maidan at Renukut	02.06.2012	24.4495	83.03751

Note:

- All samples were collected in transparent polythene bags labeled and sealed
- All samples were stored at 6^0C, and out of direct sunlight, from the time of collection till analysis.

Table 1C: Details of Cereal Samples Collected from Singrauli

S. No.	Sample Code	Location	Date of Collection	Latitude in degree	Longitude in degree
1	Rice	Rice from Lal Bahadur's House at Chilika Daad	31.05.2012	24.121	82.70272
2	Mixed Pulses	Mixed Pulses from Shushil's house at Obra Village	01.06.2012	24.18391	83.06563
3	Wheat 1	Wheat from Soni's house at Khairahi Village	01.06.2012	24.18391	83.06563
4	Wheat 2	Wheat from Shanti Devi's house at Khairahi Village	01.06.2012	24.16957	83.07621
5	Paddy	Paddy from Soni's house at Khairahi Village	01.06.2012	24.18384	82.06564

Note:

- All samples were collected in transparent polythene bags labeled and sealed
- All samples were stored at 6^0C, and out of direct sunlight, from the time of collection till analysis.

Table 2A: Results of Physico-chemical parameters and Heavy Metals in Water Samples from Singrauli

S No	Sample Code	Sample Location	TDS ppm	Ca ppm	Mg ppm	Total Hardness ppm	Cl ppm	F ppm	Pb ppm	Cd ppm	Total Cr ppm	As ppm	Hg ppm
Drinking water		**IS: 10500:2004 – Desirable Limit**	**500**	**75**	**30**	**300**	**250**	**1.0**	**0.01**	**0.003**	**0.05***	**0.01**	**0.001**
		IS: 10500:2004 – Permissible Limit	**2000**	**200**	**100**	**600**	**1000**	**1.5**	**0.01**	**0.003**	**0.05***	**0.05**	**0.001**
1	W01	Hand Pump at Dibulganj	**807**	**184**	17.08	**530**	100	0.6	ND	ND	ND	ND	**0.026**
2	W02	Well water from Kalika Singh's House, Anpara	**624**	**220**	ND	**410**	70	0.2	BDL	ND	ND	BDL	**0.008**
3	W03	Water supplied by Renusagar Power Project (NTPC) to Garbandha Village	125	60	2.44	160	20	ND	ND	ND	ND	ND	ND
4	W04	Well Water, Garbandha Village	**852**	**224**	ND	**500**	30	0.5	BDL	ND	ND	ND	ND
5	W06	Hand pump in Prahlad's House at Chilika Daad	**683**	**220**	ND	**540**	80	0.1	BDL	ND	ND	ND	**0.003**
6	W07	Hand Pump at Chilika Daad Near Kashmir Valley School	**754**	**208**	19.52	**600**	130	ND	BDL	ND	ND	ND	BDL
7	W08	Water supplied by NTPC to Chilika Daad	111	**80**	4.88	220	10	ND	ND	ND	ND	ND	ND
8	W14	Water from tap supplied by UPID, near gate of VIP colony, Renukut	64	6.4	3.90	56	10	0.3	ND	ND	ND	ND	ND
9	W15	Hand pump in front of Rambhajan's house at Kusmaha village – Filtered water	389	**80**	29.28	**320**	50	**1.8**	ND	ND	ND	ND	ND
10	W16	Hand pump in front of Rambhajan's house at Kusmaha village – Unfiltered water	335	48	**43.92**	300	20	**2.1**	BDL	ND	ND	ND	ND
11	W19	Hand Pump at Chilika Daad	**501**	**136**	**51.24**	**550**	60	0.3	ND	ND	ND	**0.002**	ND
12	W20	Hand Pump at Dibulganj in front of former Pradhan's house	**1150**	**200**	**36.60**	**650**	70	**0.9**	BDL	ND	ND	ND	ND
13	W21	Hand pump in front of Govt. school at Kirwani village, in front of Kailash's house	299	**100**	12.20	200	20	0.4	BDL	ND	ND	ND	ND

14	W22	Hand pump at Obra, Malviya Nagar	127	**80**	7.32	200	30	0.4	ND	ND	ND	ND	ND
15	W23	Hand pump at bus stand Renukut near Ramlila Maidan	**1130**	**224**	21.96	**650**	100	**0.9**	ND	ND	ND	ND	ND
Surface water													
16	W10	Water from Renuka River at Obra	92	60	26.84	230	8	0.1	BDL	ND	ND	**0.008**	ND
17	W13	Rihand Dam where Dongiya Nallah meets to Rihand Dam (Renukut – Pipri)	633	**188**	7.32	**500**	30	0.2	ND	ND	ND	BDL	**0.010**
18	W17	Obra dam where Murdhawa Nallah (Ganda nala/Thad Pathar) meets	536	76	2.44	200	30	**1.8**	BDL	ND	ND	**0.019**	ND
Effluents		**Prescribed Limit in EPA Act (1986)**	**---**	**---**	**---**	**---**	**---**	**2.0**	**0.10**	**2.0**	**2.0**	**0.20**	**0.01**
19	W05	Water from Ash Pond of Shakti Nagar NTPC	89	60	9.76	170	10	ND	BDL	ND	ND	0.020	ND
20	W09	Water from Ballia Nallah	103	76	17.08	220	10	0.1	BDL	ND	ND	ND	ND
21	W11	Jharia Nallah at Obra near Shushil’s House	325	120	ND	250	10	0.2	0.047	BDL	ND	BDL	ND
22	W12	Dongiya Nallah at Renukut (Pipri) Effluent of Aaditya Birla Chemicals (India) Ltd (ABCL)	**4370**	**562**	**41.48**	**1550**	**1530**	**4.5**	BDL	ND	ND	BDL	**0.127**
23	W18	Murdhawa Nallah (Ganda nala/Thad Pathar)	1200	64	4.88	180	100	**1.9**	BDL	ND	ND	**0.170**	ND

*The limit is for Hexavallent Chromium

Table 2B: Results of Heavy Metals in Soil Samples from Singrauli

S No	Sample Code	Sample Location	Pb ppm	Cd ppm	Total Cr ppm	As ppm	Hg ppm
1	S 01	Soil from Anpara Village, beside Anpara Power Plant	10.94	ND	31.36	1.58	1.64
2	S 02	Chilika Daad near Coal Depot	25.89	ND	39.87	1.76	1.75
3	S 03	Sector 10 at Obra	BDL	BDL	23.07	2.66	0.42
4	S 04	Soil near Rihand dam and Dongiya Nallah (Renukut – Pipri)	35.12	BDL	24.02	6.36	10.09
5	S 05	Soil in front of Rambhajan's house at Kusmaha village	13.11	BDL	11.50	0.67	0.57
6	S 06	Soil in front of Kailash's house at Khairahi village	29.52	ND	38.81	7.67	0.50
7	S 07	Soil from near Ramlila Maidan at Renukut	10.40	BDL	41.57	0.52	0.50

Notes:
- ND: Not detected
- BDL: Below detection limit

Table 2C: Results of Heavy Metals in Cereal Samples from Singrauli

S No	Sample Code	Sample Location	Pb ppm	Cd ppm	Total Cr ppm	As ppm	Hg ppm
1	Rice	Rice from Lal Bahadur's House at Chilika Daad	ND	ND	ND	0.173	ND
2	Mixed Pulses	Mixed Pulses from Shushil's house at Obra Village	ND	ND	ND	0.041	ND
3	Wheat 1	Wheat from Soni's house at Khairahi Village	BDL	ND	ND	ND	BDL
4	Wheat 2	Wheat from Shanti Devi's house at Khairahi Village	BDL	ND	ND	ND	ND
5	Paddy	Paddy from Soni's house at Khairahi Village	ND	ND	1.601	0.120	ND

Notes:
- ND: Not detected
- BDL: Below detection limit

Table 2D: Results of Methyl Mercury in Fish Samples from Singrauli

Sample Code	Sample Location	Methyl Mercury (Calculated as the element) ppm
Standard – PFA[1]		0.25
Fish 1 (Rohu or *Labeo rohita*)	Shaktinagar, Near Baliya Nallah (NTPC effluent discharge)	0.505
Fish 2 (Malli or *Wallago attu*)	Belva Dah, Rihand Reservoir (near Anpara ash pond)	ND
Fish 3 (Rohu or *Labeo rohita*)	Near Dhungiya Nallah, Rihand Reservoir (Kannoria Chemicals effluent discharge)	0.447

1. Food Safety and Standards (Contaminants, toxins and residues) Regulations, 2011 set a limit of methyl mercury (calculated as element) as 0.25 ppm.

Table 2E: Results of Mercury in Human Blood, Hair and Nail Samples from Singrauli

S. No.	Name	Age	Gender	Symptoms	Blood (ppb)	Hair (ppm)	Nail (ppm)
1	Saraju Nisa, Chilika Daad	45	Female	Abdominal pain, joint pain, white lesions (skin discoloration), burning extremities, electrifying feeling throughout body.	78.68	ND	ND
2	Ram Bularo Prajapati, Chilika Daad	47	Male	Joint pain, scaly skins. Uses Tobacco and Pan	45.26	ND	ND
3	Jeera Lal, Chilika Daad	26	Male	Kidney problems, stomach ache	29.46	ND	1.44
4	Manmati, Chilika Daad	45	Female	Skin discoloration, joint pain	ND	ND	0.90
5	Manmati Devi, Chilika Daad	41	Female	Joint pain, burning extremities	ND	ND	0.18
6	Lata Devi, Chilika Daad	26	Female	Starting case of skin discoloration	ND	1.57	7.02
7	Sugari Devi, Chilika Daad	45	Female	Pink discoloration. Her husband an NTPC employee has tingling problem	15.48	ND	0.16
8	Himanshu, Chilika Daad	08	Male	Diabetes from the age of 1.5 years	38.67	30.65	ND
9	Abrania, Dibulganj	50	Female	Abdominal burning, tingling, muscular spasm, joint pain	17.83	31.32	No Sample
10	Sushil, Dibulganj	23	Male	Speaking difficulty, stammering	26.23	15.26	ND
11	Vimla, Dibulganj	33	Female	Swelling in legs, blurred vision, pain in legs	61.47	10.71	2.09
12	Hirvatiya, Dibulganj	43	Female	Hip pain, skin discoloration, joint pain, because of stone in her abdomen she has been operated twice	32.91	ND	ND

13	Priyanka Bharati, Dibulganj	16	Female	Burning sensation, on reading she sheds tears, abdominal pain	23.62	26.50	ND
14	Soni, Kirwani	10	Female	Body pain, numbness in left side of body. Eats fish	10.31	10.92	ND
15	Kailash, Khairahi	38	Male	Burning extremities, electrifying feeling, joint pain, and muscular spasm. Eats fish 2-3 days in a week, takes alcohol/pan occasionally	113.48	3.84	ND
16	Shanti Devi, Khairahi	42	Female	Muscular spasm, blurred vision, joint pain from last 4 years, burning extremities. Eats fish 2-3 times in a month	76.26	1.58	3.04
17	Manik Chand, Obra	63	Male	Burning sensation in foot, swelling in legs, tingling, and blurred vision	29.92	1.17	0.08
18	Mahato Kharwar, Obra	48	Male	Right leg has become short in length from last 6-7 years, knee pain, trembling in hands, muscular spasm, burning extremities in foot.	29.64	ND	ND
19	Kunti Devi, Malviya Nagar, Obra	46	Female	Joint pain, blurred vision, swelled knees, not able to walk properly because of pain. Fisherman family eats fish 2-3 days in a week.	22.58	6.85	ND
Average Concentration					**34.30**	**7.39**	**0.83**

Annexure 1: Village Wise Distribution of Mercury in Human Blood, Hair and Nail in Singrauli

Village		Blood	Hair	Nail
Chilika Daad	Number of Persons	8	8	8
	Minimum concentration of Hg found	0 ppb	0 ppm	0 ppm
	Maximum concentration of Hg found	78.68 ppb	30.65 ppm	7.02 ppm
	Percentage of the persons detected with mercury	62.5%	25%	62.5%
	Standard Deviation	27.92	10.77	2.40
Dibulganj	Number of Persons	5	5	4
	Minimum concentration of Hg found	17.83 ppb	0 ppm	0 ppm
	Maximum concentration of Hg found	61.47 ppb	31.32 ppm	2.09 ppm
	Percentage of the persons detected with mercury	100%	80%	25%
	Standard Deviation	17.12	12.52	1.04
Khairahi - Kirwani	Number of Persons	3	3	3
	Minimum concentration of Hg found	10.31 ppb	1.58 ppm	0 ppm
	Maximum concentration of Hg found	113.48 ppb	10.92 ppm	3.04 ppm
	Percentage of the persons detected with mercury	100%	100%	33.3%
	Standard Deviation	52.25	4.87	1.76
Obra	Number of Persons	3	3	3
	Minimum concentration of Hg found	22.58 ppb	0 ppm	0 ppm
	Maximum concentration of Hg found	29.92 ppb	6.85 ppm	0.08 ppm
	Percentage of the persons detected with mercury	100%	66.7%	33.3%
	Standard Deviation	4.16	3.66	0.05

Annexure 2: Concentration of Mercury in Human Blood, Hair and Nail in Singrauli on Gender basis

S. No	Female	Blood (ppb)	Hair (ppm)	Nail (ppm)	Male	Blood (ppb)	Hair (ppm)	Nail (ppm)
1	Saraju Nisa (CD)	78.68	ND	ND	Ram Bularo Prajapati (CD)	45.26	ND	ND
2	Manmati (CD)	ND	ND	0.90	Jeera Lal (CD)	29.46	ND	1.44
3	Manmati Devi (CD)	ND	ND	0.18	Himanshu (CD)	38.67	30.65	ND
4	Lata Devi (CD)	ND	1.57	7.02	Shushil (DG)	26.23	15.26	ND
5	Sugari Devi (CD)	15.48	ND	0.16	Kailash (Khairahi)	113.48	3.84	ND
6	Abrania (DG)	17.83	31.32	---	Manik Chand (Obra)	29.92	1.17	0.08
7	Vimla (DG)	61.47	10.71	2.09	Mahato Kharwar (Obra)	29.64	ND	ND
8	Hirvatiya (DG)	32.91	ND	ND				
9	Priyanka Bharti (DG)	23.62	26.50	ND				
10	Soni (Kirwani)	10.31	10.92	ND				
11	Shanti Devi (Khairahi)	76.26	1.58	3.04				
12	Kunti Devi (Obra)	22.58	6.85	ND				
Number of Persons Tested		**12**	**12**	**11**		**7**	**7**	**7**
Percentage of persons detected with mercury		**75%**	**58.3%**	**54.5%**		**100%**	**57.1%**	**28.6%**
Average Concentration of mercury		**28.26**	**7.45**	**1.22**		**44.66**	**7.27**	**0.22**
Minimum concentration of mercury found		**0**	**0**	**0**		**26.23**	**0**	**0**
Maximum concentration of mercury found		**78.68**	**31.32**	**7.02**		**113.48**	**30.65**	**1.44**

CD – Chilika Daad

DG – Dibulganj