**Road Map to Solution of Water Pollution Problems in India: Metal and Pesticide Contamination**

## Background

The presence of pesticides and heavy metal contamination pose a major threat to water resources. This has serious implications to human health and the environment. Many studies in India have shown that there are high levels of pesticide and metal contamination in the water resources across India. However, there are currently no solutions to appropriately address this problem. Therefore, there is an urgent need to develop a plan to appropriately handle metal and pesticide contamination in water. A workshop, sponsored by the American Chemical Society (ACS), hosted by Global Innovation Imperatives (Gii), and organized by Sut Ahuja, Program Chair, with the help of The Energy and Resources Institute (TERI), Gautam Buddha University and the Green Chemistry Network Centre, DU, was held on January 15-18, 2014 in Delhi, India to foster creative solutions of global significance, particularly on water contamination issues.

## Definition of the problem

Clean water is one of the most basic and vital element of life because we need to drink it to maintain our health and to grow food to nourish our bodies. Despite water's clear importance, there is mismanagement of this resource, which has led to millions of deaths and has severely constrained the development potential of many countries. Today, at least 783 million people lack access to clean water and 2.5 billion people do not have access to adequate sanitation (UN-Water, 2012 & 2015).

Up to 90% of wastewater in developing countries[1] flows untreated into lakes, rivers and productive coastal zones, thereby endangering health, access to clean water and natural ecosystems (Corcoran et al, 2010). With increasing population and growing global agricultural water consumption, the load on an already-burdened resource is ever increasing. Pesticide and metal contamination of water resources is a serious problem, primarily because of industrialization and heavy use of chemicals in agricultural practices. Specifically, human activities like mining,

[1] Developing countries are defined according to their Gross National Income (GNI) per capita per year. Countries with a GNI of US$ 11,905 and less are defined as developing (specified by the World Bank, 2012).

waste discharge from industries and agriculture have produced large quantities of waste products that contain metals, causes water contamination. Consuming these metals, even in extremely low quantities, poses a severe threat to human health.

Organic contaminants such as pesticides also contaminate water resources either by leaching through the soil or as runoff from agricultural and urban landscapes. Some pesticides like DDT are still in use in India, even though the government is committed to banning its use (Deccan Herald, 2015). According to the World Health Organization, an estimated 3 million cases of pesticide poisoning are reported every year worldwide, resulting in over 250,000 deaths (World Health Organization, 2015). Furthermore, both metals and pesticides can accumulate in food and pose long-term risks to human health. Decontaminating water containing pesticides or metals requires energy and resources. Current efforts to develop a systematic and sustainable approach to prevent and manage pesticide and metal contamination in water are inadequate. This workshop was designed to develop a road map to solutions of water pollution problems from metals and pesticides.

**Key Highlights of the Workshop**

- Status of metals and pesticides contamination in India was discussed in detail.
- Distinguished participants deliberated on the issues related to cleaning water contaminated by metal and pesticides.
- Resource recovery procedures were outlined for controlling contamination of water resources.
- Specific technology was discussed for chromium contamination.
- Participants discussed and created a future road map for solving water contamination in India, the outcomes of which are included in this white paper.


Key
Zones
1 North India
2 West India
3 South India
4 Central India
5 East India
6 North-East India
TAJIKISTAN
AFGHANISTAN
PAKISTAN
CHINA
NEPAL
BHUTAN
BANGLADESH
BURMA
SRI LANKA
Jammu & Kashmir
Himachal Pradesh
Punjab
Chandigarh
UttaraKhand
Haryana
Delhi
Rajasthan
Uttar Pradesh
Bihar
Sikkim
Arunachal Pradesh
Asom
Nagaland
Meghalaya
Manipur
Tripura
Mizoram
Gujarat
Madhya Pradesh
Chhattisgarh
Jharkhand
West Bengal
Odisha
Diu
Daman
Dadra & Nagar Haveli
Maharashtra
Telangana
Puducherry (Yanam)
Goa
Karnataka
Andhra Pradesh
Puducherry (Mahe)
Puducherry (Puducherry)
Puducherry (Karaikal)
Tamilnadu
Kerala
Lakshadweep (India)
Andaman & Nicobar Islands (India)
Arabian Sea
Bay of Bengal
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Andaman Sea
INDIAN OCEAN
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**Map 1: This map depicts six geographical zones of India, namely North, West, South, Central, East and Northeast zones[2].**

In order to provide a comprehensive view about the current status of metal and pesticide contamination, the papers present pertinent information spread across six geographical zones in India (see map).:

**North Zone**

Current Status of Metal Contamination of Water: A hydrochemical study (Gupta et al, 2014) conducted to evaluate the extent of heavy metal pollution in the Gomti River, which extends through Uttar Pradesh, and associated ecological risks revealed that mean metal concentrations (mg/l) in river water were 0.024 for Cd, 0.063 for Cr, 0.022 for Cr, 0.029 for Mn, 0.044 for Ni, 0.018 for Pb and 0.067 for Zn. Even though these levels remain below the maximum limit set by the Central Pollution Control Board of India (2 mg/l for Cd, 2 mg/l for Cr, 3 mg/l for Cu, 2 mg/l for Mn, 3 mg/l for Ni, 0.1mg/l for Pb and 5mg/l for Zn) for inland surface water, the results showed elevated concentrations of these metals in sediments and locally abundant mollusks (*Viviparus bengalensis*). In river sediments, the concentrations (mg/kg dry wt) were 5.0 for Cd, 16.2 for Cr, 23.2 for Cr, 203.2 for Mn, 23.9 for Ni, 46.2 for Pb and 76.3 for Zn, while in *V. bengalensis* mean metal concentrations (mg/kg, dry wt) were 0.57 for Cd, 12.0 for Cr, 30.7 for Cu, 29.9 for Mn, 8.8 for Ni, 3.6 for Pb and 48.3 for Zn. The results indicated elevated concentrations of Cu, Zn and Mn in *V. bengalensis* as compared to other nonessential elements. In certain cases, industrial units were linked to the presence of heavy metals in soils (a nonpoint source of metal contamination in water). For example, soils in the vicinity of a paper industry site in the Nahan Area of Himachal Pradesh had 10 times the permissible limit of cadmium set by the World Health Organization (0.005 ppm) (Sharma et al, 2014).

[2] The workshop's brainstorming session included discussion on these six zones, as mentioned in the report presented during the Second International Workshop on Sustainability and Water Quality: Remediation of Pesticides and Metal Contamination, titled "Status of Metal and Pesticide Contamination in Water (India)" (Singh et al, 2014).

METAL CONTAMINATION IN RIVER YAMUNA IN THE NORTH ZONE

Metal contamination requires urgent intervention in the case of the Yamuna River. In a study conducted by Kaushik and colleagues, samples were collected from 14 different sites and assessment was done by metal enrichment factor of the sediments. The study concluded that the Yamuna River was particularly polluted with nickel (Ni) and cadmium (Cd). The study also showed that Cd contamination was of recent origin compared to nickel which had uniform enrichment throughout the river., Cd showed more heterogeneous deposition with certain sites having very high levels. Chromium (Cr) pollution in the Yamuna River was found to be temperate, with the exception of certain sites that were downstream of dyeing and paint industries. The anthropogenic contamination of the Yamuna by iron (Fe) was found to be insignificant. In another study conducted by Singh et al 2014, the largest concentration of Pb in river water was found to be 392 µg/L downstream of the river near Allahabad in Uttar Pradesh, indicating a high value of the hazard index.

(Source: Kaushik et al, 2009 & Singh et al, 2014)

Current Status of Pesticide Contamination of Water: In a study conducted in Punjab (with a sample size of 1904 women in reproductive age group and 1762 children below 12 years of age from 35 villages) (Thakur et al, 2010), spontaneous abortion (20.6 per 1000 live births) and premature births (6.7 per 1000 live births) were found to be significantly higher in areas affected by heavy metal and pesticide pollution ($p<0.05$). Heptachlor, chlorpyriphos, β-endosulfan, dimethoate and aldrin were found to be higher than permissible limits in 23.9%, 21.7%, 19.6%, 6.5% and 6.5% groundwater samples, respectively. A pesticide analysis of tap water in Millennium City Gurgaon, Haryana, India revealed detection of the following pesticides: chlorobenzilate, hexachloro-benzene, benzenether, pp-DDT, op-DDT, pp-DDE, pp-DDD, α-HCH, β-HCH, lindane, vinclozolin, conumaphos, malathion, phosalone, cyfluthrin, cypermethrin, deltamethrin, permethrin, fenvalerate, fluvalinate, cyhalothrin, carbofurn, propoxeur, carbaryl, cymiazol, amitraz, bromprophylate, chinomethionate (Nishtha, Lokhande, and Dhar, 2012). A study undertaken by Sankararamakrishnan, Kumar Sharma, and Sanghi in 2005 in Kanpur, northern India, showed the presence of high concentrations of both organochlorine and organophosphorous pesticides in the surface and groundwater samples. High concentrations of γ-HCH (hexachlorohexane) (0.259 µg/l) and malathion (2.618 µg/l) were detected in the surface water samples collected from the Ganges River in Kanpur. Moreover, in the groundwater samples collected from various hand pumps located in agricultural and industrial areas, dieldrin was also detected. The maximum concentration values of γ-HCH, malathion, and dieldrin were 0.900, 29.835 and 16.227 µg/l, respectively.

**East Zone**

Current Status of Metal Contamination of Water: Geochemical speciation and risk assessment conducted in various sites of Mahanadi Basin (in Orissa) revealed high environmental risk of Cd, Ni, Co and Pb because of their higher availability in exchangeable fraction (Sundaray, Nayak, Lin, & Bhatta, 2011). Sundaray and coworkers stated that the toxic metals like Ni, Pb and Cd are of concern, which occasionally may be associated with adverse biological effects based on the comparison with sediment quality guidelines. In an assessment of the occurrence of various heavy metals in surface water of the Ganga river around Kolkata, Fe, Pb, and Mn were found to exceed their limits for use as source water for drinking purposes (0.3, 0.1, and 0.5 mg $L^{-1}$, respectively) in 20%, 6%, and 6% of the samples analyzed (in comparison to the limits as prescribed by the Bureau of Indian Standards) (Wasim Aktar, Paramasivam, Ganguly, Purkait, & Sengupta, 2010).

DRDO ARSENIC REMOVAL TECHNOLOGY FROM WEST BENGAL, INDIA

The ever-rising incidence of arsenic poisoning of ground water has posed a major challenge to maintaining the quality of drinking water for large masses of population in West-Bengal, India. The DRDO arsenic removal technology (DART), which was patented in India as well as internationally, has provided an implementable and sustainable solution to this wide-spread scourge (Process for producing potable water: India Patent No. 221708, Filtering Device For the Removal of Arsenic from water: UK – PatentNo.UK12065148, Filtering Device For the Removal of Arsenic from water: Vietnam patent No. WO2007026370 A1, Patent application No. 0308,484 pending with the USA). The attractiveness of the DRDO technology results from the low cost of implementation and is available commercially. A few thousand house-hold filters have been installed in many villages in several States in the country, by a Non-Government Organization (viz., Save The Environment, Kolkata) to whom technology was transferred by the DRDO.

DART has generated considerable positive social spin offs, and has been in field operations successfully since September 2003 in several villages in the country. Moreover, the technology has also since demonstrated successful community-level scaling up (on a limited scale) in pilot studies conducted since 2008; and there are no technological limitations or impediments in further scaling up of this technology to an even larger scale of operations, if desired or needed.

Source: Department of Science and Technology, 2015

Current Status of Pesticide Contamination of Water: Singh and colleagues in 2011 reported the presence of both organochlorine and organophosphorous pesticides in the water of River Ganga at Bhagalpur. The water samples had high concentrations of Methyl parathion, Endosulfan and DDT. The study also surveyed the current use-practice by the farmers and observed that toxic pesticides like endosulfan were still in use in high quantities. In a unique study of pesticide residue level in tea ecosystems of Hill and Dooars regions of West Bengal, India (Bishnu, Chakrabarti, Chakraborty, & Saha, 2009); residues of organophosphorus (e.g. ethion and chlorpyrifos), organochlorine (e.g. heptachlor, dicofol, α-endosulfan, β-endosulfan, endosulfan sulfate) and synthetic pyrethroid (e.g. cypermethrin and deltamethrin) pesticides were found in manufactured tea, fresh tea leaves, soils and water bodies. This highlights the fact that residues of banned items like heptachlor and chlorpyrifos in manufactured tea may pose health hazards to its consumers.

## West Zone

Current Status of Metal Contamination of Water: In 2013 Kumar and coworkers reported a high degree of contamination in water and sediments of river Sabarmati and Kharicut canal at Ahmedabad, Gujarat. Some sites have chromium levels higher than the Central Pollution Control Board (CPCB) standard of 0.05 mg/l. Another study reported cadmium concentrations in groundwater to be as high as 7.35 and 11.80 µg/L in two sampling areas in the Gulf of Khambhat (GoK), an inlet of the Arabian Sea in the state of Gujarat, India (Upadhyaya et al. 2013). Moreover, trace element levels in groundwater of the GoK region were found to be higher in comparison with some of European and Asian sites. A groundwater analysis in the Thane Region of Maharashtra, India shows that most of the groundwater sampling stations are heavily contaminated with heavy metals (As, Cd, Hg, and Ni) (Bhagure & Mirgane, 2011).

Current Status of Pesticide Contamination of Water: A gas chromatographic analysis of organochlorine pesticides in Lake Anasagar of Ajmer, Rajasthan, India (Charan, Sharma, & Sharma, 2010) revealed the presence of heptachlor, β-HCH, γ-HCH, aldrin, DDT and endosulfan (with averages ranging from 0.0224 ppm, 0.1035 ppm, 0.0478 ppm, 0.0041 ppm, 0.1381 ppm and 0.5051 ppm, respectively). Among these agrochemicals, the level of endosulfan, DDT and γ-HCH were found to be significantly high in the lake.

## Northeast Zone

Current Status of Metal Contamination of Water: The problem of arsenic contamination is at its worst in the Bengal delta plain, which is formed by the Ganga–Padma–Meghna–Brahmaputra river basin (also known as the worst arsenic-affected alluvial basin). Chetia and colleagues in 2011 stated that in respect to the permissible limit formulated by the World Health Organization (WHO: As 0.01 ppm, Fe 1.0 ppm, and Mn 0.3 ppm for potable water), their study showed that out of the 222 groundwater samples from six blocks of Golaghat district (Assam), 67%, 76.4%, and 28.5% were found contaminated with higher metal contents (for total As, Fe, and Mn, respectively). A similar study conducted on groundwater in the Brahmaputra flood plain of the Barpeta district, Assam, India, revealed that the concentration of iron exceeds the WHO-recommended levels of 0.3 mg/L in about 80% of the samples, manganese values exceed 0.4 mg/L in about 22.5% of the samples, and lead values also exceed the limit in 22.5% of the samples (Haloi & Sarma, 2012). Moreover, cadmium is reported in only four sampling locations and three of them exceed the WHO permissible limit (0.003 mg/L).

Current Status of Pesticide Contamination of Water: In the northeast region of India (Assam), a study demonstrated that the mean levels of total DDT and HCH were 743 µg/L and 627 µg/L, respectively for district Nagaon, while 417 µg /L and 348 µg L/1 were found for district Dibrugarh in 331 human blood samples (Mishra, Sharma, and Kumar, 2011). The data set clearly reflected a 'trickle-down effect' of using pesticides and corroborates with the existing data that OCPs,[must define on first use] mainly DDT and HCH, are still being used for vector control and agriculture in northeast India. Another study in the same region reported that the mean HCH concentrations in surface water samples were 4403 ng/L and 4911 ng/L, and groundwater samples were 5168 ng/L and 5574 ng/L in samples from Dibrugarh and Nagaon districts, respectively (Mishra and Sharma, 2011). Furthermore, total DDT levels were 5402 ng/L and 6121 ng/L in surface water and 6549 ng/L and 6904 ng/L in groundwater from Dibrugarh and Nagaon, respectively. DDT levels in groundwater were found to be the highest among the levels reported so far. The dominant OCPs were found to be β-HCH among HCHs and p,p′-DDT among DDTs.

**Central Zone**

Current Status of Metal Contamination of Water: In a study conducted in Madhya Pradesh (Shrivastava and Jain, 2012), the Narmada River showed a significant degree of heavy metal contamination linked with seasonal variations during the year. An assessment of groundwater quality in and around Jagdalpur, Bastar district, Chattisgarh, India showed that the samples analyzed had higher Fe levels than the tolerance value (WHO: Fe .03mg/l) and varies from 0.04 to 6.22 mg/l (mean: 1.354 mg/l) (Behera, Das, and Rana, 2012).

Current Status of Pesticide Contamination of Water: Despite its ban in India, endosulfan was found in samples collected in Gwalior district of Madhya Pradesh, thereby indicating that it is still being applied to control different types of pests in agriculture and is being used extensively by farmers. The mean concentration of β endosulfan in different sites in the district was 3.42±4.86, 1.87±3.36, 1.89±3.14, and 0.64±1.21 ng/L during winter, summer, pre-monsoon, and post-monsoon, respectively (Rao and Wani, 2015). Moreover, the different classes of pesticides detected in Tighra wetlands during one year of investigation were HCB, BHC, aldrin, endosulfan, DDT, DDE, endrin, chloropyrifos, methyl parathion, diazion, and dichlorovos. The spatial distribution showed that pesticide concentration is highest where human influence is the maximum. Unfortunately, most of the pesticides banned in India are still being used in Gwalior, and these pesticides have found their way to the Tighra Reservoir, which is a source of drinking water for the majority of the population in Gwalior.

**South Zone**

Current Status of Metal Contamination of Water: A study by Jayaprakash et al, 2012, on the sediments of Buckingham Canal reveals that molybdenum, mercury, tin, copper, and zinc levels are quite high in Buckingham Canal sediments, suggesting that the rapid urban and industrial development of Chennai Metropolitan City has negatively influenced the surrounding aquatic ecosystem. Similarly, in another study conducted in Sivakasi, Virudhunagar, and Aruppukkottai area (Tamil Nadu), the concentration of lead and manganese were found to be above the maximum permissible standards for drinking water, prescribed by WHO and BIS (Muthulakshmi, Ramu, and Kannan, 2012). In a bioaccumulation study (Laxmi Priya et al, 2011) in sediments and water, and in tissue parts of *Mugil cephalus* and *Crassostrea madrasensis* in two locations of Pulicat Lake and the southeast coast of India, it was observed that the geoaccumulation index for Pulicat Lake sediments indicate that the sediments are extremely contaminated with Cd and moderately contaminated with Cu and Ni. Additionally, Zn, Cu and Pb have elevated concentrations in various parts of fish and oysters when compared with other metals.

Current Status of Pesticide Contamination of Water: In order to explore the anthropogenic nexus on organochlorine pesticide pollution in Tamiraparani River basin, South India, Kumarasamy and coworkersl (2012) investigated a total of 96 surface water and sediment samples at 12 sampling stations. The additive concentrations in surface water and sediments were in the range of 0.1 to 79.9 ng/l and 0.12 to 3,938.7 ng/g dry weight (dw), respectively. Moreover, the levels of dichlorodiphenyltrichloroethanes (DDTs), aldrin, dieldrin, *cis*-chlordane, transchlordane, and mirex were found to be dominant in the sediments. Organochlorine pesticide residues were reported in a study conducted in Karnataka, India (Dhananjayan and Muralidharan, 2010) to be 77.9 µg/kg in *Anguilla bicolor bicolour* (an inland wetlands fish). Although the aforementioned quantity is well below the tolerance limits recommended for fish, it reflects the persistence of pesticides in water bodies that leads to bioaccumulation.

In another study by David Wilson and coworkers (2013), OCPs in soil sediments from Godavari were investigated in two significantly polluted locations of Godavari, namely Kotipalli and Dangeru area. The concentrations of various pesticides in sediments ranged from 8.36 to 17.62 ng/g for heptacholorepoxide, 1.36 to 86.94 ng/g for trans-chlordane, 0.92 to 32.16 ng/g for cis-chlordane, 1.01 to 13.96 ng/g for PP-DDE, 1.18 to 38.80 ng/g for endosulfan, 2.22 to 68.20 ng/g for Endosulfan sulfate, 15.84 to 563.82 ng/g for DDT, and 5.61 to 47.25 ng/g for endrin-ketone. This study showed that Kotapalli and Dangeru area of Godavari river are significantly contaminated with DDT, trans-Chlordane and endosulfan sulfate. Recently Patil and coworkers (2015) published a review on distribution profile, status and trends of organochlorine pesticide (OCPs) contamination in Kaveri (Cauvery) river, which is one of the largest rivers in southern India that serving water for agriculture, domestic and industrial purposes for centuries. Presence of OCPs such as hexachlorocyclohexane, (HCH), dichloro-diphenyltrichloroethane (DDT), endosulfan, aldrin, dieldrin, heptachlor epoxide was reported in this river. Kaveri River water was found to contain HCHs, DDTs and endosulfan residues up to 2,300 ng/L, 3,600 ng/L and 15,400 ng/L, respectively, while in sediment, HCHs and DDTs were reported with the maximum concentration of 158 ng/g dw and 9.15 ng/g dw, respectively. Fish and shrimp samples collected from the river were also found to contain levels of HCHs (228 ng/g) and DDTs (2,805 ng/g). The levels of OCPs in the Kaveri River water and sediment exceed safety guidelines of Canada and European Union, which may pose a threat to aquatic organisms. Based on this information, further monitoring studies are warranted to understand the contamination status, its impacts on biota to help design mitigation measures for protection of Kaveri River and its ecosystem.

PESTICIDE

CONTAMINATION: A CASE STUDY FROM KARNATAKA

Widespread use of pesticides has resulted in a detectable presence in water bodies. In this study, water samples from the lakes of Bijapur, Karnataka, were analyzed, using a gas liquid chromatographic column. A total of 7 samples were taken from the lakes and showed that the water from the lakes contained significantly high quantities of chloropyrifos, 4-bromo-2-chlorophenol, and endosulphan. Endosulphan was detected in the range of 0.00025 to 0.005mg/L, while a concentration of 4-bromo-2-chlorophenol was found to be in the range of 0.01 to 0.009mg/L. The concentration of chlorpyriphos ethyl was above the WHO limit with 0.0002 to 0.004mg/L, whereas captan was recorded to have a concentration below the limit of WHO. On the other hand, fipronil at .004mg/L was detected in only one sample, and none of the samples showed monochrotophos (Pujeri et al, 2010). Furthermore, oxyfluorfen concentration was recorded as 0.0025 mg/L, which is below the permissible limit. (Source: Pujeri, Pujar, Hiremath, and Yadawe, 2010)

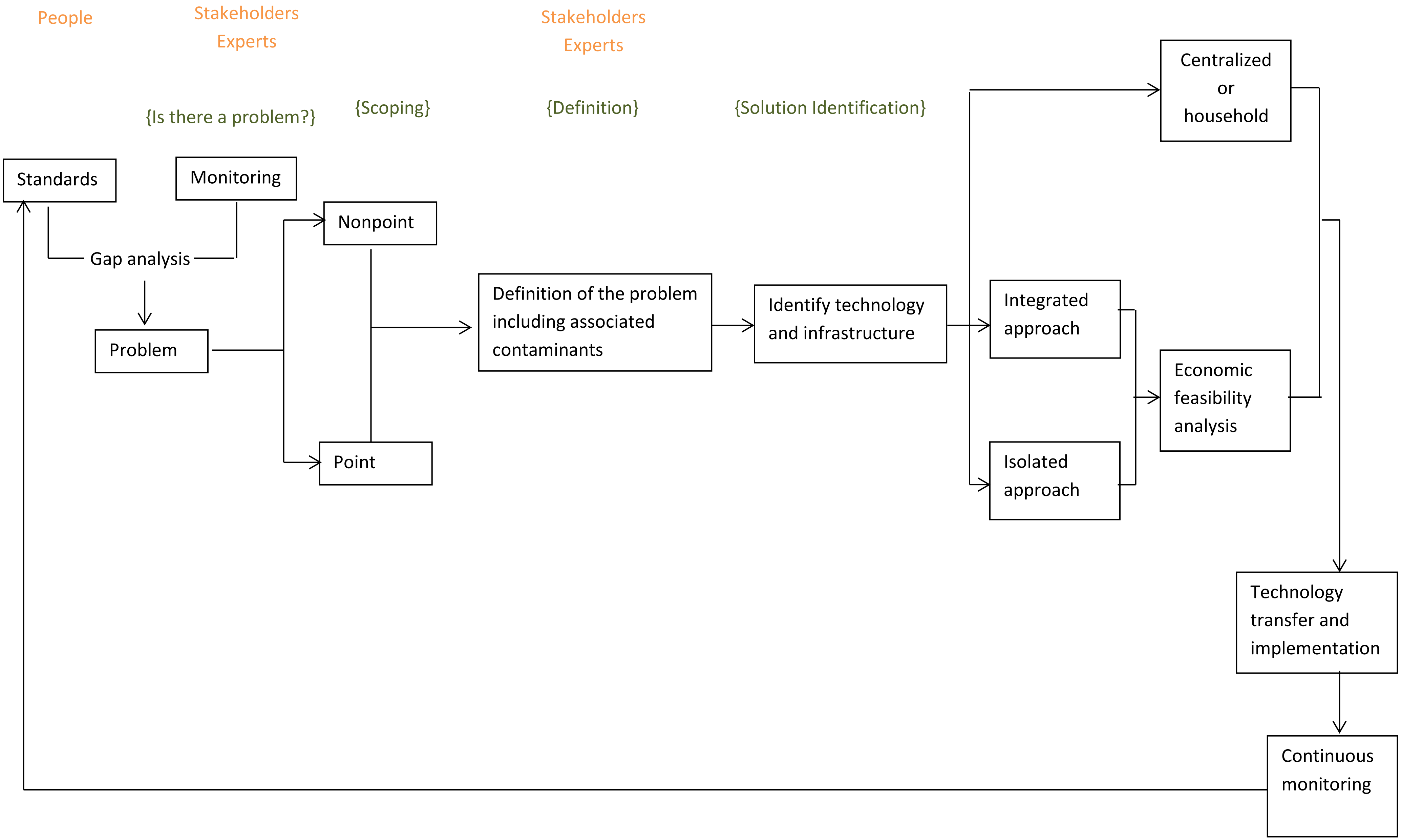


Figure A: Conceptual framework for addressing water contamination issues pertaining to metal and pesticide contamination.

## Recommended Approach

As a recommended approach, the white paper presents a conceptual framework to tackle issues related to contamination of water resources. The framework is further explained with a specific example of its adaptation in case of chromium contamination.

The systematic approach to design any pertinent remediation method is diagrammatically depicted in Figure A. The figure outlines the thought process that allows easy implementations by defining various actions, along with the sequence.

## People/Stakeholders/Experts

The text in orange color represents the community that is either affecting the process or is being affected by the process. “People” are the section of society who are affected by the water contamination issue and “Stakeholders/Experts” are those who are responsible for taking the remediation steps.

## Defining Standards

Looking towards the methodology, the first and foremost step to assure contaminant-free water must be defining the standards pertaining to specific contaminants such as metals, pesticides, and organic content. The standards may or may not vary locally but should be in accordance to the standards prescribed by the Central Pollution Control Board, the government of India or any other organizations such as WHO, EPA, etc. The state pollution control boards, in different zones, should enact strict guidelines specifying the tolerable limits for various contaminants. These guidelines may differ from state to state depending on the existing contamination in that particular state. After the guidelines are set, a continuous monitoring system is required to track these data. After this step, a gap can be identified, showing the difference in the permissible quantity of the contaminant and actual quantity found in the contaminated water.

## Point/Nonpoint

The problem thus identified has to be further qualitatively defined as point or nonpoint problem. A nonpoint problem is defined as one where the source of the contaminant is not one single point but widespread (for instance, when agrochemicals seep down into the soil and mix with groundwater). On the contrary, a point contamination (or point problem) is defined as one where contaminants leach out of a particular area (a single point), thereby making that area contaminated. A classic example of this is contamination caused by the tannery industry, which is a source of point contamination.

**Gap Analysis**

The gap analysis and point/ nonpoint examination should lead to definition of the problem. It is also suggested by the panel of the committee to define the problem by specifying the associated contaminants. Consequently, based on the problem defined, a solution should be provided. The solution can be either technological or infrastructural.

**Integrated/Isolated Approach**

The solution proposed can have an integrated approach or isolated approach. As the name suggests an integrated approach would incorporate multiple technologies/remediation methods. On the other hand, an isolated approach would use only single technique or methods for de-contaminating water. The selection of the approach would depend on the severity and type of the contaminants in conjunction with the feasibility of the contaminant being removed using a single technology.

**Centralized/Household Implementation**

Furthermore, the implementation of the solution can be categorized as “Centralized” or “Household”-based. Centralized solutions can be policies framed by the government to curb pollution, or decontamination work of a particular site by the government (example: Ganga Action Plan (GAP) launched in 1986 to reduce the contamination levels in the river). Household solutions can involve usage of various types of filters to remove contaminants from the polluted water.

**Economic Feasibility**

Any technology or solution is rendered useless if it does not suit the economics of the user. The affordability of the solution proposed in the entire process is of prime importance to the “people” who will utilize the suggested intervention. It is for this very reason an economic feasibility study becomes vital. Hence, economic feasibility should be a prerequisite in selecting a concept to be pursued further to develop into a technology or a solution. However, it is worth mentioning that a continuous check is of principal significance to complete and maintain this virtuous cycle of problem identification and the proposal of decontamination solutions.

**Framework adaptation to technology intervention: Tannery industries and Cr pollution**

As a working example of the aforementioned conceptual framework, the remediation measures for curtailing chromium contamination from tannery waste is illustrated in the Figure B.

One of the major problems associated with the tannery industry is presence of chromium ranging between 2000- 5000 mg/l in the aqueous effluent. The primary stakeholders involved in monitoring these are the Tannery Industry, NGOs working in the area and the scientific community involved in assessment of the impact of heavy metal contamination issues. The local communities, including people living around the tanneries, are those who are immediately affected by contamination. Currently, 1,848,100 people are at risk because of tannery operations. Moreover, the source of contamination is a point source. Considering the fact that nearly 2000- 3000 tons of chromium escapes into the environment annually, the experts involved in establishing remediation measures must also define the problems of associated contaminants (like zinc, lead, copper and nickel) in order to achieve a holistic technology based solution.

To resolve the problem, a solution based on the bio-extraction of chromium utilizing efficient fungal strains was utilized. Furthermore, an inexpensive nutrient source for the growth of the fungi was identified. Cultivation of plants on tannery sludge in presence of mycorrhiza in conjunction with the application of fermentation technology coupled with 'Metal impregnated resin' led to the successful extraction of chromium. One of the key issues in adaptation of this isolated intervention-based technology (isolated in reference to a single point source of contamination and a single technology intervention) is its economic feasibility that may provide impetus towards additional revenue generation from the process. Once the technology is successfully implemented, its continuous monitoring will assist in bridging the gap between the existing acceptable standards of chromium in water and the actual concentration of chromium, present in excess as contaminant, in tannery waste.

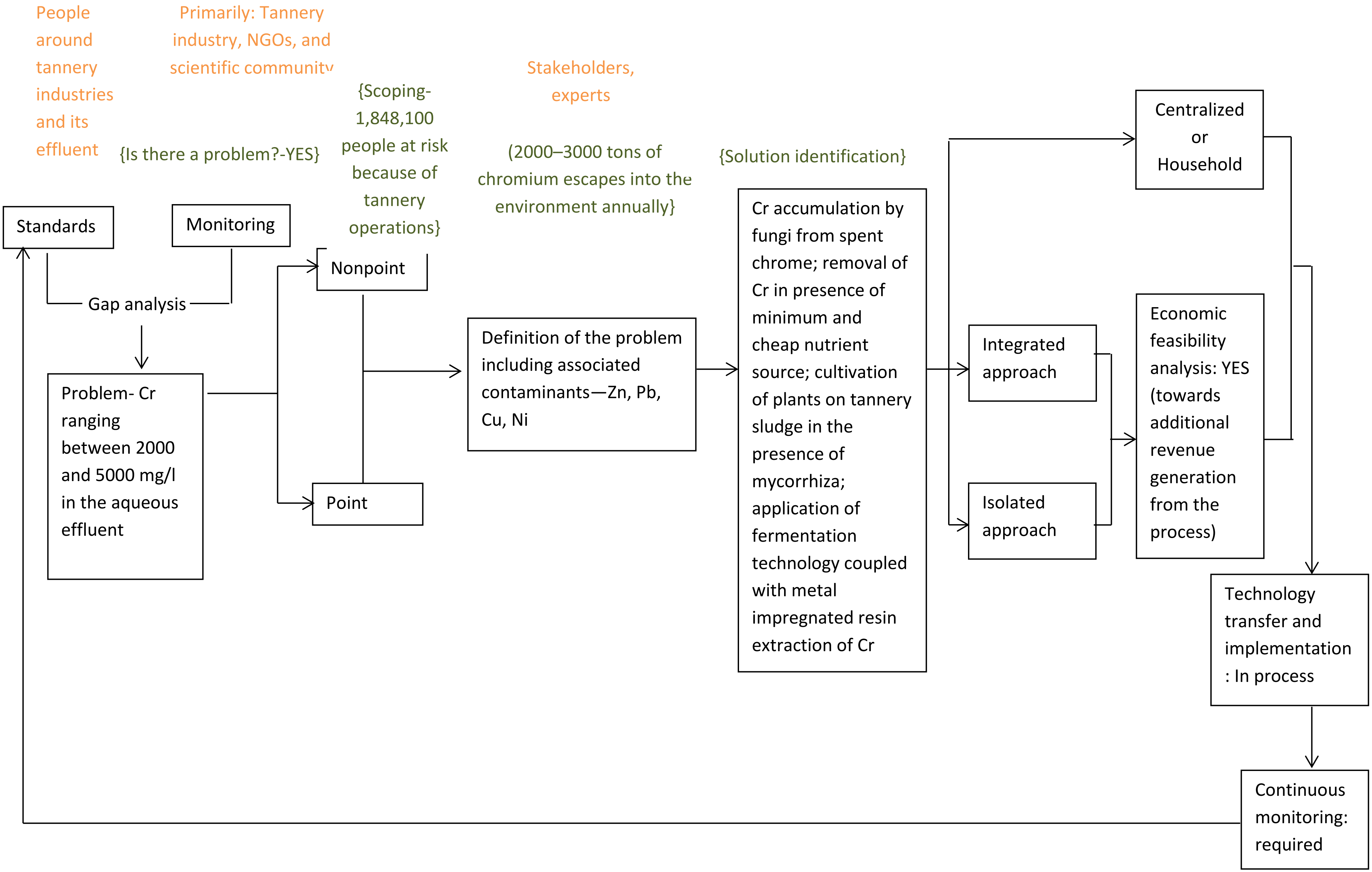


Figure B: Framework adaptation to technology intervention: Tannery industries and Cr pollution.

## Conclusions

This workshop was designed to offer sustainable and socio-economic measures for the removal of water contaminants.

The concerns voiced by the experts on the issues of water quality revealed that the implemented policies have uncertainties; therefore there is an urgent need for green framework to provide one process for refining and building consensus on it. Moreover, the fragmentation and lack of co-ordination between the research field and industries is one of the key concerns. The nature of the problem and the inevitable increasing spread of contaminants in groundwater demands coherent approach of science and engineering for the development of various wastewater technologies.

During discussions, the participants designed a conceptual framework for addressing water contamination issues pertaining to metal and pesticide contamination, keeping in view the six geographical zones of the country. The broad framework can be effectively used to develop zone-wise, region-specific interventions. The conceptual framework may be used to design any region-specific remediation method. An example of the framework adaptation was presented for tannery industries.. The development of different inexpensive resins for selective and cyclic recovery of heavy metals is underway.

The overriding message from government officials and policymakers was that a ready reference such as the conceptual framework can assist in designing effective remediation solutions.

**The following people participated in the American Chemical Society (ACS)—Global Innovation Imperatives (Gii) workshop held in January 2014 in India and contributed to the composition of this white paper:**

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**References**

Behera, B., Das, M., & Rana, G. S. (2012). Studies on ground water pollution due to iron content and water quality in and around, Jagdalpur, Bastar district, Chattisgarh, India. *Journal of Chemical and Pharmaceutical Research*, *4*(8), 3803–3807.

Bhagure, G., & Mirgane, S. R. (2011). Heavy metal concentrations in groundwaters and soils of Thane Region of Maharashtra, India. *Environmental Monitoring and Assessment*, *173*(1-4), 643–652. doi:10.1007/s10661-010-1412-9

Bishnu, A., Chakrabarti, K., Chakraborty, A., & Saha, T. (2009). Pesticide residue level in tea ecosystems of Hill and Dooars regions of West Bengal, India.

*Environmental Monitoring and Assessment*, *149*(1-4), 457–464. doi:10.1007/s10661-008-0222-9

Charan, P. D., Sharma, R., & Sharma, K. C. (2010). Gas chromatographic analysis of organochlorine pesticides in Lake Anasagar of Ajmer, Rajasthan (India). *Journal of environmental science & engineering*, *52*(1), 37.

Chetia, M., Chatterjee, S., Banerjee, S., Nath, M., Singh, L., Srivastava, R., & Sarma, H. (2011). Groundwater arsenic contamination in Brahmaputra river basin: a water quality assessment in Golaghat (Assam), India. *Environmental Monitoring and Assessment*, *173*(1-4), 371–385. doi:10.1007/s10661-010-1393-8

Corcoran, E., C. Nellemann, E. Baker, R. Bos, D. Osborn, H. Savelli. (2010). Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. *United Nations Environment Programme, UN-HABITAT, GRID-Arendal.*

Deccan Herald. (2015). India-United Nations pact to end DDT use by 2020. Retrieved from http://www.deccanherald.com/content/497314/india-united-nations-pact-end.html

Department of Science and Technology. (2015). R&D Activities related to Arsenic Contamination in Drinking Water- Salient Efforts of Department of Science and Technology (DST). Page 21. Retrieved from http://www.dst.gov.in/Arsenic_Compendium.pdf

Dhananjayan, V., & Muralidharan, S. (2010). Organochlorine Pesticide Residues in Inland Wetland Fishes of Karnataka, India and Their Implications on Human Dietary Intake. *Bulletin of Environmental Contamination and Toxicology*, *85*(6), 619–623. doi:10.1007/s00128-010-0122-x

Gupta, S. K., Mayuri C., Kumar P., Singh J., & Bux F. (2014). Evaluation of ecological risk of metal contamination in river Gomti, India: A biomonitoring approach. *Ecotoxicology and Environmental Safety,* 110, 49-55.

Haloi, N., & Sarma, H. P. (2012). Heavy metal contaminations in the groundwater of Brahmaputra flood plain: an assessment of water quality in Barpeta District, Assam (India). *Environmental Monitoring and Assessment*, *184*(10), 6229–6237. doi:10.1007/s10661-011-2415-x

Jayaprakash, M., Nagarajan, R., Velmurugan, P. M., Sathiyamoorthy, J., Krishnamurthy, R. R., & Urban, B. (2012). Assessment of trace metal contamination in a historical freshwater canal (Buckingham Canal), Chennai, India. *Environmental Monitoring and Assessment*, *184*(12), 7407–7424. doi:10.1007/s10661-011-2509-5

Kaushik, A., Kansal, A., Santosh, Meena, Kumari, S., & Kaushik, C. P. (2009). Heavy metal contamination of river Yamuna, Haryana, India: Assessment by Metal Enrichment Factor of the Sediments. *Journal of Hazardous Materials*, *164*(1), 265–270. doi:http://dx.doi.org/10.1016/j.jhazmat.2008.08.031

Kumar, R., Solanki, R., & Kumar, J. I. N. (2013). Seasonal variation in heavy metal contamination in water and sediments of river Sabarmati and Kharicut canal at Ahmedabad, Gujarat. *Environmental Monitoring and Assessment*, *185*(1), 359–368. doi:10.1007/s10661-012-2558-4

Kumarasamy, P., Govindaraj, S., Vignesh, S., Rajendran, R. B., & James, R. A. (2012). Anthropogenic nexus on organochlorine pesticide pollution: a case study with Tamiraparani river basin, South India. *Environmental Monitoring and Assessment*, *184*(6), 3861–3873. doi:10.1007/s10661-011-2229-x

Laxmi Priya, S., Senthilkumar, B., Hariharan, G., Paneer Selvam, A., Purvaja, R., & Ramesh, R. (2011). Bioaccumulation of heavy metals in mullet (Mugil cephalus) and oyster (Crassostrea madrasensis) from Pulicat lake, south east coast of India. *Toxicology and Industrial Health* , *27* (2 ), 117–126. Retrieved from http://tih.sagepub.com/content/27/2/117.abstract

Mishra, K, Sharma, R. C., & Kumar, S. (2011). Organochlorine pollutants in human blood and their relation with age, gender and habitat from North-east India. *Chemosphere*, *85*(3), 454–464. doi:http://dx.doi.org/10.1016/j.chemosphere.2011.07.074

Mishra, Kumkum, & Sharma, R. (2011). Contamination of aquatic system by chlorinated pesticides and their spatial distribution over North-East India. *Toxicology and Environmental Health Sciences*, *3*(3), 144–155. doi:10.1007/s13530-011-0092-3

Muthulakshmi, L., Ramu, A., & Kannan, N. (2012). Seasonal distribution of some heavy metal concentrations in ground water of Virudhunagar district, Tamilnadu, South India. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, *11*(2), 32–37.

Nishtha, K., Lokhande, R. S., & Dhar, J. K. (2012). Physico-Chemical, Bacteriological and Pesticide analysis of Tap Water in Millennium City Gurgoan, Haryana, India. *Res. J. Environment Sci*, *1*(2), 1–7.

Patil, N. N., Selvaraj, K. K., Krishnamoorthy, V. K., Elaiyaraja, A., Ramaswamy, B. R. (2015). Organochlorine pesticide contamination in the Kaveri (Cauvery) River, India: A review on distribution profile, status and trends. In: Water Challenges and Solutions on a Global Scale (eds S. Ahuja et al.,), ACS symposium series, American Chemical Society, 1206, 115-128.

Pujeri, U., Pujar, A., Hiremath, S., & Yadawe, M. (2010). The Status of Ppesticide Pollution inf Surface Water (Lakes) of Bijapur. *International Journal of Applied Biology and Pharmaceutical Technology*, *1*(2).

Rao, R. J., & Wani, K. A. (2015). Monitoring of organochlorine and organophosphorus pesticide residues in water during different seasons of Tighra reservoir Gwalior, Madhya Pradesh, India. *Environmental monitoring and assessment*, *187*(11), 1-14.

Sankararamakrishnan, N., Kumar Sharma, A., & Sanghi, R. (2005). Organochlorine and organophosphorous pesticide residues in ground water and surface waters of Kanpur, Uttar Pradesh, India. *Environment International*, *31*(1), 113–120. doi:http://dx.doi.org/10.1016/j.envint.2004.08.001

Sharma, M. C., Baxi, S., Sharma, K. K., Singh, M., & Patel, S. (2014). Heavy Metal Ions Levels and Related Physicochemical Parameters in Soils in The Vicinity of a Paper Industry Location in Nahan Area of Himachal Pradesh. *J Environ Anal Toxicol,* 4:236. doi: 10.4172/2161-0525.1000236

Shrivastava, B. A. V., & Jain, P. (2012). Health Hazards Associated With Heavy Metal Contamination With Reference To Narmada River At Nimar Region Of Madhya Pradesh. *International Journal of Engineering*, *1*(6).

Singh, A. K., Srivastava, S. C., Verma, P., Ansari, A., & Verma, A. (2014). Hazard assessment of metals in invasive fish species of the Yamuna River, India in relation to bioaccumulation factor and exposure concentration for human health implications. *Environmental monitoring and assessment*, *186*(6), 3823-3836.

Singh, L., Choudhary, S. K., & Singh, P. K. (2011). Organochlorine and organophosphorous pesticides residues in water of river Ganga at Bhagalpur, Bihar, India. *International Journal of Research in Chemistry and Environment*, *1*(1), 77–84.

Singh, R., Gaur, V., Adholeya, A., & Sharma, R. (2014). Status of Metal and Pesticide Contamination in Water (India). Report presented during Second International Workshop on Sustainability and Water Quality: Remediation of Pesticides and Metal Contamination. New Delhi.

Sundaray, S. K., Nayak, B. B., Lin, S., & Bhatta, D. (2011). Geochemical speciation and risk assessment of heavy metals in the river estuarine sediments—A case study: Mahanadi basin, India. *Journal of Hazardous Materials*, *186*(2–3), 1837–1846. doi:http://dx.doi.org/10.1016/j.jhazmat.2010.12.081

Thakur, J. S., Prinja, S., Singh, D., Rajwanshi, A., Prasad, R., Parwana, H. K., & Kumar, R. (2010). Adverse reproductive and child health outcomes among people living near highly toxic waste water drains in Punjab, India. *Journal of Epidemiology and Community Health* , *64* (2 ), 148–154. Retrieved from http://jech.bmj.com/content/64/2/148.abstract

UN-Water. (2012). UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water Report. Retrieved from http://www.un.org/waterforlifedecade/pdf/glaas_report_2012_eng.pdf

UN-Water. (2015) The Post 2015 Water Thematic Consultation Report. Retrieved from http://www.unwater.org/downloads/Final9Aug2013_WATER_THEMATIC_CONSULTATION_REPORT.pdf

Upadhyaya, D., Survaiya, M., Basha, S., Mandal, S., Thorat, R. B., Haldar, S., … Mody, K. (2013). Occurrence and distribution of selected heavy metals and boron in groundwater of the Gulf of Khambhat region, Gujarat, India. *Environmental Science and Pollution Research*, 1–11. doi:10.1007/s11356-013-2376-4

Wasim Aktar, M., Paramasivam, M., Ganguly, M., Purkait, S., & Sengupta, D. (2010). Assessment and occurrence of various heavy metals in surface water of Ganga river around Kolkata: a study for toxicity and ecological impact. *Environmental Monitoring and Assessment*, *160*(1-4), 207–213. doi:10.1007/s10661-008-0688-5

David Wilson, N., Nageswara Rao, I., Narasimha Reddy, K. (2013). Concentration of Organo Chlorine pesticide residues in sediments from the Godavari River of East Godavari District of Andhra Pradesh. Journal of Chemical, Biological and Physical Sciences, 3(3), 2279-92.

World Health Organization. 2015. The impact of pesticides on health. Retrieved from: http://www.who.int/mental_health/prevention/suicide/en/PesticidesHealth2.pdf [Last accessed on 2015 Oct 7].