# Long Range Atmospheric Transport and Deposition of Persistent Organic Pollutants and Mercury in the Himalaya

Mark D. Loewen[1], Subodh. Sharma[2], Gregg Tomy[3], Feiyue Wang[1], Paul Bullock[4], Frank Wania[5]

[1]*Environmental Science Program & Department of Chemistry, University of Manitoba,* *mloewen@cc.umanitoba.ca; [2]Department of Biological Science and Environmental Sciences, Kathmandu University kuhimal@ku.edu.np; [3]Freshwater Institute, Department of Fisheries and Ocean. tomyG@DFO-MPO.GC.CA; [4]Department of Soil Science, University of Manitoba. bullockp@Ms.UManitoba.CA; [5]Division of Physical Sciences, University of Toronto. frank.wania@utoronto.ca*

**Abstract**

*The long- range atmospheric transport and deposition of persistent organic pollutants (POPs) and mercury in alpine regions is reviewed with a specific focus on the Himalaya. Measurements of contamination in this region are sparse, likely due to the significant resources required to work in extreme environments, as well as difficulties working at high altitude. While levels of POPs in water at high elevation in Solo Khumbu (5000m a.s.l.) do not appear to be high enough to be of concern to human health, levels in the Kumaon District, of Uttaranchal, India (foothills of the Himalaya) tend to have much higher levels, which exceed the World Health Organization (WHO) guidelines. It is largely unknown how deposition of contaminants varies with respect to altitude and longitude in the Himalaya. Because of vast differences in precipitation amounts in the form of rain or snow due to orographic effects, proximity to oceans, and monsoonal weather patterns, as well as proximity to sources of contamination, POPs and mercury deposition rates are expected to vary not only on an altitudinal scale but also from east to west.*

## 1. Introduction

The Himalaya is a vast mountain system consisting of a series of parallel and converging ranges that covers an area of roughly $6 \cdot 10^5$ km$^2$. It stretches from the Indus River in northern Pakistan eastward across the territories of Jammu and Kashmir, down into northern India and across parts of southern Tibet and over most of Nepal (Fig. 1). Mount Everest (8848 m a.s.l), recognized globally as a geographic landmark, represents the highest peak in the Himalayan mountains and in the world.

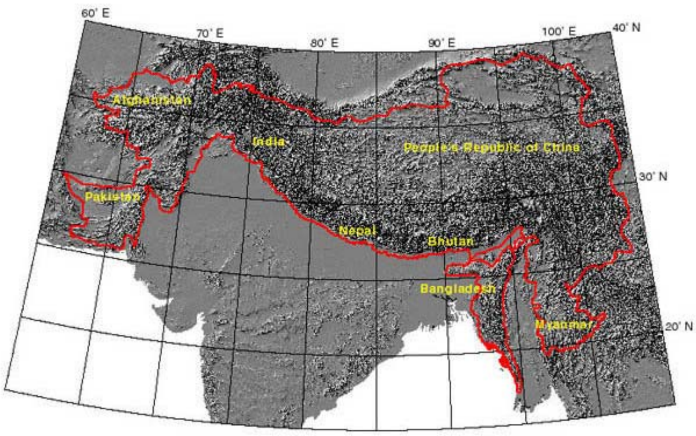


Figure 1: Himalaya, Hindu Kush Mountain Range. (Scale: 1:20 million Albers equal-area projection, USGS Digital Elevation model of the world GTOPO30)

Mountain regions have traditionally been considered pristine environments. High altitudes above 3000m in the Himalaya are largely unpopulated by people. The lack of human habitation and agricultural impact above these elevations, except during the summer seasons when high alpine pastures are used for grazing, has given rise to the thought that this mountain region is largely free of pollution. However, volatile and semi- volatile toxic contaminants such as certain pesticides and mercury do not heed the boundaries of human habitation. These contaminants are easily volatilized in regions of use, transported in the air and concentrated in colder climates. The Himalaya is considered the "third pole" (Bahadur, 1993) and is likely acting as a distillation tower or "cold finger" where airborne chemicals are deposited at a certain average temperature (related to altitude), according to their vapour pressure; the greater the vapour pressure of the contaminant (up to a maximum), the more freely it will be transported and deposited at higher elevation (colder average temperature).

This is of significant concern in the case of the Himalaya considering it is surrounded by highly populated and rapidly industrializing countries exhibiting increasing levels of pesticide usage and polluting industries. Given that melting snow and glaciers in the Himalaya supplies the water for perhaps one sixth of the world's population, it is imperative that this phenomenon be investigated further. While work on this issue has been started in some high elevation regions of Nepal (Ev-K2-CNR, Italy/Royal Nepal Academy of Science and Technology) and China (Peking University) it is critical to expand this work in this vast region and integrate it to fully understand the nature of these environmental processes. This manuscript outlines the current understanding of contaminant deposition in alpine regions and highlights the gaps in knowledge especially in the Himalayan region.

## 2. Mountains as Regional Contaminant Convergence Zones

### *2.1 Persistent Organic Pollutants*

Evidence is emerging that mountain regions have higher-than-expected concentrations and deposition rates of selected persistent organic pollutants (POPs) (Wania, 1999). Earliest indications for this phenomenon came from a global survey of contaminants in vegetation, which reported the highest levels of hexachlorobenzene (HCB) in low latitudes in sites at high elevation (Calamari et al., 1991). Global studies of POPs in mountain ranges indicate that this is a ubiquitous phenomenon and that mountain regions may function as regional convergence zones including the Himalaya (Dua et al. 1999, Galassi et al.1997, Sarkar et al. 2003).

The accumulation of POPs in high mountains suggests that a cold condensation effect, similar to that occurring on a global scale, may be operating on an altitudinal scale as well as on the latitudinal scale. The effect, which refers to the process of POPs being volatilized from warmer source regions, transported through the atmosphere, and condensing in colder regions, is well known on the latitudinal scale (Wania, 1999), resulting in long-range transport of POPs to polar regions. Indeed, the chemical transfer efficiency from valley to mountain may be higher than that from tropical to Polar regions, simply because of the closer spatial proximity of mountain regions to source regions.

An additional factor is the high rate of precipitation in many mountain regions, often in the form of snow, which may provide a very powerful pump for removing contaminants from the atmosphere to the surface (Blais et al., 1998). Orographic effects often result in precipitation rates in high altitudes that are many times higher than in neighbouring lowlands. Snow is believed to be a very efficient scavenger of both particles and non-polar organic compounds, capable of effectively cleansing the atmosphere.

### *2.2 Mercury*

Like POPs, elemental mercury is semi-volatile (the vapor pressure is 0.167 Pa at 25 ºC) and likely exhibits similar patterns of transport in the atmosphere to alpine regions. Atmospheric mercury is very stable and has a mean global troposphere residence time of about 6 to 8 months (Schroeder et al., 1998). Therefore elemental mercury distribution on the planet is governed by regional as well as global air movement patterns. Studies conducted in the Canadian Arctic have reported high levels of mercury in various aquatic species (AMAP, 2000). Vertical distribution of elemental mercury in the atmosphere above Canada indicates a uniform concentration of between 1.5 and 1.7ngm$^{-3}$ up to an altitude of 7km (Banic et al, 2003). This indicates that mercury has the capacity to move into mountain environments up to very high altitudes. Schuster et al. (2002) also described the temporal trends of deposition of total mercury in glaciers of the continental U.S., which indicated that regional trends in mercury deposition have dramatically increased in the U.S. since the 1950's until its peak in the 90s, coinciding with accelerated growth in industrialization and subsequent environmental regulation.

While snow deposited Hg(II) can be photoreduced to Hg(0) and reemitted back into the atmosphere, it is largely unknown how precipitation leads to terrestrial and aquatic deposition of the various species of mercury in mountains. Methylmercury, the biologically active and toxic form of mercury can be formed biotically and, to a lesser degree abiotically. Of particular concern is the atmospheric deposition of mercury in aquatic ecosystems and its subsequent biotic methylation by certain bacteria (e.g., sulphate reducing bacteria) in typically nutrient and sulphate rich waters.

This convergence effect of POPs and mercury in mountain regions raises serious and timely concerns, among which are its impact on:

- the local ecosystem, in particular high altitude lakes (Blais et al., 2001a, Schindler, 1999),
- human populations relying on animals grazing at high altitude and consuming fish from high altitude waters, and,
- water supplies derived from snow (Schindler, 1999).

## 3. Chemical Contamination in the Himalaya

The Himalaya is the world's highest mountain range. The area is in very close proximity to lowland with extremely high population density and associated large pollution sources. The average annual temperature difference between the Indo Gangetic plain and the top of Mt. Everest is likely the steepest temperature gradient over distance in the world. Mountains and lowlands are linked by distinct weather patterns, showing a strong seasonal variability.

### *3.1 Sources for POPs contamination in the Himalaya*

The Himalaya are wedged in between India and China, the two most populous countries in the world. High population density often results in high usage of pesticides and high emissions of air pollutants. The Indian subcontinent and China have experienced heavy use of organochlorine pesticides, such as hexachlorocyclohexanes (HCHs) and DDT, for agricultural and public health purposes. These and other POPs might impact the Himalayan mountain ecosystems adversely. It has been estimated that since its initial formulation, more than $10^8$ kg of DDT has been used in India (Santillo et al. 1997). India banned DDT for agricultural purposes in 1989, but continues to use between 5000 to 10,000 kg per year for malaria control (Santillo et al. 1997). Technical HCH, once the most heavily used pesticide in India with annual consumption exceeding $6\times10^7$ kg, was banned in 1997, but lindane (γ-HCH) has been used as a replacement since that time (Santillo et al. 1997). Pesticide use in China is more difficult to assess, but from the 1970s until its ban in 1983, China was the largest producer and user of technical HCH (Li et al. 1998). The total amount produced during that time is estimated to be $10^9$ kg (Li et al. 1998).

Villagers that inhabit the Himalaya and surrounding areas generally rely on snowmelt and glacier fed rivers and streams for potable water. During the melting months, semi-volatile POPs 'trapped' in glaciers and snow are expected to be released into surface waters. In subalpine lakes in the Canadian Rockies, melting glaciers have already been shown to be a major source of semi-volatile POPs (Blais et al., 2001). Animals grazing on high altitude pastures in the Himalaya are likely exposed to POPs. As the milk and body from these animals are used as important food sources for people living at high altitude, these contaminants may be affecting people living at high altitude.

### *3.2 Sources for mercury contamination in the Himalaya*

Levels of emission in the form of aqueous and atmospheric mercury on the Indian subcontinent and China are alarming. A report from India (Srivastava, 2003) recently outlined the sources of mercury and its levels in the environment. Elevated levels of elemental mercury in the vicinity of chlor-alkali industry may be contributing to long-range transport to the Himalaya. Caustic soda production in these plants requires the use of mercury cell technology where it is used as a cathode in this electrolytic process. While there are other technologies to produce caustic soda, the mercury cell process remains the most common type in India. Annual Indian production of 500 million kilograms of caustic soda leads to the average mercury release of 142mg $kg^{-1}$ of caustic soda production for a total of 79,000kg of mercury per year. The average global best figure for mercury emission from chlor-alkali plants is 0.2 to 2.5mg $kg^{-1}$ of caustic soda production. Other industries contributing to atmospheric mercury emissions are steel industries, plastics industry, medical instrument production, electrical appliances, precious metal mining as well as coal burning ($7.5\text{X}10^{10}$kg of coal) which contributes to elemental gaseous mercury emissions, ionic mercury, and organomercury compounds associated with particulates.

The total annual amount of atmospheric mercury emission from coal fire plants during the mid 1990s has been estimated to be $2.14X10^5$kg in China alone and an additional 89,000kg is associated with ash and cinder production (Global Mercury Assessment Working Group, 2002). Of the mercury in fly ash and cinder, 28% is known to be in the form of organic mercury, which is known to bioaccumulate. While oligotrophic lakes in the Himalaya may not be capable of producing methymercury, particulate deposition of organomercury compounds may occur at high altitudes in certain regions of the Himalaya. From 1978-1995 coal consumption in China had been increasing at a rate of approximately 5% per annum. Atmospheric concentrations of elemental mercury in the Asian plume have been measured at 7ng $m^{-3}$. Other contributing factors of mercury industrial usage, atmospheric transport, deposition and impact of these factors on the Himalayan region is presently unknown.

**4. References**


Arctic Monitoring and Assessment Programme (AMAP). 2000. AMAP Trends and Effects Programme, Section B, Trend Monitoring Programme, Table B2. Arctic Monitoring and Assessment Programme, Olso Norway.

Bahadur J.. 1993. *Snow and Glacier Hydrology,* Young G.J. (ed.), IAHS 218, 181-190.

Banic CM, Beauchamp ST, Tordon RJ, Schroeder WH, Steffen A, Anlauf KA. Wong HKT, 2003. Vertical Distribution of Gaseous Elemental Mercury in Canada. *J. Geophys. Res.* 108, ACH 61-613.

Blais JM, Schindler DW, Muir DCG, Kimpe LE, Donald DB, Rosenberg B., 1998. Accumulation of persistent organochlorine compounds in mountains of western Canada. *Nature* 395, 585-588.

Blais JM, Schindler DW, Sharp M, Braekevelt E, Lafreniere M, McDonald K, Muir DCG, Strachan WMJ, 2001. Fluxes of semivolatile organochlorine compounds in Bow Lake, a high-altitude, glacier-fed, subalpine lake in the Canadian Rocky Mountains. *Limnology and Oceanography* 46, 2019-2031.

Dua VK, Kumari R, Johri RK, Ojha VP, Shukla RP, Sharma VP., 1998. Organochlorine Pesticide Residues in Water from Five Lakes of Nainital (U.P.), India. *Bull. Environ. Contam. Toxicol.* 60, 209-215.

Galassi S, Valsecchi S, Tartari, GA., 1997. The distribution of PCBs and chlorinated pesticides in two connected Himalayan Lakes. *Water, Air and Soil Pollution* 99, 717-725.

Global Mercury Assessment Group. Meeting 9-13 September, 2002.

Li YF, Cai DJ, Singh A., 1998. Technical hexachlorocyclohexane use trends in China and their impact on the environment. *Arch. Environ. Contam. Toxicol.* 35, 688-697.

Santillo D, Johnston P, Stringer R., 1997. A catalogue of gross contaminantion. Organochlorine production and exposure in India. *Pesticide News* 36*,* 4-6.

Sarkar UK, Basheer VS, Singh AK, Srivastava SM., 2003. Organochlorine pesticide residues in water and fish samples: First report from rivers and streams of Kumaon Himalaya Region, India. *Bull. Environ. Contam. Toxicol.* 70, 485-493.

Schindler, DW., 1999. From acid rain to toxic snow. *Ambio* 28, 350-355.

Schuster PF, Krabbenhoft DP, Naftz DL, Cecil LD, Olson ML, Dewild JF, Susong DD, Green JR, and Abbott ML., 2002. Atmospheric mercury deposition during the last 270 years: A glacial ice core record of natural and anthropogenic sources. *Environ. Sci. Technol.* 36,2303-2310.

Schroeder, W.H., K. G. Anlauf, L. A. Barrie, J. Y. Lu, A. Steffen, D. R. Schneeberger, T. Berg., 1998. *Nature* 394, 331-332.

Srivastav,a RC., 2003. Guidance and Awareness Raising Materials under new UNEP Mercury Programs (Indian Scenario), UN chemicals.

Wani, F., 1999. On the origin of elevated levels of persistent chemicals in the environment. *Environ. Sci. Pollut. Res.* 6, 11-19.