

## ARSENIC CONTAMINATED GROUNDWATER IN CHINA AND ITS TREATMENT OPTIONS, A REVIEW

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**Abstract.** A high concentration of arsenic in groundwater is a worldwide problem, high concentration of arsenic in groundwater has been documented as a major health issue around the globe. According to WHO standard, the maximum contamination level for total arsenic in water is 10 µg/L. China is one of the most affected country facing health issues because of arsenic contamination in groundwater that is often greater than established limits for human health. Although arsenic is present in several geographical regions in mainland China, Northern China has been identified as high-risk area. It has been estimated that 19.6 million people are at risk of being exposed to arsenic contaminated groundwater — especially rural areas, as those communities use groundwater for drinking water and household chores. To overcome the aforementioned problem, it is important to know the actual concentration level of arsenic in China and introduce a strategy to remove arsenic contamination. This paper provides a comprehensive overview on arsenic contamination status, sources and exposure pathways in China. It also aims to review the arsenic removal technologies which are easily available. Furthermore, it can be a useful resource for researchers as well as policy makers to identify and investigate useful treatment options.

**Keywords:** *water pollution, arsenic poisoning, human health, water treatment, remedy, China*

### Introduction

The term water pollution usually refers to the introduction of physical, chemical, or biological materials in a body of water which affects its usage in the future. Water pollution has different types of contaminants, from which arsenic is a more poisonous and harmful one. Arsenic is the 12th most common element in nature and it usually appears in three allotropic forms including black, yellow and gray. If heated, it rapidly oxidizes to arsenic trioxide (As<sub>2</sub>O<sub>3</sub>) and has a garlic odor (Fendorf et al., 2010a). Arsenic is also known as the “King of Poisons”. It is classified as carcinogen, mutagens and teratogen. Generally, in groundwater, natural occurrences of high arsenic levels were reported in aquifers — especially unconsolidated sediment aquifers throughout the world and have been connected to several adverse health effects. Arsenic content in water can harm the immune system, kidney, lungs and liver. In addition to this, it causes bladder cancers. Due to these major health risks, World Health Organization (WHO, 2004) has established a standard value (10 µg/L) which states that the maximum arsenic contaminant level in water for drinking water should not exceed 10 µg/L. Arsenic originates from different sources particularly geological surroundings such as a polluted environment, polluted bodies containing manganese oxides, irons, and arsenic-rich

minerals. There are extensive scientific research-based investigations in high arsenic level in groundwater all over the world (Sanjrani et al., 2017).

Arsenic contamination has been found in more than 70 countries but, the countries which are at the top of list for arsenic poisoning in groundwater are: India, Cambodia, Vietnam, Chile, Argentina, America and China. In other parts of the world, high concentration of arsenic has also been found in the bodies of water, including parts of the USA, Chile, Mexico, Argentina, Hungary, Japan, Canada, Poland, Ghana, Bangladesh, India, China, Afghanistan, Pakistan, Myanmar, Taiwan, are also reported to have arsenic contaminated water (WHO, 1999; Nickson et al., 2000; Niedzielski et al., 2001; Smedley and Kinniburgh, 2002; Guo and Wang, 2005; Marchiset-Ferlay et al., 2012; Ahmad et al., 2013; Horner and Beauchemin, 2013; Oguri et al., 2014; Quratul-Ain et al., 2017; Sanjrani et al., 2018; Zheng, 2018). In 2004, World health organization (WHO, 2004) issued a list of countries with arsenic issues in water. The list is shown in *Table 1*.

**Table 1.** List of countries affected by arsenic contamination

<b>Americas</b>	United States of America, Alaska, Chile, Peru, Dominica, Honduras, Nicaragua, Argentina, El Salvador, Mexico
<b>Africa</b>	South Africa, Ghana, Zimbabwe
<b>Asia</b>	India, Bangladesh, Japan, China, Cambodia, Iran, Pakistan, Myanmar, Vietnam, Nepal, Thailand
<b>Europe</b>	United Kingdom, Austria, Finland, Romania, France, Greece, Italy, Hungary, Russia, Croatia, Serbia, Germany
<b>Pacific</b>	New Zealand, Australia

Among the countries that produce arsenic, China is the top producer of white-arsenic who produces almost 50% world-share, followed by other countries such as Peru, Chile and Morocco. Studies have identified some areas of high-risk for arsenic contamination belong to northern areas of China, including the Xinjiang province, the Shanxi province, the Inner-Mongolia province, the Henan province, the Shandong province and the Jiangsu province. All of the provinces contain naturally occurring arsenic with a concentration exceeding 10 µg/L (Nickson et al., 1998; Smith et al., 2000; Sun et al., 2003; Li, 2005; Xie et al., 2008; He and Charlet, 2013). In recent decades, it estimated that more than 19.6 million people are likely to be at risk of waterborne diseases. Moreover their lives are in danger due to arsenic contamination in groundwater (Rodríguez-Lado et al., 2013). There is collaboration between Switzerland and China, a special team is conducting research on ground-breaking studies, using geological maps and geological data to pin-point areas more likely to be put at high-risk due to the poison (SWI, 2012). The conducted study shows the increasing health-threat in China, including those areas which were not previously at risk. Each year, approximately 19.0 million Chinese people get sick because of polluted water from either industrial or agricultural activities, which cause approximately 60,000 premature deaths (Sun et al., 2011; IWR, 2011). There is a particular health threat in northern China because communities who belong to this area mostly depend on groundwater for their lives. China is a big country with more than 10 million drinking wells which are difficult to screen. It is expected that recent advanced research will help policy makers and authorities in China manage their well-screening programs as contaminated wells need to be treated. (Chan and Griffiths, 2010; WHO, 2011; CR, 2013). The situation needs be

quickly placed under control and there is an urgent need to arrange drinking water free of arsenic to communities who belongs to rural areas. In this regard, many different approaches may be applied for different bodies of water. Treatment options are available for arsenic contaminated water. These treatment options include pond water, surface water and harvesting rainwater. There are also other treatment possibilities such as to create a safe environment while also providing low-cost and small level fitted systems for removal of arsenic from groundwater for removal of arsenic from groundwater. In rural areas, it may not be feasible to install such a system for many families; however with the government supports rainwater harvesting could be possible option to acquire safe water for more households (Cheng et al., 2004; Sarkar et al., 2010).

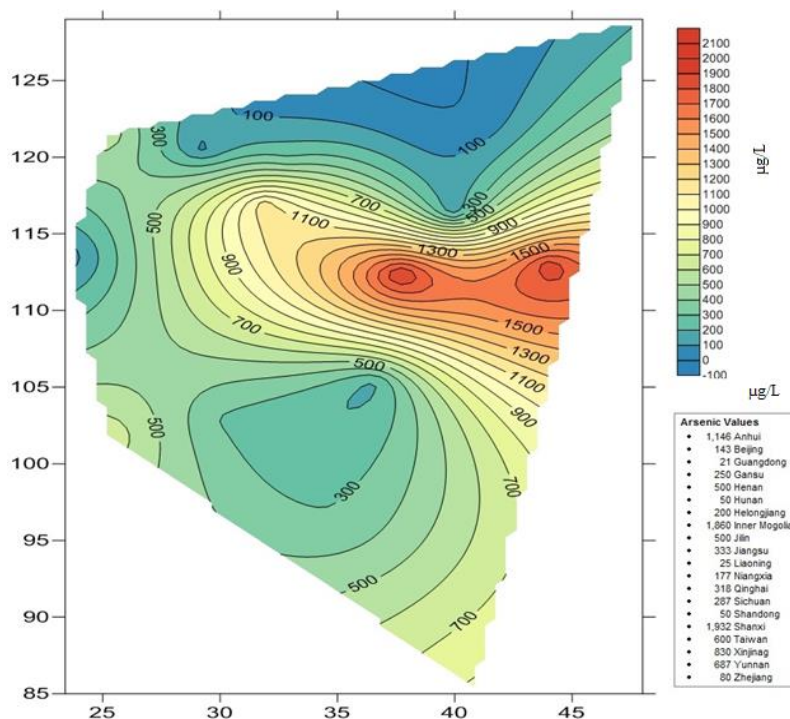
Around the world, arsenic is being removed in many areas. With the introduction of many arsenic removal technologies, it is easy to treat the water. These technologies helps in arsenic remediation, including activated alumina, ion exchange, membrane filtration, reverse osmosis, modified coagulation-filtration, and also enhanced lime-softening. However, affected rural areas or developing areas need ideal and effective technology that should be versatile, low-cost, transferable and adoptable for both community application and household units (USEPA, 2000; Berg et al., 2006; Visoottiviseth and Ahmed, 2008).

While considering the serious issues of arsenic pollution in groundwater of several regions of China and it treatment technologies, this paper aims to review recent status of arsenic contamination in several regions of China which are highly affected exceeding WHO standard level 10 ug/L. This paper also aims to review about its sources and reasons for mobilization, exposure pathways as well as suitable technologies for arsenic removal which can be applied for treatment. This paper will prove to be a helpful and useful resource for readers and researchers or policy makers in regards to the identification and investigation for the better solutions.

### ***Contamination level of arsenic and affected areas in China***

The distribution of arsenic concentration drawn (as shown by contour lines) in groundwater of different provinces in China and is presented in *Figure 1*. Investigations have identified several basin areas around China where groundwater frequently contains >10µg/L arsenic, which exceeds the current drinking water standard established by the Chinese Environmental Protection Agency for Public Water Supply. Every province has different arsenic range; after reviewing several studies, a map has been drawn to this review paper to help one understand the situation of arsenic in every province clearly. In the map, the most affected regions with arsenic contaminated aquifers indicated by the color red. Arsenic pollution occurs in many provinces (Beijing, Guangdng, Gansu, Henan, Hunan, Heilongjiang, Inner Mongolia, Jilin, Jiangsu, Liaoning, Ningxia, Qinghai, Sichuan, Shandong, Shanxi, Taiwan, Xinjiang, Yunnan and Zhejiang) (*Table 2*). It is important to take note of the method in which arsenic contamination has been detected in water samples. Many different organizations (government and non-government groups) have employed both field-kits and in-laboratory research to identify arsenic contaminated waters. These studies have yielded accurate results. These findings are based on the data from (Tseng et al., 1968; Huang et al., 1985; Wang et al., 1993; Luo, 1993; Jin et al., 2003; Chen et al., 2003; Pang et al., 2003; Liu et al., 2003; Deng et al., 2004; Guo and Wang, 2005; Pei et al., 2005; Shen et al., 2005; Li et al., 2006; Luo et al., 2006; Yu et al., 2007; Yang et al., 2008; Guo et al., 2008; Xie et al.,

2008; Han et al., 2009; Zhu et al., 2009; Liu et al., 2009; Qin and Xu, 2010; Huang et al., 2010; Li et al., 2010; Jiang et al., 2010; Hao and Xing, 2010; Bo and Luo, 2010; He et al., 2010; Shi et al., 2010; Tang et al., 2010; Zhang et al., 2010; Han et al., 2010; Wang et al., 2010; Yang et al., 2011; Xie et al., 2011a, 2011b; Bian et al., 2012; Chen et al., 2012; Wen et al., 2013; Gao et al., 2013; Guo, 2013; Guo, 2014) previously published literatures. Most affected areas to date, rounded about 3998 individuals with arsenicosis, including children most who have been identified living in rural areas of the Shanxi province, in Northern, China (Wang et al., 2007; Sun et al., 2011).



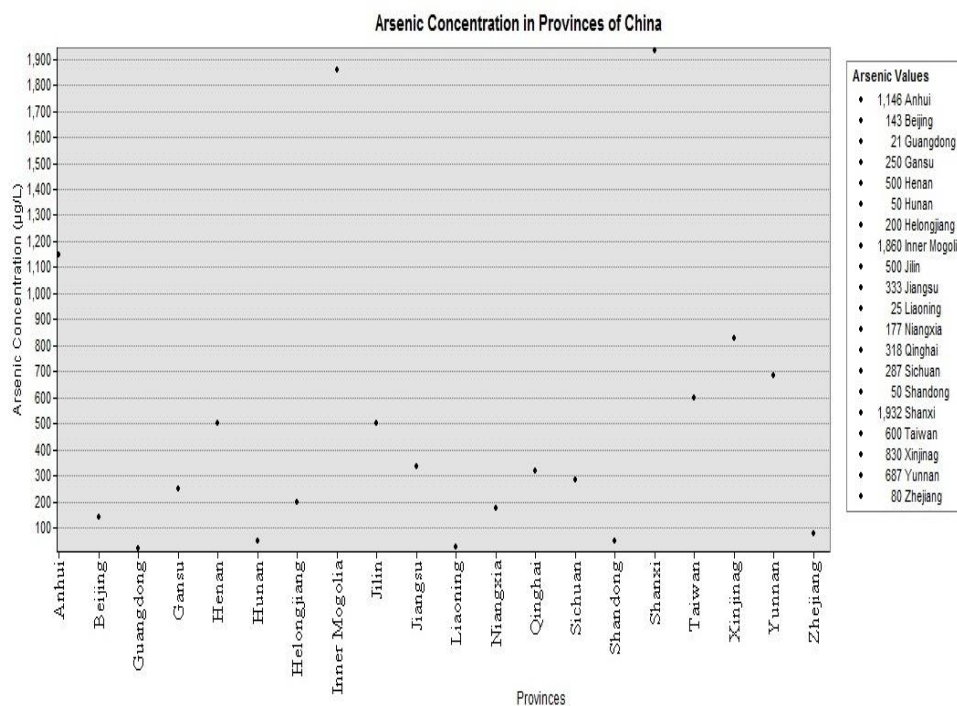
**Figure 1.** Contamination level of arsenic

The arsenic problem in China was first documented in the late 1970's and early 1980's; arsenic-specific changes were diagnosed in the Kuitun area of the Xinjiang province. Later in 1989, Inner Mongolia was reported as another serious arsenicosis area, followed by Shanxi province around 1994 (SWI, 2012, Unicef). Researchers are still interested in some areas because the arsenic value may vary every year especially in Shanxi province of China. Moreover, the Shanxi province has been recognized as a famous area with significant exposure in terms of high arsenic concentration (up to 1932  $\mu\text{g/L}$ ) level (Figure 2). According to new recent research the area of China with the highest arsenic content is Datong Basin. Its maximum arsenic content (2610.9  $\mu\text{g/L}$ ) was detected at the depth of 26.8 m (Sun, 2004; Xie et al., 2013). The Shanxi province—especially Datong Basin—has a high level of arsenic in groundwater, which many use as drinking water. Datong Basin is one of the most water-stressed regions (Xie et al., 2011c), in the world. In this water stressed region, surface water supply is usually very limited; therefore, alternative sources for portable, drinking water and house hold and irrigation water is mostly groundwater. The nexus of population growth and climate change in the region has exacerbated the use of groundwater resources with dramatic

impact both on its quality and quantity (Wang et al., 2009). The current challenge is to understand the process and also focus on how to decontaminate the widely occurring geogenic arsenic in groundwater in this region of China so the water supply meets the required WHO standards (Xie et al., 2012).

**Table 2.** Arsenic information in provinces of China

S. No	Province	Areas	Max As (µg/L)	References
1	Anhui	Fuyang,Dangshan,Wuhe, Tianchang	1146	Wen et al., 2013; Guo, 2014; Sun et al., 2011; Jin et al., 2003; Li et al., 2006; Qin and Xu, 2010; Yu et al., 2007
2	Beijing	Shunyi	143	Guo, 2014; Wen et al., 2013; Jin et al., 2003; Pang et al., 2003
3	Guangdng	Fuoshan	>21	Guo, 2014; Huang et al., 2010, 2014; Wen et al., 2013; Fan, 2014
4	Gansu	Yumen, Qin'an, Datong, Menyuan	≥250	Guo, 2014; Wen et al., 2013; Jin et al., 2003; Yu et al., 2007
5	Henan	Qixian	≥500	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Li et al., 2010
6	Hunan	Shimen	≥50	Guo, 2014; Wen et al., 2013; Yu et al., 2007
7	Heilongjiang	Lindian, Zhaoyuan, Dorbod, Anda as parts of Songnen Plain	200	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Hao and Xing, 2010
8	InnerMongolia	Dengkou, Linhe, Hangjinhouqi, Wuyuan, Wulateqianqi, Wulatehouqi, Wulatezhongqi, Tuoketuo, Tumotezuqi, Tumoteyouqi, Alashanzuoqi, as Hetao Plain; Keshenketengqi, Sunidyouqi, Sonidzuqi, Naimanqi, Ewenkizuzizhiqi, Xinbaragzuqi, Taibusqi, Horinger	1860	Guo, 2008, 2014; Wen et al., 2013; Bo and Luo, 2010; He et al., 2010; Luo et al., 2006; Luo, 1993; Yang et al., 2008
9	Jilin	Tongyu, Yaonan, Daan, Shuangliao as parts of Songnen Plain	≥500	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Bian et al., 2012; Tang et al. 2010
10	Jiangsu	Sihong, Nantong, Xuyi	333	Guo, 2014; Wen et al., 2013; Han et al., 2009; Zhang et al., 2010
11	Liaoning	Kangping	25	Guo, 2014; Wen et al., 2013; Liu et al., 2003
12	Ningxia	Pingluo, Helan, Huinun, Qingtongxia, Xixia as parts of Yinchuan Plain, Zhongwei, Zhongning	177	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Han et al., 2010
13	Qinghai	Guide, Datong, Menyuan	318	Guo, 2014; Wen et al., 2013; Jin et al., 2003; Shi et al., 2010
14	Sichuan	Jinchuan, Luding	287	Guo, 2014; Wen et al., 2013; Deng et al., 2004
15	Shandong	Dongchangfu, Yanggu, Yuncheng, Tengzhou, Jiaxiang, Guanxian, Liangshan	≥50	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Shen et al., 2005
16	Shanxi	Shanyin, Yingxian, Shuozhou as parts of Datong Basin; Fenyang, Xiaoyi, Pingyao, Wenshui, Jiexiu, Yuci, Qixian, Tianzhen, Xiaodianqu, Qingxu, Loufan, Dingrang, Yicheng, Yanhu, Yongji, Tengchong, Gengma, Eryuan	1932	Guo et al., 2005, 2013, 2014; Wen et al., 2013; Jin et al., 2003; Pei et al., 2005; Wang et al., 2010; Xie et al., 2008, 2011a, 2011b
17	Taiwan	Jiayi, Tainan	600	Guo, 2014; Wen et al., 2013; Li et al., 2006; Chen et al., 2003; Tseng et al., 1968
18	Xinjiang	Kuiteng, Wusu, Tacheng, Sulei, Bachu, Luntai, Awat, Shawan, Bohu	830	Guo, 2014; Wen et al., 2013; Yu et al., 2007; Huang et al., 1985; Wang et al., 1993; Zhu et al., 2009
19	Yunnan	Changning, Mengla	687	Guo, 2014; Yu et al., 2007; Chen et al., 2012; Liu et al., 2009; Yang et al., 2011
20	Zhejiang	Nanxun, Tongxiang	80	Guo, 2014; Jin et al., 2003; Jiang et al., 2010



**Figure 2.** Arsenic contamination level in different provinces of China

### Sources and Mobility of Arsenic

Natural occurrences of arsenic-contaminated groundwater have brought severe associated health risks. Arsenic may enter water bodies, air and land by transportation through water runoffs and wind-blown dust etc. Arsenic in the atmosphere comes from geological activities such as volcanoes, and organisms — especially microorganisms— and industrial activity in as the burning of fossil fuels as well as other activities. It has been previously accepted that the major sources of arsenic contamination in the groundwater of China are geological deposits, which is present in 200 minerals. Except geo and mining environments, other two main environmental conditions are known to be linked to natural arsenic in groundwater systems (Deng et al., 2009) (i) aerobic alkaline environments in closed basins in semiarid and in arid regions, where pH is high and leads to alkaline desorption of arsenic from mineral oxides, and (ii) aquifers are in under reducing conditions, where the release of arsenic is closely related to reductive dissolution of arsenic-bearing iron (hydro)oxides in sediments. In groundwater, there are two common types of forms of arsenic including Arsenite and Arsenate. Arsenite is always present under more reducing conditions whereas arsenate almost always present under oxidizing conditions. Several related studies in China have indicated the arsenic-enriched groundwater to be classified as reducing conditions (Smedley et al., 2003; Guo and Wang, 2005; Zhang and Guo, 2007; Guo et al., 2010; Hagiwara et al., 2011; Xie et al., 2013), particularly in the arid regions, where such conditions in alluvial and lacustrine aquifer sediments are often concomitant with high salinity and/or alkalinity. In some areas, mostly Taiwan, arsenic release has also been associated with anoxic aquifers (Lee et al., 2009).

As stated earlier, previous studies indicate that the sediment–water interactions cause geogenic enrichment of arsenic in groundwater. Furthermore, arsenic content ranging

from 1 to 10 mg/kg can cause enrichment of dissolved arsenic in groundwater may exceed 1000 µg/L (Smedley and Kinniburgh, 2002). It is critical to document the source of arsenic in sedimentary aquifers to improve our understanding of arsenic enrichment mechanism. Efforts have been made by different organizations to document the potential sources of arsenic in aquifers and it has been indicated that the sources of arsenic in sedimentary aquifers are related to chemical weathering of the minerals, which contain arsenic within it (Saunders et al., 2004; Zheng, 2007). Studies have reviewed and explained the link between natural arsenic contaminated aquifers and weathering. Several minerals related to arsenic and occurrences are documented in detail in *Table 3*.

**Table 3.** Arsenic minerals occurring in nature

S. No	Mineral	Composition	Occurrence
1	Native arsenic	As	Hydrothermal veins and deposits that contain other arsenic minerals
2	Niccolite	NiAs	A minor-component of Ni-Cu ores in high-temperature hydrothermal veins
3	Safflorite	(Co,Fe)As <sub>2</sub>	Hydrothermal veins
4	Realgar	As <sub>2</sub> S <sub>3</sub>	Vein deposits often associated with orpiment clays, and lime stones, deposits from hot springs
5	Orpiment	As <sub>2</sub> S <sub>3</sub>	Hydrothermal veins, hot springs, volcanic sublimation products
6	Cobaltite	CoAsS	Medium-temperature hydrothermal deposits, metamorphic rocks
7	Arsenopyrite	FeAsS	The most abundant arsenic mineral, dominantly in vein of hydrothermal origin, found in pegmatites, high-temperature gold, quartz and tin veins, in contact metamorphic sulfide deposits, also in gneisses, schist and other metamorphic rocks
8	Arsenianpyrite	Fe(As,S) <sub>2</sub>	Hydrothermal veins, accessory mineral in igneous rocks, pegmatites and contact metamorphic deposits
9	Lollingite	FeAs <sub>2</sub>	Mesothermal deposits associated with other sulfides and calcite gangue
10	Tennantite	(Cu,Fe) <sub>12</sub> As <sub>4</sub> S <sub>13</sub>	Hydrothermal veins and contact metamorphic deposits
11	Enargite	Cu <sub>3</sub> AsS <sub>4</sub>	Hydrothermal vein deposits formed at medium temperatures
12	Arsenolite	As <sub>2</sub> O <sub>3</sub>	Secondary mineral formed by oxidation of FeAsS, native arsenic and other arsenic minerals
13	Scorodite	FeAsO <sub>4</sub> ·2H <sub>2</sub> O	Secondary mineral formed by oxidation of arsenic-bearing sulfides
14	Annabergite	(Ni,Co) <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub> ·8H <sub>2</sub> O	Secondary mineral formed by the alteration of Co-Ni-bearing arsenides and sulfides, in the oxidized zone of hydrothermal mineral deposits
15	Hoernesite	Mg <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub> ·H <sub>2</sub> O	Secondary mineral, in limestone blocks and volcanic tuff
16	Symplesite	Fe <sup>2+</sup> <sub>3</sub> (AsO <sub>4</sub> ) <sub>2</sub> ·8H <sub>2</sub> O	Secondary mineral in the oxidized zone of some arsenic rich Hydrothermal mineral
17	Conichalcite	CaCu(AsO <sub>4</sub> )OH	Secondary mineral in the oxidized zone of Cu deposits, and alteration product of enargite

Source: Modified from (Smedley and Kinniburgh, 2002; Anthony et al., 1990; Anthony et al., 2000)

Although large areas such as the Tarim basin (Xinjiang), the Ejina basin (Inner Mongolia), the Heihe basin (Gansu), the Qaidam basin (Qinghai), the Northeastern plain (Inner Mongolia, Jilin, and Liaoning), and the North China plain (Henan and Shandong) are known as being potentially affected, the worst situation of arsenic problems in China has been documented in Inner Mongolia and the Datong Basin, where several studies have been conducted. More recently, the controlling factors

(Saunders et al., 2004; Xie et al., 2008, 2009a, 2009b) have been documented to understand the arsenic mobilization in aquifers system at the Datong basin. Fe-hydroxides/oxides were the major causes for arsenic in aquifer systems at Datong (Xie et al., 2008, 2009a, 2009b). However, the source of the geogenic arsenic in some areas is a controversial issue and has yet to be determined. Although results of the preliminary geochemical survey have indicated that the bedrocks around the basin were the potential sources for arsenic in the aquifer system (Xie et al., 2013), more detailed work is still needed to answer this open question.

It is already generally accepted that the reduction of arsenic-bearing Fe oxides/hydroxides through organic carbon oxidation can be said to promote the mobilization of arsenic. However, the mechanisms involved are still not fully understood. Studies are being conducted to understand the processes controlling the mobilization of arsenic. Therefore, it is important to understand the transformation of Fe minerals within the aquifer system in order to elucidate the mechanisms involved in the release of arsenic into groundwater. Studies (Jiang, 2001; Xie et al., 2008, 2013) have shed a light on arsenic mobilization and the associated dissolution/precipitation and transformation of Fe minerals. Studies have presented Fe isotope compositions of Fe leached from aquifer sediments which were collected from a well-known arsenic-contaminated site in China at the Datong Basin; the results demonstrate that in various Fe pools, the Fe isotopic composition may be produced through microbial Fe(III) reduction and the secondary Fe(II) phases formation. The Fe isotope compositions and the distinct arsenic concentrations in HCl extracted poor-crystalline Fe phases and crystalline Fe(III) provide a framework to interpret arsenic mobilization in aquifers in the Datong Basin, China (Jiang, 2001, Xie et al., 2008, 2013; Zhu et al., 2009; Lee et al., 2009).

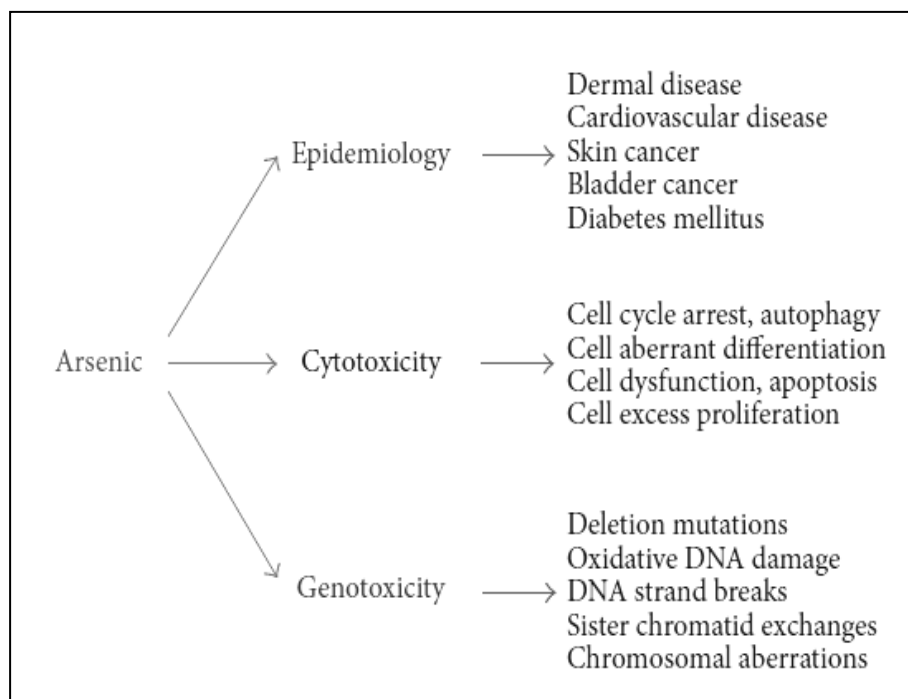
Generally, Arsenic pyrites/ferrous hydroxides are arsenic-rich minerals which are stable in reducing environment under water-table and are mostly concentrated in organic deposits. However, the different anthropogenic activities accelerate the oxidation process and arsenic release from the minerals. Adsorption onto iron hydroxide is not a problem, while adsorption of arsenic onto iron hydroxide returns to the reduced-environment under the water-table and mixes with water and ultimately poisons the water. The hypothesis elaborates the recent phenomenon that the origin of arsenic-rich groundwater is human-made. Moreover, the different geological processes such as weathering, erosion, sedimentation, and use of irrigation and fertilizers accelerate the processes (Xie et al., 2008, 2009b, 2012; Hagiwara et al., 2011; Maity et al., 2012; Jiang, 2001).

### ***Exposure pathways and toxic effects of arsenic to human health***

Several studies have been conducted to document the toxicity of arsenic and its effects on human health in various arsenic-contaminated regions around the globe (Engel and Smith, 2004; Raven, 2009). Usually arsenic enters human-beings through two pathways; first, direct consumption of drinking water that contains arsenic and second, for populations not exposed to elevated arsenic in drinking water to have indirect contact through food intake and the cultivation of crops. Undetectable in its early stages, arsenic poisoning takes between 8 and 14 years to impact health, depending on the amount of arsenic ingested, nutritional status, and immune response of the individual (Raven, 2009; Fontcuberta et al., 2011). Toxicity depends on the amount of arsenic intake, which can be classified into acute, sub-acute and chronic toxicity



respectively. Arsenic contamination in drinking-water threatens health around the world and affects an estimated amount of more than 150 million people. While around 110 millions belong to highly affected ten countries in South and South-east Asia including Bangladesh, Vietnam, China, Taiwan, Laos, Cambodia, Myanmar, India, Pakistan, and Nepal (WHO, 1999; Hsueh et al., 1995; Brammer, 2008; Raven, 2009; Fontcuberta et al., 2011). Recent studies have also documented that human intakes of arsenic, especially inorganic in a range of  $0.05 \text{ mgL}^{-1}$  leads to arsenicosis. Arsenic is associated with a several non-neoplastic diseases, such as cerebrovascular disease, cardiac disease, leuco-melanosis and hyperkeratosis, diabetes mellitus, pulmonary disease and diseases of the capillaries, arteries and arterioles (Fontcuberta et al., 2011). Chronic arsenic ingestion from drinking water is known to cause skin cancer affected by arsenite and arsenate. Chronic exposure to inorganic As causes several disorders upon different biological systems such as the digestive system, respiratory system, cardiovascular system, hematopoietic system, endocrine system, renal system, neurological system, and reproductive system. These diseases ultimately increase the risk for bladder, kidney, liver, lung cancer, and diseases of the blood-vessels of the legs and feet, and possibly high blood pressure which is shown in *Figure 3* (Mandal et al., 1996; Maharjan et al., 2005; Saha, 2009; Shukla et al., 2010; Fendorf et al., 2010b; Chakraborti et al., 2010; WHO, 2011).



**Figure 3.** Arsenic toxicity in human (Saha, 2009; Shukla et al., 2010)

The major arsenicosis regions are presently documented in large deltas and along the largest rivers merging from the Himalayas (Fendorf et al., 2010a) such as in the Bengal delta (Chakraborti et al., 2010), other parts of India (Saha, 2009; Shukla et al., 2010), Nepal (Thakur et al., 2011), Pakistan (Malik et al., 2009), Myanmar, Vietnam, Cambodia (Berg et al., 2007; Polya et al., 2008) and China (He and Charlet, 2013). Therefore, arsenic free water is urgently needed to mitigate arsenic toxicity and protect

the health and well being of people living in acute arsenic problem areas — especially in rural areas where the groundwater is the only source for drinking water. The populations exposed to to arsenic around the world are shown in the *Table 4*. It was first realized in the late 1970s and early 1908s that there were arsenic issues in China; firstly patients from Kuitun area of Xinjiang province were diagnosed to have arsenicosis. Later Inner Mongolia was documented as another areawith the worst arsenicosis in 1989, followed by the Shanxi province around 1994, and recently the Datong Basin has the worst arseni ccontamination levels, which has brought health risks communities belonging to rural areas (Sun, 2004; Kongkea et al., 2010, Xie et al., 2013, He and Charlet, 2013).

**Table 4.** *Estimated Number of people exposed to arsenic contamination in selected countries*

Countries	Population exposed to As	Reference
India	102585	WHO 1999, UNICEF 2013
China	31385	
Bangladesh	30969	
Pakistan	23202	
Vietnam	15603	
USA	6225	
Italy	5210	
Mexico	5041	
Japan	4910	
Taiwan	4133	
Argentina	2551	
Cambodia	2422	
Nepal	1465	
Hungary	1422	
Canada	1404	
Chile	1046	

In China, several provinces have arsenic contamination in its groundwater, which crosses the standard range of 10 ug/ml. However, epidemiological studies on the effects of arsenic exposure from drinking water on public health indicated a carcinogenic effect. As arsenic bring cancers of the skin, liver, lung, bladder and kidney, and probability, experts indicated that a concentration level of 50 µg As/L could lead to cancer in 1 in 100 individuals. In the case of chronic poisoning, this deadly element accumulates in skin, hair and nails, resulting in strong pigmentation of hand and foot, also known as keratosis, and problems in other body system such as respiratory, neurological, high blood pressure, endocrine, cardiovascular and metabolic dysfunctions/disorders (Yunus et al., 2011; McClintock et al., 2012; Ferlay et al., 2015).

### Treatment options for remediation of arsenic contaminated water

Several methods are available for the determination of arsenic in water by WHO and several studies have been conducted for arsenic removal (Kartinen and Martin, 1995; Joshi and Chaudhury, 1996; Gates, 1998; Leupin et al., 2005; Mondal et al., 2013; Sharma et al., 2005a; Sharma, 2007a, 2007b). The most common of these methods include:

- (i) Atomic absorption spectroscopic method – (a) hydride generation atomic absorption (AAS – HG) and (b) electrothermal atomic absorption (AAS – GF).
- (ii) Silver diethyldithiocarbamate method (SDDC).

- (iii) Inductively coupled plasma (ICP) method – (a) mass spectrometry (ICP-MS) and (b) atomic emission spectrometry (ICP-AES).
- (iv) Anodic stripping voltammetry (ASV).

There are also several available options suited for arranging drinking water with low arsenic content such as:

- (i) Explore alternative source of water with low arsenic content.
- (ii) Treatment/removal of arsenic from the water source.

It is accepted that arsenic is found in shallow groundwater, while deep groundwater is either free of arsenic content or have low content. However, the depth to arsenic free aquifers differs between the locations so a detailed server is needed. The second option is to use surface water i.e lakes, rivers and ponds which are arsenic free or have a low arsenic content. The third option is to harvest rainwater, historically it is a way to utilize rainwater for domestic water supply and it has been used around the globe (BGS, 2004; Ahmed et al., 2005; WHO, 2011).

The aim of this section is to review and update the recent advances made in the technological development in arsenic removal technologies and to explore the potential of those advances so we can document the problem of arsenic contamination. There will be a special focus on the efficiency, applicability and social acceptability of the various technologies. In the 1990s, several methods were introduced for the removal of arsenic from water through large conventional treatment plants. The most commonly used technologies include adsorption onto sportive media, ion exchange resin and membrane processes, oxidation (biological and chemical), co-precipitation and adsorption onto coagulated flocs, lime treatment, and bacterial treatment, which can be applied for arsenic removal (Gates, 1998; Leupin et al., 2005; Sharma et al., 2005a; Sharma, 2007a, 2007b; Mondal et al., 2013) These techniques are still being used all around the world, several techniques are defined below.

### ***Arsenic removal by Oxidation***

Arsenic [As(III) and As(V)] is present in groundwater so oxidation is a pretreatment process which is conducted for converting arsenite to arsenate/AsIII, then to AsV and finally AsV precipitation is takes place. This process is important for anoxic/anaerobic groundwater because AsIII is the pre-dominant form of arsenic at aneutral pH (Sharma et al., 2007). Free chlorine, chlorine dioxide, hypochlorite, chloroamine, ferrate, ozone, oxygen, hydrogen peroxide, permanganate, and fulton's reagent are used for the oxidation of AsIII into AsV (Sharma et al., 2005b; Sharma and Sohn, 2009), but in developing countries, hypochloride, atmospheric oxygen and permanganate are being used. During the process of oxidation — which can take up to a couple of weeks hydrogen peroxide and chloroamine are slower than permanganate, chlorine and ozone (Islam, 2005, 2007). It is accepted that free Chlorine or hypochlorite is very effective for the oxidation of AsII, while theoxidation of AsIII is well achieved by ozone. However, chlorine dioxide is prohibited to use for surface water, American environmental agencies paymuch attention to this factor (Sarker, 2010). About the removalof arsenic, Utilizing FeO4<sup>2-</sup> forpurifying water is recommended HFO (hydrous ferric oxide) appears to be the most important phase responsible for removing the arsenic from ground water around the world. It is well documented that High arsenic came into contact with iron oxides in the shallow aquifer, which could possibly lead to arsenic removal (Young, 1996; BGS, 2004; Ahmed et al., 2005; Lena et al., 2014; Shankar et al., 2014; Wegelin et al., 2000). Thus, for the removal of arsenic from water,

oxidation/precipitation technology is very effective (Yoon and Lee, 2005; Sharma et al., 2005b).

### ***Arsenic removal by In-situ Oxidation***

DPHE Danida Arsenic Mitigation Pilot Project is applied for In-situ oxidation of iron and arsenic in the aquifer. Stored aerated tube-well water is released back into the aquifer. The dissolved oxygen in water oxidizes arsenite to arsenate (less mobile) and the ferrous iron in the aquifer is oxidized to ferric iron which leads to a reduction in arsenic content in tube-well water. Results of the experiment in-situ oxidation show that arsenic in tube-well water is reduced to about half due to underground-precipitation and adsorption on ferric iron. In-situ oxidation has also been achieved by pumping the oxygenated water into the groundwater aquifer to reduce the arsenic content in the pumped groundwater. While its potential for the removal of arsenic is only little, the results indicate that arsenic concentrations can be reduced in the groundwater zone before water extraction (Dutta et al., 2004; Sharma et al., 2007).

### ***Arsenic removal by Photochemical, Solar photo-catalytic Oxidation***

Photochemical and photo-catalytic oxidation of AsIII have been used in many studies for arsenic removal. The most widely tested chemical oxidant in presence of naturally occurring iron in the field is UV-light assisted oxidation of AsIII (Miller et al., 2011) because FeIII - hydr-oxide and chloride species can absorb photons to provide highly oxidizing hydr-oxyl and di-chloro radicals which converts AsIII to AsV (Ryu et al., 2013), as SORAS is a simple technique of solar oxidation for arsenic in transparent bottles to reduce arsenic content of drinking water (Emett and Khoe, 2001). It is also indicated that the efficient oxidation of AsIII to AsV can be achieved by photo-catalytic oxidation (PCO) (Bissen et al., 2001). Here ultraviolet radiations speedup the oxidation of AsIII in presence of other oxidants or oxygen. Ultraviolet radiation/solar light help to create/generate the hydroxyl-radicals via the the process of photolysis of Fe(III) i.e (FeOH<sub>2</sub><sup>+</sup>) and both oxygen and hydroxyle radicals accelerate the rate of oxidation.

It has also been investigated that adsorption of arsenic on TiO<sub>2</sub> takes place while the oxidation process of AsIII to AsV is through photo-catalytic oxidation and TiO<sub>2</sub>. This can provide safe water; we know this because from experiments formentioned, it shows that it reduced arsenic levels to less than the standard limit given by WHO for drinking-water (Anthony et al., 1990, 2000; McNeill and Edwards, 1995; Dutta et al., 2004, 2005; Choong et al., 2007; Ravenscroft, 2009). This experiment is still being used in Bangladesh and indicated that this process averagely can reduce one-third of arsenic content from water.

### ***Arsenic removal by Biological oxidation***

Study (Pallier et al., 2010) documented that some micro-organisms such as Gallionella ferruginea and Leptothrixochracea support and accelerate biotic-oxidation of iron. The study (Pallier et al., 2010) was conducted in the laboratory where iron-oxides and micro-organisms (Gallionella ferruginea and Leptothrixochracea) were deposited in a filter-medium, which has a favorable environment for the adsorption of arsenic, as AsIII cannot be efficiently absorbed onto iron-oxides. These micro-organisms are assigned to oxidize AsIII to AsV, which got adsorbed in FeIII. This leads to up-to 95% removal of arsenic. Kinetics of bacterial oxidation of AsIII and oever all removal of

AsV by sorption onto bio-genic manganese-oxides during ground-water treatment was also studied (Sharma et al., 2007; Pallier et al., 2010; Hu et al., 2012). Biological oxidation is a new technique of the oxidation of iron and manganese as a treatment technique for arsenic removal. These biological treatment techniques are the natural biological processes, and it takes a couple of days for remediation of metals in soil and groundwater by certain plants and micro-organisms. During treatment, the following sequences of reactions have taken place in the treatment system:

- a. FeII to FeIII and MnII to MnIV (oxidation).
- b. AsIII to AsV (oxidation).
- c. MnO<sub>2</sub> (Precipitation).
- d. Abiotic-oxidation of AsIII by MnO<sub>2</sub>.
- e. AsV sorption via MnO<sub>2</sub>.

Whereas steps (a) and (b) are biotic steps (c) to (e) are abiotic. This natural process for treatment has been found excellent as it can lead to up-to 95% of the removal of arsenic (Pallier et al., 2010).

### ***Arsenic removal by Coagulation–flocculation***

Coagulation-flocculation has got attention for the removal of arsenic from water, it is most commonly used for larger-capacity facilities and it requires the formation of a floc used to remove arsenic from groundwater. Coagulation-flocculation usually requires Fe and Al based coagulants among other various chemical coagulants i.e ferric chloride, or ferric sulfate or aluminium sulfate, need to be added and dissolved in water under efficient stirring for 1-10 minutes. Positive-charged cat-ionic coagulants have to decrease the negative charge of colloids. In this process, aggregation of particles forms larger particles. It is described that this technique obtained enough amount for removal, which rounded out to more than 90% of AsV and 77% of AsIII. While using 9.2 ppm of Fe<sup>3+</sup> aluminium or when ferric hydroxide micro-flocs are formed, As trivalent arsenic occurs in non-ionized form. For efficient removal, oxidation of As(III) to As(V) is thus required as a pretreatment. This surely can be achieved with the addition of bleaching powder (chlorine) or potassium permanganate. It has been documented that this technique is good for removal of arsenic below standard drinking water and also Fe based coagulants have also been investigated by several authors (Cheng et al., 1994; Appelo et al., 1999; Song et al., 2006; Sharma et al., 2007; Andrianisa et al., 2008; Gupta et al., 2009; Baskan and Pala, 2010; Lakshmanan et al., 2010; Van Halem et al., 2010; Lacasa et al., 2011). Recently, Hu et al. (2012) has used it and found the same.

Some of chemical coagulants are being used, whereas Fe based coagulants have been documented to be most efficient in water treatment than others e.g Al based coagulants (D.P.H.E, 2001; Katsoyiannis et al., 2004). For efficient removal of arsenic from water, the arsenic needs to be adsorbed on amorphous metal hydr-oxides formed from coagulant. There is critical limitation in the process of coagulation/flocculation, it produces a large amount of sludge along with a big concentration of arsenic (Hering et al., 1996; Appelo et al., 1999; D.P.H.E, 2001; Song et al., 2006; Sharma et al., 2007; Andrianisa et al., 2008; Gupta et al., 2009; Baskan and Pala, 2010; Lakshmanan et al., 2010; Van Halem et al., 2010; Lacasa et al., 2011). Real management of the contaminated sludge is needed for safeguarding the environment from secondary pollution and thus reduces the applicability of this method in field conditions.

### ***Arsenic removal by Electro-coagulation***

Coagulation/flocculation has an alternative way known to be electro-coagulation which has a different the process, instead of adding a chemical reagent as ferric-chloride; metallic cat-ions are directly generated in the effluent to be treated while applying current between iron electrodes for dissolving soluble anodes. Generally, Electrolytic-oxidation of a sacrificial iron anode creates FeIII oxy-hydroxides / precipitates in the arsenic contaminated water in electro-coagulation. While with FeIII precipitated arsenic produces bi-nuclear inner-sphere complexes and it further aggregates to form a floc. Then metallic cat-ions and hydroxides are formed and colloids neutralize negatively charged which allow them to coagulate and finally create helpful results (Ghurye et al., 2004; Katsoyiannis and Zouboulis, 2006a, 2006b).

### ***Arsenic removal by Electro-Chemical***

In this method, a small amount of electricity is needed to create rust in arsenic contaminated water. The rust binds to arsenic, settling and/or filtering. The rust can then remove from the water (Jain and Singh, 2012).

### ***Arsenic removal by Adsorption***

This is one of the processes of adsorption, in which, solid particles are used for removing substances from solutions such as gas or liquid. Removal of arsenic by this technique onto activated/coated surfaces has been famous and used the most in many countries. Some of its benefits are its low cost, high removal efficiency, easy operation and handling and also its sludge-free day-to-day operations. There is an extra advantage of this technology a number of the adsorbents can be reused and regenerated. Several studies have addressed the arsenic-removal by adsorption via many adsorbents (Wilkie and Hering, 1996; Mohan and Pittman, 2007), including commercial activated carbon, activated alumina, layered double hydroxide, natural/modified clays and zeolites. Mohan and Pittman (2007) and Wilkie and Hering (1996) have reviewed and addressed approximately 40 different types of adsorbents using published literature, with more than 500 references. Recently, gaps in exploration and improvement in new adsorbents are being found. A few years back adsorption based on zeolites (Raven et al., 1998), iron oxides (Grafe et al., 2001; Zhu et al., 2013), alumina (Kanematsu et al., 2013), clays (Swarnkar and Tomar, 2012), etc. to adsorb arsenic from water and the removal of arsenic by adsorption processes/techniques probably depended on pH and the speciation of arsenic with better AsV removals as compared to AsIII at a pH level lower than 7 (Giménez et al., 2010; Anjum et al., 2011; Sun et al., 2013; Han et al., 2013; Zhu et al., 2013). Several other studies such as Kanematsu et al. (2013) reviewed that the general rate of arsenic adsorption and capacity adsorbents further depend on the presence of other ions such as: silicate, phosphate, HCO<sup>-3</sup>, and Ca<sup>2+</sup>. These ions compete for the adsorption sites; some other studies (Lin and Wu, 2001; Singh and Pant, 2004) also substantiated this fact. It is documented that the most widely tested aluminium-oxide is activated alumina (AA) (Giles et al., 2011; Genuchten et al., 2012; Kanematsu et al., 2013). There are some other adsorption methods used for removal of arsenic from water, which are discussed in the section below.

### ***Arsenic removal by Bucket Treatment Unit***

The Techniques of Bucket Treatment Unit (B.T.U) is an extremely effective and affordable treatment technique for the removal of arsenic within the household. Locally available materials can be used to build the treatment unit and if operated properly and smoothly, it is effective for removing of arsenic from water. These technology units are generally based on chemical doses of 2 mg/L of potassium permanganate and 200 mg/L aluminum sulfate in a crushed powder form. In both lab and field conditions, these units were documented to provide good performances in removing arsenic.

Bucket Treatment Unit (B.T.U) was proposed by the DPHE-Danida Project which is based on the principles of co-precipitation, coagulation and adsorption techniques/processes. In this technique, there are two buckets, each one has a 20 liter capacity, and are placed one above the other. The further the process is conducted; chemicals are put manually with arsenic contaminated water in the upper red bucket. Mixing of chemicals is done by vigorous stirring with a wooden stick for about 30 to 60 seconds, followed by the flocculation process by gentle stirring for about 90 second. It takes 1-2 hours to settle. Once the water is settles, the water from the top red bucket is further allowed to flow via plastic pipe into the lower the green bucket, where a filter is already installed. In the lower bucket, which should have sand filter and a valve sludge does not build up in the upper bucket. This is how practically a treated water container (EPA, 2000a, 2000b; Giles et al., 2011).

### ***Arsenic removal by Membrane technology (MT)***

Membrane technologies, i.e RO, have been documented as reliable and efficient for arsenic removal. RO has proven to be the best practiced technology which can completely purify water. It is generally accepted that RO is superior in both pilot-scale and lab experiments; results have shown more than 95% As(V) and 74% As(III) removal efficiencies (BAMWSP, 2001; Tripathy and Raichur, 2008). Membrane processes get rid of arsenic through electric repulsion, filtration, and adsorption of arsenic containing compounds. With the help of poly-sulfone thin film and nano-filtration membrane (BQ01), the distinction between the removal of As(III) and As(V) was explored (Sarkar et al., 2000). It has been observed that the elimination of As(V) was much higher than that of As(III). Furthermore, another study (Kohnhorst and Paul, 2000) was conducted on the nano-filtration operating conditions, it was concluded that there is no effect on arsenic removal by the trans-membrane pressure, temperature or cross-flow velocity (Kohnhorst and Paul, 2000). This technique is proven to be the best and results shows that up to 99% of the arsenic can be removed (Sheng et al., 2006; Xi et al., 2014) through the conducted studies.

### ***Arsenic removal by nano-filtration Technology***

Arsenic is being removed from groundwater by nano-filtration (NF) membrane configuration. It has played a key role in controlling operation performances and membrane fouling. The nano-filtration (NF) membrane surface puts negatively charged above its iso-electric point (approximately at pH 5.9–6.4). Generally, alkaline/neutral pH is adjusted for raw groundwater so it brings up the effect of electrical charge repulsion and ion removal efficiencies, which is improved by nano-filtration (NF). This nano-filtration (NF) system has an efficiency of up to 92~94% for arsenic removal (Xie et al., 2015; Song et al., 2015).

### *Arsenic removal by Activated alumina (AA)*

Activated alumina (AA) successfully removed arsenic from water supply systems and it was the first adsorptive medium for water supplies (Xie et al., 2008). Activated alumina is defined as a physical/chemical process, which is used particularly for the removal of arsenic and other ions. In this process, ions in feed water are sorbed to the oxidized Activated alumina (AA) surface. It is the widely tested aluminum oxide. It is prepared at high temperature, generally by the thermal de-hydration of aluminium hydroxide  $\text{Al}(\text{OH})_3$ . It has diameter approximately 0.3–0.6 mm; in addition, it has a high surface area for impressive sorption properties as it is a porous, granular material. The AA is used in the contaminants such as fluoride, arsenic NOM, silica and selenium. (Holl, 2010). It has been reported that, alum-impregnated AA can be adsorbent for AsV rather than untreated AA at a pH range of 2.8–11.5. When employed in batch mode, AsV concentration could be decreased down from  $10\text{mgL}^{-1}$  (10,000 ppb) to 40 ppb (Katsoyiannis and Zouboulis, 2006a, 2006b).

### *Arsenic removal by Stevens Institute Technology*

In this technology, the process resembles the previously mentioned B.T.U as Bucket Treatment Unit (B.T.U) proposed by DPHE-Danida Project which is mostly based on the principles of co-precipitation, coagulation and adsorption techniques/processes. This technology is also involved in two buckets, the first bucket is to mix chemicals (such as calcium hypo-chloride and iron sulphate) then supply in packets. The other bucket is used to separate flocs, where two processes have taken place (a) sedimentation and (b) filtration. The second bucket has a second inner bucket with slits on the sides to help sedimentation and to keep the filter sand bed in place (EPA, 2000a). This technology has been mostly used in Bangladesh and has been effective. The results of tested samples show that 80 to 95% of the samples reduce arsenic concentration to less than 0.05 mg/L (EPA, 2000a, 2000b).

### *Arsenic removal by iron coating*

An experimental study has been conducted (Seidel et al., 2001), where an iron coating method is used as a simple groundwater remediation technology, which has great potential. Moreover, it is affordable, especially in villages and rural areas where groundwater is used by communities for drinking purposes. Under different conditions, coated iron oxide/hydroxide was investigated for the arsenic removal mechanism using an electron probe microanalysis, scanning-electron microscopy(SEM)/X-ray absorption spectroscopy, and fourier transformation infrared spectroscopy. It has proven to be an effective method for arsenic removal. Generally, the 4-step develop aquifer iron coating method, alternating injection of oxidant, iron salt and oxygen-free water. In situ the removal of arsenic from ground water in an aquifer was achieved by simultaneous injections of As(V) and Fe(II) reagents. The technique of adsorption or co-precipitation brings arsenic fixation with fine particles of goethite by way of bi-dentate bi-nuclear complexes. Therefore, the study documents that the technology results in high arsenic removal efficiency by the situ aquifer iron coating technique. This is likely resulted by the expanded particular surface area of the small goethite particles, which enhanced arsenic sorption capability and/or from coprecipitation of arsenic on the surface of goethite particles.



### ***Arsenic removal by hollow fiber nano-filtration membranes with a sulfo-nated poly ether ether ketone coating***

In 2015, this technique got high attention when experimental studies were done (Saitua et al., 2005). The overall performance of this technique for arsenic removal from drinking water was tested. The membrane works well and does not allow above 95% of As(V) to contaminate the water. Furthermore, the membrane properties were studied, and rejects arsenic in the presence of interfering ions. Results indicated that di-electric exclusion might be able to rationally explain the rejection deviation from the Donnan exclusion effect. The valence of the ions played a major role, where there was a presence of interfering ions. Finally, cost estimation was conducted at 1000 m<sup>3</sup> h<sup>-1</sup>, which is about 0.15 US\$ per 3 m when using the proposed SPEEK coated hollow fiber membrane for a plant. Results from different sources indicate that a SPEEK composite nano-filtration membrane is mostly suitable and efficient for removing arsenic from groundwater (Pinon-Miramontes et al., 2003; Saitua et al., 2005; Shih, 2005; Harisha et al., 2010).

### ***Arsenic removal by Naturally Occurring Iron***

This method has been found effective in Asian countries, where naturally occurring iron is used to precipitate the ground water and for removing arsenic by adsorption (Ahmed, 2001).

### **Concluding Remarks and future perspective**

Arsenic is worldwide problem; arsenic has been documented in the Americas, Africa, Asia, Europe and Pacific countries. Arsenic in groundwater can found in several geographical regions in mainland China. Studies identify areas of high-risk arsenic contamination in the north of China, including Xinjiang, Shanxi, Inner Mongolia, Henan, Shandong and Jiangsu. The most affected areas to date, rounded about 3998 individuals with arsenicosis, including children, with most living in rural areas of the Shanxi province, in northern China.

Arsenic has created health problems around the world. The major arsenicosis regions are presently documented in large deltas and along biggest rivers merging from the Himalayas, such as in the Bengal delta, other parts of India, Nepal, Pakistan, Myanmar, Vietnam, Cambodia and China. Usually, arsenic enters human-beings through two pathways; first, direct consumption of drinking water contaminated by arsenic and second, for populations not exposed to elevated arsenic in drinking water, the indirect intake through foods and crops cultivated using arsenic-contaminated water represent the main sources of arsenic intake for humans.

Several available options suited for arranging drinking water with low arsenic content such as: (i) Explore alternative source of water with low arsenic content and (ii) Treatment/removal of arsenic from the water source. The most commonly used technologies include adsorption onto sorptive media, ion exchange resin and membrane processes, oxidation (biological and chemical), co-precipitation and adsorption onto coagulated flocs, lime treatment, and bacterial treatment, which can all be applied for arsenic removal.

Aeration/Fe precipitation/filtration is developed to remove arsenic; this technology has been accepted in China. The modification of commercial adsorbents (e.g., activated

carbon and activated alumina) and modification of natural mineral materials (e.g., zeolites) seem to be an approach to lower the operating cost and improve arsenic removal efficiency. Recently, several technologies to remove arsenic from drinking water have been introduced. Many of them are described in this review; each have their own advantages and disadvantages. Most of these technologies for removal of arsenic involve the direct removal of AsV or converting AsIII to AsV followed by removal of AsV.

While talking about future perspective, the government should monitor and document industrial and agricultural activities as they brought the arsenic pollution issue to the bodies of water in the first place.

Mining or chemical plants should be documented to deal with sewage, sludge storage and waste treatment. Sub departments should be developed and should be supervised by well-known persons; there should also be sampling and analysis of the discharge from industrial plants, which aim to supply safe drinking water to people in rural areas, including arsenic control. The government should take additional steps and put restrictions, if there is a not safe water source. Investment should be employed on the great engineering system for water transportation and water quality should be well documented. Small treatment facilities installations should be recommended in rural areas.

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## APPENDIX

**Table S1.** Arsenic affected areas in China

S.NO	PROVINCES	Max As ( $\mu\text{g/L}$ )	Coordinates in decimal	
			Lat	Long
1	Anhui	1146	31.833333	117
2	Beijing	143	39.916667	116.383333
3	Guangdong	21	23.4	113.5
4	Gansu	$\geq 250$	38	102
5	Henan	$\geq 500$	33.9	113.5
6	Hunan	$\geq 50$	27.4	111.8
7	Helongjiang	200	48	129
8	Inner Mogolia	1860	44	113
9	Jilin	$\geq 500$	43.7	126.2
10	Jiangsu	333	32.9	119.8
11	Liaoning	25	41.1	122.3
12	Niangxia	177	36.6	105.32
13	Qinghai	318	35	96
14	Sichuan	287	30.133333	102.933333
15	Shandong	$\geq 50$	36.4	118.4
16	Shanxi	1932	37.7	112.4
17	Taiwan	600	25.033333	121.633333
18	Xinjinag	830	41	85
19	Yunnan	687	25.05	101.866667
20	Zhejiang	80	29.2	120.5