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RESEARCH ARTICLE

ARSENIC IN DRINKING WATER IN PAKISTAN AND ASSOCIATED HEALTH RISKS

Mehwish Niazi.

MSc (Zoology) University of Sargodha Sub-Campus Mianwali, Pakistan.

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Abstract

This paper first reviews the arsenic nature, and its mobilization in environment. Arsenic is a significant element of earth crust and also in a human body. General sources of arsenic are air, food, cigarette smoke and beverages. Being soluble in water it exists in ionic forms and affects the humans who consume arsenic contaminated water. Its effects are severe and long lasting. Pakistan is one of those countries where most of the ground water is contaminated with arsenic. Different organizations such as World Health Organization, International Agency for Research in Oncology & International Agency for Research in Cancer and the United States Environmental Protection Agency has set up the maximum permissible value of arsenic in drinking water for various countries. IARC has ranked arsenic a group 1 human carcinogen which causes lung, bladder and urinary cancers. In Punjab (Pakistan) 20% of population is exposed to over 10 µg/L in drinking water and 3% of population is exposed to over 50 µg/L and in Sindh 36% of population is exposed to arsenic via drinking water. In Punjab and Sindh drinking water is contaminated with arsenic above the permissible value defined by World Health Organization (WHO), while KPK is less affected. Baluchistan is almost safe from arsenicism.

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Introduction:-

Being universal element arsenic is present in abundance in earth's crust and positioned as 20th in earth's crust, 14th in seawater and characterized as 12th abundant element in human body. (Khan and Ho, 2011). Various natural processes such as weathering reaction, biological activities, anthropogenic activities and volcanic emanations are involved in mobilization of arsenic in environment (Toor and Tahir, 2008). Earth crust contains high level of arsenic due to which arsenic can easily leach in to the underground water (Kaltreider *et al.*, 2001).

Water is most fundamental element in life like oxygen without it we could die in few days. More than two thirds of human body is comprised of water; brain consists of 95 % water while 82 % and 90 % water exists in blood and lungs (Tareen *et al.*, 2013). As Arsenic is soluble in water it subsists in two primary forms: arsenite (As+3) and arsenate (As+5). Both these forms are toxic and have severe and long lasting effects to a wide variety of organisms including humans also (Abbas and Cheema, 2015).

General sources of organic or inorganic arsenic exposure are air, food and beverages and fundamental source is drinking water. International Agency for Research on Cancer (IARC) classified arsenic as human carcinogen of skin

and lung, and it is attributed to cancer of digestive and urinary systems also (Chen; 1992). Humans are exposed to arsenic via inhalation of dust particles and by ingestion through drinking water (Rich *et al.*, 1996).

It is reported that arsenic concentration in well waters ranges from 0.01 to 1.82 mg/l, which is approximately 0.5mg/l (Pershagen, 1981). It is reported that at some places in Punjab and Sindh province the level of arsenic in drinking water is beyond the acceptable limit defined by World health organization (WHO) which is (10µg/L) (Khattak *et al.*, 2016). Arsenic is exposed to human population via ingestion of arsenic contaminated water, foods, drugs, smoking, it exerts serious and prolonged effects on health (Singh *et al.*, 2006).

Endothelial cell dysfunction, inflammation and angiogenesis are associated with cognitive dysfunction and these are proposed mechanisms which cause Alzheimer's disease (Bryant *et al.*, 2011). Epidemiological studies are conducted in different areas of the world, which revealed that arsenic exposure influences human health severely it causes cancers of liver, lung, bladder, kidneys and also cause skin cancers include hyperkeratosis and hyper pigmentation and it is also associated with neurological disorders such as amnesia and peripheral neuropathy, diabetes and arteriosclerosis (Raschid-Sally, 2000).

Regional Status of Arsenic Exposure in Pakistan

It is difficult to quantify the people who are subjected to arsenic poisoning especially in those areas where geo-chemical resources are limited. Estimations are extensive and based on four principles; (1) Frequency of recently documented cases of arsenicosis (2) Probability of ingested concentrations surpassing 50 µ g/L (3) Number of people living in arsenic exposed areas (4) Liable aptitude of region to mitigate/remediate against arsenic contamination (Thakur *et al.*, 2010).

Table No 1:-National level survey for Arsenic Contamination.

Province	Total samples (No.)		Arsenic conc. >10 µg/L		Arsenic conc. >50 µg/L		References
	Field	Lab	Field	Lab	Field	Lab	
Punjab	31,693	4,611	32.5	31.4	10.0	9.0	Ramay <i>et al.</i> , 2007
Sindh	67,556	4,825	24.0	36.0	7.8	17.0	Ramay <i>et al.</i> , 2007
KPK	1,560	156	0.30	22.0	0.0	0.6	Ahmed <i>et al.</i> , 2004
Baluchistan	619	71	1.30	1.40	0.0	0.0	Ahmed <i>et al.</i> , 2004

Table - 1

It is commonly observed from this table that water of Punjab and Sindh is affected from arsenic and Khyber Pakhtunkhwa (KPK) is less affected. Baluchistan is almost safe from arsenicism.

Punjab Province

Most populated province of Pakistan is Punjab where drinking water sources have been reported to contain Arsenic concentration above the safe limit defined by WHO and 20% of population is exposed to Arsenic (Bahadar *et al.*, 2014).

District	No. of Samples	Source	Arsenic conc.	Ref
Layyah	250	Ground water	0-150 µg/L	Soomro <i>et al.</i> , 2011
Faislabad	64	Ground water	9 µg/L	Hussain <i>et al.</i> , 2016
Sheikhupura	-	Hand pump	65-70 µg/L	Abbas <i>et al.</i> , 2014
Multan	75	Ground water	>50 µg/L	Hagras, 2013
Muzaffargarh	49	Shallow water and ground water	>50 µg/L	Naqvi <i>et al.</i> , 2013
Rahim Yar Khan	-	Rotor pump	>20 µg/L	Mahar <i>et al.</i> , 2015

Table - 2

Sindh Province

Epidemiological investigations are conducted in Sindh to expose the severe health effects of arsenic. Their findings revealed that 61-73 % population is exposed to severe and prolonged effects of arsenic on human population residing on the bank of Manchar Lake (**Kazi et al., 2009**). The general population of 30 to 40 % living in Bobak village near Manchar Lake are exposed to high levels of arsenic, which cause several dermal diseases such as skin lesions and rough skin with black dots (**Arain et al., 2009**).

District	Study Area	Source	Total Noof samples	No of samples showing arsenic	Arsenic conc.	Ref
Thatta	Ghulamula	Ground water	75	10	81 µg/L	Arain et al., 2014
				11	81 µg/L	
				12	45 µg/L	
				13	90 µg/L	
				14	76 µg/L	
				15	63 µg/L	
Khairpur		Tube wells, hand pumps and dug wells	45	30	<10 µg/L	Arain et al., 2006
				9	25-50 µg/L	
				6	100-250 µg/L	
Tando Allah Yar		Hand pumps, electric pumps, open wells and dug wells	107	82	10 µg/L	Majidano et al., 2010
				37	200 µg/L	
				60	100 µg/L	
Matiari		Pumps and Motor pumps	85	22	50 µg/L	Uqaili, 2016
				18	20 µg/L	

Table - 3

Khyber Pakhtunkhwa (KPK) Province

District	Source	Arsenic.conc	Ref
Mardan	Ground water, Tap water	>10 micro g/L	Khattak et al.,2016
Sawat	Ground water, shallow water	0.2 micro g/L	Alam et al.,2008

Table - 4

Health Problems with Arsenic in Drinking Water

Arsenic in drinking water is ranked as a known human carcinogen by International Agency for Research of Oncology (IARO) and it cause skin, bladder and lung cancer. (**Memon et al., 2014**). Most of the human population is exposed to arsenic through ingestion, inhalation and through skin contact. Chronic respiratory diseases are caused by most of the lung carcinogens but few studies revealed that the population exposed to arsenic has non-malignant respiratory effects, but few studies reported high-risk assessment (**Ehrenstein et al., 2005**). Lung tumors, which are caused by arsenic exposure, show different genetic and epigenetic modifications when compared with the studies on individuals, which were living in arsenic free environment. Only inorganic arsenic is not involved in molecular alterations in arsenic -induced tumors but the product which are produced in arsenic metabolism play major role in such alterations (**Hubax et al., 2013**). It is estimated that the rate of mortality from lung cancer by consuming arsenic contaminated water is higher than that of lung bladder and kidney cancers including cardiovascular diseases (**Smith et al., 2009**).

Exposure of Arsine (AsH₃) causes anemia due to massive intravascular hemolysis. Changes in sodium and potassium levels act as earliest indicators of erythrocytes impairment (**Chabowska et al., 2002**). It is reported that arsenic-induced apoptosis is induced as a result of over expression of BCR-ABL gene in human lymphoblast cells. Arsenic as a tumor causing agent and it is selective in inducing apoptosis in promyelocytic leukemia cells. It is studied that arsenic induces modifications in other signaling pathways via apoptosis (**Tchounwou et al., 2003**).

Arsenic was characterized as a first chemical agent, which cause liver disease in humans. Chronic exposures of arsenic over periods of months and years cause accumulation of arsenic in liver and badly affect the hepatic system (Clarkson *et al.*, 1991). Hyperkeratosis, hyper pigmentation and respiratory complications due to ingestion of arsenic in drinking water stimulate changes in hormonal and mucosal immune response (Luqueno *et al.*, 2013). The chronic arsenic exposure cause skin de pigmentation which results in white spots that looks like rain drops, this condition is medically described as leukomelanosis (Singh and Kumar; 2012). It is estimated that high arsenic exposure via drinking water into young children aged less than 20 years (RR=10.6, 95% CI 2.9-39.2, p<0.001) suffered from liver cancer and become target of mortality (Tantry *et al.*, 2015). When arsenic is present in arsenate and arsenite ionic form these ions replaces the phosphate ions and thiol group in cell and disrupt the normal functioning of cells (Shahid *et al.*, 2015). High levels of arsenic ingested by pregnant women exerts serious effects on reproductive and developmental systems, arsenic can cross the placental barrier and cause miscarriages, low-birth weight deliveries, and neonatal and postnatal mortalities (Lubin *et al.*, 2007). Arsenic may affect internal organs, impair their normal functioning without causing any visible external symptoms, and become difficult to recognize. Hair, nails, urine and blood can be indicators of arsenic exposure before the external appearances (Petrusevski *et al.*, 2007). Arsenic affects children at higher rates because the symptoms are difficult to recognize at early (Bhatia *et al.*, 2014).

System	Effects	Ref
Cardiovascular system	Myocardial depolarization and cardiac arrhythmias, hypertension and atherosclerosis.	McCarty <i>et al.</i> , 2011
Blood forming System	Intravascular hemolysis, Erythrocytes impairment and anemia.	Pakulska <i>et al.</i> , 2006
Respiratory system	Lung tumors and bronchial epithelial cell malignant transformation.	Wang <i>et al.</i> , 2011
Nervous system	Polyneuropathy, EEG abnormalities and, in extreme cases, hallucinations, disorientation and agitation.	Rodri <i>et al.</i> , 2003
Dermal system	Melanosis (diffuse and spotted), keratosis of palm and sole (spotted or diffuse), leukomelanosis (rain drop pigmentation), and hyperkeratosis.	Khan <i>et al.</i> , 2003
Renal system	Protein urea, oliguria, mitochondrial damage in tubular cells	Saha <i>et al.</i> , 1998
Hepatic system	Liver enlargement and hepatic fibrosis	Guhamazumder, 2008

Table - 5



Figure 1:-Keratosis of palm and sole (spotted or diffuse)

Role of Metabolism of Arsenic in its Toxicity

Two main types of reactions take place in Arsenic metabolism: (a) Pentavalent arsenic goes reduction reactions and convert into trivalent arsenic and (b) In oxidation reaction. These trivalent forms of arsenic are successively methylated to form mono, di and trimethylated products by using S- adenosyl methionine which act as methyl donor and glutathione (GSH) act as a co-factor (Pritchard, 2007). After ingestion, transition from blood into tissues arsenate undergoes reduction reaction and reduced to arsenite. In Liver, arsenic undergoes methylation reaction and methylated to form mono-methylated arsenic acid (MMAV), which further reduced to form mono-methyl arsenous

acid (MMA III). This is converted into dimethyl-arsenic acid (DMA V) through a series of methylation reactions. In this process of methylation, some reactive oxygen species (ROS) are formed (Lee *et al.*, 2010). Arsenic metabolism is followed by methylation process because methylated arsenic is excreted fast and easily than inorganic arsenic (Rossman, 2003).

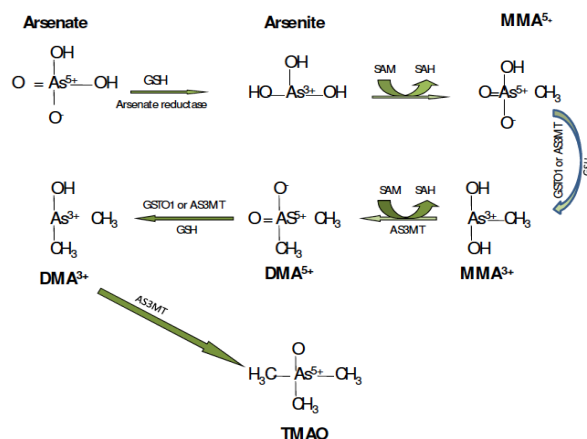


Figure - 2

Figure-2 showing the metabolism of arsenic in which arsenate is reduced to arsenite and methylated to form pentavalent and trivalent forms of arsenic, dimethyl arsenic acid and dimethyl arsenous acid and trimethyl oxide are also generated. Enzymes involved in reaction are GSH, reduced glutathione; GSTO1, glutathione S-transferase omega-1; SAM, Sadenosylmethione;SAH, S-adenosylhomocysteine; AS³MT, arsenic methyltransferase(Cyt 19) (Ebele, 2009).

Worldwide Extent of Arsenic Problems

The maximum acceptable levels of dissolved arsenic in drinking water are 0.01mg/l and 0.05mg/l according to the World Health Organization and the United States Environmental Protection Agency, respectively. Several countries in the world have identified excess amount arsenic in drinking water including Argentina, Bangladesh, Chile, China, Hungary, India, Japan, Mexico, Mongolia, Poland, Taiwan, and the United States (Khalequzzaman *et al.*, 2005). Most of the countries have found that their waters are contaminated with arsenic due to mining wastes; countries included Korea, Poland and Brazil. It is estimated in 2001 that approximately 130 million people are exposed to arsenic concentrations beyond the 50 $\mu\text{g L}^{-1}$ (Halem *et al.*, 2009).

Table 6:-Showing three Arsenic affected countries with Maximum approved parameter for Arsenic concentration in drinking water defined by WHO.

Countries	Maximum Approved parameter	References
Pakistan	50 $\mu\text{g L}^{-1}$	Rahman <i>et al.</i> , 2009
Bangladesh	50 $\mu\text{g L}^{-1}$	Naidu <i>et al.</i> , 2006
USA	10 $\mu\text{g L}^{-1}$	Shakoor <i>et al.</i> , 2015

Table – 6

In 1988, the EPA documented that continuing ingestion of arsenic 50 $\mu\text{g L}^{-1}$ results in skin cancer rate of 1 in 400 in US, in 1992 EPA assessed that mortality risk of internal cancer is approximately 1.3 in 100 at 50 $\mu\text{g L}^{-1}$. In 1999, NRC reported that overall cancer mortality risk is approximately 1 in 100 at 50 $\mu\text{g L}^{-1}$ (Talibi *et al.*). IARC have been classified arsenic as a group 1 human carcinogen and toxic agent which also cause a wide variety of other diseases except cancer and almost every part of internal system of human body is disturbed through arsenic (Naujokas *et al.*, 2012). Most of the ground and surface water of Pakistan has exceeded the level of heavy metals defined by WHO (Gilani *et al.*, 2013). According to a British Geological Survey study in 1998 on shallow tube-wells in 61 of the 64 districts in Bangladesh, 46% of the samples were above 0.010 mg/L and 27% were above 0.050 mg/L. When combined with the estimated 1999 population, it was estimated that the number of people exposed to arsenic concentrations above 0.05 mg/l is 28-35 million and the number of those exposed to more than 0.01 mg/l is 46-57 million (BGS, 2000). The US EPA suggested that by lowering the arsenic standard from 50 to 10 $\mu\text{g L}^{-1}$ could reduce

the mortality rate which is due to skin, lung and bladder cancers and from heart diseases (Kapaj *et al.*, 2006).

Conclusion:-

It is derived that Arsenic is an element, which is hazardous to health mainly in ionic form in water. It influences human health mainly by the consumption of water. There are many countries in the world where drinking water has exceeded the maximum permissible level of arsenic defined by World Health Organization (WHO). Arsenic is a toxicant as well as a potent carcinogen which causes the lungs, urinary and bladder cancers. Pakistan is affected with arsenicism specifically Punjab and Sindh provinces. Drinking water of Lyyah and Faisalabad districts of Punjab is badly affected. Ground water of Khairpur and Thatta (Sindh) have maximum concentration of Arsenic. KPK is less affected and Baluchistan has shown no arsenic concentration in experimental water samples.

Abbreviations:-

WHO: World Health Organization
 E PA: Environmental Protection Agency
 NRC: Nature Reviews Cancer
 IARC: International Agency for Research in Cancer
 IARO: International Agency for Research in Oncology

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