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Methyl Mercury Exposure through Seafood Diet and Its Effect on Aquatic Life and Health in United Arab Emirates

Jolly Jacob[1]

[1] Department of Applied Sciences, College of Arts and Sciences, Abu Dhabi University, Abu Dhabi, UAE

Correspondence: Jolly Jacob, Department of Applied Sciences, College of Arts and Sciences, Abu Dhabi University, Abu Dhabi, UAE. Tel: 97-125-015-808. E-mail: jolly.jacob@adu.ac.ae

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Abstract

Methylmercury bioaccumulates and concentrates through the aquatic food chain and is known for its potent toxicity, exposure to methylmercury is linked to increased health risks of humans as well as aquatic life. This paper reviews the existing comprehensive literature highlighting the interaction between Dissolved organic matter (DOM) and MeHg, the process of bioaccumulation and current unresolved risks due to MeHg contamination in aquatic life and its related health hazards. This review particularly focuses on the dietary exposure to methylmercury through seafood in UAE. Though further research is warranted on new factors that influence MeHg uptake and toxicity and bio-indicators of exposure to MeHg, that leads to cardiovascular and neurologic effects in adult populations in UAE, it is has been concluded that to protect human health and aquatic life, it is important to take necessary steps in order to eliminate or at least reduce the sources of methylmercury dietary exposure to national population.

Keywords: methylmercury, contamination of aquatic life, UAE, seafood risks

1. Introduction

The United Arab Emirates (UAE) has rapidly grown in the last 40 years from a subsistence and nomadic fishing population of about 400,000 to a diversified multicultural and industrial based population of more than 4.4 million (Cassen, 1978; United Nations, 2007). The modernization in UAE has been more rapid than any other nation in the history of the world. Two of the cities Dubai and Abu Dhabi in UAE are well known international urban centers and by some measures Abu Dhabi is one of the world's richest cities (Gimbel, 2007). UAE owns approximately 8 percent of the total world's oil reserves which is contained in Abu Dhabi, the largest emirate of UAE out of the seven emirates (U.S. Energy Information Administration, 2010). This rapid development can be mainly attributed to oil exports, through seafood, mainly shrimps and fish are also of significant value for both local consumption as well as export revenue in Arabian Gulf area. And therefore, for various socio-economic reasons it becomes imperative and crucial to maintain good and healthy aquatic environmental quality (Price et al., 1993). In UAE, there has been a significant improvement in the past few decades in national health due to the diversified food supply. Life expectancy (at birth) increased from 53 years in 1960 for UAE nationals, to 65 years in 1975, and then to 78 years in 2006 (WHO, 2007). Apart from increase in life expectancy due to the technology revolution, the new dietary pattern has posed various health risks mainly consist of growing dietary exposure to anthropogenic contaminants. In addition, the recent data also revealed that the country is also recorded the growing prevalence of obesity (Davidson, Krometis, Al-Harthi, & Gibson, 2012).

Over the past few decades marine contamination has been a leading concern in the wake of rapid urbanization and industrialization of Arabian Gulf coastal areas. Metal contamination is of particular concern as heavy metals such as cadmium, mercury and zinc are frequently discharged resulting from shipping traffic of Gulf or from municipal and industrial effluents, and these metal contaminants can enter through the food chain and can bio-accumulate in the tissues of living organisms (Fleming et al., 2006). Major concern is mercury contamination which causes pollution of seafood such as shellfish, fish, oyster and other variety of seafood especially in densely populated places (Bortoli, Gerotto, Marchiori, Palonta, & Tronco, 1995). Most scientifically challenging contaminants out of the other metal contaminants that threatens the aquatic resources are the increasing levels of mercury (Hg) (Krabbenhoft, 2003). Methyl mercury (MeHg) bio-accumulates in fish, a species that is at the top-level of aquatic food chain, MeHg is an organic component that conforms from inorganic mercury and its concentration in fish is approximately 1-10 million times higher than MeHg concentrations found usually in surrounding waters (US Environmental Protection Agency USEPA, 2001; Lawrence & Mason, 2001). The mercury toxicity is mainly transported by dissolved organic matter (DOM) (Strober et al., 1995) which is the major contributor to the pool of organic matter in sea water. Thus, it plays a vital role in the global carbon cycle (Mopper & Degens, 1979; Cauwet, 1978). Further, DOM strongly interacts with mercury, thereby affecting its mobility, speciation, toxicity and solubility in the aquatic environment (Ravichandran, 2004). This paper reviews the process of bioaccumulation of methylmercury through DOM and its effect on the aquatic life and the entire food chain; the study also presents a broad risk assessment of national public health of UAE due to dietary exposure to MeHg.

2. Method

Standard literature review method has been used to evaluate the effect of methylmercury dietary exposure through seafood in UAE. Various empirical studies and journals were reviewed to evaluate the process of bioaccumulation of methylmercury in aquatic environment through DOM and its subsequent effect on the entire food chain. UAE-specific studies were reviewed to examine the dietary exposure to methylmercury and its effect amongst the national population.

3. Results

The review of relevant studies have been categorized into three sections, the first section shows what is DOM and how it interacts with methylmercury in aquatic environment. The next section describes the associated risk of methylmercury in aquatic environment and on the entire food chain and last section provides an insight into formation of methylmercury, its dietary exposure in UAE and its associated risks.

3.1 Dissolved Organic Matter

DOM (Dissolved Organic Matter) is composed of various organic soluble materials that are derived from partially decomposed organic materials (e.g. plant residues and soil organic matter) and other soluble particles released by living organisms (e.g. algae, bacteria, and plants). It is present in all soils dissolved either in flood water or soil solution, but its concentration is usually heavy in aquatic ecosystems and wetland than in agricultural soils. Thus it plays a significant role as it is a source of carbon for microorganisms and also helps in nutrient supply and sequestration (Wright & Reddy, 2009). DOM acts as an organic substrate that fuels the growth of heterotrophic bacteria and algae (Tuchman, 1996; Bernhardt & Likens, 2002). The DOM composition in water body is based on thousands of molecules (Sleighter et al., 2010; Stenson et al., 2003). The nature of source materials and the carbon cycling processes within the ecosystem, that includes terrestrial watershed influences dissolved organic matter’s chemical characteristics in a water body (McKnight & Aiken, 1998; Aiken & Cotsaris, 1995; Fellman et al., 2010). Hence the origin, chemical composition and fate of the various DOM pool components in aquatic systems are not known entirely (Hansell, 2002).

As for its molecular composition DOM has a complex mix of molecules and the unique presence of these molecules in DOM reacts with mercury (Hg) varies. For example, studies of DOM binding mercury have shown that only limited fragment of molecules present in DOM possess the essential functional groups that can help in strongly binding mercury (Haitzer et al., 2002). Even though small fragments of DOM molecules react with Hg, usually large fractions of molecules in DOM are inert with respect to interactions with Hg, particularly under conditions where the concentration of mercury (nanograms per liter) is much less than DOM (milligrams per liter) (Gerbig, Ryan, & Aiken, 2012).

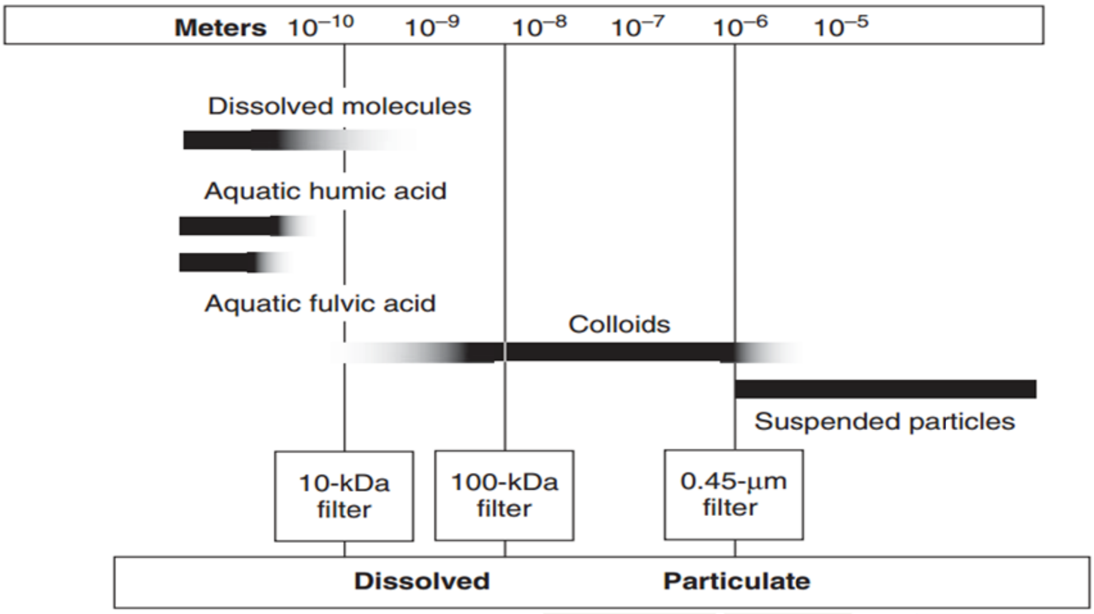

Figure 1. Conceptual diagrammatical representation the distribution of organic matter by size between dissolved organic carbon and particulate in natural waters (Gerbig, Ryan, & Aiken, 2012)

Basically DOM comprises a complex mix of molecules; with heterogeneous continuum of low to high weight of molecules of organic compounds that exhibits different reactivity and solubility. As shown in Figure 1 organic matter are arbitrarily divided into particulate and dissolved organic carbon in natural waters, this division is based on filtration process, which happens generally via 0.45- or 0.7-µm filters (Gerbig, Ryan, & Aiken, 2012). The situation further complicated, in certain processes, of compound pool that DOM is comprised of which may counteract with each other with respect to particular reaction/reactions. The presence of both the compounds (dissolution- inhibiting and dissolution- promoting) is responsible for DOM interactions with bulk and colloidal nano-particulate HgS (s) (Waples et al., 2005; Slowey, 2010). The significant factor that contributes and controls DOM reactivity with mercury are the differences in carbon content and variance in the nature and amount of DOM present in the ecosystems.

3.1.1 Interaction between Dissolved Organic Matter (DOM) and Methylmercury

More than 60 percent of dissolved Hg in coastal waters is associated with suspended particles and organic matters (Fitzgerald & Lyons, 1973). Perhaps one of the key aspects of the cycle of mercury in a water body is its affinity with ligands that are presented in DOM (Driscoll et al., 1995; Lamborg et al., 2004). Dissolved Organic Matter in aquatic environment is ubiquitous and is bound to trace metals; in fact there is increasing evidence that the interaction of DOM with mercury affect their solubility, speciation, toxicity and mobility (Buffle et al., 1988; Loux, 1998). Several previous studies have also shown that there is heavy interactions between DOM and Hg and have indicated that there is a positive correlation between the concentrations of DOM and Hg in many natural waters (Lindberg & Harriss, 1974; Andren & Harriss, 1975; Meili et al., 1991; Mierle & Ingram, 1991; Hurley et al., 1995; Driscoll et al., 1995; Watras et al., 1995; Kolka et al., 1999; Baeyens et al., 1996; Shanley et al., 2002).

The effect of DOM depends on the composition of the micro flora on the uptake ionic mercury Hg^{2+} by microbes as bacteria that reduce iron and sulphate can transform mercury into neurotoxic MeHg which promptly biomagnifies in the food web. On the contrary, complexes of Hg^{2+} can restrict the methylation process, thereby helping to reduce the toxicity and bioaccumulation of this metal (Moye et al., 2002; Drexel et al., 2002; Haitzer et al., 2003; Gorski et al., 2008).

Though it is clearly understood that MeHg is biomagnified and bio-accumulated in aquatic food chain, the environmental factors that influence or control the process of methylation of mercury is not clear. Studies have shown that even low concentrations (~3 mg/L) of natural DOM in aquatic environment influence the methylation and biological uptake of Hg by strongly complexing the Hg^{2+} and methylmercury (MeHg) with organic and inorganic ligands presented in DOM (Dong, Liang, Brooks, Southworth, & Gu, 2010). On the other hand, study by (Ravichandran, 2004), shows that DOM affects the production as well as bioaccumulation of MeHg, fish bioaccumulates mercury the most. The photochemical reduction of Hg^{2+} to elemental mercury DOM plays a key role and subsequently re-oxidation of elemental mercury to Hg^{2+} as a result of this process; it affects the bioavailability and volatilization loss of mercury to organisms. Studies by researchers proves that strong ligands presented in high molecular weight (HMW) DOM can effectively bind Hg thus reducing the availability of Hg^{2+} and MeHg to organisms such as bacteria and phytoplankton (Gorski et al., 2008; Gilmour et al., 2011; Luengen et al., 2012).

Mercury accumulation at higher trophic levels can be reduced with the help of increased algal biomass which will help in the dilution of Hg in consumed algal cells. Under increased algal biomass the bloom dilution will reduce the concentration of mercury per cell, as result it would not only reduce dietary input to grazers but also lower bioaccumulation in eutrophic systems that is rich in algal biomass (Pickhardt, Folt, Chen, Klaue, & Blum, 2002). Although some research has suggested that the structure of DOM may have an indirect impact on the rate of Hg photoreactions; however the exact mechanism of DOM is unknown that facilitates mercury reduction (O'Driscoll et al., 2006). A study conducted by Wedyan, Ababneh, and Al-Rousan (2012) established the fact that there is strong affinity between organic matter and mercury which is primarily related to the physical characteristic of these compounds and not to their chemical reactivity, these physical characteristics play the most significant role in the Hg distribution in the sediments. DOM facilitates the mobility of Hg across the column of water and sediment and also results in enhanced sequestration and concentrations of mercury in sediments (Wallschlager et al., 1996; Cossa & Gobeil, 2000). The source of organic matter and dissolved mercury in sediments is the activity of microorganisms. The DOM in these sediments are consumed by different types of bacteria, as the mercury deposited under new layers of sediments and these bacteria live few millimeters under the water interface, a level where oxygen cannot reach. Chemical reactions that involve iron and sulfur are the source of energy for bacteria and these reactions also generate toxic byproduct which is methylmercury (Wedyan, Ababneh, & Al-Rousan, 2012). Accumulation of mercury in fish is a public health concern globally, reason being fishes are the primary source of toxic MeHg to humans. In the next section we will focus and review the existing literature on the effects of dietary exposure to methylmercury amongst the seafood consumer in UAE.

3.2 Mercury and Methylmercury Associated Risks

Mercury (Hg) is a pollutant that can be found even in distant areas that are far from the actual emission sources. The level of toxicity is differential and is depended on the form of this metal present in atmosphere and that moves between water, sediment, soil and organisms. Mercury (Hg) can enter the aquatic environment through various pathways. Usually this element enters the aquatic ecosystems through the material discharged and transported in the atmosphere or directly from the watershed (Driscoll et al., 2007). Once mercury enters in the water, it is converted into methylmercury (MeHg) by bacteria this process is known as organic complexing. Methylmercury is a neuro-toxic substance and can cause damages to nerve tissue (US EPA, 2001; Environmental and Health Concerns, 2002).

Methylmercury (MeHg) and inorganic mercury Hg (II) from wet and dry atmospheric deposition enters the aquatic environment directly where they are transported to the shores that is bound to either dissolved organic carbon or to suspended humus or soil, MeHg and Hg (II) can enter the water body by leaching onto the upper soil layers from groundwater flow (Morel et al., 1998; USEPA, 1997; Fitzgerald et al., 2007). In the aquatic system the speciation of mercury is determined by the sequence of complicated biogeochemical processes which includes transportation and transformation (Morel et al., 1998; Fitzgerald et al., 2007). The bioaccumulation of Hg in living organisms especially in fishes poses an environmental mercury threat on the entire food chain (Zhou & Wong, 2000; Kennedy, 2003; Nevado et al., 2003; Hylander & Goodsite, 2006). Where smaller fishes eat the MeHg contaminated microorganisms such as plankton, larger fishes feed on the smaller ones, and so the process goes and the fishes that live long feeding on other fishes accumulate higher levels of MeHg in their tissues (Environmental Protection Agency, 2009).

The level of MeHg presented in water body is influenced by the amount of algae presented in it (Graham, 2002). Studies have shown that in an aquatic environment the concentration of elemental mercury is reduced as elemental mercury is converted to methyl mercury by algae/aquatic plants (Graham, 2002; Green, 2002). When MeHg is transferred from algae to herbivore fish it starts to affect fishes by getting interlocked with the proteins within the tissues (Wooltron, 2002). It is then transferred through the aquatic food chain to and eventually to humans through consumption (Meyers, 1998; Wooltron, 2002).

Studies have shown that prolonged exposure to MeHg has negative effects on the developing brain and the central nervous system (Castoldi et al., 2008; Newland, Paletz, & Reed, 2008). However, mercury is present in almost every food and it is difficult for humans to survive only on food that do not contain mercury. The usual mercury intake per week from food is 0.3–1.5 µg/kg body weight (WHO/FAO Provisional tolerable weekly intake (PTWI)). Around 90% of dietary exposure to mercury is through seafood and fish products and 95–100% of MeHg is absorbed from the intestinal tract, perhaps mostly these products contain methylmercury (Patrick, 2002). MeHg is the most toxic form of mercury and is not properly excreted from human body as it is highly lipophilic and therefore considered to be the highest risks to public health (Davidson, Krometis, Al-Harthi, & Gibson, 2012).

3.3 Formation of Methylmercury and Its Dietary Exposure in UAE

In UAE around 90 percent of citizens eat fish at least one meal a week, primary Emirati staple diet has historically been the domestically harvested seafood. There are numerous health benefits that have been documented related to the consumption of fish which includes risk reduction of chronic heart disease; however, fish/seafood also act as agents for heavy metals such as mercury, pathogenic microorganisms such as Vibrio spp. and other toxins like dioxin estimates of the illness resulting from seafood consumption focus on exposure to mercury. Although numerous metals can result in adverse health effects if consumed in seafood, mercury is generally regarded as of greatest concern. Toxicity to aquatic organisms is majorly caused by the heavy metal contamination of the aquatic environment (Buggiani & Vannucchi, 1980). Al-Ghais (1995) investigated the level of metal (such as copper, cobalt, managanese, lead, nickel) concentration in the heart and liver and mercury concentration in muscle tissue using a large sample size of Sparus Sarba a popular fish of UAE that was collected over the period of 4 months and found a heavy mercury concentration in the tissues of these fishes.

3.3.1 Methylmercury Contamination

There have been increasingly serious threats in UAE to aquatic ecosystems and human beings who rely on marine resources for various purposes such as industry, food and also recreation due to heavy metal contamination of marine and costal environments that are introduced via variety of activities and sources including industrial effluents, sewage and brine discharges, oil pollution and coastal modifications (Naser, 2013). The region that is majorly impacted anthropogenically is the Arabian Gulf amongst other regions in the world. Along the Arabian Gulf 83,600 km^2 is occupied by the UAE, with an estimated population of around 7.5 million (as of 2011). The UAE has a diversified modern economy and resultantly faces similar issues that other industrial nations do in relation to public health and environmental problems due to various industrial activities (Gibson et al., 2013a).

Characteristics that contribute to fragile marine ecosystem of Gulf are shallow, warm water, high evaporation rate, relatively slow surface current, and poor flushing, these may in turn aggravate consequences related to heavy metal contamination (De More, Fowler, Wyse, & Azemard, 2004). A study by Gibson et al. (2013b) shows the level of seafood contamination in fish harvested in Sharjah that was estimated using mean and confidence interval values showing high mercury contamination. As per the findings MeHg node was found in continuous triangular distribution (minimum-0.033, mode-0.068 and maximum-0.098) presented in units of mg/kg, the results were particularly observed in *Redspot emperor*.

3.3.2 Dietary Exposure

According to Gibson et al. (2013b), UAE resident could be at the risk of over dietary exposure to methylmercury from consumption of seafood as their level of mercury dietary exposure is much higher than the reference dose due to consumption of fish as maintained by the U.S. Environmental Protection Agency.

Table 1. Estimated accountability of disease due to exposure to methylmercury in the UAE (Gibson & Farah, 2012)

Exposure route	Risks evaluated	Exposure indicators	Adverse health conditions	Attributable fatalities in 2008 (95% CI)	Attributable health care facility visits in 2008 (95% CI)
Food (eating)	Seafood contamination	Methylmercury	Neurological disorders	4(0, 10)	27000(0, 67,000)

Study conducted by Davidson, Krometis, Al-Harthi, and Gibson (2012) using stochastic model estimated that 1 in 5 run into daily risk of dietary exposure to methylmercury through consumption of seafood which is much higher and exceeds the Food and Agriculture Organization and Word Health Organization (FAO/WHO) provisional tolerable intake on a weekly basis. The benchmark for organic MeHg exposure, that they used was WHO/FAO Provisional tolerable weekly intake (PTWI) of 1.6 μg/kg body weight (0.00023 mg/(kg day)) (WHO Technical Report, 2003). Table 2 shows the parameters of varying effects of seafood sensitivity.

Table 2. Sensitivity effects of varying seafood parameters

		MeHg Contamination		Serving Size		Daily Consumption Frequency	
Parameter	Base Case	−10%	10%	−10%	10%	−10%	10%
Average probability* of exceeding MeHg benchmark**	1:05	1:05	1:04	1:05	1:04	N/A	N/A
Daily cases exceeding MeHg benchmark	451,019	375,140	514,800	375,439	514,681	401,273	490,445

*For instance, 1:05 suggests 1 in 5consumers of seafood in the UAE will exceed the benchmark of MeHg on any given day. **FAO/WHO provisional tolerable weekly intake (PTWI) benchmark of 1.6 μg/kg body weight as daily max: 0.00023 mg/kg body weight (WHO Technical Report, 2003). Adopted from (Davidson, Krometis, Al-Harthi, & Gibson, 2012).

Potential human illness symptoms due to lead, mercury or manganese contamination and dietary exposure include neurological effects (including loss of IQ amongst children whose mothers are exposed to MeHg); exposure to other metals such as cadmium can lead to cancers; and cardiovascular disease results from exposure to arsenic (U.S. Environmental Protection Agency, 2008).

As reported, these high probabilities of exceeding levels of reference dose of PTWI of MeHg through dietary exposure of seafood consumers in UAE may give way to additional regulations and policies to reduce this metal exposure. A level of mercury that can be consumed without negative effects by humans over a lifetime is a reference dose (Baker, 2003). Though some researchers still have not drawn to close a possible solution related to MeHg contamination and they continue to attempt to stipulate a standard for safe exposure to mercury levels so that useful advisories on consumption of fish and seafood could be issued effectively (Myers, 1998; Graham, 2003). Nonetheless, any measures taken to limit the exposure of MeHg must be adequately balanced with the various considerable health benefits that are related to the consumption of seafood, particularly keeping the rising levels of obesity in mind that has been recently observed amongst the population of UAE (UAE-UNC, 2010).

4. Discussion

This review reveals that mercury contamination of marine environment in UAE can pose considerable threat to public health. The dominant and major source of mercury exposure is considered to be dietary intake amongst the general population. The inorganic Hg is converted into methyl mercury (organic Hg) once it is released in the aquatic environment where it primarily accumulates in shellfish and fish at approximate concentrations of 1000–10,000 times higher than its presence in other form of foods (Rice et al., 2000). The risk of dietary exposure to Hg through the consumption of shellfish and is subjected to the level of mercury in the seafood and the amount of fish and shellfish eaten on daily/weekly basis. Hence, the Environmental Protection Agency (EPA) and food and drug administration (FDA) have specially advised to avoid consuming fish with high mercury levels to young children, nursing mothers, pregnant women and women who are likely to get pregnant (Mahaffey, 2004; USFDA, 2006). The major concern is the exceeding WHO PTWI levels of dietary exposure to MeHg in UAE and its neurotoxicity effect that can hamper the development of brain and lead to neurological disorders.

Though comprehensive studies have been conducted to determine the bio-accumulation and toxicity of these metals in marine environment and especially in fishes in America and Europe (Pedan et al., 1973; Nickless et al., 1972; Hardisty et al., 1974; Badsha & Sainsbury, 1978), very few, rather limited studies are available in UAE that determine the level of metal contamination in the marine flora and fauna. There is a need for more Empirical studies in UAE that need to be conducted in future to evaluate specific health risks associated with estimated MeHg exposure to better understand the relationship of dose and its related response in terms of public health outcomes (Steenland, 1996; Cohen et al., 2005). There are only limited studies available in regards to the concentrations of these metal contaminants that exist in coastal waters of UAE, and fewer corresponding data on methylmercury concentrations in seafood. Due to this limitation of UAE-specific information, it is challenging to assess the exact nature of public health risks specifically posed by MeHg dietary exposure through seafood (Al Zarooni & Elshorbagy, 2006). Thus, this review may be helpful in providing information for future investigation on the alarming methylmercury contamination of aquatic ecosystem in UAE.

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