Chapter

Natural Polonium-210 in Bivalve Species in Peninsular Malaysia Waters as Recent Pollution Indicator

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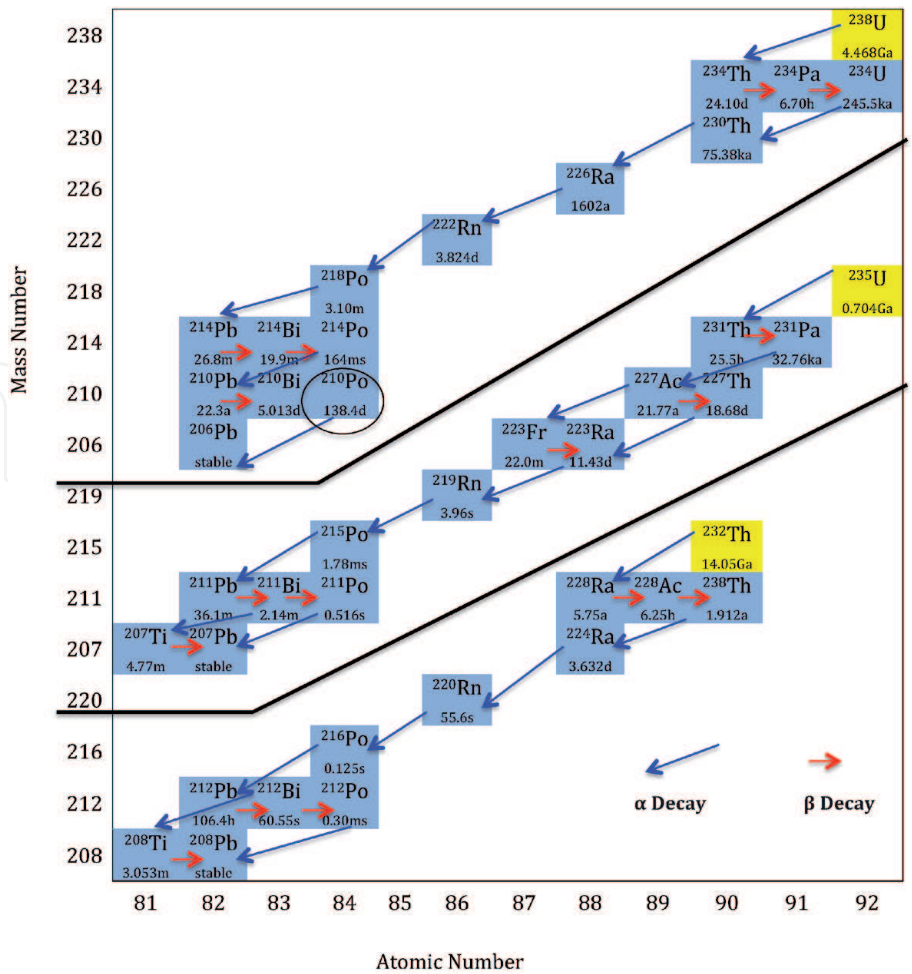
Abstract

Po-210 is an alpha rays emitter in U-238 decay series and a natural radionuclide found in the ocean, and bivalve is the best biological indicator compared to the other organisms because of their feeding methods that are filter-feeding and suspension-feeding. They are able to accumulate toxic substances from marine environment in their tissue and researches were conducted in edible tissues of *Meretrix meretrix, Perna virid, Glauconome virens, Anadara granosa, Anadara ovalis, Pholas orientalis, Donax* sp.*, Polymesoda bengalensis, Phapia undulata,* and *Tellina virgate.* Result showed Po-210 activity distributions were ranging from 2.61 ± 1.50 to 517.46 ± 56.64 Bq/kg. The lowest value of Po-210 activity recorded in *Anadara granosa* and the highest value recorded in *Donax* sp. Small-sized of bivalve species contained higher Po-210 activity than the larger one. Higher Po-210 contents in bivalve obtained from the west coast of Peninsular Malaysia might be closely related to anthropogenic factors from the coastline. This study also found that *Donax* sp. is able to be a good indicator of environmental pollutants as it accumulates Po-210 in higher concentrations than other bivalve species. *Donax* sp. can be found in several parts of Malaysia and available in large quantities but it appears to be seasonal. While for seafood safety monitoring, *Anadara granosa* is capable of becoming a good benchmark for seafood security as it found in most parts of Malaysia. It is not seasonal and a kind of Malaysian favorite seafood.

Keywords: Polonium-210, bivalves, species, pollution, seafood

1. Introduction of Polonium-210

Polonium (Po) is a highly radioactive and semi-metal element that is rarely encountered with the symbol Po and atomic number 84. Polonium is a radioactive element that occurs naturally in very low concentrations in the earth's crust (about one per million trillion). Po has a low melting point and reactive metal in its pure form. Over 25 isotopes of polonium are known, with atomic masses between Po-192 to Po-218 (isotopes are different forms of an element that have the same number of protons in the nucleus but different numbers of neutrons). All isotopes of polonium radioactive but only three have a long half-life that enables to do research which is polonium-208 (42 years), polonium-209 (2.9 years), and Po-210 (138.4 days).



Note: The only long lived polonium isotope, ^{210}Po, is circled.

Figure 1.
The naturally occurring U-238, U-235 and Th-232 decay series, all of which contain polonium isotopes. Source: Carvalho [1].

Po-210 is a natural isotope that has a low melting point, volatile with 50% will vaporize at a temperature of 55° C within 45 hours. Po-210 is soluble in dilute acid but partially soluble in alkali. Po-210 is a product of the radioactive decay series of uranium-238 together with lead-210, it is one of the two products of decay of radon-222 and it decays to lead-206, which generate stable alpha particles. The energy released by the decay is more than 140 watts and temperature reach above 500° C.

Polonium-210 (Po-210) is produced by the natural decay of uranium-238, released widely in small amounts in the earth's crust (**Figure 1**). Uranium ores contain less than 0.1 mg of Po-210 per ton due to lack of Po-210 source. It will produce by synthetically in nuclear reactors by bombarding bismuth-209 (stable isotope) with neutrons. This form bismuth-210, which has a half-life of 5 days and beta emitter decays to produce Po-210. A large number of milligrams of Po-210 can be produced in addition to Po-209 and Po-208 by bombardment of bismuth-210.

Po-210 is usually used as a chemical to eliminate the effects of static electricity in the industrial paper processing machinery, sheet, plastics and synthetic fibers [2]. Po-210 is generally coated on a support foil and put in the brush holder, tube or other. The alpha particles from polonium ionize adjacent air and air ions then neutralize static electricity on the surface in contact with air. These devices typically need to be replaced every year because of the short half-life of this radioisotope. Po-210 is also used in brushes to remove dust from photographic film and camera lenses. Static electricity eraser materials usually contain tens to hundreds of Po-210 mCi. Po-210 can also be combined with beryllium to produce neutron sources and used as a catalyst for the production of neutrons of the first phase in the creation of atomic weapons [3]. Moreover, Po-210 is also a source of heat for the thermoelectric device.

In the environment, the contaminants of Po-210 is present as naturally and synthetically. Po-210 is highly toxic to human health because it has a high affinity and actively bind tightly and gathered on the particles and tissues of the organism addition to being the main contributor with 90% of the radiation dose and toxicity of naturally accepted by many marine organisms [1]. Humans are exposed to natural radiation in the high rate is through the consumption of food, especially seafood because marine organisms have a high capacity of bioaccumulation of radionuclides and other toxic elements from water. Determination of radioactivity in seafood such as crustaceans, mollusks and fish can be an indicator of the ecosystem and food security situation at the time. The level of this element influenced the quality of the marine environment, marine life and affect human health as the highest trophic level of the food chain. Then the objectives of this writing are (i) to determine the distribution of Po-210 in tissues of different species of bivalves, (ii) to compare the Po-210 concentrations in the tissues of bivalves from different locations, and (iii) to identify the pollution sources of Po-210 in the bivalves species.

2. Polonium-210 in marine ecosystem

2.1 Environment

In the vicinity, Po-210 is naturally present in very low concentrations. Po-210 is produced from the decay of radon-222, it can be found in the atmosphere. Po-210 is also released into the atmosphere during processing phosphate rock to elemental phosphorus. Previous studies have found the deposition from the atmosphere on tobacco leaves are in high concentrations [4]. The content of Po-210 in tobacco smoke is also high and the health impact is greater in smokers than non-smokers. In the marine environment, Po-210 is produced in large quantities by the decay of Pb-210 from the atmosphere. Then small amounts of Po-210 in the ocean are comes from the atmospheric Po-210. While, Po-210 concentrations in river and sea is usually widely varied as they involve the geological system and weathering processes of an area. The concentration of Po-210 is also increased by the presence of industrial activity around the river and the sea [5]. Polonium has existed widely in the environment and the natural background radiation wildlife. Therefore, the study and measurement concentration of polonium is important not only for physical health but also important in the field of geochronology and environmental science.

2.2 Water

Water covers 71% entire surface of the earth and an important medium ecosystem. All the natural elements dissolved in water and water into a source of nutrient storage and transfer medium of nutrients in the ecosystem abiotic and biotic [6]. Then, Po-210 has the same features as the nutrients contained in the surface waters where nutrients and Po-210 is taken as food by phytoplankton and released to other areas such as the euphotic zone [1]. Based on a study by Hong et al. [7] along Japanese waters, Po-210 concentrations in water columns decrease with depth and from winter to summer. Most studies Po-210 and Pb-210 found, the ratio of Po-210/Pb-210 in seawater is less than 1.0 and Po-210 becomes more reactive to organic particles than particles of inorganic [8, 9]. Po-210 activity against organic particles resembling the profile element where the concentrations of nutrients in surface water is low and increased in the mid-depth and reduced to a maximum depth [9, 10]. Po-210 concentrations in seawater are usually depending on the season, chemical and biological factors [7].

2.3 Sediment

Sediment is broken stone fragments that are chemically or by natural weathering. Sediment is the transition between the sandstone. Sediment deposition can occur anywhere and the sea is the last settlement. Sediment interaction with living organisms in aquatic ecosystems is high. There are nutrients in sediments and to be medium for marine life such as seaweed and benthic survive [11].

While sediment is one of the essential components for aquatic life and also a place for accumulate pollutants. Sediment can be an indicator of pollution due to contaminants in aquatic systems deposited on the seabed. Accumulation of pollutants in sediment at the seabed is important for pollution studies. Feature Po-210 has a high affinity bind to the particle that makes the sediment as the main source of contamination indicator Po-210 [12].

Generally, the content of Po-210 increased with increasing amount of silt, clay and organic matter [13]. Po-210 concentrations were high in the sediments occurs as sedimentary fragments of organic waste. Then, sediments rich with Po-210 is an important medium for removal polonium from water column into the organisms [14].

2.4 Marine flora

Marine flora is an important resource in the stability of marine ecosystems and phytoplankton is a primary source in the entire food chain of marine life. Phytoplankton accumulate Po-210 were found in the water column without involving light energy and temperature. This method involves passive adsorption on the surface of cells and cell control the intake of Po-210 in phytoplankton [15]. Po-210 concentrations in marine phytoplankton are varied and depend on the size and composition of the proteins in the cell [15]. Analysis by Cherry and Shannon [16] found the concentration range of Po-210 in phytoplankton at the Peru waters is ranging from 32 Bq/kg to 132 Bq/kg, and studied by Heyraud and Cherry [17] is about 237 Bq/kg. In addition, analysis by Folsom and Beasley [18] found concentration of Po-210 is too low, so the 0:07 Bq/kg in dinoflagellate taken from waters off California are experiencing an explosion of algae bloom.

Laboratory studies have found the accumulation of Po-210 by bacteria and phytoplankton depends on the cell structure protein [19, 20] and it is consistent with studies that have been conducted in animal protein [21, 22]. Seaweed or algae is rich in protein but Po-210 concentration is high in seaweed [14]. The level concentration of Po-210 is high in seaweed during winter and low during summer [23]. Finally the levels of Po-210 in marine biota were also influenced by the changing seasons with ranging from 10 Bq/kg to 70 Bq/kg especially in crab, squid and fish [17].

2.5 Edible seafood - bivalve

The feeding activities of bivalve usually proportion the contents of water column and sediment–water interface of seabed. These relationships provide ecosystem services that affect the entire food chain. Bivalves are an essential component in the river and ocean because it can act as a filter for bacteria, algae and other small particles. The ability of bivalves as a natural filter improves water quality, particularly marine ecosystems. Malaysian water is rich coastal area of sandy and muddy mangrove habitat is suitable for a variety of flora and fauna. Malaysia's tropical climate is hot and humid all year creating diversity on land and sea. This makes Malaysia is rich in marine life, especially species of shelled bivalves. Species of bivalves are often used as a food source population is as clams (*Meretrix meretrix*), Mussels (*Perna viridis* & *Glaucoma virens*), Shellfish (*Anadara granosa*), Conch shell (*Anadara ovalis*), Mentarang (*Pholas orientalis*), mussels (*Donax* sp.), seashell mangrove (*Polymesoda bengalensis*) and lala (*Phapia undulate* & *Tellina virgata*) and others can be found throughout Malaysia, especially coastal areas of Peninsular Malaysia (**Figure 2**).

Previous studies have found particularly bivalves *Mytilus* sp. able to accumulate toxic heavy metals found in the environment [24, 25]. These organisms accumulate many contaminants found in the water column as well as a bio-indicator contamination of an area [26]. Many studies have been conducted and found that alpha particles naturally released Po-210 accumulated in the tissues of various marine organisms, especially in organisms at high levels and concentrations higher than Pb-210 [22, 27] and tissue hepatopancreas in animals marine invertebrates has the highest concentration of natural dose in the marine ecosystem [17, 28, 29]. In the United Kingdom, researchers are focusing on fish and shellfish in areas that are not contaminated to trace the source of natural radionuclides produced by anthropogenic. The concentration of radionuclides Pb-210, Ra-226, U-238 and Th-232 in marine organisms is much lower than the concentration of Po-210 and varied according to diet of the users [30]. The study by Carvalho [31] found that the main exposure Shaheof Po-210 is through the consumption of seafood, the accumulation of these radionuclides is three times higher than people who consume foods mainland.

Bivalve is an organism that takes phytoplankton and suspended particles in the bottom of the sea as a food source. The variations levels of Po-210 in the edible tissue of bivalve is always different based on the digestive technique either using filtration or suspension method [32, 33]. Bivalves that do food intake filtration techniques have concentrations of Po-210 higher than the suspension food intake [34].

Connan et al. [23] found that the concentration of Po-210 in bivalve is highly during winter than summer season. This situation points out that the bivalves less accumulated Po-210 during summer than winter season. In winter season bivalves will produce the gametogenesis and reproductive processes will occur during the summer period [35]. Then there is the interconnection between Po-210 concentrations in bivalves with a variety of physiological, biochemical and sexual abuse that are reported to the concentration of heavy metals in bivalves [36]. Po-210 concentration is also dependent on the sampling location. The study conducted

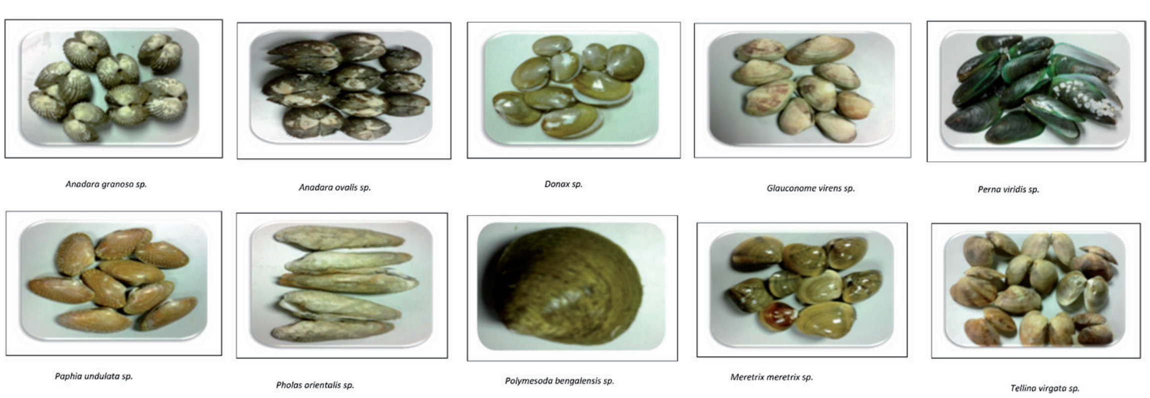


Figure 2.
Various edible species of bivalve in Malaysia waters.

by McDonald et al. [37] in six different sampling locations in Scotland, England, France and Monaco have found concentrations of Po-210 in the soft tissues of the organism is in the ranging from 111 Bq/kg to 459 Bq/kg and depending on the size of bivalve [38]. The level of Po-210 in edible tissue usually increased with decreasing size of bivalve as well reported by Bustamante et al. [34]. But the contrast findings reported by Conan et al. [23], where the larger size of bivalve containing high level Po-210. The difference of this study was more pronounced with age and associating the difference of each species of bivalves metabolism.

The distribution contents of Po-210 in tissue as well as organs with different species, life and habitat of bivalves are not well documented. According to Wildgust et al. [39], digestive organ tissue is about 10% of the total body weight but from that 15–36% is containing Po-210. The digestive system is the main route of Po-210 entering into bivalve body from marine environment. The highest level of Po-210 was recorded in the digestive tissues of *Chlamys Vaira* [34]. The high concentration of Po-210 has also been found in the digestive tissues of several species such as *M.trossulus, Pyessoensis* and *B.cornutus* [40, 41]. The level of Po-210 is different based on the function of organs as well described by Connan et al., [23].

In *Chlamys islandicus*, Po-210 concentrations were the highest recorded in the gill tissue, where the gill is the first organ of polonium entering into the bivalve body [34]. However Connan et al. [23] reported the digestive organ, gills and mantle of oyster containing highest level of Po-210 among other tissues. The concentration of Po-210 in soft tissue of *Chlamys varia* is two to three times higher than *Mytilus edulis* and suitable as pollution indicator but Po-210 concentrations recorded by this species is lower than *Chlamys varia* [34]. Po-210 concentrations in the digestive system was strong relationship with the changing contents of suspended particles, then proposed a major input Po-210 in the organism is of leachate sediment particles in the water column.

3. Human health and pollution indicator

3.1 Human health

Alpha particles are able to penetrate several sheets of paper or epidermis of the skin and can be stopped by clothing and skin. Thus, alpha radiation represents internal contamination and internal radiation hazard only if the particles inhaled, ingested or injected and penetrated through the opening cuts. By weight, Po-210 is 250,000 times more toxic than hydrogen cyanide and one gram of Po-210 can result in 50 million to 50 million of morbidity and mortality in humans [42]. Po-210 only becomes carcinogenic when introduced into the body. External physical exposure is less dangerous. The primary means of exposure is through ingestion of food and water as well as inhalation of air containing Po-210. Animal studies have found that 50–90% of Po-210 was taken through food and drink will soon leave the body through the feces and the remainder enters the bloodstream [43].

Generally, lung and kidney is important organ compare with others organ in human body. Almost 45% of Po-210, which is eaten, will be stored in the lungs, kidneys and liver, while 10% is stored in bone marrow and the remainder is distributed throughout the body [1]. Through breathing, Po-210 in the air will be deposited in the lungs. Po-210 is inhaled during breathing, either from radon in the air or cigarette smoke, can be stored in the mucous lining of the respiratory tract. The alpha particles emitted in the lungs can cause the cells lining the airways disturbed and damaged. Cell damage can potentially lead to lung cancer. The effect usually occurs in the kidney compared to the lungs, although higher doses in the lungs. Alpha particles are free from Po-210 can interrupt the system by destroying

DNA cells, modifying the structure and function of cells and cause mortality cells. Previous studies have found the risk of mortality from cancer can be occurred and Carpenter et al. [44] reported the radiation of these radionuclides would be affecting the tissue and genetic cause by the alpha particles emitted.

3.2 Po-210 as polluter and pollution indicator

Pollution is the entry of pollutants such as chemicals, noise, heat, light and energy into the environment resulting in destructive effect to endanger human health, natural resources and threatened ecosystems and interfere with the amenity and environmental use. Definition of pollution more informed in accordance with the Environmental Quality Act 1974 which states that pollution is any change either directly or indirectly to the physical properties, chemical, biological or radiation level of any part of the environment with the release, issue or placing waste to the detriment of beneficial uses, which gives rise to a dangerous situation or may be harmful to the health, safety or welfare or other organisms, plants and animals.

Water and ocean play an important role in controlling the balance of wildlife and the environment. Compared pollution on land can be seen clearly and more easily manage, pollution at sea cannot be delimited. Its negative impact will occur globally and are rapidly but cannot be seen with the naked eye. Sea was made barrels such as plastic waste, industrial waste and oil. This situation led to disruption of the ecosystem, destroying habitat and marine life. Even in small concentrations, pollutant toxic components capable of retarding the ability of marine life to breed and grow. The fact that the toxic substance decomposes difficult due to long life than through the food chain causing it to accumulate and poison the animals, especially marine shellfish and its impact will be seen in the highest levels of human food [45].

Radioactive contamination is usually expressed in units of radioactivity per unit area but for international unit (SI) is the Becquerel per square meter (Bq/m^2). The SI unit for measurement pollution in the organism is a unit of radioactivity per unit weight of organisms as Bq/kg. Radioactive contamination may be fixed or removable. In the case of fixed contamination, the radioactive material is distributed by definition, but still measurable. Monitoring involves the measurement of radioactive contamination or radiation dose of radionuclides associated with the assessment or control of exposure to radiation or radioactive substances and the interpretation of results [46]. Methodological and technical details for the design and operation of environmental radiation monitoring program at different types of radionuclides will be guided by the International Atomic Energy Agency standard protocol.

As reported by Utusan Malaysia [47], industrial waste pollution flowing into the sea in Malaysia, especially in the industrial states of Penang, Selangor and Johor had to be addressed. This is because the pollution can affect marine life and the next source of food and traditional fishing economy. For example, the local shellfish contain heavy metals lead and other toxic substances to be used as case studies of high institutes of higher learning and overseas. In fact, many may recall, not long ago there were countries that had prevented the importation of scallops from our country. Another consequence, shellfish breeders Sungai Juru, Penang, which is a major producer of oyster country, reported losses of up to half of the shell as a result of death, death or disability due to the quality of seawater in the state is too bad. In fact, the actual farming shellfish aquaculture is one of the main branches of the state, with cockles *Anadara* sp. 40,000 tonnes in 1991 [48].

The seafood and the result is the main source of protein coastal population. Toxic pollutants and radionuclides are present in marine environments can also exist and be detected in the tissues of marine life. The concentration of toxic substances in the tissues of marine life increases with increasing trophic level. Po-210 radioisotope study in bivalves has been widely carried out abroad. In Malaysia, the research focused on the determination of trace elements, metal and heavy metal and radionuclide studies to be lacking. The main natural radiation exposure is through the consumption of seafood containing radioactive elements [49]. Therefore, many countries and international organizations have been monitoring and determining the health risks of seafood through diet by population and dose seafood safety by the use of human [30, 40, 50–52].

Today many researchers conducting a study on natural radionuclides e.g., Po-210 because a lot negative impact on human health were reported. Previous studies have found marine organisms accumulate Po-210 in high concentrations and food chain is one of the main routes of distribution and accumulation of Po-210 in marine organisms (e.g. [21, 53, 54]).

Ongoing studies towards the marine environmental conditions are important to all countries in an effort to reduce and prevent pollution from becoming widespread. Therefore, constant and systematic monitoring is necessary. The usage of marine organism as a bio-indicator for heavy metal pollutions has shown promising results [8]. Bivalve of *Mytilus* sp. has been a good pollution indicator and is widely used due to its ability to accumulate heavy metals from its environmental habitat [24].

Recently, biological indicator has been used to monitor the concentration level of heavy metals and both the stable and unstable radioactive materials in the marine environments in which has become the norm for researchers worldwide. Organisms capable of accumulating pollutants such as bivalve are preferred as indicators in order to determine the presence of specific pollutants in the environment.

The main characteristics for the bio-indicating organisms are the ability to accumulate widely-spread pollutants, can be easily found throughout the region geographically, may survived a whole year round, highly sensitive and tolerant of pollutants without affecting the organisms itself, may be easily obtain for sampling and preservation as well as showing positive correlation between pollutant concentration and environmental pollution [55]. In addition to its ability to act as a pollutant source and environmental quality bio-indicator, it also allows comparisons between elements such as heavy metals and radioisotopes in organisms from different geographical areas.

4. Sampling and methodology

Malaysia has nearly 4800 km of coastline area that includes sandy beaches and muddy beaches. The region is rich in rich resources and livelihoods that are vital to the stability of the ecosystem and contribute to the national economy. This makes Malaysia rich in marine life, especially for bivalve species. These species can be found throughout Malaysia, especially the coastal areas of Peninsular Malaysia.

The sampling has been carried out carried out during March to December of 2012 around the shoreline areas of interest around Peninsular Malaysia and the sampling location is as shown in **Figure 3**. The bivalve samples were purchased from around the coastal areas of each state (**Table 1**).

The samples obtained were frozen and taken back to the Chemical Oceanography Laboratory, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor. In the laboratory, the species of each sample was identified. A total of 10 species per species were taken at random for analysis. Once the species was identified, the samples were cleaned from sediment, epiphyte, epifauna and washed with distilled water. The soft tissue portion of the bivalve was removed and separated from the shell. The weight of wet tissue was measured using an electronic

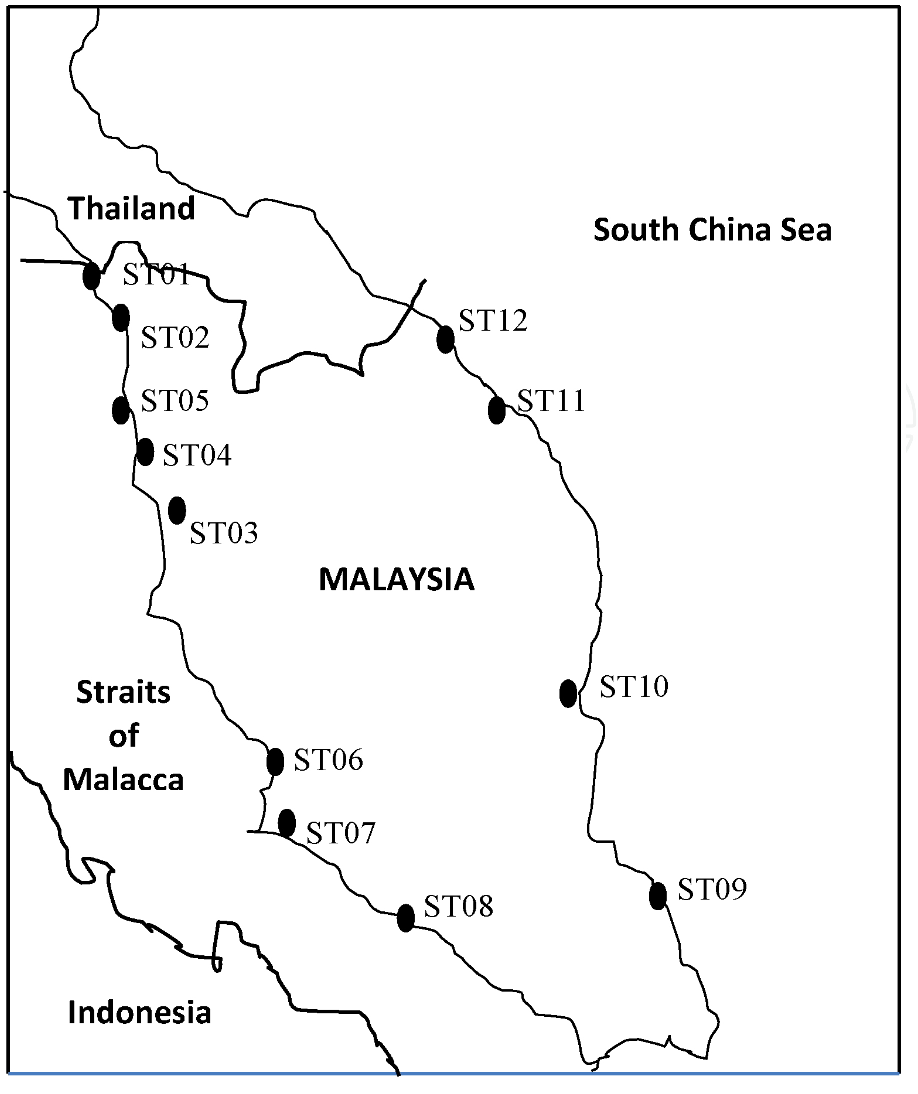


Figure 3.
Sampling location conducting during this study.

State	Station	Location	Date of sampling
Perlis	ST01	Penjaja Kuala Perlis	April 2012
Kedah	ST02	Pasar Basah Kuala Kedah	April 2012
Perak	ST03	Pasar Kuala Gula	April 2012
Pulau Pinang	ST04	Pasar Basah Juru, Seberang Perai	April 2012
	ST05	Pasar Bayan Baru	July 2012
Selangor	ST06	Penjaja Pantai Remis, Kuala Selangor	September 2012
	ST07	Pasar Basah Tanjung Karang	September 2012
Melaka	ST08	Penjaja Sebatu	December 2012
Johor	ST09	Pasar Basah Mersing	March 2012
Pahang	ST10	Pasar Nelayan Berserah, Kuantan	July 2012
Terengganu	ST11	Penjaja Setiu, Kuala Terengganu	October 2012
Kelantan	ST12	Pasar Siti Katijah, Tok Bali	July 2012

Table 1.
List of sampling sites were conducted during this study.

scale and readings were taken. Then, the samples were dried in an oven at 60°C for 24 hours to obtain the dry weight of the tissue. Once dried, the dry weight of tissue is taken. The difference in weight is between 15 and 20%. The dried samples were incised using mortar and stored in aluminum foil for radiochemical analysis.

A modified radiochemical separation method has been used for Po-210 analysis in the organism samples (e.g., [56–58]). The known Po-209 traces were added to 0.5 g of dried samples. Then, the samples were dissolved and digested using HNO_3 and H_2O_2. Once digested, the solution is filtered and heated to a moderate temperature for the evaporation process to occur till it dries. The dried sample solution was dissolved in 50 ml of 0.5 M HCl. The ascorbic acid was added to lower Fe (III) and Po-210 was deposited on silver discs of 2 cm in diameter for 3 to 4 hours at 70 to 90° C. The silver discs were then dried and the Po-210 activity was calculated with the Alpha Spectrometer system. Po-210 radiochemical analysis was performed within 2 months from the date of sampling and activity was calculated on the sampling date. The quality of the method and analysis were determined using the IAEA-134 standard reference material.

5. Distribution of Po-210 in the edible tissues of bivalve species from Malaysian waters

The results showed that the concentration range of Po-210 in the studied bivalves was in between of 2.61–517.46 Bq/kg based on **Table 2**. The lowest Po-210 concentrations in bivalve tissue were recorded in *Anadara granosa*, and the highest values were recorded in *Donax* sp. In general, it can be observed that the concentration of Po-210 in the bivalve tissue decreased with increasing tissue weight and shell size. This relationship is shown in species *Anadara granosa, Anadara ovalis, Meretrix meretrix, Paphia undalata, Pholas orientalis* and *Polymesoda bengalensis.* The concentration of Po-210 was found to be higher for the smaller-sized individuals compared to larger ones. Based on Ryan et al. [38], the Po-210 concentration depends on size. The results are concordant with previous study [34, 46, 59].

Bivalves filtering water from environment for food intake which Po-210 present in the environment [60]. The concentration of Po-210 in bivalves depends on the content of Po-210 found in food [61], the rate of food intake, the degree of absorption of food by bivalves [62] and the rate of Po-210 metabolism [46]; all these

Species	Size range (mm)	Range of Po-210 concentration (Bq/kg)
Anadara granosa	15–32	2.61–308.54
Donax sp.	15–24	34.34–517. 46
Anadara ovalis	21–56	3.03–221.65
Meretrix meretrix	25–57	12.45–419.12
Perna viridis	55–80	12.45–41.10
Paphia undulata	30–45	28.0–288.0
Pholas orientalis	65–104	18.13–200.2
Glauconome virens	22–35	47.71–234.97
Polymesoda bengalensis	55–66	4.92–50.14
Tellina virgata	29–39	31.37–169.54

Table 2.
The range of size and Po-210 concentration for ten species in this study.

factors depend on the size and weight of bivalves. The concentration of Po-210 in small-sized bivalve tissues is higher because it has a higher rate of metabolism to grow and its nutritional activity is higher than that of larger and older bivalves [63]. In terms of general physiology of life, the small size of organism is still in juvenile stage, therefore, has yet to have a matured organ system. The juvenile organ system is unable to function properly as it contains substances that cannot be absorbed by the juvenile organ and accumulates in the body [46].

Moreover, physically smaller size and weight contributes to a smaller volume. When the amount of Po-210 read as per the volume of bivalve will give a greater concentration reading value then a higher concentration of Po-210 is found in the bivalve smaller in size with low volume. A factor that also contributes to the high concentration of Po-210 in small-sized bivalve species is movement. The smaller and lighter size facilitates the movement of bivalve, the more movements performed the wider the area traversed then the more Po-210 from the environment will accumulate in the tissues.

However, it differs with *Donax* sp., *Perna viridis, Pholas orientalis* and *Glauconome virens* in which has shown that an increased size of the shell exhibits higher concentration of Po-210 in the tissue. As for *Pholas orientalis* and *Tellina virgate,* the level of Po-210 is proportion with tissue weight as similar as published by Conan et al. [23]. According to the study conducted, larger-sized bivalves have higher concentrations of Po-210. The differences in the results of our study are more clear shows by relating the effects of age and the difference in metabolic rate of each species of bivalve.

In addition, the physical characteristics of the thickness and physical structure of the shell may also be contributing [64]. Notably, *Donax sp.* and *Pholas orientalis* has thin and consistent shells for every size. Physically, the absorption of Po-210 from the environment is high at a larger surface area. *Donax* sp. and *Pholas orientalis* the larger ones have a surface area for greater absorption. Thus, the concentration of Po-210 is higher with increasing size. The feature of having a consistent shell thickness for each size can also be observed in *Perna viridis* However, these features are not seen in *Tellina virgata* and *Glauconome virens* because it has a thick shell and its thickness increases with increasing size.

5.1 Concentration of Po-210 in different species of bivalve tissues

Based on **Figure 4**, it can be seen that the highest average Po-210 concentration in the bivalve tissues was recorded in *Donax* sp., followed by *Meretrix meretrix, Glauconome virens, Paphia undulata, Tellina virgata, Anadara granosa* and *Pholas orientalis* with a Po-210 concentration more than 50.0 Bq/kg. On the other hand, the *Anadara ovalis, Perna viridis,* and *Polymesoda bengalensis* recorded an average less than 50.0 Bq/kg. The same characteristics can be observed in the five species that record the highest Po-210 concentration values are taxonomically from the order Veneroida. Veneroids generally have thick and muscular valve muscles of the same size [65], most of these species move actively against the sessile. It tends to be filtered eater and eat through chambers paired with suspension with folded gill structure features. Veneroida habitat is at the base of shallow substrate shallow water and sandy beaches [66]. For *Anadara granosa*, nutrient uptake from the water column and direct interaction with sediment on the seabed is a factor of high Po-210 concentration in its tissues [67]. Bivalve is an organism that takes phytoplankton and suspended particles on the seabed as food sources. The activity of Po-210 in organic particles resembles the profile of nutrient elements where the concentration is low on the surface of the water and increases at mid-depth and decreases at maximum depth [9, 10]. The variation rate of Po-210 concentration in

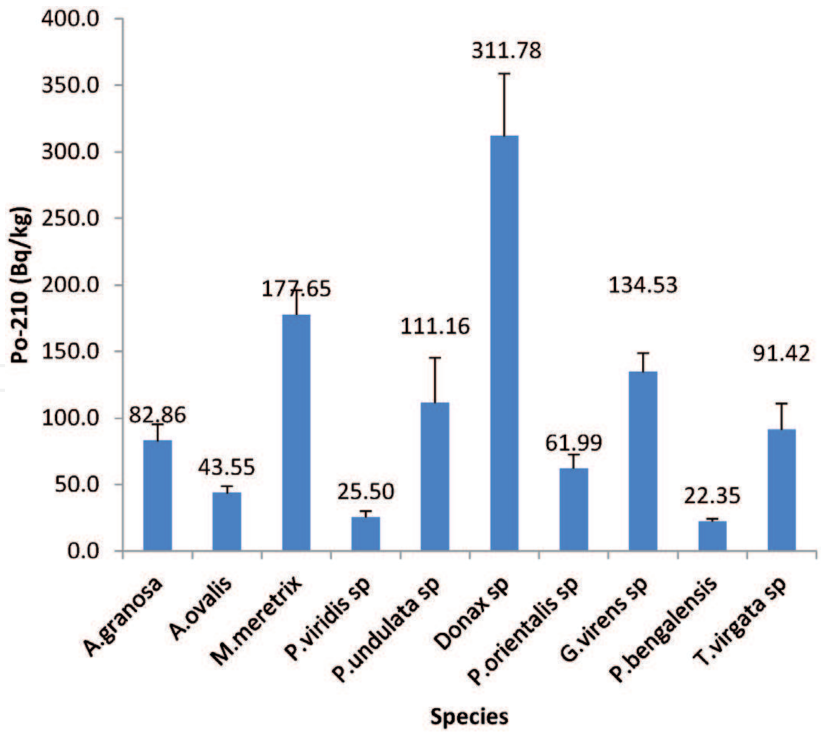


Figure 4.
Contents of Po-210 in edible tissue of bivalve species.

most bivalves is also high based on its nutritional techniques. Bivalve that performs filtered food intake technique has a higher content of Po-210 concentration than those that perform food intake technique by suspension [34].

The habitat of bivalves also influences the concentration of Po-210 in its tissue [67]. The results of this study found that bivalves living in muds such as *Pholas orientalis* and *Polymesoda bengalensis* have lower average readings compared to *Polymesoda bengalensis* that lives in mangrove swamps. In general, the content of Po-210 increases with increasing silt, clay and organic matter [13]. The high Po-210 concentration in the sediment is due to the sedimentation of organic debris. Therefore, sediment rich in Po-210 is an important medium for the transfer of polonium from water column to the organisms [14].

Differences in sizes may also contribute to the content of Po-210 concentrations in bivalve tissues. Small-sized bivalve species contain higher concentrations of Po-210 than larger ones. The average sample size of *Donax* sp., is 20 mm, followed by *Anadara granosa* with an average size of 25 mm, *Glauconome virens* with an average size of 29 mm, *Tellina virgate* with an average size of 33 mm and *Meretrix meretrix* with an average size of 34 mm. Meanwhile, the largest average size is the *Pholas orientalis* with an average size of 89 mm following *Perna viridis* with an average size of 62 mm and *Polymesoda bengalensis* with an average size of 60 mm. The same findings were obtained as distribution in each species, which the smaller the bivalve's size, the higher the Po-210 concentration in the tissue. The physical factors such as smaller size and weight also contributes to the concentrations. The small size gives the lower volume value, therefore the higher Po-210 concentration value will be found in the smaller sized bivalves tissue as the amount of Po-210 concentration obtained will be divided by the weight of the sample of the studied organism.

5.2 Contents of Po-210 at different pollution sources

The highest average concentration of Po-210 in the tissue of *Anadara Granosa* was recorded in samples taken from Kedah following by Johor and Perlis with the concentrations of >60.0 Bq /kg (**Table 3**). These three areas are located in the west coast of Peninsular Malaysia. The highest average concentration of Po-210 recorded in the tissues of *Anadara ovalis* from Melaka with an average concentration of 107 Bq/kg followed by samples from Perak at 41 Bq/kg. Whereas, for *Meretrix meretrix* the highest concentration was from the location of Kelantan, followed by samples from Perlis at a value more than 100 Bq/kg. For *Paphia undulata,* samples from the Pahang are deemed higher than the samples taken in Selangor. Lastly, a higher concentration was recorded in Perlis for *Pholas orientals* rather than samples from Selangor. Overall, the relationship between Po-210 concentration and sampling location is unclear as not all bivalves species are obtained from each location. However, the sampling location located west coast of Peninsular Malaysia recorded higher Po-210 concentration in most bivalves species studied. The concentration of Po-210 in seawater depends on the season, chemical and biological factors [68, 69]. Connan et al. [23] found that Po-210 concentration was higher during winter and lower in summer. This situation indicates that bivalves accumulate less Po-210 during the summer than in winter. Winter is the season for bivalves to undergo gametogenesis while reproduction process occurs throughout the summer [35]. Thus, there is an association between Po-210 concentration levels in bivalves with physiological, biochemical and sexual variations as well as seasonal changes. The discrepancy in the results of this study may be due to the sampling conducted throughout March to December 2012. The inconsistent weather changes throughout the year may be the factor for different Po-210 concentrations for each species from different locations. Previous study by Khan [46] showed Po-210 concentration among mussels varied significantly based on the season and the concentration is lesser during monsoon due to physiological and metabolic changes.

Besides that, the concentration of Po-210 also depends on the sampling location. A study conducted by McDonald et al. [37], six different sampling sites in Scotland, England, France and Monaco has shown that the concentration of Po-210 in the soft tissue of the organism was in the range 111–459 Bq/kg. The level of industrial development in an area contributes to the anthropogenic entry of Po-210 into the sea [1]. In this study, the Po-210 concentration values were higher in bivalves sample taken from west coast of Peninsular Malaysia rather than samples taken from the east coast location. The Straits of Malacca is a strategic location for major international shipping lane and the concentration of agriculture, industry and urbanization on the west coast of Peninsular Malaysia, which lead to the pollution [70]. The removal and release of toxic materials from ships may be a factor of high Po-210 concentration. The industries such as coal power station and processing factories at the west coast of Peninsular Malaysia discharge or release their effluents through air, river or sea and finally settle into the ocean. The effluent and radionuclide derivatives also contribute to the high concentration of Po-210 in bivalve's tissue. In general, samples obtained from west coast such as Perlis, Penang, Johor and Kedah gave higher readings of almost all bivalves species studied. No obvious factor can be discussed due to the lack of industrial area in Perlis. The possibility is probably due to both location geographically are close to Thailand. Seasonal factors and wind speeds may be associated with high Po-210 concentration content in samples from this location [71]. The transfer of particles containing Po-210 from the air, land or nearby ocean may occur because Po-210 is known to have a high affinity bound to the particles [12]. According to the study of Theng et al. [72], the concentration of Po-210 in clams in Kuala Selangor is based on environmental factors and sampling location. The content of the Po-210 concentration in the bivalve studied was different at different locations (**Table 4**). Mustafha et al. [80] stated the Po-210 concentration vary greatly in different locations.

State	Species of bivalve (Bq/kg)									
	A.granosa	*A.ovalis*	*M.meretrix*	*P.viridis*	*P.undulata*	*Donax* **sp.**	*P.orientalis*	*G.virens*	*P.bengalensis*	*T.virgata*
Perlis	98.09	24.21	187.63	—	—	—	71.66	—	—	91.42
Kedah	124.77	—	97.38	—	—	—	—	—	—	—
Perak	72.78	41.05	—	—	—	—	—	—	—	—
Pulau Pinang	93.53	—	—	—	—	—	—	134.53	—	—
Selangor	70.44	23.90	163.31	—	40.49	311.78	52.31	—	—	—
Melaka	16.48	107.16	—	—	—	—	—	—	—	—
Johor	105.64	—	—	25.50	—	—	—	—	—	—
Pahang	—	—	—	—	181.61	—	—	—	—	—
Terengganu	—	—	—	—	—	—	—	—	22.35	—
Kelantan	—	—	284.39	—	—	—	—	—	—	—

Notice: (–) samples unavailable during sampling.

Table 3.
Average contents of Po-210 in various species of bivalve from different states in peninsular Malaysia.

Location	Po-210 (Bq/kg)	References
Peninsular Malaysia	2.61–518	This study
Kapar, Malaysia	4.61–240	Alam et al. [71]
Cuba	21–30	Alonso-Hernandez et al. [56]
England	16–36	Young et al. [73]
India	305–597	Suriyanarayanan et al. [14]
Ribble Estuary	29	Rollo et al. [74]
Portuguese Coast	5.8–132	Carvalho [75]
Kuala Selangor, Malaysia	31.2–92.4	Theng and Mohamed [76]
Kudankulam Coast, India	5.4–248	Khan and Wesley [77]
Tiruchirappalli, India	57.42–106	Shaheed et al. [78]
Kalpakkam, India	35.19	Iyengar et al. [79]

Table 4.
Concentration of Po-210 in mollusks tissue results from studies around the world.

6. Conclusion

The study found that the concentration of Po-210 is varied in different species of bivalve. Biological, chemical and physical factors as well as seasonal and sampling location contribute to the different concentration of Po-210 in the bivalve tissues studied. The study found that the distribution range of the concentration of Po-210 in bivalves were between 2.61–517.46 Bq/kg. The lowest concentration of Po-210 in bivalve tissues recorded in *Anadara granosa* and the highest was recorded in *Donax* sp., Smaller size bivalve species contain high concentration of Po-210 compare to bivalve with larger size. In addition, high concentration of Po-210 in bivalve tissues from the west coast of Peninsular Malaysia were observed to have a relationship with the anthropogenic factors which is industrial activity and shipping routes along the coastal.

Recent finding in this research showed that for the observation of environment pollution specifically marine pollution *Donax* sp. can be a good indicator because it accumulated more Po-210 compared other species. Although, *Donax* sp. is present seasonally, it can easily found in Malaysia and large quantity. As for seafood safety monitoring, *Anadara granosa* able to act as a good indicator as it can easily found in parts of Malaysia all year and in addition to being the main food in Malaysia.

7. Suggestion for the future research

1. Further studies on the impact of taking seafood containing Po-210 can be carried out using the data from this research and based on the total daily intake of seafood by the locals. Through risk assessment, safety dose and the risk of disease can be determined.

2. More study should be done on *Donax* sp. including life cycles, contents of others trace elements and may be used as a good indicator of pollution.

3. Radionuclide monitoring studies need to be done in each species of marine organisms that act as the main seafood source for the local people.

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Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

Thanks.

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