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Heavy metal and radioactive contamination in the sea

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Abstract

Seas and oceans have always been affected by human activities. These activities leave various and harmful effects on the marine environment in different dimensions. The extent of these destructive impacts depends on how humans interact with nature. Generally, two types of these impacts, which include pollution and physical destruction, can be examined and tracked. Pollution usually arises from human intervention, either directly or indirectly, and the entry of materials or energy into the marine environment, which in turn causes harm to biological resources, human health, prevents various marine activities such as fishing, and leads to qualitative disturbances in the use of seawater and a reduction in marine facilities. On the other hand, physical destruction includes the destruction of marine habitats directly due to grounding of ships, their anchoring, or construction activities. In general, the destruction of marine habitats is primarily caused by shipping activities. Thus, the pollution aspect is of greater importance.

Keywords: Pollution; Water; Heavy metal; Contamination.

1. Introduction

1.1. Sources of Pollution

Three sources of marine pollution that have been extensively studied include coastal, atmospheric, and offshore sources. Coastal sources are divided into two groups: point coastal source and non-point coastal source. Point sources include the direct discharge of polluted water from coastal industries and development sites into the sea such as factory and hospital waste (Ojaghi *et al*., 2021). While non-point sources include extensive activities such as agriculture and forestry, which often lead to the infiltration of various substances into groundwater that ultimately flows into the seas (Tekman *et al*., 2023).

It is worth noting that point and non-point sources do not necessarily have to be located next to the sea and its shores. Today, urban coastal areas are considered major sources of pollution, as in many parts of the world, especially in developed countries, urban waste and sewage are discharged into the seas without any specific treatment.

The emission of greenhouse gases from airplanes into the atmosphere is a source of marine pollution. Pollutant compounds are dispersed over a wide area depending on the prevailing wind direction and weather conditions in the region, and they can remain in the atmosphere for a short or long period. These compounds usually enter the seas through rainfall. Atmospheric pollutants more than through persistent organic pollutants, some of which are volatile compounds and highly toxic, contaminate marine environments.

Offshore sources are generally generated by ships. Although ships pollute marine environments in various ways, they account for a small share (about 10 percent) of the total pollution (Tan, 2005).

1.2. Types of Pollutants

Based on conducted studies, marine pollutants are divided into three major groups, which include:

1) <u>Biological Contaminants and Hazards</u>

This group of pollutants includes pathogens such as bacteria, viruses, and parasites, and toxins that are generally produced by biological parameters.

2) <u>Chemical Contaminants and Hazards</u>

Chemical pollutants are divided into two major groups: organic and inorganic (non-organic) pollutants. In the group of organic pollutants, compounds such as: pesticides and PCBs; hydrocarbons and various petroleum compounds; and Persistent Toxic Substances (PTS) are placed, while heavy metals are considered one of the main mineral pollutants (Xiang *et al*., 2022).

3) <u>Radioactive Hazards</u>

Exposure to very high levels of radiation, such as from being near a nuclear explosion, can have acute health effects such as skin burns and acute radiation syndrome. It can also lead to long-term health effects such as cancer and cardiovascular disease. In this research, mainly heavy metal pollution and radioactive compounds have been addressed (Yamamoto, 2013).

1.3. Heavy metals pollution

The term heavy metals generally refer to a group of metallic elements with atomic weights between 63.546 and 200.590, and a specific gravity greater than 4, which mainly includes

Alkali metals, Alkaline earth metals, Lanthanides, and Actinides. These metals are natural compounds of the Earth's crust.

Minor amounts of some of their types, such as cobalt, copper, and zinc, are essential micronutrients that play a major role in metabolic activities. In contrast, metals such as mercury, lead, and cadmium not only have no vital or beneficial role for microorganisms but also have severe harmful effects. Heavy metals usually have the properties of toxic resistant compounds, and since these compounds are non-degradable, they typically bioaccumulate and cause acute or chronic toxic effects. Their toxicity and pathogenicity vary depending on the types of heavy metals; for example, mercury and some of its compounds, even when absorbed in small amounts, have severe effects on the brain and central nervous system, while short-term contact with Nickel has no effect, but prolonged contact causes skin irritation or liver damage.

Heavy metals are found in marine environments worldwide, especially in sedimentary habitats. These metals primarily enter marine environments through river currents or atmospheric deposits, and despite their consumption in industrial stages, the direct entry of these compounds from industrial sources has decreased (Figure 1). The deposition of metals in heavily polluted areas such as bays and ports, as well as the dredging of shipping channels that contain large amounts of contaminated compounds that later enter the sea, is very common.

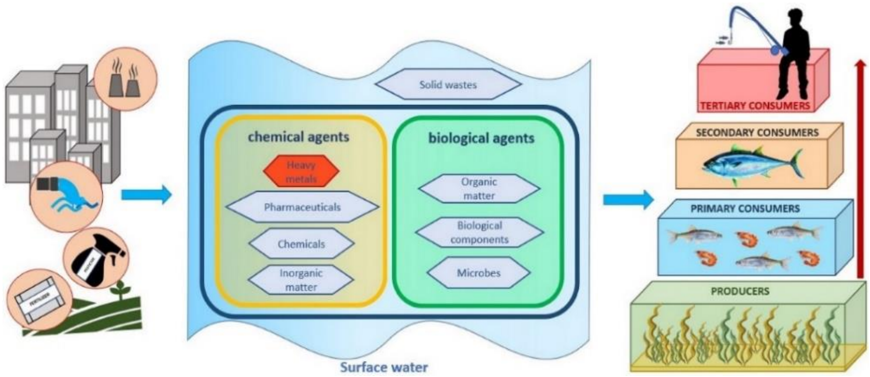

Figure 1. Ways of entry of some heavy metals (cadmium, arsenic, mercury, lead, barium, selenium, and chromium) into waters and the atmosphere (Piwowarska *et al.*, 2024).

1.4. Radioactive material pollution

From the beginning of the creation of the world, radioactive materials have existed. More than 60 radioactive elements exist in nature (Eisenbud and Gesell, 1997), which are categorized into three groups:

1. The very ancient group (primordial) that existed before the formation of the Earth.
2. The primary group (cosmogenic) that has arisen due to the interaction of cosmic rays.
3. The human-produced group (human produced) that has formed or increased due to human activities.

In the first group, elements such as Uranium 235 (U^{235}), Uranium 238 (U^{238}), Thorium 232 (T^{232}), Radium 226 (Ra^{226}), Radon 222 (Rn^{222}), and Potassium 40 (K) 40 are included, which have existed since the beginning of the world.

The second group usually has a source outside the solar system and includes elements such as Carbon 14 (C^{14}), Tritium (H^3), and Beryllium (Be^7).

In the third group, elements like Tritium (H^3), Iodine 131 (I^{131}), Iodine 129 (I^{129}), Cesium 137 (Cs^{137}), Strontium 90 (Sr^{90}), Technetium 99 (Tc^{99}), and Plutonium 239 (Pu^{239}) are found, which have amounts less than the aforementioned elements in nature.

Therefore, the result of the emission of particles and electromagnetic waves of isotopes, alpha, beta, and gamma radiation of unstable radioactive elements of some chemical elements is a natural phenomenon. In this regard, radioactive compounds also exist naturally in seawater. The natural and primary sources of these compounds in seawater are rocks and minerals that are in contact with the waters. In some specific areas, radioactive gases that are released from molten magmas dissolve in the waters. Studies show that three natural sources of radioactive compounds in the seas include potassium-40 and also the decay products of uranium and thorium.

Human activities in some areas cause an increase in radioactivity (Figure 2). Recent research by scientists has enabled humans to produce unstable isotopes; this instability is eliminated by their return to a stable state. During these processes, emitted radiation energy is released, which has various applications, including electricity generation or motor fuel (Love, 1951).

Human sources of marine radioactive pollution include the discharge of cooling water from nuclear power plants and wastewater from reprocessing plants, the release of radioactive materials from ships, military weapon testing, and the storage of solid nuclear waste, which, of course, the latter has been strictly prohibited by the London Dumping Convention.

The human and environmental threats of these materials are highly dependent on the activity, biological distribution, and half-life of radioisotopes. Severe exposure to large amounts of radioactive compounds causes various cancers and other diseases such as genetic abnormalities. In short-term assessments, no lethal damage from these compounds has been observed; however, it is worth mentioning that the damage and effects of these materials do not usually occur immediately after contact, while non-lethal genetic damage typically becomes apparent in subsequent generations (Kachel, 2008).

The most prominent way radioactive compounds enter marine environments is related to nuclear industry activities and the accumulation of radioactive waste. Among the most important examples of this case are the discharge of radioactive wastewater from the reprocessing section in Sellafield, England, and the accumulation of nuclear waste from warships in Russian waters.

Figure 2. The exit of compounds and radioactive materials from the seabed

1.5. The entry of contaminated water into the bodies of individuals

Contaminated water with heavy metals and radioactive materials has acute and chronic effects on individuals involved with them, especially divers and naval personnel who are in direct and continuous contact with the waters. These compounds enter the bodies of individuals through various means, the most common of which are:

- Skin (dermal)
- Gastrointestinal system
- Respiratory system
- Mucous membranes (ears, nose, and mouth)

Skin contact

Skin contact is one of the most common ways for contaminated compounds to enter the bodies of individuals. Since these compounds do not evaporate in water, they are positioned with high density and under high hydrostatic pressure in the space between water and the surface of human skin, and under certain conditions, they have effects on the body that exceed inhalation and digestion of these compounds. Contaminated compounds are usually absorbed through the skin by creating a layer that remains in contact with the skin for a long time, leading to contamination.

Studies and reports indicate that divers who do not immediately remove their suits after diving and spend about 30 to 40 minutes or more in diving suits create a suitable environment for the absorption of contaminated compounds through the skin. An important point here is that the presence of scratches and skin wounds is very noteworthy, as through this way, contaminated materials and compounds are absorbed more easily and quickly (Barsky *et al*., 2006).

Gastrointestinal system

Research shows that in many cases, divers swallow some water while diving. If this occurs in an area with contaminated water, it causes gastrointestinal problems for them. In this regard, numerous reports have been published about the occurrence of nausea and indigestion in divers after diving, which is related to their swallowing of contaminated compounds (Barsky, 2001).

Respiratory system and mucosal systems

Contaminated waters from mucosal membranes such as the ear, nose, and mouth not only cause the entry of water, especially problems and diseases in these organs, but also damage the respiratory system and lungs, creating serious issues for divers. In this regard, reports have been published indicating that due to headaches, eye irritation, nasal, respiratory tract, and throat issues in divers after diving in waters containing contaminated compounds, especially organic compounds, irritants, and other types of pollution exist (Barsky, 2004).

Conclusion

2. Effects of contaminated water with heavy metals and radioactive materials on human health

Studies and researches show that contaminated waters have various effects on human health, the most common of which include nausea, diarrhea and vomiting, oral ulcers, skin lesions, skin irritation, seizures, kidney and liver problems, blood pressure issues, neurological problems, arthritic pain, and indigestion. Of course, a noteworthy point is the persistence and repetition of diving activities in contaminated waters, as researchers' studies indicate that the persistence and repetition of diving activities in waters contaminated with heavy metals lead to the development of tumors and various cancers, including: skin cancer, colon, stomach, blood, malignant lymphoma, brain, lung, testicle, prostate, and other types of unknown cancers. Reports indicate that in this regard, cancers of the digestive system, brain, central nervous system, skin, and lungs are among the most common cases reported in divers over the years (Richter *et al*., 2003).

In addition to the aforementioned cases of various tumors and cancers, problems and genetic abnormalities are among the most important signs of contamination with radioactive waters that occur over time. The tables below represent the impact of heavy metals and radioactive materials on human health in details.

Contaminant	Drinking water guidelines	Drinking water NATO guidelines	Environmental concentration	Health risks (Quemeralis, 2006)	Sources/Uses/Potentially contaminated areas
Heavy metals					
Aluminum	0.1 mg/L		<65 mg/L	Nausea, vomiting, diarrhea, mouth ulcers, skin ulcers, skin rashes and arthritic pain	Mining and agriculture, and coal combustion

Contaminant	Drinking water guidelines	Drinking water NATO guidelines	Environmental concentration	Health risks (Quemeralis, 2006)	Sources/Uses/Potentially contaminated areas
Antimony	0.006 mg/L		<9.1 mg/L	Nausea, vomiting, and diarrhea	Industrial dust, auto exhaust and home heating oil
Arsenic	0.025 mg/L	0.3 mg/L	<280 mg/L	Skin cancer	Mining, agriculture and forestry
Cadmium	0.005 mg/L		<166 mg/L	Nausea, vomiting, diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure	Metal plating and coating operations, nickel-cadmium and solar batteries and in pigments
Chromium	0.05 mg/L		<215 µg/L	Damage to liver, kidney circulatory and nerve tissues, skin irritation	Stainless steel, protective coating on metal, magnetic tapes, and pigments for paints, cement, paper, rubber, composition floor covering and other materials, its soluble forms are used in wood preservatives
Copper	1 mg/L		<600 µg/L	Gastrointestinal disturbance, including nausea and vomiting, liver or kidney damage	Household plumbing materials
Lead	0.01 mg/L		<100 µg/L	Kidney problems or high blood pressure	Alkyl lead fuel additives
Manganese	0.05 mg/L		<2.8 mg/L	Neurological problems	Manufacture of alloys, steel, iron products, mining
Mercury'	0.001 mg/L		<10 mg/L	Kidney and brain damage	Dry-cell batteries, florescent light bulbs, switches, and other control equipment, silver and gold mining, and dental amalgams
Selenium	0.01 mg/L		<330 µg/L	Hair and fingernail changes; damage to the peripheral nervous	Electronic and photocopier components, glass, pigments, rubber, metal alloys, textiles,

Contaminant	Drinking water guidelines	Drinking water NATO guidelines	Environmental concentration	Health risks (Quemeralis, 2006)	Sources/Uses/Potentially contaminated areas
				system; fatigue and irritability; damage to kidney and liver tissue, and the circulatory system	petroleum, medical therapeutic emulsions
Uranium	0.02 mg/L		<0.003 mg/L	Lung cancer	Mining
Zinc	5 mg/L		<3.0 mg/L	Gastrointestinal distress, nausea and diarrhea	Mining, Zinc production facilities, iron and steel production, corrosion of galvanized structures, coal and fuel combustion, waste disposal and incineration, the use of zinc-containing fertilizers and pesticides
Radiological					
Natural					
Lead-210	0.1 Bq/L		<12.67 mBq/L	Increased risk of getting cancer	Nuclear weapon testing, Uranium mining,
Radium-224	2 Bq/L			Increased risk of getting cancer	Nuclear power generation,
Radium-226	0.6 Bq/L			Increased risk of getting cancer	Industrial/medical Uses of Radioisotopes
Radium-228	0.5 Bq/L			Increased risk of getting cancer	
Thorium-228	2 Bq/L			Increased risk of getting cancer	
Thorium-230	0.4 Bq/L			Increased risk of getting cancer	
Thorium-232	0.1 Bq/L			Increased risk of getting cancer	
Thorium-234	20 Bq/L			Increased risk of getting cancer	
Uranim-235	4 Bq/L			Increased risk of getting cancer	
Uranim-238	4 Bq/L			Increased risk of getting cancer	

Contaminant	Drinking water guidelines	Drinking water NATO guidelines	Environmental concentration	Health risks (Quemeralis, 2006)	Sources/Uses/Potentially contaminated areas
Artificial					
Cesium-134	7 Bq/L		<13.69 mBq/L	Increased risk of getting cancer	
Cesium-137	10 Bq/L			Increased risk of getting cancer	
Iodine-125	10 Bq/L			Increased risk of getting cancer	
Iodine-131	6 Bq/L			Increased risk of getting cancer	
Molybdenum -99	70 Bq/L			Increased risk of getting cancer	
Strontium-90	5 Bq/L			Increased risk of getting cancer	
Tritium	7000 Bq/L		<12.24 mBq/L	Increased risk of getting cancer	
Total radiological compounds		300,000 Bq/L			

3. Methods and Ways to Combat Heavy Metal and Radioactive Material Pollution in the Seas

Polluted waters and diving in them have specific principles and rules. The importance of the issue is such that in most countries of the world, such as the United States and Canada, protocols and guidelines have been prepared for this purpose and provided to relevant individuals.

For example, one can refer to the activities of organizations such as:

- Naval Sea Systems Command Fleet Readiness Center Southeast Naval Air Station
- Directorate of Dive Safety (D Dive S) Defense R &D Canada
- National Oceanic and Atmospheric Administration (NOAA)

These organizations and entities have provided guidelines for familiarization and how to dive in waters contaminated with various compounds, especially heavy metals and radioactive compounds.

This section will examine the basic principles and common methods for diving in polluted waters (Wells, 1984; Tajada, 1985). These general principles and methods are as follows:

1. Before starting diving activities, it is necessary to have a complete understanding of the dive site and the physical and chemical condition of its water, and this information should be made available to divers and related personnel.
2. All rivers and operational areas where divers and naval personnel practice and operate must be continuously evaluated, and the type and changes in their pollution must be reported.
3. Divers and personnel with open wounds on their bodies are not allowed to engage in activities. If these individuals undergo surgeries for the complete healing of the wound site, they are only allowed to dive with the approval of a qualified physician.
4. Before diving, divers must be fully vaccinated against diseases such as diphtheria, tetanus, smallpox, and typhoid, and if possible, a regular vaccination program should be considered for naval personnel, especially divers who continuously engage in diving activities in various waters.
5. Before and after diving, the divers' ear canals should be rinsed with a 2% acetic acid solution in aluminum acetate (Domeboro solution).
6. If possible, divers should use full diving gear. This gear includes a full face mask, a dry suit with attached boots, a hood, and dry gloves.
7. Before diving in contaminated waters, all diving equipment and systems should be thoroughly inspected.
8. Diving suits and hoods should be carefully checked to ensure there are no tears or holes in them.
9. Exhaust valves should be carefully inspected to completely prevent the entry of water droplets into the mouths and lungs of divers.
10. Studies show that lightweight fiberglass diving hoods are a suitable and common tool for diving in contaminated waters (Figure 3).

Figure 3. The recommended full diving suit for diving in polluted waters includes a full face cover, gloves attached to the suit, and also dry boots attached to the suit

11. Finally, immediately after exiting, divers and their equipment (clothes, regulators, etc.) must be thoroughly rinsed with fresh water for at least 6 minutes and then disinfected with antiseptic solutions such as Betadine.
12. In general, a precise plan must be made for decontaminating divers after exiting polluted waters. These plans should be tailored to the type of contaminants and consider factors such as the chemicals needed for cleaning contaminants, providing sufficient amounts of fresh water, washing equipment, and also suitable basins for this work.
13. All personnel involved in the decontamination process must have complete awareness of the tools and equipment and how to carry out this operation.
14. Continuous medical examinations and check-ups, especially for divers who are constantly active in contaminated waters, are mandatory and essential.
15. Finally, specific protocols and guidelines have been prepared according to the geographical conditions and operational areas of the divers, types of contaminants, and how to deal with them, and these should be provided to the divers so that they can operate with full awareness and information.

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