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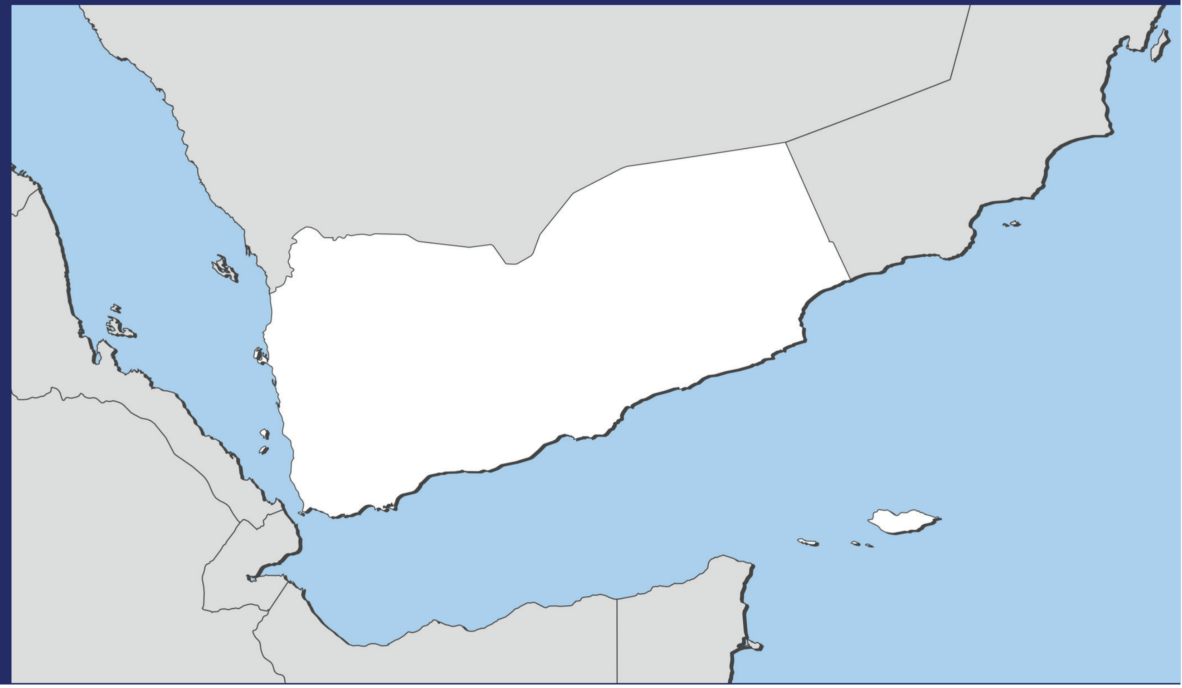

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The Effects of Lead, Cadmium, Mercury and Arsenic on Fish, Sediment and Seawater in Red Sea and the Gulf of Aden at Three Different Locations in Yemen

BY

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ABSTRACT

Increased humanely use of Toxic Heavy Metals such as Lead (Pb), Cadmium (Cd), Mercury (Hg) and Arsenic (As) and their access to the marine environment has caused much concern over the last century. These Toxic Heavy Metals known in the marine environment may lead to toxic effects, even if they are relatively low concentrations at present in living organisms.

In this study, the samples were collected from the three different Cities of Yemeni coasts. The Cities are named as Al-Hodaeidah, Aden and AL-Mukalla, the trial was undertaken for the period of seasons: winter 2011, summer 2012 and winter 2013.

Fresh samples were procured from the showrooms for sale at the public auction adjacent to the fishing grounds. Four species of fish were collected and analyzed: (emperor) *Lethrinus mahsena*, (Longtail tuna) *Thunnus tonggol*, (Pickhandle Barracuda) *Sphyraena jello* and (Areolate grouper) *Epinephelus areolatus*. The samples were as follows: 81 samples of Filtered Surface Seawater, Sediment and 324 fish samples (for Muscle, Lver and Gills)), Which were digested using appropriate acids, tools and different methods, and then measured the concentrations of heavy metals in the samples using atomic absorption spectrometer.

The obtained results showed that the concentration (mg/L) of the heavy metal in Filtered Surface Seawater (Pb 0.061±0.005, Cd 0.007±0.001, Hg 0.007±0.0005 and As 0.008±0.0003) was lower than that of the concentration (µg/g) of heavy metal in sediment (Pb 60.016±2.18, Cd 1.745±1.121, Hg 0.019±0.007 and As 0.099±0.009), while the concentration (µg/g) of heavy metals in fish parts (Pb 0.197 ± 0.096, Cd 0.124 ± 0.075, Hg 0.058 ± 0.043 and As 0.083 ± 0.043).

The mean concentration of Pb, Cd, Hg and As in muscle was 0.101±0.012, 0.046±0.010 , 0.058±0.002 and 0.089±0.002 $\mu g.g^{-1}$ dry wt.

respectively; whereas in liver was 0.196±0.033, 0.132±0.020, 0.102±0.007 and 0.115±0.0005 $\mu g.g^{-1}$ dry wt. respectively; whereas in gill was 0.294±0.042, 0.196±0.063, 0.016±0.0006 and 0.034±0.0005 $\mu g.g^{-1}$ dry wt. respectively.

The results showed that, the heavy metals concentrations were high in stations AL- Hodaeidah and AL- Mukalla and low in station of Aden. Also the heavy metals concentrations were high in summer and low in winter.

The heavy metals concentrations were in higher values in the Liver and Gill and lower in Muscles because the Muscular tissues is not considered as a site of active Mineral accumulation.

During the present study, Pb levels have been seen to be maximum in gill from *L. mahsena* and *S. jello*, and in liver from *T. tonggol* and *E. areolatus*, minimum in muscle in all the fish species.

Cd levels, too, are found to be maximum in gill, minimum in muscle and intermediate in liver of all the fish species.

Hg and As levels, are found to be maximum in liver of all the fish species, except *S. jello* .It was higher in muscle, minimum in gill in all the fish species and intermediate in muscle in all the fish species except *S. jello* .

In all the investigated fish species, *L. mahsena, T. tonggol, S. jello* and *E. areolatus*, gill accumulates found the highest levels of Pb and Cd, while in liver accumulates found the highest levels of Hg and As.

Linear correlation incorporating paired variables (Filtered Surface Seawater - Fish, Sediment - Fish and Filtered Surface Seawater - Sediment) and correlation analyses between metals in muscles, liver and gills tissue exhibited several significant correlations indicating a common metal pollution.

The results were analyzed and tested for differences between group means of stations and seasons for significance ($P \leq 0.05$) using the analysis of variance one way ANOVA and two ways ANOVA technique. The obtained results showed that the heavy metals concentrations were significantly higher, during the summer season for Filtered Surface Seawater, Sediment and Fish tissues samples in all stations during the study period.

The results showed that heavy metals concentrations were significantly higher during the summer season. Water, sediment and fish tissues of most samples at all sites during the study period, due to the waste of ships, fishing boats and industrial facilities on the coast, as well as to the high rate of environmental variables in the summer. And the sources of this pollution from land as well as from the marine environment and when compared with local and international studies results were less concentrations, and the risk of these minerals to the marine environment and fish as the Yemeni people feed these fish, we recommend that these concentrations remain at this level and there are studies And follow-up so that the concentration of these elements does not increase their risk to the environment, fish and humans.

List of Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviations	Explanation
AAS	Atomic Absorption Spectrometry
ANOVA	Analysis of variance
ANZECC	Australian and New Zealand Environment and Conservation Council
AOAC	Association of Official Analytical Chemists
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASEAN	Association of Southeast Asian Nations
BAFs	*Bureau of Agriculture and Fisheries Standards*
BAMU	Babasaheb Ambedkar Marathwada University
BCFs	Bio concentration factor
CCME	Canadian Council of Ministers of the Environment
CVAAS	Cold Vapor atomic absorption spectrometry
DMA	Di methyl arsinic acid
DNA	Deoxyribonucleic acid
DORM-2	Certified Reference Meterial
dry wt.	dry weight
EPA	Environmental Protection Agency
ESMBHU	Environmental Sciences and Marine Biology, Hadramout University in Yemen
FAAS	Flame Atomic Absorption Spectrophotometer
FAO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration
FIMS	Flow Injection Mercury System

g/cm^3	grams per cubic centimeter
GB3097	The Seawater Quality Standard of China(National Standard GB 3097-1997).
GFAAS	Graphite Furnace Atomic Absorption Spectrophotometer
HCL	Hollow Cathode Lamp
HGAAS	Hydride generation atomic absorption spectrometry
IARC	The International Agency for Research on Cancer
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrophotometer
ISO 9001	International Organization for Standardization
MAFF	Ministry of Agriculture, Forestry and Fisheries of Japan.
MALs	maximum allowable limits
MCL	Maximum Contaminant Level
MEPC	The Marine Environment Protection Committee
mg/kg	Milligrams per kilogram
mg/L	Milligrams per Liter
MMA	Mono methyl arsonic acid
MRL	Minimum Risk Level
MTs	Metallothioneins
ND	Not Detected
NPS	nonpoint source pollution
ppm	part per million (equal mg/L or µg/g)
ppb	part per billion (equal µg/L or µg/kg)
PERSGA	The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden
PS	point source
PVC	Poly vinyl chloride
R	Pearson’s correlation coefficients

ROS	reactive oxygen species
RSS	Royal Scientific Society
SD	standard deviation
U.S.A	United States of America
UAE	United Arab Emirates
UKAS	United Kingdom Accreditation Service
UNEP	United Nations Environmental program
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
wet wt.	wet weight
WHO	World Health Organization
Yemen EPA	Yemen Environment Protection Authority
µg/g	Micrograms per gram
µg/L	Micrograms per Liter
µL	Micro liter
µm	Micrometer
JIPC	Jeddah Islamic Port Coast
NCSJ	Northern Coast Side of Jeddah
CSBTS	China State Bureau of Quality and Technical Supervision

Chapter 1

Introduction

1- INTRODUCTION

In recent years, considerable attention has been given to environmental problems in Yemen where the Red Sea and Gulf of Aden was considered one of the special areas by the International Marine Organization in 1987. Due to its strategic position in linking the Indian Ocean with the Red Sea, many ships and tankers pass through it and affect the nature of the water (oil spills and waste products) in the Red Sea and Gulf of Aden. As the currents in this area are weak and circulating, The oil and other pollutants are detained there for long periods, causing damage to the marine species. The Advisory Group of experts which met at the headquarters of the Organization in London from the 2nd to the 4th April 1986 in compliance with Assembly resolution A587 (Resolution MEPC. 29, 1987), named the Gulf of Aden an area exposed to danger of pollution as a result of maritime traffic.

The Action Plan for the Red Sea and Gulf of Aden was established in 1982 and later revised in 1995 and 2005. In addition, the PERSGA member states adopted the Regional Convention for the Conservation of the Red Sea and Gulf of Aden Environment (Jeddah Convention) and the attached Protocol concerning Regional Cooperation in Combating Pollution by oil and other Harmful Substances in Cases of Emergency in 1982, which entered into force in 1985. Two additional protocols were adopted in 2005 concerning protection form land-based activities and conservation of marine biodiversity-establishment of a regional network of protected areas. More recently another protocol concerning facilitation of movement of personnel and equipment during emergency was adopted in 2009. The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA), established in September 1995, is the coordinating body and is involved in the implementation of the Regional Convention and Protocols, and the Action Plan. PERSGA also has the responsibility for the developing and implementation of the GEF supported, MEAs joined capacity building projects such as Strategic Action Program (SAP). The waters of the Gulf of Aden are now under constant threat from passing ships; the Gulf is moreover exposed to catastrophic pollution at any time because a large number of oil tankers transporting a major proportion of the requirements of the European industrial countries pass through the Gulf.

The oil spills accidents have mainly caused by vessels running aground, collisions where the vessels break open, or by deliberative spills of other waste products, chemicals or radioactive substances into the sea water. In addition to the previous sources of oil pollution, oil and oil products discharged with storm water from municipalities comes from cars, machinery spills at filling stations and garages etc. Most attention was given to the oil pollution, but other pollutants were not detected. Hence, in this dissertation I will concentrate on the Heavy Metals pollution in the Aden, Al-Hodaeidah and AL-Mukalla Harbors, where no previous data or reports have been carried out, and to establish a base data on which further estimations will depend on.

1-1 Background

Oceans cover approximately 70% of the earth's total surface area. Out of the total water content of earth 97% is present in the oceans. They are the main regulatory agents of earth's climate. About 60% of the world's population live within 60 km of a coastline and use coastal resources for their livelihood (Sheela *et al*., 2012). It was thought that it was impossible for human beings occupying only one third of the surface of the globe, to pollute the vast expanse of oceans, under the assumption that the marine realm is capable of serving as a sink for all the pollution caused by anthropogenic activities. However, in reality, this is not true. Even in small quantities, pollutants can affect marine communities and species.

1-1-1 Coastal Environment

The coastal region is an amalgam of land, sea and fresh water ecosystems. Coastal ecosystems such as estuaries, wetlands and mangrove forests are highly valuable for coastal communities. The world's wealth of biodiversity is found to be in highly diverse marine and coastal habitats. Coastal ecosystems are mainly affected by inputs from urban waste waters, direct industrial discharges, harbour related operations and urban runoff water carrying materials from land development areas (Lavieren *et al*., 2012).

During the last century, great concern and attention have been directed towards the impact of human activities on the coastal ecosystems (Philips *et al.,* 2003). Monitoring of coastal ecosystem is vital in terms of better understanding of the past processes, present patterns and future trends (Metcalfe *et al*., 2011).

1-1-2 Coastal Pollution

The evaluation of the characteristics and principal impacts of major pollutants such as oil, sewage, solid wastes, toxic chemicals, pesticides, Heavy Metals, and radioactive wastes in coastal and marine environments is essential. More than a quarter of all these pollutants can be expected to ultimately end up in the coastal environment (Fikirdesici *et al.,* 2012). Some of these substances are biodegradable while others are non-biodegradable. Their cumulative effect over a long period could be quite harmful to the marine environment.

1-1-3 Heavy Metals Pollution

The term Heavy Metals refers to a group of metals and metalloids with specific gravity greater than 4 g/cm^3 or 5 times or more than that of water (Duruibe *et al*., 2007).

Some of these Heavy Metals such as Mercury, Lead and Cadmium are toxic to living organisms even at low concentrations, Heavy Metals combine with body's biomolecules like enzymes and proteins to form stable biotoxic compounds, thereby mutilating their structures and hindering the functions of these essential biomolecules (Duruibe *et al*., 2007).

In the last decades, contamination of aquatic systems by Heavy Metals has become a global problem. Heavy Metals may enter aquatic systems from different natural and anthropogenic sources, including industrial or domestic wastewater, application of pesticides and inorganic fertilizers, storm runoff, leaching from landfills, shipping and harbour activities, geological weathering of the earth's crust and atmospheric deposition (Yilmaz, 2009). In natural aquatic ecosystems, metals occur in low concentrations. As Heavy Metals cannot be degraded, they are deposited, assimilated or incorporated in water, sediment and aquatic organisms, thereby causing Heavy Metals pollution in water bodies (Abdel-Baki *et al*., 2011).

Heavy Metals enter fish through a number of routes: via skin, gills, food and non-food particles. Once absorbed, Heavy Metals are transported in the blood stream to either a storage point or to the liver for transformation and/or storage (Obasohan, 2007).

Heavy Metals tend to accumulate in the body tissues such as liver, muscles and bones and threaten the health of humans who consume them. Therefore, the Heavy Metals are amongst a class of pollutants which has captured the attention of many scientific researchers around the globe.

Over the last six decades, the world has witnessed numerous tragedies involving Heavy Metals pollution. An example of such problems occurred in 1952, around the Japanese fishing harbour of Minamata. Sewage containing mercury had previously been discharged into the Bay of Minamata from a polyvinyl plant operated by a company called Chisso. The mercury accumulated in seafood leading eventually to mercury poisoning in a population which consumed fish from the bay. The resulting disease called Minamata disease led to nearly 1000 deaths. Another example of Heavy Metals pollution occurred in 1955 in the vicinity of Toyama city, along the

Jinzu River in Japan. A disease known by the locals as Itai-itai (It hurts! It hurts!) occurred in the population from the consumption of rice, fish and bivalves that were cadmium contaminated from wastewaters discharged by nearby mining plants (Dural *et al*., 2007).

The 1986 Sandoz disaster along the upper Rhine and the 1998 contamination of the Coto de Donana nature reserve in southern Spain are few other examples of the numerous environmental disasters owed to Heavy Metals pollution (Chen and Chen, 2001).

The world's ever growing human population has increased the need for food supply. The demand for fish and shellfish products has increased greatly because they are very good and cheap protein sources. Worldwide, people obtain about a quarter of their animal protein from fish and shellfish (Bahnasawy *et al*., 2009). In 2012, more than 86 percent (136 million tons) of world fish production was utilized for direct human consumption (FAO, 2014).

Heavy Metals are considered as the most important pollutants, since they are present throughout the ecosystem and are detectable in critical amounts. Heavy Metals, such as mercury, cadmium, copper, lead and zinc are of the most important pollutants which effect aquatic environment and the fish. They are extremely dangerous for the health of fish (Authman *et al*.,2015).

Most of these metals are characterized by being accumulated in tissues, and lead to the poisoning of fish. These metals can effectively influence the vital operations and reproduction of fish; weaken the immune system, and induce pathological changes. Such as, fish are used as bio-indicators to playing an important role in monitoring Heavy Metals pollution.

In the past few decades, there has been a growing interest in assessing the levels of Heavy Metals in food including fish. Such interests were intended to ensure the safety of the food supply in order to minimize the potential hazardous effect on human health (Authman *et al*.,2015).

1-1-4 Correlation between Aquatic Life and Heavy Metals

Fish are at the top of the aquatic food chain and therefore, are more likely to accumulate large amounts of Heavy Metals from the water (Yilmaz, 2009). Fish are used the major indicator for estimating the amount of Heavy Metals referred to as pollution. When these fish are consumed, they become a high risk potential for human consumption. Various organs in fish absorb Heavy Metals due to their affinity for them. These results are in this fish concentrating metals at different levels of various organs in the body of fish. Hence, this process makes it imperative to determine the concentrations of Heavy Metals in fish population from the bodies of Seawater.

1-1-5 Heavy Metals in Seawater

The pollution of aquatic systems has become a major concern worldwide (Abdel-Baki *et al*., 2011). There are a variety of sources that will pollute aquatic systems with Heavy Metals. These include animal matter, wet and dry fallouts of atmospheric particulate matter and human activities. The concentration, bioavailability and toxicity of Heavy Metals in aquatic systems can be affected by various factors, including pH and temperature (Belin *et al*., 2013). Poor quality of surface water is caused in two ways. The pollution of surface water can either be due to point source (PS) or nonpoint source pollution (NPS). Point source pollution is mainly municipal sewage discharge and industrial wastewater loads. Municipal sewage discharge is from urban or highly residential areas, while industrial wastewater is from a variety of manufacturers (Wu and Chen, 2013). When rainfall or irrigation water runs over land it will carry and deposit pollutants into rivers, lakes and coastal waters. This is seen as nonpoint source pollution (Wu and Chen, 2013). Heavy Metals will be distributed between the aqueous phase and bed sediments in aquatic systems (Varol and Şen, 2012). Only a small percentage of the free metal ions stay dissolved in water. The majority of the ions get deposited in the sediment due to adsorption, hydrolysis and co-precipitation of the free ions (Varol and Şen, 2012).

1-1-6 Heavy Metals in Sediments

As an important component of water environment, sediment is not only the place where pollutants accumulate from the water body, but also it is a secondary pollution source which has a potential impact on water quality (Wang *et al*., 2011). Sediment represents one of ultimate sinks for Heavy Metals discharged into the aquatic environment. Therefore, sediment quality is a good indicator of pollution in the water column, where it tends to concentrate the Heavy Metals (Saeed and Shaker, 2008). Heavy Metals are distributed in sediments in four fractions, as exchangeable bound, iron–manganese oxide, organic matter and residual species (Dean, 2002).

According to Aydinlap and Marinova (2003), the Heavy Metals in the soil, may be found in one or more of the following forms:

a) Dissolved (in soil solution).

b) Exchangeable (in organic and inorganic components).

c) As structural components of the lattices of soil minerals.

d) As insoluble precipitates with other soil components.

The first two forms are available to the plants, while the other two are potentially available in the longer term. The sediments play an important role as it has a along residence time, therefore, is an important source for the assessment of an anthropogenic contamination in coastal environment (Jain *et al.,* 2005). In order to protect the aquatic life community comprehensive methods for identifying and assessing the severity of sediment contamination. Due to the ecological importance and the persistence of pollutants in the aquatic ecosystem, sediments are more appropriate to be monitored in environmental evaluations and understand their potential toxic impacts (Kwon and Lee, 2001). Sediment pollution, especially from Heavy Metals, has an important impact on the water environment and a direct potential threat on human and aquatic (Wang *et al*., 2011).

1-1-7 Heavy Metals in Fishes

Fishes represent the peak of consumers in the water system. Fishes have ability to collect these metals in concentrations higher than water because of feed on organic materials in aquatic environments (Olaifa *et al.,* 2004). Fishes have been found to be good indicators of the Heavy Metals contamination levels in the aquatic systems because they occupy different atrophic levels (Burger *et al.,* 2002). According to Burger *et al.,* (2002) there are two main routes of Heavy Metals exposure:

1. The primary route of intake of these chemicals in fish species is via gill or transport of dissolved contaminants in water across biological membranes and ionic exchange.

2. The secondary route is through the intestine by food or sediment particles with subsequent transport across the gut.

The food may also be important source for Heavy Metals accumulation in fish (Clearwater *et al.,* 2000). In aquatic ecosystem, metals are transferred to the fish through food chain that could ultimately affect the health of people consuming this fish.

Accumulation of these metals in the bodies of fish affected by different factors such as pH, water hardness and level of pollution in the surrounding water added to the age and physiological situation of fish (Van den Broek *et al*., 2002). Industrial and domestic waste containing Heavy Metals and hydrocarbon accumulate in aquatic food chains as possible to cause acute and chronic damages in fish communities and lead to reduceability to growthand reproduce (Schulz and Martins, 2001).

According to Rapid bio-assessment protocols in US EPA(1999): the advantages of using fish as bio-monitoring are:

1. Fishes are good indicators of long-term (several years) effects and broad habitat conditions because they are relatively long-lived and mobile (Karr *et al*., 1986).

2. Fishes assemblages generally include a range of species that represent a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, piscivores). They tend to integrate effects of lower trophic levels; thus, fish assemblage structure is reflective of integrated environmental health.

3. The consuming of fishes by humans, were making them important for assessing contamination.

4. Fish are relatively easy to collect and identify to the species level. Most specimens can be sorted and identified in the field by experienced fisheries professionals, and subsequently released unharmed.

5. Environmental requirements of most fishes are comparatively well known. Life history information is extensive for many species, and information on fish distributions is commonly available.

6. Aquatic life uses (water quality standards) are typically characterized in terms of fisheries (cold water, cool water, warm water, sport, forage).Monitoring fish provides direct evaluation of “fish ability” and “fish propagation”, which emphasizes the importance of fish to anglers and commercial fishermen .

7. Fish account for nearly half of the endangered vertebrate species and subspecies in the United States (Barbour, *et al*., 1999).

1-2 Environmental Contaminants – Heavy Metals

The presence of Heavy Metals in the environment has reached alarming dimensions. The discharges of residues by industry and above all, refineries lead to the contamination of soil and water by Heavy Metals (Bolana *et al*., 2014). Heavy Metals that pose more threat to human health are mercury (Hg), cadmium (Cd), lead (Pb) and arsenic (As) (Järup, 2003). Not only the industry, but also coastal urban development allows large quantities of metals to be released into the marine environment through the discharge of waste waters. Unlike other organic compounds, metals do not suffer chemical or biological degradation, so their concentration in either soil or water can remain at very high levels even after long periods of time after their introduction in the habitats (Adriano *et al*., 2004).

1-2-1 Source and Toxicity

1-2-1-1 Lead

Lead (Pb) is a toxic metal that occurs naturally in the environment. However, most lead concentrations that are found in the environment are a result of human activities. Due to the application of lead in gasoline, an unnatural lead-cycle has consisted. In car engines lead is burned and lead salts are generated. These lead salts enter the environment through the exhausts of cars. The larger particles drop to the ground immediately and pollute soils or surface waters, while the smaller particles travel long distances through air and remain in the atmosphere to later fall as rain. This lead-cycle caused by human production is much more extended than the natural lead-cycle and has caused lead pollution to be an issue of worldwide concern. Lead, in water, accumulates in the body of fish and other marine organisms and it is eventually ingested by humans who consume these fish and seafood products (Oforka *et al*., 2012). The presence of Pb in the human body causes damage to the nervous system through several mechanisms. Neuropsychological research over the years has revealed that Pb exposure can result in declines in intelligence, memory, processing speed, comprehension and reading, visuospatial, motor and executive skills. Among the cognitive deficits induced by Pb toxicity, visuospatial deficits appear to be major. Anxiety, depression and phobia can also occur, while outcome, intervention, and rehabilitation results are largely dependent on the level of toxic exposure. There is also a growing evidence of antisocial behaviour linked to early Pb exposure (Mason *et al*., 2014).

1-2-1-2 Cadmium

Cadmium (Cd) is a toxic Heavy Metals of great environmental concern. Cd levels in the environment vary widely and emissions to the environment are normally transported continually between the three main environmental compartments: air, water and soils. Cd in water can be accumulated in the body of marine organisms and can eventually enter the body of humans who consume these seafood products. the concentrations of Cd call for caution as cumulative effects might constitute health hazards to aquatic life including man who feeds on fish (Oronsaye *et al*.,2010).

Ingestion of Cd can rapidly cause feelings of nausea, vomiting, abdominal cramp and headache, as well as diarrhoea and shock. Itai-itai disease in Japan was identified among people living in Cadmium-polluted areas where rice was irrigated. Target organs include liver, placenta, kidneys, lungs, brain and bones (Reilly, 2002).

Cadmium is known to accumulate in the body particularly in the kidneys causing renal failure, bone fragility and pains (itai-itai disease) (DEFRA and Environment Agency 2002).

In the late 1960s environmental cadmium contamination was established as the cause of an epidemic of bone disease (itai-itai disease) in Japan. Since that time, increasing scientific interest has been devoted to cadmium as an environmental contaminant. Awareness is now been disseminated in some countries concerning the small margin of safety between existing intake levels and levels that may cause adverse health effect to the population (Dural *et al*., 2007).

1-2-1-3 Mercury

Mercury is an environmental contaminant that is present in fish and seafood products largely as methylmercury (MeHg). Aquatic organisms possess a remarkable capacity to turn inorganic mercury into MeHg, thus rendering mercury more easily transferable throughout the aquatic food chain (Diez, 2008). Human health hazards from environmental mercury were tragically realized during the severe pollution incidents of Minamata and Niigata in Japan owing to consumption of fish contaminated by MeHg which was discharged from acetaldehyde manufacturing plants. After these tragic events, considerable efforts have been expended on monitoring mercury in the aquatic environment, and limits on mercury levels in seafood have been established in different countries. Hg is one of the most toxic elements among the studied Heavy Metals and exposure to high level of this element could permanently damage the brain, kidneys and developing foetus (FAO/WHO, 2004). There are considerable amounts of mercury as a hazardous environmental toxicant in fish that can be entered quickly in human body, mostly affecting the nervous system (Shah *et al*., 2010 a, b); and in particular is present as a very toxic and absorbable form, methyl mercury, in food (Jureša and Blanuša, 2003).

1-2-1-4 Arsenic

Arsenic as a ubiquitous metalloid is one of the most toxic elements for human and animal health that cause toxic and detrimental biological effects such as different kinds of cancer. Studies on total diet arsenic in different countries have indicated that fish is one of the most significant dietary dishes in this respect (Lin and Liao, 2008; Shah *et al*., 2009, 2010 a, b). According to the authentic international agencies or organizations, there are very strict legal regulations on maximum allowable limits (MALs) of arsenic and mercury in fish and seafood . The MALs have been reported 1 µg/g wet weight according to Australia standards and United Kingdom food limits (Australia New Zealand Food Authority, 1998; Agah *et al*., 2009 and 2010). However, the United States Environmental Protection Agency reported 1.3 µg/g of wet weight as arsenic MAL in fish (Eisler, 1994). Humans may be exposed to arsenic via contaminated drinking water and food, especially seafood (Francesconi, 2010), which is generally contaminated with higher concentrations of arsenic than found in other foods (Lorenzana *et al*., 2009). Countries like Japan, China, and Korea obtain their food from marine sources, which constitute a major part of their diet (Li *et al*., 2003 and Contreras-Acuña *et al*., 2014). In view of the suspected human carcinogenicity of arsenite, the United States Environmental Protection Agency (USEPA) has set a human health criterion for total dissolved arsenic in sea water (0.0175 g/L) for the consumption of fish products (Neff, 1997). Millions of people worldwide are at risk due to long-term arsenic-contaminated groundwater consumption (Milton and Rahman, 2002), which has become a global public health problem. Inorganic arsenite has been classified by the International Agency for Research on Cancer as a human carcinogen (Neff, 1997). Acute toxicity symptoms of inorganic arsenic in humans include cardiovascular disturbances, gastrointestinal disorders, and kidney and liver failure, whereas chronic exposure may lead to hyperkeratosis, skin pigmentations, and cancer of skin, lung, bladder, liver, and kidney (Kunito *et al*., 2008).

The EPA critical value for human consumption of arsenic in fish is 1.0 µg/g which is equivalent to 1,000 ppb wet weight (EPA, 1989).

1-2-2 Acute and Chronic Effects of Heavy Metals

Accumulation of Heavy Metals in aquatic organisms could lead to a decrease in fecundity of fish populations or it could impact on reproduction. Heavy Metals may also alter the physiological activities and biochemical parameters in tissues and blood of aquatic organisms (Vinodhini and Narayanan, 2008). Since the control of reproduction in fishes is complex and affected by a wide range of environmental factors as well as hormones, even low levels of pollution could affect reproduction. Hence, at low levels, even though fish might not show any ill effects, it can lead to long term decline in fish supply.

Exposure to these Heavy Metals could ultimately lead to health risks associated with the consumption of fish by humans. Some of these health risks such as renal failure and liver damage can be caused by exposure to lead (Pb). Prolonged exposure to Pb can lead to mental retardation, coma and eventual death (Rahman *et al*., 2012). Studies have shown that cadmium (Cd) can cause chronic toxicity such as impaired kidney function, hypertension and hepatic dysfunction whereas copper and zinc may cause kidney problems such as nephritis and anuria (Rahman *et al*., 2012).

1-2-3 Entry Paths and Behavior of Heavy Metals in Aquatic Systems

The presence of Heavy Metals in aquatic ecosystems is a concern due to their toxicity, long persistence and their accumulative behaviour (Rahman *et al*., 2012). They include Mercury, Lead, Cadmium and Arsenic, among others. Even though very low levels of pollution may not show any immediate acute effects on aquatic organisms, it might lead to long term (chronic) effects. This could happen via metal accumulation in the reproductive organs or it could affect sperm or ova when released into the water (Ebrahimi and Taherianfard, 2011). Industrialized areas are at higher risk of contamination with a wide variety of industrial chemicals. These can leach into the soil and groundwater where they enter the food chain and accumulate in animals higher up the food chain (Diamanti-Kandarakis *et al*., 2009).

1-2-4 Presence of Heavy Metals in Aquatic Systems

There are various routes through which Heavy Metals can pollute aquatic systems. Deposition of atmospheric pollutants on solid surfaces, or on the surface of water bodies as well as the erosion of soil are the more natural routes for Heavy Metals pollution (Alhashemi *et al*., 2012). The concentration of most metals is usually low in pristine environments (Varol and Şen, 2012). Varol and Şen, (2012) states that the main anthropogenic sources of Heavy Metals pollution are mining, smelting activities, disposal of untreated and partially treated effluents which contain toxic metals as well as metal chelates from various industries. According to Harguinteguy *et al*., (2014) human activities, which include mining, will produce pollutants that are discharged into aquatic systems either in dissolved or suspended form. This can significantly decrease water quality and increase the ecological risk to human health. Pollutants can enter the environment through a variety of ways, such as storm water sinks, surface runoff, leaching and effluent discharge among others. Heavy Metals can be released into aquatic systems either as pulses or discontinuously (Harguinteguy *et al*., 2014). When Heavy Metals are released into aquatic systems it will bind to particulate and organic matter. Eventually the Heavy Metals will be incorporated into the sediment. Sediment is an important reservoir of Heavy Metals. Many studies were done that investigated the presence and effects of Heavy Metals in aquatic ecosystems as well as aquatic organisms (Chourpagar and Kulkarni, 2011; Omoloye, 2009).

1-2-5 The Effects of Heavy Metals in Aquatic Systems

Toxicity, abundance, persistence and bio-accumulation of Heavy Metals pose several challenges when they end up in aquatic systems. The discharge of Heavy Metals into aquatic systems may lead to accumulation of the metals in the sediment. This will lead to metals being biomagnified along the aquatic food chain (Fu *et al.*, 2014).

Accumulation of Heavy Metals may result in very high toxic levels, which can severely impact on aquatic organisms. Toxic effects of Heavy Metals on aquatic organisms can be observed at points far from where the pollution occurred due to the non-degradability of these metals (Fu *et al.*, 2014). Surrounding environmental factors interact with Heavy Metals in the sediment which can affect their concentrations in the sediment (Fu *et al.*, 2014). Accumulation of Heavy Metals by aquatic organisms is normally from their direct environment. The distribution of the metals in the organism will depend on the mode of exposure. Organisms will be exposed to contamination either via their diet or through the water which is their primary habitat (Alhashemi *et al.*, 2012). Different metals will have different effects on aquatic organisms. The gills and the liver of fishes can give an indication of Heavy Metals accumulation. The gills will give an indication of the concentration of Heavy Metals in the water, whereas the liver indicates the concentration of the metals stored in the organism (Alhashemi *et al.*, 2012).Low levels of Pb pollution showed adverse effects on fish health as well as reproduction (Ebrahimi and Taherianfard, 2011). This includes disruption in the normal steroid-synthesis pattern and impaired hormone production. The quality and quantity of sperm and ova reproduced will also be affected. This will ultimately lead to extinction of fish stocks in affected aquatic systems (Ebrahimi and Taherianfard, 2011).

1-2-6 Bioaccumulation of Heavy Metals in Fish.

Bioaccumulation is the incorporation and retention of metals by organisms from their surrounding environment (Ebrahimi and Taherianfard, 2011). Eneji *et al*., (2011) states that aquatic organisms bioaccumulate Heavy Metals in considerable amounts which may stay in the organism over a long period of time. According to Strydom *et al*, (2006) metals can have the following effects on fishes: (i) act as mutagenic or genotoxic compounds; (ii) increased metal concentrations can change xenobiotic metabolic pathways and (iii) can affect various metabolic activities such as glycolysis, amino acid- and carbohydrate metabolism. The ability of aquatic organisms to digest Heavy Metals in the system determines the rate at which Heavy Metals bioaccumulation in aquatic organisms. Furthermore, the rate of bioaccumulation of Heavy Metals in aquatic organisms is determined by the concentration of metals in the aquatic system (Eneji *et al*., 2011), the feeding habits of the organism and the mode of exposure to Heavy Metals, which affects the amount of bioaccumulation in different tissues of organisms (Alhashemi *et al*., 2012). Gills and the liver are normally the prime sites for bioaccumulation of Heavy Metals (Alhashemi *et al*., 2012).

Fishes are both situated at the top of the aquatic food chain. Crabs are typically benthic organisms and will give a better indication of the contamination of surface sediment (Zhao *et al*., 2012). Various studies have indicated a correlation of Heavy Metals in tissue of organisms and the size of the organism. Bigger organisms display higher bioaccumulation rates of Heavy Metals (Davies *et al*., 2006).

1-3 Review of Literature

1-3-1 Related Works done in the Region and around the World

Due to their toxicity and accumulation in biota, determination the levels of Heavy Metals in commercial fish species have received considerable attention in different countries in the region and around the world. Such interest aimed at ensuring the safety of the food supply and minimizing the potential hazard effect on human health. Some of the important documented contributions relevant to the present study are as follows:

In Egypt, Al-Ghanim *et al.,* (2015) Studied the Differential Uptake of Heavy Metals (Cu, Zn, Cd, Pb, Fe, Mn, Cr, Se, As, and Hg) by Gill, Muscles and Liver of Four Selected Fish Species (*Lethrinus nebulosus, Cetoscarus pulchellus, Plectorhynchus schotaf* and *Epinephelus spp*) from Red Sea. There was a highly significant (P< 0.01) difference among the 4 fish species and between organs for the accumulation of all 10 metals. Cd was detected in the lowest concentration. The liver accumulated the highest concentration of metals and muscles had the concentration of all studied metals. It has been observed that *Lethrinus nebulosus* species accumulated the highest concentration of total analyzed elements in this study, which indicate that this species have more potential to accumulate all of metals in each tissue (Al-Ghanim *et al.,* 2015).

In Saudi Arabia, vanadium (V), Cd, Zn, arsenic (As), Ni, Pb and mercury (Hg) levels in most common available fish species in Saudi markets were determined by (Al-Bader, 2008) .The maximum Cd, Pb, Hg and As concentrations in fish Samples were 0.049 , 0.244 , 0.002 and 0.042 $\mu g\ g^{-1}$, respectively . Results showed that the concentrations of metals were below the maximum allowed limit by the Saudi and international legislations for fish human consumption permissible limit (Al- Bader, 2008).

Younis *et al*., (2015) Studied the Bioaccumulation of Heavy Metals (Cd , Cu, Pb, Zn and Hg) in Fish (muscles, gills and liver), Squids and Crustaceans from the Red Sea, Jeddah Coast, Saudi Arabia. Ten fish species (*Epinephelus areolatus, Epinephelus radiates, Anthias squamipinnis, Plectorhinchus chaetodonoides, Snubnose emperor, Dicentrarchus labrax, Acanthopagrus bifasciatus, lutjanus kasmira, lutjanus ehrenbergii* and *Acanthurus gahhm*) as well as three specimens of crustaceans and two Specimens of squids collected from Jeddah coastal water during 2014. The obtained results declared that, the average concentrations of Heavy Metals were as follows: Cd (0.098, 0.20, 0.106), Pb (0.3, 0.257, 0.196) µg/g wet weight in the muscle, gills and liver, respectively. While, the concentration of Hg was invariably undetectable in all samples of different organs of the collected fish species. The average concentration of Cd, Pb and Hg in the soft part of the investigated crustaceans and squids were relatively higher compared with the muscle tissues in the examined fish species (Younis *et al*., 2015).

In Oman, (Mora *et al*., 2004) Studied the Distribution of Heavy Metals in marine bivalves, fish and coastal sediments in the Arabian Gulf and Gulf of Oman. Samples collected in Bahrain, Oman, Qatar, and the United Arab Emirates (UAE) during 2000–2001. Sediment metal loadings were generally not remarkable, although hot spots were noted in Bahrain (Cu, Hg, Pb, Zn) and on the east coast of the UAE (As, Co, Cr, Ni). Concentrations of As and Hg were typically low in sediments and the total Hg levels in top predator fish commonly consumed in the region were <0.5 µg g^{-1} and posed no threat to public health. Very high Cd concentrations (up to 195 µg g^{-1}) in the liver of some fish from southern Oman may result from food-chain bioaccumulation of elevated Cd levels brought into the productive surface waters by upwelling in the region. Very high As concentrations (up to 156 µg g^{-1}) were measured in certain bivalve species from the region. Although not certain, the As is probably derived from natural origins rather than anthropogenic contamination (Mora *et al.,* 2004).

In Jordan, Heavy Metals (Cd, Cr, Pb, Cu, Ni and Zn) pollution in sediment cores from the Gulf of Aqaba, Red Sea, was investigated by (Al-Najjar *et al.,* 2011). He found that levels of these Heavy Metals in sediments collected from five major areas representing different anthropogenic activities were relatively low compared to reported values from polluted areas. Concentrations of Pb and Cd in surface sediments Samples were 4.07 and 5.25 µg g^{-1}, respectively. He found that Result could be used to assess the magnitude of pollution at each site and guide rational management decisions. Moreover, the data constitutes a baseline against which future anthropogenic effects can be assessed (Al-Najjar *et al.,* 2011).

Ismail and Abu-Hilal , (2008) determined concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn in muscles, livers, gills, gonads, and stomachs of three Fish Species (*Ctenochaetus striatus, Scarus ferrugineus and Zebrasoma xanthurum*) From the Jordan Gulf of Aqaba, Red Sea. The values fall below the acceptable levels for human consumption recommended by FAO and WHO which means that they do not pose a significant threat to the health of human consumers. The results indicate that relatively high concentrations of Heavy Metals were found in liver and gill of the examined species, which suggest the possibility of using these two organs, particularly the liver, as bioindicators of metals present in the surrounding environment (Ismail and Abu-Hilal, 2008).

In Tunis, (Ennouri *et al.,* 2008) studied the Evaluation of (Cd, Pb, Hg and Zn) levels in *Sardinella aurita* and zooplankton collected from the Gulf of Tunis. The analysis of the Heavy Metals was carried out in three organs, (liver, gills and muscle) and were determined by atomic absorption spectrophotometer. The obtained results indicate that *Sardinella* was more contaminated by Heavy Metals than zooplankton in the Gulf of Tunis. This difference could be related to the food chain position occupied by this fish. The liver of *Sardinella* has the highest level of cadmium, but the gills are the main organ which accumulates Pb, Hg and Zn. Heavy metals in the edible parts of *Sardinella aurita*¸ from the Gulf of Tunis were in the safety levels for human uses (Ennouri *et al*., 2008).

In Pakistan, (Shah *et al*., 2010) Studied the Determination of total Mercury in Muscle Tissues of Marine Fish Species by Ultrasonic Assisted Extraction Followed by Cold Vapor Atomic Absorption Spectrometry. Determination of total mercury (Hg) in muscle tissues of marine fish species. For this purpose four fish species were collected from fish markets of Karachi, Pakistan. Total Hg concentration was determined by cold vapor atomic absorption spectrometry. The limit of detection (LOD) and limit of quantitation (LOQ) of Hg were 0.133 and 0.445 µg/kg respectively. The Hg concentration in muscle tissues were obtained in the range of 0.721 to 1.41 µg /kg on dry weight(Shah *et al*., 2010).

In India, (Mukherjee and Bhupander, 2011) studied the assessment of Arsenic, Cadmium and Mercury Level in Commonly Consumed Coastal Fishes from Bay of Bengal, India. Toxic Heavy Metals concentrations were determined in muscle tissue of six marine fish species. Determinations of cadmium were carried out using graphite furnace Atomic Absorption Spectrometry. Hydride generator coupled to atomic absorption spectrophotometer was used to analyze total mercury (cold vapor mode) and arsenic (heating mode). The concentrations of arsenic, cadmium and mercury were in range of 0.02-2.34 µg g^{-1}, 0.01-2.10 µg g^{-1} and 0.07-1.60 µg g^{-1} dry wt., respectively. Arsenic was the highest in average concentration followed by mercury and cadmium and their average concentrations were 0.66±0.09 µg g^{-1}, 0.62±0.05 µg g^{-1} and 0.47±0.07 µg g^{-1} dry wt., respectively. The Pearson product moment correlation was calculated and found that cadmium was positively correlated with mercury. Since there is a bioaccumulation of toxic Heavy Metals in fish tissues (Mukherjee and Bhupander, 2011).

Saravanamurugan *et al.,* (2013) studied the Heavy Metals Accumulation on Water, Sediment and some Commercial Important Fin-Fishes from Kalpakkam Region, Southeast Coast of India. The present investigation of the Heavy Metals concentration in water, sediment and five fin-fishes (*Rastrelliger kanagurta* , *Caranx williamsii* , *Nemipterus bipunctatus, Thryssa vitrirostris and Oreochromis mossambica*) of the Kalpakkam region, Southeast coast of India, during November 2011. There was an appreciable increase in metal concentration from the water sample to sediment samples. Metals concentration in water and sediment samples during the present study was in the following order of abundance; Cd > Hg > Pb and Cd > Pb > Hg. Five fresh fish species were collected from this coast and analysed for Heavy Metals content of muscle, gills and liver tissues. In the fin-fishes, the liver accumulates more concentration of metals than the muscle and gills. The order of Heavy Metals concentration in various organs is muscle Pb > Cd > Hg, in gills Cd > Pb >Hg and in liver Pb > Cd > Hg (Saravanamurugan *et al.,* 2013).

Prasath *et al.,* (2008) used Atomic Absorption Spectrophotometer for the detection of accumulation of Heavy Metals (Zn, Cu, Fe, Mn, Co, Pb, Cd and Ni) in water, sediments and fish (*Mugil cephalus*) at Poompuhar coast (southeast coast of India) before and after Tsunami. Accumulation of Heavy Metals was observed in the order of Sediments > Fish > Water. In water, the order was found to be Cd > Pb ; Pb recorded a minimum of 0.006 $\mu g.L^{-1}$ In sediments, the order was Pb ≈ Cd; Mn recorded a maximum of 851.1 $\mu g.g^{-1}$ and a minimum of below detectable levels were found in Pb, Co, Cd and Ni. In fish, the order was found to be Pb ≈ Cd ; a minimum of below detectable levels were found in Pb and Cd (Prasath *et al.,* 2008).

Thomas and Mohaideen, (2014) studied the Seasonal Variation of Heavy Metals (As, Cd, Cr, Pb and Hg) Distribution in Ennore Sea Shore, Chennai. Heavy Metals concentrations in fish, water and sediment collected near seashore of Bay of Bengal in Ennore located in North Chennai, Tamilnadu. The concentrations of 5 Heavy Metals were determined in water, sediment and marine species Indo-Pacific king mackerel popularly known as Spotted Seer fish (*Scomberomorus Guttus*) from Ennore in 4 different seasons. The concentrations of Heavy Metals in each sample were determined using AAS method. The study shows that the concentrations of most of the Heavy Metals in fish are higher in summer season and that in water and sediments are higher in monsoon and post-monsoon seasons respectively (Thomas and Mohaideen, 2014).

In Indonesia,(Simanjuntak *et al*., 2012) Studied the assessment of Heavy Metals (Al, Zn, Cu, Cd, Pb and Hg) In Demersal Fishes Of Kuala Tanjung Coast,North Sumatra.muscle and liver of *Chiloscyllium punctatum, Chiloscyllium indicum, Johnius belangeri, Nibea soldado, Otolithes ruber, Paratrypauchen microcephalus, Cynoglossus lingua,* and *Cynoglossus puncticeps* from Kuala Tanjung coastal waters. The levels of Al, Zn, Cu, Cd and Pb were measured by Graphite Furnace Atomic Absorption Spectroscopy technique; whereas Hg was measured by Cold Vapour Atomic Fluorescence Spectroscopy technique. The bioaccumulation of Al, Zn and Cu was predominant followed by Cd, Pb and Hg both in muscle and liver tissue of fish sample. The concentration range of Cd, Pb and Hg in muscle was 0.001-6.400, <LD-0.04 and 0.002-0.047 $mg.kg^{-1}$ wet weight respectively; whereas in liver was 0.005-0.1800, <LD-0.10 and 0.008-0.030 $mg.kg^{-1}$ wet weight respectively. *J. belangeri* and *O. Ruber* accumulated the highest levels of Al, Zn and Hg; while the highest levels of Cu, Cd and Pb were detected in *C. indicum* and *C. punctatum*. (Simanjuntak *et al*., 2012).

Kojadinovic *et al.,* (2007) studied the Bioaccumulation of Heavy Metals in pelagic Fish from the Western Indian Ocean. Heavy Metals were analyzed in fish of commercial interest to determine their importance in marine systems of the Western Indian Ocean and their bioaccumulation patterns. The results are equivalent or lower than levels reported in ichthyofauna worldwide. Certain values of muscular Cd, Hg, Pb and Zn were however above thresholds for human consumption. Levels varied among tissues, species and with fish length, but were seldom influenced by the nutritional condition of the fish, its gender and its reproductive status. Correlations between hepatic Hg and Se levels in Swordfish (r^2 = 0.747) and Yellowfin Tunas (r^2 = 0.226), and among metalloth- ionein linking metals imply the existence of detoxification processes in these species. Differences in levels between fish from the Mozambique Channel and Reunion Island probably reflect differences of diets rather than differences of elemental availability in both environments (Kojadinovic *et al.,* 2007).

In Iran (Sobhanardakani *et al.,* 2011), studied the Toxic Metal (Pb, Hg and As) Contamination of Muscle, Gill and Liver Tissues of *Otolithes rubber, Pampus argenteus, Parastromateus niger, Scomberomorus commerson* and *Onchorynchus mykiss* . Analysis of lead and arsenic was carried out by anodic stripping voltammetry method. Hg analysis was done spectrophotometrically. It was found that mercury concentration reaches to maximum in the gill of *Parastromateus niger* (0.47 µg/g) followed by the liver of *Otolithes rubber* (0.001 µg/g), lead content reaches to maximum in the gill of *Parastromateus niger* (0.11 µg/g), followed by the liver of *Scomberomorus commerson*, (0.005 µg/g), arsenic concentration is highest in the liver of *Otolithes rubber* (0.26 µg/g), followed by the muscle of *Pampus argenteus* (0.007 µg/g). The results of this study indicate that the concentration of Pb, Hg and As in the different tissues of the studied marine organisms were significantly lower than the permissible levels for these toxic metals (Sobhanardakani *et al.,* 2011).

Khezri *et al*., (2014) studied the assessment level of Heavy Metals (Pb, Cd, Hg) in four fish species (*Scomberomorus Commerson, Otolithes Ruber, Acanthpagrus Latus, Euryglossa orientalis*) of Arabian Gulf (Bushehr- Iran). In each of species the sequence of metal concentrations in different tissues was as following: Liver> Gill> muscle, and in the different fishes, this order was: *Euryglossa orientalis* > *Acanthpagrus Latus* > *Otolithes Ruber* > *Scomberomorus Commerson* . Cd^{+2} and Hg^{+2} concentrations in the tissues of *Acanthpagrus Latus* and *Euryglossa orientalis* and the Pb^{+2} level in the liver of this species also Cd^{+2} concentration in liver of *Scomberomorus Commerson*, were found higher than the permissible limits set by FAO/WHO. Results showed that, relationships between size and metal concentrations in four species (in confidence level %95) are significant, positive and negative. Highly significant positive and negative relationships were found between fish length and Hg^{+2}, Cd^{+2} levels in muscle of Otolithes Ruber (Khezri *et al*., 2014).

Velayatzadeh *et al*., (2014) studied the Determination of mercury, cadmium, arsenic and lead in muscle and liver of *Liza dussumieri* from the Arabian Gulf, Iran. Heavy Metals levels in fish samples were analyzed by Perkin Elmer 4100 atomic absorption. This study focused on the concentration of Heavy Metals of Hg, As, Cd and Pb in muscle and liver of *Liza dussumieri* significant difference ($P<0.05$). The mean estimated concentrations for Hg, Cd and As in the present study in samples from Boshehr was higher than in Deylam . Level of Pb in muscle of *Liza dussumieri* from Deylam was higher in Boshehr, Pb concentration in liver (0.498 ± 0.014 $mgKg^{-1}$) of *Liza dussumieri* from Boshehr were higher in Deylam. The mean estimated concentrations for Hg, Cd and Pb in the present study were lower than international Standards for these metals as declare by the World Health Organization (WHO), Ministry of Agriculture, Fisheries and Food (UK), Food and Agriculture Organization (FAO) and National

Health and Medical Research Council (Australia) (Velayatzadeh *et al*., 2014).

In Nigeria (Christopher *et al*., 2009), studied the Distribution of Pb, Zn, Cd, As and Hg in Bones, Gills, Livers and Muscles of Tilapia (O. niloticus) from Henshaw town beach market in Calabar. The results showed that the muscle of Tilapia contained the least concentrations of the Heavy Metals determined (Christopher *et al*., 2009).

In Spain, (Olmedo *et al*., 2013) studied the Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. Arsenic was measured with direct flow injection through hydride generation system coupled to the atomic absorption spectrometer. Total mercury was determined in a atomic absorption spectrometer equipped with mercury hydride system, whereas the Pb, Cd and Sn were analysed by graphite furnace atomic absorption spectrometry after microwave-assisted digestion. High mercury concentrations were found in some predatory species (blue shark, cat shark, swordfish and tuna), although they were below the regulatory maximum levels. In the case of cadmium, bivalve mollusks such as canned clams and mussels presented higher concentrations than fish, but almost none of the samples analyzed exceeded the maximum levels. Lead concentrations were almost negligible with the exception of frozen common sole, which showed median levels above the legal limit. Arsenic concentrations were higher in crustaceans such as fresh and frozen shrimps. The risk assessment performed indicated that fish and shellfish products were safe for the average consumer, although a potential risk cannot be dismissed for regular or excessive consumers of particular fish species, such as tuna, swordfish, blue shark and cat shark (for mercury) and common sole (for lead) (Olmedo *et al*., 2013).

In Bulgaria, (Stancheva *et al*., 2013) studied the Determination of Heavy Metals (Pb, Cd, As and Hg) in Black Sea grey mullet (*Mugil* *cephalus*). The fish samples were collected from two different Black sea areas – Varna Lake and Nesebar. Determination of As, Cd, and Pb were carried out on a Perkin Elmer Zeeman 3030 spectrometer with an HGA-600 atomizer, whereas Hg was analyzed by Milestone Direct Mercury Analyzer. Detected levels of As in the studied regions gives exceed those of other analyzed elements. The samples from both regions showed the higher levels of As in edible tissue than gills, especially from Region of Nesebar (1.1 mg/kg wet wt.). The results for other Heavy Metals are several times lower than arsenic and were found in range 0.01–0.12 mg/kg wet wt. All studied elements (except As) presented higher amounts from Varna Lake grey mullet compared with Neserbar region samples (Stancheva *et al.,* 2013).

Another study performed by (Stancheva *et al.,* 2014), Determination of Heavy Metals (Cd, Ni, Cr, As, Hg Cu, Fe, Mn, Pb and Zn) concentrations of most consumed fish species from Bulgarian Black Sea coast. Five fish species - bluefish (*Pomatomus saltatrix*), gray mullet (*Mugil cephalus*), Mediterranean horse mackerel (*Trachurus mediterraneus ponticus*), shad (*Alosa pontica*) and sprat (*Sprattus sprattus sulinus*) collected from two sites across Bulgarian Black Sea coast were determined. The samples were digested with nitric acid followed by appropriate spectroscopic determination (Atomic Emission Spectroscopy with Inductively Coupled Plasma, Flame Atomic Absorption Spectroscopy or Electrotermal Atomic Absorption Spectroscopy. The level of As in the edible part of gray mullet (Mugil cephalus) has shown a value higher than limits set from various health organizations (1.1 ± 0.1 mg/kg). On the contrary this fish species accumulates the other investigated Heavy Metals such as Hg, Zn, Fe and Pb to lower extend. The concentration of Zn and Fe showed the highest value for all fish species. With some exceptions (The concentration of As was generally low in all the species compared with both the data in the literature and world food standards except the value for gray mullet (Mugil cephalus) the concentration of studied Heavy Metals elements was within the acceptable levels for food source for human consumption (Stancheva *et al*., 2014).

In Sri Lanka,(Jinadasa *et al*., 2010) studied the Mercury, Cadmium and Lead levels in three Commercially Important Marine Fish Species (yellowfin tuna, *Thunnus albacores* (n=25), sword fish, *Xiphias gladius* (n=35), and red snapper, *Lutjanus sp* (n=12)) of in Sri Lanka .Total Hg was measured by cold vapor atomic absorption spectrometry whereas the Pb and Cd were analysed by graphite furnace atomic absorption spectrometry after microwave-assisted digestion. Swordfish contains highest mercury and cadmium concentrations while yellowfin tuna contained the highest lead concentrations. The mean concentrations of Heavy Metals in fish muscles were found to be 1.24± 0.72 mg/kg (Hg), 0.13±0.83 mg/kg (Cd) and 0.03±0.04 mg/kg (Pb) in swordfish and 0.39± 0.19 mg/kg (Hg), 0.02±0.02 mg/kg (Cd) and 0.06±0.06 mg/kg (Pb) in yellow fin tuna. In red snapper concentrations were 0.17± 0.06 mg/kg (Hg), 0.02±0.01 mg/kg (Cd) and 0.04±0.05 mg/kg (Pb) (Jinadasa *et al*., 2010).

In Turkey, (Emmanuelle *et al*., 2014) studied the Estimation of Some Heavy Metals Intake through Tuna Loins (*Thunnus Sp*) Produced in Côte D'ivoire . Three Heavy Metals in tuna loins of four tuna species from two industries in Côte d'Ivoire during September 2011 to September 2013. Cadmium (Cd) and lead (Pb) concentrations were measured by graphite furnace atomic absorption spectrometry and Mercury (Hg) was measured by cold vapour atomic absorption spectrometry. Results showed that the concentration varied from 0.029 to 0.470 with a mean of 0.203 ± 0.103 mg/kg for Hg; from 0.002 to 0.092 with a mean of 0.015 ± 0.014 mg/kg for Cd and from 0.016 to 0.310 with a mean of 0.162 ± 0.057 mg/kg for Pb. These concentrations are lower than the maximum permissible values in European and Ivoirian regulation (Emmanuelle *et al*., 2014).

In USA, Bhoyroo *et al*., (2015) studied the Detection of Heavy Metals bio- accumulation in scombrids for the determination of possible health hazard. Concentrations of Heavy Metals (Zn, Cu, Ni, Cr) and Heavy Metals (Pb, Hg, Cd, As) were detected in the muscle tissues of four commercially edible fishes belonging to the scombridae and related families including yellow fin tuna (*Thunnus albacares*), Dogtooth tuna (*Gymnosarda unicolor*), Marlin (*Makaira mazara*) and the dolphin fish (*Coryphaena hippuru*) in the EEZ (Exclusive Economic Zone) of Mauritius. The concentrations were within the range 1.34-10.03, 0.0-1.42, 0.23-0.89, 0.0-2.43, 0.0, 3.60-5.44, 0.03-0.13 and 0.03-0.07 mg/kg wet weight respectively for summer and winter seasons. Inter-species variations with respect to elemental accumulations were not significantly different as compared to seasonal variations for the accumulation of chromium, zinc and lead. Marlin and Dorado caught during the summer season exceeded the authorised level of chromium in muscle tissues according to international standards (Bhoyroo *et al*., 2015).

1-3-2 Studies Concerning Heavy Metals in Yemen

Al-Dohail *et al*., (2014) studied the effects of lead, cadmium and mercury on *Moolgarda seheli* and seawater in Khawr-Mukalla, Hadhramout Coast and Gulf of Aden. This experiment was carried out to determine the concentration of Heavy Metals in muscles, liver and gills of Blue spot mullet, *Moolgarda seheli* and filtered surface water. The results showed that there were no significant differences ($P>0.05$), regarding the concentration of Pb^{2+},Cd^{2+} and Hg^{2+} in muscles of *M.seheli* throughout the seasons: winter, spring, summer and autumn, whereas there were significant differences ($P<0.05$) in liver and gills of *M.seheli*. Besides, there were no significant differences ($P>0.05$), regarding the concentration of Pb^{2+}, Cd^{2+} and Hg^{2+} in the filtered surface water of Mid-Khawr and Mouth-Khawr except End-

Khawr, for the period of all seasons. From these results, we concluded that the Heavy Metals (Pb^{2+},Cd^{2+} and Hg^{2+})in the muscles and gills of *M.seheli*, at Khawr-Mukalla sites were still in range scale of international pollution standard except in the liver of *M.seheli* which was high a little bit, whereas filtered surface seawater at Khawr-Mukalla sites were polluted. Therefore, the treatment of sewage before drain into Khawr-Mukalla is necessary to save the marine ecosystem in better condition in order to reduce pollution, as well as further studies are necessary to monitoring the pollution by Heavy Metals in this area (Al-Dohail *et al*., (2014).

Algahri *et al*., (2011) studied theLead, Mercury and Cadmium in Tuna Fish Caught at the cost of Hadramout – Yemen . Mercury levels in tuna fish are determined by hydride generation atomic absorption spectrophotometry, while cadmium and lead levels were determined by flame atomic absorption spectrophotometry. Lead contents varied, from 0.118 µg/g to 0.193 µg/g with an average value of 0.146 µg/g. Mercury contents varied, from 0.012 µg/g to 0.184 µg/g with an average value of 0.057 µg/g. Cadmium contents varied, from 0.013 µg/g to 0.023 µg/g with an average value of 0.017 µg/g .The content of these investigated toxic elements are well below the permissible levels. Their contribution to the body burden can be therefore considered negligible and the fish seem to be safe for human consumption (Algahri *et al*., 2011).

Heba *et al*., (2015) studied the Determination of some Heavy Metals (Ni, Co, Cu, Cd and Mn) in Tissues and Organs of three Commercial Fish Species(*Arius sp*., *T*. *tanggol* and *Mugil sp*.) at AL-Hodaeidah, Red Sea Coast of Western Yemen were made by using Atomic Absorption Spectrophotometer. The results indicated that the fish species revealed variations among Heavy Metals contents in both tissues and organs. Results obtained from fish organs indicated that the three fish species exhibited variations in Heavy Metals concentrations. Although, values of Heavy Metals obtained from tissues in the present study were within the acceptable worldwide range, however, they were lower than those reported in parts from other regions of the world which are considered as polluted areas. The occurrence of Heavy Metals in tissues and organs of the examined species may be due to the anthropogenic activities, feeding behavior of the fish species, fat content and of any other environmental factors in the study area. Moreover, the difference in Heavy Metals accumulation in different organs may be due to the differences in their physiological and biochemical functions. In order to control the Heavy Metals pollution in this area further and continuous critical investigations are urgently needed (Heba *et al*., 2015).

Heba *et al*., (2014) studied the Detection of Heavy Metals contamination in greasy grouper (*Epinephelus tauvina*) and striped mackerel (*Rastrelliger kanagurta*) from Al Hodaeidah, Red Sea coast of Yemen . Evaluated Heavy Metals contamination in the white muscle and tissue samples, using the atomic absorption spectrophotometer. The obtained results indicated that the two studied species of fish revealed wide variations among the Heavy Metals content, with the levels of Zn and Mo being highest. When the total concentrations of all Heavy Metals in both the species were compared, it was observed that the striped mackerel (*R*. *kanagurta*) has a significantly higher concentration than the greasy grouper (*E*. *tauvina*) (17.65 and 12.6 µg/g dry wt.). These results might be due to, either the fat content in the *R*. *kanagurta*, or the diet consumed by this fish. Despite certain degree of Heavy Metals contaminants in the two species of fish, it was found to be within worldwide safety standards. It is recommended that a continuous monitoring and surveillances of the Heavy Metals should be carried out regularly to keep track of any sudden contaminants leaking into these coastal areas (Heba *et al*., 2014).

Al-Abyadh (2006) studied the Estimation of the Concentrations of Heavy Metals (Pb, Mn, Cu , Fe ,Zn, Cd, Cr and Co) in *Sepia pharaonis* (Habbar) and some most commonly used fishes used as food in Aden, Yemen. Samples of *Sepia pharaonis* and different fishes were collected in August 2004 from two different locations: Sirah and Buraikah. The solution Samples were prepared by digesting the grounding dry meat slices by using nitric acid (HNO_3) and sulfuric acid (H_2SO_4). The Samples were then prepared for measurements by Atomic Absorption Spectrometer. The results of measurements, given as an average of the two locations of the heavy element contents were as follows (µg/g): Pb, Mn, Cu, Fe and Zn were 4.68, 3.67, 2.91, 27.57 and 25.54 respectively, Those of Cd, Cr and Co expressed in µg/kg were : 262.8, 120.0 and 893.0 respectively (Al-Abyadh, 2006).

Larouci (2006) studied the contamination levels with Heavy Metals (Hg, Pb, Cd, Cu, Ni, Zn, Co, Mn and Al) in some Fish and Shellfish Species in Yemeni Regional Sea. Tuna fish *Thunnus albacares*, Lobster *Panulirus versicolor* and Shrimp *Penaeus semisulcatus*, Fresh samples were purchased from near the sea public auction site locations at Aden, Hodaeideh and Hadramout governorates during production seasons of the years 2004 and 2005. Results indicated that Hg, Pb and Cd were detected in all samples of this study. Such concentration levels were below the maximum limits of total mercury, lead and cadmium in tuna, lobster and shrimp as specified by the European Community (EC). Statistical analysis of data obtained through assessing concentration levels of Heavy Metals in tuna, lobster and shrimp for this study showed that significant variations ($P \leq 0.05$) between levels exist mostly within same specie collected from different site locations at the same production season. As for as highest concentration levels of mercury, lead and cadmium assessed in fleshes of the samples, the values 0.58, 1.07 and 0.58 (mg kg^{-1} wet weight) were detected in tuna fish of Hadramout, lobster of Hadramout and medium size shrimp of Hodaeideh respectively (Larouci, 2006).

Al-Shwafi (2002) studied the Level of Heavy Metals (Zn, Cu, Pb, and Cd) in four species of fish (*Crenidens Crenidens, Scomberomorus Commerson, Rastrelliger Kanagurta* and *Thunnus Albacares*) were studied in the Red Sea of Yemen and the Gulf of Aden. Flame Atomic absorption spectrophotometer was used for the determination of the metals.Mean concentration of Pb and Cd in *Thunnus Albacares* in the Red Sea and Gulf of Aden of Yemen 0.25 and 0.11 (ppm dry Wt.)0.31 and 0.27 (ppm dry Wt.) respectively. Mean concentration of Pb and Cd in *Crenidens Crenidens* in the Red Sea and Gulf of Aden of Yemen 0.18 and 0.13 (ppm dry Wt.)0.22 and 0.25 (ppm dry Wt.) respectively. Mean concentration of Pb and Cd in *Scomberomorus Commerson* in the Red Sea and Gulf of Aden of Yemen 0.23 and 0.09 (ppm dry Wt.)0.27 and 1.07 (ppm dry Wt.) respectively. Mean concentration of Pb and Cd in *Rastrelliger Kanagurta* in the Red Sea and Gulf of Aden of Yemen, 0.03 and 0.03 (ppm dry Wt.) 0.05 and 0.07 (ppm dry Wt.) respectively. The results show that, the variations within the muscle tissues of fish were mainly attributed due to the geochemical nature of beach deposits rather than anthropogenic input. Thus it was concluded that the investigated Heavy Metals do not present an environmental hazards for the present time. Cd, Pb are harmful and causing the cancer diseases (Al-Shwafi, 2002).

Al-Shwafi and Rushdi (2008) studied the Heavy metal concentrations in marine green, brown, and red seaweeds from coastal waters of Yemen, the Gulf of Aden. The divisions included Chlorophyta—green plants (*Halimeda tuna, Rhizoclonium kochiamum, Caldophora koiei, Enteromorpha compressa,* and *Caulerpa racemosa* species), Phaeophyta—brown seaweeds (*Padina boryana, Turbinaria elatensis, Sargassum binderi, Cystoseira myrica,* and *Sargassum boveanum* species), and Rhodophyta—red seaweeds (*Hypnea cornuta, Champia parvula, Galaxaura marginate, Laurencia paniculata* and *Gracilaria foliifere* species). The heavy metals, which included cadmium

(Cd), cobalt (Co), copper (Cu), chromium (Cr), Iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn), and vanadium (V) were measured by Atomic Absorption Spectrophotometer (AAS). The concentrations of heavy metals in all algal species are in the order of Fe >> Cu > Mn > Cr > Zn > Ni >Pb > Cd > V > Co. The results also showed that the uptake of heavy metals by different marine algal divisions was in the order of Chlorophyta > Phaeophyta > Rhodophyta. These heavy metals were several order of magnitude higher than the concentrations of the same metals in seawater. This indicates that marine alga progressively uptake heavy metals from seawater (Al-Shwafi and Rushdi, 2008).

Heba *et al.,* (2003) studied the Petroleum hydrocarbons and Heavy metals (Cd, Cu, Pb, and Zn) in mollusca (*Tivela ponderosa*) from the Gulf of Aden. the Heavy metals were determined by flame A.A.S. The total concentration of Cd and Pb in Mollusca *Tivela ponderosa* ranged from 0.6 to 1.9 (µg/g) and 9.8 to 23.7 (µg/g) respectively. Level of Cd and Pb in mussels, were generally within the range of values reported for other parts of the world. The concentrations of Heavy metals may be attributed to natural rather than anthropogenic origin. Thus, it was concluded that the investigated Heavy Metals don't present environmental hazards for the present time. However, it is recommended to carry out continuous monitoring programs for the Gulf of Aden and that the concentration of Heavy Metals must remain within the prescribed worldwide ratio (Heba *et al.,* 2003).

Nomaan *et al.,* (2012) studied the assessment of Heavy Metals in Sediments from Coastal Al-Hodaeidah Governorate, Yemen .Five locations at Al-Hodaeidah sea shores were selected in order to study the availability of Heavy Metals and their concentrations in the surficial sediments (<60µm), The concentration of Ten leachable and total metals cadmium (Cd), cobalt (Co), Nickel (Ni) and lead (Pb) were determined by atomic absorption spectro photometer. The concentration of cadmium is indicating very high contamination in all the sampling sites. The metal concentration of Cd and Pb are ranges from 7.33 to 10.17 μg/g and 61.45 to 65.16 μg/g respectively. The total mean concentrations for Cd and Pb are 8.58 μg/g , and 63.56 μg/g respectively (Nomaan *et al*., 2012).

Nasr *et al*., (2006) studied the environmental assessment of Heavy Metals Pollution in Bottom Sediments of Aden Port, Yemen .Heavy Metals (Mn, Zn, Cu, Pb, Co, Cr and Ni) were measured, using Atomic Absorption Spectrophotometer for 21 sediment samples collected at different sites in Aden Port during 2004. The range and average of concentrations measured in μg g^{-1} were 14.8 - 138.06 (77.28) for Pb . To evaluate the levels of sediment contaminations, the background values of the different elements were defined, depending on the international standards. In case of Pb at most of sites, their concentrations in the sediments exceeded the background levels. The relatively high levels of Pb in the sediments of the Aden Port are due to the discharges of untreated wastewater of desalination plant, electrical power station, refinery plant, textile industry, oil spills from the oil pipes, as well as domestic wastewater (Nasr *et al*., 2006).

Heba *et al*., (2004) studied the Background levels of Heavy Metals (Zn, Cu, Cd, Pb, Cr, Fe, Ni and Mn) in dissolved Particulate Phases of water and Sediment of Al-Hodaeidah Red Sea Coast of Yemen , Flame Atomic Absorption Spectrometry was used. The mean concentrations of dissolved metals Cd and Pb ranged from: 0.04-2.65 and 0.10-2.85, (μg/l) respectively. While for particulate metals were: 0.22- 101.63 and 2.64-832.50 (μg/g dry Wt.) respectively. The concentrations of the same metals in sediments were: 0.20- 5.80 and 4.99-6.26 (μg/g dry Wt.) respectively. High concentrations of Heavy Metals were observed in front of Al-Hodaeidah City, which could be due to the anthropogenic activities, while the low concentrations were observed in Al-Mandhar a remote area. Heavy Metals contamination in water and sediment is partially caused also by atmospheric input of local particulates from motor vehicle and from the mountainous regions which drain its water from Yemen highland to the Red Sea through different vallies. Comparing our finding with other regional data clarifies that the Heavy Metals pollution in Al-Hodaeidah coast is still localized and low (Heba *et al*., 2004).

Sagheer (2013) studied the Geochemistry in surface sediments of the Kwar Katib lagoon, Red sea, Yemen . Twenty samples were collected from this lagoon. Heavy Metals such as (Fe, Al, Mn, Cu, Ni, Zn, Pb, Cr, Ti, La, Sr, Ba, Co and As) have been analyzed in the samples. The range concentrations (µg/g) was 2.6 – 9.9 for As and 1.5 - 13.8 for Pb (Sagheer, 2013).

Szefer *et al*., (1999) studied the Distribution and relationships of selected Heavy metals in molluscs and associated sediments from the Gulf of Aden, Yemen . Concentrations of Cd, Pb, Zn, Cu, Ni, Co, Cr, Mn and Fe in the soft tissue of *Turbo coronatus, Acanthopleura haddoni, Ostrea cucullata*and *Pitar sp*., as well as in associated surface sediments (bulk and bioavailable metal concentrations), were determined by atomic absorption spectrophotometry. Large differences between size-classes of molluscs in metal concentrations were recorded. Significant spatial differences in metal concentrations in both the soft tissue of the molluscs and associated sediments studied were mostly identified. Statistically significant correlations ($p<0.01$) between concentrations of selected metals were observed. A slope of the linear regression is significantly higher than unity for Cd (3.45) in *A. haddoni*, suggesting that the bioavailability of these metal is disproportionally increased with a degree of enrichment of the sediments in Cd (Szefer *et al*., 1999).

Mostafa *et al*., (2009) studied the Metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn)in surface sediments and marine bivalves of the Hadhramout coastal area, Gulf of Aden, Yemen .Twenty three surface sediment samples (top 5 cm) were collected from five sampling sites using a Peterson grab sampler. At the same time inter-tidal and sub-tidal molluscs were collected from four sampling sites. The total metal determinations of sediments and biological tissues were performanced in Atomic Absorption Spectrometer. The range and average concentrations in the coastal sediments (μg g^{-1}dry wt.) were 0.3–2.6 (1.5) for Cd and 5.3–23 (10.3) for Pb. The range and average concentrations in rock oyster (μg g^{-1}dry wt.) were 0.2–2.1 (1.4) for Cd and 2.6–15.4 (7.9) for Pb (Mostafa *et al*., 2009).

Al-Zubaidy *et al*., (2014) studied the Investigation of Heavy Metals (Cd, Co, Cu, Zn, Pb) contamination and parasites of edible marine seafood Yemeni, Coastal waters .Concentrations of Heavy Metals were determined in muscle, liver and gill tissues of 78 samples of five different fish species (*Rastrelliger kanagurta, Scomberomorus guttatus, Epinephelus sexfasciatus, Lutjanus argentimaculatus and Lethrinus lentjan*) collected from three different sites (Al-Mena, Al-Mehwat and Al-Cornish) of the Red Sea coast of Yemen , Hodaeidah City, which showed different degrees of anthropogenic pressure during March and April, 2012. The concentration of metals was significantly affected by fish species, type of the tissue and sampling sites. In Al-Mena site, the concentrations of most tested metals were higher than in Al-Mehwat and Al- Cornish sites. The level of Heavy Metals in muscle tissues of the five fish species were within the acceptable limit set by FAO/WHO 2004 as well as Food Act 1983 (Al-Zubaidy *et al*., 2014).

Mol-Aldwila, *et al* (2017) studied the Assessment of Some Heavy Metals Pollution in Mollusca from Hadramout Coast, Yemen. Twenty Mollusca samples were collected from five sampling locations (Rassharma, Burum, AL-Mukalla, AL-Sheherand Arryidah) at Hadhramout coastal area (Yemen). The samples were collected on a seasonal basis from Augusts of 2013 to May 2014. The results showed that the concentrations of heavy metals (Ni, Co, Mn, Cd, Fe, Cu, Zn, Cr and Pb) in Mollusca were in the range of 1.67-19.17, 1.67-6.67, 2.5-13.33, 0.83-15.8, 40-458.3, 5-108.3, 21.5-118.3, 0.83-8.3 and 1.67-6.67 μg/g, respectively. The present study showed significant seasonal variations of these elements and showed that the metal concentrations in Mollusca are several times higher than those in water and lower than those in sediments. The highest concentration of these elements were recorded in the Mollusca of Burum, Al-Mukalla, Al-Shaher, Arryidah and Ras-Sharma, compared to WHO. According to WHO, the concentrations of Fe, Cr and Zn in Mollusca were below the permissible levels except for Al-Mukalla and Al-Shaher, while Mn, Cd, Cu and Pb were higher than the permissible level WHO except for Ras-Sharma.

1-4 Main Objectives

The main objectives of the study are:

1. Evaluation of the concentration of some of the metal ions such as: Lead, Cadmium, Mercury and Arsenic in some of the Yemeni Fishes.
2. Evaluation of the concentration of some of these metals ions in the flesh of fishes, which is a source of food of the Yemeni population.
3. Estimation of the concentration of some of the Heavy Metals ions in different fish tissues (liver and gill).
4. Estimation of the concentration of already known studied Heavy Metals in seawater and sediments to give an index of the effect of pollution in seawater and sediments, and the fish which live there.

1-5 Significance of Study

In undertaking this research, it is likely that the results will reveal the notions or answers to the questions of " To what extent the concentration levels of anthropogenic Heavy Metals have become threatening to the marine environment in Yemen coastal waters and " Are there any apparent impacts of such metals on human health ". The reason for selecting this type of study lies in three folds; firstly, is to gain a knowledge on the Anthropogenic sources of lead, cadmium, mercury and arsenic of Yemen coastal waters, and secondly, is to reveal if there are consequences or potential effects for the excessive use of Pb, Cd, Hg and As materials and like in a weakly regulated or poorly protected environment in Yemen coastal waters, and thirdly, is for the lack of any reliable information on the impacts of lead, cadmium, mercury and arsenic on the public health in Yemen coastal waters. The study may provide us with some important links as a result of integrating the study of geological, environmental and geochemical factors along. The integration of factors, like, sediments, seawater, metals geochemistry, may prove to be useful in providing us with key information about the potential hazards of some of the toxic metals like lead, cadmium, mercury and arsenic in fish of Yemen coastal waters, and consequently such key information may be applicable to other coastal cities of similar conditions. Moreover, The fish species in the current study may contain Heavy Metals above acceptable levels; so there is a need to monitor the Heavy Metals concentrations in the species consumed by the population of Yemen . Determining the levels of such Heavy Metals and comparing the levels with guidelines will establish the potential health risk from the consumption of such fish species. Therefore, it is important to determine the concentrations of non-essential metals in fish in order to evaluate the possible risks of fish consumption. This can serve as an indicator for the extent of pollution in Yemen coastal waters.

Chapter 2

Materials & Methods

2. Materials and Methods

2-1 The Study Area

2-1-1 Description of the Study Area

The Republic of Yemen lies on the southwestern tip (part) of the Arabian Peninsula bordering Saudi Arabia to the north and Sultanate of Oman to the east. It occupies an area of nearly 555000 square kilometers - excluding Al Ruba Al Khali Desert and has a sizeable coast line both to the Red Sea and to the Gulf of Aden/Arabian Sea (2500 km). Yemen has a large population (approximately 25.956 million in 2013, a high growth rate of approximately 3.7% per annum(Yemen Statistical Yearbook, 2013).

Fish consumption is apparently increasing at the present time because of the large increases in the price of other alternative protein sources, such as beef, goats and chickens. Yemen's marine environment is characterized by a high level of productivity and fisheries are the second most important source of export revenues in Yemen after petroleum and play an important role in reducing poverty. Al-Hodaeidah (on the southeastern side of the Red Sea), Aden (on the northwestern side of the Gulf of Aden) and AL-Mukalla (on the northeastern side of the Gulf o of Aden) are the main coastal cities (Figure 2-1) with areas larger than others in Yemen.

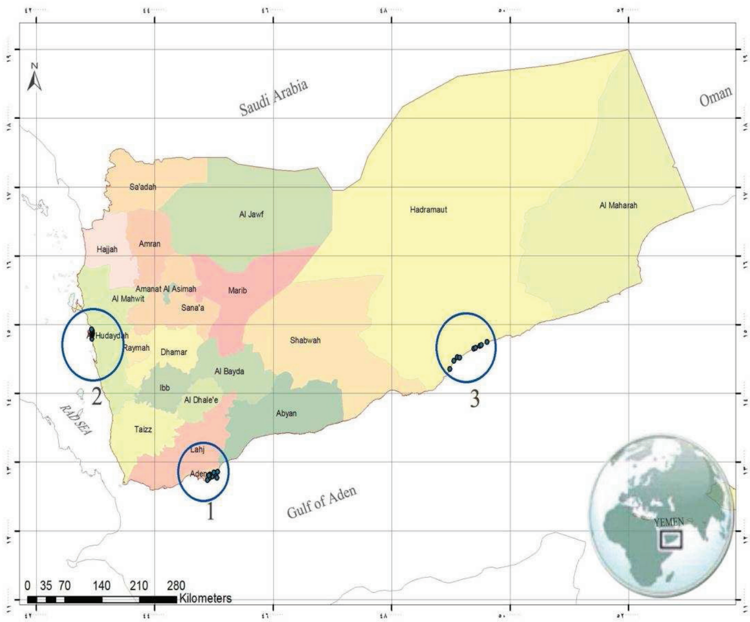


Figure 2-1. Sampling locations along the Coast of Yemen

2-1-1-1 Aden City

Aden is a port city in Yemen, located by the eastern approach to the Red Sea (the Gulf of Aden), some 170 kilometers (105.6 miles) east of Bab-el-Mandeb. It is a semi island and consists of rocks. Aden's population is 774000 in 2013 (Yemen Statistical Yearbook, 2013), The convenient location of Aden's natural Port on the major sea route between the Far East and Europe has resulted in a rich history as a trading center. Aden's importance as shipping center peaked in early 1960s, when it was the fourth busiest port in the world (Nasr *et al*., 2006).has a port with an oil refinery and an oil import/ export terminal. This terminal handles around 9.8 million tons per year (Int'l Business Publications, 2013). Nine, characteristic stations on the coastal area of the Aden port were sampled during this study (Surface seawater and sediments).The nine sites were picked up precisely and according to the importance of each one of the selected sites. The locations are shown on the map presented in the Figure 2-2.

Figure 2-2. Sampling locations along the Coast of Aden City.

2-1-1-2 Al-Hodaeidah City

Location map (Figure 2-3) shows the study area, Al-Hodaeidah Fishery port, from which the samples were collected for the determination of heavy Heavy metals. The study area was selected depending on many reasons, among which sewage effluent which is located to the south and north of the study area. In addition, the area receives the wastewater from treatment plant, which discharges large quantity of untreated sewage to the south of the Fishery Port, and to the north of Al-Hodaeidah Commercial Port. Al-Hodaeidah his located along the western coast of Yemen.

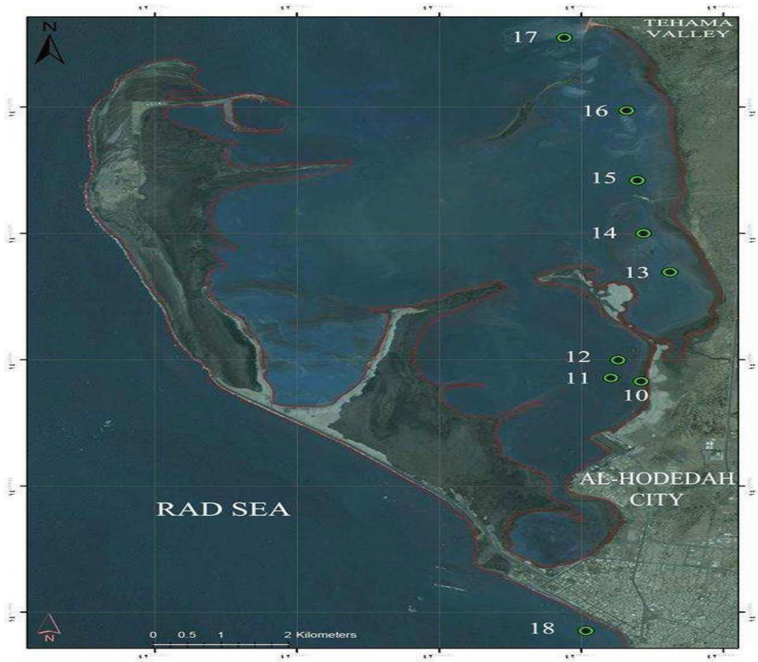


Figure 2-3. Sampling locations along the Coast of Al-Hodaeidah City.

Al-Hodaeidah is the largest coastal city in the region, and is one of the major port in Yemen, with the estimated population of 979.000 in 2013 (Yemen Statistical Yearbook, 2013). It is the city having a sewerage system of treatment plants in the region. Its municipal sewage is discharged into a series of eleven oxidation ponds which serves nearly 35% of the residential population, with about 18000 cubic meters daily discharged. It contains several types of industrial liquid effluent and animal waste. About 70% of the municipal sewage is used for agriculture purposes, including windbreaks. The remainder (30 %) is discharged through a small open channel north of the city into the seawater close to khawr Al Kathib (Yemen's NPA, 2003).

2-1-1-3 AL-Mukalla City

AL-Mukalla city (Hadhramout governorate), about 480 km east of Aden (Figure 2-4). AL-Mukalla city is the capital of Hadhramout Governorate with a population of 615000 people in 2013 (Yemen Statistical Yearbook, 2013). The native population of the urban and considered relatively civilized society, for the rest of the cities of Yemen, which is the majority of the population of rural areas, is also a meeting place for all people of Hadhramout. AL-Mukalla city overlooking of the Arabian Sea . Extending from the Burum city in the west to Al-Sheher city in the east along the coast.

Experts opinion, indicate that pollution risk in Al Mukalla is increasing day by day because of the non-treatment sewage spill into the sea. More than 150 kilometers from the shores of Al-Mukalla costs have become useless for marine life because it is boons by green algae.

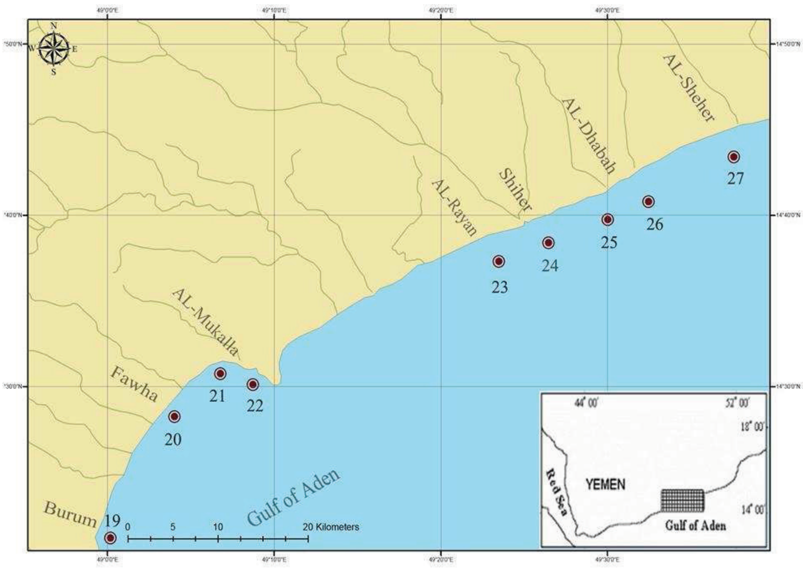


Figure 2-4. Sampling locations along the Coast of AL-Mukalla City.

For these problems and others, we chose this thesis to study the concentrations of heavy metals in the environment of Yemen coast (Aden, Al Hodaeidah and Al Mukalla) sites, which is considered as the most important indicator of the extent of the pollution. The study also included estimate of the heavy metals in filtered surface Seawater and Sediments of Yemen coast . Heavy metals pollution was also studied in selected tissues (muscles , liver and gills) of four commercially important fish species, *Lethrinus mahsena, Thunnus tonggol , Sphyraena jello* and *Epinephelus areolatus*.

2-1-2 Sampling Stations

The trial were undertaken for the period of seasons: Winter 2011, Summer 2012 and Winter 2013, during which a total of 81 Sample of filtered surface Seawater, 81 Sample of Sediments , 108 Sample of Muscles Fish, 108 Sample of Liver Fish and 108 Sample of Gills Fish were collected and analyzed.

Three stations were selected for sampling of large main coastal cities. Samples were collected from three stations. Aden city, overlooking the Gulf of Aden and Al-Hodaeidah, overlooking the Red Sea, and Al Mukalla city , overlooking the Arabian Sea (Table 2-1).

A visual characterization of the sediment samples was used in determining the composition, Type of the sediments Appendix 1 Table (1-b). For a sample of water taken from the same site.

2-1-3 Fish Species

To assess the health of the aquatic environment, aquatic organisms are usually used as biological monitors because they tend to accumulate pollutants from their environment and reflect the combined effects over a period of time (Rainbow, 2006).

Study species are often chosen depending on the monitoring purpose and the information available on environmental pollution. If the information on pollutants is available, certain indicators could be chosen for a optimum use or cost.

Therefore fish were chosen for the study. In order to meet the requirements of monitoring species (USEPA. 2000).Table 2-2 shows the fish species used in the study

This study examined Heavy metals in the muscle and the different fish tissues (liver and gill) of fish. Muscle was been chosen because it is the edible part and the result from measuring metals in muscle is used to assess the risk of Heavy metals exposure to humans consuming fish . liver and Gill , however, was chosen because the metals bioaccumulation in liver is relative higher than any other tissues in biota, so it can be a good environmental indicator of Heavy metals contamination .(Fernandes, *et al*., 2007).

And to study the relationships between the sea water and fish , the sea water was chosen as another test species. sediment was chosen in order to study the integration of pollution .

All collected organisms were weighed (wet wt.) and measured (total weight for fish and length (Measure with the head)) in Table (2-3). The details of weight and length of each season are presented in (Appendix 1, Tables 1-a).

upon return to the laboratory. Characteristics (number of individuals, length and weight) of each of the 4 species collected are given in Table 2-3 . This table also indicates the trophic level (i.e. grazer/scavenger, predator of invertebrates, predator of invertebrates and small fish, predator of small fish) and the water-column distribution (benthic, nectobenthic and neritic) for every species.

2-1-3-1 Selection of Fish Species

While making a selection for the fish species to be taken for the present study, following criteria's were taken into consideration:

1. Edible status
2. Presence at all the selected sites
3. Popularity with the people of Yemen

Based on these criterias, four widely consumed fish species were selected viz. *Lethrinus mahsena* , *Thunnus tonggol* , *Sphyraena jello* and *Epinephelus areolatus* . Their common names in Yemen are Gahash, Zainoop, Kud and Khulkhul (Kushar) respectively.

2-2 Fundamentals of Atomic Absorption Spectrometry

2-2-1 Atomic Absorption Spectrometry Instrumentation

Atomic absorption spectrometry (AAS) in analytical chemistry is a method for determining the concentration of a particular metal in a wide variety of samples. Basically AAS instrumentation consists of the primary radiation source, an atomization unit, a wavelength selector and a detector. A primary radiation source which sharp by emits the atomic lines of the metal to be determined is required. The most widely used source is the hollow cathode lamp. These lamps are designed to emit the atomic spectrum of a particular metal, and specific lamps are selected depending on the metal to be determined (Vollebregt and Vrouwe, 1997).

The atomization unit has to produce analyte atoms in the ground state. A flame or a graphite furnace typically are used to atomize the sample. The radiation emitted by the primary radiation source is absorbed upon passing through the atomization unit and conducted into the monochromator. The monochromator consists of an entrance collimator, a dispersive metal (diffraction grating), usually several mirrors and an exit collimator. The grating spectrally disperses the radiation that is passing the atomizer. The slit of the exit collimator separates the analytical line from the total spectrum, blocking off the other lines emitted by the radiation source. The detector converts the photon current (radiation flux) received into an electric signal and registers the absorption of the analytical line (Florek, 1993).

2-2-2 The Radiation Source

Hollow cathode lamps (HCL) and Super lamps (S-HCL) are the radiation sources typically used in commercially available line source AA spectrometers. The requirements regarding line width of the radiation sources are particularly high when medium- or low-resolution monochromators are used, as the half widths of absorption lines are very small (a few picometers) (Analytik Jena, 2006).

Hollow cathode lamps basically consist of a glass cylinder that contains a cathode and an anode. The glass cylinder itself is filled with neon or argon with a pressure of a few millibars. The cathode has the shape of a hollow cylinder and either consists of, or is filled with the metal of interest. Applying a voltage of several hundred volts, a glow discharge develops between the electrodes. A flow of positive gas ions (Ne^+ or Ar^+) impacts on the cathode, sputtering atoms from its surface, which are excited and emit the spectrum of the cathode material. Because of the lower pressure and lower temperature in a HCL, compared to that in the atomizer, the width of the lines emitted by the radiation source is significantly smaller than that of the absorption lines (Analytik Jena, 2006).

Depending on the wavelength of the main analytical line the exit window of the lamp is made of silica or glass. The fill gas is selected in a way that no spectral interferences are encountered between the spectrum of the fill gas and the analytical line, and to achieve the highest possible emission intensity of the analyte spectrum (Analytik Jena, 2006).

2-2-3 Atom reservoirs

2-2-3-1 Flames

Flame atomic absorption spectrometry (FAAS) is a fast and high sensitivity method for metal determinations, although problems can arise as a result of chemical and spectral interferences .

The sample is transferred into the liquid form e.g. by dissolution. The nebulizer aspirates the solution and brings it into a fine aerosol. This is directed onto an impact bead for post-nebulization in order to create an even finer aerosol. Large droplets are separated off in the mixing chamber and the aerosol is mixed with fuel gas and additional oxidant. The aerosol/fuel gas/oxidant mixture is ignited above the burner head and flame temperatures ranging from 2100 to 2800 ºC, depending on the fuel gas used are obtained. During combustion, atoms of the metal of interest in the sample are reduced to the atomic state. A radiation beam from a lamp whose cathode is made of the metal to be determined is passed through the flame and conducted into a monochromator with a suitable detector (Wu et al., 2009).

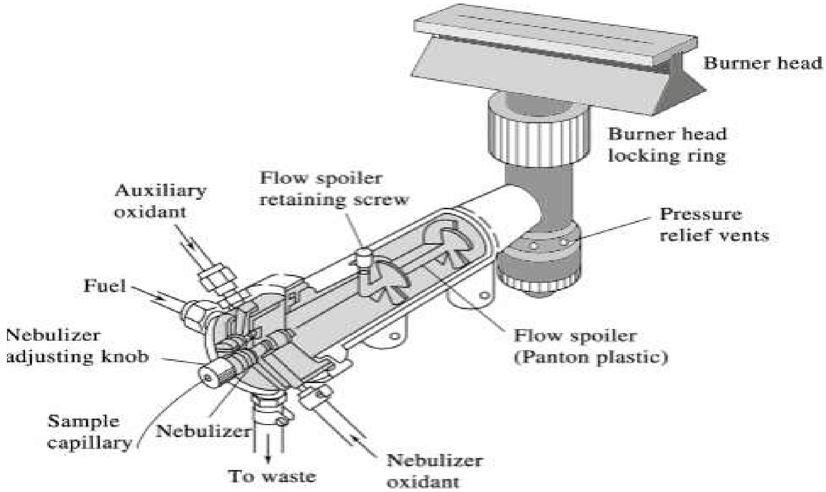


Figure 2-5 Premix burner with nebulizer for FAAS(Wu et al., 2009)**.**

The amount of absorbed radiation is proportional to the concentration of the metal to be determined. Free ground state atoms of the metal absorb radiation at characteristic wavelengths. The reduction of the radiation intensity at the analytical wavelength allows it to determine the concentration of the metal in the sample (Bernhard *et al.,* 1999).

For the instrument that used in the study (Figure 2-6), which read directly in concentration the curve corrector set to read out the proper concentration. Aspirate the samples and the concentrations determined directly.

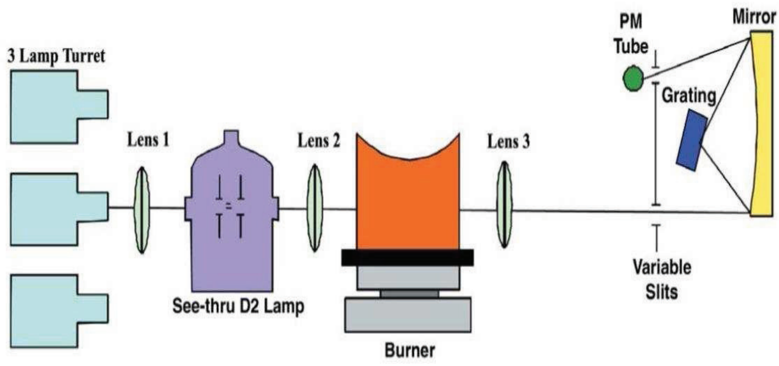


Figure 2-6 The Buck Scientific Single Beam Optical System (Buck Scientific, 1996).

The flame gases are supplied by the gas control system at constant pressure, guaranteeing well defined flow rates of fuel gas and oxidant. The most current gas mixtures used are air/acetylene and nitrous-oxide/acetylene. The latter result in higher atomization efficiencies and thus better detection limits for metals like Si, Al, Sc, Ti, V and Zr. The air/acetylene flame can be used for easy atomized metals (e.g. As and Se).

2-2-3-2 Graphite furnace atomizer

The graphite furnace atomizer which is also called an electrothermal atomizer utilizes an electrically heated cup or tube made of graphite. In modern equipment almost uniquely tubes are used. The heated graphite furnace provides the thermal energy to break the chemical bonds of the analyte substances in the sample and to produce free ground state atoms of the analyte.

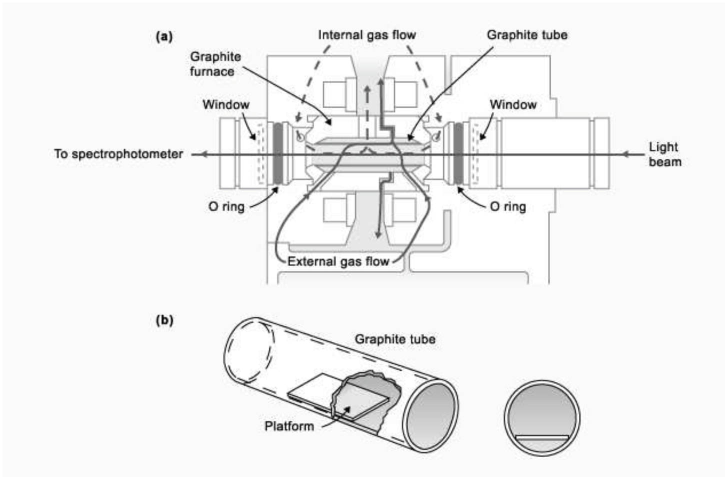


Figure 2-7 Cross-sectional view of a graphite furnace atomizer (Bernhard *et al*., 1999).

Normally the graphite tube is the heating part of the graphite furnace. The cylindrical tube is aligned horizontally in the optical path of the spectrometer and serves as the spectrometer sampling cell. A few micro liters (usually 5-50 µL) of sample are used and dispensed through a hole in the center of the tube wall onto the inner tube wall or a graphite platform. The tube is held in place between two graphite contact cylinders, which provide the electrical connections. The electrical potential applied to the contacts causes current to flow through the tube, the effect of which is a heating of the tube and the sample (Bernhard *et al*., 1999).

The entire assembly is mounted within an enclosed, water-cooled housing. Quartz windows at each end of the housing allow radiation to pass through the tube. The heated graphite is protected from oxidation by air with the end windows and two streams of Ar. An external gas flow surrounds the outside of the tube, and a separately controllable internal gas flow purges the inside of the tube. The system should regulate the internal gas flow so that the internal flow is reduced or preferably, completely interrupted during atomization. This helps to maximize sample residence times in the tube and to increase the measurement signal.

GFAAS is a highly sensitive atomic spectrometric method that provides excellent detection limits for metals in liquid and in solid samples. Routine determinations at the sub mg/L level for most metals make it ideal for environmental applications. Advances in instrumentation and techniques have made it possible to analyze samples with very complex matrices, such as those frequently found in biological and geological samples. The more sophisticated GFAAS system has turrets for several lamps and therefore is capable of sequential and automatic determinations of more than one metal (Mohadi, 2012).

The advantages of GFAAS include a higher sensitivity and lower detection limits than other methods, the possibility for direct analysis of some types of liquid samples, low spectral interferences and the requirement of very small volumes or amounts of sample (Stephan *et al*., 2008 and Morimoto *et al*., 2011).

2-2-3-3 Hydride generation

The hydride generation technique, which makes use of a separation of the analyte metal from the matrix by conversion to its volatile hydride, offers a route to the Heavy determination of several important metals , which have specific problems when determined by conventional methods. Hydride generation atomic absorption spectrometry is a measurement method which is now applied to the determination of Hg and the metals that are forming volatile hydrides (e.g. Sb, As, Bi, Ge, Pb, Se, Te and Sn) in a wide range of matrices. For example it is used for the determination of traces of these metals in biological samples and it is used in the analysis of alloys and environmental materials(Cabon and Cabon, 2000).Here the sample solution is mixed with a solution of $NaBH_4$ in a suitable flow cell. The generated hydrides are purged out of the solution using a carrier gas flow. Doing so, the analyte can often be separated completely from the matrix. Atomization may be carried out in a heated quartz tube placed in the beam of the spectrometer. Because of the relatively low temperature of the quartz tube, atomization cannot be due to thermal dissociation, but proceeds via free hydrogen radicals formed in the entrance part of the quartz tube (Ebdon *et al*., 1998 and Bye, 1989).

Hydride generation is especially valuable for the determination of Heavy levels of As and Se because the useful resonance lines of these two metals are below 200 nm, a region where there are very considerable spectral interferences from radicals in flame AAS. Other advantages include the high efficiency of analyte introduction to the atomizer, the ease of preconcentration of the analyte and the possibility of speciation (Korenovska, 2006).

2-2-3-3-1 Cold Vapor Techniques

Mercury is reduced to the metals under the conditions used for hydride generation, and can be purged directly with an inert gas from solution as atomic vapor and measured in an unheated absorption cell by AAS. This procedure, called Cold Vapor Technique results in the best detection limits for mercury. When sodium borohydride is used as the reducing agent, the interferences are similar to those mentioned for the hydride-forming metals. Most of these interferences disappear when stannous chloride is used as the reducing agent.

The cold vapor technique is particularly suited for the determination of mercury, as this metal can be reduced easily to the metals and does not require any atomization unit. In contrast to inorganic compounds, organic mercury compounds are problematic as they cannot be reduced to the metal by sodium tetrahydroborate, and particularly not by stannous chloride. An acid digestion is therefore mandatory in this case prior to the actual determination. All this preparation has to be carried out with utmost care in order to avoid contamination, analyte loss, and to ensure complete digestion (Perkin Elmer, 2000).

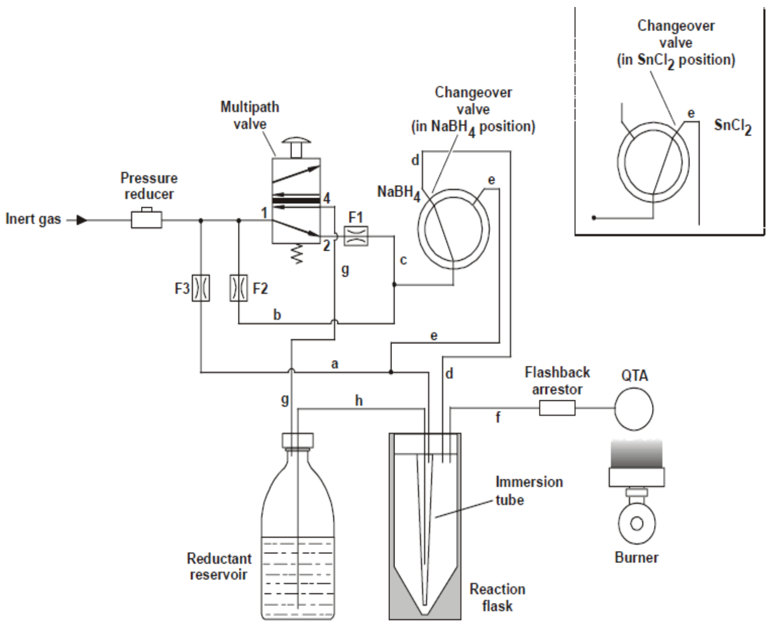


Figure 2-8 Schematic of pneumatic system(Perkin Elmer, 2000).

Two reducing agents became established for the determination of mercury. In addition to sodium tetra hydro borate, which is also used for the hydride-forming metals, stannous chloride ($SnCl_2$) is used as well, as it might offer better sensitivity and is less prone to foam formation. It has to be noted, however, that an interchange between the two reagents is not possible in the same apparatus (Perkin Elmer, 2000).

Mercury may be stabilized using:

- Potassium dichromate $K_2Cr_2O_7$
- Potassium permanganate $KMnO_4$
- Potassium bromide KBr / potassium bromate $KBrO_3$

2-3 Methodology of Analysis

2-3-1 Preparation of Samples

Aqueous solutions may sometimes be analyzed directly without pretreatment, but it is a matter of chance that the given solution should contain the correct amount of material to give a satisfactory absorbance reading. Solid samples needs some form of dissolution procedure prior to measurement, it is acceptable for both Flame, Furnace, Cold Vapor and Hydride Atomic Absorption Spectrometry to use liquid samples. Many dissolution procedures are available such as wet aching, dry aching, microwave dissolution and concentration procedures. To achieve good results, appropriate procedures were applied (collection, handling, preservation, storage and analysis) of all samples. The environmental protection agency procedure (EPA) was used as a guidance for the analysis of inorganic analyses in a variety of matrices. All chemicals used in the processes are analytical grade reagents.

2-3-2 Preparation of Standards

The standard solutions are prepared for the pure metals to be determined by dilution of stock solution (1000mg/L) (Buck Scientific puro graphics calibration standards, USA). At least three concentrations of the standard solutions should be used covering the optimum absorbance range (Jeffery *et al*., 1997). The amount of the stock solution required to prepare a working standard solution for each metals was computed. The working solutions were freshly prepared by diluting an appropriate aliquot of the stock solution through intermediate solutions. It is usual to examine the standard solutions in order of increasing concentration, and after making the measurements with one solution, deionized water is aspirated into the flame to remove all traces of solution before proceeding to the next solution. Standard solutions were prepared before the using . Glassware cleaned by stoking in 10% HNO_3 for 24 hours and rinsed gently with deionized water (Laidlaw, 2005).

2-3-2-1 Calibration

Calibration standards are prepared by diluting the stock metals solutions at the time of analysis. For best results, calibration standards should be prepared fresh each time. An analysis is to be made and discarded after use. Prepare a blank and at least four calibration standards in graduated amounts in the appropriate range. The calibration standards should be prepared using the same type of acid or combination of acids and at the same concentration as will result in the samples following processing .

2-3-3 Collection of Samples and Analysis:

Water, sediment and fish samples were collected for the purpose of determining the accumulation of heavy metals in the of Yemen coast (Al Hodaeida, Aden and Al Mukalla) study area.

All the glassware, sampling bottles (polyethylene bottles), plastic bags and other tools were first immersed in detergent solution, then rinsed in tap water and rinsed with distilled water. All the cleaned glassware, sampling bottles and bags were then drenched in 1M Nitric acid for 24 hours. Before being used, all the glassware, sampling bags and bottles were washed with deionized water and dried (US EPA, 2000).

A. Surface Seawater Sampling and Analysis

1. Surface Seawater Sampling

Seawater samples were collected seasons for analysis from one levels; the surface Seawater of each station along with sediment samples. In principle, collect seawater samples at high tide and avoid windy or rainy days). Before sampling, the bottles of samples were rinsed at least three times with water from the sampling station. The bottles were immersed to about 20-30 cm below the water surface to prevent contamination of heavy metals from air according to the Method 1669 (USEPA, 1996).

For mercury analysis water samples kept in a sealable glass container that has been well washed before being transported (Tsuguyoshi, 2004).

For Arsenic analysis Water samples (1000 mL) are collected directly into cleaned polypropylene bottles . Water samples are preserved in the field by the addition of 3 mL of pretested 6M HCl per liter of sample. The recommended holding time is 28 days Method 1632 (USEPA(1), 1998).

A total of 81 of seawater samples were collected using cleaned plastic water sampler. Each sample was taken in 1 liter polyethylene bottles. All water samples were immediately brought to the laboratory where filtered through whatman No.41 (0.45 µm pore size) filter paper. The samples were acidified with 2ml nitric acid to prevent precipitation of metals, reduce adsorption of the analyses onto the walls of containers and to avoid microbial activity, and then stored at 4°C until the chemical analyses(USEPA, 1996).

2. Surface Seawater Digestion and Analysis

i. Surface Seawater Digestion for Pb and Cd Analysis by GFAAS

Five milliliter of concentrated HCl was added to 250 ml of each surface seawater sample placed in 600 ml beaker and evaporated to 25 ml volume. The concentrate was transferred to a 50 ml volumetric flask and diluted to mark with deionized water. Prior analysis, the solutions were filtered through Whatman No.41 (0.45 μm pore size) filter paper (US EPA(2), 1992).

Analyzed for Lead (Pb) and Cadmium (Cd) using Buck Model 210 VGP, USA Made - Graphite furnace Atomic Absorption Spectrophotometer (GF AAS) in Seawater samples, before proceeding Method 200.13 (US EPA(2), 1992).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Pb and Cd analysis (Table 2-4).

For water samples and fish samples five standard solutions were made (Table 2-5).

Triplicate sub-samples of each sample were aspirated separately to compute mean metals concentrations in a given sea water and sample.

ii. Surface Seawater Digestion for Hg and As Analysis by Hydride Analyzer

Forty five millilter of surface seawater sample was measured .A volume of 5 ml of concentrated nitric acid (HNO_3, 65 %), 1ml of concentrated hydrochloric acid (HCl, 35 %) was added to each sample . Vessels Sealed and placed in microwave system. Samples were heated according to time versus pressure profiles. Vessels allowed cooling to the room temperature and then each sample transferred to a final volume of 25 ml using deionized water. The Sample may represent a safety hazard. Pre-digest sample in a hood, with vessel loosely capped to allow gases to escape, before proceeding Method 3015A (US EPA (3), 2007).

Cold Vapor Hg Analyzer (Buck Model 410), U.S.A Made, were used for analysis of Hg in Seawater samples, Perfect for EPA method 245.1(US EPA(4), 1994).

Arsenic Hydride Analyzer (Buck Model 411), U.S.A Made, were used for analysis of As in Seawater samples, Perfect for EPA method 206.3(US EPA(5), 1974).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Hg and As analysis (Table 2-6).

For water samples four standard solutions were made (Table 2-7).

Triplicate sub-samples of each sample were aspirated separately to compute mean metals concentrations in a given sea water and sample.

Blanks Three types of blanks are required for the analysis. The calibration blank is used in establishing the analytical curve, the laboratory reagent blank is used to assess possible contamination from the sample preparation procedure, and the laboratory fortified blank is used to assess routine laboratory performance.

B. Surface Sediment Sampling and Analysis

1. Surface Sediment Sampling

Sediment samples were obtained from the same sites where Seawater samples were collected. A total of 81 surface sediment samples were obtained from sampling stations during the period of the study. About 250 g of sediment was collected using cleaned stainless steel Ekman sediment sampler and packed separately in cleaned polyethylene bags. Samples were brought to the laboratory, dried in oven at (80°C) to constant weight. The collected sediment was cleaned (of wood pieces, pebbles and shells) and then passes through a 2mm mesh sieve to prepare samples for analyses and then grounded into fine powder using pestle and mortar. A sub sample of each sample was stored in cool dark place. Samples which will use for analysis of metals lic mercury content will kept in a freezer (Tsuguyoshi, 2004)

2. Surface Sediment Digestion and Analysis

The procedure for the Digestion heavy metals was based on Standard Method 3051A (Microwave – assisted acid digestion of sediments, USEPA(6). 2007).

About 0.25 g of dry sediment sample was accurately weighed and digested with 6 ml of concentrated nitric acid (HNO_3 65%) , 1 ml of Perchloric acid ($HClO_4$ 65%) and 1 ml of hydrogen peroxide (H_2O_2 30%) . Milestone Start Microwave Digestion Lab station with internal Temperature sensor and 260 terminal teach screen With HPR1000/10S High Pressure Segmented Rotor (Application Note HPR-EN-33).

Microwave Program 2 Steps (1)15.00 Min (temperature 200) (2)15.00 Min (temperature 200).

After Finish left vessels 20 min until reach the room temperature, then the digested portion was diluted to a final volume of 50 ml using deionized water (US EPA(6). (2007).

Pb and Cd Analyzed without Further Treatment , Hg and As Dulited with Factor 100 .

i. Sediment Digestion for Pb and Cd Analysis by FAAS

Flame atomic absorption spectrometry (Buck Model 210 VGP) U.S.A Made, were used for analysis of Cd and Pb in sediments, Perfect for EPA method 239.1 (US EPA(7), 1974) for Pb and 213.1 for Cd (US EPA(8), 1974).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Pb and Cd analysis (Table 2-8).

For sediments samples standard solutions were made (Table 2-9). A rinse blank (deionized water) was used to flush the uptake system to reduce memory interferences. The laboratory fortified blanks, which are made of 1 mL fortifying 1000 mg/L standard metals solutions (Buck Scientific puro graphics calibration standards), were used to assess routine instrument performance. Statistical calculations and graphing were made using Origin Software.

Triplicate sub-samples of each sample were aspirated separately to compute mean metals concentrations in a given sediments sample.

ii. Sediment Digestion for Hg and As Analysis by Hydride Analyzer

Cold Vapor Hg Analyzer (Buck Model 410), U.S.A Made, were used for analysis of Hg in sediments, Perfect for EPA method 245-5(US EPA(9) , 1974).

Arsenic Hydride Analyzer (Buck Model 411), U.S.A Made, were used for analysis of As in sediments, Perfect for EPA method 206.3(US EPA(5), 1974).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Hg and As analysis (Table 2-6).

For sediments samples four standard solutions were made (Table 2-7).

C. Fish Sampling and Analysis

1. Fish Sampling

A total of 324 specimens of four commercially important fish species, *Lethrinus mahsena, Thunnus tonggol* , *Sphyraena jello* and *Epinephelus areolatus* were collected seasons with the help of local fishermen from Aden, Al Hodaeidah and Al Mukalla during the study period of seasons (winter 2011, summer 2012 and winter 2013). Samples were placed immediately in poly-ethylene bags, put into ice box , after that brought to the laboratory at the faculty of Environmental Sciences and Marine Biology, Hadramout University.

The total length and the body wet weight of each specimen were measured to the nearest centimeter and gram respectively (US EPA(10), 2000). After measurements, fish samples were washed with deionized water, sealed in polyethylene bags and kept in a freezer at -20°C until chemical analysis (US EPA(10), 2000).

2. Fish Tissue Digestion and Analysis

Fish tissues were dried in oven at (80°C) until sample is at a constant weight. About 0.500 g of dry tissue sample (muscles, liver or gills) was accurately weighed and digested with 7ml of concentrated nitric acid (HNO_3 65%) and 1ml of hydrogen peroxide (H_2O_2 30%). Milestone Start Microwave Digestion Lab station with internal Temperature sensor and 260 terminal teach screen With HPR1000/10S High Pressure Segmented rotor (Application Note HPR-FO-07) and AOAC Official Method 999.10 (AOAC, 2005) and AOAC Official Method 974.14 (AOAC, 2005) .

Microwave Program 2 Steps (1)15.00 Min (temperature 200) (2)15.00 Min (temperature 200).

After Finish left vessels 20 min until reach the room temperature, then the digested portion was diluted to a final volume of 50 ml using deionized water , before proceeding Method 3052 (US EPA (11), 1996).

Pb Analyzed without Further Treatment , Cd diluted with Factor 2 , Hg and As Diluted with Factor 100 .

The Certified Reference Material DORM-2 Analyzed for For Pb, Cd, Hg and As Content.

i. Lead and Cadmium Analysis in Fish Tissues by GFAAS

Graphite furnace atomic absorption spectrometry (Model 220 GF), U.S.A Made, were used for analysis of Cd and Pb in fish tissue samples, Perfect for AOAC Official Method 999.10 (AOAC , 2005).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Pb and Cd analysis (Table 2-4). For fish tissue samples five standard solutions were made (Table 2-5).

ii. Mercury and Arsenic Analysis in Fish Tissues by Hydride Analyzer

Cold Vapor Hg Analyzer (Buck Model 410), U.S.A Made, were used for analysis of Hg in fish tissue samples, Perfect for AOAC Official Method 974.14 (AOAC , 2005).

Arsenic Hydride Analyzer (Buck Model 411), U.S.A Made, were used for analysis of As in fish tissue samples, Perfect for EPA method 206.3(US EPA(5), 1974).

Wavelength, energy, lamp and burner alignment and slit width were optimized for Hg and As analysis (Table 2-6).For fish tissue samples four standard solutions were made (Table 2-7).

2-4 Equipment and Supplies

For the purpose of experimental analysis, several devices and equipments were used as follows:

1. Atomic Absorption spectrophotometer the Buck Scientific Single Beam (Flame system 210, Air / Acetylene flame) U.S.A Made, were used for analysis of Cd and Pb in Surface Sediment samples.
2. Atomic Absorption spectrophotometer the Buck Scientific Single Beam (Graphite furnace Buck Scientific Model 210 VGP AAS, East Norwalk, USA)
3. Atomic Absorption spectrophotometer the Buck Scientific Single Beam Hydride Analyzer (Buck Scientific Model 411 VGP, USA Made)
4. Atomic Absorption spectrophotometer the Buck Scientific Single Beam (Combination Batch Cold Vapor Generator Quartz tube Hg Analyzer Buck Model 410 VGP U.S.A Made)
5. Atomic Absorption spectrophotometer the Buck Scientific Single Beam (Continuous Flow Hydride Generator) U.S.A Made, were used for analysis of As in All samples.
6. AA-6300 SHMADZU (Atomic Absorption Spectrophotometer). Hydride vapor generator, From SHIMADZU. (For As analysis). Mercury vapor unit, From SHIMADZU. (For Hg analysis),In Jordan.
7. Chemito-AA 201(Atomic Absorption Spectrophotometer), In India.
8. Single-metal hollow cathode lamps: (U.S.A Made), special used for particular metals:

   a. Lead Hollow Cathode Lamp
   b. Cadmium Hollow Cathode Lamp
   c. Mercury Hollow Cathode Lamp
   d. Arsenic Hollow Cathode Lamp

9. Gas Supplies:

   a. Acetylene gas supply

   b. Argon gas supply (high-purity grade, 99.99%) for use during the atomization

   c. Air compressor

Other apparatus were used

1. Milestone Start D Microwave digestion system
2. Ekman stainless-steel bottom grab Sediment Sampler. England made.
3. Plastic Water sampler, Germany made.
4. pH meter, basic WTW inoLab® model pH 720 laboratory pH meter for precise pH measurement. Germany. model.
5. Analytical balance, with capability to measure to 0.01 mg, for use in weighing solids, preparing standards, and determining dissolved solids in digests or extracts, KERN, Germany made.
6. A gravity convection drying oven with thermostatic control capable of maintaining 180°C ± 5°C, Digit heat J.P.SELECTA, Spain made.
7. (Optional) An air displacement pipette capable of delivering volumes ranging from 10-100, 20-200 µL with an assortment of high quality, disposable pipet tips.
8. Global Positioning System (GPS).
9. Mortar and pestle, ceramic or nonmetals lic material.
10. Sieve, 5-mesh (2 mm opening).
11. Polystyrene icebox
12. Capsule Filter
13. Whatman filter paper, filter type: (0.45 µm) HA, MF-membrane Germany made.

It was purchased chemicals from the company Scharlab (Spain).

2-5 Quality Control of Metals Analyses

2-5-1 Quality Assurance

Recovery studies were performed in order to establish the accuracy of the method. Recovery of the metals was determined by spiking one sample with increasing amounts of metals standard solution. The spiked samples were then taken through the same digestion procedure (as all other samples) and analyzed for heavy metals concentrations. To assess the precision of the overall procedure, the samples were divided in batch of eight and for each batch; three replicate analyses of one of the samples were conducted. Analyses of all sample digests were performed in duplicate by the instrument. Certified Reference Material (CRM), Dog Fish (DORM-2) from the National Research Council, Canada was also included in quintuplicate.

2-5-2 Inter-Laboratory Comparison

This study focused on determination on the levels of selected heavy metals namely: lead, cadmium, mercury and Arsenic in fish (muscles , liver and gill), filtered surface Seawater and sediments of the major Yemen coast city of Al-Hodaeidah, Aden and AL-Mukalla stations. The samples were collected during 2011 to 2013.

Adequate quality assurance control was ensured by inter-laboratory comparison of representative samples carried out at laboratory at the Faculty of Environmental Sciences and Marine Biology, Hadramout University in Yemen (ESMB) , laboratory at the Royal Scientific Society in Jordan (RSS) and laboratory at the Environmental Reserch at the Nanded University in India (ERN).

2-6 Statistical Analysis

All heavy metals data (lead, cadmium, mercury and Arsenic) were analyzed and tested for differences between group means of stations and seasons for significance ($P \leq 0.05$)using the analysis of variance one way ANOVA and two ways ANOVA technique. Also, group means of environmental factors were analyzed by one way ANOVA technique. All statistical analysis was performed using the Origin 9 and SPSS software packages, version 17.0 .

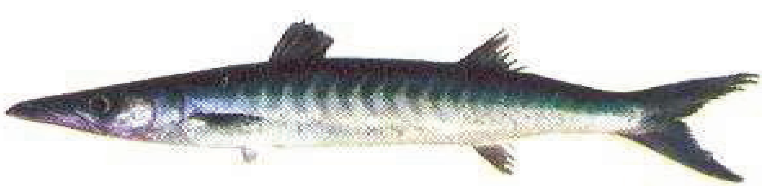
Table 2-1 Sampling stations details

Station	Longitude (E)	Latitude (N)	Description
Aden City	**45°04'88"E**	**12°77'53"N**	**overlooking the Gulf of Aden**
Al-Hodaeidah City	**42°94'05"E**	**14°91'35"N**	**overlooking the Red Sea**
AL-Mukalla City	**49°10'67"E**	**14°52'87"N**	**overlooking the Arabian Sea**

Table 2-2 Target Species for fish from three sites.

N	Family name	LETHRINIDAE
1	Common name	Gahash (emperor)
	FAO name	Ee-Mahsenaemeror
	Scientific name	*Lethrinus mahsena*
	Habitat	Demersal Life style and Feeding , Important benthic feeding fish found on coral reefs
	Trophic level	3.4±0.42
		
2	Family name	SCOMBRIDAE
	Common name	Zainoop (Longtail tuna)
	FAO name	En-Longtail tuna
	Scientific name	*Thunnus tonggol*
	Habitat	Pelagic – naritic Life style and Feeding , Important commercial and angling species Carnivore on small fish and crastease
	Trophic level	4.5 ±0.6
		

No.		
3	**Family name**	**SPHYRAENIDAE**
	Common name	**Kud, Kunat (Pickhandle Barracuda)**
	FAO name	**En-Barracuda**
	Scientific name	***Sphyraena jello***
	Habitat	**Pelagic - naritic** **Life style and Feeding ,Carnivorous fish (feeding on other smaller fish)**
	Trophic level	**4.5 ±0.6**



No.		
4	**Family name**	**SERRANIDAE**
	Common name	**Khulkhul (Areolate grouper)**
	FAO name	**En-Areolate grouper**
	Scientific name	***Epinephelus areolatus***
	Habitat	**Demersal** **Life style and Feeding , Important benthic feeding fish found on coral reefs** **Carnivore on small fish and crustaceans**
	Trophic level	**3.7±0.3**

Morfg, YEMEN FISHES GUIDE (2010). Marine Sciences Research Center (2001).

Table 2-3. The Mean weight and length of fish collected during the seasons from Aden , Al-Hodaeidah and AL-Mukalla Stations, Yemen coast

Site	Species	Size	weight (g)	length (cm)
			Mean±Std.	Mean±Std.
Aden	*Lethrinus mahsena*	Large	445.89±14.31	29.32±1.09
Aden	*Lethrinus mahsena*	Medium	358.83±54.32	26.24±1.61
Aden	*Lethrinus mahsena*	Small	252.52±24.21	24.25±1.15
Aden	*Thunnus tonggol*	Large	3513.05±411.4	73.33±2.04
Aden	*Thunnus tonggol*	Medium	2652.85±214.79	60.4±1.65
Aden	*Thunnus tonggol*	Small	1860.49±78.34	52.93±1.93
Aden	*Sphyraena jello*	Large	890.56±160.38	52.73±1.6
Aden	*Sphyraena jello*	Medium	741.84±30.8	48.37±0.7
Aden	*Sphyraena jello*	Small	587.24±30.31	44.5±0.79
Aden	*Epinephelus areolatus*	Large	798.95±49.43	40.4±0.91
Aden	*Epinephelus areolatus*	Medium	444.11±17.44	31.53±2.06
Aden	*Epinephelus areolatus*	Small	242.24±47.95	23.93±1.47
Al Hodaeidah	*Lethrinus mahsena*	Large	1085.77±75.04	37.07±0.82
Al Hodaeidah	*Lethrinus mahsena*	Medium	746.49±139.89	32.63±2.08
Al Hodaeidah	*Lethrinus mahsena*	Small	238.13±60.67	23.27±1.78
Al Hodaeidah	*Thunnus tonggol*	Large	3416.47±421.55	64.47±2.84
Al Hodaeidah	*Thunnus tonggol*	Medium	2338.1±97.98	56.5±0.85
Al Hodaeidah	*Thunnus tonggol*	Small	1878.68±94.29	52.2±0.96
Al Hodaeidah	*Sphyraena jello*	Large	1156.43±78.07	57.17±1.21
Al Hodaeidah	*Sphyraena jello*	Medium	694.31±79.85	47.5±1.42
Al Hodaeidah	*Sphyraena jello*	Small	484.48±24.65	42.37±1.28
Al Hodaeidah	*Epinephelus areolatus*	Large	911.37±66.14	39.13±0.7
Al Hodaeidah	*Epinephelus areolatus*	Medium	678.33±51.94	35.5±0.79
Al Hodaeidah	*Epinephelus areolatus*	Small	374±32.24	29.17±0.98
Al Mukalla	*Lethrinus mahsena*	Large	746.8±50.18	34.1±1.53
Al Mukalla	*Lethrinus mahsena*	Medium	544.82±51.53	30.77±0.97
Al Mukalla	*Lethrinus mahsena*	Small	359.78±37.32	26.43±1.09
Al Mukalla	*Thunnus tonggol*	Large	2893.21±147.23	62.37±1.05
Al Mukalla	*Thunnus tonggol*	Medium	2268.93±218.43	57.57±1.82
Al Mukalla	*Thunnus tonggol*	Small	1614.56±107.72	51.53±1.13
Al Mukalla	*Sphyraena jello*	Large	1037.37±175.26	55.37±3.19
Al Mukalla	*Sphyraena jello*	Medium	625.67±93.35	46.57±2.34
Al Mukalla	*Sphyraena jello*	Small	454.82±34.13	41.8±1.06
Al Mukalla	*Epinephelus areolatus*	Large	857.36±51.75	41.37±1.18
Al Mukalla	*Epinephelus areolatus*	Medium	353.8±81.85	35.33±1.92
Al Mukalla	*Epinephelus areolatus*	Small	187.48±53.95	24.13±2.4

Table 2-4. Operational parameters for Pb and Cd Analysis by GFAAS in filtered surface Seawater **and Fish**

Metal	**Pb**	**Cd**
Sample	**Sw+F**	**Sw+F**
Method	**GFAAS**	**GFAAS**
Wavelength (nm)	**283.3**	**228.8**
T Drying[a] , °C	**110-130**	**110-130**
T Pyrolysis, °C	**1000**	**900**
T Atomization, °C	**1900**	**1200**
T Clean out, °C	**2500**	**2500**
T Ramp, °C	**1400**	**1300**
Matrix modifier	**5 μL $NH_4H_2PO_4$+$Mg(NO)_2$**	**5 μL $NH_4H_2PO_4$+$Mg(NO)_2$**
Slit width (nm)	**0.8**	**1.2**
Argon flow ($mLmin^{-1}$)	**250**	**250**
Injection volume (μL)	**20**	**20**
Instrumental detection limit (mg/L)	**0.02**	**0.005**

Sw filtered surface Seawater, F fish, GFAAS graphite furnace atomic absorption spectrometry

Table 2-5. Standard Concentration for Pb and Cd Analyzed in filtered surface Seawater and Fish

Metal	**Pb**	**Cd**
Sample	filtered surface Seawater **+ Fish**	filtered surface Seawater **+ Fish**
Method	**GFAAS**	**GFAAS**
Standard Solutions (μg/L)	**0.5, 1.0, 1.5, 2.0, 2.5**	**0.125, 0.25, 0.50, 0.75, 1.0**

Table 2-6. Operational parameters for Hg and As Analysis by Hydride Analyzer in filtered surface Seawater, Sediment and Fish

Metal	Hg	As
Sample	Sw+S+F	Sw+S+F
Method	CVAAS	HGAAS
Wavelength (nm)	253.7	193.7
Operation mode	discontinuous	discontinuous
Integration mode	Peak area	Peak area
Integration time	48 sec	50 sec
Reaction time	12 sec	10 sec
T °C		900
Slit width (nm)	0.8	0.7
Flam mode		Argon-hydrogen
Instrumental detection limit (mg/L)	0.00002	0.001

Sw filtered surface Seawater , S Sediment , F fish, HGAAS hydride generation atomic absorption spectrometry , CVAAS cold vapor atomic absorption spectrometry

Table 2-7. Standard Concentration for Hg and As Analyzed in filtered surface Seawater, Sediment and Fish

Metal	Hg	As
Sample	Sw+S+F	Sw+S+F
Method	CVAAS	HGAAS
Standard Solutions (μg/L)	0.5, 1.0, 2.0, 5.0	0.5, 1.0, 2.0, 5.0

Table 2-8. Operational parameters for Pb and Cd Analysis by FAAS in Sediment

Metal	Pb	Cd
Sample	Sediment	Sediment
Method	Flam	Flam
Wavelength (nm)	283.3	228.8
Flam mode	C_2H_2/Air	C_2H_2/Air
Slit width (nm)	0.7	0.7
Lamp current (mA)	2	2
Energy (eV)	2.874	3.214
Instrumental detection limit (mg/L)	0.08	0.01

Table 2-9. Standard Concentration for Metals Analyzed in Sediment

Metal	Pb	Cd
Sample	Sediment	Sediment
Method	flam	flam
Standard Solutions (mg/L)	1.0, 2.0, 4.0, 8.0	0.05, 0.1, 0.15, 0.20, 0.25

Chapter 3

Results

3- Results

Precision and accuracy of the analytical procedure were evaluated by repeated analyses of samples and certified reference material (DORM-2 Dogfish) from the National Research Council Canada. The validity of the method has been proved by agreement between the measured and the certified concentrations in the Dogfish. The results from the analysis (Table 3-1) were all within the 95% percent confidence limit. The details of analysis of certified reference material are presented in (Appendix 2, Tables 1).

Method recovery determination was usually to evaluate the accuracy of the method applied for the analyses determination. The recovery was calculated from the analysis of spiked fish samples. This was performed by carefully spiking the standard solution prepared, which was 20-50 % of the sample concentration, in to all samples and checked to what extent the standard added could be recovered after determination through sample preparation. Spike recoveries were calculated according to the following formula;

Percent recovery = Spiked result – un Spiked result / added amount x 100 %

Recovery was assessed using spiked samples at two concentration levels. The results of the recovery study for fish , Seawater and Sediment samples are presented in (Appendix 2, Tables 2 through 4). Recoveries between 88-97% for spiked samples demonstrate the accuracy of the methods used.

Adequate quality assurance control was censured by inter-laboratory comparisons of representative samples carried out at laboratory at the Faculty of Environmental Sciences and Marine Biology, Hadramout University in Yemen (ESMBHU) , laboratory at the Royal Scientific Society in Jordan (RSS) and laboratory at the Department of Zoology at the Dr. Babasaheb Ambedkar Marathwada University in India (BAMU) limited (Appendix 2, Tables 5 and 6). RSS Jordan limited is ISO 9001 and UKAS

Quality Management 001 accredited and also BAMU India accredited for heavy metal analyses. For comparative check, parallel subsamples processed under similar analytical conditions were subjected to analysis at ESMBHU Yemen laboratory. To confirm the results, we studied the elements in the three laboratories, the Table in (Appendix 2, Tables 5 and 6) shows the compatibility of these laboratories with the first laboratory. One-way ANOVA done on comparative test data between three laboratories revealed no significance difference at *<0.05* probability level and the results were found to agree within acceptable margin of error as indicated in (Appendix 2, Tables 5 and 6).

In this chapter, the results analysis of Seawater , Sediment and fish (Muscles , Liver , Gill) , which carried out during 2011 to 2013 prepare and assortment after make some statistics analysis such as mean, standard deviation (SD), one-way and tow-way ANOVA**.** These results advance in five tables apart (3-1), (3-2), (3-3), (3-4), (3-5), (3-6) and (3-7), (3-8). Some target values such as mean concentration, overall mean concentration, SD and curve plot for any study element for filtered Seawater , Sediment and fish (Muscles , Liver and Gill) apart for all samples are given in this chapter.

3-1 Heavy Metals in Filtered Surface Seawater

Analysis of heavy metals for twenty seven filtered surface Seawater samples was carried out, for the study period of three years (three seasons). The overall means results of analysis heavy metals in the filtered surface Seawater for the three seasons, for the study sites in Yemen are presented in (Table 3-1). The details of analysis of each season are presented in (Appendix 3, Tables 1 through 4).

The results of the present study showed that there were significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of

Pb , Cd and Hg, however, there was no significant difference (*P>0.05*) regarding the concentration of As in the filtered surface Seawater of Aden, for the period of seasons: winter 2011, summer 2012 and winter 2013. The highest concentration of Pb in filtered surface Seawater of Aden was 0.055 mg/L on winter 2011 and the lowest concentration was 0.045 mg/L on summer 2012. The highest concentration of Cd in filtered surface Seawater of Aden was 0.010 mg/L on summer 2012 and the lowest concentration was 0.006 mg/L on winter 2011. The highest concentration of Hg in filtered surface Seawater of Aden was 0.007 mg/L on winter 2013 and the lowest concentration was 0.003 mg/L on summer 2012; however, there were no significant differences (*P>0.05*) regarding the concentration of As in filtered surface Seawater of Aden. The highest concentration of As in filtered surface Seawater of Aden was 0.0061 mg/L on summer 2012 and the lowest concentration was 0.0057 mg/L on winter 2011, as summarized in (Table 3-1), (Fig. 3-1).

Further, there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb and Cd , however, there was significant difference (*P<0.01*) regarding the concentration of Hg and As in the filtered surface Seawater of AL-Hodaeidah, for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Hg in filtered surface Seawater of AL-Hodaeidah was 0.008 mg/L on summer 2012 and the lowest concentration was 0.007 mg/L on winter 2011 and winter 2013.

The highest concentration of As in filtered surface Seawater of Al-Hodaeidah was 0.0087 mg/L on winter 2013 and the lowest concentration was 0.007 mg/L on winter 2011; however, there was no significant differences (*P>0.05*) regarding the concentration of Pb and Cd in filtered surface Seawater of AL-Hodaeidah. The highest concentration of Pb in filtered surface Seawater of Al-Hodaeidah was 0.087 mg/L on summer 2012 and the lowest concentration was 0.072 mg/L on winter 2013 .

The highest concentration of Cd in filtered surface Seawater of Al-Hodaeidah was 0.007 mg/L on winter 2011 and the lowest concentration was 0.006 mg/L on summer 2012, as summarized in (Table 3-1).

On the other hand, the results showed that there was significant differences (*$P<0.01$*), using one way ANOVA, regarding the concentration of Pb, Cd and Hg , however, there were no significant difference ($P>0.05$) regarding the concentration of As in the filtered surface Seawater of AL-Mukalla, for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Pb in filtered surface Seawater of AL-Mukalla was 0.064 mg/L on summer 2012 and the lowest concentration was 0.033 mg/L on winter 2011. The highest concentration of Cd in filtered surface Seawater of AL-Mukalla was 0.0083 mg/L on winter 2013 and the lowest concentration was 0.006 mg/L on winter 2011, but the highest concentration of Hg in filtered surface Seawater of AL-Mukalla was 0.009 mg/L on winter 2011 and the lowest concentration was 0.006 mg/L on summer 2012; however, there was no significant differences (*$P>0.05$*) regarding the concentration of As in filtered surface Seawater of AL-Mukalla. The highest concentration of As in filtered surface Seawater of AL-Mukalla was 0.011 mg/L on summer 2012 and the lowest concentration was 0.010 mg/L on winter 2011 , as summarized in (Table 3-1).

The results of present study were analyzed by using two ways ANOVA in filtered surface Seawater sites during the seasons, it showed that there were significant differences (*$P<0.01$*) regarding the concentration of Pb, Hg and As , however, there was significant difference (*$P<0.05$*) regarding the concentration of Cd in the filtered surface Seawater of Aden, Al-Hodaeidah and AL-Mukalla station.

The highest concentration of Pb in filtered surface Seawater of AL-Hodaeidah was 0.080 mg/L, whereas the lowest concentration was 0.050 mg/L of Aden station; however, the highest concentration of Cd in filtered surface Seawater of Aden was 0.008 mg/L, whereas the lowest concentration was 0.007mg/L of Al-Hodaeidah station. The concentration of Hg in filtered surface Seawater had the same patternof Pb and Cd ; but, the highest concentration of Hg in the filtered surface Seawater of AL-Mukalla was 0.0075 mg/L, whereas the lowest concentration was 0.005 mg/L of Aden station.

The highest concentration of As in filtered surface Seawater of AL-Mukalla was 0.010 mg/L, whereas the lowest concentration was 0.006 mg/L of Aden site ,as summarized in (Table 3-1).

In addition, when the results of present study were analyzed by using two ways ANOVA in filtered surface Seawater sites during the seasons, it showed that there was significant differences *(P<0.01*) , analyze by using two ways ANOVA, regarding the concentration of Cd and Hg , however, there was significant difference (*P<0.05*) regarding the concentration of As, however, there were no significant difference (*P>0.05*) regarding the concentration of Pb in the filtered surface Seawater sites for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Pb in the filtered surface Seawater was 0.065 mg/L on summer, whereas the lowest concentration was 0.056 mg/L on winter; however, the highest concentration of Cd in filtered surface Seawater was 0.008 mg/L on summer, whereas the lowest concentration was 0.006 mg/L on winter regarding the all Yemen sites (AL-Hodaeidah, Aden and AL-Mukalla).

Also, the concentration of Hg in the filtered surface Seawater had the same pattern of Pb and Cd ; but, the highest concentration of Hg in filtered surface Seawater sites was 0.007 mg/L on winter, whereas the lowest concentration was 0.006 mg/L on summer, the highest concentration of As in filtered surface Seawater was 0.0083 mg/L on summer, whereas the lowest concentration was 0.0077 mg/L on winter ,as summarized in (Table 3-1).

Table (3-1): The mean of concentration (**mg/L**) for lead, cadmium, mercury and Arsenic during the seasons in the **filtered surface Seawater** of AL-Hodaeidah, Aden and AL-Mukalla stations, Yemen coast.

Site	Metal ion	Seasons			Total mean ± SD for Sites
		Winter 2011	Summer 2012	Winter 2013	
Aden	Pb	0.055 ± 0.004	0.045 ± 0.007	0.051 ± 0.005	0.050± 0.005
	Cd	0.006±0.002	0.010±0.003	0.009±0.001	0.008±0.002
	Hg	0.005±0.000	0.003±0.000	0.007±0.002	0.005±0.002
	As	0.0057±0.000	0.0061±0.000	0.006±0.000	0.006±0.000
AL-Hodaeidah	Pb	0.080±0.020	0.087±0.027	0.072±0.021	0.080± 0.008
	Cd	0.007±0.002	0.006±0.001	0.007±0.000	0.0070±0.000
	Hg	0.007±0.001	0.008±0.000	0.007±0.001	0.0073±0.000
	As	0.007±0.001	0.0082±0.000	0.0087±0.000	0.008±0.000
AL- Mukalla	Pb	0.033±0.002	0.064±0.026	0.064±0.018	0.054± 0.018
	Cd	0.006±0.000	0.0082±0.000	0.0083±0.000	0.0075±0.001
	Hg	0.009±0.000	0.0067±0.000	0.0069±0.000	0.0075±0.001
	As	0.010±0.002	0.011±0.002	0.010±0.000	0.010±0.000
Total mean ± SD for Seasons	Pb	0.056± 0.023	0.065± 0.027	0.062± 0.018	0.061±0.005
	Cd	0.006±0.002	0.008±0.002	0.008±0.001	0.007±0.001
	Hg	0.007±0.002	0.006±0.002	0.007±0.001	0.007±0.0005
	As	0.0077±0.002	0.0083±0.002	0.0082±0.002	0.008±0.0003

Results are expressed as mean ± SD. Mean values in the same row with different superscript letters indicate significant (*P<0.05*) difference.

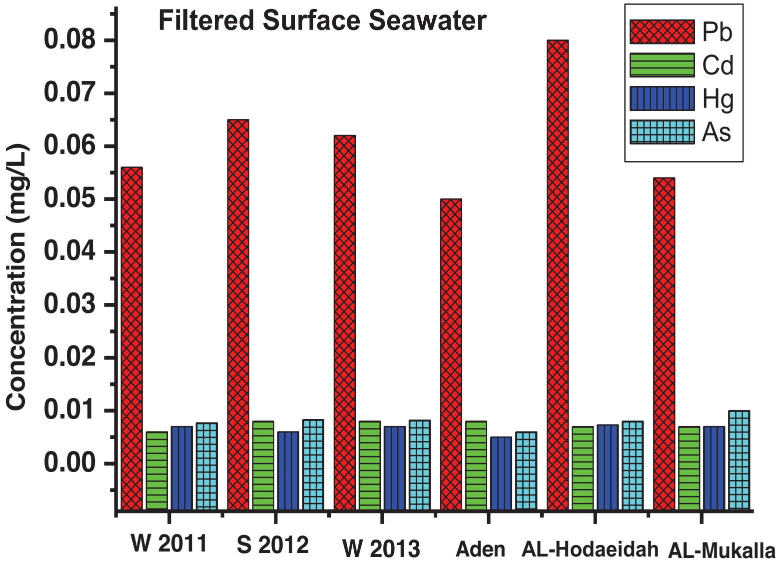


Fig. (3-1): The mean of concentration (mg/L) for lead, cadmium, mercury and Arsenic during the seasons in the filtered surface Seawater of Aden , Al-Hodaeidah and AL-Mukalla stations, (W= Winter, S= Summer).

3-2 Heavy Metal in Sediment

Analysis of heavy metals in Sediment was carried out for three seasons, for the two years 2011 and 2013. The overall results of analysis heavy metals in Sediment samples in the study sites are presented in (Table 3-2), (Fig. 3-2) and the details of analysis of each season are presented in (Appendix 4, Tables 1 through 4).

The results of the present study showed that there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd and Hg , however, there was significant difference (*P<0.05*) regarding the concentration of As in the sediments of Aden, for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Pb in sediments of Aden was 35.104 µg/g (dry wt.) on summer 2012 and the lowest concentration was 33.507 µg/g (dry wt.) on winter 2011 , The highest concentration of Cd in sediments of Aden was 2.111 µg/g (dry wt.) on summer 2012 and the lowest concentration was 1.775 µg/g (dry wt.) on winter 2011, but the highest concentration of Hg in sediments of Aden was 0.023 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.013 µg/g (dry wt.) on winter 2011 and the highest concentration of As in sediments of Aden was 0.111 µg/g (dry wt.) on summer 2012 and the lowest concentration was 0.100 µg/g (dry wt.) on winter 2013 , as summarized in (Table 3-2), (Fig. 3-2).

Further, there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the sediments of AL-Hodaeidah, for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Pb in sediments of Al-Hodaeidah was 78.305 µg/g (dry wt.) on winter 2011 and the lowest concentration was 73.426 µg/g (dry wt.) on summer 2013, The highest concentration of Cd in sediments of Al-Hodaeidah was 2.499 µg/g (dry wt.) on winter 2013 and the lowest concentration was 2.354 µg/g (dry wt.) on summer 2012, The highest concentration of Hg in sediments of Al-Hodaeidah was 0.026 µg/g (dry wt.) on summer 2012 and the lowest concentration was 0.011 µg/g (dry wt.) on winter 2011 and the highest concentration of As in sediments of Al-Hodaeidah was 0.109 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.086 µg/g (dry wt.) on winter 2011, as summarized in (Table 3-2), (Fig. 3-2).

On the other hand, the results showed that there were significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the sediments of AL-Mukalla, for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Pb in sediments of AL-Mukalla was 72.579 µg/g (dry wt.) on summer 2012 and the lowest concentration was 64.677 µg/g (dry wt.) on winter 2013. the highest concentration of Cd in sediments of AL-Mukalla was 0.959 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.664 µg/g (dry wt.) on winter 2011, The highest concentration of Hg in sediments of AL-Mukalla was 0.027 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.010 µg/g (dry wt.) on winter 2011 and the highest concentration of As in sediments of AL-Mukalla was 0.110 µg/g (dry wt.) on summer 2012 and the lowest concentration was 0.079 µg/g (dry wt.) on winter 2011 , as summarized in (Table 3-2), (Fig. 3-2).

In the results of present study were analyzed by using two ways ANOVA in Sediments sites during the seasons, it showed that there were significant differences (*P<0.01*) regarding the concentration of Pb and Cd, however, there were not significant difference (*P>0.05*) regarding the concentration of Hg and As in the sediments of Aden, Al-Hodaeidah and AL-Mukalla stations.

The highest concentration of Pb in sediments of Al-Hodaeidah was 76.542 µg/g (dry wt.) , whereas the lowest concentration was 34.433 µg/g (dry wt.) of Aden station; however, the highest concentration of Cd in sediments of Al-Hodaeidah was 2.424 µg/g (dry wt.) , whereas the lowest concentration was 8.347 µg/g (dry wt.) of AL-Mukalla station.The highest concentration of Hg in the sediments of Al-Hodaeidah was 0.021 µg/g (dry wt.) , whereas the lowest concentration was 0.016 µg/g (dry wt.) of AL-Mukalla station. The concentration of As in sediments had the same pattern of Pb, Cd and Hg ; but, the highest concentration of As in sediments of Aden was 0.104 µg/g (dry wt.) , whereas the lowest concentration was 0.096 µg/g of AL-Mukalla site ,as summarized in (Table 3-2),(Fig. 3-2).

In addition, when the results of present study were analyzed by using two ways ANOVA in sediments sites during the seasons, it showed that there was significant differences (*P<0.01*) regarding the concentration of Pb, Cd, Hg and As in the sediments sites for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Pb in the sediments was 61.859 µg/g (dry wt.) on winter, whereas the lowest concentration was 57.597 µg/g (dry wt.) on summer; however, the highest concentration of Cd in sediments was 1.834 µg/g (dry wt.) on winter, whereas the lowest concentration was 1.619 µg/g (dry wt.) on winter; however, the highest concentration of Hg in sediments was 0.025 µg/g (dry wt.) on winter, whereas the lowest concentration was 0.011 µg/g (dry wt.) on winter regarding the all Yemen sites (Al-Hodaeidah Aden and AL-Mukalla). Also, the concentration of As in the sediments had the same pattern of Pb, Cd and Hg ; but, the highest concentration of As in sediments sites was 0.107 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.089 µg/g (dry wt.) on winter ,as summarized in (Table 3-2), (Fig. 3-2).

Table (3-2): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the seasons in the sediments of AL- Hodaeida, Aden and AL-Mukalla stations.

Site	Metal ion	Seasons			Total mean ± SD for
		Winter 2011	Summer 2012	Winter 2013	
Aden	Pb	33.507± 1.132	35.104± 0.416	34.688± 1.285	34.433± 0.828
	Cd	1.775±0.201	2.111±0.839	2.045±0.310	1.977±0.238
	Hg	0.013±0.000	0.022±0.006	0.023±0.003	0.019±0.003
	As	0.102±0.007	0.111±0.008	0.100±0.007	0.104±0.008
AL- Hodaeidah	Pb	78.305±1.268	77.896±0.194	73.426±0.489	76.542± 2.706
	Cd	2.420±0.836	2.354±0.762	2.499±0.043	2.424±0.518
	Hg	0.011±0.002	0.026±0.014	0.025±0.008	0.021±0.007
	As	0.086±0.012	0.101±0.015	0.109±0.016	0.099±0.008
AL- Mukalla	Pb	69.962±1.970	72.579±1.456	64.677±2.242	69.073± 4.025
	Cd	0.664±0.348	0.882±0.408	0.959±0.363	0.835±0.290
	Hg	0.010±0.002	0.011±0.003	0.027±0.016	0.016±0.006
	As	0.079±0.010	0.110±0.014	0.100±0.013	0.096±0.007
Total mean ± SD for Seasons	Pb	60.592± 23.82	61.859± 23.32	57.597± 20.31	60.016±2.18
	Cd	1.619±7.409	1.782±6.601	1.834±6.590	1.745±1.121
	Hg	0.011±0.002	0.020±0.011	0.025±0.010	0.019±0.007
	As	0.089±0.014	0.107±0.013	0.103±0.013	0.099±0.009

Results are expressed as mean ± SD.Mean values in the same row with different superscript letters indicate significant ($P<0.05$) difference.

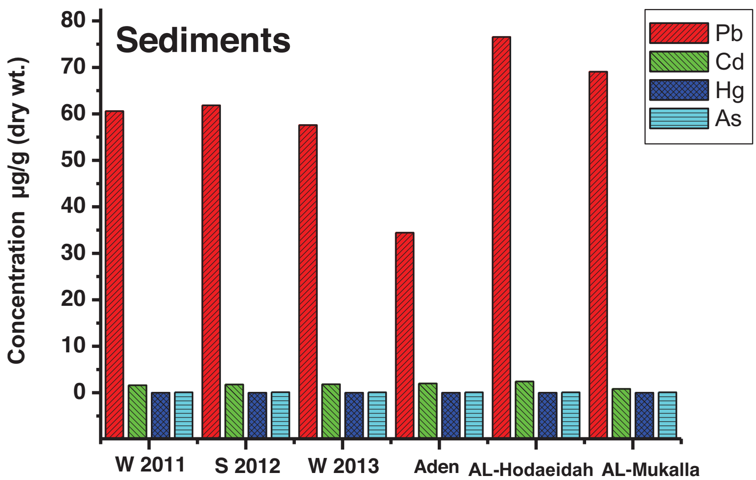


Fig. (3-2): The mean of concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the seasons in the sediments of AL-Hodaeidah, Aden and AL-Mukalla stations, (W= Winter, S= Summer).

3-3 Heavy Metals in Fish

3-3-1 Heavy Metals in Muscles Fish

The analysis of heavy metals in Muscles Fish samples was carried out, during the study period .The overall results of analysis for heavy metals in Muscles Fish samples collected from the study sites are presented in (Table 3-3 and 3-4), (Fig. 3-3 and 3-4). The analysis details for each season are presented in (Appendix 5, Table 1 through 4). The ANOVA analysis results are presented in (Appendix 8, Table 1 through 6) .

The results showed that there were no significant differences (P>0.05), using one way ANOVA, regarding the concentration of Pb, Hg and As , however, there was significant difference (*P<0.01*) regarding the concentration of Cd in the Muscles of fish studied of Aden ,for the duration of the seasons: winter 2011, summer 2012 and winter 2013. At Aden ; however, the highest concentration of Pb in the Muscles of fish was 0.075 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.059 µg/g (dry wt.) on winter 2011. Also, the highest concentration of Cd in the Muscles of fish was 0.052 µg/g (dry wt.) on Summer 2012, whereas the lowest concentration was 0.024 µg/g (dry wt.) on winter 2011; on the other hand, the highest concentration of Hg in the Muscles of fish was 0.061 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.059 µg/g (dry wt.) on winter, Also, the highest concentration of As in the Muscles of fish was 0.091 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.082 µg/g (dry wt.) on winter , as summarized in (Table 3-3), (Fig. 3-3).

Further, there was no significant differences (P>0.05), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Muscles of fish studied of AL-Hodaeidah, for the duration of the seasons: winter 2011, summer 2012 and winter 2013. At AL-Hodaeidah ; however, the highest concentration of Pb in Muscles of fish was 0.151 µg/g (dry wt.) on summer and the lowest concentration was 0.114 µg/g (dry wt.) on winter, but the highest concentration of Cd in Muscles of fish was 0.062 µg/g (dry wt.) on summer 2012 and the lowest concentration was 0.052 µg/g (dry wt.) on winter 2011, the highest concentration of Hg in Muscles of fish was 0.060 µg/g (dry wt.) on winter 2011 and the lowest concentration was 0.053 µg/g (dry wt.) on winter 2013 and the highest concentration of As in Muscles of fish was 0.093 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.091 µg/g (dry wt.) on summer, as summarized in (Table 3-3), (Fig. 3-3).

On the other hand, the results showed that there were not significant differences ($P>0.05$), using one way ANOVA, regarding the concentration of Pb , Hg and As , however, there was significant difference ($P<0.05$) regarding the concentration of Cd in the Muscles of fish studied of AL-Mukalla, for the duration of the seasons: winter 2011, summer 2012 and winter 2013. At AL-Mukalla ; however, the highest concentration of Pb in the Muscles of fish was 0.104 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.091 µg/g (dry wt.) on winter 2011. Also, the highest concentration of Cd in the Muscles of fish was 0.051 µg/g (dry wt.) on winter 2013, whereas the lowest concentration was 0.028 µg/g (dry wt.) on winter 2011; on the other hand, the highest concentration of Hg in the Muscles of fish was 0.058 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.055 µg/g (dry wt.) on winter, Also, the highest concentration of As in the Muscles of fish was 0.091 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.085 µg/g (dry wt.) on winter , as summarized in (Table 3-3) , (Fig. 3-3).

The results showed that there were significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Hg and As , however, there was significant difference ($P<0.05$) regarding the concentration of Cd in the Muscles of fish studied of Aden, for the duration of the Four types of fish studied: *Lethrinus mahsena*, *Thunnus tonggol, Sphyraena jello* and *Epinephelus areolatus*. and not significant differences (P>0.05) regarding the concentration of Pb and Hg , however, there was significant difference (*P<0.05*) regarding the concentration of Cd , however, there was significant difference (*P<0.01*) regarding the concentration of As in the Muscles of fish studied of Aden, for the duration of the of size: Large , Medium and Small . at Aden ; however, the highest concentration of Pb in the Muscles of fish was 0.116 µg/g (dry wt.) on Large *E. areolatus* and the lowest concentration was 0.020 µg/g (dry wt.) on small *S. jello*. Also, the highest concentration of Cd in the Muscles of fish was 0.073 µg/g (dry wt.) on Large *L. mahsena*, whereas the lowest concentration was 0.018 µg/g (dry wt.) on small *S. jello*. Also, the highest concentration of As in the Muscles of fish was 0.108 µg/g (dry wt.) on Large *L. mahsena*, whereas the lowest concentration was 0.043 µg/g (dry wt.) on small *T. tonggol* ; on the other hand, the highest concentration of Hg in the Muscles of fish was 0.087 µg/g (dry wt.) on small *L. mahsena*, whereas the lowest concentration was 0.021 µg/g (dry wt.) on small *T. tonggol*, as summarized in (Table 3-4),(Fig. 3-4).

Further, there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As for the duration of the Four types of fish studied and significant differences (*P<0.05*) regarding the concentration of Pb, Cd and As , however, there was not significant difference (P>0.05) regarding the concentration of Hg in the Muscles of fish studied of AL-Hodeida, for the duration of the size: Large , Medium and Small .

The highest concentration of Pb in Muscles of fish was 0.311 µg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.045 µg/g (dry wt.) on Small *S. jello*, The highest concentration of Cd in Muscles of fish was 0.134 µg/g (dry wt.) on Large *E. areolatus* and the lowest concentration was 0.021 µg/g (dry wt.) on Small *S. jello*. The highest concentration of Hg in Muscles of fish was 0.08 µg/g (dry wt.) on Large *E. areolatus* and the lowest concentration was 0.025 µg/g (dry wt.) on Small *T. tonggol* and The highest concentration of As in Muscles of fish was 0.119 µg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.047 µg/g (dry wt.) on Small *T. tonggol* , as summarized in (Table 3-4), (Fig. 3-4).

On the other hand, the results showed that there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Hg and As , however, there was significant difference (*P<0.05*) regarding the concentration of Cd for the duration of the Four types of fish studied and not significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Cd and Hg , however, there was significant difference (*P<0.01*) regarding the concentration of As in the Muscles of fish studied of AL-Mukalla, for the duration of the size: Large , Medium and Small. At AL-Mukalla ; however, the highest concentration of Pb in the Muscles of fish was 0.151 µg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.023 µg/g (dry wt.) on Small *S. jello* . Also, the highest concentration of Cd in the Muscles of fish was 0.076 µg/g (dry wt.) on Large *E. areolatus* , whereas the lowest concentration was 0.021 µg/g (dry wt.) on Small *S. jello* , Also, the highest concentration of Hg in the Muscles of fish was 0.085 µg/g (dry wt.) on Large *E. areolatus* , whereas the lowest concentration was 0.023 µg/g (dry wt.) on Small *T. tonggol* , Also, the highest concentration of As in the Muscles of fish was 0.114 µg/g (dry wt.) on Large *L. mahsena* , whereas the lowest concentration was 0.046 µg/g (dry wt.) on Small *T. tonggol* , as summarized in (Table 3-4), (Fig. 3-4).

In the results of present study were analyzed by using two ways ANOVA in Muscles of fish sites during the seasons, it showed that there were not significant differences (*P>0.05*) regarding the concentration of Hg and As , however, there was significant difference (*P<0.01*) regarding the concentration of Pb and Cd in the Muscles of fish of Aden, AL-Hodaeidah and AL-Mukalla station.

The highest concentration of Pb in Muscles of fish of AL-Hodaeidah was 0.138 µg/g (dry wt.) , whereas the lowest concentration was 0.068 µg/g (dry wt.) of Aden station; however, the highest concentration of Cd in Muscles of fish of Al-Hodaeidah was 0.057 µg/g (dry wt.) , whereas the lowest concentration was 0.039 µg/g (dry wt.) of Aden site ; but, the highest concentration of Hg in the Muscles of fish of Aden was 0.060 µg/g (dry wt.) , whereas the lowest concentration was 0.057 µg/g (dry wt.) of AL-Mukalla station, The concentration of As in Muscles of fish had the same pattern of Pb and Cd, and the highest concentration of As in Muscles of fish of Al-Hodaeidah was 0.092 µg/g (dry wt.) , whereas the lowest concentration was 0.086 µg/g (dry wt.) of Aden site ,as summarized in (Table 3-3),(Fig. 3-3).

In addition, when the results of present study were analyzed by using two ways ANOVA in Muscles of fish sites during the seasons, it showed that there were not significant differences ($P>0.05$) regarding the concentration of Pb , Hg and As , however, there was significant difference ($P<0.01$) regarding the concentration of Cd in the Muscles of fish sites for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Pb in the Muscles of fish was 0.109 µg/g (dry wt.) on winter 2013, whereas the lowest concentration was 0.088 µg/g (dry wt.) on winter 2011; however, the highest concentration of Cd in Muscles of fish was 0.054 µg/g (dry wt.) on summer 2012, whereas the lowest concentration was 0.035 µg/g (dry wt.) on winter 2011; Also, the concentration of Hg in the Muscles of fish had the same pattern of Pb and Cd; but, the highest concentration of Hg in Muscles of fish was 0.059 µg/g (dry wt.) on summer , whereas the lowest concentration was 0.056 µg/g (dry wt.) on winter regarding the all Yemen sites (AL-Hodaeidah, Aden and AL-Mukalla). Also, the concentration of As in Muscles of fish sites was 0.091

μg/g (dry wt.) on summer, whereas the lowest concentration was 0.087 μg/g (dry wt.) on winter ,as summarized in (Table 3-4) ,(Fig. 3-4).

The results of present study were analyzed by using two ways ANOVA in the Muscles of Four types of fish studied during the sizes, it showed that there were significant differences (*P<0.01*) regarding the concentration of Pb, Cd, Hg and As in the Muscles of fish of *L. mahsena* , *T. tonggol* , *S. jello* and *E. areolatus* during the sizes.

The highest concentration of Pb in Muscles of fish of *E. areolatus* was 0.137 μg/g (dry wt.) , whereas the lowest concentration was 0.037 μg/g (dry wt.) of *S. jello* ; however, the highest concentration of Cd in Muscles of fish of *E. areolatus* was 0.069 μg/g (dry wt.) , whereas the lowest concentration was 0.029 μg/g (dry wt.) of *S. jello* ; however, the highest concentration of Hg in Muscles of fish of *E. areolatus* was 0.071 μg/g (dry wt.) , whereas the lowest concentration was 0.030 μg/g (dry wt.) of *T. tonggol* ; but , the highest concentration of As in the Muscles of fish of *L. mahsena* was 0.106 μg/g (dry wt.) , whereas the lowest concentration was 0.071 μg/g (dry wt.) of *T. tonggol* ,as summarized in (Table 3-4) , (Fig. 3-4).

In addition, when the results of present study were analyzed by using two ways ANOVA in the Muscles of Four types of fish studied during the sizes, it showed that there were significant differences (*P<0.01*) regarding the concentration of Pb, Cd, Hg and As in the Muscles of Four types of fish studied during the sizes: Large , Medium and Small .

The highest concentration of Pb , Cd, Hg and As in the Muscles of fish was 0.124 , 0.060, 0.065 and 0.104 μg/g (dry wt.) respectively on Large , whereas the lowest concentration was 0.081, 0.032, 0.050 and 0.075 μg/g(dry wt.) respectively on Small fish ,as summarized in (Table 3-4),(Fig. 3-4).

Table (3-3): The mean of Concentration ***µ*g/g (dry wt.)** for lead, cadmium, mercury and Arsenic during the seasons in the **Muscles** samples for the study period

Site	Metal ion	Seasons			Total mean ± SD for
		Winter 2011	Summer 2012	Winter 2013	
Aden	Pb	0.059± 0.028	0.071± 0.032	0.075± 0.035	0.068± 0.031
	Cd	0.024±0.010	0.052±0.021	0.041±0.019	0.039±0.015
	Hg	0.059±0.022	0.061±0.025	0.059±0.023	0.060±0.023
	As	0.082±0.018	0.091±0.020	0.085±0.021	0.086±0.020
AL- Hodaeidah	Pb	0.114±0.065	0.151±0.080	0.149±0.078	0.138± 0.073
	Cd	0.052±0.033	0.062±0.033	0.057±0.036	0.057±0.034
	Hg	0.060±0.017	0.058±0.016	0.053±0.021	0.057±0.018
	As	0.092±0.022	0.091±0.021	0.093±0.019	0.092±0.020
AL- Mukalla	Pb	0.091±0.038	0.098±0.052	0.104±0.049	0.098± 0.046
	Cd	0.028±0.010	0.050±0.026	0.051±0.024	0.043±0.016
	Hg	0.055±0.016	0.058±0.024	0.056±0.025	0.057±0.021
	As	0.088±0.020	0.091±0.018	0.085±0.019	0.088±0.019
Total mean ± SD for Seasons	Pb	0.088± 0.051	0.107± 0.066	0.109± 0.064	0.101±0.012
	Cd	0.035±0.015	0.054±0.026	0.049±0.027	0.046±0.010
	Hg	0.058±0.018	0.059±0.022	0.056±0.023	0.058±0.002
	As	0.087±0.020	0.091±0.019	0.088±0.020	0.089±0.002

Table (3-4): The mean of Concentration ***µ*g/g (dry wt.)** for lead, cadmium, mercury and Arsenic during the fish size in the **Muscles** samples for the different fish species study.

Species	Metal ion	Sizes of fish			Total mean ± SD for Species
		Large	Medium	Small	
Lethrinus mahsena	Pb	0.184± 0.030	0.120± 0.014	0.091± 0.020	0.132± 0.048
	Cd	0.065±0.005	0.050±0.003	0.033±0.027	0.049±0.016
	Hg	0.063±0.002	0.062±0.006	0.062±0.010	0.062±0.0005
	As	0.114±0.005	0.105±0.009	0.100±0.008	0.106±0.007
Thunnus tonggol	Pb	0.116±0.018	0.104±0.019	0.080±0.018	0.100± 0.018
	Cd	0.046±0.017	0.036±0.012	0.029±0.010	0.037±0.008
	Hg	0.036±0.008	0.030±0.005	0.023±0.003	0.030±0.006
	As	0.100±0.009	0.067±0.007	0.045±0.002	0.071±0.028
Sphyraena jello	Pb	0.046±0.006	0.035±0.008	0.029±0.006	0.037± 0.009
	Cd	0.040±0.008	0.028±0.006	0.020±0.003	0.029±0.010
	Hg	0.078±0.008	0.072±0.006	0.056±0.010	0.069±0.011
	As	0.103±0.006	0.089±0.006	0.077±0.008	0.090±0.013
Epinephelus areolatus	Pb	0.152±0.008	0.134±0.013	0.125±0.012	0.137± 0.014
	Cd	0.088±0.027	0.073±0.025	0.047±0.020	0.069±0.021
	Hg	0.083±0.009	0.072±0.007	0.058±0.007	0.071±0.012
	As	0.099±0.008	0.088±0.004	0.078±0.004	0.088±0.010
Total mean ± SD for Sizes	Pb	0.124± 0.059	0.098± 0.044	0.081± 0.040	0.101±0.046
	Cd	0.060±0.022	0.047±0.020	0.032±0.011	0.046±0.017
	Hg	0.065±0.021	0.059±0.020	0.050±0.018	0.058±0.019
	As	0.104±0.007	0.087±0.016	0.075±0.023	0.089±0.014

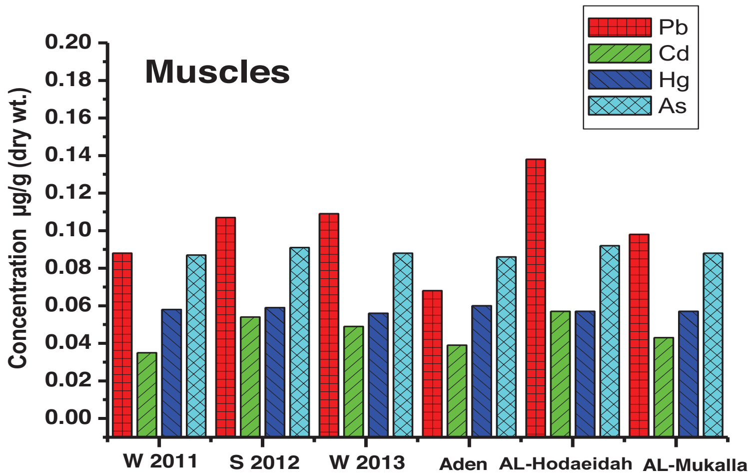


Fig. (3-3): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the seasons in the Muscles samples for the study period, (W= Winter, S= Summer).

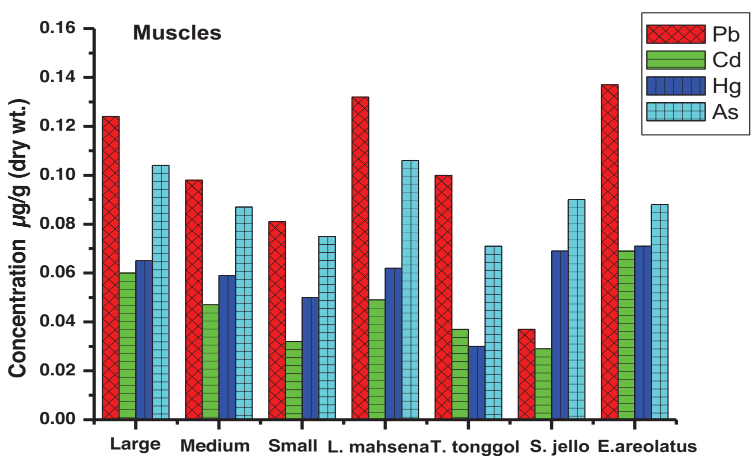


Fig. (3-4): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the fish size in the Muscles samples for the different fish species study.

3-3-2 Heavy Metals in Liver

Analysis of heavy metals for thirty six Liver samples was carried out, for the study period of two years (three seasons). The overall means results of analysis heavy metals in Liver samples for the three seasons, for the study sites in Yemen are presented in (Table 3-5 and 3-6),(Fig. 3-5 and 3-6). The details of analysis of each season are presented in (Appendix 6, Tables 1 through 4).

The results showed that there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Hg and As , however, there was significant difference (*P<0.05*) regarding the concentration of Cd in the Liver of fish studied of Aden, for the period of seasons: winter 2011, summer 2012 and winter 2013. At Aden ; however, the highest concentration of Pb in the Liver of fish was 0.150 µg/g (dry wt.) on Summer and the lowest concentration was 0.110 µg/g (dry wt.) on winter 2011 ; on the other hand, the highest concentration of Cd in the Liver of fish was 0.130 µg/g (dry wt.) on winter 2013, whereas the lowest concentration was 0.057 µg/g (dry wt.) on winter 2011, Also , the highest concentration of Hg in the Liver of fish was 0.104 µg/g (dry wt.) on winter 2011, whereas the lowest concentration was 0.100 µg/g (dry wt.) on winter 2013 ; but , the highest concentration of As in the Liver of fish was 0.116 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.108 µg/g (dry wt.) on winter , as summarized in (Table 3-5),(Fig. 3-5).

Further, there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Liver of fish studied of AL-Hodeida, for the period of seasons: winter 2011, summer 2012 and winter 2013. At Al-Hodaeidah ; the highest concentration of Pb in Liver of fish was 0.330 µg/g (dry wt.) on summer and the lowest concentration was 0.200 µg/g (dry wt.) on winter, The highest concentration of Cd in Liver of fish was 0.223 µg/g (dry wt.) on summer and the lowest concentration was 0.206 µg/g (dry wt.) on winter ; but, the highest concentration of Hg in Liver of fish was 0.116 µg/g (dry wt.) on winter 2011 and the lowest concentration was 0.100 µg/g (dry wt.) on winter 2013 , Also , the highest concentration of As in Liver of fish was 0.126 µg/g (dry wt.) on winter 2011 and the lowest concentration was 0.115 µg/g (dry wt.) on winter 2013, as summarized in (Table 3-5),(Fig. 3-5).

On the other hand, the results showed that there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb , Cd, Hg and As in the Liver of fish studied of AL-Mukalla for the period of seasons: winter 2011, summer 2012 and winter 2013. At AL-Mukalla ; however, the highest concentration of Pb in the Liver of fish was 0.187 µg/g (dry wt.) on summer and the lowest concentration was 0.168 µg/g (dry wt.) on winter 2011.

Also, the highest concentration of Cd in the Liver of fish was 0.082 µg/g (dry wt.) on summer and winter 2013, whereas the lowest concentration was 0.062 µg/g (dry wt.) on winter 2011; on the other hand, the highest concentration of Hg in the Liver of fish was 0.107 µg/g (dry wt.) on winter 2011, whereas the lowest concentration was 0.087 µg/g (dry wt.) on winter 2013, Also, the highest concentration of As in the Liver of fish was 0.121 µg/g (dry wt.) on winter 2013, whereas the lowest concentration was 0.110 µg/g (dry wt.) on winter 2011 , as summarized in (Table 3-5),(Fig. 3-5).

The results showed that there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Liver of fish studied of Aden, for the duration of the Four types of fish studied: *L. mahsena*, *T. tonggol, S. jello* and *E. areolatus*. and no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Cd and Hg , however, there was significant difference (*P<0.05*) regarding the concentration of As in the Liver of fish studied of Aden, for the duration of the of size: Large , Medium and Small. At Aden ; however, the highest concentration of Pb in the Liver of fish was 0.267 µg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.038 µg/g (dry wt.) on small *S. jello*. Also, the highest concentration of Cd in the Liver of fish was 0.172 µg/g (dry wt.) on Large *T. tonggol*, whereas the lowest concentration was 0.028 µg/g (dry wt.) on small *S. jello*. Also, the highest concentration of Hg in the Liver of fish was 0.157 µg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.036 µg/g (dry wt.) on small *S. jello* and Also, the highest concentration of As in the Liver of fish was 0.177 µg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.04 µg/g (dry wt.) on small S. jello , as summarized in (Table 3-6), (Fig. 3-6).

Further, there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Liver of fish studied of AL-Hodaeidah, for the duration of the Four types of fish studied and no significant differences (*P>0.05*) regarding the concentration of Pb, Cd and Hg , however, there was significant difference (*P<0.05*) regarding the concentration of As in the Liver of fish studied of AL-Hodaeidah, for the duration of the of size: Large , Medium and Small. At Al-Hodaeidah ; the highest concentration of Pb in Liver of fish was 0.763 µg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.058 µg/g (dry wt.) on Small *S. jello*, but the highest concentration of Cd in Liver of fish was 0.662 µg/g (dry wt.) on Large *E. areolatus* and the lowest concentration was 0.055 µg/g (dry wt.) on Medium *S. jello* ; on the other hand, the highest concentration of Hg in Liver of fish was 0.17 µg/g (dry wt.) on Large *T. tonggol* and the lowest concentration was 0.055 µg/g (dry wt.) on Small S. jello and as well, the highest concentration of As in Liver of fish was 0.181 µg/g (dry wt.) on Large *T. tonggol* and the lowest concentration was 0.069 µg/g (dry wt.) on Small *S. jello* , as summarized in Table 3-6,(Fig. 3-6).

On the other hand, the results showed that there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Liver of fish studied of AL-Mukalla ,for the duration of the Four types of fish studied and no significant differences (*P>0.05*) regarding the concentration of Pb and As , however, there was significant difference (*P<0.01*) regarding the concentration of Cd , however, there was significant difference (*P<0.05*) regarding the concentration of Hg in the Liver of fish studied of AL-Mukalla, for the duration of the of size: Large , Medium and Small. At AL-Mukalla ; however, the highest concentration of Pb in the Liver of fish was 0.370 µg/g (dry wt.) on Medium *L. mahsena* and the lowest concentration was 0.034 µg/g (dry wt.) on Small S. jello ; on the other hand, the highest concentration of Cd in the Liver of fish was 0.111 µg/g (dry wt.) on Large *E. areolatus*, whereas the lowest concentration was 0.041 µg/g (dry wt.) on Small *S. jello* , Also, the highest concentration of Hg in the Liver of fish was 0.136 µg/g (dry wt.) on Large *E. areolatus*, whereas the lowest concentration was 0.040 µg/g (dry wt.) on Small *S. jello*, , but , the highest concentration of As in the Liver of fish was 0.193 µg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.049 µg/g (dry wt.) on Small *S. jello* , as summarized in (Table 3-6), (Fig. 3-6).

Results of the present study were analyzed by using two ways ANOVA in Liver of fish sites during the seasons, it showed that there were no significant differences (*P>0.05*) regarding the concentration of Hg and As , however, there was significant difference (*P<0.01*) regarding the concentration of Pb and Cd in the Liver of fish of Aden, Al-Hodaeidah and AL-Mukalla site.

The highest concentration of Pb in Liver of fish of Al-Hodaeidah was 0.278 µg/g (dry wt.) , whereas the lowest concentration was 0.135 µg/g (dry wt.) of Aden site ; however, the highest concentration of Cd in Liver of fish of Al-Hodaeidah was 0.216 µg/g (dry wt.) , but the lowest concentration was 0.075 µg/g (dry wt.) of AL-Mukalla site , Also , the highest concentration of Hg in the Liver of fish of AL-Hodaeidah was 0.106 µg/g (dry wt.) , whereas the lowest concentration was 0.097 µg/g (dry wt.) of AL-Mukalla site , whereas the concentration of As in Liver of fish had the same pattern of Pb, but the highest concentration of As in Liver of fish of Al-Hodaeidah was 0.120 µg/g (dry wt.) , whereas the lowest concentration was 0.112 µg/g (dry wt.) of Aden site , as summarized in (Table 3-5),(Fig. 3-5).

In addition, when the results of present study were analyzed by using two ways ANOVA in Liver of fish sites during the seasons, it showed that there were no significant differences (*P>0.05*) regarding the concentration of Pb, Cd, Hg and As in the Liver of fish sites for the period of seasons: winter 2011, summer 2012 and winter 2013 .

The highest concentration of Pb in the Liver of fish was 0.222 µg/g (dry wt.) on Summer , whereas the lowest concentration was 0.159 µg/g (dry wt.) on winter 2011; however, the highest concentration of Cd in Liver of fish was 0.144 µg/g (dry wt.) on Summer , whereas the lowest concentration was 0.108 µg/g (dry wt.) on winter 2011; but, the highest concentration of Hg in the Liver of fish had the same pattern of Pb and Cd; but, the highest concentration of Hg in Liver of fish was 0.109 µg/g (dry wt.) on winter 2011 , whereas the lowest concentration was 0.095 µg/g (dry wt.) on winter 2013 regarding the all Yemen sites (AL-Hodaeidah, Aden and AL-Mukalla). Also, the highest concentration of As in Liver of fish sites was 0.116 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.115 µg/g (dry wt.) on winter 2011,as summarized in (Table 3-5),(Fig. 3-5).

The results of present study were analyzed by using two ways ANOVA in the Liver of Four types of fish studied during the sizes, it showed that there was significant differences (*P<0.01*) regarding the concentration of Pb, Cd, Hg and As in the Liver of fish of *L. mahsena*, *T. tonggol* , *S. jello* and *E. areolatus* during the sizes .

The highest concentration of Pb in Liver of fish of *L. mahsena* was 0.428 µg/g (dry wt.) , whereas the lowest concentration was 0.062 µg/g (dry wt.) of *S. jello* ; however, the highest concentration of Cd in Liver of fish of *E. areolatus* was 0.289 µg/g (dry wt.) , whereas the lowest concentration was 0.061 µg/g (dry wt.) of *S. jello* ; however, the highest concentration of Hg in Liver of fish of *T. tonggol* was 0.127 µg/g (dry wt.) , whereas the lowest concentration was 0.060 µg/g (dry wt.) of *S. jello* , Also , the highest concentration of As in the Liver of fish of *T. tonggol* was 0.147 µg/g (dry wt.) , whereas the lowest concentration was 0.070 µg/g (dry wt.) of *S. jello* ,as summarized in (Table 3-6),(Fig. 3-6).

In addition, when the results of present study were analyzed by using two ways ANOVA in the Liver of Four types of fish studied during the sizes, it showed that there was significant differences ($P<0.01$) regarding the concentration of Hg and As , however, there was no significant difference ($P>0.05$) regarding the concentration of Pb and Cd in the Muscles of Four types of fish studied during the sizes: Large , Medium and Small .

The highest concentration of Pb , Cd, Hg and As in the Liver of fish was 0.217, 0.151, 0.115 and 0.133 µg/g (dry wt.) respectively on Large , whereas the lowest concentration was 0.174, 0.121, 0.085 and 0.100 µg/g (dry wt.) respectively on Small fish ,as summarized in (Table 3-6),(Fig. 3-6).

Table (3-5): The mean of Concentration **μg/g (dry wt.)** for lead, cadmium, mercury and Arsenic during the seasons in the **Liver** samples for the study period

Site	Metal ion	Seasons			Total mean ± SD
		Winter 2011	Summer 2012	Winter 2013	
Aden	Pb	0.110± 0.042	0.150± 0.096	0.144± 0.086	0.135± 0.072
	Cd	0.057±0.026	0.126±0.093	0.130±0.070	0.104±0.058
	Hg	0.104±0.043	0.101±0.036	0.100±0.027	0.101±0.035
	As	0.109±0.034	0.116±0.034	0.108±0.033	0.112±0.034
AL-Hodaeidah	Pb	0.200±0.118	0.330±0.352	0.304±0.305	0.278± 0.256
	Cd	0.206±0.204	0.223±0.252	0.218±0.242	0.216±0.232
	Hg	0.116±0.044	0.104±0.041	0.100±0.031	0.106±0.038
	As	0.126±0.038	0.119±0.036	0.115±0.028	0.120±0.032
AL-Mukalla	Pb	0.168±0.096	0.187±0.147	0.169±0.107	0.175± 0.114
	Cd	0.062±0.019	0.082±0.025	0.082±0.024	0.075±0.022
	Hg	0.107±0.041	0.097±0.026	0.087±0.024	0.097±0.028
	As	0.110±0.035	0.113±0.036	0.121±0.045	0.114±0.038
Total mean ± SD for Seasons	Pb	0.159± 0.096	0.222± 0.234	0.206± 0.200	0.196±0.033
	Cd	0.108±0.136	0.144±0.162	0.143±0.153	0.132±0.020
	Hg	0.109±0.042	0.101±0.034	0.095±0.028	0.102±0.007
	As	0.115±0.036	0.116±0.035	0.115±0.035	0.115±0.0005

Table (3-6): The mean of Concentration ***μ*g/g (dry wt.)** for lead, cadmium, mercury and Arsenic during the fish size in the **Liver** samples for the different fish species study.

Species	Metal ion	Sizes of fish			Total mean ± SD
		Large	Medium	Small	
Lethrinus mahsena	Pb	0.456± 0.278	0.433± 0.258	0.394± 0.233	0.428± 0.031
	Cd	0.092±0.016	0.082±0.014	0.079±0.018	0.084±0.007
	Hg	0.096±0.015	0.094±0.016	0.093±0.019	0.094±0.001
	As	0.128±0.006	0.121±0.007	0.114±0.021	0.121±0.007
Thunnus tonggol	Pb	0.158±0.022	0.137±0.012	0.115±0.016	0.137± 0.022
	Cd	0.126±0.049	0.084±0.030	0.065±0.023	0.092±0.031
	Hg	0.149±0.032	0.133±0.032	0.098±0.018	0.127± 0.026
	As	0.184±0.014	0.138±0.014	0.121±0.016	0.147±0.032
Sphyraena jello	Pb	0.081±0.026	0.063±0.026	0.043±0.013	0.062± 0.019
	Cd	0.073±0.033	0.047±0.015	0.063±0.049	0.061±0.013
	Hg	0.074±0.014	0.062±0.007	0.043±0.010	0.060±0.016
	As	0.087±0.010	0.071±0.004	0.053±0.013	0.070±0.017
Epinephelus areolatus	Pb	0.174±0.026	0.152±0.025	0.144±0.024	0.156± 0.015
	Cd	0.312±0.268	0.277±0.241	0.278±0.215	0.289±0.020
	Hg	0.141±0.010	0.126±0.007	0.106±0.010	0.124± 0.017
	As	0.134±0.012	0.123±0.011	0.114±0.010	0.123±0.010
Total mean ± SD for Sizes	Pb	0.217± 0.164	0.196± 0.162	0.174± 0.153	0.196±0.022
	Cd	0.151±0.110	0.123±0.104	0.121±0.105	0.132±0.017
	Hg	0.115±0.036	0.104±0.033	0.085±0.028	0.101±0.015
	As	0.133±0.040	0.113±0.029	0.100±0.032	0.115±0.017

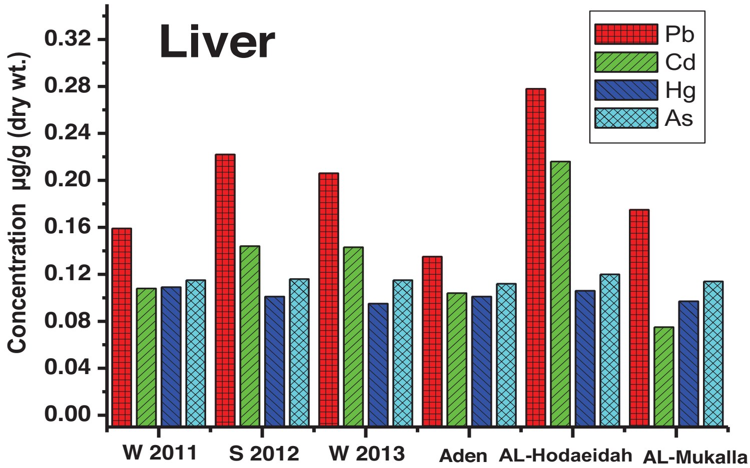


Fig. (3-5): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the seasons in the Liver samples for the study period(W= Winter, S= Summer).

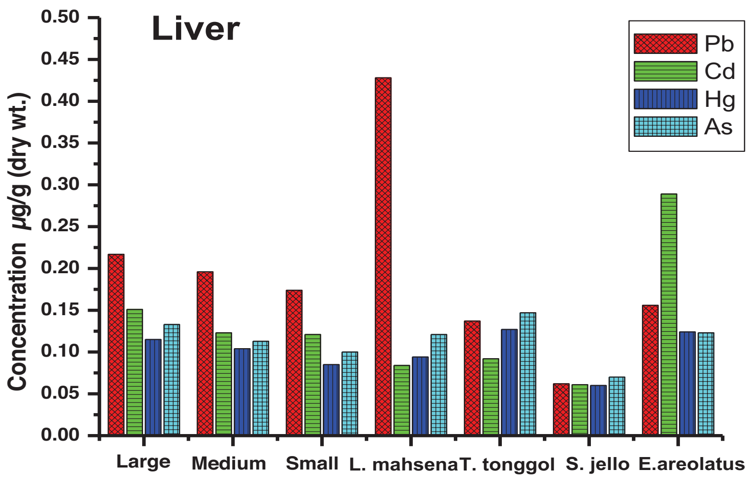


Fig. (3-6): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the fish size in the Liver samples for the different fish species study.

3-3-3 Heavy Metals in Gill

Analysis of heavy metals in Gill was carried out for three seasons, for the two years 2011 and 2013. The overall results of analysis heavy metals in Gill samples in the study sites are presented in (Table 3-7 and 3-8),(Fig. 3-7 and 3-8). The details of analysis of each season are presented in (Appendix 7, Tables 1 through 4).

The results showed that there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As , in the Gill of fish studied of Aden, for the period of seasons: winter 2011, summer 2012 and winter 2013. At Aden; however, the highest concentration of Pb in the Gill of fish was 0.290 µg/g (dry wt.) on Summer and the lowest concentration was 0.212 µg/g (dry wt.) on winter 2013, Also, the highest concentration of Cd in the Gill of fish was 0.348 µg/g (dry wt.) on Summer , whereas the lowest concentration was 0.092 µg/g (dry wt.) on winter 2011 , Also, the highest concentration of Hg in the Gill of fish was 0.0124 µg/g (dry wt.) on Summer, whereas the lowest concentration was 0.0118 µg/g (dry wt.) on winter 2013, Also, the highest concentration of As in the Gill of fish was 0.022 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.020µg/g (dry wt.) on winter , as summarized in (Table 3-7), (Fig. 3-7).

Further, there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Gill of fish studied of AL-Hodeida, for the period of seasons: winter 2011, summer 2012 and winter 2013. At Al-Hodaeidah ; however, the highest concentration of Pb in Gill of fish was 0.414 µg/g (dry wt.) on summer and the lowest concentration was 0.293 µg/g (dry wt.) on winter 2011; on the other hand, the highest concentration of Cd in Gill of fish was 0.246 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.186 µg/g(dry wt.) on winter 2011, Also , the highest concentration of Hg in Gill of fish was 0.022 µg/g (dry wt.) on winter 2013 and the lowest concentration was 0.019 µg/g (dry wt.) on winter 2011; but, the highest concentration of As in Gill of fish was 0.033 µg/g(dry wt.) on winter 2011 and the lowest concentration was 0.030 µg/g (dry wt.) on summer , as summarized in (Table 3-7),(Fig. 3-7).

On the other hand, the results showed that there was no significant differences (*P>0.05*), using one way ANOVA, regarding the concentration of Pb , Cd, Hg and As in the Gill of fish studied of AL-Mukalla for the period of seasons: winter 2011, summer 2012 and winter 2013. At AL-Mukalla ; however, the highest concentration of Pb in the Gill of fish was 0.319 µg/g (dry wt.) on summer and the lowest concentration was 0.260 µg/g (dry wt.) on winter 2013, Also, the highest concentration of Cd in the Gill of fish was 0.126 µg/g (dry wt.) on summer, whereas the lowest concentration was 0.093 µg/g (dry wt.) on winter 2011; on the other hand, the highest concentration of Hg in the Gill of fish was 0.015 µg/g (dry wt.) on summer and winter 2013, whereas the lowest concentration was 0.014 µg/g (dry wt.) on winter 2011, Also, the highest concentration of As in the Gill of fish was 0.051 µg/g (dry wt.) on summer , whereas the lowest concentration was 0.049 µg/g (dry wt.) on winter 2013 , as summarized in (Table 3-7),(Fig. 3-7).

The results showed that there was significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Gill of fish studied of Aden, for the duration of the Four types of fish studied: *L. mahsena*, *T. tonggol, S. jello* and *E. areolatus* and no significant differences (*P>0.05*) regarding the concentration of Pb and Cd , however, there was significant difference (*P<0.01*) regarding the concentration of Hg and As in the Gill of fish studied of Aden, for the duration of the of size: Large, Medium and Small. At Aden; however, the highest concentration of Pb in the Gill of fish was 0.727 µg/g (dry wt.) on Small *L. mahsena* and the lowest concentration was 0.047 µg/g (dry wt.) on small *S. jello* ; but , the highest concentration of Cd in the Gill of fish was 0.609 μg/g (dry wt.) on Small *E. areolatus*, whereas the lowest concentration was 0.033 μg/g (dry wt.) on small *S. jello* ; on the other hand, the highest concentration of Hg in the Gill of fish was 0.018 μg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.008 μg/g (dry wt.) on small *L. mahsena* and Also, the highest concentration of As in the Gill of fish was 0.048 μg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.010 μg/g (dry wt.) on small *S. jello* , as summarized in (Table 3-7), (Fig. 3-7).

Further, there was significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Cd and Hg , however, there was significant difference ($P<0.05$) regarding the concentration of As for the duration of the Four types of fish studied and not significant differences ($P>0.05$) regarding the concentration of Pb, Cd and As , however, there was significant difference ($P<0.05$) regarding the concentration of Hg in the Gill of fish studied of AL-Hodeida, for the duration of the size: Large , Medium and Small. At Al-Hodaeidah ; however, the highest concentration of Pb in Gill of fish was 1.040 μg/g (dry wt.) on Large *L. mahsena* and the lowest concentration was 0.075 μg/g (dry wt.) on Small *S. jello* ; but, the highest concentration of Cd in Gill of fish was 0.571 μg/g (dry wt.) on Large *E. areolatus* and the lowest concentration was 0.078 μg/g (dry wt.) on Medium *S. jello*; on the other hand, the highest concentration of Hg in Gill of fish was 0.035 μg/g (dry wt.) on Large *T. tonggol* and the lowest concentration was 0.010 μg/g (dry wt.) on Small *E. areolatus* and Also, the highest concentration of As in Gill of fish was 0.072 μg/g (dry wt.) on Large *T. tonggol* and the lowest concentration was 0.011 μg/g (dry wt.) on Small *E. areolatus* , as summarized in (Table 3-8), (Fig. 3-8).

On the other hand, the results showed that there was significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As for the duration of the Four types of fish studied and not significant differences (*P>0.05*) regarding the concentration of Pb, Hg and As , however, there was significant difference (*P<0.05*) regarding the concentration of Cd in the Gill of fish studied of AL-Mukalla, for the duration of the size: Large , Medium and Small. At AL-Mukalla ; however, the highest concentration of Pb in the Gill of fish was 0.904 µg/g (dry wt.) on Small *L. mahsena* and the lowest concentration was 0.045 µg/g (dry wt.) on Medium *S. jello* ; on the other hand, the highest concentration of Cd in the Gill of fish was 0.297 µg/g (dry wt.) on Large *T. tonggol* , whereas the lowest concentration was 0.060 µg/g (dry wt.) on Small *S. jello* ; on the other hand, the highest concentration of Hg in the Gill of fish was 0.023 µg/g (dry wt.) on Large *S. jello* , whereas the lowest concentration was 0.008 µg/g (dry wt.) on Small *E. areolatus*, but, the highest concentration of As in the Gill of fish was 0.118 µg/g (dry wt.) on Large *E. areolatus*, whereas the lowest concentration was 0.017 µg/g (dry wt.) on Small *L. mahsena* , as summarized in (Table 3-8), (Fig. 3-8).

In present study the results were analyzed by using two ways ANOVA in Gill of fish sites during the seasons, it showed that there was significant differences (*P<0.01*) regarding the concentration of Cd, Hg and As , however, there was no significant difference (*P>0.05*) regarding the concentration of Pb in the Gill of fish of Aden, Al-Hodaeidah and AL-Mukalla station.

The highest concentration of Pb in Gill of fish of Al-Hodaeidah was 0.337 µg/g(dry wt.), whereas the lowest concentration was 0.248 µg/g (dry wt.) of Aden station; however, the highest concentration of Cd in Gill of fish of Aden was 0.250 µg/g (dry wt.) , but the lowest concentration was 0.113 µg/g (dry wt.) of AL-Mukalla site , also, the highest concentration of Hg in the Gill of fish of Al-Hodaeidah was 0.020 µg/g (dry wt.) , whereas the lowest concentration was 0.012 µg/g (dry wt.) of Aden station; on the other hand, the highest concentration of As in Gill of fish of AL-Mukalla was 0.050 µg/g (dry wt.) , whereas the lowest concentration was 0.021 µg/g (dry wt.) of Aden site, as summarized in (Table 3-7), (Fig. 3-7).

In addition, when the results of present study were analyzed by using two ways ANOVA in Gill of fish sites during the seasons, it showed that there was significant differences ($P<0.05$) regarding the concentration of Cd , however, there was no significant difference ($P>0.05$) regarding the concentration of Pb, Hg and As in the Gill of fish sites for the period of seasons: winter 2011, summer 2012 and winter 2013 . The highest concentration of Pb in the Gill of fish was 0.341 µg/g (dry wt.) on Summer, whereas the lowest concentration was 0.258 µg/g (dry wt.) on winter 2013; however, the highest concentration of Cd in Gill of fish was 0.238 µg/g (dry wt.) on Summer , whereas the lowest concentration was 0.124 µg/g (dry wt.) on winter 2011; but, the highest concentration of Hg in the Gill of fish had the same pattern of Pb and Cd; but, the highest concentration of Hg in Gill of fish was 0.0163 µg/g (dry wt.) on winter 2013 , whereas the lowest concentration was 0.015 µg/g (dry wt.) on winter 2011 regarding the all Yemen sites (AL-Hodaeidah, Aden and AL-Mukalla) ; on the other hand, the highest concentration of As in Gill of fish sites was 0.035 µg/g (dry wt.) on winter 2011, whereas the lowest concentration was 0.034 µg/g (dry wt.) on Summer ,as summarized in (Table 3-7), (Fig. 3-7).

In the results of present study were analyzed by using two ways ANOVA in the Gill of Four types of fish studied during the sizes, it showed that there was significant differences ($P<0.01$) regarding the concentration of Pb, Cd, Hg and As in the Gill of fish of *L. mahsena* , *T. tonggol* , *S. jello* and *E. areolatus* during the sizes .

The highest concentration of Pb in Gill of fish of *L. mahsena* was 0.845 µg/g (dry wt.), whereas the lowest concentration was 0.067 µg/g (dry wt.) of *S. jello* ; however, the highest concentration of Cd in Gill of fish of *E. areolatus* was 0.365 µg/g (dry wt.), whereas the lowest concentration was

0.077 µg/g (dry wt.) of *S. jello* ; however, the highest concentration of Hg in Gill of fish of *T. tonggol* was 0.020 µg/g (dry wt.) , whereas the lowest concentration was 0.010 µg/g (dry wt.) of *E. areolatus*, in addition, the highest concentration of As in the Gill of fish of *E. areolatus* was 0.045 µg/g (dry wt.), whereas the lowest concentration was 0.025 µg/g (dry wt.) of *S. jello*, as summarized in (Table 3-8), (Fig. 3-8).

In addition, when the results of present study were analyzed by using two ways ANOVA in the Gill of Four types of fish studied during the sizes, it showed that there was significant differences ($P<0.01$) regarding the concentration of Hg, however, there was no significant difference ($P>0.05$) regarding the concentration of Pb, Cd and As in the Gill of Four types of fish studied during the sizes: Large , Medium and Small .

The highest concentration of Pb , Cd, Hg and As in the Gill of fish was 0.307, 0.244, 0.018 and 0.042 µg/g (dry wt.) respectively on Large , whereas the lowest concentration was 0.282, 0.153 , 0.013 and 0.027 µg/g (dry wt.) respectively on Small fish, as summarized in (Table 3-8), (Fig. 3-8).

Table (3-7): The mean of Concentration ***µ*g/g (dry wt.)** for lead, cadmium, mercury and Arsenic during the seasons in the **Gill** samples for the study period

Site	Metal ion	Seasons			Total mean ± SD
		Winter 2011	Summer 2012	Winter 2013	
Aden	Pb	0.243± 0.225	0.290± 0.366	0.212± 0.219	0.248± 0.267
	Cd	0.092±0.075	0.348±0.354	0.310±0.296	0.250±0.228
	Hg	0.0123±0.003	0.0124±0.003	0.0118±0.003	0.012±0.003
	As	0.020±0.009	0.022±0.010	0.020±0.009	0.021±0.009
AL-Hodaeidah	Pb	0.293±0.308	0.414±0.535	0.304±0.308	0.337± 0.379
	Cd	0.186±0.115	0.238±0.206	0.246±0.230	0.224±0.174
	Hg	0.019±0.006	0.020±0.007	0.022±0.010	0.020±0.007
	As	0.033±0.019	0.030±0.017	0.032±0.018	0.031±0.018
AL- Mukalla	Pb	0.317±0.385	0.319±0.411	0.260±0.278	0.298± 0.356
	Cd	0.093±0.069	0.126±0.066	0.120±0.061	0.113±0.064
	Hg	0.014±0.005	0.015±0.006	0.015±0.006	0.015±0.005
	As	0.051±0.041	0.051±0.036	0.049±0.039	0.050±0.039
Total mean ± SD for Seasons	Pb	0.284± 0.306	0.341±0.434	0.258± 0.266	0.294±0.042
	Cd	0.124±0.097	0.238±0.250	0.226±0.228	0.196±0.063
	Hg	0.015±0.005	0.0157±0.006	0.0163±0.008	0.016±0.0006
	As	0.035±0.029	0.034±0.026	0.034±0.028	0.034±0.0005

Table (3-8): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the fish size in the **Gill** samples for the different fish species study.

Species	Metal ion	Sizes of fish			Total mean ± SD for Species
		Large	Medium	Small	
Lethrinus mahsena	Pb	0.853± 0.192	0.848± 0.275	0.835± 0.247	0.845± 0.009
	Cd	0.096±0.011	0.086±0.008	0.078±0.018	0.087±0.009
	Hg	0.016±0.005	0.014±0.005	0.011±0.004	0.014±0.002
	As	0.032±0.010	0.026±0.008	0.020±0.005	0.026±0.006
Thunnus tonggol	Pb	0.148±0.041	0.131±0.031	0.120±0.031	0.133± 0.014
	Cd	0.401±0.133	0.239±0.118	0.118±0.054	0.253±0.142
	Hg	0.025±0.008	0.019±0.005	0.015±0.004	0.020± 0.005
	As	0.060±0.010	0.036±0.011	0.027±0.007	0.041±0.017
Sphyraena jello	Pb	0.084±0.025	0.066±0.023	0.052±0.021	0.067± 0.016
	Cd	0.083±0.034	0.068±0.025	0.081±0.063	0.077±0.008
	Hg	0.022±0.006	0.019±0.004	0.016±0.003	0.019±0.003
	As	0.029±0.005	0.025±0.004	0.020±0.003	0.025±0.005
Epinephelus areolatus	Pb	0.144±0.010	0.133±0.012	0.121±0.014	0.133± 0.011
	Cd	0.397±0.299	0.364±0.305	0.333±0.334	0.365±0.032
	Hg	0.011±0.001	0.011±0.002	0.009±0.001	0.010± 0.001
	As	0.048±0.052	0.046±0.051	0.042±0.045	0.045±0.003
Total mean ± SD for Sizes	Pb	0.307± 0.365	0.294± 0.370	0.282± 0.370	0.294±0.012
	Cd	0.244±0.179	0.189±0.139	0.153±0.122	0.195±0.046
	Hg	0.018±0.006	0.016±0.004	0.013±0.003	0.016±0.002
	As	0.042±0.014	0.033±0.010	0.027±0.010	0.034±0.008

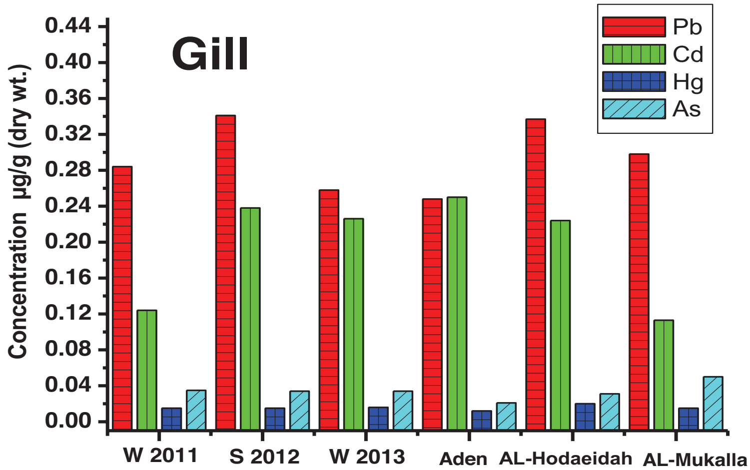


Fig. (3-7): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the seasons in the Gill samples for the study period(W= Winter, S= Summer).

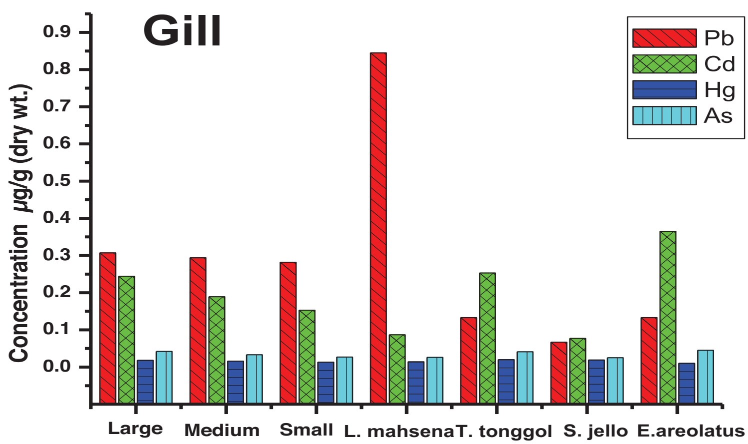


Fig. (3-8): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic during the fish size in the Gill samples for the different fish species study.

3-3-4 Heavy Metals in different organs

3-3-4-1 Lead

The average concentration of Lead throughout all the three Sizes in Muscles Fish was 0.091 µg/g dry wt (At Small) to 0.184 µg/g dry wt (At large) for *L. mahsena* and from 0.080 µg/g dry wt (At Small) to 0.116 µg/g dry wt (At large) for *T. tonggol*. and from 0.029 µg/g dry wt (At Small) to 0.046 µg/g dry wt (At large) for *S. jello* and from 0.125 µg/g dry wt (At Small) to 0.152 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Lead throughout all the three Sizes in Liver Fish was 0.394 µg/g dry wt (At Small) to 0.456 µg/g dry wt (At large) for *L. mahsena* and from 0.115 µg/g dry wt (At Small) to 0.158 µg/g dry wt (At large) for *T. tonggol*. and from 0.043 µg/g dry wt (At Small) to 0.081 µg/g dry wt (At large) for *S. jello* and from 0.144 µg/g dry wt (At Small) to 0.174 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Lead throughout all the three Sizes in Gill Fish was 0.835 µg/g dry wt (At Small) to 0.853 µg/g dry wt (At large) for *L. mahsena* and from 0.120 µg/g dry wt (At Small) to 0.148 µg/g dry wt (At large) for *T. tonggol*. and from 0.052 µg/g dry wt (At Small) to 0.084 µg/g dry wt (At large) for *S. jello* and from 0.121 µg/g dry wt (At Small) to 0.144 µg/g dry wt (At large) for *E. areolatus*.

The high concentration of Pb (0.845± 0.009 µg/g dry wt.) was found in the Gill tissue of *L. mahsena* (Table 3-8), while in the lowest concentration of lead level (0.037±0.009 µg/g dry wt.) was detected in the muscle tissue of *S. jello* (Table 3-4). The mean concentration of Pb in the Muscles , Liver s and Gills of the four studied fish species varied from a minimum of 0.037± 0.009, 0.062±0.019 and 0.067±0.016 in *S. jello*, to a maximum value of

0.137±0.014; 0.428±0.031 and 0.845±0.009 in *E. areolatus* , *L. mahsena* (Table 3-9), (Fig. 3-8).

Table (3-9): The mean of Concentration μg/g (dry wt.) for lead, cadmium, mercury and Arsenic in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

species	Metal ion	Organ			Total mean ± SD for Species
		Muscles	Liver	Gill	
Lethrinus mahsena	Pb	0.132± 0.048	0.428± 0.031	0.845± 0.009	0.468 ± 0.358
	Cd	0.049±0.016	0.084±0.007	0.087±0.009	0.073 ± 0.021
	Hg	0.062±0.0005	0.094±0.001	0.014±0.002	0.057 ± 0.040
	As	0.106±0.007	0.121±0.007	0.026±0.006	0.084 ± 0.051
Thunnus tonggol	Pb	0.100± 0.018	0.137± 0.022	0.133± 0.014	0.123 ± 0.020
	Cd	0.037±0.008	0.092±0.031	0.253±0.142	0.127 ± 0.112
	Hg	0.030±0.006	0.127± 0.026	0.020± 0.005	0.059 ± 0.059
	As	0.071±0.028	0.147±0.032	0.041±0.017	0.086 ± 0.055
Sphyraena jello	Pb	0.037± 0.009	0.062± 0.019	0.067± 0.016	0.055 ± 0.016
	Cd	0.029±0.010	0.061±0.013	0.077±0.008	0.056 ± 0.024
	Hg	0.069±0.011	0.060±0.016	0.019±0.003	0.049 ± 0.027
	As	0.090±0.013	0.070±0.017	0.025±0.005	0.062 ± 0.033
Epinephelus areolatus	Pb	0.137± 0.014	0.156± 0.015	0.133± 0.011	0.142 ± 0.012
	Cd	0.069±0.021	0.289±0.020	0.365±0.032	0.241 ± 0.154
	Hg	0.071±0.012	0.124± 0.017	0.010± 0.001	0.068 ± 0.057
	As	0.132± 0.048	0.123±0.010	0.045±0.003	0.100 ± 0.048
Total mean ± SD for Tissue	Pb	0.102±0.046	0.196±0.160	0.294 ± 0.368	0.197 ± 0.096
	Cd	0.046 ± 0.017	0.132 ± 0.106	0.196 ± 0.139	0.124 ± 0.075
	Hg	0.058 ± 0.019	0.101 ± 0.031	0.016 ± 0.005	0.058 ± 0.043
	As	0.099 ± 0.026	0.115 ± 0.032	0.034 ± 0.010	0.083 ± 0.043

Fig. (3-9): The mean of Concentration µg/g (dry wt.) for lead, cadmium, mercury and Arsenic in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

Table (3-10): The covariance analysis between mean concentration of Pb (µg/g) among in some types of fishes in Yemeni seas and different variables.

Source	Type III Sum of Squares	df	Mean Square	F	p	Partial Eta Squared(R^2)
Corrected Model	11.090a	11	1.008	42.000	0.000	0.597
Intercept	0.005	1	0.005	0.202	0.653	0.001
Seasons	0.121	2	0.060	2.513	0.083	0.016
Tissue	2.013	2	1.007	41.940	0.000	0.212
Species	4.315	3	1.438	59.921	0.000	0.366
Site	0.515	2	0.257	10.727	0.000	0.064
Weight (Kg)	0.000	1	0.000	0.016	0.899	0.000
Length (M)	0.035	1	0.035	1.474	0.226	0.005
Error	7.489	312	0.024			
Total	31.180	324				
Corrected Total	18.579	323				

a. R Squared =0.597 (Adjusted R Squared =0.583)

Table (3-10) shows the covariance analysis between mean concentration of Pb among in some types of fishes and different variables. These different variables include; tissue, type and area of the fish.

After included the weight and length factors to show the related impact in the change of concentration of Pb to the three periods of time, the covariance analysis was not statistically significant in which the (*p<0.01*). The mean concentration of Pb to the species of fish, among the tissues of the fish and among three different areas of fishing were also statistically significant with the p value are similar (*p<0.01*), where the impact of these differences in concentration ratio of Pb were (37%, 21% and 6%) respectively.

Table (3-11): The mean concentration of Pb (μg/g) among the areas, type and the tissues of the fish.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	P [b]
Al-Mukalla	Aden	-0.048*	0.017	0.012
	Al-Hodaeidah	-0.075*	0.017	0.008
(I) Species	(J) Species			
Lethrinus mahsena	*Thunnus tonggol*	0.446*	0.051	0.000
	Sphyraena jello	0.484*	0.057	0.000
	E. areolatus	0.342*	0.027	0.000
E. areolatus	*Sphyraena jello*	0.143*	0.046	0.013
(I) Tissue	(J) Tissue			
Muscles	Liver	-0.094*	0.021	0.000
	Gill	-0.193*	0.021	0.000
Liver	Gill	-0.099*	0.021	0.000

Based on estimated marginal means

*. The mean difference is significant at the 0.05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Table (3-11) shows the mean concentration of Pb among the areas, type and the tissues of the fish. The concentration of Pb were concentrated at Between Al-Mukalla and Aden , Al-Hodaeidah in which the mean concentration of Pb among fishes were (0.048 and 0.075) Towards Aden, Al-Hodaeidah respectively, these results were statistically significant ($p<0.01$).

The differences in the mean concentration of Pb among the different types of the fishes were found between *L. smahsen* and three other types and the mean concentration was in *T. tonggol* (0.446), *S. jell*o (0.484) and *E. areolatus* (0.342), The direction of the type of fish *L. mahsena* , these difference was statistically significant ($p<0.01$).

Also found between *E. areolatus* and *S. jello* (0.143), The direction of the type of fish *E. areolatus*, these difference was statistically significant ($p < 0.05$).

According the concentration of Pb among the tissues of the fish was found among the Muscles and Liver (0.094), Muscles and Gill (0.193) The direction of the average lead concentration in the Liver and Gill respectively, and Liver and Gill, (0.099) The direction of the average lead concentration in the Gill and these results were statistically significant ($p<0.01$).

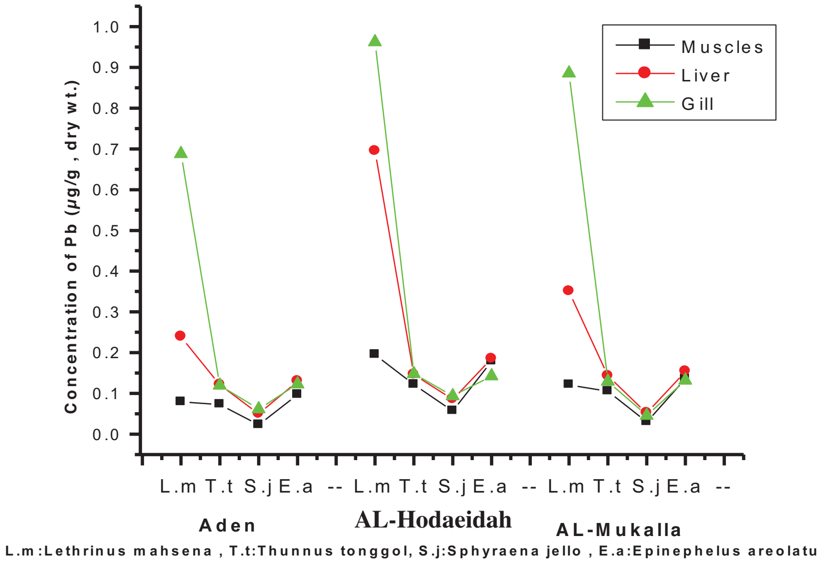


Fig. (3-10): The mean of Concentration µg/g (dry wt.) for Lead in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

3-3-4-2 Cadmium

The average concentration of Cadmium throughout all the three Sizes in Muscles Fish was 0.091 µg/g dry wt (At Small) to 0.184 µg/g dry wt (At large) for *L. mahsena* and from 0.029 µg/g dry wt (At Small) to 0.046 µg/g dry wt (At large) for *T. tonggol*. and from 0.020 µg/g dry wt (At Small) to 0.040 µg/g dry wt (At large) for *S. jello* and from 0.047 µg/g dry wt (At Small) to 0.088 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Cadmium throughout all the three Sizes in Liver Fish was 0.079 µg/g dry wt (At Small) to 0.092 µg/g dry wt (At large) for *L. mahsena* and from 0.065 µg/g dry wt (At Small) to 0.126 µg/g dry wt (At large) for *T. tonggol*. and from 0.047 µg/g dry wt (At Medium) to 0.073 µg/g dry wt (At large) for *S. jello* and from 0.277 µg/g dry wt (At Medium) to 0.312 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Cadmium throughout all the three Sizes in Liver Fish was 0.079 µg/g dry wt (At Small) to 0.092 µg/g dry wt (At large) for *L. mahsena* and from 0.065 µg/g dry wt (At Small) to 0.126 µg/g dry wt (At large) for *T. tonggol*. and from 0.047 µg/g dry wt (At Medium) to 0.073 µg/g dry wt (At large) for *S. jello* and from 0.277 µg/g dry wt (At Medium) to 0.312 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Cadmium throughout all the three Sizes in Gill Fish was 0.078 µg/g dry wt (At Small) to 0.096 µg/g dry wt (At large) for *L. mahsena* and from 0.118 µg/g dry wt (At Small) to 0.401 µg/g dry wt (At large) for *T. tonggol*. and from 0.068 µg/g dry wt (At Medium) to 0.083 µg/g dry wt (At large) for *S. jello* and from 0.333 µg/g dry wt (At Medium) to 0.397 µg/g dry wt (At large) for *E. areolatus*.

The high concentration of Cd (0.365±0.032 µg/g dry wt.) was found in the Gill tissue of *E. areolatus* (Table 3-8), while in the lowest concentration of Cadmium level (0.029±0.010 µg/g dry wt.) was detected in the muscle tissue of *S. jello* (Table 3-4). The mean concentration of Cd in the Muscles , Liver s and Gills of the four studied fish species varied from a minimum of 0.029±0.010, 0.061±0.013 and 0.077±0.008 in *S. jello*, to a maximum value of 0.069±0.021; 0.289±0.020 and 0.365±0.032 in *E. areolatus* (Table 3-9).

Table (3-12): The covariance analysis between mean concentration of Cd (µg/g) among in some types of fishes in Yemeni seas and different variables.

Source	Type III Sum of Squares	df	Mean Square	F	P	Partial Eta Squared
Corrected Model	3.789[a]	11	0.344	23.659	0.000	0.455
Intercept	0.022	1	0.022	1.530	0.217	0.005
Seasons	0.192	2	0.096	6.599	0.002	0.041
Tissue	1.212	2	0.606	41.640	0.000	0.211
Species	1.705	3	0.568	39.048	0.000	0.273
Site	0.289	2	0.144	9.922	0.000	0.060
Wight (Kg)	0.084	1	0.084	5.745	0.017	0.018
Length (M)	0.004	1	0.004	0.301	0.584	0.001
Error	4.542	312	0.015			
Total	13.350	324				
Corrected Total	8.331	323				

a. R Squared =0.455 (Adjusted R Squared =0.436)

Table (3-12) shows the covariance analysis between mean concentration of Cd among in some types of fishes in Yemeni seas and different variables. These different variables include; time, tissue, type and area of the fish. After included the weight and length factors to show the related impact in the change of concentration of Cd to the three periods of time, the covariance analysis was statistically significant in which the ($p<0.01$). The mean concentration of Cd to the species of fish, among the tissues of the fish and among three different areas of fishing were also statistically significant with the p value are similar ($p<0.01$), where the impact of these differences in concentration ratio of Cd were (21%, 27% and 6%) respectively.

Table (3-13): The mean concentration of Cd (µg/g) among the areas, type and the tissues of the fish.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	P b
Al-Mukalla	Aden	-0.048*	0.017	0.012
	Al-Hodaeidah	-0.075*	0.017	0.000
(I) Species	(J) Species			
E. areolatus	*Lethrinus mahsena*	0.173*	0.021	0.000
	Thunnus tonggol	0.246*	0.038	0.000
	Sphyraena jello	0.182*	0.036	0.000
(I) Tissue	(J) Tissue			
Muscles	Liver	-0.086*	0.016	0.000
	Gill	-0.149*	0.016	0.000
Liver	Gill	-0.064*	0.016	0.000
(I) Time	(J) Time			
Phase 2011	Phase 2012	-0.052*	0.016	0.006
	Phase 2013	-0.052*	0.017	0.005

Based on estimated marginal means *. The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.

Table (3-13) shows the mean concentration of Cd among the areas, type and the tissues of the fish. The concentration of Cd were concentrated at Between Al-Mukalla and Aden , Al-Hodaeidah in which the mean concentration of Cd among fishes were (0.048 and 0.075) Towards Aden, Al-Hodaeidah respectively, these results were statistically significant ($p<0.05$).

The differences in the mean concentration of Cd among the different types of the fishes were found between *E. areolatus* and three other types and the mean concentration was in *L. mahsena* (0.173), *T. tonggol* (0.246) and *S. jello* (0.182) , The direction of the type of fish *E. areolatus* , these difference was statistically significant ($p<0.01$).

According the concentration of Cd among the tissues of the fish was found among the Muscles and Liver (0.086), Muscles and Gill (0.149) The direction of the average lead concentration in the Liver and Gill respectively, and Liver and Gill (0.064) The direction of the average lead concentration in the Gill and these results were statistically significant (*p<0.01*).

The focus of statistical significance in the ratio of the concentration of cadmium between time stages in 2011 differences than between 2012 and 2013 on the one hand and the differences towards the point in time in 2012 a difference in average (0.052) and stage time in 2013 a difference of (0.052) and at the level of statistical significance (*p<0.01*).

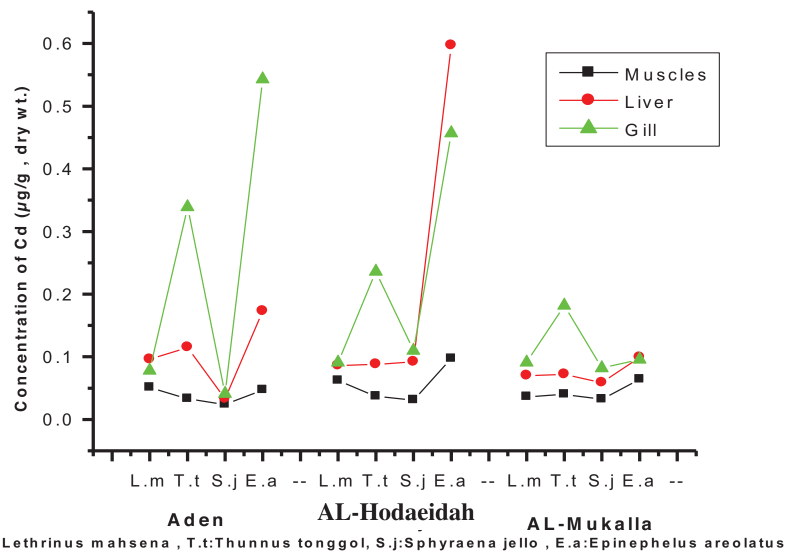


Fig. (3-11): The mean of Concentration µg/g (dry wt.) for Cadmium in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

3-3-4-3 Mercury

The average concentration of Mercury throughout all the three Sizes in Muscles Fish was 0.062 µg/g dry wt (At Small) to 0.063 µg/g dry wt (At large) for *L. mahsena* and from 0.023 µg/g dry wt (At Small) to 0.036 µg/g dry wt (At large) for *T. tonggol*. and from 0.056 µg/g dry wt (At Small) to 0.078 µg/g dry wt (At large) for *S. jello* and from 0.058 µg/g dry wt (At Small) to 0.083 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Mercury throughout all the three Sizes in Liver Fish was 0.093 µg/g dry wt (At Small) to 0.063 µg/g dry wt (At large) for *L. mahsena* and from 0.098 µg/g dry wt (At Small) to 0.149 µg/g dry wt (At large) for *T. tonggol*. and from 0.043 µg/g dry wt (At Small) to 0.074 µg/g dry wt (At large) for *S. jello* and from 0.106 µg/g dry wt (At Small) to 0.141 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Mercury throughout all the three Sizes in Gill Fish was 0.011 µg/g dry wt (At Small) to 0.016 µg/g dry wt (At large) for *L. mahsena* and from 0.015 µg/g dry wt (At Small) to 0.025 µg/g dry wt (At large) for *T. tonggol*. and from 0.016 µg/g dry wt (At Small) to 0.022 µg/g dry wt (At large) for *S. jello* and from 0.009 µg/g dry wt (At Small) to 0.011 µg/g dry wt (At large) for *E. areolatus*.

The high concentration of Hg (0.127± 0.026 µg/g dry wt.) was found in the Liver s tissue of *T. tonggol* (Table 3-6), while in the lowest concentration of Mercury level (0.010± 0.001 g/g dry wt.) was detected in the Gills tissue of *E. areolatus* (Table 3-8). The mean concentration of Hg in the Muscles , Liver s and Gills of the four studied fish species varied from a minimum of 0.030±0.006, 0.060±0.016 and 0.010± 0.001 in *T. tonggol* , *S. jello and E. areolatus*, to a maximum value of 0.071±0.012; 0.127± 0.026 and 0.020± 0.005 in *E. areolatus* , *T. tonggol* (Table 3-9).

Table (3-14): The covariance analysis between mean concentration of Hg (µg/g) among in some types of fishes in Yemeni seas and different variables.

Source	Type III Sum of Squares	df	Mean Square	F	P	Partial Eta Squared
Corrected Model	0.428[a]	11	0.039	79.945	0.000	0.738
Intercept	0.002	1	0.002	4.235	0.040	0.013
Seasons	0.001	2	0.000	0.970	0.380	0.006
Tissue	0.397	2	0.198	407.259	0.000	0.723
Species	0.024	3	0.008	16.126	0.000	0.134
Site	0.001	2	0.000	0.551	0.577	0.004
Wight	0.001	1	0.001	1.611	0.205	0.005
Length	0.001	1	0.001	1.367	0.243	0.004
Error	0.152	312	0.000			
Total	1.683	324				
Corrected Total	0.580	323				

a. R Squared = 0.738 (Adjusted R Squared = 0.729)

Table (3-14) shows the covariance analysis between mean concentration of Hg among in some types of fishes in Yemeni seas and different variables. These different variables include; tissue and type of the fish.

After included the weight and length factors to show the related impact in the change of concentration of Hg to the three periods of time and area, the covariance analysis was not statistically significant in which the ($p>0.05$).

The mean concentration of Hg to the species of fish, among the tissues of the fish were also statistically significant with the p value are similar ($p<0.01$), where the impact of these differences in concentration ratio of Hg were (72%, 13%) respectively, and not statistically significant in the among three different areas of fishing.

Table (3-15): The mean concentration of Hg (µg/g) among the areas, type and the tissues of the fish.

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	P [b]
Lethrinus mahsena	*Thunnus tonggol*	0.030*	0.007	0.000
Thunnus tonggol	*E. areolatus*	-0.040*	0.007	0.000
Sphyraena jello	*E. areolatus*	-0.030*	0.007	0.000
(I) Tissue	(J) Tissue			
Muscles	Liver	-0.043*	0.003	0.000
	Gill	0.042*	0.003	0.000
Liver	Gill	0.086*	0.003	0.000

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Table (3-15) shows the differences in the mean concentration of Hg among the different types of the fishes were found between *L. mahsena* and *T. tonggol* , *T. tonggol* and *E. areolatus* , *S. jello* and *E. areolatus* (0.030), (0.040) and (0.030) respectively, The direction of the type of fish *L. mahsena and E. areolatus* , these difference was statistically significant ($p<0.01$).

According the concentration of Hg among the tissues of the fish was found among the Muscles and Liver (0.043), Muscles and Gill (0.042) The direction of the average lead concentration in the Liver and Muscles respectively, and Liver and Gill (0.086) The direction of the average lead concentration in the Liver and these results were statistically significant ($p < 0.01$).

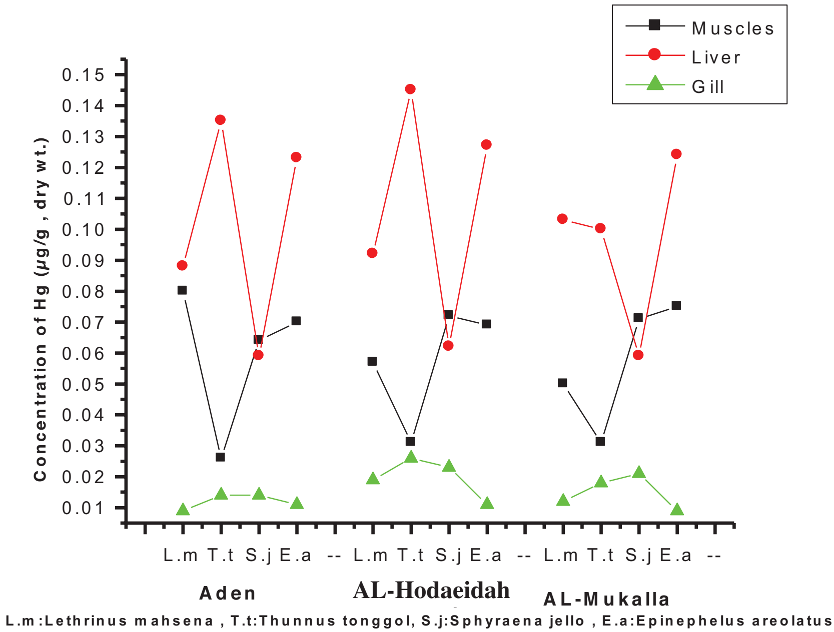


Fig. (3-12): The mean of Concentration µg/g (dry wt.) for Mercury in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

3-3-4-4 Arsenic

The average concentration of Arsenic throughout all the three Sizes in Muscles Fish was 0.100 µg/g dry wt (At Small) to 0.114 µg/g dry wt (At large) for *L. mahsena* and from 0.045 µg/g dry wt (At Small) to 0.100 µg/g dry wt (At large) for *T. tonggol*. and from 0.077 µg/g dry wt (At Small) to 0.103 µg/g dry wt (At large) for *S. jello* and from 0.078 µg/g dry wt (At Small) to 0.099 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Arsenic throughout all the three Sizes in Liver Fish was 0.114 µg/g dry wt (At Small) to 0.128 µg/g dry wt (At large) for *L. mahsena* and from 0.121 µg/g dry wt (At Small) to 0.184 µg/g dry wt (At large) for *T. tonggol*. and from 0.053 µg/g dry wt (At Small) to 0.087 µg/g dry wt (At large) for *S. jello* and from 0.114 µg/g dry wt (At Small) to 0.134 µg/g dry wt (At large) for *E. areolatus*.

The average concentration of Arsenic throughout all the three Sizes in Gill Fish was 0.020 µg/g dry wt (At Small) to 0.032 µg/g dry wt (At large) for *L. mahsena* and from 0.027 µg/g dry wt (At Small) to 0.060 µg/g dry wt (At large) for *T. tonggol*. and from 0.020 µg/g dry wt (At Small) to 0.029 µg/g dry wt (At large) for *S. jello* and from 0.042 µg/g dry wt (At Small) to 0.048 µg/g dry wt (At large) for *E. areolatus*.

The high concentration of As (0.147±0.032 µg/g dry wt.) was found in the Liver s tissue of *T. tonggol* (Table 3-6), while in the lowest concentration of Arsenic level (0.025±0.005 µg/g (dry wt.) was detected in the Gills tissue of *S. jello* (Table 3-8). The mean concentration of As in the Muscles , Liver s and Gills of the four studied fish species varied from a minimum of 0.071±0.028 , 0.070±0.017 and 0.025±0.005 µg/g (dry wt.) in *T. tonggol* , *S. jello and S. jello*, to a maximum value of 0.132± 0.048; 0.147±0.032 and 0.045±0.003 µg/g (dry wt.) in *E. areolatus* , *T. tonggol and E. areolatus* (Table 3-9).

Table (3-16): The covariance analysis between mean concentration of As (µg/g) among in some types of fishes in Yemeni seas and different variables.

Source	Type III Sum of Squares	df	Mean Square	F	P	Partial Eta Squared
Corrected Model	0.446[a]	11	0.041	72.024	0.000	0.717
Intercept	0.005	1	0.005	9.118	0.003	0.028
Seasons	0.000	2	0.000	0.023	0.977	0.000
Tissue	0.370	2	0.185	328.712	0.000	0.678
Species	0.030	3	0.010	17.989	0.000	0.147
Site	0.009	2	0.004	7.855	0.000	0.048
Wight (Kg)	0.005	1	0.005	9.093	0.003	0.028
Length (M)	0.000	1	0.000	0.452	0.502	0.001
Error	0.176	312	0.001			
Total	2.666	324				
Corrected Total	0.622	323				

a. R Squared = 0.717 (Adjusted R Squared = 0.707)

Table (3-16) shows the covariance analysis between mean concentration of As among in some types of fishes in Yemeni seas and different variables. These different variables include; tissue, type and area of the fish.

After included the weight and length factors to show the related impact in the change of concentration of As to the three periods of time, the covariance analysis was not statistically significant in which the ($p>0.05$). The mean concentration of As to the species of fish, among the tissues of the fish and among three different areas of fishing were also statistically significant with the p value are similar ($p<0.01$), where the impact of these differences in concentration ratio of As were (68%, 15% and 5%) respectively.

Table (3-17): The mean concentration of As (µg/g) among the areas, type and the tissues of the fish.

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	P [b]
Lethrinus mahsena	*Thunnus tonggol*	0.049*	0.007	0.000
	Sphyraena jello	0.033*	0.007	0.010
Thunnus tonggol	*E. areolatus*	-0.049*	0.006	0.000
Sphyraena jello	*E. areolatus*	-0.033*	0.006	0.010
(I) Tissue	(J) Tissue			
Muscles	Liver	-0.027*	0.003	0.000
	Gill	0.055*	0.003	0.000
Liver	Gill	0.081*	0.003	0.000
(I) Site	(J) Site			
Aden	Al-Mukalla	-0.013*	0.003	0.000

Based on estimated marginal means

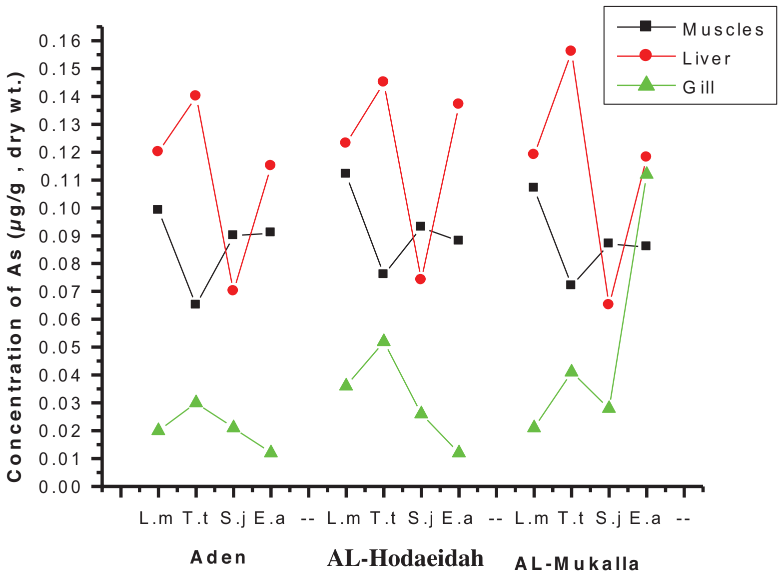
*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

Table (3-17) shows the mean concentration of As among the areas, type and the tissues of the fish. The concentration of As were concentrated at Between Aden and Al-Mukalla in which the mean concentration of As among fishes were (0.013) Towards Al-Mukalla , these results were statistically significant ($p<0.01$).

The differences in the mean concentration of As among the different types of the fishes were found between *L. mahsena* and two other types and the mean concentration was in *T. tonggol* (0.049) and *S. jello* (0.033) , The direction of the type of fish *L. mahsena* , these difference was statistically significant ($p<0.05$). and the differences in the mean concentration of Hg among the different types of the fishes were found between *T. tonggol* and *E. areolatus* , *S. jello* and *E. areolatus* (0.049), (0.033) respectively, The direction of the type of fish *E. areolatus*, these difference was statistically significant (p<0.05).

According the concentration of As among the tissues of the fish was found among the Muscles and Liver (0.027), Muscles and Gill (0.055) The direction of the average lead concentration in the Liver and Muscles respectively, and Liver and Gill (0.081) The direction of the average lead concentration in the Liver and these results were statistically significant ($p < 0.01$).



L.m :Lethrinus mahsena , T.t:Thunnus tonggol, S.j:Sphyraena jello , E.a:Epinephelus areolatus

Fig. (3-13): The mean of Concentration µg/g (dry wt.) for Arsenic in different organs Muscles , Liver s and Gills of the four studied fish species collected from AL-Hodaeidah, Aden and AL-Mukalla station.

3-4 Statistically Evaluation

The details of analysis of each statics ANOVA are presented in (Appendix 8, Tables 1 through 6).

3-4-1 Correlation analyses between concentration of heavy metals in the Seawater and the fish.

The relationship between metals level in Seawater and fish are represented by correlation coefficient (r) in (Table 3-18).

Table (3-18): Correlation analyses between concentration of heavy metals in the Seawater and the fish in the same Seawater

Species		Pb Seawater	Cd Seawater	Hg Seawater	As Seawater
Lethrinus mahsena	R	-0.181	0.034	-0.371**	0.342**
Thunnus tonggol	R	-0.037	-0.016	-0.223*	0.305**
Sphyraena jello	R	-0.294**	0.049	-0.299**	0.499**
Epinephelus areolatus	R	-0.123	-0.028	-0.027	0.357**

* Significant correlation ($P<0.05$); ** Significant correlation ($P<0.01$)

Table (3-18) shows the comparison the concentration of heavy metals in the Filtered Surface Seawater and the fish in the same Seawater , there was significant negative correlations between the concentration of Hg in the *L. mahsena* and Filtered Surface Seawater and *S. jello* and Filtered Surface Seawater , the p value in both association were similar ($p<0.01$), and at a level ($p<0.05$) with the same metal in the fish type *T. tonggol*, also has been significant negative correlations with lead metal Pb in a sample of Seawater closely morally backward at a level ($p<0.01$) with the same metal in one type of fish is *S. jello*, also, the concentration of As among four types of fishes (*L. mahsena*, *T. tonggol*, *S. jello* and *E. areolatus*) was also has significant positive correlations to the concentration of same metal in the Filtered Surface Seawater Which are all (*$p<0.01$*).

3-4-2 Correlation analyses between concentration of heavy metals in the sediments and fish

The relationship between metals level in sediments and fish are represented by correlation coefficient (r) in (Table 3-19).

Table (3-19): Correlation analyses between concentration of heavy metals in the sediments and the fish in the same Seawater

Species		Pb Sediments	Cd Sediments	Hg Sediments	As Sediments
Lethrinus mahsena	R	0.004	0.394**	0.199	0.301**
Thunnus tonggol	R	-0.107	0.196	0.098	0.396**
Sphyraena jello	R	-0.018	0.100	0.091	0.352**
Epinephelus areolatus	R	0.080	0.276*	0.482**	0.635**

* Significant correlation ($P<0.05$); ** Significant correlation ($P<0.01$)

Table (3-19) shows the comparison the concentration of heavy metals in the sediments and the fish in the same Seawater , there was significant positive correlations between the concentration of Cd in the *L. mahsena* and sediments ($p<0.01$) and *E. areolatus* and sediments ($p<0.05$), and the significant positive correlations was also found between Hg in the *E. areolatus* and sediments in which the ($p<0.01$). The concentration of As among four types of fishes (*L. mahsena*, *T. tonggol*, *S. jello* and *E. areolatus*) was also has significant positive correlations to the concentration of same metal in the sediments , which are all ($p<0.01$). There was no significant association between the fishes and other metals.

3-4-3 Correlation analyses between concentration of heavy metals in the sediments and the Filtered Surface Seawater

The relationship between metals level in Seawater and sediment are represented by correlation coefficient (r) in (Table 3-20).

Table (3-20): Pearson's correlation coefficient (r) between heavy metals level in Filtered Surface Seawater (mg/l) and Sediments (µg/g dry wt.) samples collected from the AL-Hodaeidah, Aden and AL-Mukalla sites.

Site	Seawater	Sediments			
		Pb	Cd	Hg	As
Aden	Pb	-0.084	-0.553**	-0.488**	-0.535**
	Cd	-0.105	0.601**	0.431*	0.681**
	Hg	0.273	-0.072	0.207	-0.468*
	As	0.418*	0.519**	-0.038	-0.183
AL-Hodaeidah	Pb	-0.042	0.020	0.260	0.058
	Cd	0.194	-0.373	0.346	0.391*
	Hg	-0.530**	-0.235	-0.025	0.150
	As	0.221	0.414*	0.519**	0.347
AL- Mukalla	Pb	0.111	0.536**	0.553**	0.382*
	Cd	-0.112	0.794**	-0.030	0.683**
	Hg	0.609**	-0.722**	0.030	-0.750**
	As	-0.124	0.410*	-0.127	-0.121

* Significant correlation (*P<0.05*); ** Significant correlation (*P<0.01*)

Table (3-20) The comparison the concentration of heavy metals in the Filtered Surface Seawater and the sediments. For the samples that are taken from the Filtered Surface Seawater in the Aden site there were significant negative correlations for the concentration of Pb in the Filtered Surface Seawater at a level (*p<0.01*) and other heavy (Cd, Hg and As) meals in the sediments with middle relative factors and at a level (*$p<0.01$*) the Cd heavy metal in the Filtered Surface Seawater was significant positive correlations with Cd and As in the sediments and with Hg heavy metal in the sediments at a level (*$p<0.05$*). The Hg heavy metal in the Filtered Surface Seawater was significant negative correlations with As in the sediment and As in the Filtered Surface Seawater with Pb in the sediments at level (*$p<0.05$*). Finally, at level (*$p<0.01$*) the As in the Filtered Surface Seawater was also significant positive correlations with Cd in the sediments.

In Al-Hodaeidah site, there was significant positive correlations between the Cd in the Seawater and the As in the sediments at a level (*$p<0.05$*) and the significant negative correlations was found between Hg in the Seawater and Pb at a level (*$p<0.01$*). Finally there were significant positive correlations between the As in the Seawater and the Cd in the sediments at a level (*$p<0.05$*) and at a level (*$p<0.01$*) with Hg.

In AL-Mukallala site, was significant positive correlations at a level (*$p<0.01$*) between the Pb in the Seawater and Hg and Cd in the sediments and at a level (*$p<0.05$*) with As. The significant positive correlations was found between Cd in the surface Seawater with Cd and As in the sediments at level (*$p<0.01$*) and at (*$p<0.01$*) the Hg in the surface Seawater was significant negative correlations with the Cd and As in the sediments and directly with Pb , Finally there was significant positive correlations between the As in the surface Seawater and the Cd in the sediments at a level (*$p<0.05$*) .

3-4-4 Correlation analyses between metals in Muscles

The relationship between metals level in Muscles tissue are represented by correlation coefficient (r) in (Table 3-21).

Table (3-21): Correlation analyses between metals in Muscles tissue

Site		Pb	Cd	Hg	As
Aden	Pb	1	-	-	-
	Cd	0.673**	1	-	-
	Hg	0.133	0.325	1	-
	As	0.208	0.454**	0.771**	1
AL-Hodaeidah	Pb	1	-	-	-
	Cd	0.624**	1	-	-
	Hg	-0.046	0.390*	1	-
	As	0.399*	0.339*	0.472**	1
AL- Mukalla	Pb	1	-	-	-
	Cd	0.491**	1	-	-
	Hg	-0.072	0.494**	1	-
	As	0.226	0.132	0.383*	1

* Significant correlation ($P<0.05$); ** Significant correlation ($P<0.01$)

Notes from the (Table 3-21) above for the province of Aden and the presence of significant positive correlations at the level of ($p<0.01$) between the Pb in fish muscle tissue with Cd in the same Muscle tissue, also has been associated with Cd morally significant positive correlations at the level of ($p<0.01$) with As in the same Muscle tissue, and has been associated with Hg significant positive correlations morally at a level ($p<0.01$) with As in the same Muscle tissue.

In Al-Hodaeidah site, showed a significant positive correlations at a level ($p<0.01$) between the Pb in fish muscle tissue with Cd and at a level ($p<0.05$) with As in the same Muscle tissue, also it has been associated with

Cd closely morally significant positive correlations at the level of (*p<0.05*) with Hg and As Hg in the same fabric, and has been associated with Hg significant positive correlations morally at a level (*p<0.01*) with As in the same Muscle tissue.

3-4-5 Correlation Analyses between Metals in Liver

The relationship between metals level in Liver tissue are represented by correlation coefficient (r) in (Table 3-22).

Table (3-22): Correlation analyses between metals in Liver tissue

Site		Pb	Cd	Hg	As
Aden	Pb	1	-	-	-
	Cd	0.266	1	-	-
	Hg	0.194	0.474**	1	-
	As	0.510**	0.481**	0.805**	1
AL-Hodaeidah	Pb	1	-	-	-
	Cd	-0.202	1	-	-
	Hg	-0.176	0.325	1	-
	As	0.093	0.331*	0.887**	1
AL-Mukalla	Pb	1	-	-	-
	Cd	0.123	1	-	-
	Hg	0.375*	0.584**	1	-
	As	0.367*	0.493**	0.560**	1

[*] Significant correlation (*P<0.05*); [**] Significant correlation (*P<0.01*)

Notes from the (Table 3-22) above for the Aden site and the presence of significant positive correlations at the level of (*p<0.01*) between the Pb in the tissue of fish Liver with As in the same Liver tissue, also has been associated with Cd significant positive correlations morally at a level

($p<0.01$) with Hg and As in the same Liver tissue, and has been associated with Hg significant positive correlations morally at a level ($p<0.01$) with As in the same Liver tissue.

In Al-Hodaeidah site, show a significant positive correlations at a level ($p<0.05$) between the Cd into the tissue of fish Liver with As in the same Liver tissue, also has been associated with Hg significant positive correlations morally at a level ($p<0.01$) into the fabric of fish Liver As with metal arsenic in the same Liver tissue.

In AL-Mukallala site, show a significant positive correlations at the level of ($p< 0.05$) between the Pb in the tissue of fish Liver with Hg and As in the same Liver tissue, and has been associated with Cd into the tissue of fish Liver significant positive correlations morally at a level ($p< 0.01$) with Hg and As in the same Liver tissue, also has been associated with Hg in fish Liver tissue was significant positive correlations at the level of ($p< 0.01$) with As in the same Liver tissue

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3-4-6 Correlation analyses between metals in Gill

The relationship between metals level in Gill tissue are represented by correlation coefficient (r) in (Table 3-23).

Notes from the (Table 3-23) for the Aden site and the presence of significant negative correlations at the level of ($p< 0.01$) between the Pb in the tissue of the Gills of fish with Hg in the same Gill , while linked to Hg in the tissue of the Gills of fish significant positive correlations morally at a level ($p< 0.01$) with As in the same Gill.

In Al-Hodaeidah site, showed a significant negative correlations at the level of ($p< 0.05$) between the Pb in the tissue of the Gills of fish with Cd in the same Gill , while correlation to Hg in the tissue of the Gills of fish significant positive correlations morally at a level (*p*< *0.01*) with As in the same Gill.

Table (3-23): Correlation analyses between metals in Gill tissue

Site		Pb	Cd	Hg	As
Aden	Pb	1	-	-	-
	Cd	-0.294	1	-	-
	Hg	-0.554**	0.183	1	-
	As	0.006	0.083	0.652**	1
AL-Hodaeidah	Pb	1	-	-	-
	Cd	-0.357*	1	-	-
	Hg	-0.065	-0.298	1	-
	As	0.173	-0.200	0.822**	1
AL-Mukalla	Pb	1	-	-	-
	Cd	-0.134	1	-	-
	Hg	-0.393*	0.363*	1	-
	As	-0.382*	0.090	-0.499**	1

* Significant correlation ($P<0.05$); ** Significant correlation ($P<0.01$)

In AL-Mukallala site, showed a significant negative correlations at the level of (*p*< *0.05*) between the Pb in the tissue of the Gills of fish with Hg and As in the same Gill , and has been associated with Hg is significant negative correlations at the level of (*p*< *0.01*) with As in the same Gill , while the Cd was associated in the Gills of fish tissue significant positive correlations morally closely at the level of (*p*< *0.05*) with Hg in the same Gill.

Chapter 4

Discussion

4- Discussion

4-1 Heavy Metals in Filtered Surface Seawater

Overall, the results of the present study showed that they were significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the filtered surface seawater of Yemen coast (AL-Hodaeidah, Aden and AL-Mukalla) sites, except As in Aden and AL Mukalla, and except Pb and Cd in Al-Hodaeidah , for the period of seasons: winter 2011, summer 2012 and winter 2013 (Table 3).

On the other hand, thus results were analyzed by using two ways ANOVA, there were significant differences ($P<0.01$), regarding the concentration of Cd and Hg, however, there was a significant difference ($P<0.05$) regarding the concentration of As in the filtered surface seawater of Yemen sites for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Pb, Cd and As were (0.065± 0.027, 0.008±0.002 and 0.0083±0.002 mg/L, respectively) in the filtered surface seawater of Yemen coast was obtained in the summer, whereas the highest concentration of Hg was 0.007±0.002 mg/L in the filtered surface seawater of Yemen coast was achieved in winter (Table 3-1).

This result may be explained by the fact that amount of draining sewage on summer were higher compared with winter and also due to high water temperature on summer season.

The interpretation of these results is comparable to those reported by Ibrahim and Omar, (2013) reported that the concentrations of metals are increased during summer due to increase the water temperature; and Kaur and Mehra, (2012) reported that the high heavy metal concentration during the summer may be attributed to increased water temperature during the summer that may result in increased metal toxicity. Also Hg has a different character than Pb, Cd and As and has able to evaporate in the air; As supported also by Wang *et al*. (2012) who pointed out that the distribution of Hg was different to the other heavy metals due to Hg is easy to vaporize and to move from one place to another .

Also the above results and the initial interpretation given are comparable to those reported in 2014 by Al-Dohail *et al*; showed that the highest concentration of Pb in summer, but the highest concentration of Hg in the filtered surface seawater was from Khawr-Mukalla, Hadhramout Coast, Yemen, in Autumn (Al-Dohail *et al*., 2014).

However, our results showed low concentration compared with other studies which mentioned by Thomas and Mohaideen, (2013) showed that the concentration of Cd was 0.014 mg/L and As was 0.013 mg/L in summer, but the concentration of Pb was 0.012 mg/L and Hg was 0.014 mg/L in Winter from near seashore of Bay of Bengal in Marina, its the longest urban beach in India (Thomas and Mohaideen, 2013).

However, our results are in a good agreement with those found by Mastan, (2014) showed that the concentration of Pb was 0.034 ± 0.002 mg/L and Cd was 0.012 ± 0.001 mg/L in water from the Kolleru Lake, India, on summer (Mastan, 2014).

The results of the present study were analyzed by using two ways ANOVA in filtered surface seawater of Yemen sites during the seasons, it showed that there were significant differences ($P<0.01$) regarding the concentration of Pb, Hg and As, however, there was a significant difference ($P<0.05$) regarding the concentration of Cd in the filtered surface seawater of AL-Hodeida, Aden and AL-Mukalla station.

The highest concentration of Pb was 0.080± 0.008 mg/L achieved in Al-Hodaeidah , however, the highest concentration of Cd was 0.008±0.002

mg/L achieved in Aden, but the Hg was 0.0075±0.001 mg/L and As was 0.010±0.000 mg/L in the filtered surface seawater were found in AL-Mukalla.

The CSBTS (1997), ANZECC and ARMCANZ (2000) and ASEAN (2008) guidelines for maximum permissible limit of Lead in Seawater is 0.001, 0.0044 and 0.0085 mg/l. As the range of Lead detected was higher than the permissible limit.

There are several possible explanations for this result perhaps attributed to partially caused also by atmospheric input of local particulates from motor vehicle, mountainous regions which drain its water from Yemen highland to the Red Sea through different vallies, precipitation, petroleum rich substrate of the area, influence of sewage discharge, agricultural and industrial effluents into this site, chemical distribution and partitioning between seawater and the sediment and the vigorous mixing of shallow coastal sediments increases the solubility of Pb in seawater as a result of oxygen saturated water (MAFF, 1993; Heba *et al*., 2004; Al-Shwafi, *et al*.,2005; Saleh and Marie, 2014).

The CSBTS (1997) and ANZECC and ARMCANZ (2000) guidelines for maximum permissible limit of Cadmium in Seawater is 0.001 and 0.0007 mg/l. As the range of Cadmium detected was higher than the permissible limit. But ASEAN (2008) guidelines for maximum permissible are limit of Cadmium in Seawater is 0.01 mg/l. As the range of Cadmium detected is below than the permissible limit.

These high concentrations of Cd in Aden may be attributed to point source and non-point source pollution among which are PVC products, runoff from waste Ni-Cd batteries, paint, color pigments and solid waste (Salim, 2012).

These results further support the idea of Scrap-iron store at Labour Island in Aden site is the most likely source of Pb and Cd in the Seawater (Szefer *et al*., 1999).

One interesting finding is showed positive linear relationships between the concentrations of the Cd in filtered surface seawater against their concentration levels in sediments (Table 3-21) this indicates that the source of the former Cd in filtered surface seawater is possibly from mineral weathering and chemical distribution and partitioning between filtered surface seawater and the sediment. These results are in agreement with those obtained by (Al-Shwafi, *et al*., 2005).

These results corroborate the ideas of Pyle *et al*., (2005), who suggested that when pollution particulate or sedimentary material is dispersed through an ecosystem, it equilibrates with water, detritus, and living food materials, resulting in ongoing pollution of all environmental compartments (Pyle *et al*., 2005). The detected positive correlation between the concentration of Cd in the filtered surface seawater and sediment, in the present study, supports this argument.

The CSBTS (1997), ANZECC and ARMCANZ (2000) and ASEAN (2008) guidelines for maximum permissible limit of Mercury in Seawater is 0.00005, 0.0001 and 0.00016 mg/l. As the range of Mercury detected was higher than the permissible limit.

The CSBTS (1997) guidelines for maximum permissible limit of Arsenic in Seawater is 0.020 mg/l. As the range of Arsenic detected is below than the permissible limit.

The present high concentration of Hg and As in AL-Mukalla may be due to the petroleum rich substrate of the area, Oil pollution and atmospheric fallout could be responsible for the increased levels, also high values of As in the site may be attributed to agriculture.

Also the above results and the initial interpretation given are comparable to those reported by Saleh and Marie (2014) pointed out that the concentration of Pb was 0.03±0.004 mg/L and Cd was 0.02±0.004 mg/L in summer from along the coast of Al-Shaykh Younes facing Al-Hodaeidah city, Yemen (Saleh and Marie, 2014).

The interpretation of these results is comparable to those reported by Al-Dohail *et al.,* (2014) pointed out that the concentration of Pb was 0.058 - 0.132 mg/L, Cd was 0.014 -0.030 mg/L, Hg was 0.005 -0.008 mg/L in Khawr-Mukalla, Hadhramout Coast, Yemen. This differs from the findings presented here may be attributed to drain sewage at first time into Khawr-Mukalla and non-coastal currents (Al-Dohail *et al.,* 2014) and a good agreement with those are found by Montaser *et al.,* (2010) pointed out that the concentration of Pb was 0.064 - 0.082 mg/L, Cd was 0.002 -0.005 mg/L in Jeddah Coast, Saudi Arabia.

However, our results are in a good agreement with those found by (Irwandi and Farida, 2009) who reported that the concentration of Hg of filtered surface seawater was 0.002 - 0.005 mg/L in the Langkawi island, Malaysia (Irwandi and Farida, 2009). Besides, Daniszewski, (2013) pointed out that the concentration of Pb was 0.03- 0.07 mg/L, which is below the permissible limit of 0.1 mg/L set for inland surface water, in the water samples collected from sea water in Międzyzdroje, Baltic coast, Poland.

However, our results were high concentration compared with other studies which mentioned by Al-Shiwafi *et al.,* (2005) showed that the concentration of Pb was 0.050 µg/L and Cd was 0.760 µg/L in winter from Al-Hodaeidah Coast, Yemen (Al-Shiwafi *et al.,* 2005).

Also, Heba *et al.,* (2004) pointed out that the concentration of Pb was 0.10-2.85 µg/L and Cd was 0.04-2.65 µg/L in summer from Red Sea coast , Al Hodeida, Yemen (Heba *et al.,* 2004).

On the other hand, were high concentration compared with other studies which mentioned by Al-sulami *et al.,* (2002) pointed out that the concentration of Pb was 0.0002 - 0.003 mg/L, Cd was 0.0001 -0.002 mg/L in Eastern Coast of Saudi Arabia (Al-sulami *et al.,* 2002). Besides, Anand and

Kala (2015) pointed out that the concentration of Pb was 0.005-0.021 mg/L, Cd was 0.0001-0.003 mg/L in South East Coast of India (Anand and Kala, 2015). Besides, Abeshi *et al.,* (2007) who reported that the concentration of Hg of filtered surface seawater was 0.007-0.287 µg/L in Adriatic Sea, Albania (Abeshi *et al.,* 2007) Besides, Balkis *et al.,* (2009) who reported that the concentration of Hg of filtered surface seawater was 0.03 µg/L in Gökova Bay, Turkey (Balkis *et al.,* 2009).

However, our results were low concentration compared with other studies which mentioned by (Irwandi and Farida, 2009) who reported that the concentration of Pb of filtered surface seawater was 1.58-4.73 mg/L and Cd was 0.01-0.02 mg/L in the Langkawi Island, Malaysia (Irwandi and Farida, 2009). Besides, (Ali *et al.,* 2011 a) pointed out that the concentration of Pb was 1.21 mg/L, Cd was 0.04 mg/L in Isalmic Port Coast, Red Sea, Jeddah, Saudi Arabia (Ali *et al.,* 2011 a). Besides, (Saeed and Shaker, 2008) pointed out that the concentration of Pb was 0.065 mg/L, Cd was 0.044 mg/L in northern Delta Lakes, Egypt (Saeed and Shaker, 2008). Besides, (Wang *et al.,* 2012) pointed out that the concentration of Pb was 0.61 mg/L, Cd was 0.92 mg/L and Hg was 0.030 mg/L in Jinzhou bay, China (Wang *et al.,* 2012). Besides, Daniszewski, (2013) pointed out that the concentration of Cd was 0.39- 0.52 mg/L, the values obtained were found to be below the permissible limit of 2.0 mg/L set for inland surface water. Hg was 0.03- 0.05 mg/L which was very much above the maximum limit of 0.01 mg/L set for inland surface water in the water samples collected from sea water in Międzyzdroje, Baltic coast, Poland (Daniszewski, 2013).

Based on these informations, Yemen coast of the present study is low polluted compared with other locations.

4-2 Heavy Metals in Sediments

Overall, the results of the present study showed that they were significant differences ($P<0.01$), using one way and two ways ANOVA, regarding to the concentration of Pb, Cd, Hg and As in the sediments of Yemen coast (Aden, Al-Hodaeidah and AL-Mukalla) stations, for the period of seasons: winter 2011, summer 2012 and winter 2013 (Table 3-2).

The highest concentration of Pb, Cd, Hg and As were (61.859± 23.323, 1.782±0.660, 0.020±0.011 and 0.107±0.013 µg/g (dry wt.), respectively) in the surface sediments of Yemeni coast was obtained on summer (Table 3-2).

This result may be explained by the fact that during summer that region faced with decreasing internal currents and water supplies that might have caused increase of heavy metals comparison with winter season, wastewater discharge from the city and rainfalls.

The interpretation of these results is comparable to those reported by Al Hudaifi (2016) reported that the concentrations of Pb , Cd and Hg metals in the sediments from Khawr-Mukalla Hadhramout Coast, Yemen, are increased during the summer because of high temperature in the area as well as more amount of draining sewage to the study area during summer season (Al Hudaifi, 2016); and Ali and Masoud, (2013) reported that the concentrations of Pb and Cd in the sediments at spring and summer were more than autumn and winter from along the coastline of the Hormuzgan Province (northern of the Strait of Hormuz) (Ali and Masoud, 2013).

The obtained results for lead and their interpretation are comparable to those reported in 2016 by Alimi and Alhudify, showed that the concentration of Cd was 0.89- 2.83 µg/g (dry wt.) in the surface sediments of al-mukalla coast, Yemen (Al-Alimi and Alhudify, 2016).

Also the above results and the initial interpretation given are comparable to those reported in 2009 by Mostafa *et al*; showed that the concentration of Cd was 0.3 -2.6 µg/g (dry wt.) in winter from Hadhramout coastal area, Gulf of Aden, Yemen (Mostafa *et al.,* 2009); and Al Hudaifi (2016) showed that the concentration of Cd was 2.931 ± 0.71 µg/g (dry wt.) and Hg was 0.111 ± 0.07 µg/g (dry wt.) in summer from Khawr-Mukalla, Hadhramout Coast, Yemen who suggested to drain sewage at first time into Khawr-Mukalla and non-coastal currents (Al Hudaifi, 2016).

However, our results were low concentration compared with other studies which mentioned by Sagheer, (2013) showed that the concentration of As was 2.6 – 9.9 µg/g (dry wt.) from Kwar Katib lagoon, Red sea, Al-Hodaeidah Coast, Yemen who suggested that the heavy metal content of the sediments of lagoon are widely controlled by lithogenic influences whilst the sediment of the port reflects, the anthropogenic and lithogenic influences. The activity in the port and sewage outfall results in an increase of concentration of the heavy metal (Sagheer, 2013).

Besides, Thomas and Mohaideen, (2013) showed that the concentration of Hg was 0.486 µg/g (dry wt.) and As was 0.879 µg/g (dry wt.) in summer from near seashore of Bay of Bengal in Marina, the longest urban beach in India (Thomas and Mohaideen, 2013).

These high different between the results may reference to various factors as rainfalls and physiochemical parameters such as soluble oxygen, temperature, equilibrium, increase salinity, pH, suspended particles, redox potential sulfides and phosphates, chemical interactions, chloride and sulfate ions increase (Tack *et al.,* 1996 ; Levkov and Krstic, 2002; Ali and Masoud, 2013), Substrate of organic and suspended matters in water is another effective factors in the concentration of metals in sediments (Kamala-Kannan *et al.,* 2008).

The CCME (2002) and ANZECC and ARMCANZ (2000) guidelines for maximum permissible limit of Mercury in Sediment as 0.130 – 0.700 µg/g (dry wt.) and 0.15 – 1.0 µg/g (dry wt.). As the range of Mercury detected is below than the permissible limit.

The CCME (2002) and ANZECC and ARMCANZ (2000) guidelines for maximum permissible limit of Arsenic in Sediment as 7.24– 41.6 µg/g (dry wt.) and 20.0 – 70.0 µg/g (dry wt.). As the range of Arsenic detected is below than the permissible limit.

The concentration of Pb and Cd in the sediments of Yemeni coasts (Aden, Al-Hodaeidah and AL-Mukalla) stations, using two ways ANOVA, showed that there were significant differences ($P<0.01$), whereas there were no significant differences ($P>0.05$) between these sites regarding to the concentration of Hg and As.

The highest concentration of Pb and Cd were 76.542± 2.706 and 2.424 ±0. 518 µg/g (dry wit.) in the sediments was found in Al-Hodeida.

The CCME (2002) and ANZECC and ARMCANZ (2000) guidelines for maximum permissible limit of Lead in Sediment are given as (ISQG - PEL) 30.2 - 112.0 µg/g (dry wt.) and (ISQG-Low to ISQG-High) 50.0 – 220.0 µg/g (dry wt.).

As the detected Lead remained higher than ISQG CCME (2002) and ISQG-Low ANZECC and ARMCANZ (2000) values but were below the PEL CCME (2002) and ISQG-High ANZECC and ARMCANZ (2000) permissible limits.

These Pb levels were lower than USEPA guidelines levels of 112 µg/g (dry wt.) in sediments.

The CCME (2002) and ANZECC and ARMCANZ (2000) guidelines for maximum permissible limit of Cadmium in Sediment are given as (ISQG - PEL) 0.70 – 4.20 µg/g (dry wt.) and (ISQG-Low to ISQG-High) 1.50 – 10.0 µg/g (dry wt.).

As the detected Cadmium remained higher than ISQG CCME (2002) and ISQG-Low ANZECC and ARMCANZ (2000) values but were below the

PEL CCME (2002) and ISQG-High ANZECC and ARMCANZ (2000) permissible limits.

Cadmium concentrations in uncontaminated marine sediments usually are in the range of 0.1 to 0.6 µg/g (dry wt.) (Neff, 2002). Safety limits criteria

The present high concentration of Pb and Cd in Al-Hodaeidah may be It seems possible that these results are due to high traffic density of motor cycles, movement of pollutants, wastewater discharge from the city, physical characteristics of the Red Sea, effluents from Al-Hodaeidah landing port, industrial pollution, atmospheric emission, leachates from defused Ni-Cd batteries and Cd plated items, ship wrecks, and oil enrichment in the vicinity areas (Heba and Al-Mudaffer 2000; Heba *et al*., 2000; Saleh and Marie, 2014).

A possible explanation for this might be that fluvial inputs of minerals with high contents of Pb and Cd in to the coastal regions from the Tihama coastal plain of Yemen. Another possibility is that the vigorous mixing of shallow coastal sediments increases the solubility of Pb and Cd in seawater as a result of oxygen saturated water (Al-Shiwafi, *et al*., 2005).

The interpretation of these results is comparable to those reported by Nomaan *et al*. (2012) showed that the concentration of Pb was 61.45± 1.25 µg/g (dry wt.) and Cd was 7.33± 0.31 µg/g (dry wt.) in the sediments from Al-Hodaeidah Coast, Yemen who suggested that higher Cd concentrations might be the different amounts of anthropogenic inputs such as oil pollution and untreated sewage and waste of factories near the study sites (Nomaan *et al*., 2012).

Also the above results and the initial interpretation given are comparable to those reported in 2014 by Saleh and Marie; pointed out that the concentration of Cd was 2.8±0.22-5.5±0.17 µg/g (dry wt.) in summer from along the coast of Al-Shaykh Younes facing Al-Hodaeidah city, Yemen. who suggested that the higher heavy metals contents in the sediments of the polluted site may refer to several reasons including sewage discharge of Al-Hodaeidah city, the industrial pollution, ship wrecks, and oil enrichment in the vicinity areas (Saleh and Marie, 2014).

The obtained results for lead and their interpretation are comparable to those reported in 2006 by Nasr *et al*; pointed out that the concentration of Pb was 14.8 -138.06 (77.28) µg/g (dry wt.) in bottom Sediments from Aden Port, Yemen (Nasr *et al*., 2006).

The obtained results for Cadmium and their interpretation are comparable to those reported in 2004 by Heba *et al* ; pointed out that the concentration of Cd was 0.20- 5.80 µg/g (dry wt.) in summer from Red Sea coast, Al Hodeida, Yemen (Heba *et al*., 2004); and a good agreement with those found by Saeed and Shaker, (2008) pointed out that the concentration of Pb was 61.620 µg/g (dry wt.) in northern Delta Lakes, Egypt (Saeed and Shaker, 2008).

The interpretation of these results are comparable to those reported by Al Hudaifi, (2016) reported that the high concentrations (44.51, 4.1 and 0.2 µg/g (dry wt.) of metals, Pb, Cd and Hg respectively) in summer and the lowest values 16.75 µg/g (dry wt.) in winter, 1.11 µg/g (dry wt.) in spring and 0.03 µg/g (dry wt.) was accrued in autumn for the metals Pb, Cd and Hg respectively in the sediments from Khawr-Mukalla Hadhramout Coast, Yemen, (Al Hudaifi, 2016).

On the other hand, our results were high concentration compared with other studies which mentioned by Al-Shiwafi *et al*. (2005) showed that the concentration of Pb was 2.4 µg/g and Cd was 0.2 µg/g in winter from Al-Hodaeidah Coast, Yemen (Al-Shiwafi *et al*., 2005); Al-Alimi and Alhudify (2016) showed that the concentration of Pb was 5.65- 20.13 µg/g (dry wt.) on summer in al-mukalla coast, Yemen (Al-Alimi and Alhudify, 2016); Mostafa *et al*. (2009) showed that the concentration of Pb was 5.3 - 23.0 µg/g (dry wt.) on winter in Hadhramout coastal area, Gulf of Aden, Yemen

(Mostafa *et al*., 2009); Sagheer, (2013) showed that the concentration of Pb was 1.5 - 13.8 µg/g (dry wt.) in Kwar Katib lagoon, Red sea, Al-Hodaeidah Coast, Yemen (Sagheer, 2013); Heba, *et al*. (2004) pointed out that the concentration of Pb was 4.990-6.260 µg/g (dry wt.) in Red Sea coast , Al-Hodeida, Yemen (Heba, *et al*., 2004).

Also, were high concentration compared with other studies which mentioned by Nayaka *et al*. (2009) pointed out that the concentration of Pb was 32.000 µg/g (dry wt.) and Cd was 0.030 µg/g (dry wt.) in India (Nayaka *et al*., 2009). Besides, Ahdy and Khaled, (2009) pointed out that the concentration of Pb was 20.672-35.624 µg/g (dry wt.) and Cd was 0.524-0.924 µg/g (dry wt.) in Western Part of Egyptian Mediterranean Sea (Ahdy and Khaled, 2009). Besides, Asha *et al*. (2010) pointed out that the concentration of Pb was 16.740-43.070 µg/g (dry wt.) in U-Tapao Canal, Songkhla, Thailand (Asha *et al*., 2010). Besides, Anand and Kala, (2015) pointed out that the concentration of Pb was 15.43 - 51.40 µg/g (dry wt.) and Cd was 0.520 - 6.250 µg/g (dry wt.) in South East Coast of India (Anand and Kala., 2015). Besides, Al-Najjar *et al*. (2011) pointed out that the concentration of Pb was 0.123-4.07 µg/g (dry wt.) and Cd was 4.79 - 5.25 µg/g dry weight in Aqaba, Red Sea Jordan (Al-Najjar *et al*., 2011).

These high different between the results may reference to various factors as leaded gasoline, movement of pollutants, wastewater discharge from the city, physical characteristics of the Red Sea, effluents from landing port, industrial pollution, rainfalls, municipal runoffs, atmospheric deposition and oil enrichment in the vicinity areas.

Taking into consideration that the Red Sea is an enclosed sea and has a slow turnover rate of 6 years for the surface Seawater layer and 200 years for the whole water body as well as it is the most saline water body of the world seas, the accumulation of chemical pollutants is expected to increase annually in all its components, changing its quality and affecting its aquatic life.

However, our results were low concentration compared with other studies which mentioned by Al-sulami *et al*. (2002) who reported that the concentration of Pb of sediments was 148.00µg/g (dry wt.), Cd was 40.00 µg/g (dry wt.), Hg was 1.30µg/g (dry wt.) and As was 4.80µg/g (dry wt.) in the Eastern Coast of Saudi Arabia (Al-sulami *et al*., 2002). Besides, Ali *et al*., 2011a, pointed out that the concentration of Cd was 35.50µg/g (dry wt.), Hg was 1.85µg/g (dry wt.) in Isalmic Port Coast, Red Sea, Jeddah, Saudi Arabia (Ali *et al*., 2011a). Besides, Saeed and Shaker, (2008) pointed out that the concentration of Cd was 30.30µg/g (dry wt.) in northern Delta Lakes, Egypt (Saeed and Shaker, 2008). Besides, (Ali *et al*., 2011b) pointed out that the concentration of Cd, Hg and As was 35.10, 0.28 and 5.72µg/g (dry wt.) respectively, in Jeddah Islamic Port Coast (JIPC), Red Sea, Jeddah Coast, Saudi Arabia and the concentration of Cd, Hg and As was 27.90, 0.70 and 0.44µg/g (dry wt.) respectively, in Northern Coast Side of Jeddah (NCSJ), Red Sea, Jeddah Coast, Saudi Arabia (Ali *et al*., 2011b). Besides, Sirinawin and Sompongchaiyakul, (2005) pointed out that the concentration of Hg was 0.36 - 1.60µg/g (dry wt.) in Trinidad and Venezuela, Gulf of Paria and north coast of Venezuela (Sirinawin and Sompongchaiyakul, 2005). Besides, Astudillo *et al*. (2005) who reported that the concentration of Hg of sediments was 0.10µg/g (dry wt.) and As was 9.60µg/g (dry wt.) in South China Sea, east coast of Peninsular Malaysia (Astudillo *et al*., 2005). Besides, Rezaee *et al*. (2010) was reported that the concentration of Hg of sediments was 0.022-0.077 µg/g (dry wt.) in Gökova Bay, Turkey (Rezaee *et al*., 2010). Besides, Ergul *et al*. (2008) who reported that the concentration of As of sediments was 5.700 - 23.500 µg/g (dry wt.) in Black Sea, Turkey (Ergul *et al*., 2008). Besides, Mora *et al*. (2004) who reported that the concentration of As of sediments was 1.000-6.300, 0.700-9.600, 3.160- 6.880 and 0.740- 5.010 µg/g (dry wt.) in Qatar, UAE, Bahrain and Oman respectively. And Pb was 0.673-99.000 µg/ g (dry wt.) and Hg was 0.0025- 0.2202 µg/g (dry wt.) in Bahrain

(Mora *et al.,* 2004). Besides, Asha *et al*. (2010) who reported that the concentration of Pb of sediments was 32.900-206.100 µg/g (dry wt.) in Jeddah, Saudi Arabia(Asha *et al*., 2010).

Based on these information's, Yemeni coast in the present study is low polluted when it is compared with other locations.

However, the overall concentrations of Pb and Cd observed in this study are comparable to or even lower than those reported previously within the region (Saleh and Marie, 2014; Nomaan *et al*., 2012; Nasr *et al*., 2006; Heba *et al*., 2004; Al-Shiwafi *et al*., 2005; Al Hudaifi, 2016; Al-Alimi and Al-Hudaifi, 2016; Mostafa *et al*., 2009; Sagheer, 2013).While the apparent discrepancy is mainly attributed to the difference in the laboratory analytical procedures used in sample analyses, the exact localities where the samples were collected also needs to be taken into account.

The analysis results of the surface seawater and sediment samples from the coastal region of the Red Sea and Gulf of Aden coast of Yemen showed that mainly natural with some anthropogenic inputs are the sources of Heavy metals to region. This is indicated by the low concentrations of all metals except for Pb and Cd in seawater and sediments, which designate possible anthropogenic sources.

The main natural sources are from rock weathering, mineral dissolution in sediments and regional dust transport. Minor anthropogenic inputs are local wastes from coastal facilities and human and developmental activities in main coastal cities (Aden, Al-Hodaeidah and Al-mukalla).

The sources of these metals to the coastal region may also include atmospheric inputs, dredging, direct dumping and sewage sludge.

The physical processes and current direction might have an impact on the special distribution of these metals along the Yemeni coastal.

When contaminated particulate or sedimentary material is dispersed through an ecosystem, it equilibrates with water, detritus, and living food materials, resulting in ongoing contamination of all environmental compartments (Pyle *et al*. 2005). The detected positive correlation (Table 3-21) between the concentration of each metal in the sea water and sediment, in the present study, supports this argument.

A remarkable relationship between heavy metals concentrations in aquatic organisms and sediments were observed by Saeed and Shaker, (2008).

4-3 Heavy Metals in Fish

4-3-1 Heavy Metals in Muscles Fish

Overall, the present study showed that there were no significant differences ($P>0.05$), using one way ANOVA regarding the concentration of Pb, Cd, Hg and As in muscles of four commercially important fish species, *Lethrinus mahsena*, *Thunnus tonggol, Sphyraena jello* and *Epinephelus areolatus* (Table 5-1) throughout the seasons: winter 2011, summer 2012 and winter 2013 at Yemen coast (Aden, Al-Hodaeidah and AL-Mukalla) except Cd in Aden and Al-Mukalla sites there was significant difference ($P<0.01$).

On the other hand, these results of the present study were analyzed by using two ways ANOVA in muscles of fish of Yemen sites during the seasons, it showed that there were not significant differences ($P>0.05$) regarding the concentration of Pb, Hg and As, however, there was significant difference ($P<0.01$) regarding the concentration of Cd in the muscles of fish of Yemen sites for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Cd was 0.054±0.026 μg/g (dry wt.) in muscles of fish species studied was on summer.

The present high concentration of Cd in summer may be attributed to various factors as sewage, increase in the water temperature during summer increases heavy metals uptake in the fishes as compared to the winter season, higher metabolic rate in the fishes, migratory patterns of fishes, concentration, exposure time, route of metal uptake and feeding habits (Khaled, 2004; Ali and Abdel-Satar, 2005; Beamish *et al.,* 2005; Obasohan *et al.,* 2008; Jezierska *et al.,* 2009; Ibrahim and Omar, 2013; Al-Dohail *et al.,* 2014).

In addition, seasonal changes in feeding rate, in gaining or losing weight, or in synthesis of metal binding proteins, are all responsible for storage of the metals (Farkas *et al.,* 2000).

The interpretation of these results is comparable to those reported by Al-Dohail *et al.,* (2014) showed that the highest concentration of Cd in muscles of *M. seheli* was found on summer and the lowest concentration was obtained on winter who suggested that the amount of draining sewage on summer were higher compared with other seasons as a result of using water in this season by population of Mukalla city as well as seawater are more mixing by moving current (upwelling) in autumn that lead to dispersion the metals in seawater column. This suggestion also supported by environmental data for the high temperature in the summer at Khor al-Mukalla (Al-Dohail *et al.,* 2014).

These results are in accord with recent studies indicating that heavy metal content of fish tissues indicate the influence of season as one source of variations or fluctuations on the metal concentration (Dural *et al.,* 2007; Ersoy and Celik, 2009; Mendil *et al.,* 2010). Seasonal fluctuations of metals might be resulted from different factors such as growth and reproductive cycles and changes in water temperature (Ersoy and Celik, 2009; Saei-Dehkordi *et al.,* 2010).

According to this study the muscles of fish usually accumulates higher levels of Cd was (0.054±0.026 μg/g dry wt.) at summer. This result was nearly similar to other studies conducted in Turkey (0.060±0.000 μg/g dry wt.) (Olgunoğlu and Olgunoğlu, 2011). Also, in Turkey (0.01-0.08 (0.03±0.01) μg/g dry wt.) (Aktan and Tekin-Özan, 2012).

On the other hand, our results illustrated high concentration compared with other studies which mentioned by Al-Dohail *et al*. (2014) showed that the concentration of Cd was 0.01 ± 0.002 µg/g (dry wt.) in muscles of fish, Blue spot mullet, *Moolgarda seheli* from Khawr-Mukalla, Hadhramout Coast, Yemen, at summer (Al-Dohail *et al*., 2014).

Besides, Karim *et al*. (2016) showed that the concentration of Cd was 0.00058± 0.0004 µg/g (dry wt.) in Flesh of Octopus vulgaris from the north east of Morocco, Mediterranean coast at summer (Karim *et al*., 2016).

However, our results were low concentration compared with other studies which mentioned by Sadegh *et al*. (2013) showed that the concentration of Cd was 20.800 µg/g (wet wt.) in muscle of *Platycephalus indicus* from Khamir port, the Northeastern Persian Gulf at summer (Sadegh *et al*., 2013).

These high differences between the results may reference to various factors such as temperature, migratory patterns of fishes, concentration exposure time, route of metal uptake and feeding habits.

It is assumed that the presence of the area near the strait of Bab Al-Mandab, where the water coming from both the Red Sea and the Indian Ocean mixes and consequently changes its nature, especially during the monsoons, is responsible mainly for elevated tissue Cd concentrations in the Muscles fish inhabiting the area. However, some sewage outflow can be additional anthropogenic sources of Cd in the Aden and Al-Hodaeidah .

Overall, the results of the present study showed that they were significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the muscles of four commercially important fish species of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) sites, for the duration of the four types of fish studied: *Lethrinus mahsena*, *Thunnus tonggol, Sphyraena jello* and *Epinephelus areolatus*.

The highest concentration of Pb, Cd and Hg were 0.137± 0.014, 0.069±0.021 and 0.071±0.012 µg/g (dry wt.), respectively) in muscles of fish of *Epinephelus areolatus*; but, the highest concentration of As was 0.106±0.007 µg/g (dry wt.) in the muscles of fish of *Lethrinus mahsena*, as summarized in (Table 5-2).

The present high concentration of Pb, Cd and Hg in *E. areolatus* and high concentration of As in *L. mahsena* have been usually attributed to their habitat and feeding behavior. *E. areolatus* and *L. mahsena* tend to be near the sediment region (Kilgour, 1991; Olukolajo, 2008; Bahnasawy *et al.,* 2009).

A possible explanation for this might be due to lipid content in the tissue and excretion percentage of these toxic metals from their body (Asante *et al.,* 2014).

This result may confirm previous studies of several authors who reported that *E. areolatus* usually accumulates higher levels of heavy metals than other species (Brewer *et al.,* 2007; Abu Hilal, 2008; Alina, 2012).

In another study in Bahrain, Musaiger and Souza, (2008) found higher levels of Hg in muscles of *E. areolatus* than nine fish species from the manama city of Bahrain (Musaiger and Souza, 2008); and Brewer *et al.,* 2007, found higher levels of Hg in muscles of *E. areolatus* than other fish species from the Lihir Islands group is in Papua New Guinea's New Ireland (Brewer *et al.,* 2007).

These results are in agreement with Saei-Dehkordi *et al.,* (2010) attributed the Heavy metals burden in aquatic inhabitants is associated with biological and ecological factors such as feeding habits and habitat, respectively (Henry *et al.,* 2004; Sankar *et al.,* 2006; Kojadinovic *et al.,* 2007). Regarding to their habitat, demersal fish species had the highest muscular arsenic 0.481 ± 0.307 µg/g of wet weight concentrations.

There is strong correlation (Table 3-22) between Cd and Pb in Muscles (at Aden, r = 0.673; at Al-Hodaeidah , r = 0.624; at Al-Mukalla , r = 0.491) . Associations between metals are important, as they determine the bioavailability and potential toxicity to fish in an aquatic system (Luoma, 1983).

The interpretation of these results are comparable to those reported by Heba *et al*. (2014) showed that the concentration of Pb was 0.10 µg/g (dry wt.) in muscles of *Epinephelus tauvina* During summer in Red Sea, Al-Hodaeidah , Yemen (Heba *et al*., 2014).

Also the above results and the initial interpretation given are comparable to those reported in 2010 by Ganbi, showed that the concentration of Cd was 0.029 µg/g (wet wt.) in muscles of *Epinephelus areolatus* from the Red Sea, Jeddah Coast, Saudi Arabia (Ganbi, 2010).

The obtained results for lead and Cadmium and their interpretation are comparable to those reported by Younis *et al*. (2015) showed that the concentration of Pb was 0.127- 0.188 µg/g (dry wt.) and Cd was 0.052 µg/g (dry wt.) in muscles of *Epinephelus areolatus* from the Red Sea, Jeddah Coast, Saudi Arabia (Younis *et al*., 2015).

However, our results are in a good agreement with those found by Pugalendhi and Maheswari, (2007) showed that the concentration of Pb was 0.100±0.09 µg/g (dry wt.) in muscles of *Epinephelus areolatus* from Tuticorin, India (Pugalendhi and Maheswari, 2007).

Besides, Al sulami, (2002) showed that the concentration of As was 0.25-0.9 µg/g (dry wt.) and Hg was 0.08-0.2 µg/g (dry wt.) in muscles of *L. mahsena* from Arabian Gulf Along the Eastern Coast, Saudi Arabia (Al sulami, 2002); Al-Ghanim *et al*, 2015, pointed out that the concentration of Pb was 0.20 ± 0.02 µg/g (dry wt.), As was 0.11 ± 0.02 µg/g (dry wt.), in *L. mahsena* from Red Sea, Egypt (Al-Ghanim *et al*., 2015); Algahri *et al*. (2011) pointed out that the concentration of Pb was 0.118- 0.193 µg/g (wet wt.), Cd was 0.013- 0.023 µg/g (wet wt.), Hg was 0.012- 0.184 µg/g (wet wt.) in tuna fish Hadhramout Coast Yemen (Algahri *et al.,* 2011); Al Zubaidy *et al*., 2014, pointed out that the concentration of Pb was 0.12 ± 0.21 µg/g (dry wt.), in *L. mahsena* from Red Sea of Al-Cornish Hodeidah Yemen (Al Zubaidy *et al.,* 2014); Larouci, 2006, pointed out that the concentration of Cd was 0.09 ± 0.010 µg/g (wet wt.), in *T. albacares* from Aden Yemen (Larouci, 2006); Ali , 2011, pointed out that the concentration of Pb was 0.10 - 2.10 µg/g (dry wt.), Cd was 0.06-1.06 µg/g in *L. mahsena* from Jeddah Coast, Saudi Arabia (Ali, 2011 b).

On the other hand, our results were high concentration compared with other studies which mentioned by Obaidat *et al*. (2015) showed that the concentration of As was 0.002±0 (mg/kg wet weight) in muscles of *Lethrinus nebulosus*, in Red Sea Jordan (Obaidat *et al*., 2015); Al Bader, (2008) pointed out that the concentration of Pb was 0.022 µg/g (wet wt.), Cd was 0.004 µg/g (wet wt.), Hg was 0.003 µg/g (wet wt.) and As was 0.025 µg/g (wet wt.) in *E. areolatus* from Saudi Arabia (Al Bader, 2008). Besides, Musaiger and Souza, (2008) pointed out that the concentration of Pb was <0.02 µg/g (wet wt.), Cd was <0.02 µg/g (wet wt.), and Hg was 0.02 µg/g (wet wt.) from Bahrain (Musaiger and Souza, 2008).

However, our results were low concentration compared with other studies which mentioned by Al Zubaidy *et al*. (2014) showed that the concentration of Pb was 1.66±0.30 - 2.23±0.93 µg/g (dry wt.) and Cd was 0.33±0.03 - 0.46±0.22 µg/g (dry wt.) in muscles of *Epinephelus sexfasciatus* during winter in Red Sea, Al-Hodaeidah , Yemen (Al Zubaidy *et al*., 2014).

Besides, Heba *et al*. (2014) showed that the concentration of Cd was 0.50 µg/g (dry wt.) in muscles of *Epinephelus tauvina* during summer in Red Sea, Al-Hodaeidah , Yemen, who suggested that higher Cd concentrations might be either the fat content, or the diet consumed by this fish (Heba *et al*., 2014).

These high differences between the results may reference to their habitat and feeding behavior. *E. areolatus* and *L. mahsena* tend to be near the sediment region, as well as the metal content in food and the bioconcentration capacity of each species (Farkas *et al*., 2000; Huang *et al*., 2003); and location in relation to prey high in As from anthropogenic sources (Bellante *et al*., 2012).

In general, cadmium residues in fish muscle cannot be related to concentrations in water (Moore and Ramamoorthy 1984), and no such correlations (Table 3-19) were found in this study. But, Significant positive correlations (Table 3-20) between the concentrations Cd in *E. areolatus* and Cd in the surrounding Sediments were obtained. The following correlations were determined from the content of Cd in *E. areolatus*, 0.276. This leads to the hypothesis of preferential Cd uptake from the Sediments.

Significant positive correlations (Table 3-20) between the concentrations Hg in of each type of fish and Hg in the surrounding Sediments were obtained. The following correlations were determined from the content of Hg in *E. areolatus*, 0.482.

This leads to the hypothesis of preferential Hg uptake from the Sediments.

Significant positive correlations (Table 3-19 and Table 3-20) between the concentrations As in each type of fish and As in the surrounding sea water and Sediments were obtained. The following correlations were determined from the content of As in *L. mahsena*, 0.342 and 0.301.

This leads to the hypothesis of preferential As uptake from the Seawater column and Sediments.

The results in the present study were analyzed by using two ways ANOVA in muscles of fish of Yemen sites during the seasons, it showed that there were significant differences ($P<0.01$) regarding the concentration of Pb and Cd in the muscles of fish of AL-Hodeida, Aden and AL-Mukalla sites.

The highest concentration of Pb and Cd were 0.138± 0.073 and 0.057±0.034 µg/g (dry wt.), respectively) achieved in Al-Hodaeidah .

The present high concentration of Pb and Cd in Al-Hodaeidah may be due to the geochemical nature of beach deposits and anthropogenic activities, (Heba *et al.,* 2015; Al-Shwafi, 2002, Al-Shwafi *et al.,*2005), feeding behavior of the fish species, fat content, the in their diet uptake (Heba *et al.,* 2014; Heba *et al.,* 2015).

The interpretation of these results are comparable to those reported by Al Zubaidy *et al.,* (2014) showed that the concentration of Pb was 0.12±0.21 - 3.05±0.62 µg/g (dry wt.) and Cd was 0.18±0.54 - 0.64±0.28 µg/g (dry wt.) in muscles of five fish species collected from Red Sea, Hodeida City, Yemen. Who suggested that higher Cd concentrations might be this confirms that Al-Mena (Al-Hodaeidah) site is affected by industrial waste discharge taking place in that area, exposed to more pollutants and economic activities are very high at this site. Fishes, water and sediment quality within the area are influenced by sewage and oil spill from ships (Al Zubaidy *et al.,* 2014).

Also the above results and the initial interpretation given are comparable to those reported in 2014 by Heba *et al*; showed that the concentration of Pb was 0.10 - 0.85 µg/g (dry wt.) in muscles of greasy grouper (*Epinephelus tauvina*) and striped mackerel (*Rastrelliger kanagurta*) from Al-Hodeida, Red Sea coast of Yemen (Heba *et al.,* 2014).

The obtained results for lead and Cadmium and their interpretation are comparable to those reported in 2002 by Al-Shwafi, showed that the concentration of Pb was 0.03 ± 0.01- 0.25 ± 0.09 µg/g (dry wt.) and Cd was 0.03 ± 0.02 - 0.13 ± 0.04 µg/g (dry wt.) in muscles of different fish species in the Red Sea of Yemen (Al-Shwafi, 2002).

However, our results are in a good agreement with those found by Huang, (2003) pointed out that the concentration of Pb was 0.08 ± 0.02 µg/g (dry wt.) and Cd was 0.04 ± 0.00 µg/g (dry wt.) in *Lethrinus mahsena* from

Eastern Taiwan (Huang, 2003); El-Moselhy *et al*., (2014) pointed out that the concentration of Pb was 0.25 ± 0.07 µg/g (dry wt.) and Cd was 0.05 ± 0.01 µg/g (dry wt.) in *Lethrinus sp*. from Red Sea, Egypt (El-Moselhy *et al*., 2014); Emmanuelle *et al*., (2014) pointed out that the concentration of Pb was 0.17 ± 0.05 µg/g (dry wt.) and Cd was 0.02 ± 0.02 µg/g (dry wt.) in *Thunnus albacares* from Abidjan (Emmanuelle *et al*., 2014); Islam *et al*., (2010) pointed out that the concentration of Pb was 0.07 ± 0.03 - 0.13 ± 0.08 µg/g (dry wt.) and Cd was 0.06 ± 0.01 µg/g (dry wt.) in *Thunnus thynnus* from Korea (Islam *et al*., 2010); Saei-Dehkordi and Fallah , (2011) pointed out that the concentration of Pb was 0.113±0.035 µg/g (dry wt.) and Cd was 0.049±0.024 µg/g (dry wt.) in *Sphyraena jello* from Iran (Saei-Dehkordi and Fallah , 2011).

On the other hand, our results were high concentration compared with other studies which mentioned by Metian *et al*., (2013) pointed out that the concentration of Pb was <0.08 µg/g (dry wt.) in *Lethrinus laticaudis* from New Caledonia (Metian *et al*., 2013); Kojadinovic, (2007) pointed out that the concentration of Pb was 0.09±0.14 µg/g (dry wt.) in *Thunnus thynnus* from Austria (Kojadinovic, 2007); Agusa *et al*., (2006) pointed out that the concentration of Pb was 0.017 µg/g (dry wt.) and Cd was 0.008 µg/g (dry wt.) in *Sphyraena obtusata* from Southeast Asia (Agusa *et al*., 2006); Brewer *et al*., (2007) pointed out that the concentration of Pb was <0.01 µg/g (dry wt.) and Cd was <0.01 µg/g (dry wt.) in *Epinephalus morrhua* from Australia (Agusa *et al*., 2006).

Considering that the dry weight represents 23–33% of the corresponding wet weight (Burger and Gochfeld, 2005).

Our results were high concentration compared with other studies which mentioned by Suppin *et al*., (2005) pointed out that the concentration of Pb was 0.013 µg/g (wet wt.) and Cd was 0.014 µg/g (wet wt.) in *Thunnus thynnus* from Austria (Suppin *et al*., 2005); Olmedo *et al*., (2013) pointed out that the concentration of Pb was 0.004 µg/g (wet wt.) and Cd was 0.008 µg/g (wet wt.) in *Thunnus thynnus* from Spain (Olmedo *et al.,* 2013).

Some of these values are very small compared with the obtained readings in the current study, however, not be surprising because the marine environment of the ocean is generally less polluting for the sea that are surrounded by industrialized countries, or that are over a lot of ships, such as the Gulf of Aden line.

However, our results showed low concentration compared with other studies which mentioned by Heba *et al*. (2014) illustrated that the concentration of Cd was 0.30 - 0.50 µg/g (dry wt.) in muscles of greasy grouper (*Epinephelus tauvina*) and striped mackerel (*Rastrelliger kanagurta*) from Al-Hodeidah, Red Sea coast of Yemen (Heba *et al*., 2014).

Besides, Heba *et al*. (2015) showed that the concentration of Cd was 0.60 µg/g (dry wt.), in muscles of three Commercial Fish Species from Al-Hodaeidah , Red Sea Coast of Western Yemen (Heba *et al*., 2015).

Besides, Rushdie *et al*., 1994)Vshowed that the concentration of Pb was 1.95 -3.8 0 µg/g (dry wt.) in muscles of different types of fish from Al-Hodaeidah , Yemen (Rushdie *et al*., 1994); Al- Adrise *et al*. (2002) showed that the concentration of Pb was 2.95 - 3.13 µg/g (dry wt.) and Cd was 0.14 - 2.56 µg/g (dry wt.) in muscles of different types of fish from Al-Hodaeidah , Yemen (Al- Adrise *et al*., 2002); AL- Mudaffr *et al*. (1994) showed that the concentration of Pb was 1.60 - 3.80 µg/g (dry wt.) and Cd was 2.40 - 3.60 µg/g (dry wt.) in muscles of different types of fish from Al-Hodaeidah , Yemen (AL-Mudaffr *et al*., 1994).

However, when comparing these results with previous studies in other areas, we found that our results were low concentration compared with other studies which mentioned by Ali, (2011 a) pointed out that the concentration of Pb was 6.10 µg/g (dry wt.) and Cd was 1.06 µg/g (dry wt.) in *Lethrinus mahsena* from Red Sea at Jeddah Isalmic Port Coast, Saudi Arabia (Ali, 2011 a); Zyadah, (2012) pointed out that the concentration of Pb was 0.8 ± 0.3µg/g (dry wt.) and Cd was 0.55 ± 0.2 µg/g (dry wt.) in *L. mahsena* from Arabian Gulf Coast at the Eastern Province, Saudi Arabia (Zyadah, 2012); Ashraf, (2004) pointed out that the concentration of Pb was 0.53±0.08 µg/g (dry wt.) and Cd was 0.16±0.11 µg/g (dry wt.) in *T. tonggol* from Saudi Arabia (Ashraf, 2004); Abu Hilal and Ismail, (2008) pointed out that the concentration of Pb was 5.0-5.6 µg/g (dry wt.) and Cd was 0.9-1.0 µg/g (dry wt.) in *Epinephelus fasciatus* from Jordan (Abu Hilal and Ismail, 2008); Renieri *et al*., (2014) pointed out that the concentration of Cd was 1.83µg/g (dry wt.) in *Sphyraena sphyraena* from Mediterranean Sea , Italy (Renieri *et al*., 2014).

The high different between the results, may reference to various factors as the geochemical nature of beach deposits and anthropogenic activities, feeding behavior of the fish species, fat content, the in their diet uptake.

Based on this information, Yemen coast in the present study is low polluted when it is compared with other locations.

Also Overall, the results showed that there were significant differences ($P<0.01$), using two way ANOVA, regarding the concentration of Pb, Cd, Hg and As, in the muscles of fish in the muscles of Four types of fish studied of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) stations, for the period of size: Large, Medium and Small.

The highest concentration of Pb, Cd, Hg and As were 0.124±0.059, 0.060±0.022, 0.065±0.021 and 0.104±0.007 µg/g (dry wt.), respectively in muscles of fish, were observed to be more concentrated in the larger sizes of fish, as shown in (Table 3-4).

The present high concentration of Pb, Cd, Hg and As in the larger sizes of fish may be attributed to various factors as large fish that prey upon smaller fish can accumulate more of the chemical in their bodies. It is better to eat the smaller fish within the same species, the strong affinity of metallothionine protein with these metals. This is usually more pronounced in bigger fishes (Allen-Gil, *et al.,* 1997; Szefer, *et al.,* 2003; Burger *et al.,* 2004; Kojadinovic *et al.,* 2006; Burger *et al.,* 2007; Aghoghovwia and Ikogha, 2014).

Many studies have recognized size as an influencing factor into the amount of concentration accumulated by fish (Al-Yousf *et al.,* 2000; Canli and Atli, 2003; McKinley *et al.,* 2012).

Increase in body mercury level with fish size is probably related to the affinity of this metal to the muscle tissue (Green and Knutzen, 2003; Voigt, 2004).

The high concentrations of heavy metals in the surrounding water could result in continued metal accumulation in fish and increase of metal concentrations with fish size (Yi and Zhang 2011; Liu *et al.,* 2015). Metals like cadmium is low in juvenile stages but it are accumulated with age. The size and maturity stage of the fishes influence its accumulation levels. Cd concentration in the muscle tissue is found to increase with the size of the fishes (Unnikrishnan *et al.,* 2003).

The positive correlations presented in our data (Table 3-22) between specific heavy metal pairs in the Muscles indicated that these metals had the same distribution characteristics or may reflect similar levels of contamination and/or release from the same source of pollution (Li *et al.,* 2009; Yi *et al.,* 2011).

4-3-2 Heavy Metals in Liver

Overall, the present study showed that there were not significant differences ($P>0.05$) using one way and two way ANOVA regarding the concentration of Pb, Cd, Hg and As in Liver of four commercially important fish species, *L. mahsena, T. tonggol, S. jello* and *E. areolatus* throughout the seasons: winter 2011, summer 2012 and winter 2013 at Yemen coast (Aden, Al-Hodaeidah and AL-Mukalla); except Cd in Aden site there was significant difference ($P<0.05$).

The highest concentration of Cd was 0.144±0.162 µg/g (dry wt.) in Liver of fish species studied was on summer.

The present high concentration of Cd in summer may be attributed to various factors as differences in local pollution, industrial wastes, bioavailability of metals (variations among physiochemical factors) and fish metabolism (growth cycle, reproduction and feeding). physiological changes, minor role of annual cycles of pH and metal concentration in the water and metal level of the diet in the seasonal pattern of metal concentration in liver described by (Filazi *et al.,* 2003 ; Khaled, 2004 ; Ali and Abdel-Satar, 2005; Mendil *et al.,* 2005; Farkas *et al.,* 2000; Ersoy and Celik ,2009; Dural *et al.,* 2010; Belhoucine *et al.,* 2014). This observation probably indicates that due to the liver has ability to accumulate the heavy metals, and then its excrete from liver is difficult as mentioned by (Khaled, 2004).

These results are in accord with (Al-Dohail *et al.,* 2014) indicating that the highest concentration of Cd in liver of fish was found on summer and the lowest concentration was obtained on winter, who suggested that the amount of draining sewage on summer were higher compared with other seasons as a result of using water in this season by population of Al-Mukalla city as well as seawater are more mixing by moving current (upwelling) in autumn that lead to dispersion the metals in seawater column. This suggestion also supported by environmental data for the high temperature in the summer at Khor Al-Mukalla (Al-Dohail *et al.,* 2014).

According to this study the Liver of fish usually accumulates higher levels of Cd was (0.144±0.162 µg/g dry wt.) at summer. This result was nearly similar to other studies conducted in Yemen (0.031 ± 0.003 µg/g dry wt.) (Al-Dohail *et al.,* 2014), in Turkey (0.01-0.36 µg/g dry wt.) (Aktan and Tekin-Özan, 2012), in Algerian was (0.25-0.29 µg/g dry wt.) (Fatma *et al.,* 2015).

On the other hand, higher levels of Cd were reported in Tunisia (0.547 µg/g dry wt.) (Chouba *et al.,* 2007), in Mediterranean Sea in the region of Alexandria (1.492 ±0.002 µg/g wet wt.) (Khaled, 2009), in Iran was (0.70 ± 0.24 - 2.03 ± 0.55 µg/g dry wt.) (Safahieh *et al.,* 2011).

Overall, the results of the present study showed that they were significant differences ($P<0.01$), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Liver of four commercially important fish species of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) sites, for the duration of the Four types of fish studied: *L. mahsena, T. tonggol, S. jello* and *E. areolatus*.

The highest concentration of Pb was 0.428± 0.031 µg/g (dry wt.) in Liver of *L. mahsena*, but, the highest concentration of Cd was 0.289±0.020 µg/g (dry wt.) in the Liver of *E. areolatus*; as summarized in (Table 3-6).

The present high concentration of Pb and Cd in *L. mahsena* and *E. areolatus* may be attributed to various factors, demersal or bottom-dwelling species, food preferences, organism mobility or other attributes of behaviour with respect to the environment (Saei-Dehkordi *et al.,* 2010; Gaspic *et al.,* 2002; Kucuksezgin *et al.,* 2001; Marcotrigiano and Storelli, 2003; Yi *et al.*, 2011), strong binding with cystine residues of MT (Kaoud and El-Dahshan, 2010), lipid content in the tissue and excretion percentage of these toxic metals from their body (Asante et *al*., 2014), increased metabolic rate, water temperature (Jezierska and Witeska, 2006).

However, our results are in a good agreement with those found by Abu Hilal and Ismail, (2008) pointed out that the concentration of Cd was 0.6 µg/g (dry wt.) in Liver of *Epinephelus fasciatus* from Jordan (Abu Hilal and Ismail, 2008); and Wong *et al*., (2001) pointed out that the concentration of Cd was 0.25 ± 0.04 µg/g (dry wt.) in Liver of *E. areolatus* from Hong Kong, China (Wong *et al*., 2001).

In the other hand, our results were high concentration compared with other studies which mentioned by Younis *et al*., (2015) showed that the concentration of Cd was 0.005 µg/g (wet wt.) in Liver of *Epinephelus areolatus* from Saudi Arabia (Younis *et al*., 2015); and Brewer *et al*., (2007) showed that the concentration of Cd was <0.01 µg/g (wet wt.) in Liver of *Epinephalus morrhua* from Australia (Brewer *et al*., 2007).

However, our results in this part of study were low concentration compared with other studies which mentioned by Al Zubaidy *et al*. (2014) showed that the concentration of Pb was 1.40±0.35 - 1.95±2.703 µg/g (wet wt.) in Liver of *Lethrinus lentjan* and Cd was 0.52±0.100 - 0.86±0.52 µg/g (wet wt.) in Liver of *Epinephelus sexfasciatus* during winter from Red Sea, Al-Hodaeidah , Yemen (Al Zubaidy *et al*., 2014); and Heba *et al*. (2015) showed that the concentration of Cd was 1.60 and 2.90 µg/g (dry wt.) in Liver of *Arirus sp*. and *Mugil sp*. during summer from Red Sea, Al-Hodaeidah , Yemen (Heba *et al*., 2015).

Besides, Al Ghanim *et al*., (2015) showed that the concentration of Pb was 0.97±0.05 µg/g (dry wt.) in Liver of *L. mahsena* and Cd was 1.99±0.23 µg/g (dry wt.) in Liver of *Epinephelus spp* from Red Sea, Egypt (Al Ghanim *et al*., 2015); and Ali, (2011 a) showed that the concentration of Pb was 6.72 µg/g (dry wt.) in Liver of *L. mahsena* and Cd was 2.97µg/g (dry wt.) in Liver of *Caranx sexfaciatus* from Red Sea at Jeddah Isalmic Port Coast, (Ali, 2011 a); and El-Moselhy *et al.,* (2014) showed that the concentration of Pb was 1.09 ± 0.84 µg/g (wet wt.) in Liver of *Lethrinus sp*. and Cd was 0.86 ± 0.15 µg/g (wet wt.) in Liver of *Epinephelus sp*. from Red Sea, Egypt (El-Moselhy *et al*., 2014).

On the other hand, the highest concentration of Hg and As were 0.127± 0.026 and 0.147±0.032 µg/g (dry wt.) respectively in the Liver of fish of *T*. *tonggol*; as summarized in (Table 3-6).

The present high concentration of Hg and As in *T*. *tonggol* may be attributed to various factors, including feeding habits, species, age and size of fish, bioavailability of chemicals in food and water, exposing time, bioaccumulation (Kalay and Canli, 2000; Storelli *et al*., 2005; Rejomon *et al*., 2010; Al-Busaidi *et al*., 2011; Abdul-Wahab *et al*., 2013), high mobility and metabolism (Marcotrigiano and Storelli, 2003; Damiano *et al*., 2011), a slow demethylation process, implying the formation of HgSe (mercuric selenide) (Kehrig *et al*., 2008).

Another possible explanation for this is that the differences in Hg concentrations have been linked to the diet and hence the trophic level of the fish species (Saei-Dehkordi *et al*., 2010; Mortazavi and Sharifian, 2011).

The observed increase in As could be attributed to differences in metabolism (Saei-Dehkordi *et al*., 2010).

The high positive correlations presented in our data (Table 3-23) between As and Hg in Liver. Since there is a bioaccumulation of toxic heavy metals in fish tissues (Khoshnood *et al*., 2012).

These results are in agreement with Lima *et al*. (2005) assessed the level of mercury and selenium in fish samples from Cachoeira (ParãState, Brazil) and found a highest level of Hg concentration in carnivorous species than noncarnivorous (Lima *et al*., 2005). Similarly in our study, *T*. *tonggol* had highest averaged Hg concentration.

However, our results are in a good agreement with those found by Khoshnood *et al*. (2012) which showed that the concentration of Hg was 0.209 ± 0.092 µg/g (dry wt.) and As was 0.140 ± 0.032 µg/g (dry wt.) in Liver of *T. tonggol* from northern of Persian Gulf (Khoshnood *et al.,* 2012); and Shooshtari *et al*. (2011) showed that the concentration of Hg was 0.314-0.146 µg/g (dry wt.) in Liver of *Caspiomyzon wagneri* from Iran (Shooshtari *et al.,* 2011).

On the other hand, our results were high concentration compared with other studies which mentioned by Sobhanardakani *et al*. (2011) showed that the concentration of Hg was 0.060 µg/g (wet wt.) and As was 0.026 µg/g (wet wt.) in Liver of *Scomberomorus commerson* from Iran (Sobhanardakani *et al.,* 2011).

However, our results in present study were low concentration compared with other studies which mentioned by Kojadinovic *et al*. (2007) showed that the concentration of Hg was 3.27± 8.11 µg/g (dry wt.) in Liver of *Thunnus albacares* from the Western Indian Ocean, Reunion Island, east of Madagascar (Kojadinovic *et al.,* 2007).

These high differences between the results may reference to related to their food source.

Significant positive correlations (Table 3-19) between the concentrations As in each type of fish and As in the surrounding sea water were obtained. The following correlations were determined from the content of As in *T. tonggol*, 0.305.

This leads to the hypothesis of preferential As uptake from the water column. But, significant negative correlations (Table 3-19) between the concentrations Hg in each type of fish and Hg in the surrounding sea water were obtained. The following correlations were determined from the content of Hg in *T. tonggol*, -0.223.

Support the conclusion discussed previously that the Hg may have entered the fish bodies from the food chain.

The significant positive correlations (Pearson's correlation coefficients) observed between the concentrations of some metals in the water and those in the fish tissue suggest that the detected metals some what follow the same pattern of variations and the tissue levels are influenced by water concentrations. Adding to that the negative correlations between some metals concentrations in Seawater and fish tissue may reflect the increase of metals in fish tissue as their concentrations in Seawater decreases (Authman *et al*., 2012).

Fish accumulate As predominantly via their diet, but in contrast to Hg for example, As seems not to biomagnify. Several studies, including a three organism food chain study (autotrophic grazer–zooplanktonic grazer–guppy) by Maeda *et al*. (1990), indeed pointed out that metabolization of As occurs instead of magnification.

These results are in agreement with Liu *et al*., (2015) findings which As is a metalloid, showing both metallic and non-metallic characteristics, and is capable of forming both cationic and anionic salts (Shibata *et al*., 1992). It exists in the marine environment globally, and transfers to cetaceans through the food chain (Kubota *et al*., 2001). Therefore, hepatic As has also been applied in the study of dolphins' feeding habits and location in relation to prey high in As from anthropogenic sources (Bellante *et al*., 2012).

The results of the present study were analyzed by using two ways ANOVA in Liver of fish of Yemen sites during the seasons, it showed that there were significant difference ($P<0.01$) regarding the concentration of Pb and Cd in the Liver of fish of AL-Hodeida, Aden and AL-Mukalla sites.

The highest concentration of Pb and Cd were 0.278± 0.256 and 0.216±0.232 µg/g (dry wt.) respectively in the Liver were found in Al-Hodaeidah site (Table 3-5).

The present high concentration of Pb and Cd in Al-Hodaeidah site may be attributed to sewage and oil spill from ships.

The interpretation of these results are comparable to those reported by (Heba *et al.,* 2004) who all sewage outfalls contain high levels of Lead and Cadmium. However, the principal source of Pb contaminants in the marine environment appears to be the exhaust of vehicles which run with leaded fuels. Also, lead reaches the sea by rain and wind blown dust (Heba *et al*., 2004)

Also the above results and the initial interpretation given are comparable to those reported in 2014 by Al Zubaidy *et al*; who that the concentrations of Lead and Cadmium were higher in Al-Hodaeidah site than the other two sites. This confirms that Al-Hodaeidah site is affected by industrial waste discharge taking place in that area, exposed to more pollutants and economic activities are very high at this site. Fishes, water and sediment quality within the area are influenced by sewage and oil spill from ships (Al Zubaidy *et al*., 2014).

Our results in this study were in a good agreement with those found by Agusa *et al*. (2006) which showed that the concentration of Pb was 0.050-0.229 µg/g (dry wt.) in Liver of *Sphyraena obtusata* from Southeast Asia, Cambodia, Indonesia, Malaysia and Thailand (Agusa *et al*., 2006).

On the other hand, our results were high concentration compared with other studies which mentioned by Metian *et al*. (2013) illustrated that the concentration of Pb was 0.11± 0.07 (0.06–0.19) µg/g (dry wt.) in Liver of *L. laticaudis* from New Caledonia (Metian *et al*., 2013); and Heba *et al*. (2015) showed that the concentration of Cd was ND-2.90 µg/g (dry wt.) in Liver of *T. tonggol* and Mugil sp from Al-Hodaeidah ,Yemen (Heba *et al*., 2015); and Chen ,(2002) showed that the concentration of Pb was 0.07 µg/g (wet wt.) and Cd was 0.025 µg/g (wet wt.) in Liver of *S. putnamae* from Taiwan (Chen , 2002).

However, our results showed low concentration compared with other studies which mentioned by Huang, (2003) showed that the concentration of Pb was 0.39 ± 0.14 µg/g (wet wt.) and Cd was 0.35 ± 0.06 µg/g (wet wt.) in Liver of *L. mahsena* from Eastern Taiwan (Huang, 2003); and Ali, (2011 b) showed that the concentration of Pb was 1.10 -6.72 µg/g (dry wt.) and Cd was 1.16-2.06 µg/g (dry wt.) in Liver of *L. mahsena* from Red Sea, Jeddah Coast, Saudi Arabia (Ali, 2011 b); and Denton *et al*. (2006) showed that the concentration of Pb was 0.77 µg/g (dry wt.) and Cd was 1.90 µg/g (dry wt.) in Liver of *L. rubrioperculatus* from Australia (Denton *et al*., 2006).

The high different between the results may reference to different degrees of anthropogenic pressure.

Based on these information's Yemen coast in the present study is low polluted when it is compared with other locations in the world.

Also Overall, the results showed that there were no significant difference ($P>0.05$) regarding the concentration of Pb and Cd, however, there was significant differences ($P<0.01$) regarding the concentration of Hg and As in the Liver of Four types fish studied of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) site, for the period of size: Large , Medium and Small. The highest concentration of Hg and As were 0.115±0.036 and 0.133±0.040 µg/g (dry wt.) in Liver of fish, were observed to be more concentrated in the larger sizes of fish, as shown in (Table 3-6).

The present high concentration of Hg and As in larger sizes of fish may be attributed to various factors, the preferred prey, bioavailability of mercury in each marine environment, and environment variables, such as net primary production, the specific metabolism of the metal in the fish and the tissue type considered, the competition between the opposing effects of ageing and tissue growth, the availability of the metal in the environment (Evans *et al.,* 1993), although metal contents in fish are usually specific to a species (Gaspic *et al*., 2002).

4-3-3 Heavy Metals in Gill

Overall, the results of the present study showed that they were no significant differences (P>0.05), using one way ANOVA, regarding the concentration of Pb , Cd , Hg and As in Gill of fish of Yemen stations for the period of seasons: winter 2011, summer 2012 and winter 2013.

On the other hand, these results of were analyzed achieved by using two ways ANOVA in Gill of fish of Yemen stations during the seasons, it showed that there were significant differences (P<0.05) regarding the concentration of Cd in the Gill of fish of Yemen stations for the period of seasons: winter 2011, summer 2012 and winter 2013.

The highest concentration of Cd in Gill of fish was 0.238±0.250 µg/g (dry wt.) on summer, as summarized in (Table 3-7).

These observations probably as indicated in the case of liver tissue which mentioned above, beside that in water, Gills are the main surface during exchange of ions metals (Qadir and Malik, 2011).

However, our results are in a good agreement with those found by Inayat *et al*. (2014) showed that the concentration of Cd was 0.12- 0.35 µg/g (dry wt.) in Gill of *Mystusseenghala* and *Wallagoattu* from Pakistan, in summer (Inayat *et al*., 2014); and Yancheva *et al*. (2014) showed that the concentration of Cd was 0.300±0.01 µg/g (dry wt.) in Gill of *Scardinius erythrophthalmus* from the Topolnitsa reservoir (Bulgaria), on summer (Yancheva *et al*., 2014); and Dali Youcef *et al*. (2014) showed that the concentration of Cd was 0.34 ± 0.20 µg/g (wet wt.) in Gill of of *Cyprinus carpio* from Sikkak dam at Ainyoucef (Wilaya of Tlemcen) Algeria , in summer (Dali Youcef *et al*., 2014).

On the other hand, our results were high concentration compared with other studies which mentioned by Aktan and Tekin-Özan (2012) showed that the concentration of Cd was 0.04-0.31 (0.12±0.10) µg/g (dry wt.) in Gill of

Scomber japonicus from Antalya Bay, Turkey, in summer (Aktan and Tekin-Özan, 2012); and Al-Dohail *et al*. (2014) showed that the concentration of Cd was 0.026 ± 0.01 µg/g (dry wt.) in Gill of fish, Blue spot mullet, *Moolgarda seheli* from Khawr-Mukalla, Hadhramout Coast, Yemen, on summer (Al-Dohail *et al*., 2014); and Karim *et al*. (2016) showed that the concentration of Cd was 0.00058± 0.0002 µg/g (dry wt.) in Gill of *Octopus vulgaris* from the north east of Morocco, Mediterranean coast in summer (Karim *et al*., 2016); and Bashir and Alhemmali, (2015) showed that the concentration of Cd was 0.05±0.01- 0.19±0.1 µg/g (dry wt.) in Gill of *Arius maculatus* from Kapar Coastal Waters, Malaysia, in Rainy season (Bashir and Alhemmali, 2015).

However, our results were low concentration compared with other studies which mentioned via Bahnasawy *et al*. (2009) showed that the concentration of Cd was 4.190 ±0.470 µg/g (dry wt.) in Gill of *Liza aurata* from Lake Manzala, in summer (Bahnasawy *et al*., 2008); and Khaled, (2009) showed that the concentration of Cd was 0.647±0.004 µg/g (wet wt.) in Gill of *Mugil species* from the Mediterranean Sea in the region of Alexandria, in summer (Khaled, 2009).

These high different between the results may reference to various factors as differences in local pollution, bioavail- ability of metals (variations among physiochemical factors), some other indirect activities such as energy demand activities, atmospheric deposition and runoff inputting.

Overall, the results of the present study illustrated that they were significant differences (*P<0.01*), using one way ANOVA, regarding the concentration of Pb, Cd, Hg and As in the Gill of fish species of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) sites, for the duration of the four types of fish studied: *L. mahsena*, *T. tonggol*, *S. jello* and *E. areolatus*.

The highest concentration of Pb was 0.845± 0.009 µg/g (dry wt.), in Gill of fish of *L. mahsena*, but, the highest concentration of Cd and As were 0.365±0.032 and 0.045±0.003 µg/g (dry wt.), respectively in the Gill of fish of *E. areolatus*; on the other hand, the highest concentration of Hg was 0.020± 0.005 µg/g (dry wt.), in the Gill of fish of *T. tonggol*; as summarized in (Table 3-8).

The present high concentration of Pb in *L. mahsena* may be attributed to various factors, the metal complexion with the mucus that is impossible to remove completely from the lamellae before analysis, the similarity of lead and calcium in their deposition and mobilization from the Gill, the result of a water contamination caused by environmental pollution.

Similar results are found in high Pb concentrations in Gills were recorded by Kargin, 1998; Avenant-Oldewage and Marx, 2000; Abu Hilal and Ismail, 2008 ; Qadir and Malik, 2011).

These results are in agreement with Masoud *et al.,* (2007) findings, which showed that the Gill exhibited high accumulation of Pb and attributed this to the similarity of lead and calcium in their deposition and mobilization from the Gill (Masoud *et al.,* 2007).

These results are in agreement with those obtained by Rogers and Wood (2004) showed that fish may uptake Pb and Cd via the branchial Ca^{2+} uptake pathways and thus compete with each other for this uptake sites leading to the inverse relationship between them at Gill uptake sites which agreed with the negative correlation, presented in our data (table 3-24), between Pb and Cd in Gill tissues.

The present high concentration of Cd and As in *E. areolatus*; suggesting that their Gills could accumulate Heavy metals from the environment. *E. areolatus* are both omnivorous feeders (the former being a bottom feeder), metabolism, biological and ecological factors such as feeding habits and habitat, have a close relationship with sediment.

These results are in line with those of previous studies that showed marked high accumulation of Cd in fish Gills (Kalay and Canli, 2000; Al-

Yousuf *et al.,* 2000; Usero *et al.,* 2004; Demirak *et al.,* 2006; Abu Hilal and Ismail 2008; Vinodhini and Narayanan 2008; Younis *et al.,* 2015).

However, the high levels of As in the bottom feeder fish demonstrated that feeding habits and habitat play important roles in metal accumulation in fish.

Significant positive correlations (Table 3-19 and Table 3-20) between the concentrations As in each type of fish and As in the surrounding sea water and Sediments were obtained. The following correlations were determined from the content of As in *E. areolatus*, 0.357 and 0.635 .This leads to the hypothesis of preferential As uptake from the water column and Sediments.

The present high concentration of Hg in *T. tonggol* may be attributed to various factors, arising from diet, differences in sample size and fish length-weight, tropic position, movement pattern, migratory patterns of fishes, living and feeding habits, linkage exists between the trans epithelial movements of mercury and a mechanism requiring metabolic energy, possibly through a competition process with carrier-mediated cations transport, chloride and sulfate ions increase, additionally, Hg accumulated via the diet a more environmentally realistic route of uptake.

However, our results are in a good agreement with those found by Al Zubaidy *et al*. (2014) showed that the concentration of Pb was 1.20±0.95 - 1.70±0.90 µg/g (wet wt.) in Gill of *Lethrinus lentjan* and Cd was 0.25±0.07 - 0.54±0.10 µg/g (wet wt.) in Gill of *Epinephelus sexfasciatus* During winter from Red Sea, Al-Hodaeidah , Yemen (Al Zubaidy *et al.,* 2014); and Al Ghanim *et al.,* (2015) showed that the concentration of Pb was 0.23±0.02 µg/g (dry wt.) in Gill of *L. mahsena* and Cd was 0.54±0.07 µg/g (dry wt.) in Gill of *Epinephelus spp* from Red Sea, Egypt (Al Ghanim *et al.,* 2015); and Khoshnood *et al*. (2012) showed that the concentration of Cd was 0.117 ± 0.087 µg/g (dry wt.) and As was 0.087 ± 0.029 µg/g (dry wt.) in Gill of

Epinephelus coioides from northern of Arabian Gulf (Khoshnood *et al*., 2012); and Al-Bader, (2008) pointed out that the concentration of As was 0.039 µg/g (dry wt.) in Gill of *E. areolatus* from Saudi Arabia (Al-Bader, 2008); and Sobhanardakani *et al*. (2011) showed that the concentration of Hg was 0.037 µg/g (wet wt.) in Gill of *Scomberomorus commerson* from Iran (Sobhanardakani *et al*., 2011).

On the other hand, our results were high concentration compared with other studies which mentioned by Wong *et al*. (2001) pointed out that the concentration of Cd was 0.01 µg/g (dry wt.) in Gill of *E. areolatus* from Hong Kong, China (Wong *et al*., 2001); and Younis *et al*., (2015) showed that the concentration of Cd was 0.107 µg/g (wet wt.) in Gill of *E.areolatus* from the Red Sea, Jeddah Coast, Saudi Arabia (Younis *et al*., 2015).

However, our results in this study were low concentration compared with other studies which mentioned by El-Moselhy *et al*., (2014) showed that the concentration of Pb was 3.09±0.79 µg/g (wet wt.) in Gill of *Lethrinus sp*. and Cd was 0.75 ± 0.24 µg/g (wet wt.) in Gill of *Epinephelus sp*. from Red Sea, Egypt (El-Moselhy *et al*., 2014); and Abu Hilal and Ismail, (2008) pointed out that the concentration of Cd was 2.0-2.50 µg/g (dry wt.) in Gill of *Epinephelus fasciatus* from Jordan (Abu Hilal and Ismail, 2008); and Al Ghanim *et al*., (2015) showed that the concentration of As was 1.29±0.08 µg/g (dry wt.) in Gill of *Epinephelus spp* from Red Sea, Egypt (Al Ghanim *et al*., 2015); and Khoshnood *et al*. (2012) showed that the concentration of Hg was 0.182 ± 0.078 µg/g (dry wt.) in Gill of *T. tonggol* from northern of Arabian Gulf (Khoshnood *et al*., 2012); and Ganbi, (2010) showed that the concentration of Cd was 1.160±0.29 µg/g (wet wt.) and As was 5.391±0.043 µg/g (wet wt.) in Gill of *E. areolatus* from Jeddah, Saudi Arabia (Ganbi, 2010); and Al-Wesabi *et al*., (2015) showed that the concentration of Pb was 0.85- 3.15 µg/g (wet wt.) in Gill of *Lerthinus harak* from the Red Sea coast, Jeddah, Saudi Arabia (Al-Wesabi *et al*., 2015).

These high different between the results may reference to differences in local pollution.

The results of this present study were analyzed by using two ways ANOVA in Gill of fish of Yemen sites during the seasons, it showed that there were significant difference ($P<0.01$) regarding the concentration of Cd , Hg and As in the Gill of fish of AL-Hodeida, Aden and AL-Mukalla sites.

The highest concentration of Cd was 0.250±0.228 µg/g (dry wt.) in the Gill were found in Aden; but the highest concentration of Hg was 0.020±0.007 µg/g (dry wt.) achieved in Al-Hodaeidah , whereas the highest concentration of As was 0.050±0.039 µg/g (dry wt.) achieved in AL-Mukalla, (Table 3-7).

A possible explanation for this might be to electricity generating stations cooling waters and effluents, sewage disposals and storm waters (Nasr *et al.,* 2006). Another possible explanation for this is that Scrap-iron store at Labour Island is the most likely source of Pb and Cd in the Seawater, Oil Harbour and municipal sewages are expected sources to be responsible for elevated tissue Cd concentrations in Seawater from Sahel Abyen and Sira Island (Szefer *et al.,* 1999).

This result may be explained by the fact that Aden area was the highest among the other stations, It is assumed that the presence of the area near the strait of Bab Al-Mandab, where the water coming from both the Red Sea and the Indian Ocean mixes and consequently changes its nature, especially during the seasonal monsoons, is responsible mainly for elevated Gill tissue Cd concentrations in the fish inhabiting the Aden area. However, some sewage outflow can be additional anthropogenic sources of Cd in the area. (Szefer *et al.,* 1999). Apparently, Cd contamination gradients exist in the Gulf of Aden waters. (Szefer *et al.,* 1999; Heba *et al.,* 2004).

These high concentrations of Hg in Al-Hodaeidah may be attributed to various factors as petroleum spills, shipping, sewage input, runoff of intermittent stream. Most mining activities occur far from the coast. However, the concentration of mining products in the coastal area (gypsum, salts, cement).

We found that Hg were significantly higher in Gill samples from Al-Hodaeidah than Aden and AL-Mukalla. However, there were four fish different species being investigated at three locations. Therefore, these differences may be due to species differences rather than differences in locality.

Mercury concentrations in sediments along the Yemen coast ranged from 0.009 to 0.028 $\mu g\ g^{-1}$ dry weight. Sediment contribution either to the water column or fish burden would be expected to be limited.

Based on a mercury inventory report, Yemen has a different and complex situation regarding the use and release of mercury compared to some other developed and developing countries. Nevertheless, Yemen still can estimate the possible release of mercury into the environment based on the UNEP Toolkit. The main pathways for all releases of mercury, the total air emitted is 715.92 kg/yr, for water is 2467.91 kg/yr, for land is 6851.92 kg/yr and for general waste is 13571.93 kg/yr (Yemen EPA, 2008).

These high concentrations of As in AL-Mukalla may be attributed to various factors as agriculture, Variations in bioavailability caused by geographical, seasonal, and environmental differences.

The positive correlations presented in our data (table 3-19), recorded between the levels of As in the seawater with As contents in tissues of the fish may be explained by the high concentration of As detected in these tissues (Saleh and Marie, 2014).

Weak correlations ($p>0.05$) between the Pb, Cd, Hg and As in each sampling site fish samples suggest that the metals might come from different sources as also reported by Boamponsem *et al*., (2010).

However, our results are in a good agreement with those found by Al Zubaidy *et al*. (2014) in *Lethrinus lentjan* and *Epinephelus sexfasciatus* from Red Sea, Al-Hodaeidah (Al-Cornish and Al-Mehwat), Yemen and a good agreement with those found by Mwashote, (2003) in *S. jello* from Kenya and a good agreement with those found by Sobhanardakani *et al*. (2011) in *Scomberomorus commerson* from Iran and a good agreement with those found by Younis *et al*. (2015) in *E. areolatus* from Saudi Arabia.

On the other hand, were high concentration compared with other studies which mentioned by Pugalendhi, (2007) in *E. areolatus* from India.

However, our results were low concentration compared with other studies, high results have been reported in *L. mahsena* from the Arabian Gulf Along the Eastern Coast, Saudi Arabia by Al sulami, (2002) and in *E. areolatus* from Saudi Arabia by Ganbi, (2010) and in *Epinephelus fasciatus* from Red Sea Jordan by Abu Hilal and Ismail, (2008) and in *L. mahsena* from Red Sea, Egypt by Al Ghanim *et al*. (2015).

Based on this information, Yemen coast in the present study is low polluted when it is compared with other locations.

Also overall, the results showed that there were no significant difference ($P>0.05$) regarding the concentration of Pb, Cd and As , however, there was significant differences ($P<0.01$) regarding the concentration of Hg in the Gill of four types of fish studied of Yemen coast (AL-Hodeida, Aden and AL-Mukalla) site, for the period of size: Large, Medium and Small.

The highest concentration of Hg was 0.018±0.006 µg/g (dry wt.) in Gill of fish, were observed to be more concentrated in the larger sizes of fish, as shown in (Table 3-8).

The present high concentration of Hg in larger sizes of Gill fish may be attributed to various factors as water pH and acidic conditions favouring mercury methylation as well as increased water temperature, which also is known to increase methylation rates (Doetzel, 2007), Sulphate reducing bacteria has been shown to be a controlling factor of mercury methylation in sediments (Choi and Bartha, 1994). and Fish biology also influences mercury levels, with age, size and diet affecting bioaccumulation rates (Doetzel, 2007) although metal contents in fish are usually specific to a species (Gaspic *et al.,* 2002), reflect the role of trophic transfer of Hg through the food chain (Alonso *et al.,* 2000; Kehrig *et al.,* 2008).

4-3-4 Heavy Metals in different Organs

During the present study, Pb levels have been seen to be maximum in Gill from *L. mahsena* and *S. jello*, and in liver from *T. tonggol* and *E. areolatus*, minimum in muscle in all the fish species.

Cd levels, too, are found to be maximum in Gill, minimum in muscle and intermediate in liver in all the fish species.

Hg and As levels, are found to be maximum in liver in all the fish species, except *S. jello* It was higher in muscle, minimum in Gill in all the fish species and intermediate in muscle in all the fish species except *S. jello* .

In all the investigated fish species, *L. mahsena, T. tonggol, S. jello* and *E. areolatus*, Gill accumulates the highest levels of Pb and Cd. Liver accumulates the highest levels of Hg and As.

The highest accumulation of metals in Gill as compared to other organs has been recorded a similar trend has been observed in *E. fasciatus* by Abu Hilal (2008) and in *E. areolatus* by Younis *et al*. (2004). The highest accumulation of metals in liver as compared to other organs has been widely recorded in earlier studies conducted by Chen and Chen (1999,2001), Krishnamurti and Nair (1999), Haung (2003), Yilmaz (2005), Has-Schon *et al*. (2006), Benson *et al*. (2007), Yilmaz *et al*. (2007), Ismail and Abu-Hilal (2008), Tepe *et al*. (2008), Turkmen *et al*. (2008).

Liver is the major detoxification organ and many poisonous materials absorbed from the environment are detoxified in the liver. Studies carried out with different fish species have shown that heavy metals accumulate mainly in metabolically active liver that stores metals to detoxicate by producing metallothioneins (Carpene and Vasak, 1989). Metallothioneins (MTs) are cysteine rich low molecular weight proteins having capacity to bind to physiological as well as xenobiotic heavy metals through a thiol group of cysteine. The higher levels of Heavy metals in liver relative to other tissues is, therefore, attributed to the affinity of MT proteins with these heavy metals (Ikem *et al.,* 2003).

During the present study, muscle of all the fish species has been found to accumulate lesser metals as compared to liver and Gill. Muscle tissue is not considered to be an active site for metal accumulation (Legorburu *et al.,* 1988 and Khaled, 2004).

Studies comparing the metal accumulation in muscle and liver of fish show lower metal concentration in the former. This trend has been recorded in marine fishes, in *L. mahsena,* by Ali (2011 a, b), Huang (2003), in *T. albacores,* by Kojadinovic (2007), in *S.putnamae,* by Chen (2002) and in *Solea solea,* and *Sparus aurata*, by Yilmaz *et al*. (2007).

Cd and Pb, have no biological role and hence they are harmful to living organisms even at considerably low concentrations.

In this study, the overall mean concentrations of metals were found to accumulate in the order of Pb > Hg > As > Cd , Except in Fish species *S. jello* mean concentrations of metals were found to accumulate in the order of Hg > As > Pb > Cd.

Although it is not always the rule, these results were in conformity with the observations of Al sulami, 2002 (Pb > Hg > Cd > As) and Burger *et al*., 2005 (Hg > As > Pb > Cd).

These results are suggesting that there is mobilisation and balance between these two matrices.While the sediment analysis revealed Pb > Cd > As > Hg , the seawater analysis revealed only Pb > As > Cd > Hg.

Analysis of heavy metals in sediments offers more convenient and more accurate means of detecting and assessing the degree of water pollution (Tam and Wong, 2000).

Although it is well known that fish muscle is not an active tissue in accumulating heavy metals (Bahnasawy *et al*., 2009), the present study concerned with the heavy metal concentrations in the fish muscles because it is the most consumed portion by the Yemen people. Furthermore it was documented that some fish in polluted regions may accumulate substantial amounts of metals in their tissues which sometimes exceeded the maximum acceptable levels.

Lead accumulation in different organs showed the order *L. mahsena* >*E. areolatus* > *T. tonggol* > *S. jello*.

Overall ranking revealed from the results that among the four fish species the *L. mahsena* accumulated the highest concentration of all the heavy metals, which indicates that this species have more potential to accumulate these metals in each liver and Gills. It may be due to the feeding habits of the fish, lipid content in the tissue and excretion percentage of these toxic metals from their body.

Cadmium, Mercury and Arsenic accumulation in different organs showed the order *E. areolatus* > *T. tonggol* > *L. mahsena*> *S. jello*.

The arrangement order of Pb and Cd content in tissues of the polluted fish was Gill > liver > muscle, whereas in case of Hg and As the order was liver > Gill > muscle (Table 3-9).

The great amount of Pb and Cd in Gills of fish may be the result of a water contamination caused by environmental pollution.

4-3-5 Heavy Metal Concentrations vs. International dietary Standards

4-3-5-1 Lead

The FAO/WHO (2004) and Yemen Standardization (2006) guidelines for a prescribed maximum permissible limit of Lead in Fish are 1.50 µg/g (dry wt.) and 1.00 µg/g (dry wt.).

The main highest concentration of Pb in the muscles, livers and Gills of the four studied fish species was 0.137± 0.014 µg/g (dry wt.) in large *E. areolatus* and 0.428± 0.031; 0.845± 0.009 µg/g (dry wt.) in *L. mahsena*. At Site AL-Hodeida.

The values obtained for Pb in the muscles, livers and Gills were below the Pb prescribed standard safe limits of 1.00 - 1.50 µg/g dry wt.) for food fish (FAO/WHO (2004) and Standard Specification for Yemen, 2006).

Based on this information, Yemen coast in the present study is low polluted when it is compared with other locations.

4-3-5-2 Cadmium

The FAO/WHO (2004) and Yemen Standardization (2006) guidelines for a prescribed maximum permissible limit of Cadmium in Fish are 1.00 µg/g (dry wt.) and 0.2 µg/g (dry wt.).

In summer, the main highest concentration of Cadmium in the muscles and livers of the four studied fish species were 0.069±0.021 and 0.289±0.020 µg/g (dry wt.) in large *E. areolatus* in Year 2012 at Site Al-Hodaeidah whereas in Gills was having 0.365±0.032 µg/g (dry wt.) in *E. areolatus* in Year 2012 at Site Aden. The values obtained for Cd in the muscles, livers and Gills were below the Cd prescribed standard safe limits of 1.0 µg/g (dry wt.) for food fish FAO/WHO (2004).

But, the Yemen Standardization (2006) guidelines for maximum permissible limit of Cadmium in Fish are given as 0.2 µg/g (dry wt.). As the range of Cadmium detected was higher than the permissible limit in livers and Gills *E. areolatus* and Gills *T. tonggol fish*.

4-3-5-3 Mercury

The FAO/WHO (2004) and Yemen Standardization (2006) guidelines for prescribed maximum permissible limit of Mercury in Fish are 0.50 µg/g (dry wt.).

The main highest concentration of Hg in the muscles, livers and Gills of the four studied fish species was 0.071±0.012 µg/g (dry wt.) in *E. areolatus* (at large); 0.127± 0.026 and 0.020± 0.005 µg/g (dry wt.) in large *T. tonggol* at Site AL-Mukalla. The FAO/WHO (2004) and Yemen Standardization (2006) guidelines for prescribed maximum permissible limit of Mercury in Muscles Fish are 0.50 µg/g (dry wt.).

As the detected Mercury remained below the FAO/WHO (2004) and Yemen Standardization (2006) permissible limits.

3-3-5-4 Arsenic

The FAO/WHO (2004) and Yemen Standardization (2006) guidelines for a prescribed maximum permissible limit of Arsenic in Fish are 0.10 - 5.00 µg/g (dry wt.) and 1.0 µg/g (dry wt.).

The main highest concentration of As in the muscles, livers and Gills of the four studied fish species was 0.106±0.007 µg/g (dry wt.) in *L. mahsena* (at large); 0.147±0.032 µg/g (dry wt.) in *T. tonggol* (at large) and 0.045±0.003 µg/g (dry wt.) in *Epinephelus areolatus* at Site AL-Mukalla.

As the detected Arsenic remained below the FAO/WHO (2004) and Yemen Standardization (2006) permissible limits.

Chapter 5

Conclusions & Recommendations

5. Conclusions and Recommendations

5.1. Conclusion

The following can be concluded from this study results:

The present work has been done considering the constant spread pollution of heavy metals in Seawater bodies. Pollution among Seawater bodies is a major global problem. This contaminates not only the Seawater but also the sediment and aquatic life such as fish.

The Seawater, sediments and fish samples were collected from the Three different Cities of Yemeni coasts. Aden, Al-Hodaeidah and AL-Mukalla were chosen for the sample collection. *Lethrinus mahsena*, *Thunnus tonggol*,*Sphyraena jello* and *Epinephelus areolatus* fish samples were considered for the study as they are more common eatable fish among the population.

The study was carried out in the all three seasons of winter 2011, summer 2012 and winter 2013 in order to check seasonal variation of heavy metal pollution.

Total 81 samples of each Seawater, Sediment and Fish (108 samples of each muscles, liver and gills) were analyzed. The four heavy metals lead, Cadmium, Mercury and arsenic were detected in the samples in the year 2011, 2012 and 2013.

Heavy metal concentration in Seawater samples shows that high concentration of Lead is found more At Site Al-Hodaeidah (0.080± 0.008 mg/l) in Summer 2012, Site Al-Hodaeidah is polluted highly. Lead content in all locations in all seasons was higher than the permissible limits according to international standards.

The Cadmium in Seawater in the Summer season shows that Site Aden is highly polluted in Summer 2012 with 0.008±0.002 mg/l . As the range of Cadmium detected is below than the permissible limit.

The Arsenic concentration was found high at Site AL- Mukalla, 0.010±0.000 mg/l in Year 2012 (Summer season). As the range of Arsenic detected is below than the permissible limit.

The Mercury concentration was found high at Site AL- Mukalla, 0.0075±0.001 mg/l in Year 2011 (Winter season). Mercury content in all locations in all seasons was higher than the permissible limits according to international standards.

The concentration of these metals in sediment samples was detected and it was found that the higher Lead concentration was at Site AL- Hudaydah, 76.542± 2.706 µg/g dry wt in Year 2012 (Summer season)

The Site Al-Hodaeidah was found highly polluted with Cadmium in Year 2012 with 2.424 ±0.518 µg/g dry wt (Summer season).

As the detected Lead and Cadmium remained higher than ISQG CCME (2002) and ISQG-Low ANZECC & ARMCANZ (2000) values but were below the PEL CCME (2002) and ISQG-High ANZECC & ARMCANZ (2000) permissible limits.

The Arsenic concentration was found high at Site Aden , 0.107±0.013 µg/g dry wt in Year 2012 (Summer season).

The Mercury concentration was found high at Site AL- Mukalla, 0.020±0.011 µg/g dry wt in Year 2012 (Summer season). As the range of Arsenic and Mercury detected is below than the permissible limit.

Four species of fish *Lethrinus mahsena*, *Thunnus tonggol*, *Sphyraena jello* and *Epinephelus areolatus* was examined and Lead, Cadmium, Mercury and Arsenic concentration.

The highest mean concentration of Pb in the muscles, livers and gills of the four studied fish species was 0.137± 0.014 µg/g dry wt in large

Epinephelus areolatus and 0.428± 0.031 ; 0.845± 0.009 µg/g dry wt in *Lethrinus mahsena*. At Site AL- Hodeida.

The values obtained for Pb in the muscles, livers and gills were below the Pb prescribed standard safe limits of 1.00 - 1.50 µg/g dry wt.) for food fish (FAO/WHO (2004) and Standard Specification for Yemen, 2006).

In Summer, the highest mean concentration of Cadmium in the muscles and livers of the four studied fish species were 0.069±0.021 and 0.289±0.020 µg/g dry wt in large *Epinephelus areolatus* in Year 2012 at Site Al-Hodaeidah whereas in gills was having 0.365±0.032 µg/g dry wt in *Epinephelus areolatus* in Year 2012 at Site Aden.

The values obtained for Cd in the muscles, livers and gills were below the Cd prescribed standard safe limits of 1.0 µg/g (dry wt) for food fish (WHO).

But, the Standard Specification for Yemen (2006) guidelines for maximum permissible limit of Cadmium in Fish are given as 0.2 µg/g dry wt. As the range of Cadmium detected was higher than the permissible limit in livers and gills *Epinephelus areolatus* and gills *Thunnus tonggol fish*.

The highest mean concentration of Hg in the muscles, livers and gills of the four studied fish species was 0.071±0.012 µg/g (dry wt) in *Epinephelus areolatus* (at large) ; 0.127± 0.026 and 0.020± 0.005 µg/g (dry wt) in large *Thunnus tonggol* at Site AL-Mukalla.

The WHO and Standard Specification for Yemen (2006) guidelines for prescribed maximum permissible limit of Mercury in Muscles Fish are 0.50 µg/g dry wt. As the detected Mercury remained below the WHO and Standard Specification for Yemen (2006) permissible limits.

The highest mean concentration of As in the muscles, livers and gills of the four studied fish species was 0.106±0.007 in *Lethrinus mahsena* (at large) ; 0.147±0.032 in *Thunnus tonggol* (at large) and 0.045±0.003 µg/g (dry wt.) in *Epinephelus areolatus* at Site AL-Mukalla.

As the detected Arsenic remained below the FAO/WHO (2004) and Yemen Standardization (2006) permissible limits.

From the heavy metal concentrations mentioned above we can see that somewhere the concentration is crossing the limits as permissible by the World Health Organization. It suggests a high risk to the health of human being on the consumption of contaminated fish.

5.2. Recommendations

Therefore it is recommended that the practice of Heavy metals detection should be continued in order to update whether the heavy metal concentration is above or below the permissible limits and if it is above the limit then precautions must be taken to avoid possible consumption of contaminated eatables. It is also recommended that awareness should be spread among the people regarding the hazards on consumption of polluted Seawater and related eatables.

From the study results outcome the following can be recommended:

The following recommendations might be of particular interests

- Enforcement of Marine Protection regulations in Yemen is urgently required.

1. Building-up of local capacities is highly recommended to acquire capabilities in assessing and monitoring marine pollution at regular bases.
2. There is a need for regulating cooperation among authorities whose major concern is protecting marine environment at national and international levels.
3. Establishment of Risk analysis system in Yemen would enable authorities working in the field of marine protection to achieve safety of fish and shellfish used for human consumption.

4. Initiating strategies for public awareness about marine pollution would be a major contribution in lowering activities that cause marine pollution.
5. Strengthening of a data-base information system would be a great help for researchers to carry out scientific studies in subsequent bases.
6. Devoting more efforts for carrying out further studies on assessment of contamination in other marine species with other pollutant would help in drawing a complete picture with regards of pollution status in regional sea catchments area of Yemen .
7. We recommend Yemeni's people that it is better for health to eat small fish we previously mentioned in the study.
8. Revelation that consuming the small fish which previously mentioned in the study is better and safer than large fish of the same species.

Chapter 6

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6. References

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Appendices

Appendix 1

Table (1-a): The weight and length of fish collected during the seasons from AL-Hodaeidah, Aden and AL-Mukalla stations, Yemen coast.

Site	Species	Size	Seasons					
			Winter 2011		Summer 2012		Winter 2013	
			weight (g)	length (cm)	weight (g)	length (cm)	weight (g)	length (cm)
Aden	*Lethrinus mahsena*	Large	450.71	30.65	427.49	29.15	459.46	28.15
		Medium	400.24	27.83	389.58	26.70	286.67	24.20
		Small	270.55	25.10	266.68	24.92	220.32	22.72
	Thunnus tonggol	Large	3000.62	70.90	3938.77	75.60	3599.75	73.50
		Medium	2687.89	60.40	2881.49	62.30	2389.18	58.50
		Small	1756.98	53.80	1900.11	50.40	1924.39	54.60
	Sphyraena jello	Large	750.41	53.20	1100.51	54.30	820.77	50.70
		Medium	738.52	48.50	778.94	49.10	708.05	47.50
		Small	579.20	44.30	625.55	45.50	556.96	43.70
	Epinephelus areolatus	Large	798.06	40.50	856.46	41.40	742.32	39.30
		Medium	421.58	32.70	460.36	33.10	450.40	28.80
		Small	190.75	22.20	235.16	24.00	300.81	25.60
AL Hodaeidah	*Lethrinus mahsena*	Large	1171.67	38.00	998.39	36.10	1087.24	37.10
		Medium	850.91	33.20	828.12	34.70	560.44	30.00
		Small	212.93	22.50	184.16	21.70	317.29	25.60
	Thunnus tonggol	Large	2874.41	60.80	3558.78	65.50	3816.21	67.10
		Medium	2430.67	57.30	2211.98	55.40	2371.65	56.80
		Small	1977.35	53.20	1761.88	51.00	1896.82	52.40
	Sphyraena jello	Large	1052.51	55.80	1203.10	57.10	1213.67	58.60
		Medium	788.11	49.30	691.02	47.10	603.79	46.10
		Small	453.75	40.70	489.74	42.90	509.94	43.50
	Epinephelus areolatus	Large	986.55	40.00	833.87	38.40	913.70	39.00
		Medium	747.53	36.50	646.15	35.30	641.32	34.70
		Small	392.14	29.50	398.69	30.10	331.18	27.90
Al Mukalla	*Lethrinus mahsena*	Large	800.53	36.00	685.41	32.50	754.47	33.80
		Medium	529.59	30.50	494.42	29.80	610.46	32.00
		Small	317.29	25.10	403.45	27.60	358.59	26.60
	Thunnus tonggol	Large	3025.37	63.30	2952.84	62.80	2701.42	61.00
		Medium	2516.15	59.60	2278.67	57.70	2011.98	55.40
		Small	1488.11	50.20	1736.77	52.80	1618.79	51.60
	Sphyraena jello	Large	1256.34	59.30	998.55	54.80	857.21	52.00
		Medium	747.09	49.60	588.67	45.70	541.26	44.40
		Small	499.78	43.20	438.46	41.30	426.22	40.90
	Epinephelus areolatus	Large	856.46	41.20	917.57	42.80	798.06	40.10
		Medium	280.10	35.60	320.94	37.40	460.36	33.00
		Small	250.91	26.70	185.16	24.50	126.38	21.20

Appendix 1

Table (1-b): Information of sites for sediments and sea water samples in AL-Hodaeidah, Aden and AL-Mukalla

Station No.	Longitude (E)	Latitude (N)	Site	Location	Sediments Particle
1	44°88'80"	12°73'94"	Aden	Aden oil refineries	Sand
2	44°91'85"	12°76'57"	Aden	Oil **Harbour**	Sand
3	44°90'95"	12°80'99"	Aden	**industrial areas**	Sand
4	44°92'51"	12°81'95"	Aden	**Al-Hiswah**	Sand
5	44°99'80"	12°84'63"	Aden	Caltex	Silt – Clay
6	45°02'18"	12°81'16"	Aden	**Labour Island**	Silt – Clay
7	44°96'72"	12°78'98"	Aden	**Ras Marbat Harbour Tawahi**	Silt – Clay
8	45°04'88"	12°77'53"	Aden	**Sira Island**	Silt – Clay
9	45°06'07"	12°86'12"	Aden	**Sahel Abyen**	Silt – Clay
10	42°94'24"	14°85'31"	**AL-Hodaeidah**	**Harbour**	Silt – Clay
11	42°93'84"	14°85'39"	**AL-Hodaeidah**	**Harbour**	Silt – Clay
12	42°93'93"	14°85'78"	**AL-Hodaeidah**	**Al-Kathib shore**	Sand
13	42°94'63"	14°87'74"	**AL-Hodaeidah**	**Al-Kathib shore**	Sand
14	42°94'27"	14°88'61"	**AL-Hodaeidah**	**Cornish location**	Silt – Clay
15	42°94'19"	14°89'79"	**AL-Hodaeidah**	**Cornish location**	Silt – Clay
16	42°94'05"	14°91'35"	**AL-Hodaeidah**	**Almehwat site**	Silt – Clay
17	42°93'22"	14°92'98"	**AL-Hodaeidah**	**Almehwat site**	Silt – Clay
18	42°93'51"	14°79'74"	**AL-Hodaeidah**	**Al-Manjer location**	Granule
19	48°98'35"	14°35'70"	**AL-Mukalla**	**Burum Harbour**	Silt – Clay
20	49°04'80"	14°47'54"	**AL-Mukalla**	**Fowah**	Silt – Clay
21	49°10'67"	14°52'87"	**AL-Mukalla**	**AL-Mukalla**	Silt – Clay
22	49°14'91"	14°52'23"	**AL-Mukalla**	**Harbour**	Silt – Clay
23	49°38'36"	14°65'41"	**AL-Mukalla**	**Riyyan**	Sand
24	49°41'50"	14°66'36"	**AL-Mukalla**	**Shiher**	Sand
25	49°48'71"	14°69'14"	**AL-Mukalla**	**AL-DhabahHarbour**	Sand
26	49°51'12"	14°70'59"	**AL-Mukalla**	**AL-DhabahHarbour**	Sand
27	49°61'07"	14°75'14"	**AL-Mukalla**	**Al SheherHarbour**	Silt – Clay

`Appendix 2

Table (1): Analytical results (in µg g^{-1}) of certified reference material DORM-2 (Dogfish muscle and liver, National Research Council Canada), showing local laboratory values and recommended values.

Element	Measured value (Mean±SD)	n	Certified value (Mean±SD)	% recovery
Lead	0.058 ±0.002	6	0.065 ±0.007	89
Cadmium	0.040 ±0.005	6	0.043 ±0.008	93
Mercury	4.39 ±0.18	6	4.64 ±0.26	95
Arsenic	15.84±0.70	6	16.4±1.10	97

Table (2): Percentage recovery of detected heavy metals in the muscles of *Thunnus tonggol* and *Epinephelus areolatus* sample.

Heavy metals	Unspiked concentration (µg/g)	Sample Name	Added amount(mg/l)	Spiked concentration (µg/g)	% recovery
Lead	0.129	*Thunnus tonggol*(0.5g)	0.05	0.175	92
	0.123	*Epinephelus areolatus*(0.5g)	0.07	0.186	90
Cadmium	0.030	*Thunnus tonggol* (0.5g)	0.02	0.049	95
	0.097	*Epinephelus areolatus* (0.5g)	0.05	0.144	94
Mercury	0.021	*Thunnus tonggol* (0.5g)	0.01	0.030	90
	0.051	*Epinephelus areolatus* (0.5g)	0.02	0.069	90
Arsenic	0.091	*Thunnus tonggol* (0.5g)	0.04	0.129	95
	0.104	*Epinephelus areolatus* (0.5g)	0.05	0.151	94

Table (3): Percentage recovery of detected heavy metals in Seawater sample.

Heavy metals	Unspiked concentration (µg/l)	Sample Name	Added amount(µg/l)	Spiked concentration (µg/l)	% recovery
Lead	59	Aden Seawater(45 ml)	30	88	97
Cadmium	9	Al Hodeidah Seawater (45 ml)	5	13.8	96
Mercury	8	Al Mukalla Seawater (45 ml)	4	11.6	90
Arsenic	10	Al Mukalla Seawater (45 ml)	5	14.4	88

Table (4): Percentage recovery of detected heavy metals in Sediment sample

Heavy metals	Unspiked concentration (µg/g)	Sample Name	Added amount(mg/l)	Spiked concentration (µg/g)	% recovery
Lead	**32.718**	**Aden Sediment (0.25 g)**	**15**	**46.462**	**92**
Cadmium	**2.531**	**Al HodeidahSediment (0.25 g)**	**1.5**	**3.965**	**96**
Mercury	**11(ng/g)**	**Al Mukalla Sediment (0.25 g)**	**5(ng/g)**	**15.8(ng/g)**	**96**
Arsenic	**85(ng/g)**	**Al Mukalla Sediment (0.25 g)**	**40(ng/g)**	**122(ng/g)**	**93**

Table (5): shows the concentrations (mg/L) Hg and As in surface water and concentrations (µg/g) in Sediments, muscles, liver and gill and squid studied signatories estimated in laboratories used in the study at Winter 2011.

Site	Sample	Inter-laboratory comparison results at Winter 2011					
		ESMBHU Yemen		RSS Jordan		BAMU India	
		Hg	As	Hg	As	Hg	As
Aden	Sea water	0.005±0.000	0.0057±0.00	0.005±0.00	0.007±0.00	0.005±0.00	50.000.006±
	Sediments	0.013±0.000	0.102±0.007	0.024±0.00	0.082±0.00	0.016±0.00	0.107±0.006
	muscles	0.059±0.022	0.082±0.018	0.054±0.00	0.078±0.00	0.057±0.019	0.0240.081±
	liver	0.104±0.043	0.109±0.034	0.102±0.00	0.098±0.00	0.108±0.035	0.0770.105±
	gill	0.012±0.003	0.020±0.009	0.013±0.00	0.018±0.00	0.011±0.004	0.0160.024±
AL-Hodaeidah	Sea water	0.007±0.001	0.007±0.001	0.005±0.00	0.010±0.00	0.005±0.00	0.0040.007±
	Sediments	0.011±0.002	0.086±0.012	0.013±0.00	0.078±0.00	0.010±0.001	0±0.0130.09
	muscles	0.060±0.017	0.092±0.022	0.061±0.00	0.088±0.00	0.064±0.022	0.0090.070±
	liver	0.116±0.044	0.126±0.038	0.088±0.00	0.107±0.00	0.104±0.035	0.0080.120±
	gill	0.019±0.006	0.033±0.019	0.014±0.00	0.028±0.00	0.016±0.009	0.0090.032±
AL-Mukalla	Sea water	0.009±0.00	0.010±0.002	0.018±0.00	0.018±0.00	0.010±0.00	0.0160.023±
	Sediments	0.010±0.002	0.079±0.010	0.012±0.00	0.075±0.00	0.011±0.003	0.0470.082±
	muscles	0.055±0.016	0.088±0.020	0.063±0.00	0.076±0.00	0.053±0.018	0.0270.092±
	liver	0.107±0.041	0.110±0.035	0.130±0.00	0.105±0.00	0.121±0.036	0.0110.116±
	gill	0.014±0.005	0.051±0.041	0.005±0.00	0.046±0.00	0.009±0.003	0.0090.050±

Table (6): shows the concentrations (mg/L) Pb and Cd in surface water and concentrations (µg/g) in Sediments, muscles, liver and gill and squid studied signatories estimated in laboratories used in the study at Summer 2012.

Site	sample	Inter-laboratory comparison results at Summer 2012					
		ESMBHU Yemen		RSS Jordan		BAMU India	
		Pb	Cd	Pb	Cd	Pb	Cd
Aden	Sea water	0.045 ± 0.007	0.010±0.003	0.040 ± 0.00	0.008± 0.00	0.047±0.003	0.00180.009±
	Sediments	35.104± 0.416	0.8392.111±	28.104± 0.00	1.983± 0.00	33.331±0.234	0.009±049.2
	muscles	0.071± 0.032	0.052±0.021	0.068± 0.00	0.050± 0.00	0.064±0.014	40.020.057±
	liver	0.150± 0.096	0.126±0.093	0.146± 0.00	0.109± 0.00	0.137±0.078	0.0360.115±
	gill	0.290± 0.366	0.348±0.354	0.270± 0.00	0.328± 0.00	0.284±0.147	30.180.352±
AL-Hodaeidah	Sea water	0.087±0.027	0.006±0.001	0.082± 0.00	0.005± 0.00	0.097±0.042	20.00±0.007
	Sediments	0.19477.896±	2.354±0.762	74.342± 0.00	2.142± 0.00	77.955±0.110	±0.000958.2
	muscles	0.151±0.080	0.062±0.033	0.142± 0.00	0.060± 0.00	0.139±0.073	0.0150.057±
	liver	0.330±0.352	0.223±0.252	0.320± 0.00	0.210± 0.00	0.299±0.212	10.030.215±
	gill	0.414±0.535	0.238±0.206	0.387± 0.00	0.259± 0.00	0.222±0.1571	50.100.288±
AL-Mukalla	Sea water	0.064±0.026	0.008±0.000	0.062± 0.00	0.007± 0.00	0.059±0.022	0.001±0.006
	Sediments	1.45672.579±	0.882±0.408	78.324± 0.00	0.697± 0.00	0.18483.440±	0.0250.764±
	muscles	0.098±0.052	0.050±0.026	0.092± 0.00	0.040± 0.00	0.082±0.057	0.0240.046±
	liver	0.187±0.147	0.082±0.025	0.183± 0.00	0.076± 0.00	0.179±0.057	0.0270.073±
	gill	0.319±0.411	0.126±0.066	0.296± 0.00	0.114± 0.00	0.305±0.024	0.0150.123±

Appendix 3

Table (1): Lead concentrations (mg/L) in Seawater samples

Sample No.	Site	Seawater							
		Seasons						Total	
		Winter 2011		Summer 2012		Winter 2013			
		Pb (mg/L)		Pb (mg/L)		Pb (mg/L)		Pb (mg/L)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.057	0.002	0.041	0.005	0.043	0.001	0.047	0.009
2		0.058	0.001	0.039	0.005	0.045	0.003	0.047	0.010
3		0.050	0.001	0.047	0.007	0.046	0.001	0.048	0.002
4		0.052	0.001	0.054	0.003	0.052	0.002	0.053	0.001
5		0.059	0.000	0.052	0.002	0.053	0.004	0.055	0.004
6		0.051	0.002	0.055	0.001	0.055	0.004	0.054	0.002
7		0.054	0.001	0.038	0.002	0.057	0.003	0.050	0.010
8		0.052	0.000	0.041	0.002	0.055	0.003	0.049	0.007
9		0.059	0.001	0.042	0.002	0.054	0.001	0.052	0.009
Mean ± SD		0.055	0.004	0.045	0.007	0.051	0.005	0.051	0.003
10	AL Hodaeidah	0.052	0.001	0.054	0.003	0.052	0.000	0.053	0.001
11		0.054	0.002	0.052	0.002	0.052	0.001	0.053	0.001
12		0.052	0.001	0.061	0.002	0.053	0.001	0.055	0.005
13		0.094	0.003	0.103	0.008	0.098	0.000	0.098	0.005
14		0.094	0.003	0.124	0.006	0.097	0.001	0.105	0.017
15		0.094	0.004	0.121	0.010	0.101	0.008	0.105	0.014
16		0.093	0.001	0.083	0.006	0.066	0.001	0.081	0.014
17		0.094	0.001	0.088	0.013	0.066	0.001	0.083	0.015
18		0.091	0.000	0.094	0.005	0.066	0.000	0.084	0.015
Mean ± SD		0.080	0.020	0.087	0.027	0.072	0.021	0.080	0.021
19	Al Mukalla	0.032	0.000	0.047	0.003	0.051	0.001	0.043	0.010
20		0.036	0.000	0.102	0.004	0.089	0.001	0.076	0.035
21		0.031	0.000	0.093	0.003	0.089	0.000	0.071	0.035
22		0.033	0.001	0.100	0.003	0.086	0.002	0.073	0.035
23		0.034	0.000	0.052	0.002	0.052	0.001	0.046	0.010
24		0.033	0.000	0.053	0.001	0.051	0.000	0.046	0.011
25		0.032	0.001	0.043	0.003	0.053	0.001	0.043	0.011
26		0.032	0.000	0.040	0.002	0.053	0.000	0.042	0.011
27		0.031	0.001	0.045	0.002	0.052	0.000	0.043	0.011
Mean ± SD		0.033	0.002	0.064	0.026	0.064	0.018	0.054	0.015
Total Mean ± SD		0.056	0.023	0.065	0.027	0.062	0.018	0.061	0.020

Table (2): Cadmium concentrations (mg/L) in Seawater samples

Sample No.	Site	Seawater							
		Seasons						Total	
		Winter 2011		Summer 2012		Winter 2013			
		Cd (mg/L)		Cd (mg/L)		Cd (mg/L)		Cd (mg/L)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.008	0.000	0.011	0.000	0.009	0.000	0.009	0.002
2		0.008	0.000	0.010	0.001	0.009	0.000	0.009	0.001
3		0.008	0.000	0.011	0.000	0.009	0.000	0.009	0.002
4		0.005	0.000	0.006	0.000	0.007	0.000	0.006	0.001
5		0.005	0.000	0.006	0.000	0.007	0.000	0.006	0.001
6		0.005	0.000	0.006	0.000	0.007	0.000	0.006	0.001
7		0.005	0.000	0.011	0.000	0.010	0.000	0.009	0.003
8		0.005	0.000	0.013	0.002	0.010	0.000	0.009	0.004
9		0.005	0.000	0.013	0.000	0.010	0.000	0.009	0.004
Mean ± SD		0.006	0.002	0.010	0.003	0.009	0.001	0.008	0.002
10	AL Hodaeidah	0.009	0.000	0.006	0.000	0.007	0.000	0.007	0.002
11		0.009	0.000	0.006	0.000	0.007	0.000	0.007	0.002
12		0.010	0.000	0.006	0.000	0.007	0.000	0.008	0.002
13		0.007	0.000	0.008	0.000	0.008	0.000	0.008	0.001
14		0.006	0.000	0.008	0.000	0.008	0.000	0.007	0.001
15		0.007	0.000	0.008	0.000	0.008	0.000	0.008	0.001
16		0.006	0.000	0.005	0.000	0.007	0.000	0.006	0.001
17		0.006	0.000	0.005	0.000	0.007	0.000	0.006	0.001
18		0.006	0.000	0.005	0.000	0.007	0.000	0.006	0.001
Mean ± SD		0.007 (0.006-0.01)	0.002	0.006	0.001	0.007 (0.007-0.008)	0.000	0.007 (0.006-0.008)	0.000
19	Al Mukalla	0.007	0.000	0.008	0.000	0.009	0.000	0.008	0.001
20		0.007	0.000	0.008	0.000	0.009	0.000	0.008	0.001
21		0.007	0.000	0.008	0.000	0.009	0.000	0.008	0.001
22		0.005	0.000	0.007	0.000	0.007	0.000	0.006	0.001
23		0.005	0.000	0.008	0.000	0.007	0.000	0.007	0.002
24		0.005	0.000	0.008	0.000	0.007	0.000	0.007	0.002
25		0.005	0.000	0.009	0.000	0.009	0.000	0.008	0.002
26		0.005	0.000	0.009	0.000	0.009	0.000	0.008	0.002
27		0.005	0.000	0.009	0.000	0.009	0.000	0.008	0.002
Mean ± SD		0.006	0.000	0.0082	0.000	0.0083	0.000	0.0076	0.000
Total Mean ± SD		0.006	0.002	0.008	0.002	0.008	0.001	80.00	0.001

Table (3): Mercury concentrations (mg/L) in Seawater samples

Sample No.	Site	Seawater							
		Seasons						Total	
		Winter 2011		Summer 2012		Winter 2013			
		Hg (mg/L)		Hg (mg/L)		Hg (mg/L)		Hg (mg/L)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.005	0.000	0.003	0.000	0.009	0.000	0.006	0.003
2		0.004	0.000	0.003	0.000	0.009	0.000	0.005	0.003
3		0.005	0.000	0.003	0.000	0.009	0.000	0.006	0.003
4		0.005	0.000	0.003	0.000	0.007	0.000	0.005	0.002
5		0.005	0.000	0.003	0.000	0.007	0.000	0.005	0.002
6		0.005	0.000	0.003	0.000	0.007	0.000	0.005	0.002
7		0.005	0.000	0.004	0.000	0.005	0.000	0.005	0.001
8		0.006	0.000	0.004	0.000	0.005	0.000	0.005	0.001
9		0.005	0.000	0.004	0.000	0.005	0.000	0.005	0.001
Mean ± SD		0.005	0.000	0.003	0.000	0.007	0.002	0.005	0.000
10	AL Hodaeidah	0.005	0.000	0.009	0.000	0.007	0.000	0.007	0.002
11		0.006	0.000	0.009	0.000	0.007	0.000	0.007	0.002
12		0.005	0.000	0.009	0.000	0.007	0.000	0.007	0.002
13		0.007	0.000	0.007	0.000	0.005	0.000	0.006	0.001
14		0.008	0.000	0.007	0.000	0.006	0.000	0.007	0.001
15		0.007	0.000	0.007	0.000	0.006	0.000	0.007	0.001
16		0.007	0.000	0.008	0.000	0.008	0.000	0.008	0.001
17		0.007	0.000	0.008	0.000	0.008	0.000	0.008	0.001
18		0.007	0.000	0.008	0.000	0.008	0.000	0.008	0.001
Mean ± SD		0.007	0.001	0.008	0.000	0.007	0.001	0.0072	0.000
19	Al Mukalla	0.010	0.000	0.006	0.000	0.006	0.000	0.007	0.002
20		0.009	0.000	0.006	0.000	0.006	0.000	0.007	0.002
21		0.010	0.000	0.006	0.000	0.006	0.000	0.007	0.002
22		0.008	0.000	0.007	0.000	0.007	0.000	0.007	0.001
23		0.008	0.000	0.007	0.000	0.007	0.000	0.007	0.001
24		0.008	0.000	0.007	0.000	0.007	0.000	0.007	0.001
25		0.010	0.000	0.007	0.000	0.008	0.000	0.008	0.002
26		0.010	0.000	0.007	0.000	0.008	0.000	0.008	0.002
27		0.009	0.000	0.007	0.000	0.007	0.000	0.008	0.001
Mean ± SD		0.009	0.000	0.0067	0.000	0.0069	0.000	0.0073	0.000
Total Mean ± SD		0.007	0.002	0.006	0.002	0.007	0.001	0.007	0.001

Table (4): Arsenic concentrations (mg/L) in Seawater samples

Sample No.	Site	Seawater							
		Seasons						Total	
		Winter 2011		Summer 2012		Winter 2013			
		As (mg/L)		As (mg/L)		As (mg/L)		As (mg/L)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.005	0.000	0.006	0.000	0.005	0.000	0.005	0.001
2		0.005	0.000	0.006	0.000	0.005	0.000	0.005	0.001
3		0.005	0.000	0.006	0.000	0.005	0.000	0.005	0.001
4		0.006	0.000	0.006	0.000	0.007	0.000	0.006	0.001
5		0.006	0.000	0.007	0.000	0.007	0.000	0.007	0.001
6		0.006	0.000	0.006	0.000	0.007	0.000	0.006	0.001
7		0.006	0.000	0.006	0.000	0.006	0.000	0.006	0.000
8		0.006	0.000	0.006	0.000	0.006	0.000	0.006	0.000
9		0.006	0.000	0.006	0.000	0.006	0.000	0.006	0.000
Mean ± SD		0.0057	0.000	0.0061	0.000	0.006	0.000	0.0058	0.000
10	AL Hodaeidah	0.006	0.000	0.007	0.000	0.009	0.000	0.007	0.002
11		0.006	0.000	0.008	0.000	0.009	0.000	0.008	0.002
12		0.006	0.000	0.008	0.000	0.009	0.000	0.008	0.002
13		0.008	0.000	0.009	0.000	0.009	0.000	0.009	0.001
14		0.009	0.000	0.009	0.000	0.009	0.000	0.009	0.000
15		0.008	0.000	0.009	0.000	0.009	0.000	0.009	0.001
16		0.008	0.000	0.008	0.000	0.008	0.000	0.008	0.000
17		0.008	0.001	0.008	0.000	0.008	0.000	0.008	0.000
18		0.008	0.000	0.008	0.000	0.008	0.000	0.008	0.000
Mean ± SD		0.007	0.001	0.0082	0.000	0.0087	0.000	0.008	0.000
19	Al Mukalla	0.012	0.000	0.013	0.000	0.010	0.000	0.012	0.002
20		0.012	0.000	0.013	0.000	0.010	0.000	0.012	0.002
21		0.012	0.000	0.013	0.000	0.010	0.000	0.012	0.002
22		0.009	0.000	0.009	0.000	0.010	0.000	0.009	0.001
23		0.009	0.000	0.009	0.000	0.010	0.000	0.009	0.001
24		0.008	0.000	0.009	0.000	0.010	0.000	0.009	0.001
25		0.011	0.000	0.011	0.000	0.011	0.000	0.011	0.000
26		0.010	0.000	0.011	0.000	0.012	0.000	0.011	0.001
27		0.011	0.000	0.011	0.000	0.011	0.000	0.011	0.000
Mean ± SD		0.010	0.002	0.011	0.002	0.010	0.000	0.011	0.001
Total Mean ± SD		0.0077	0.002	0.00834	0.002	0.00829	0.002	0.008	0.002

Appendix 4

Table (1): Lead concentrations (µg/g) in Sediment samples

Sample No.	Site	Sediments							
		Seasons						Total	
		Winter 2011		Summer 2012		Winter 2013			
		Pb (µg/g)		Pb (µg/g)		Pb (µg/g)		Pb (µg/g)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	32.017	0.112	35.391	0.302	33.127	0.750	33.512	1.720
2		33.127	1.684	35.719	0.309	34.821	0.720	34.556	1.316
3		32.933	0.150	35.660	0.344	33.078	0.147	33.890	1.534
4		34.773	1.173	35.026	0.039	35.679	0.946	35.159	0.467
5		34.947	0.274	35.048	0.053	35.723	0.452	35.239	0.422
6		35.137	0.146	35.050	0.043	36.990	0.011	35.726	1.096
7		32.990	0.046	34.720	0.221	34.244	0.207	33.985	0.894
8		32.923	0.112	34.483	0.081	34.630	0.544	34.012	0.946
9		32.718	0.179	34.837	0.110	33.903	0.089	33.819	1.062
10	AL Hodaeidah	77.140	0.642	77.771	0.034	73.173	0.001	76.028	2.493
11		76.857	0.143	77.668	0.331	73.123	0.002	75.883	2.424
12		77.307	0.500	77.690	0.090	73.127	0.000	76.041	2.531
13		77.633	0.167	77.847	0.127	74.033	0.005	76.504	2.143
14		78.040	0.106	78.043	0.071	74.042	0.003	76.708	2.309
15		78.017	0.085	77.717	0.114	74.151	0.009	76.628	2.151
16		79.963	0.229	78.090	0.026	73.073	0.029	77.042	3.563
17		79.980	0.090	78.117	0.046	73.081	0.007	77.059	3.569
18		79.810	0.132	78.119	0.028	73.032	0.005	76.987	3.528
19	Al Mukalla	70.848	0.636	70.720	0.185	64.001	0.224	68.523	3.917
20		72.213	0.435	70.720	0.288	62.577	0.336	68.503	5.186
21		71.597	0.515	70.660	0.208	63.065	0.063	68.441	4.679
22		67.138	0.045	73.213	0.058	68.110	0.035	69.487	3.263
23		67.969	0.039	73.011	0.034	67.046	0.166	69.342	3.211
24		67.297	0.158	73.080	0.075	67.617	0.413	69.331	3.250
25		70.080	0.148	73.959	0.114	63.721	0.497	69.253	5.169
26		71.047	0.116	73.820	0.062	63.050	0.111	69.306	5.592
27		71.473	0.550	74.025	0.045	62.907	0.038	69.468	5.824
	Mean±SD	60.592	19.875	61.859	19.424	57.597	16.967	60.016	18.703

Table (2): Cadmium concentrations (µg/g) in Sediment samples

Sample No.	Site	Sediments							
		Seasons						Total	
		Winter2011		Summer 2012		Winter 2013			
		Cd (*µg/g*)		Cd (*µg/g*)		Cd (*µg/g*)		Cd (*µg/g*)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	1.777	0.020	2.019	0.045	2.045	0.015	1.947	1.480
2		1.782	0.050	2.012	0.093	2.039	0.006	1.944	1.412
3		1.788	0.010	2.021	0.060	2.037	0.035	1.948	1.394
4		1.768	0.021	2.104	0.016	2.081	0.026	1.984	1.874
5		1.770	0.002	2.107	0.020	2.092	0.025	1.989	1.908
6		1.769	0.007	2.104	0.027	2.073	0.033	1.982	1.851
7		1.729	0.006	2.224	0.030	2.012	0.004	1.988	2.485
8		1.796	0.006	2.205	0.061	2.012	0.001	2.004	2.048
9		1.793	0.009	2.202	0.019	2.012	0.002	2.002	2.045
10	AL Hodaeidah	2.339	0.001	2.302	0.064	2.503	0.021	2.381	1.072
11		2.342	0.002	2.307	0.057	2.504	0.054	2.384	1.050
12		2.340	0.002	2.297	0.029	2.503	0.032	2.380	1.087
13		2.389	0.172	2.300	0.038	2.499	0.014	2.396	0.993
14		2.395	0.008	2.303	0.016	2.496	0.037	2.397	0.966
15		2.392	0.048	2.311	0.006	2.501	0.002	2.400	0.952
16		2.526	0.035	2.452	0.072	2.490	0.032	2.489	0.368
17		2.525	0.040	2.457	0.026	2.499	0.001	2.493	0.343
18		2.531	0.020	2.458	0.040	2.497	0.002	2.495	0.367
19	Al Mukalla	0.705	0.006	0.914	0.050	1.002	0.025	0.873	1.522
20		0.705	0.002	0.924	0.035	0.992	0.005	0.873	1.500
21		0.705	0.003	0.918	0.110	0.993	0.039	0.871	1.494
22		0.625	0.003	0.898	0.097	0.911	0.002	0.811	1.615
23		0.625	0.002	0.891	0.065	0.911	0.004	0.808	1.598
24		0.625	0.003	0.901	0.025	0.918	0.036	0.814	1.647
25		0.659	0.015	0.816	0.015	0.968	0.013	0.814	1.541
26		0.662	0.036	0.830	0.051	0.969	0.025	0.820	1.536
27		0.662	0.012	0.843	0.087	0.968	0.031	0.824	1.539
Mean±SD		619.1	1740.	807.1	6230.	808.1	6940.	745.1	6820.

Table (3): Mercury concentrations (µg/g) in Sediment samples

Sample No.	Site	Sediments							
		Seasons						Total	
		Winter2011		Summer 2012		Winter 2013			
		Hg (µg/g)		Hg (µg/g)		Hg (µg/g)		Hg (µg/g)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.013	0.000	0.029	0.000	0.027	0.000	0.023	0.009
2		0.013	0.000	0.029	0.000	0.027	0.000	0.023	0.009
3		0.013	0.000	0.030	0.000	0.027	0.000	0.023	0.009
4		0.012	0.000	0.020	0.000	0.023	0.000	0.018	0.006
5		0.012	0.000	0.021	0.000	0.023	0.000	0.019	0.006
6		0.012	0.000	0.021	0.000	0.023	0.000	0.019	0.006
7		0.014	0.000	0.017	0.000	0.020	0.000	0.017	0.003
8		0.014	0.000	0.017	0.000	0.020	0.000	0.017	0.003
9		0.014	0.000	0.017	0.000	0.020	0.000	0.017	0.003
10	AL Hodaeidah	0.014	0.003	0.023	0.000	0.032	0.000	0.023	0.009
11		0.012	0.000	0.023	0.000	0.031	0.000	0.022	0.010
12		0.012	0.000	0.023	0.000	0.032	0.000	0.022	0.010
13		0.012	0.000	0.042	0.000	0.029	0.000	0.028	0.015
14		0.012	0.000	0.043	0.000	0.030	0.000	0.028	0.016
15		0.012	0.000	0.043	0.000	0.029	0.000	0.028	0.016
16		0.008	0.000	0.011	0.000	0.015	0.000	0.011	0.004
17		0.009	0.000	0.012	0.000	0.015	0.000	0.012	0.003
18		0.009	0.000	0.012	0.000	0.015	0.000	0.012	0.003
19	Al Mukalla	0.008	0.000	0.013	0.000	0.023	0.000	0.015	0.008
20		0.008	0.000	0.013	0.000	0.023	0.000	0.015	0.008
21		0.008	0.000	0.013	0.000	0.023	0.000	0.015	0.008
22		0.011	0.000	0.011	0.000	0.047	0.000	0.023	0.021
23		0.011	0.000	0.012	0.000	0.047	0.000	0.023	0.021
24		0.011	0.000	0.012	0.000	0.047	0.000	0.023	0.021
25		0.011	0.000	0.007	0.000	0.011	0.000	0.010	0.002
26		0.011	0.000	0.007	0.000	0.010	0.000	0.009	0.002
27		0.011	0.000	0.007	0.000	0.010	0.000	0.009	0.002
Mean±SD		0.011	0.002	0.019	0.011	0.025	0.010	0.019	0.006

Table (4): Arsenic concentrations (µg/g) in Sediment samples

Sample No.	Site	Sediments							
		Seasons						Total	
		Winter2011		Summer 2012		Winter 2013			
		As (µg/g)		As (µg/g)		As (µg/g)		As (µg/g)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	Aden	0.105	0.000	0.114	0.000	0.103	0.000	0.107	0.006
2		0.102	0.000	0.111	0.000	0.100	0.000	0.104	0.006
3		0.103	0.001	0.112	0.001	0.101	0.000	0.105	0.006
4		0.092	0.000	0.101	0.000	0.091	0.000	0.095	0.006
5		0.092	0.000	0.100	0.000	0.090	0.000	0.094	0.005
6		0.093	0.000	0.101	0.000	0.091	0.000	0.095	0.005
7		0.109	0.000	0.119	0.000	0.107	0.000	0.112	0.006
8		0.109	0.000	0.119	0.000	0.107	0.000	0.112	0.006
9		0.109	0.000	0.119	0.000	0.107	0.000	0.112	0.006
10	AL Hodaeidah	0.093	0.000	0.110	0.000	0.087	0.000	0.097	0.012
11		0.093	0.000	0.109	0.000	0.089	0.001	0.097	0.011
12		0.092	0.000	0.109	0.000	0.089	0.000	0.097	0.011
13		0.096	0.000	0.113	0.000	0.118	0.000	0.109	0.012
14		0.096	0.000	0.113	0.000	0.118	0.000	0.109	0.012
15		0.096	0.000	0.113	0.000	0.118	0.000	0.109	0.012
16		0.069	0.000	0.081	0.000	0.122	0.000	0.091	0.028
17		0.070	0.000	0.083	0.000	0.122	0.000	0.092	0.027
18		0.070	0.000	0.082	0.000	0.122	0.000	0.091	0.027
19	Al Mukalla	0.065	0.001	0.091	0.001	0.110	0.001	0.089	0.023
20		0.066	0.000	0.092	0.000	0.110	0.000	0.089	0.022
21		0.065	0.000	0.091	0.000	0.109	0.000	0.088	0.022
22		0.086	0.001	0.120	0.001	0.083	0.001	0.096	0.021
23		0.084	0.001	0.118	0.001	0.084	0.000	0.095	0.020
24		0.084	0.000	0.118	0.001	0.083	0.000	0.095	0.020
25		0.086	0.000	0.120	0.001	0.110	0.001	0.105	0.017
26		0.086	0.000	0.120	0.000	0.108	0.001	0.105	0.017
27		0.085	0.000	0.120	0.000	0.108	0.001	0.104	0.018
Mean±SD		0.089	0.014	0.107	0.013	0.103	0.013	0.099	0.008

Appendix 5

Table (1): Lead concentrations (µg/g) in muscles samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Pb (µg/g)		Pb (µg/g)		Pb (µg/g)		Pb (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.076	0.004	0.100	0.002	0.094	0.002	0.090	0.012
		Medium	0.066	0.003	0.088	0.001	0.079	0.001	0.078	0.011
		Small	0.051	0.000	0.086	0.000	0.076	0.000	0.071	0.018
	Thunnus tonggol	Large	0.083	0.001	0.092	0.002	0.074	0.005	0.083	0.009
		Medium	0.073	0.002	0.091	0.001	0.073	0.004	0.079	0.011
		Small	0.043	0.001	0.068	0.002	0.063	0.002	0.058	0.013
	Sphyraena jello	Large	0.025	0.000	0.024	0.001	0.035	0.000	0.028	0.006
		Medium	0.021	0.001	0.020	0.001	0.024	0.000	0.021	0.002
		Small	0.018	0.001	0.019	0.000	0.022	0.000	0.020	0.002
	Epinephelus areolatus	Large	0.112	0.001	0.112	0.000	0.124	0.000	0.116	0.007
		Medium	0.072	0.001	0.084	0.000	0.122	0.000	0.093	0.026
		Small	0.065	0.000	0.072	0.000	0.113	0.000	0.083	0.026
Al Hodaeidah	*Lethrinus mahsena*	Large	0.234	0.004	0.341	0.006	0.357	0.002	0.311	0.067
		Medium	0.129	0.002	0.160	0.002	0.175	0.001	0.154	0.023
		Small	0.076	0.002	0.148	0.002	0.132	0.001	0.119	0.038
	Thunnus tonggol	Large	0.129	0.001	0.172	0.003	0.138	0.001	0.146	0.023
		Medium	0.097	0.001	0.171	0.000	0.124	0.002	0.130	0.037
		Small	0.058	0.000	0.103	0.008	0.107	0.002	0.089	0.027
	Sphyraena jello	Large	0.058	0.001	0.074	0.000	0.082	0.001	0.071	0.012
		Medium	0.034	0.001	0.054	0.002	0.078	0.000	0.055	0.022
		Small	0.031	0.000	0.045	0.001	0.058	0.000	0.045	0.013
	Epinephelus areolatus	Large	0.187	0.000	0.198	0.000	0.187	0.000	0.191	0.006
		Medium	0.167	0.000	0.188	0.001	0.184	0.000	0.179	0.011
		Small	0.165	0.000	0.163	0.002	0.171	0.000	0.167	0.004
Al Mukalla	*Lethrinus mahsena*	Large	0.138	0.002	0.156	0.003	0.159	0.000	0.151	0.011
		Medium	0.117	0.002	0.127	0.002	0.141	0.000	0.128	0.012
		Small	0.077	0.002	0.078	0.005	0.099	0.002	0.085	0.012
	Thunnus tonggol	Large	0.096	0.002	0.144	0.005	0.114	0.002	0.118	0.024
		Medium	0.091	0.001	0.111	0.000	0.101	0.001	0.101	0.010
		Small	0.079	0.000	0.107	0.001	0.097	0.001	0.094	0.014
	Sphyraena jello	Large	0.056	0.000	0.021	0.000	0.037	0.000	0.038	0.017
		Medium	0.034	0.001	0.019	0.000	0.031	0.001	0.028	0.008
		Small	0.023	0.001	0.018	0.000	0.028	0.000	0.023	0.005
	Epinephelus areolatus	Large	0.133	0.000	0.146	0.000	0.171	0.000	0.150	0.019
		Medium	0.126	0.000	0.130	0.000	0.135	0.000	0.130	0.005
		Small	0.123	0.001	0.123	0.000	0.132	0.000	0.126	0.005
Mean±SD			0.088	0.051	0.107	0.066	0.109	0.064	0.101	0.059

Table (2): Cadmium concentrations (μg/g)in muscles samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Cd (μg/g)		Cd (μg/g)		Cd (μg/g)		Cd (μg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.052	0.001	0.094	0.001	0.074	0.000	0.073	0.021
		Medium	0.033	0.000	0.059	0.000	0.044	0.000	0.045	0.013
		Small	0.029	0.000	0.041	0.000	0.033	0.000	0.034	0.006
	Thunnus tonggol	Large	0.022	0.000	0.061	0.002	0.045	0.000	0.043	0.020
		Medium	0.020	0.000	0.033	0.000	0.041	0.000	0.031	0.010
		Small	0.016	0.000	0.026	0.000	0.033	0.000	0.025	0.009
	Sphyraena jello	Large	0.022	0.000	0.048	0.001	0.020	0.001	0.030	0.015
		Medium	0.020	0.000	0.038	0.000	0.016	0.001	0.024	0.012
		Small	0.018	0.000	0.023	0.000	0.013	0.000	0.018	0.005
	Epinephelus areolatus	Large	0.026	0.000	0.072	0.001	0.066	0.001	0.055	0.025
		Medium	0.020	0.000	0.070	0.001	0.060	0.000	0.050	0.026
		Small	0.015	0.000	0.056	0.000	0.041	0.000	0.037	0.021
Al Hodaeida h	*Lethrinus mahsena*	Large	0.088	0.000	0.072	0.000	0.078	0.001	0.079	0.008
		Medium	0.072	0.000	0.063	0.001	0.066	0.000	0.067	0.005
		Small	0.035	0.001	0.040	0.000	0.044	0.000	0.040	0.005
	Thunnus tonggol	Large	0.030	0.001	0.065	0.001	0.044	0.000	0.046	0.018
		Medium	0.028	0.000	0.052	0.000	0.031	0.000	0.037	0.013
		Small	0.019	0.000	0.040	0.000	0.022	0.000	0.027	0.012
	Sphyraena jello	Large	0.045	0.000	0.045	0.000	0.034	0.000	0.041	0.006
		Medium	0.029	0.001	0.034	0.000	0.028	0.000	0.030	0.003
		Small	0.018	0.000	0.025	0.000	0.021	0.000	0.021	0.004
	Epinephelus areolatus	Large	0.117	0.001	0.146	0.001	0.137	0.000	0.134	0.015
		Medium	0.097	0.002	0.101	0.002	0.109	0.001	0.102	0.006
		Small	0.042	0.001	0.055	0.000	0.067	0.001	0.055	0.012
Al Mukalla	*Lethrinus mahsena*	Large	0.047	0.000	0.041	0.001	0.043	0.000	0.044	0.003
		Medium	0.041	0.000	0.034	0.000	0.037	0.000	0.037	0.003
		Small	0.031	0.000	0.022	0.000	0.024	0.000	0.026	0.005
	Thunnus tonggol	Large	0.026	0.000	0.059	0.001	0.059	0.000	0.048	0.019
		Medium	0.023	0.000	0.047	0.001	0.049	0.000	0.039	0.014
		Small	0.020	0.000	0.040	0.001	0.042	0.000	0.034	0.012
	Sphyraena jello	Large	0.041	0.000	0.051	0.001	0.054	0.000	0.049	0.007
		Medium	0.023	0.000	0.029	0.000	0.031	0.000	0.028	0.004
		Small	0.019	0.000	0.021	0.000	0.022	0.000	0.021	0.002
	Epinephelus areolatus	Large	0.028	0.000	0.102	0.000	0.100	0.000	0.076	0.042
		Medium	0.016	0.000	0.094	0.000	0.092	0.000	0.067	0.044
		Small	0.016	0.000	0.065	0.000	0.062	0.000	0.048	0.028
Mean±SD			0.034	0.024	450.0	0.026	0.049	70.02	0.046	0.024

Table (3): Mercury concentrations (µg/g)in muscles samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Hg (µg/g)		Hg (µg/g)		Hg (µg/g)		Hg (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.077	0.000	0.072	0.000	0.076	0.000	0.075	0.003
		Medium	0.079	0.000	0.076	0.000	0.077	0.000	0.078	0.002
		Small	0.089	0.000	0.087	0.001	0.085	0.000	0.087	0.002
	Thunnus tonggol	Large	0.034	0.000	0.025	0.000	0.037	0.000	0.032	0.006
		Medium	0.029	0.000	0.022	0.000	0.031	0.000	0.027	0.005
		Small	0.021	0.000	0.019	0.000	0.021	0.000	0.021	0.001
	Sphyraena jello	Large	0.074	0.000	0.082	0.000	0.069	0.000	0.075	0.007
		Medium	0.064	0.000	0.070	0.000	0.067	0.000	0.067	0.003
		Small	0.055	0.000	0.060	0.000	0.033	0.000	0.049	0.014
	Epinephelus areolatus	Large	0.080	0.000	0.088	0.000	0.089	0.000	0.085	0.005
		Medium	0.061	0.000	0.075	0.000	0.072	0.000	0.069	0.007
		Small	0.052	0.000	0.060	0.000	0.058	0.000	0.057	0.004
Al Hodaeidah	*Lethrinus mahsena*	Large	0.052	0.000	0.058	0.000	0.053	0.000	0.055	0.003
		Medium	0.066	0.000	0.056	0.000	0.053	0.000	0.058	0.007
		Small	0.069	0.000	0.054	0.000	0.050	0.000	0.058	0.010
	Thunnus tonggol	Large	0.047	0.000	0.043	0.000	0.023	0.000	0.038	0.013
		Medium	0.038	0.000	0.034	0.000	0.022	0.000	0.031	0.009
		Small	0.024	0.000	0.030	0.000	0.019	0.000	0.025	0.006
	Sphyraena jello	Large	0.082	0.000	0.073	0.000	0.075	0.000	0.077	0.005
		Medium	0.078	0.000	0.074	0.000	0.071	0.000	0.074	0.003
		Small	0.067	0.000	0.061	0.000	0.063	0.000	0.064	0.003
	Epinephelus areolatus	Large	0.080	0.001	0.083	0.000	0.078	0.000	0.080	0.002
		Medium	0.066	0.000	0.074	0.000	0.072	0.000	0.071	0.004
		Small	0.052	0.000	0.054	0.000	0.057	0.000	0.055	0.003
Al Mukalla	*Lethrinus mahsena*	Large	0.068	0.000	0.054	0.000	0.058	0.000	0.060	0.007
		Medium	0.062	0.000	0.044	0.000	0.043	0.000	0.050	0.011
		Small	0.060	0.000	0.038	0.000	0.022	0.000	0.040	0.019
	Thunnus tonggol	Large	0.041	0.000	0.040	0.000	0.033	0.000	0.038	0.004
		Medium	0.033	0.000	0.032	0.000	0.030	0.000	0.032	0.002
		Small	0.023	0.000	0.022	0.000	0.025	0.000	0.023	0.002
	Sphyraena jello	Large	0.071	0.000	0.087	0.000	0.091	0.000	0.083	0.011
		Medium	0.068	0.001	0.072	0.000	0.084	0.000	0.075	0.008
		Small	0.050	0.000	0.056	0.000	0.059	0.000	0.055	0.005
	Epinephelus areolatus	Large	0.068	0.001	0.102	0.001	0.083	0.000	0.085	0.017
		Medium	0.066	0.000	0.081	0.000	0.081	0.000	0.076	0.008
		Small	0.051	0.000	0.072	0.000	0.067	0.000	0.064	0.011
Mean±SD			0.058	0.018	0.059	0.022	0.056	0.023	0.058	0.020

Table (4): Arsenic concentrations (μg/g)in muscles samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			As (μg/g)		As (μg/g)		As (μg/g)		As (μg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.105	0.000	0.109	0.000	0.110	0.000	0.108	0.003
		Medium	0.083	0.001	0.102	0.000	0.108	0.001	0.098	0.013
		Small	0.081	0.001	0.101	0.000	0.096	0.001	0.093	0.010
	Thunnus tonggol	Large	0.091	0.001	0.099	0.001	0.089	0.001	0.093	0.005
		Medium	0.058	0.000	0.063	0.000	0.056	0.000	0.059	0.003
		Small	0.042	0.000	0.046	0.000	0.041	0.000	0.043	0.002
	Sphyraena jello	Large	0.104	0.000	0.113	0.000	0.102	0.000	0.106	0.006
		Medium	0.083	0.000	0.090	0.000	0.081	0.000	0.084	0.005
		Small	0.077	0.000	0.084	0.000	0.075	0.000	0.079	0.004
	Epinephelus areolatus	Large	0.104	0.000	0.113	0.000	0.102	0.000	0.106	0.006
		Medium	0.085	0.000	0.093	0.000	0.084	0.000	0.087	0.005
		Small	0.077	0.000	0.084	0.000	0.076	0.000	0.079	0.004
Al Hodaeidah	*Lethrinus mahsena*	Large	0.121	0.000	0.117	0.000	0.119	0.000	0.119	0.002
		Medium	0.113	0.000	0.112	0.000	0.109	0.001	0.111	0.002
		Small	0.109	0.000	0.110	0.001	0.101	0.000	0.106	0.005
	Thunnus tonggol	Large	0.117	0.000	0.107	0.001	0.095	0.000	0.106	0.011
		Medium	0.077	0.000	0.070	0.000	0.075	0.000	0.074	0.004
		Small	0.049	0.000	0.044	0.000	0.048	0.000	0.047	0.002
	Sphyraena jello	Large	0.094	0.001	0.104	0.001	0.112	0.001	0.103	0.009
		Medium	0.087	0.000	0.092	0.000	0.099	0.000	0.093	0.006
		Small	0.069	0.000	0.085	0.000	0.091	0.000	0.082	0.011
	Epinephelus areolatus	Large	0.104	0.002	0.095	0.001	0.102	0.002	0.101	0.005
		Medium	0.093	0.000	0.084	0.000	0.091	0.000	0.089	0.004
		Small	0.078	0.001	0.071	0.000	0.076	0.001	0.075	0.004
Al Mukalla	*Lethrinus mahsena*	Large	0.115	0.000	0.116	0.000	0.113	0.000	0.114	0.001
		Medium	0.102	0.000	0.113	0.000	0.103	0.000	0.106	0.006
		Small	0.100	0.000	0.101	0.000	0.100	0.000	0.101	0.001
	Thunnus tonggol	Large	0.111	0.000	0.098	0.001	0.096	0.000	0.102	0.008
		Medium	0.067	0.000	0.072	0.000	0.066	0.000	0.068	0.003
		Small	0.045	0.000	0.048	0.000	0.044	0.000	0.046	0.002
	Sphyraena jello	Large	0.100	0.001	0.100	0.001	0.098	0.001	0.100	0.001
		Medium	0.089	0.001	0.095	0.001	0.087	0.001	0.090	0.004
		Small	0.070	0.001	0.075	0.001	0.069	0.001	0.071	0.003
	Epinephelus areolatus	Large	0.089	0.002	0.096	0.002	0.088	0.002	0.091	0.004
		Medium	0.086	0.001	0.093	0.001	0.085	0.001	0.088	0.004
		Small	0.077	0.000	0.083	0.000	0.076	0.000	0.078	0.004
Mean±SD			0.088	0.020	0.091	0.020	0.088	0.020	0.089	0.019

Appendix 6

Table (1): Lead concentrations (µg/g) in Liver samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Pb (µg/g)		Pb (µg/g)		Pb (µg/g)		Pb (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.179	0.004	0.314	0.003	0.308	0.003	0.267	0.076
		Medium	0.131	0.003	0.300	0.002	0.260	0.008	0.230	0.088
		Small	0.128	0.001	0.285	0.004	0.246	0.005	0.220	0.082
	Thunnus tonggol	Large	0.129	0.003	0.151	0.000	0.132	0.005	0.137	0.012
		Medium	0.112	0.001	0.130	0.000	0.127	0.004	0.123	0.010
		Small	0.094	0.003	0.101	0.003	0.115	0.002	0.103	0.011
	Sphyraena jello	Large	0.074	0.001	0.057	0.002	0.073	0.001	0.068	0.010
		Medium	0.044	0.001	0.051	0.000	0.035	0.000	0.044	0.008
		Small	0.035	0.000	0.046	0.001	0.032	0.000	0.038	0.007
	Epinephelus areolatus	Large	0.150	0.000	0.130	0.000	0.144	0.000	0.141	0.010
		Medium	0.130	0.001	0.122	0.000	0.134	0.000	0.129	0.006
		Small	0.119	0.000	0.117	0.000	0.128	0.000	0.122	0.006
Al Hodaeidah	*Lethrinus mahsena*	Large	0.454	0.010	0.999	0.006	0.836	0.002	0.763	0.280
		Medium	0.375	0.005	0.899	0.008	0.821	0.003	0.698	0.283
		Small	0.293	0.004	0.818	0.016	0.754	0.005	0.622	0.287
	Thunnus tonggol	Large	0.199	0.004	0.182	0.002	0.163	0.000	0.181	0.018
		Medium	0.145	0.004	0.150	0.002	0.145	0.003	0.147	0.003
		Small	0.098	0.000	0.105	0.004	0.127	0.001	0.110	0.015
	Sphyraena jello	Large	0.133	0.001	0.094	0.003	0.100	0.001	0.109	0.021
		Medium	0.101	0.002	0.086	0.004	0.085	0.000	0.090	0.009
		Small	0.049	0.001	0.056	0.003	0.068	0.000	0.058	0.009
	Epinephelus areolatus	Large	0.194	0.000	0.200	0.000	0.191	0.000	0.195	0.004
		Medium	0.179	0.000	0.188	0.001	0.186	0.000	0.185	0.005
		Small	0.178	0.001	0.179	0.000	0.166	0.000	0.175	0.007
Al Mukalla	*Lethrinus mahsena*	Large	0.333	0.005	0.427	0.016	0.251	0.004	0.337	0.088
		Medium	0.292	0.004	0.429	0.019	0.390	0.006	0.370	0.071
		Small	0.317	0.016	0.393	0.003	0.316	0.005	0.342	0.044
	Thunnus tonggol	Large	0.147	0.001	0.157	0.004	0.163	0.002	0.156	0.008
		Medium	0.140	0.001	0.139	0.001	0.145	0.002	0.141	0.003
		Small	0.123	0.002	0.132	0.001	0.140	0.001	0.132	0.008
	Sphyraena jello	Large	0.094	0.002	0.047	0.001	0.061	0.002	0.067	0.024
		Medium	0.087	0.001	0.033	0.001	0.047	0.001	0.056	0.028
		Small	0.034	0.001	0.030	0.000	0.036	0.000	0.034	0.003
	Epinephelus areolatus	Large	0.185	0.000	0.169	0.000	0.199	0.000	0.184	0.015
		Medium	0.137	0.000	0.144	0.000	0.148	0.000	0.143	0.006
		Small	0.130	0.000	0.140	0.000	0.136	0.000	0.135	0.005
Mean±SD			0.159	0.096	0.222	0.234	0.206	0.200	0.196	0.174

Table (2): Cadmium concentrations (µg/g)in Liver samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Cd (µg/g)		Cd (µg/g)		Cd (µg/g)		Cd (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.098	0.000	0.102	0.002	0.123	0.001	0.107	0.013
		Medium	0.083	0.001	0.091	0.000	0.112	0.002	0.095	0.015
		Small	0.074	0.001	0.088	0.001	0.098	0.000	0.087	0.012
	Thunnus tonggol	Large	0.094	0.001	0.223	0.007	0.200	0.001	0.172	0.069
		Medium	0.043	0.000	0.131	0.002	0.123	0.001	0.099	0.048
		Small	0.031	0.000	0.088	0.001	0.102	0.001	0.074	0.038
	Sphyraena jello	Large	0.031	0.000	0.028	0.001	0.055	0.001	0.038	0.015
		Medium	0.028	0.000	0.019	0.000	0.050	0.001	0.032	0.016
		Small	0.026	0.000	0.018	0.000	0.038	0.000	0.028	0.010
	Epinephelus areolatus	Large	0.068	0.000	0.222	0.003	0.203	0.000	0.164	0.084
		Medium	0.057	0.000	0.191	0.004	0.187	0.001	0.145	0.076
		Small	0.051	0.000	0.314	0.005	0.264	0.001	0.209	0.139
Al Hodaeidah	*Lethrinus mahsena*	Large	0.077	0.000	0.093	0.001	0.101	0.000	0.090	0.012
		Medium	0.078	0.000	0.078	0.000	0.082	0.000	0.080	0.002
		Small	0.114	0.001	0.074	0.001	0.076	0.000	0.088	0.023
	Thunnus tonggol	Large	0.104	0.003	0.100	0.001	0.107	0.001	0.104	0.004
		Medium	0.077	0.000	0.095	0.001	0.099	0.000	0.091	0.012
		Small	0.072	0.000	0.067	0.000	0.074	0.000	0.071	0.004
	Sphyraena jello	Large	0.136	0.001	0.080	0.001	0.083	0.001	0.100	0.032
		Medium	0.047	0.003	0.055	0.000	0.062	0.000	0.055	0.008
		Small	0.157	0.001	0.128	0.000	0.080	0.000	0.122	0.039
	Epinephelus areolatus	Large	0.615	0.005	0.705	0.003	0.667	0.002	0.662	0.045
		Medium	0.549	0.006	0.625	0.003	0.603	0.001	0.592	0.039
		Small	0.443	0.003	0.581	0.002	0.581	0.001	0.535	0.080
Al Mukalla	*Lethrinus mahsena*	Large	0.072	0.000	0.081	0.001	0.084	0.000	0.079	0.006
		Medium	0.062	0.001	0.073	0.001	0.075	0.000	0.070	0.007
		Small	0.060	0.000	0.061	0.001	0.064	0.000	0.062	0.002
	Thunnus tonggol	Large	0.096	0.000	0.111	0.004	0.098	0.001	0.102	0.008
		Medium	0.050	0.000	0.067	0.001	0.072	0.000	0.063	0.012
		Small	0.034	0.000	0.058	0.001	0.061	0.000	0.051	0.015
	Sphyraena jello	Large	0.067	0.000	0.093	0.003	0.085	0.000	0.082	0.013
		Medium	0.049	0.000	0.061	0.001	0.056	0.000	0.055	0.006
		Small	0.031	0.000	0.044	0.001	0.048	0.000	0.041	0.009
	Epinephelus areolatus	Large	0.077	0.000	0.128	0.000	0.128	0.000	0.111	0.030
		Medium	0.067	0.001	0.107	0.000	0.109	0.000	0.094	0.024
		Small	0.078	0.000	0.094	0.000	0.101	0.000	0.091	0.012
Mean±SD			0.108	0.136	0.144	0.162	0.143	0.153	0.132	0.148

Table (3): Mercury concentrations (µg/g)in Liver samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Hg (µg/g)		Hg (µg/g)		Hg (µg/g)		Hg (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.082	0.000	0.082	0.000	0.081	0.000	0.082	0.000
		Medium	0.092	0.000	0.089	0.000	0.089	0.001	0.090	0.002
		Small	0.093	0.000	0.092	0.000	0.091	0.000	0.092	0.001
	Thunnus tonggol	Large	0.177	0.001	0.162	0.000	0.133	0.000	0.157	0.023
		Medium	0.140	0.000	0.132	0.000	0.129	0.000	0.134	0.006
		Small	0.118	0.000	0.110	0.000	0.118	0.000	0.115	0.004
	Sphyraena jello	Large	0.069	0.000	0.072	0.001	0.083	0.000	0.075	0.007
		Medium	0.054	0.000	0.069	0.000	0.071	0.000	0.065	0.009
		Small	0.028	0.000	0.036	0.000	0.044	0.000	0.036	0.008
	Epinephelus areolatus	Large	0.154	0.000	0.141	0.000	0.127	0.000	0.141	0.014
		Medium	0.137	0.001	0.130	0.000	0.120	0.000	0.129	0.009
		Small	0.098	0.000	0.101	0.000	0.100	0.001	0.100	0.001
Al Hodaeidah	*Lethrinus mahsena*	Large	0.101	0.001	0.094	0.002	0.088	0.000	0.094	0.006
		Medium	0.116	0.000	0.076	0.000	0.075	0.000	0.089	0.024
		Small	0.134	0.000	0.073	0.000	0.070	0.000	0.092	0.036
	Thunnus tonggol	Large	0.187	0.001	0.177	0.000	0.145	0.000	0.170	0.022
		Medium	0.177	0.000	0.166	0.000	0.141	0.000	0.161	0.019
		Small	0.108	0.001	0.098	0.000	0.104	0.001	0.103	0.005
	Sphyraena jello	Large	0.060	0.000	0.070	0.000	0.072	0.000	0.067	0.006
		Medium	0.059	0.000	0.064	0.000	0.069	0.000	0.064	0.005
		Small	0.051	0.000	0.053	0.000	0.060	0.000	0.055	0.004
	Epinephelus areolatus	Large	0.152	0.000	0.148	0.000	0.138	0.000	0.146	0.007
		Medium	0.127	0.001	0.120	0.001	0.123	0.000	0.123	0.003
		Small	0.120	0.000	0.110	0.000	0.102	0.000	0.110	0.009
Al Mukalla	*Lethrinus mahsena*	Large	0.126	0.000	0.109	0.000	0.097	0.000	0.111	0.015
		Medium	0.118	0.000	0.104	0.000	0.087	0.001	0.103	0.016
		Small	0.108	0.000	0.098	0.001	0.081	0.000	0.096	0.014
	Thunnus tonggol	Large	0.157	0.002	0.113	0.000	0.093	0.000	0.121	0.033
		Medium	0.142	0.001	0.102	0.000	0.071	0.000	0.105	0.035
		Small	0.083	0.000	0.078	0.000	0.067	0.000	0.076	0.009
	Sphyraena jello	Large	0.056	0.000	0.098	0.000	0.090	0.000	0.081	0.022
		Medium	0.050	0.000	0.060	0.000	0.061	0.000	0.057	0.006
		Small	0.034	0.000	0.041	0.000	0.044	0.000	0.040	0.005
	Epinephelus areolatus	Large	0.145	0.000	0.131	0.001	0.133	0.000	0.136	0.007
		Medium	0.136	0.000	0.128	0.000	0.115	0.000	0.126	0.011
		Small	0.128	0.000	0.099	0.000	0.101	0.000	0.109	0.016
Mean±SD			0.109	0.042	0.101	0.034	0.095	0.028	0.101	0.033

Table (4): Arsenic concentrations (µg/g)in Liver samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			As (µg/g)		As (µg/g)		As (µg/g)		As (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.136	0.002	0.140	0.000	0.121	0.000	0.133	0.010
		Medium	0.114	0.001	0.140	0.000	0.119	0.001	0.124	0.014
		Small	0.103	0.000	0.107	0.000	0.103	0.001	0.104	0.002
	Thunnus tonggol	Large	0.179	0.003	0.182	0.001	0.170	0.001	0.177	0.006
		Medium	0.130	0.000	0.131	0.001	0.137	0.001	0.132	0.004
		Small	0.105	0.001	0.126	0.000	0.105	0.000	0.112	0.012
	Sphyraena jello	Large	0.097	0.000	0.106	0.000	0.095	0.000	0.099	0.006
		Medium	0.070	0.000	0.077	0.000	0.069	0.000	0.072	0.004
		Small	0.039	0.000	0.042	0.000	0.038	0.000	0.040	0.002
	Epinephelus areolatus	Large	0.127	0.000	0.122	0.000	0.126	0.000	0.125	0.003
		Medium	0.112	0.002	0.111	0.000	0.119	0.001	0.114	0.004
		Small	0.107	0.000	0.110	0.001	0.104	0.000	0.107	0.003
Al Hodaeidah	*Lethrinus mahsena*	Large	0.121	0.000	0.129	0.000	0.121	0.000	0.124	0.005
		Medium	0.121	0.000	0.121	0.000	0.112	0.000	0.118	0.005
		Small	0.174	0.001	0.113	0.001	0.091	0.001	0.126	0.043
	Thunnus tonggol	Large	0.199	0.001	0.194	0.002	0.149	0.000	0.181	0.027
		Medium	0.135	0.000	0.132	0.000	0.135	0.000	0.134	0.002
		Small	0.122	0.000	0.120	0.000	0.121	0.000	0.121	0.001
	Sphyraena jello	Large	0.084	0.000	0.077	0.000	0.083	0.000	0.081	0.004
		Medium	0.076	0.000	0.069	0.000	0.075	0.000	0.073	0.004
		Small	0.072	0.000	0.065	0.000	0.070	0.000	0.069	0.003
	Epinephelus areolatus	Large	0.150	0.000	0.148	0.000	0.149	0.000	0.149	0.001
		Medium	0.138	0.000	0.136	0.000	0.137	0.000	0.137	0.001
		Small	0.118	0.000	0.126	0.000	0.134	0.006	0.126	0.008
Al Mukalla	*Lethrinus mahsena*	Large	0.127	0.000	0.129	0.000	0.126	0.000	0.127	0.001
		Medium	0.112	0.000	0.125	0.001	0.123	0.000	0.120	0.007
		Small	0.109	0.000	0.103	0.001	0.119	0.000	0.110	0.008
	Thunnus tonggol	Large	0.186	0.001	0.196	0.002	0.196	0.001	0.193	0.006
		Medium	0.128	0.000	0.131	0.000	0.179	0.001	0.146	0.029
		Small	0.107	0.000	0.118	0.001	0.164	0.000	0.129	0.030
	Sphyraena jello	Large	0.078	0.000	0.084	0.000	0.077	0.000	0.080	0.004
		Medium	0.065	0.000	0.070	0.000	0.064	0.000	0.066	0.003
		Small	0.048	0.001	0.052	0.001	0.047	0.001	0.049	0.002
	Epinephelus areolatus	Large	0.129	0.000	0.120	0.000	0.135	0.001	0.128	0.008
		Medium	0.118	0.000	0.119	0.000	0.115	0.000	0.117	0.002
		Small	0.109	0.000	0.106	0.001	0.109	0.000	0.108	0.001
Mean±SD			0.115	0.036	0.116	0.035	0.115	0.035	0.115	0.034

Appendix 7

Table (1): Lead concentrations (µg/g)in Gill samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Pb (µg/g)		Pb (µg/g)		Pb (µg/g)		Pb (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.541	0.026	0.814	0.011	0.640	0.003	0.665	0.138
		Medium	0.576	0.008	0.861	0.004	0.579	0.008	0.672	0.164
		Small	0.697	0.005	0.998	0.009	0.486	0.003	0.727	0.257
	Thunnus tonggol	Large	0.195	0.002	0.111	0.002	0.094	0.003	0.133	0.054
		Medium	0.180	0.001	0.100	0.001	0.089	0.001	0.123	0.049
		Small	0.141	0.002	0.085	0.004	0.084	0.000	0.103	0.032
	Sphyraena jello	Large	0.095	0.002	0.071	0.002	0.072	0.001	0.079	0.013
		Medium	0.059	0.001	0.054	0.003	0.063	0.001	0.058	0.005
		Small	0.055	0.002	0.041	0.001	0.045	0.000	0.047	0.007
	Epinephelus areolatus	Large	0.138	0.000	0.123	0.000	0.135	0.000	0.132	0.008
		Medium	0.128	0.000	0.115	0.000	0.133	0.000	0.125	0.009
		Small	0.113	0.000	0.103	0.000	0.118	0.000	0.111	0.007
Al Hodaeidah	*Lethrinus mahsena*	Large	0.940	0.042	1.191	0.002	0.989	0.007	1.040	0.133
		Medium	0.743	0.013	1.466	0.373	0.711	0.008	0.973	0.427
		Small	0.696	0.011	1.224	0.014	0.699	0.006	0.873	0.304
	Thunnus tonggol	Large	0.189	0.003	0.106	0.004	0.178	0.001	0.158	0.045
		Medium	0.137	0.004	0.117	0.004	0.159	0.001	0.138	0.021
		Small	0.135	0.002	0.179	0.002	0.136	0.002	0.150	0.025
	Sphyraena jello	Large	0.116	0.002	0.107	0.011	0.117	0.002	0.113	0.006
		Medium	0.091	0.001	0.084	0.003	0.106	0.002	0.094	0.011
		Small	0.058	0.001	0.071	0.001	0.095	0.000	0.075	0.019
	Epinephelus areolatus	Large	0.141	0.000	0.148	0.000	0.153	0.000	0.147	0.006
		Medium	0.136	0.000	0.137	0.000	0.159	0.000	0.144	0.013
		Small	0.132	0.000	0.136	0.000	0.148	0.000	0.138	0.008
Al Mukalla	*Lethrinus mahsena*	Large	0.878	0.003	0.914	0.005	0.774	0.012	0.855	0.073
		Medium	0.983	0.005	0.978	0.003	0.734	0.002	0.898	0.142
		Small	0.987	0.006	1.093	0.008	0.633	0.008	0.904	0.241
	Thunnus tonggol	Large	0.181	0.003	0.112	0.002	0.164	0.001	0.153	0.036
		Medium	0.157	0.002	0.105	0.004	0.134	0.002	0.132	0.026
		Small	0.107	0.002	0.096	0.003	0.116	0.003	0.106	0.010
	Sphyraena jello	Large	0.055	0.001	0.057	0.003	0.067	0.002	0.059	0.006
		Medium	0.034	0.000	0.046	0.000	0.056	0.000	0.045	0.011
		Small	0.025	0.001	0.036	0.002	0.040	0.001	0.033	0.008
	Epinephelus areolatus	Large	0.157	0.000	0.150	0.000	0.148	0.000	0.152	0.005
		Medium	0.122	0.001	0.132	0.000	0.137	0.000	0.130	0.008
		Small	0.114	0.000	0.109	0.000	0.115	0.000	0.112	0.003
Mean±SD			0.284	0.306	0.341	0.434	0.258	0.266	0.294	0.330

Table (2): Cadmium concentrations (µg/g)in Gill samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Cd (µg/g)		Cd (µg/g)		Cd (µg/g)		Cd (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.078	0.001	0.109	0.000	0.099	0.001	0.095	0.016
		Medium	0.072	0.000	0.089	0.001	0.079	0.001	0.080	0.009
		Small	0.067	0.001	0.043	0.002	0.065	0.000	0.058	0.013
	Thunnus tonggol	Large	0.313	0.002	0.651	0.007	0.590	0.002	0.518	0.180
		Medium	0.140	0.000	0.472	0.003	0.409	0.004	0.340	0.177
		Small	0.079	0.000	0.194	0.003	0.206	0.001	0.160	0.070
	Sphyraena jello	Large	0.041	0.000	0.039	0.000	0.073	0.001	0.051	0.019
		Medium	0.038	0.000	0.033	0.001	0.045	0.000	0.038	0.006
		Small	0.036	0.000	0.031	0.000	0.032	0.000	0.033	0.003
	Epinephelus areolatus	Large	0.089	0.001	0.772	0.011	0.675	0.009	0.512	0.369
		Medium	0.081	0.000	0.838	0.040	0.601	0.001	0.507	0.388
		Small	0.069	0.000	0.911	0.005	0.847	0.001	0.609	0.469
Al Hodaeidah	*Lethrinus mahsena*	Large	0.080	0.000	0.101	0.000	0.109	0.000	0.096	0.015
		Medium	0.081	0.001	0.089	0.000	0.091	0.000	0.087	0.005
		Small	0.108	0.001	0.083	0.003	0.080	0.000	0.090	0.015
	Thunnus tonggol	Large	0.433	0.001	0.381	0.002	0.354	0.000	0.389	0.040
		Medium	0.221	0.001	0.177	0.000	0.207	0.001	0.202	0.022
		Small	0.095	0.001	0.105	0.001	0.155	0.000	0.118	0.032
	Sphyraena jello	Large	0.148	0.000	0.087	0.001	0.062	0.000	0.099	0.044
		Medium	0.094	0.000	0.084	0.001	0.057	0.000	0.078	0.019
		Small	0.206	0.001	0.168	0.002	0.081	0.001	0.152	0.064
	Epinephelus areolatus	Large	0.378	0.005	0.635	0.003	0.700	0.001	0.571	0.170
		Medium	0.204	0.001	0.615	0.003	0.644	0.000	0.488	0.246
		Small	0.181	0.000	0.336	0.004	0.418	0.001	0.312	0.120
Al Mukalla	*Lethrinus mahsena*	Large	0.091	0.000	0.100	0.001	0.098	0.001	0.096	0.005
		Medium	0.085	0.000	0.094	0.000	0.095	0.000	0.091	0.006
		Small	0.081	0.000	0.091	0.001	0.088	0.000	0.086	0.005
	Thunnus tonggol	Large	0.293	0.000	0.301	0.002	0.296	0.003	0.297	0.004
		Medium	0.148	0.000	0.199	0.001	0.179	0.000	0.175	0.025
		Small	0.058	0.001	0.075	0.002	0.094	0.001	0.075	0.018
	Sphyraena jello	Large	0.094	0.000	0.111	0.003	0.095	0.000	0.100	0.010
		Medium	0.074	0.000	0.094	0.003	0.090	0.000	0.086	0.011
		Small	0.042	0.000	0.066	0.000	0.071	0.001	0.060	0.015
	Epinephelus areolatus	Large	0.059	0.000	0.145	0.001	0.124	0.000	0.109	0.045
		Medium	0.053	0.000	0.129	0.000	0.113	0.000	0.098	0.040
		Small	0.039	0.000	0.102	0.000	0.101	0.000	0.081	0.036
Mean±SD			0.124	0.097	0.238	0.250	0.226	0.228	0.195	0.175

Table (3): Mercury concentrations (µg/g) in Gill samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			Hg (µg/g)		Hg (µg/g)		Hg (µg/g)		Hg (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.012	0.000	0.011	0.000	0.010	0.000	0.011	0.001
		Medium	0.010	0.000	0.009	0.000	0.008	0.000	0.009	0.001
		Small	0.009	0.000	0.008	0.000	0.008	0.000	0.008	0.001
	Thunnus tonggol	Large	0.017	0.000	0.018	0.000	0.019	0.000	0.018	0.001
		Medium	0.011	0.000	0.015	0.000	0.015	0.000	0.014	0.002
		Small	0.009	0.000	0.010	0.000	0.010	0.000	0.010	0.001
	Sphyraena jello	Large	0.016	0.000	0.015	0.000	0.014	0.000	0.015	0.001
		Medium	0.015	0.000	0.015	0.000	0.013	0.000	0.014	0.001
		Small	0.015	0.000	0.014	0.000	0.011	0.000	0.013	0.002
	Epinephelus areolatus	Large	0.012	0.000	0.012	0.000	0.013	0.000	0.012	0.001
		Medium	0.012	0.000	0.012	0.000	0.012	0.000	0.012	0.000
		Small	0.010	0.000	0.010	0.000	0.009	0.000	0.010	0.001
Al Hodaeidah	*Lethrinus mahsena*	Large	0.022	0.000	0.020	0.000	0.023	0.000	0.022	0.002
		Medium	0.019	0.000	0.018	0.000	0.023	0.000	0.020	0.002
		Small	0.016	0.000	0.015	0.000	0.017	0.000	0.016	0.001
	Thunnus tonggol	Large	0.028	0.000	0.033	0.000	0.044	0.000	0.035	0.009
		Medium	0.025	0.000	0.027	0.000	0.023	0.000	0.025	0.002
		Small	0.018	0.000	0.021	0.000	0.020	0.000	0.019	0.001
	Sphyraena jello	Large	0.025	0.000	0.027	0.000	0.034	0.000	0.029	0.005
		Medium	0.022	0.000	0.023	0.000	0.024	0.000	0.023	0.001
		Small	0.012	0.000	0.019	0.000	0.022	0.000	0.018	0.005
	Epinephelus areolatus	Large	0.013	0.000	0.012	0.000	0.012	0.000	0.012	0.000
		Medium	0.012	0.000	0.012	0.000	0.011	0.000	0.011	0.000
		Small	0.011	0.000	0.010	0.000	0.010	0.000	0.010	0.000
Al Mukalla	*Lethrinus mahsena*	Large	0.012	0.000	0.012	0.000	0.018	0.000	0.014	0.004
		Medium	0.010	0.000	0.010	0.000	0.015	0.000	0.012	0.003
		Small	0.009	0.000	0.009	0.000	0.010	0.000	0.010	0.001
	Thunnus tonggol	Large	0.022	0.000	0.021	0.000	0.022	0.000	0.021	0.001
		Medium	0.017	0.000	0.019	0.000	0.018	0.000	0.018	0.001
		Small	0.014	0.000	0.015	0.000	0.016	0.000	0.015	0.001
	Sphyraena jello	Large	0.022	0.000	0.025	0.000	0.022	0.000	0.023	0.002
		Medium	0.021	0.000	0.022	0.000	0.020	0.000	0.021	0.001
		Small	0.017	0.000	0.020	0.000	0.018	0.000	0.018	0.001
	Epinephelus areolatus	Large	0.011	0.000	0.010	0.000	0.008	0.000	0.010	0.002
		Medium	0.010	0.000	0.009	0.000	0.007	0.000	0.009	0.001
		Small	0.009	0.000	0.008	0.000	0.007	0.000	0.008	0.001
Mean±SD			0.015	0.005	0.016	0.006	0.016	0.008	0.016	0.006

Table (4): Arsenic concentrations (µg/g) in Gill samples

Site	Species	Size	Seasons						Total	
			Winter 2011		Summer 2012		Winter 2013			
			As (µg/g)		As (µg/g)		As (µg/g)		As (µg/g)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Aden	*Lethrinus mahsena*	Large	0.025	0.000	0.027	0.000	0.024	0.000	0.025	0.001
		Medium	0.019	0.000	0.021	0.000	0.019	0.000	0.020	0.001
		Small	0.016	0.000	0.017	0.000	0.016	0.000	0.016	0.001
	Thunnus tonggol	Large	0.047	0.000	0.051	0.000	0.046	0.000	0.048	0.003
		Medium	0.022	0.000	0.024	0.000	0.022	0.000	0.023	0.001
		Small	0.018	0.000	0.020	0.000	0.018	0.000	0.019	0.001
	Sphyraena jello	Large	0.022	0.000	0.024	0.000	0.021	0.000	0.022	0.001
		Medium	0.020	0.000	0.021	0.000	0.019	0.000	0.020	0.001
		Small	0.020	0.000	0.022	0.000	0.020	0.000	0.018	0.006
	Epinephelus areolatus	Large	0.013	0.000	0.013	0.000	0.013	0.000	0.013	0.000
		Medium	0.012	0.000	0.012	0.000	0.011	0.000	0.012	0.001
		Small	0.011	0.000	0.011	0.000	0.010	0.000	0.014	0.005
Al Hodaeidah	*Lethrinus mahsena*	Large	0.047	0.000	0.043	0.000	0.046	0.000	0.046	0.002
		Medium	0.038	0.000	0.034	0.000	0.037	0.000	0.036	0.002
		Small	0.027	0.000	0.025	0.000	0.027	0.000	0.026	0.001
	Thunnus tonggol	Large	0.075	0.001	0.068	0.001	0.073	0.001	0.072	0.004
		Medium	0.051	0.001	0.046	0.001	0.050	0.001	0.049	0.002
		Small	0.036	0.000	0.032	0.000	0.035	0.000	0.034	0.002
	Sphyraena jello	Large	0.035	0.000	0.032	0.000	0.034	0.000	0.033	0.002
		Medium	0.029	0.000	0.026	0.000	0.028	0.000	0.027	0.001
		Small	0.017	0.000	0.015	0.000	0.016	0.000	0.016	0.001
	Epinephelus areolatus	Large	0.013	0.000	0.012	0.000	0.012	0.000	0.013	0.000
		Medium	0.012	0.000	0.012	0.000	0.012	0.000	0.012	0.000
		Small	0.012	0.000	0.011	0.000	0.011	0.000	0.011	0.000
Al Mukalla	*Lethrinus mahsena*	Large	0.026	0.000	0.028	0.000	0.025	0.000	0.026	0.001
		Medium	0.020	0.000	0.022	0.000	0.020	0.000	0.021	0.001
		Small	0.016	0.000	0.018	0.000	0.016	0.000	0.017	0.001
	Thunnus tonggol	Large	0.058	0.001	0.063	0.001	0.058	0.001	0.060	0.003
		Medium	0.034	0.000	0.037	0.000	0.034	0.000	0.035	0.002
		Small	0.028	0.000	0.030	0.000	0.027	0.000	0.028	0.001
	Sphyraena jello	Large	0.031	0.000	0.034	0.000	0.031	0.000	0.032	0.002
		Medium	0.027	0.000	0.029	0.000	0.026	0.000	0.027	0.001
		Small	0.023	0.000	0.025	0.000	0.023	0.000	0.024	0.001
	Epinephelus areolatus	Large	0.125	0.000	0.116	0.000	0.115	0.000	0.118	0.006
		Medium	0.122	0.000	0.109	0.001	0.113	0.000	0.115	0.006
		Small	0.103	0.000	0.098	0.001	0.107	0.000	0.103	0.004
Mean±SD			0.035	0.029	0.034	0.026	0.034	0.028	0.034	0.027

Appendix 8

Table (1): One-way ANOVA results for the effects of seasons and species and size in Metal concentrations . Shown are F values (F) and significance (P).

Sites	Tissue	Metal (μg/g)	Season		Species		Size	
			F	P	F	P	F	P
Aden	Muscles	Pb	0.837	0.442	35.100	0.000	1.387	0.264
		Cd	7.288	0.002	4.293	0.012	3.978	0.028
		Hg	0.023	0.977	44.291	0.000	1.069	0.355
		As	0.008	0.992	12.468	0.000	8.478	0.001
	Liver	Pb	0.902	0.416	35.437	0.000	0.533	0.592
		Cd	4.226	0.023	9.000	0.000	0.426	0.657
		Hg	0.052	0.950	34.779	0.000	2.126	0.135
		As	0.147	0.864	15.185	0.000	3.804	0.033
	Gill	Pb	0.240	0.788	100.600	0.000	0.002	0.998
		Cd	3.145	0.056	11.734	0.000	0.227	0.798
		Hg	0.111	0.895	8.837	0.000	6.148	0.005
		As	1.071	0.354	6.451	0.002	5.571	0.008
Al Hodaeidah	Muscles	Pb	0.965	0.391	12.461	0.000	3.604	0.038
		Cd	0.391	0.680	16.603	0.000	5.129	0.011
		Hg	0.460	0.635	37.617	0.000	1.458	0.247
		As	0.171	0.843	5.984	0.002	3.645	0.037
	Liver	Pb	0.735	0.487	43.185	0.000	0.191	0.827
		Cd	0.018	0.982	309.586	0.000	0.090	0.914
		Hg	0.598	0.556	24.444	0.000	1.818	0.178
		As	1.814	0.179	9.677	0.000	3.816	0.032
	Gill	Pb	0.337	0.716	78.717	0.000	0.058	0.944
		Cd	0.361	0.700	17.836	0.000	1.303	0.285
		Hg	0.620	0.544	13.653	0.000	4.678	0.016
		As	0.644	0.532	4.082	0.015	0.433	0.652
Al Mukalla	Muscles	Pb	0.222	0.802	47.797	0.000	1.547	0.228
		Cd	4.745	0.015	4.215	0.013	2.945	0.067
		Hg	0.064	0.938	21.976	0.000	3.253	0.051
		As	0.451	0.641	5.276	0.005	12.538	0.000
	Liver	Pb	0.092	0.912	108.323	0.000	0.144	0.867
		Cd	3.001	0.063	6.311	0.002	7.987	0.001
		Hg	1.260	0.297	13.832	0.000	3.560	0.040
		As	0.169	0.845	30.467	0.000	2.645	0.086
	Gill	Pb	0.103	0.903	244.472	0.000	0.006	0.994
		Cd	0.850	0.437	6.939	0.001	4.827	0.014
		Hg	0.038	0.963	42.318	0.000	2.130	0.135
		As	0.035	0.966	199.734	0.000	0.493	0.615

Table (2): Two-way ANOVA analysis results for metals concentrations during the seasons at the three sites (AL-Hodaeidah, Aden and AL-Mukalla).Shown are F values (F) and significance (P).

Tissue	Factors	Pb		Cd		Hg		As	
		F	P	F	P	F	P	F	P
Muscles	Sites	15.500	0.000	4.928	0.009	0.285	0.753	0.634	0.533
	Seasons	1.755	0.178	6.454	0.002	0.176	0.839	0.009	0.991
Liver	Sites	6.169	0.003	10.298	0.000	0.673	0.512	0.111	0.895
	Seasons	1.202	0.305	0.769	0.466	1.456	0.238	0.113	0.893
Gill	Sites	0.605	0.548	4.952	0.009	17.887	0.000	9.253	0.000
	Seasons	0.540	0.584	3.675	0.029	0.410	0.664	0.312	0.733

Table (3): Two-way ANOVA analysis results for metals concentrations during the Species at the three Size (Large , Medium and Small).Shown are F values (F) and significance(P).

Tissue	Factors	Pb (µg/g)		Cd (µg/g)		Hg (µg/g)		As (µg/g)	
		F	P	F	P	F	P	F	P
Muscles	Species	31.637	0.000	20.522	0.000	84.757	0.000	44.134	0.000
	Size	9.253	0.000	17.107	0.000	18.853	0.000	49.393	0.000
Liver	Species	43.345	0.000	20.797	0.000	75.317	0.000	76.301	0.000
	Size	1.052	0.353	.690	0.504	22.962	0.000	33.473	0.000
Gill	Species	260.826	0.000	18.243	0.000	23.078	0.000	4.267	0.007
	Size	0.417	0.660	2.691	0.073	12.101	0.000	1.543	0.219

Table (4): One-way ANOVA results for the effects of seasons in Metal concentrations . Shown are F values (F) and significance (P).

Sites	Metal	Season at Seawater		Season at Sediments	
		F	P	F	P
Aden	Pb	6.984	0.004	6.034	.008
	Cd	7.784	0.002	100.590	0.000
	Hg	22.235	0.000	20.624	0.000
	As	2.043	0.152	5.472	0.011
Al Hodaeidah	Pb	0.883	0.426	103.429	0.000
	Cd	1.634	0.216	10.709	0.000
	Hg	7.736	0.003	7.554	0.003
	As	6.395	0.006	6.198	0.007
AL Mukallala	Pb	8.659	0.001	39.988	0.000
	Cd	25.997	0.000	153.955	0.000
	Hg	17.743	0.000	9.282	0.001
	As	0.952	0.400	14.986	0.000

Table (5): Two-way ANOVA analysis results for metals concentrations during the seasons at the three sites (AL-Hodaeidah, Aden and AL-Mukalla) in filtered water surface .Shown are F values (F) and significance (P).

Factors	Pb		Cd		Hg		As	
	F	P	F	P	F	P	F	P
Seasons	1.844	0.165	9.955	0.000	7.253	0.001	4.300	0.017
Sites	19.358	0.000	3.185	0.047	13.915	0.000	204.857	0.000

Table (6): Two-way ANOVA analysis results for metals concentrations during the seasons at the three sites (AL-Hodaeidah, Aden and AL-Mukalla) in Sediments .Shown are F values (F) and significance (P).

Factors	Pb		Cd		Hg		As	
	F	P	F	P	F	P	F	P
Seasons	32.228	0.000	37.514	0.000	18.897	0.000	15.312	0.000
Sites	3398.805	0.000	2118.348	0.000	2.485	0.090	2.352	0.102