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MOLLUSKAN TISSUES AS AN ACCUMULATION SITES FOR HEAVY METALS FROM LIBYAN COAST IN NORTH-EAST LIBYA

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A number of living marine gastropods (Phorcus turbinata and Patella caerulea) which are commonly inhabited the rocky beach of meso-infra littoral zones in the entire Circum-Mediterranean coast are collected from nine coastal localities (Benghazi "Ashbilia and Sabri)", Tocra, Tolmeita, Al Haniyah, Al Hamamah, Susa, Hawa Eftaih and Ras Al Hilal) in April, 2018. The inductively coupled plasma mass spectrometer (ICPMS) was performed on the soft body for measuring the environment-sensitive elements such as Fe, Sn, Sb, Cu, Zn, Pb, Ni, As, Hg and Se. All analyzed metals are mainly of anthropogenic origin (excluding Fe). The statistical treatment indicates that most heavy metals are mutually correlated, but there is an absence of strong correlations among some metals, which suggests that these metals are possibly of different sources. The concentrations of all metals are below the recommended guideline in seafood, except for As in Phorcus turbinata and Pb in Patella caerulea. Moreover, the Phorcus turbinata is a good accumulator for Fe, Ni, As and Hg, whereas Patella caerulea is a collector for Cu, Zn and Pb. Additionally, the contamination indices suggest that Susa (distillation station) and Sabri are the most polluted areas.

***Keywords**: Mollusks, Heavy metals, Pollution, Phorcus turbinata, Patella caerulea, Libya*

INTRODUCTION

In the last few decades, increasing attention has been paid to the relationship between the conformation of heavy metals and their impact on aquatic organisms. The anthropogenic activity usually deteriorates the marine water with toxic metals where arise from agricultural, industrial, and urban effluents that reach the coast through the waterways, surface runoff, and precipitation. Both benthic and pelagic species may thus become contaminated by direct uptake and / or through biomagnifications. Therefore, an eternal assessment of water quality is necessary. To reveal the presence of pollutants and to measure their toxic effect, some biological indicators can be used, which are suitable for prediction of the expectable toxic influence of known or unknown substances such mollusks, foraminifers and fishes. Metals such as Arsenic (As), Mercury (Hg), Cadmium (Cd), Copper (Cu), Chromium (Cr), lead (Pb), Iron (Fe), Manganese (Mn), Zinc (Zn) do not degrade in general; therefore, they accumulate throughout the trophic chain (Mustafa *et al.*, 2015). Heavy metal toxicity in aquatic organisms, in association with the long residence time within food chains and the potential risk of human exposure, makes it necessary to monitor the levels of these contaminants in marine organisms (Giarratano and Amin, 2010). Accumulation in living organisms leads to concentrations several orders of magnitude higher than those of the surrounding water (Casas *et al.*, 2008). Despite this the relationship between the concentration of a metal in the aqueous phase and in an organism is far from straight forward as the accumulation ratio depends on many factors; some of them have an environmental origin (temperature, pH, salinity, etc.), whereas others are related to biological factors like age, sex, sexual maturity stage, etc. (Mubiana *et al*., 2006). To achieve a better estimate of bioavailable metal exposure, it is recommended that the tissues of the organisms should be analyzed using the accumulation of trace metals, because many benthic organisms accumulate trace metals to the levels reflecting those in the environment. Tissue metal concentrations can reflect contamination, and mollusks in particular may therefore be sensitive biomonitors of anthropogenic metal inputs (Hendozko *et al.,* 2010). Marine animals accumulate considerable concentrations of heavy metal in their tissues. Although numerous metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by structure of free radicals. Consequently, metals disappear the marine ecosystem unsuitable for reproductive, growth and obliterate the biodiversity (Ghosh and Singh, 2005).

MATERIAL AND METHODS

One hundred and fifty living marine snails (gastropods) shells have been collected, 75 of living *Phorcus turbinate* and 75 of *Patella caerulea* from nine localities during spring season of April, 2018. Only soft body, the samples were put in closed container and were stored in freeze for two days. The whole mollusk were then put in 4% formalin and transported to the Laboratory at the Nuclear Materials Authority of Egypt, where the living tissues are chemically analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) instrument. The samples were washed and the soft tissues were removed from the hard shells using a Teflon knife and then sorted into pools of similar size (3.5 – 5 cm) and homogenized by an Ultra-Turrax T25 homogenizer. Ten heavy metals (Iron (Fe), Tin (Sn), Antimony (Sb), Copper (Cu), Zinc (Zn), Lead (Pb), Nickel (Ni), Arsenic (As), Mercury (Hg) and Selenium (Se)) were analyzed using ICP-MS technique (Figure 20). The soft tissues were transferred to 4 ml HNO_3, 3 ml $HClO_4$ and 5 ml HF and evaporated to dryness under 200 ̄C. The residue was dissolved with 5 ml (1:1) HNO_3 by heating. Five ml of 4 ppm indium solution was added as an internal standard. The reference and solutions were introduced by peristaltic pump with 0.18 rpm. Before each measurement, nebulizer and spray chamber were washed by introducing the solution for 3min with 0.5 rpm and 30 seconds with 0.18 rpm.

Location:
Nine localities (Figure 1) distributed along the northeastern coast of Libya extended from Ashbilia beach, Benghazi in the west to the beach facing the Madar Tower site, Ras al Hilal in the east are visited for molluskan collection.

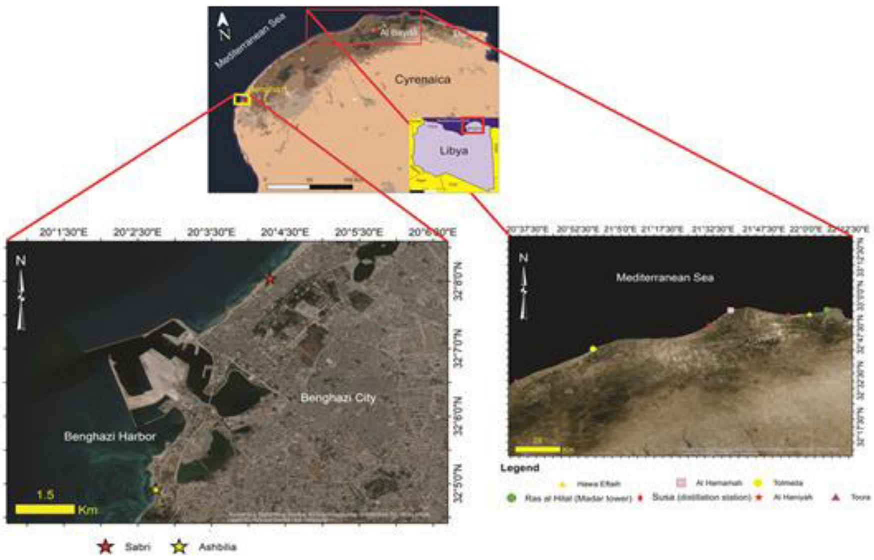

Figure 1. Location maps of the shell collection sites in the northeastern Libya. western area "Ashbilia and Sabri" and eastern area "Tocra, Tolmeta, Al Haniah, Al Hamamah, Susa, Hawa Aftaih, and Madar Tower

The stations are briefly described as follows:

Station 1 (Ashbilia):
It is located at coordinates (Latitude 32° 04΄ 55.2" N and Longitudes 020° 02΄ 44.8" E) (Figure 1). This station is situated in Benghazi City. The collected shells at this station were commonly attached to the beach rocks (Figures 1a and 1b). Some shells in particular "patellids" were heavily encrusted by marine algae.

Station 2 (Sabri):
It is located at coordinates (Latitude 32° 08΄ 02.7" N and Longitudes 020° 04΄ 17.4" E) (Figure 1). This station is situated in Benghazi City at a point named (Corniche). It is generally similar to the Ashbilia sandy to rocky beach. The collected shells at this station were commonly attached to the beach rocks and commonly represented by *P. turbinata* shells (Figure 2a).

Station 3 (Tocra):
It is located at coordinates (Latitude 32° 32΄ 33.5" N and Longitudes 020° 34΄ 04.3" E) (Figure 1). This station is at the ancient Tocra city 50km east of Benghazi city. This beach is predominantly a rocky beach with red color and rich in washed out *Posidonia oceanica* from the sea and partly covered with tar. The collected shells at this station were commonly attached to the beach rocks and represented by both *Patella* and *Phorcus* shells.

Station 4 (Tolmeita):
It is located at coordinate (Latitude 32 °42΄ 53.1" N and Longitudes 020 °56΄ 53.1" E) (Figure 1). It is generally described as largely sandy beach with some rocky patches, which was used only to build up the abounded harbor, on which some shells were attached with few washed out *Posidonia oceanica.* The collected shells at this station were commonly attached to the beach rocks and commonly represented by *P. turbinata* shells

Station 5 (Al Haniyah):
It is located at coordinate (Latitude 32° 50΄ 43.3" N and Longitudes 0.21° 31΄ 12.9" E) (Figure 1). This station represents a coastal village located at Al Jabal al Akhdar of northeast Libya and is 25 km north-west of Al-Bayda city. It is generally described as a calcarenitic rocky beach. The collected shells at this station were commonly attached to the exposed beach rocks. This locality is slightly polluted with Tar, Asphalt, and the domestic water. The *Phorcus* shells are presented in huge numbers (Figure 2b), while *Patella* were few

Station 6 (Al Hamamah):
This station represents a coastal village located at Al Jabal al Akhdar of northeast Libya and is 20 km north-west of Al-Bayda city (Figure 1). It is generally described as a calcarenitic rocky beach. The collected shells at this station were commonly attached to the exposed beach rocks. The presence of tar patches is also being observed (Figure 2c).

Station 7 (Susah):
It is located at coordinate (Latitude 32° 53΄ 44.4" N and Longitudes 021° 54΄ 44.9" E) (Figure 1). This station is a town and seaside resort in the District of Jabal al Akhdar in northeastern Libya .It is generally described as sandy beach intermittent with rocky beach. The collected shells at this station were commonly attached to the beach rocks. Some shells in particular "patellids" were heavily encrusted by marine algae

Station 8 (Hawa Ftaih):
It is located at coordinate (Latitude 32 ° 54΄ 12.4" N and Longitudes 022 ° 00΄ 55.6" E) (Figure 1). This cave is located in Cyrenaica, Eastern Libya, about 8 kilometers east of Susah (the Port of Sousa)

.It is generally described as sandy beach intermittent with fractured rocky beach. The collected shells at this station were commonly attached to the beach rocks. Some shells in particular “patellids” were heavily encrusted by marine algae.

Station 9 (Ras al Hilal):

It is located at coordinate (Latitude 32° 55´ 30.6" N and Longitudes 022° 06´ 04.6" E) (Figure 1). This station described as sandy beach intermittent with flat rocky beach. The collected shells at this station were commonly attached to the beach rocks, where few sporadic tar covering was observed (Figure 2d).

Objectives

The objectives of this paper are to assess the environmental status using living mollusks from the chemical point of view; to measure and compare the ratios of heavy metals in each species *(Patella caerulea and Phorcus turbinata*); and to use of Mollusca as an indicator of pollution using heavy metals.

The Gastropods *Phorcus turbinata* and *Patella caerulea*:

The Mollusks collect chemical pollutants at concentrations an amount of orders of scale above those observed in the water environment. Due to the widespread purpose of Mollusks as bio-monitoring marine animals in the aquatic environment, they have been the subject of numerous studies on the communication of heavy metals.

Mollusks are a large group of living organisms with more or less similar anatomies belonging to five classes, only two species (*Phorcus turbinata* and *Patella caerulea*) are used herein (Figure 3).

Figure 1. a) Rocky beach with molluskan taxa used in this study, a) A view of Sabri "station no. 2" in Benghazi city; b) Assortment of *Phorcus turbinata* at Al Haniyah "station no. 5"; c) Close view shows sporadic tar cover on calcarenite at Al Hamamah "Station no. 6"; d) A view of rocky beach of Ras al Hilal "station no. 9" with tar covering.

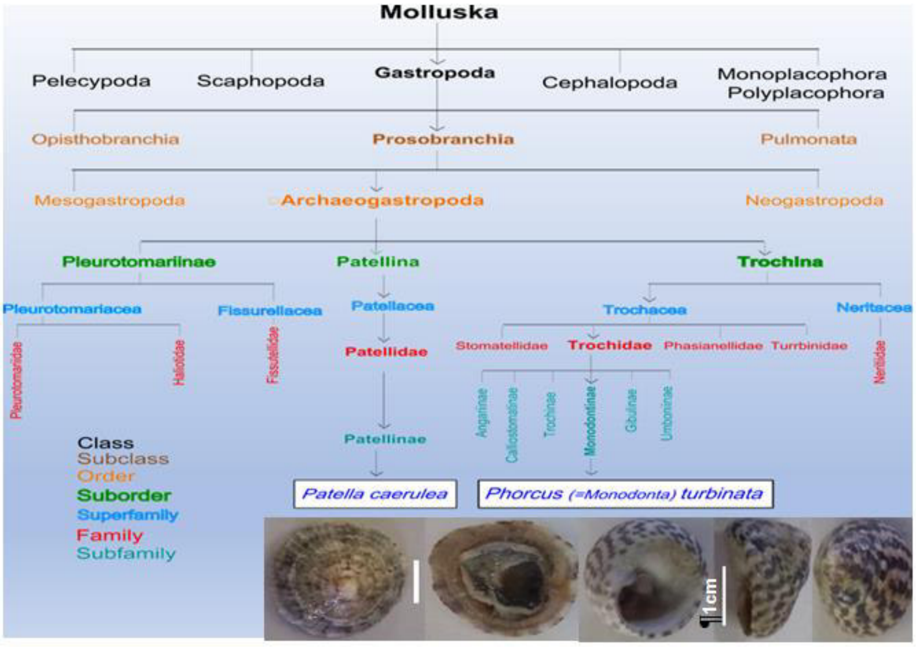

Figure 2. The taxonomical position of the studied *P. caerulea* and *P. turbinate*.

The geographical distribution of the *P. caerulea* and *P. turbinata* along the Mediterranean beach are documented from Spain to Cyprus (Figure 3). The *P. caerulea* is inhabiting the rocky shore from the infralittoral - mesolittoral depths (Sousa *et al*., 2018) (Figure 4A), Whereas, *P. turbinate* is inhabiting mesolittoral depths (Sousa *et al*., 2018) (Figure 4B).

Figure 3. The general geographical distribution of *Patella caerulea* and *Phorcus turbinata* (after Macdonald, 1982)

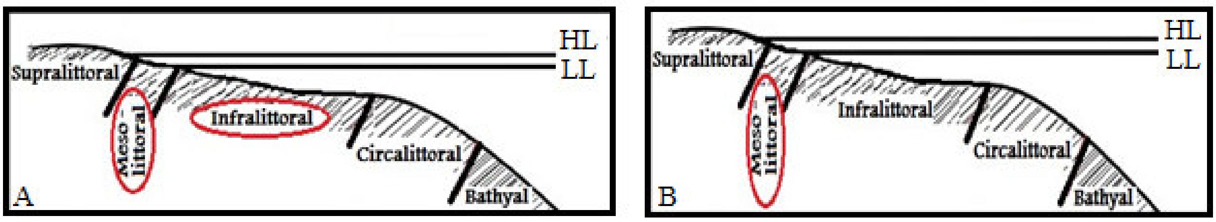

Figure 4. The environmental habitat distribution of A) *Patella caerulea* (infra-mesolittoral habitat zones) and B) *Phorcus turbinata* (mesolittoral habitat zone) (Modified after Macdonald, 1982).

RESULTS AND DISCUSSION

Environmental Geochemistry

Phorcus turbinata and *Patella caerulea* are dominant species of mollusks in the Cyrenaica coast, which is situated on the NE Libya. In this paper, we have focused on the identification of possible bioindicators for trace metal pollution in the soft bodies of these species. This is because it is necessary to identify a wider range of bioindicators and thus expand current understanding of different bioaccumulation strategies for trace metals. The influx of soil from wadis to the coast is the most important natural source of pollution in the study area, while the most important industrial sources are sewage, petroleum pollution, marine paint and desalination. A group of environment-sensitive elements such as Fe, Sn, Sb, Cu, Zn, Pb, Ni, As, Hg and Se were analyzed (Tables 1 and 2).

Table 1. Chemical analysis data (Fe in wt. % and trace elements in ppm) of the soft body of *Phorcus turbinata*

Locality	Fe	Sn	Sb	Cu	Zn	Pb	Ni	As	Hg	Se
Ashbilia	0.58	0.46	0.07	0.58	0.61	0.76	4.23	2.78	0.71	0.21
Sabri	0.88	0.57	0.29	1.68	1.81	2.97	7.00	5.11	2.07	0.39
Tocra	1.67	0.44	0.18	0.56	0.69	0.88	4.11	2.88	0.82	0.23
Tolmeita	1.12	0.17	0.22	0.48	0.65	0.79	2.25	2.33	0.31	0.10
Al Haniyah	0.59	0.11	0.02	0.16	0.21	0.45	1.00	2.00	0.55	0.04
Al Hamamah	0.62	0.06	0.19	0.19	0.21	0.39	1.00	1.87	0.50	0.12
Susa	0.91	0.34	0.41	1.55	1.89	2.86	5.53	5.00	2.28	0.28
Hawa Eftaih	0.62	0.24	0.18	0.16	0.18	0.51	1.33	1.93	0.48	0.16
Ras Al Hilal	0.38	0.40	0.33	0.31	0.46	0.56	1.94	3.13	1.00	0.17

Table 2. Chemical analysis data (Fe in wt. % and trace elements in ppm) of the soft body of *Patella caerulea*

Locality	Fe	Sn	Sb	Cu	Zn	Pb	Ni	As	Hg	Se
Ashbilia	0.05	0.33	0.12	3.49	3.51	18.18	0.66	0.97	0.18	0.17
Sabri	0.17	0.60	0.20	6.66	8.12	29.39	1.67	1.21	0.16	0.42
Tocra	0.10	0.39	0.16	3.58	3.60	18.73	1.05	1.10	0.11	0.29
Tolmeita	0.08	0.21	0.15	3.46	3.49	18.33	0.56	1.13	0.16	0.08
Al Haniyah	0.10	0.05	0.09	2.22	2.07	5.54	0.13	0.88	0.14	0.08
Al Hamamah	0.18	0.05	0.05	2.00	2.00	5.11	0.11	0.60	0.09	0.10
Susa	0.09	0.26	0.29	6.84	8.00	30.09	1.67	1.21	0.16	0.42
Hawa Eftaih	0.12	0.16	0.20	2.31	2.47	6.00	0.07	0.63	0.15	0.21
Ras Al Hilal	0.08	0.51	0.42	3.45	5.57	11.00	0.10	0.92	0.11	0.20

STATISTICAL TREATMENT

The chemical data were processed statistically using the SPSS© program. The statistical analysis includes descriptive statistics (Tables 3 and 4), Pearson's correlation coefficient (Tables 5 and 6) and factor analysis (Tables 7 and 8). The descriptive statistics show that *Phorcus turbinata* and *Patella caerulea* contain high concentrations of As (3ppm) and Pb (15.82ppm), respectively.

The correlation analysis indicates that Fe does not demonstrate any confident coherence to any of the analyzed trace elements, which indicates that natural sources (terra rossa) have a great influence on iron abundance in the study area. Moreover, most heavy metals are mutually correlated, but there is an absence of strong correlations among some metals, which suggests that these metals are possibly of different sources.

Three factors were extracted to explain approximately 93.91 and 89.52% of the total variables in *Phorcus turbinata* and *Patella caerulea*, respectively. The following is a brief discussion of these factors:

Factor one (F1):
It accounts for about 75.63 and 61.68% of the total variables in *Phorcus turbinata* and *Patella caerulea*, respectively. It shows positive loading for Sn, Sb, Cu, Zn, Pb, Ni, As, Hg and Se. It can be nominated as the factor of the environment-sensitive elements.

Factor two (F2):
It accounts for about 10.73 and 14.92% of the total variables in *Phorcus turbinata* and *Patella caerulea*, respectively. It loads positively for Fe. This factor is important in the interpretation of the influx of the wadis to the Mediterranean coast.

Factor three (F3):
It accounts for about 7.55 and 12.92% of the total variables in *Phorcus turbinata* and *Patella caerulea*, respectively. This factor is practically insignificant.

Table 3. Descriptive statistics of metals in *Phorcus turbinata* (Fe in wt. % and trace elements in ppm)

Elements	N	Minimum	Maximum	Mean	Std. Deviation
Fe	9	0.38	1.67	0.82	0.39
Sn	9	0.06	0.57	0.31	0.17
Sb	9	0.02	0.41	0.21	0.12
Cu	9	0.16	1.68	0.63	0.58
Zn	9	0.18	1.89	0.75	0.66
Pb	9	0.39	2.97	1.13	1.03
Ni	9	1.00	7.00	3.15	2.16
As	9	1.87	5.11	3.00	1.25
Hg	9	0.31	2.28	0.97	0.72
Se	9	0.04	0.39	0.19	0.10

Table 4. Descriptive statistics of metals in *Patella caerulea* (Fe in wt. % and trace elements in ppm)

Elements	N	Minimum	Maximum	Mean	Std. Deviatio
Fe	9	0.05	0.18	0.11	0.04
Sn	9	0.05	0.60	0.28	0.19
Sb	9	0.05	0.42	0.19	0.11
Cu	9	2.00	6.84	3.78	1.79
Zn	9	2.00	8.12	4.31	2.38
Pb	9	5.11	30.09	15.82	9.67
Ni	9	0.07	1.67	0.67	0.66
As	9	0.60	1.21	0.96	0.23
Hg	9	0.09	0.18	0.14	0.03
Se	9	0.08	0.42	0.22	0.13

Table 5. Correlation matrix of metals in *Phorcus turbinate*

Elements	Fe	Sn	Sb	Cu	Zn	Pb	Ni	As	Hg	Se
Fe	1.00									
Sn	0.22	1.00								
Sb	0.09	0.33	1.00							
Cu	0.27	0.63	0.62	1.00						
Zn	0.29	0.60	0.67	0.99	1.00					
Pb	0.23	0.56	0.64	0.99	0.99	1.00				
Ni	0.38	0.82	0.45	0.94	0.91	0.89	1.00			
As	0.17	0.70	0.71	0.97	0.97	0.96	0.91	1.00		
Hg	0.09	0.60	0.71	0.93	0.94	0.95	0.83	0.97	1.00	
Se	0.26	0.85	0.57	0.87	0.84	0.84	0.93	0.88	0.83	1.00

Table 6. Correlation matrix of metals in *Patella caerulea*

Elements	Fe	Sn	Sb	Cu	Zn	Pb	Ni	As	Hg	Se
Fe	1.00									
Sn	-0.06	1.00								
Sb	-0.30	0.61	1.00							
Cu	0.04	0.62	0.43	1.00						
Zn	0.05	0.72	0.63	0.96	1.00					
Pb	-0.10	0.62	0.29	0.95	0.86	1.00				
Ni	0.08	0.54	0.17	0.94	0.82	0.96	1.00			
As	-0.30	0.60	0.30	0.81	0.73	0.90	0.83	1.00		
Hg	-0.43	0.15	-0.01	0.44	0.32	0.52	0.41	0.46	1.00	
Se	0.18	0.64	0.46	0.88	0.86	0.80	0.86	0.59	0.24	1.00

Iron (Fe)

Fe is negatively correlated with the analyzed trace elements (Tables 5 and 6). The authors believe that the distribution of Fe in the study area is controlled by the influx of the wadis to the coast. Figure 5 shows that *Phorcus turbinata* is good accumulator for Fe.

The Fe contents in this species are lower than the maximum allowable level in seafood (2%, Food Standards Australia New Zealand (FSANZ, 2008). Moreover, these Fe values are higher than those in the Iskenderun Bay, North-Eastern Mediterranean Sea (0.21%, after Duysak and Ersoy, 2014).

Nickel (Ni)

Ni was measured to be in relatively low concentrations in the studied samples. The lowest concentration (0.07ppm) was measured in *Patella caerulea*, while the highest concentration (7ppm) was measured in *Phorcus turbinata* (Figure 6). The estimated maximum guideline in seafood for Ni is 70 ppm (FSANZ, 2008). Thus, the concentrations of Ni in all the samples are far below the stipulated limit.

Table 7. Factor analysis of the metals in *Phorcus turbinata*

Eigenvalue	7.56	1.07	0.76
% of Variance	75.63	10.73	7.55
Cumulative %	75.63	86.36	93.91
Factor	1	2	3
Fe	0.28	0.84	0.46
Sn	0.74	0.28	-0.52
Sb	0.68	-0.38	0.40
Cu	0.98	-0.02	0.06
Zn	0.98	-0.04	0.14
Pb	0.96	-0.10	0.12
Ni	0.95	0.23	-0.16
As	0.99	-0.13	0.00
Hg	0.95	-0.24	0.04
Se	0.93	0.11	-0.22

Table 8. Factor analysis of the metals in *Patella caerulea*

Eigenvalue	6.17	1.49	1.29
% of Variance	61.68	14.92	12.92
Cumulative %	61.68	76.59	89.52
Factor	1	2	3
Fe	-0.08	0.89	0.36
Sn	0.74	0.13	-0.41
Sb	0.50	0.03	-0.82
Cu	0.98	0.08	0.12
Zn	0.95	0.17	-0.13
Pb	0.96	-0.08	0.21
Ni	0.92	0.08	0.34
As	0.86	-0.27	0.09
Hg	0.46	-0.68	0.33
Se	0.88	0.31	0.01

Copper (Cu) and Zinc (Zn)

The correlation matrix indicates that Cu and Zn are mutual (Tables 5 and 6). Furthermore, in the study area the distributions of these elements are similar (Figs. 7 and 8), indicating their derivation from a common source. Clearly, *Patella caerulea* is fine collector for Cu and Zn. The concentrations of Cu and Zn in the studied samples are below the recommended guideline in seafood (30 and 100 ppm, respectively, FSANZ, 2008).

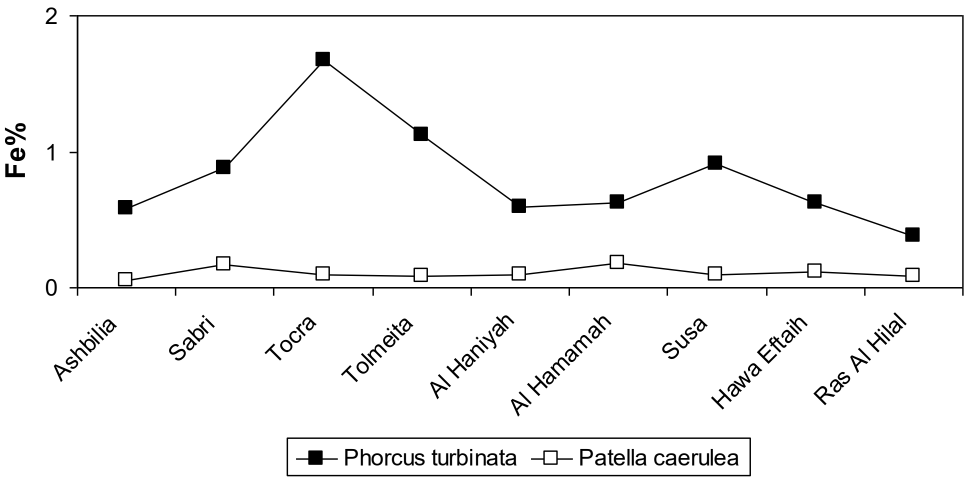

Figure 5. Distribution of Fe in the study area.

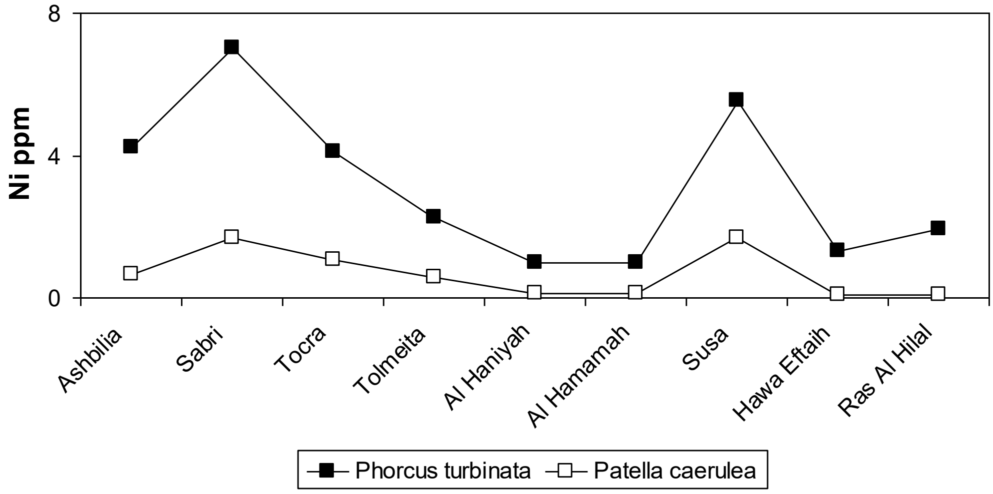

Figure 6. Distribution of Ni in the study area.

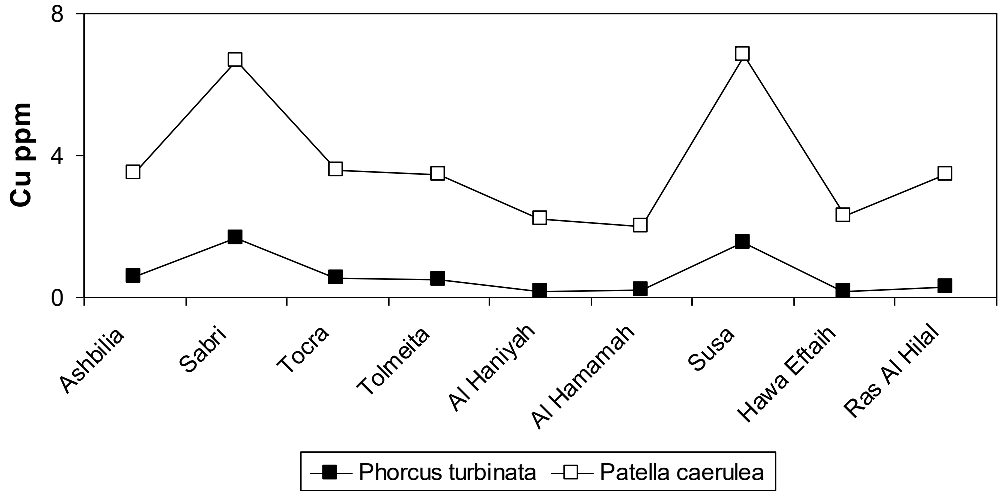

Figure 7. Distribution of Cu in the study area.

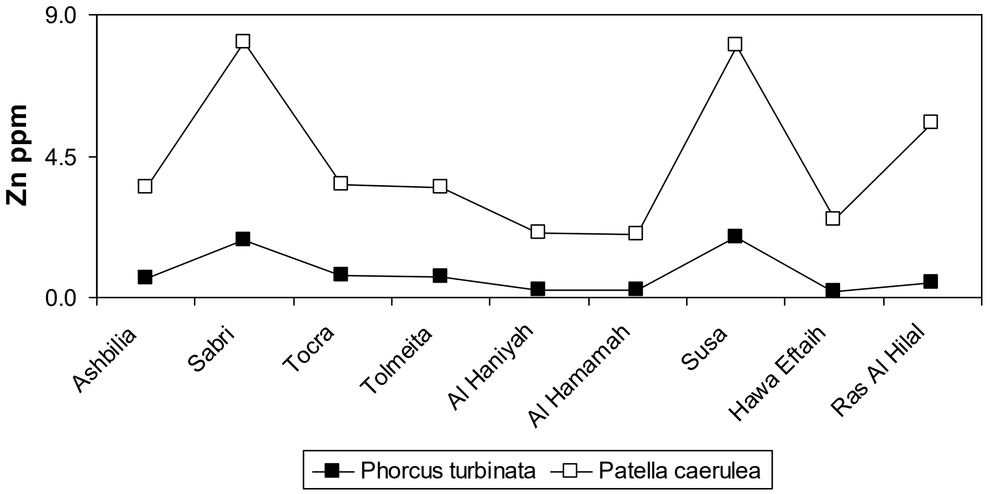

Figure 8. Distribution of Zn in the study area.

Antimony (Sb), Tin (Sn) and Selenium (Se)

The studied species have almost the same sensitivity for Sb, Se and Sn (Figs. 9-11). The Sb, Se and Sn concentrations in the study area are below the maximum recommended limits in seafood (1, 0.5 and 1 ppm, respectively, FSANZ, 2008).

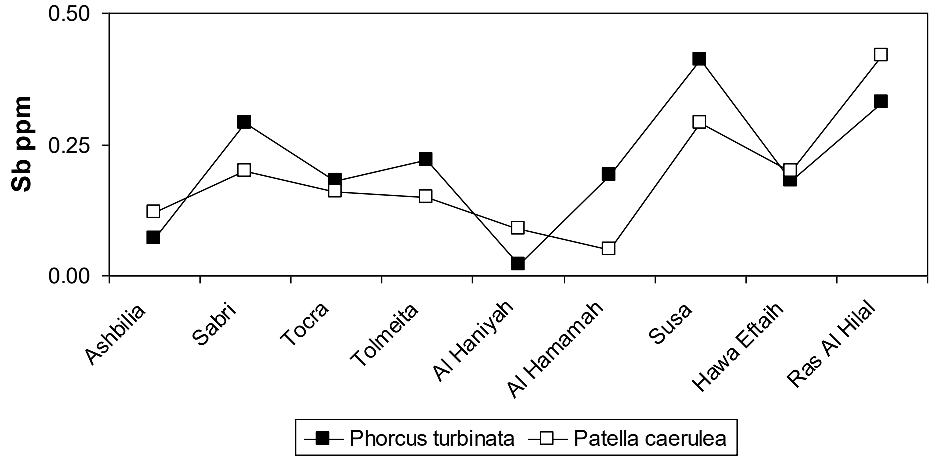

Figure 9. Distribution of Sb in the study area.

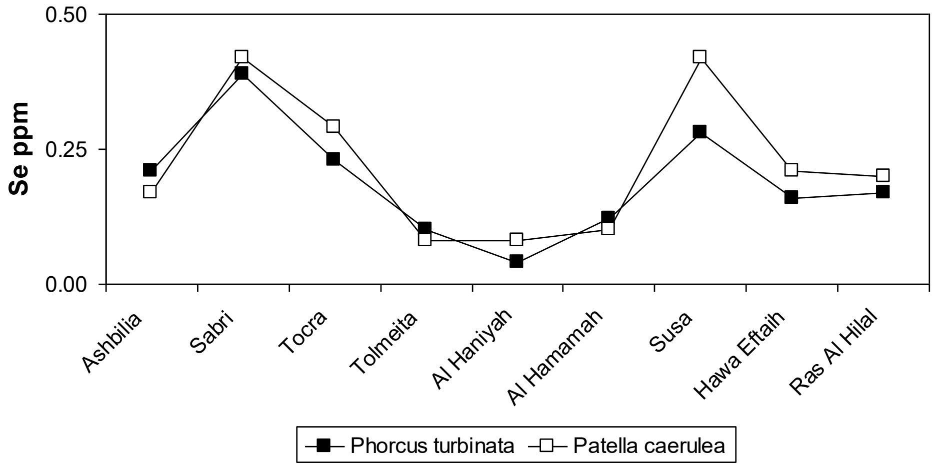

Figure 10. Distribution of Se in the study area.

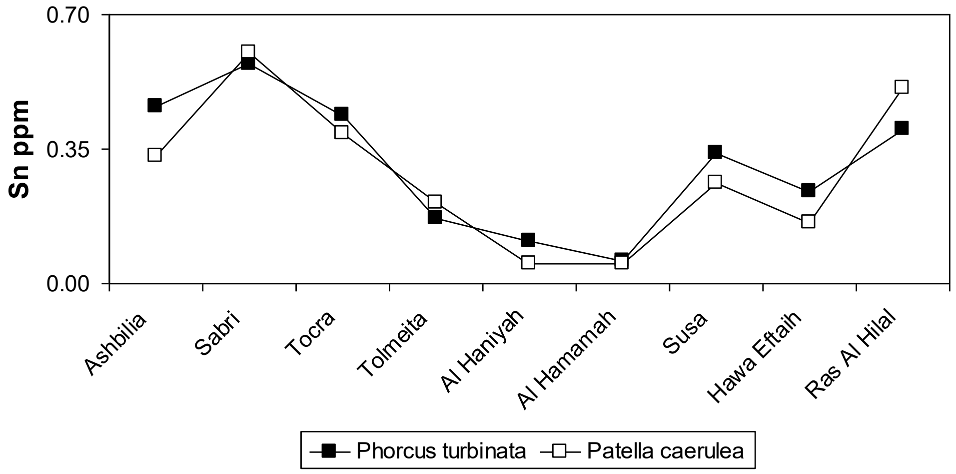

Figure 11. Distribution of Sn in the study area.

Arsenic (As)

The result shows that *Phorcus turbinata* is better accumulator for As than *Patella caerulea* (Fig. 12). Moreover, most *Phorcus turbinata* contain As concentrations above the maximum recommended limits in seafood (2 ppm, FSANZ, 2008). The possible source of the high concentration in both sites of arsenic in Sabri is the sewage of the old slaughterhouse as well as the sewage of the Benghazi Port and distillation station in Susa.

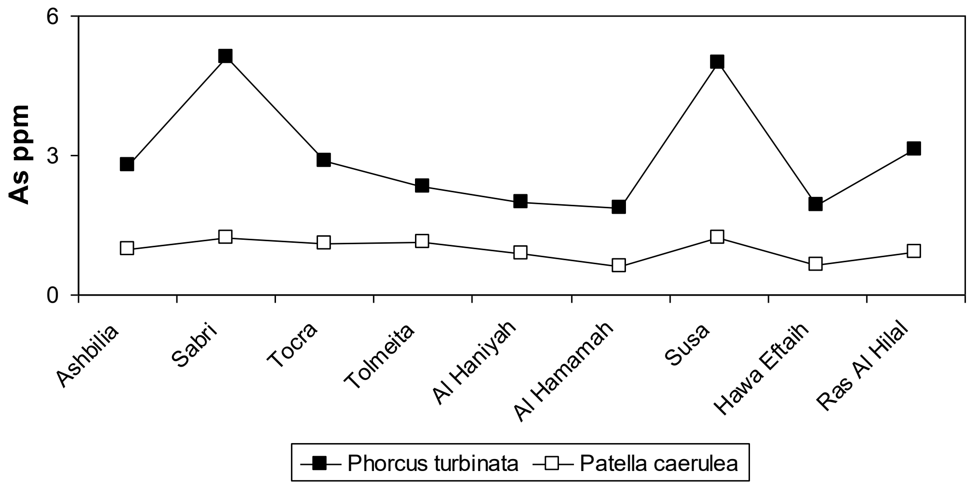

Figure 12. Distribution of As in the study area.

Mercury (Hg)

Like the arsenic, *Phorcus turbinata* is better accumulator for Hg than *Patella caerulea* (Fig. 13). The Hg level in the *Phorcus turbinata* in all localities is within the safe limits in seafood (1 ppm, FSANZ, 2008), except for the distillation station in Susa (2.28 ppm).

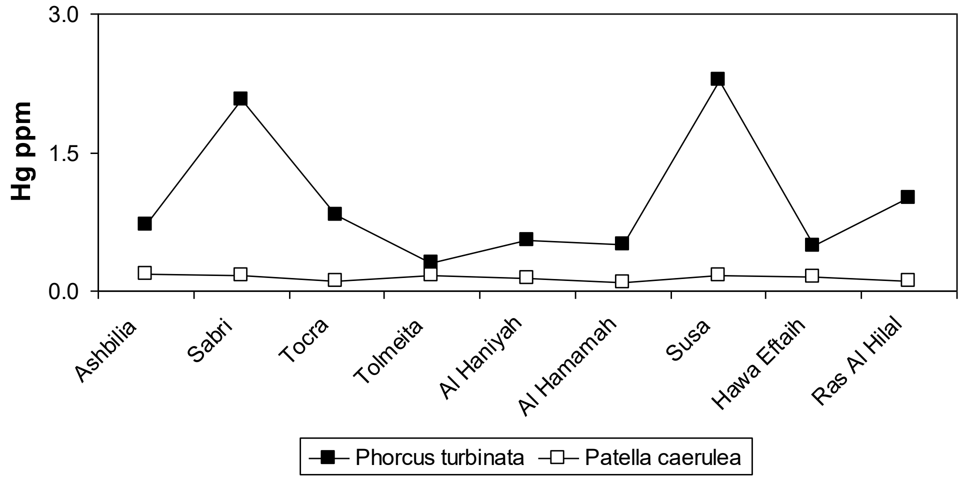

Figure 13. Distribution of Hg in the study area.

Lead (Pb)

Patella caerulea is finer collector for Pb than *Phorcus turbinata* (Fig. 14). It should be noted that the Pb values in the *Patella caerulea* are much higher than the acceptable limit in seafood (2 ppm, FSANZ, 2008). Pb pollution in the study area should be treated especially at Susa (distillation station) and Sabri.

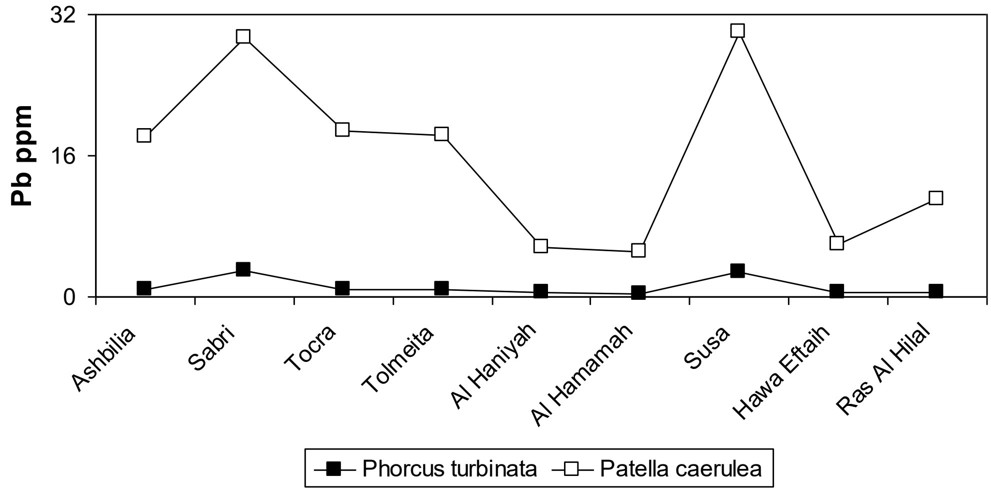

Figure 14. Distribution of Pb in the study area.

CONTAMINATION INDICES

Index of Pollution (IP)

According to Chester *et al.,* (1985) the index of pollution (IP) can be calculated according to the equation: IP = E/threshold. Where, E is the concentration of any element. Acceptable limit in seafood (FSANZ, 2008) are used as the background concentrations for metals. Whenever IP>1 this indicates that additional pollutant input has been introduced to the sample.

The IP of As, Hg and Pb for *Phorcus turbinata* is high (>1) in Susa and Sabri (Figure 15), while in the other metals the factor is low (<1). The IP of the analyzed metals for *Patella caerulea* is low (<1), except for Pb (Table 3.14 and Figure 16).

Metal Pollution Index (MPI)

Regardless the type of species, the overall metal content of mollusks at the investigated locations in the current study, was compared using the metal pollution index (MPI). According to Usero *et al.*, (1996) the MPI can be calculated with the following formula: MPI = $(Fe \times Sn \times Sb \times Cu \times Zn \times Pb \times Ni \times As \times Hg \times Se)^{1/8}$. When the MPI value is high (>1), the area is considered polluted (Usero *et al.*, 1997). The studied species display high MPI values in two localities (i.e. Susa and Sabri, Figure 17). Pollution in the Sabri sea is due to two reasons: (1) Sewage water; and (2) In this area there was a war lasted for four years and therefore there are the remains of decomposed corpses and weapons.

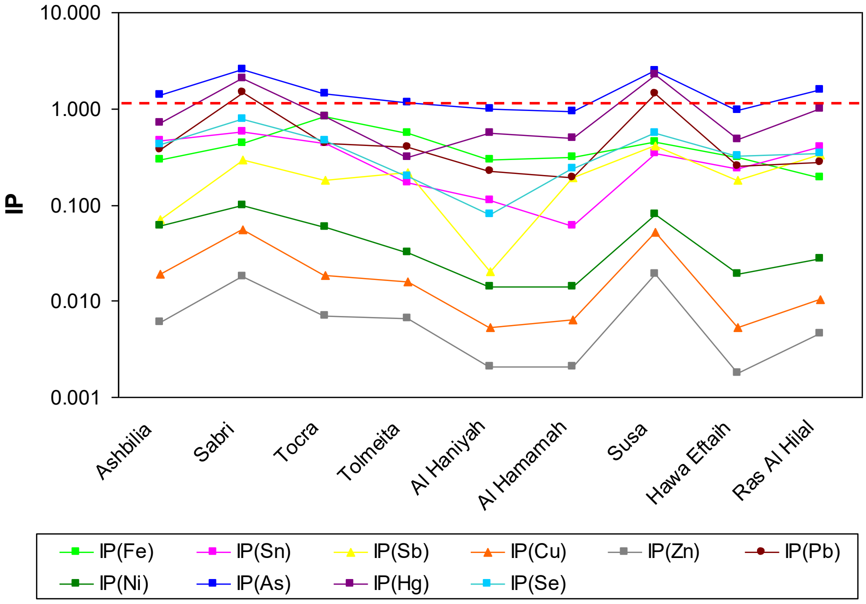

Figure 15. Index of pollution for *Phorcus turbinata*.

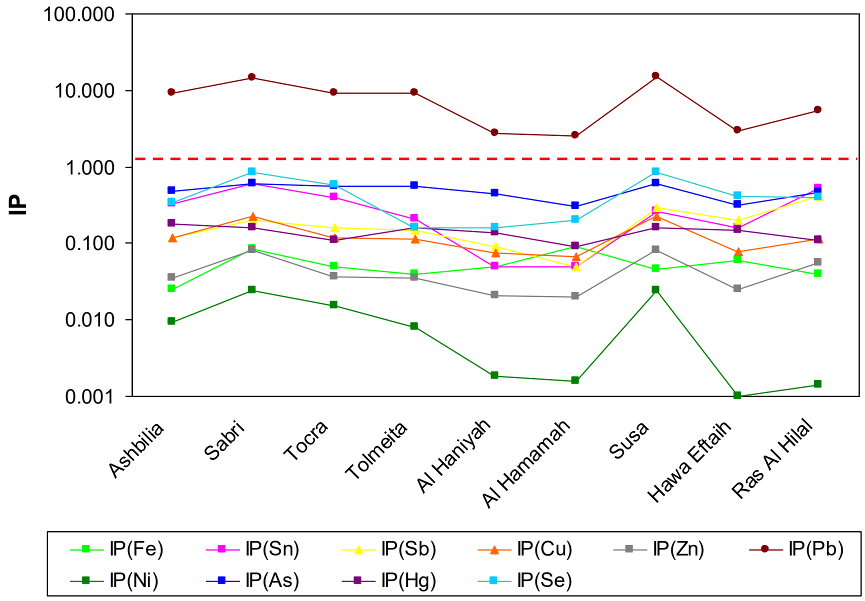

Figure 16. Index of pollution for *Patella caerulea*

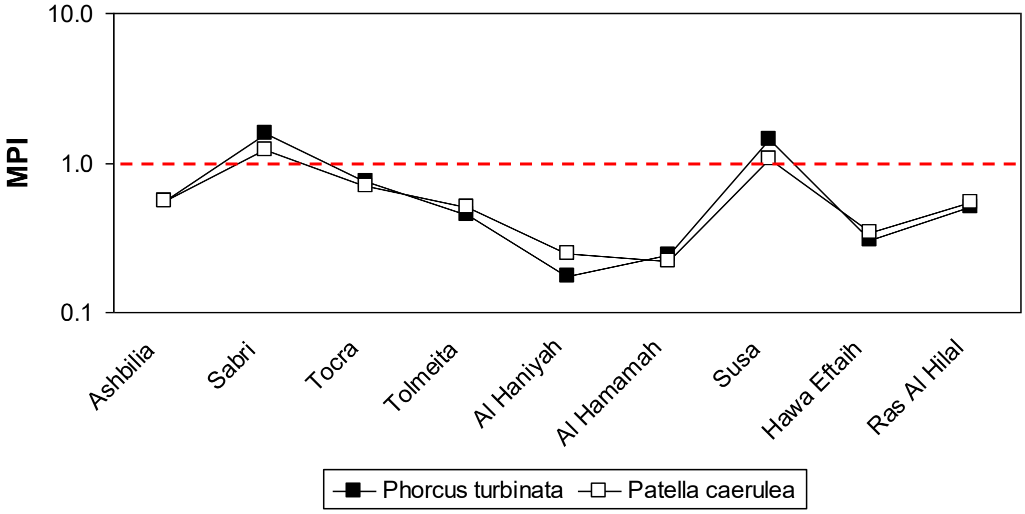

Figure 17. Metal pollution index for the studied species

CONCLUSION

The attached mollusca *Phorcus turbinata* and *Patella caerulea* proved to be a good bioindicator for heavy metals in Libyan rocky beaches. All the analyzed elements (Sn, Sb, Cu, Zn, Pb, Ni, As, Hg and Se) are mainly of anthropogenic origin (excluding Fe). The concentrations of all elements in soft tissue are below the recommended guideline in seafood (FSANZ, 2008). Exceptionally, As in *Phorcus turbinata* and Pb in *Patella caerulea* are above the recommended limit of sea food (2ppm, FSANZ, 2008). The *Phorcus turbinata* is good accumulator for Fe, Ni, As and Hg, while *Patella caerulea* is fine collector for Cu, Zn and Pb. The contamination indices show that the most polluted stations in the study area are Sabri and Susa (distillation station), the former is due to sewage water; and the remains of decomposed corpses and weapons, whereas in Suas is attributed to distillation station and the nearby sewage.

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