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Gastropod shells as pollution indicators, Red Sea coast, Egypt

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ABSTRACT

Thirty samples of gastropod shells belonging to *Nerita albicilla* and *Canarium* (*Gibberulus*) *gibbosus* from 15 stations along the Egyptian Red Sea coast were selected for chemical analysis. The analysis indicated that *Nerita* is a geochemical marker for a sizeable group of trace elements including; Cu, Pb, Zn, Ag, Th, Ba, Tl, S, Sc and Se, while *Canarium* is a good accumulator of the elements, Mo, U, Au and K. Both species have the same selectivity for Ni, Mn, Fe, As, Sr and P. The differences in sensitivity between the two species are attributed to the mode of life and incorporation of the elements within the crystal lattice of calcium carbonates composing the shells. On basis of the obtained data, the study area can be subdivided into three zones namely; almost pristine, moderately polluted zone and markedly polluted. Pollution is mostly attributed to anthropogenic sources.

1. Introduction

Marine organisms can be exposed to high metal concentrations as a result of near shore developmental activities such as coastal mining, harbor dredging, discharge of industrial and domestic effluents into the ocean, urbanization and over population (Bastidas and Garcia, 1999; Esslemont, 2000; Fallon et al., 2002; Gopinath et al., 2009). Many studies were done on the Red Sea environment, and tourism projects and their impact on coastal zone based on the ecological analysis by several authors, e.g., Kotb et al. (2001), Abd El-Wahab and El-Sorogy (2003), Wielgus et al. (2004), Shaalan (2005), El-Sorogy (2008), Madkour and Youssef (2008) and El-Sorogy et al. (2012).

The quantification of pollution magnitude in the aquatic ecosystems is a relatively new field of research. Human environment is tightly linked to the aquatic ecosystems, hence will be subjected, by way or another, to the same pollutants like marine organisms. The present work focuses on the possible toxicity of aquatic organisms by trace metals as a requisite for the protection of this ecosystem rather than an inexpensive safeguard to man, although these aims are not mutually exclusive. In a sense, all organisms pollute their immediate environment, at least by the excretion of waste products. There are few studies on the trace elements concentration in seashells. However, many studies on the tissues of organisms are carried out. Walsh et al. (1995) recorded that gastropods have the potential to act as a useful bio-monitoring system of pollutants in the marine environment.

The main objectives of the present study are to evaluate the levels of pollution along the Red Sea coast from Abu Darag on the Gulf of Suez southwards to Berenice (Fig. 1). Two gastropod species (Fig. 2) are selected for monitoring toxicity by trace metals, namely; *Nerita albicilla* (Linnaeus) and *Canarium* (*Gibberulus*) *gibbosus* (Röding). These two species have a wide geographical distribution along the Red Sea coast, moreover they are large enough, easy to be sampled and have relatively long life time. The selectivity of the two species for trace elements can be considered as geochemical markers in environmental assessment of shore lines.

1.1. Materials and methods

Fifteen shells of living *N. albicilla* and similar number of *Canarium* (*Gibberulus*) *gibbosus* were selected from rocky shore dwellers of fifteen stations to perform complete chemical analysis. These stations (Fig. 1) were chosen to cover the most polluted and most "pristine" sites along the Red Sea coast of Egypt.

The selected shells were washed and the soft tissues were separated from the shells with a glass rod. The shells were cleaned by scrubbing in distilled water with tooth brush to remove loosely attached biogenic and inorganic particles and dried at 80 °C to constant weight. Each shell was crushed and pulverized to −100 mesh grain size and then placed in adequate plastic veils. The analysis of 20 elements (Fe, Cu, Pb, Zn, Ni, Mn, U, Th, Mg, Sr, P, Se, As, Ba,

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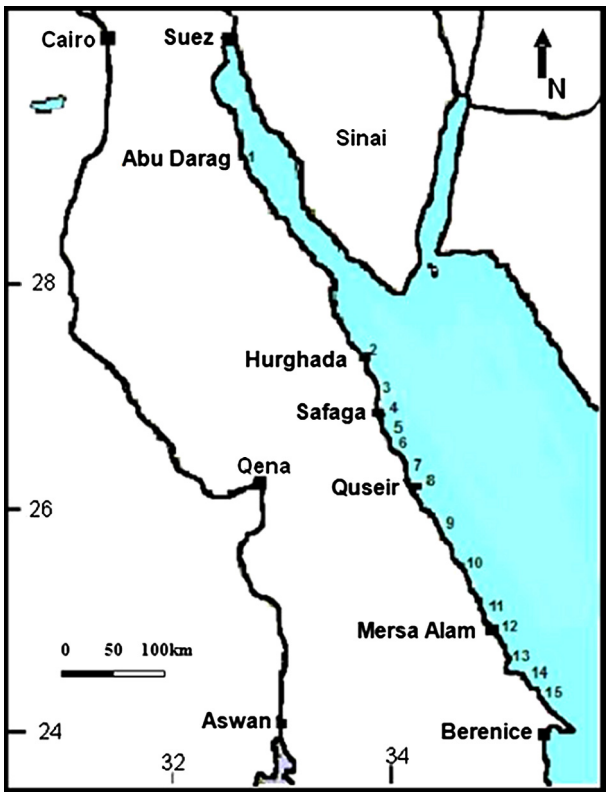

Fig. 1. Location map. Digits 1–15 represent stations of sampling.

Fig. 2. Apertural view of *Nerita albicilla* (left) and *Canarium* (*Gibberulus*) *gibbosus* (right). Bar = 2 cm.

Sc, Mo, Au, Ag, Tl and S) was done by the inductively coupled plasma-mass spectrometry (ICP-MS) in the Analytical Laboratories Ltd., Canada (Tables 1 and 2).

2. Results and discussion

The Red Sea coast has been considered, for a long time, as being relatively unpolluted or almost "pristine". Recently, some forms of pollution such as leakage from oil fields, refining, navigation, phosphate ore shipping, waste, sewage and other activities are associated with mobilization of metal into the marine environment. The modern advances point to the significance of the trace elements content for the food web and the soil–plant–animal chain. Consideration must be given to essentiality, and toxicity which depend on several factors such as concentration, form of the element, speciation, pH, oxidation–reduction potential (Eh), and other factors.

2.1. Studied elements

Tables 1 and 2 illustrate the concentrations of Fe, Cu, Pb, Zn, Ni, Mn, U, Th, Mg, Sr, P, Se, As, Ba, Sc, Mo, Au, Ag, Tl and S in the two studied gastropod species. The following is a detailed description of each element within the two species among the fifteen studied stations.

2.1.1. Iron

Iron is an essential element in the marine ecosystem, where it plays the most vital role in the biogenic activities. It is obvious that *Nerita* and *Canarium* accumulate similar concentrations of iron (0.02%, in average). However, the two species are in many cases not mutually distributed along the studied coastal landstretch. The distribution of iron in both species is very heterogeneous and it seems to be controlled by the influx of the active streams to the Red Sea coast. The maximum content of Fe in *Nerita* and *Canarium* is higher than in other species as in the gastropod shell of *Patella aspera* (35.8 ppm) as estimated by Cravo et al. (2002).

2.1.2. Copper

The highest content of Cu (3.09 ppm) is recorded at 20 km south of Hurghada for *Nerita* and 85 km north of Mersa Alam (1.51 ppm) for *Canarium* (Tables 1 and 2). These values are similar to those reported for the gastropod shells of *Helix aspera* (1.1–3.7 ppm) by Laskowski and Hopkin (1996). It seems that *Nerita* displays higher capability for Cu uptake than the *Canarium*. Possible sources of pollution by Cu, as well as other heavy metals, are renewing the old ships, removing rust, painting the ship bodies and the presence of more than three shipyards near Hurghada city can be considered as a possible source of copper. There is a specific legislation for bivalves in Spain (Boe, 1991), which establishes the maximum allowed concentration for Cu (20 mg/kg). The Cu concentration in both species is much lower than the Spanish bivalves or even the crustal average (25 ppm) as quoted by McLennan and Taylor (1999).

2.1.3. Lead

Lead varies in the analyzed shells between 0.09 and 870 ppm, with very striking selectivity for *Nerita*, which accumulates more than thousand fold the *Canarium*, in average. The latter species contains below 1 ppm Pb with a rather narrow range of variation along the beach from Suez to Berenice (Table 2), while *Nerita* appears to be significantly tolerable for accumulation of Pb and at variable magnitudes (Table 1). The upper limit of Pb content in *Nerita* is more than 40 times the crustal average (20 ppm) as quoted by McLennan and Taylor (1999).

Although the *Nerita* shells at the 20 km south of Hurghada station is the most polluted by Pb (Table 1), many other locations along the beach can also be considered as seriously polluted, e.g., 62 km north of Quseir and Wadi Gusus (Fig. 3). It is evident that *Nerita* can be used as an excellent indicator for Pb pollution in such aquatic system. The Pb content in *Nerita* is very high compared with the gastropod *H. aspera* which contains between 5.7 and 27.7 ppm (Laskowski and Hopkin, 1996). The possible sources of pollution by Pb along the Red Sea coast are variable, where leak of oil and its products seems to be the most influential, as pollution is reinforced in areas of oil shipping and harbors.

2.1.4. Zinc

Zinc is necessary for normal cell division and growth in both plants and animals but can be unsafe if exist in excessive amounts. The availability of Zn is not directly related to total concentration of the metal in the environmental compartment (Allen, 1993). The maximum concentration in *Nerita* is 7.9 ppm while it is only 2.6 ppm for *Canarium*, i.e., the former species is better accumulator

Table 1
Concentrations (ppm) of trace elements in *Nerita albicilla*.

Locations	Fe[a]	Cu	Pb	Zn	Ni	Mn	U	Th	Mg[a]	Sr	P[a]	Se	As	Ba	Sc	Mo	Au[b]	Ag[b]	Tl	S[a]
Abu Darag	0.01	1.51	350.5	7.6	0.1	11	0.1	6.4	0.24	1262	0.003	2.4	2.8	12.5	0.8	0.08	1.5	15	0.3	0.19
Hurghada City	0.03	0.73	13.19	4.7	6.1	8	0.1	2.8	0.22	1135	0.001	0.2	1.9	4.5	0.1	0.03	0.7	8	0.1	0.19
20 km S. Hurghada	0.04	3.09	870.3	7.9	34.8	8	0.1	13	0.27	1075	0.002	0.2	1.6	29.7	0.2	0.22	3.9	492	0.6	0.31
N. Safaga Bay	0.03	0.72	11.72	1.2	4.2	6	0.1	0.8	0.25	1220	0.001	0.2	1.7	2.8	0.1	0.02	0.2	7	0.1	0.18
S. Safaga Bay	0.03	1.35	104.3	2.5	4.9	14	0.1	2.3	0.20	1062	0.004	0.3	2	9.0	0.1	0.02	0.2	21	0.1	0.17
Wadi Gasus	0.02	0.84	517.5	2.1	5.1	3	0.1	3.9	0.30	1137	0.001	0.2	1.3	13	0.1	0.03	1.9	29	0.2	0.18
Hamrawein port	0.01	0.76	109.9	1.8	4.5	7	0.1	3	0.25	1143	0.003	0.2	1.8	14.5	0.1	0.03	1.1	16	0.2	0.17
Qusier City	0.02	1.07	21.23	1.8	5.7	23	0.1	1.5	0.22	1238	0.003	0.2	1.2	10.9	0.1	0.03	0.4	11	0.1	0.18
12 N. Mersa Alam	0.02	0.57	1.17	1.4	6.2	7	0.1	1.2	0.22	1151	0.001	0.2	1.8	2.6	0.2	0.03	0.2	16	0.1	0.17
85 km N. Mersa Alam	0.01	0.63	62.90	2.9	4.4	3	0.1	3.8	0.22	1112	0.002	0.3	1.9	6.8	0.1	0.03	0.6	16	0.1	0.15
40 km N. Mersa Alam	0.01	0.53	71.81	1.6	3.6	5	0.1	1.3	0.24	1149	0.001	0.2	1.8	4.0	0.2	0.02	0.2	7	0	0.14
Mersa Alam City	0.01	1.06	167.6	4.3	4.7	17	0.1	5.2	0.23	1191	0.001	0.1	1.9	8.4	0.2	0.11	0.7	21	0.2	0.1
43 km S. Mersa Alam	0.02	0.68	179.3	2.3	4.5	1	0.1	5.6	0.29	1211	0.001	0.1	1.2	13.2	0.1	0.03	0.3	16	0.2	0.09
87 km S. Mersa Alam	0.01	1.52	101.5	2.4	5.2	3	0.1	2.4	0.26	1186	0.001	0.1	1.6	5.0	0.1	0.02	0.2	8	0.1	0.15
43 km N. Berenice	0.01	0.63	238.2	1.9	4.6	3	0.1	3.2	0.23	1117	0.001	0.2	1.3	6.7	0.1	0.02	0.2	11	0.1	0.15
Mean	0.02	1.05	188	3.09	6.57	7.93	0.10	3.77	0.24	1159	0.00	0.34	1.72	9.57	0.17	0.05	0.82	46.3	0.16	0.17

[a] Concentrations measured by %.
[b] Concentrations measured by ppb.

Table 2
Concentrations (ppm) of trace elements in *Canarium* (*Gibberulus*) *gibbosus*.

Locations	Fe[a]	Cu	Pb	Zn	Ni	Mn	U	Th	Mg[a]	Sr	P[a]	Se	As	Ba	Sc	Mo	Au[b]	Ag[b]	Tl	S[a]
Abu Darag	0.04	0.64	0.93	1.5	6.6	11.0	2.7	1.6	0.03	1727	0.003	0.10	1.7	4.6	0.2	0.09	6.7	10.0	0	0.12
Hurghada City	0.03	0.57	0.37	1.3	5.6	16.0	0.3	0.4	0.03	1228	0.002	0.10	1.6	1.4	0.1	0.63	2.5	15.0	0	0.09
20 km S. Hurghada	0.01	0.25	0.17	1.1	5.9	3.0	0.1	0.2	0.02	1140	0.001	0.10	1.3	1.7	0.1	20.5	1.0	4.0	0.1	0.08
N. Safaga Bay	0.02	0.37	0.19	0.9	5.3	3.0	0.3	0.3	0.03	1669	0.002	0.10	1.3	2.6	0.1	1.30	0.2	3.0	0	0.15
S. Safaga Bay	0.03	0.74	0.30	1.3	6.5	9.0	0.5	1.2	0.02	1490	0.003	0.10	1.4	5.0	0.1	3.75	0.6	5.0	0	0.06
Wadi Gasus	0.01	0.67	0.50	2.6	4.1	2.0	0.1	0.2	0.03	1282	0.002	0.10	2.1	1.5	0.1	4.80	3.8	9.0	0	0.04
Hamrawein port	0.01	0.67	0.39	1.0	4.7	3.0	0.2	2.2	0.03	1405	0.001	0.10	1.3	0.8	0.1	0.86	0.6	4.0	0	0.05
Qusier City	0.02	0.44	0.19	0.9	4.7	4.0	0.2	0.5	0.02	1320	0.009	0.10	1.2	1.8	0.1	0.88	0.4	6.0	0	0.06
12 N. Mersa Alam	0.02	0.30	0.18	1.0	6.1	2.0	0.1	0.1	0.03	1436	0.001	0.10	1.6	0.9	0.1	2.05	0.5	7.0	0	0.08
85 km N. Mersa Alam	0.02	1.51	0.63	1.1	5.3	10.0	1.4	9.1	0.03	1536	0.002	0.15	1.0	2.0	0.2	1.70	0.2	6.0	0	0.02
40 km N. Mersa Alam	0.04	0.58	0.35	1.1	6.3	5.0	0.2	3.2	0.03	1256	0.001	0.11	1.2	3.5	0.1	5.12	0.2	8.0	0	0.01
Mersa Alam City	0.02	0.78	0.20	1.0	4.7	2.0	0.3	1.4	0.02	1533	0.002	0.10	1.2	1.9	0.1	1.24	0.2	3.0	0	0.04
43 km S. Mersa Alam	0.03	0.27	0.09	0.5	5.8	1.0	0.1	0.3	0.02	1339	0.001	0.10	0.8	0.7	0.1	1.53	0.2	4.0	0.1	0.04
87 km S. Mersa Alam	0.03	0.44	0.33	1.3	5.2	3.5	2.0	0.1	0.15	1617	0.002	0.10	1.5	3.2	0.2	0.82	1.0	6.5	0.04	0.16
43 km N. Berenice	0.02	0.30	0.15	0.8	6.4	1.0	0.1	0.2	0.02	1210	0.002	0.10	1.7	0.8	0.1	0.67	0.2	12.0	0	0.01
Mean	0.02	0.57	0.33	1.16	5.55	5.03	0.57	1.40	0.03	1413	0.00	0.10	1.39	2.16	0.12	3.06	1.22	6.83	0.04	0.07

[a] Concentrations measured by %.
[b] Concentrations measured by ppb.

for Zn. The highest uptake of Zn by *Nerita* is recorded at station 20 km south of Hurghada (Table 1) and at Wadi Gasus station for *Canarium* (Fig. 4 and Table 2). Oil harbor and municipal sewages are expected sources to be responsible for accumulation of Pb and Zn in the studied species. However, the obtained data reported that *Nerita* and *Canarium* have Zn content similar to that reported for both the gastropod shell *P. aspera* (5.5 ppm) by Cravo et al. (2002) and *H. aspera* (3.8–15.4 ppm).

2.1.5. Nickel

The maximum concentration of Ni in *Nerita* species is 34.8 ppm while it is only 6.6 ppm for *Canarium*. *Nerita* accumulates Ni up to 5 times higher than *Canarium* (Tables 1 and 2). The highest uptake of Ni by both species is recorded at stations 20 km south of Hurghada and at Abu Darag respectively.

The contribution of Ni to the marine environment can be attained through many anthropogenic ways, such as crude oil seepage, diesel fuel, drilling mud, marine paintings, sewage and landfilling.

2.1.6. Manganese

Along the coastal areas, Mn is controlled mainly by dissolved and particulate Mn derived from the shelf sediments (Fallon et al., 2002). They added, Mn has been hypothesized to substitute for Ca in the $CaCO_3$ lattice, but may also be adsorbed or occluded within aragonite as an oxide or in some aragonite phase.

Nerita and *Canarium* have almost identical selectivity with respect to Mn but they differ in the degree of concentrations, where *Nerita* has higher percentage of Mn than *Canarium*. The maximum concentration in *Nerita* is 23 ppm while it is 16 ppm in *Canarium*. The highest uptake by both *Nerita* and *Canarium* for Mn is recorded at Quseir city and Hurghada stations respectively (Tables 1 and 2). As far as the authors are aware, the role of Mn in the environment and biological diversity of molluscan shells is not yet established. Mn can be transported to the marine environment across landfill, marine paintings, construction residuals, and corrosion of steel constructions and pipelines. Both *Nerita* and *Canarium* have Mn concentration less than *P. aspera* which is 29.9 ppm (Cravo et al., 2002).

2.1.7. Uranium

Uranium is believed to be incorporated into aragonite as a complex anion, probably $UO_2(CO_3)_2^{-2}$ (Shen and Dunbar, 1995). *Nerita* recorded similar value of U in all stations (0.1 ppm) while *Canarium* varies between 0.1 and 2.7 ppm (Table 2). It is obvious that *Canarium* is a better accumulator for U than *Nerita* (Fig. 5). The highest uptake by *Canarium* for U is recorded at the station of Abu Darag.

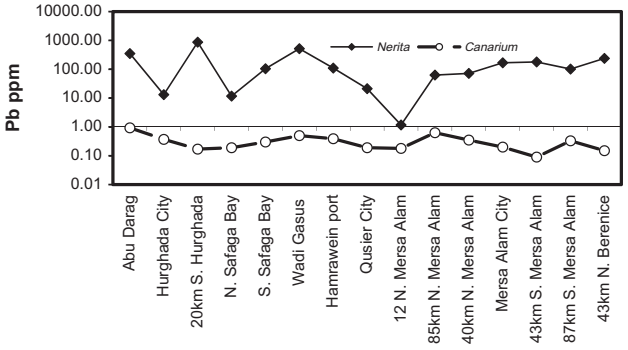

Fig. 3. Severe uptake of Pb by Nerita, relative to Canarium at the studied stations along the Red Sea coast.

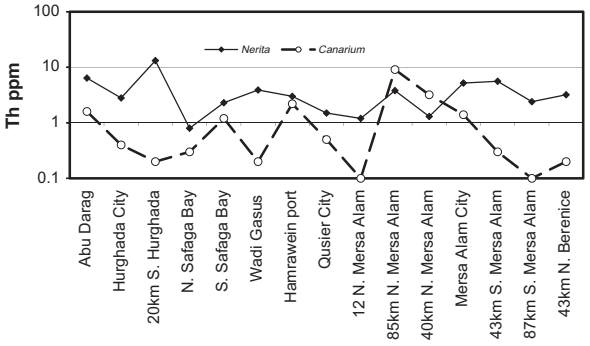

Fig. 6. Distribution of Th in *Nerita* and *Canarium* along the Red Sea coast.

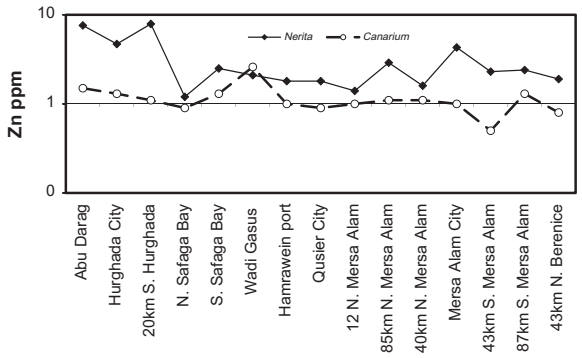

Fig. 4. Distribution of Zn in *Nerita* and *Canarium* along the Red Sea coast.

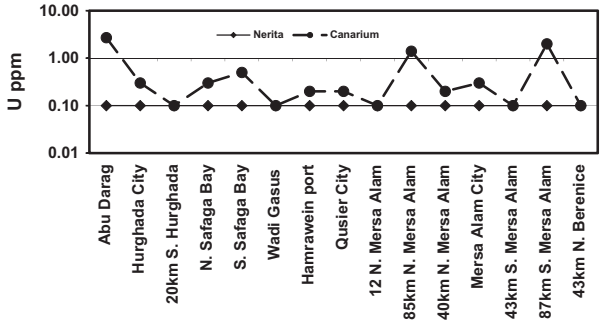

Fig. 5. Distribution of U in *Nerita* and *Canarium* along the Red Sea coast.

The U content in *Canarium* agrees fairly well with the range of other species as *Tridacna* (0.5–0.52 ppm), *Terebralia* (0.12–2.1 ppm) and coral (3.2–3.9 ppm), along the Red Sea coast in Egypt (Choukri et al., 1995). Jones and Manning (1994) considered U enrichment in sediments as a reliable guide for inferring suboxic to anoxic bottom water conditions. Spirakis (1996) observed that the higher U contents are correlated with high organic matter in sedimentary deposits. Whittaker and Kyser (1993) reported that U is generally fractionated from Th at near surface environments. Uranium is mobilized as U^{+6} under oxic conditions and precipitated as U^{+4} in reducing environments, whereas Th is relatively immobile in aqueous solutions (Anderson et al., 1983).

2.1.8. Thorium

Th is one of the naturally occurring radionuclide in the earth's crust with an average of 3.5 μg/g (Taylor and Mc Lennan, 1985). In the present study, Th reaches high levels up to 13.2 ppm, with a relative preponderance to *Nerita* over *Canarium* (Fig. 6). This concentration is very high relative to published data on average crust, biota and flora. The remarkable abnormality of Th in both species (up to 9 ppm for *Canarium* and up to 13 ppm for *Nerita*) is difficult to be interpreted. However, the better selectivity of *Nerita* may point to the importance of the mode of life, where *Nerita* is essentially living on natural or artificial solid surfaces which could be contaminated by Th and other potentially toxic metals.

The Th/U ratio is 3/1 in the endogenic rocks, while it is 1/1700 in the oceanic water (Faure, 1992), suggesting extreme relative enrichment of U in seawater. The habitat of the biota seems to be an influential and controlling factor for the U and Th accumulation. *Canarium*, being better immersed by seawater, In contrary *Nerita* which stick to beach clastics and sediments, sometimes above sea level, is imparted by the high Th from surrounding clastics and low U.

2.1.9. Magnesium

The shells of *Nerita* contain more Mg (up to 0.3%) than those of *Canarium* (0.15%). This agrees with Turekian and Armstrong (1960), where they reported that values in excess of 3000 ppm have been noted in particular with family Neritidae. In average, *Nerita* accumulates Mg up to three times higher than *Canarium*. The highest uptake by the former species for Mg is recorded at wadi Gasus, while 87 km south Mersa Alam is the highest for *Canarium* (Tables 1 and 2). The concentration of Mg in the two species along the studied stations indicates that *Nerita* is better geochemical marker for Mg than *Canarium*. The main source of Mg is probably the weathering of the wide spread clastics derived from mafic and ultramafic volcanics and metavolcanics in the Eastern Desert between Quseir and Berenice.

2.1.10. Strontium

Nerita and *Canarium* have a mutual behavior of Sr, but *Canarium* has higher level of concentration. The maximum concentration is 1262 and 1727 ppm, for *Nerita* and *Canarium* respectively (Tables 1 and 2). This is confirmed with Cravo et al. (2002), who found strontium at higher concentration level in the aragonitic rather than in the calcitic shells. They analyzed six species of the Neritidae family at Bamburi beach, Kenya, and found Sr to be varying from 1288 to 1488 ppm while it is 1318 ppm in the shell of *P. aspera* which has a calcitic shell.

The highest uptake by both species for Sr is recorded at the station of Abu Darag which is the most polluted by the potentially toxic metals such as Pb, Zn and U. Indeed, there is no evidence on the role of increasing Sr content with increasing pollution by toxic metals. The increase in Sr cannot be interpreted to just increasing of plagioclase as reported by Mousa and Ergen (1993).

2.1.11. Phosphorus

Nerita and *Canarium* have a mutual distribution towards P except at Quseir station where *Canarium* displays exceptionally high P content. The maximum concentration in *Nerita* is 0.004%, but increases to 0.009% in *Canarium* (Tables 1 and 2). This indicates that *Canarium* is more sensitive to P, where Quseir area has high potential of P dumped into the coastal zone during shipping of phosphorite ores. El-Askary et al. (1988) reported that phosphorus may be derived from terrestrial source and/or phosphatization of calcareous skeletons. Mansour et al. (1997) attributed the abundance of phosphorus in seagrass sediments due to the relative abundance of organic phosphorus, which may be related to the distribution of specific organisms in which the rate of calcite phosphatization of their shells proceeds at different rates. They also added that the replacement of carbonate particles by phosphate in the fine debris filling carbonate tests and shell-wall is a major source of phosphorus in marine sediments.

2.1.12. Selenium

The maximum concentration in *Nerita* species is 2.4 ppm, while it is only 0.15 ppm for *Canarium* (Tables 1 and 2). *Nerita* accumulates Se up to three times more than *Canarium*. The highest uptake by the former species for Se is recorded at Abu Darag station while the 85 km north Mersa Alam station shows the highest values for *Canarium*. The mutual distribution of Se in the two species indicates that *Nerita* is a better geochemical marker for Se than *Canarium*.

2.1.13. Arsenic

Nerita and *Canarium* have similar ability for uptake of arsenic, where the maximum concentration in the former species is 2.8 ppm in Abu Darag station while it is 1.4 ppm for *Canarium* (Tables 1 and 2). The United Kingdom Food Regulations estimated the maximum permissible limits (MPL) for As to be 1 mg/kg. *Nerita* and *Canarium* of the present work can be considered as polluted with respect to As in most of the sampled stations.

2.1.14. Barium

Nerita is better accumulator for Ba than *Canarium*. The maximum concentration in *Nerita* is 29.7 ppm while it is only 5 ppm in *Canarium*. The highest uptake by *Nerita* is recorded south of Hurghada while for *Canarium* at south of Safaga bay (Tables 1 and 2). The mutual distribution of Ba in the two species confirms the fact that *Nerita* is a better geochemical marker for Ba than *Canarium*. *Nerita* and *Canarium* are also filter-feeder, similar processes might be occurring. Other possible explanations are differences in bioavailability of Ba associated with the respective blooms or ontogenetic variations in the uptake and incorporation of Ba into the shell.

2.1.15. Scandium

Nerita and *Canarium* have the same behavior toward Sc. The maximum concentration in *Nerita* is 0.8 ppm, while it is only 0.2 ppm for *Canarium* (Tables 1 and 2). The highest uptake by both species for Sc is recorded at Abu Darag station. The mutual distribution of Sc in the two species indicates that *Nerita* is a better geochemical marker for Sc than *Canarium*.

2.1.16. Molybdenum and gold

It is noticeable that *Canarium* is a better accumulator for Mo and Au than *Nerita*. The maximum concentrations of Mo and Au in the former species are 20.5 ppm and 6.7 ppb respectively, while they are 0.22 ppm and 3.9 ppb for *Nerita* (Tables 1 and 2).

Canarium accumulates Mo up to 250 times and Au up to eight times higher than *Nerita*. The highest uptake by both *Nerita* and *Canarium* for Mo and Au is recorded at 20 km south of Hurghada station, except Au at Abu Darag station for *Canarium*. Mo shows no confident correlation with any of the analyzed trace or major elements. In *Nerita*, the concentration varies between 0.02 and 0.22, but the upper limit of Mo concentration increases to 5.05 ppm for the *Canarium*. Au shows confident correlation with some of the analyzed elements as Ti, Ba, Th and S in the shell of *Nerita* but such coherence is not clear for *Canarium*.

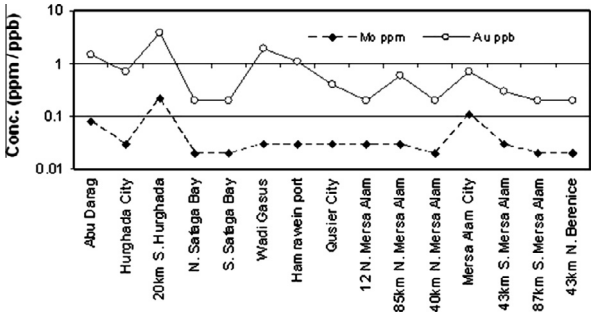

Fig. 7. The relationship between Mo and Au uptake in *Nerita*.

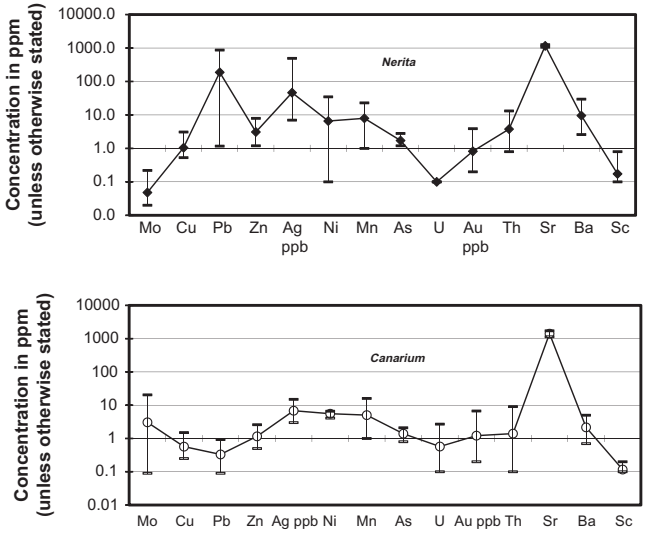

Fig. 8. Abundance of trace elements in the studied two species.

Au and Mo give a good positive relationship for *Nerita* shell (Fig. 7). Molybdenum is an important element that occurs as sulfides (e.g., MoS_2) and is commonly associated with Cu sulfides. Clasts of such sulfides can be fluxed from the basement hinterlands, and they may breakdown upon washing under seawater conditions.

2.1.17. Silver, thallium and sulfur

It is obvious that *Nerita* is a better accumulator for Ag, Tl and S than *Canarium*. The maximum concentrations in the former species are 492 ppm Ag, 0.64 ppm Tl and 0.31% S. While they are only 15 ppb Ag, 0.04 ppm Tl and 0.16% S for *Canarium* (Tables 1 and 2). The highest uptake of the three elements by both species is recorded at 20 km south of Hurghada station, except for S, in *Canarium*. The mutual distribution of Ag in the two species indicates that *Nerita* accumulates about 30 times Ag, 4 times Tl and 2 times S relative to *Canarium*. Ag shows confident correlation with some of the analyzed trace and major elements as Ni, Tl, Au, Th, Ba, S and Fe.

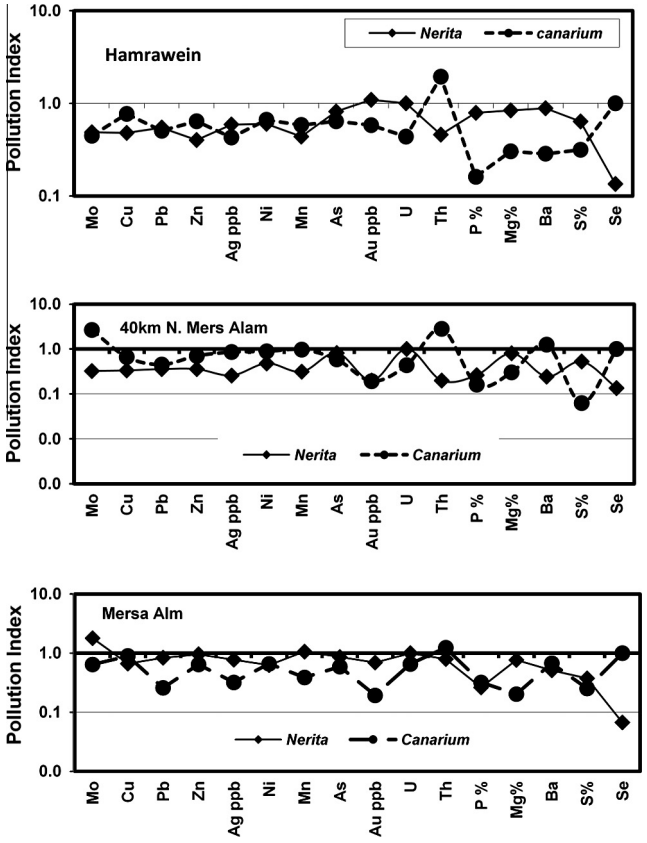

Fig. 9. The distribution of studied elements in the area from Hamrawein to Mersa Alam.

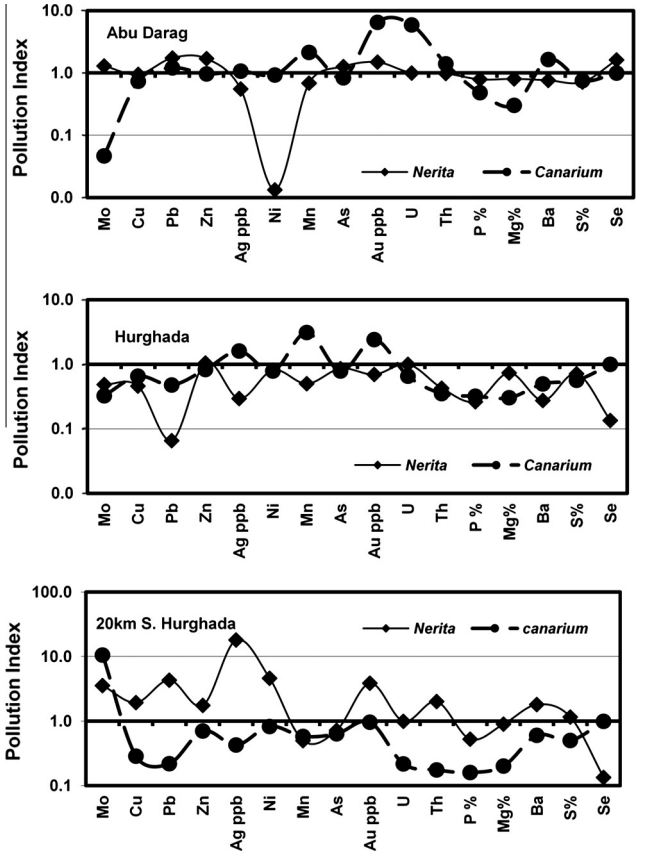

Fig. 10. Distribution of the studied elements in the studied stations from Abu Darag to 20 km to the south of Hurghada.

2.2. Nerita versus Canarium: A comparison

The selective enrichment of certain elements in gastropod shells takes place during its growth. Cravo et al. (2002) concluded that the ultimate chemical assemblage associated with a shell is dictated by two critical factors. In the early stages of shell development and growth mechanism of shell formation, and thereby the chemical composition during the shell matrix, is different from that operating during later stages of growth. During the formative stage, there is selective and preferential incorporation of certain elements. In fact, these relationships are not the same for the two present species (*Nerita* and *Canarium*). They display also very serious differences in abundance of elements, where *Nerita* is a geochemical marker for a sizeable group of trace elements including; Cu, Pb, Zn, Ag, Th, Mg, Ba, Ti, S, Sc and Se. *Canarium* is a good accumulator of the elements, Mo, U and Au, while both species display similar ability for the elements, Ni, Mn, Fe, As, Sr, Cu and P (Fig. 8).

This is possibly due to differences in their incorporation of elements within the crystal lattice of the carbonates composing the skeletons or to the mode of life (Cravo et al., 2002). According to the nature and habitat of life, species *N. albicilla* lives vegetarian, commonly in the intertidal area up to the high tide zone. It can also live for long time away from water where it stores water within shell; hence it can stand long periods of desiccation. The present collected samples of *Nerita* were still living about 30 days after the date of sampling. It lives very close to the beach, clinging on rocky shore making it more exposed to pollution and more subjected to natural and human impacts (Donald and Bosch, 1982). Also *Nerita* is among the most tolerant gastropods to the extreme conditions of heat and desiccation, which exist in the Red Sea

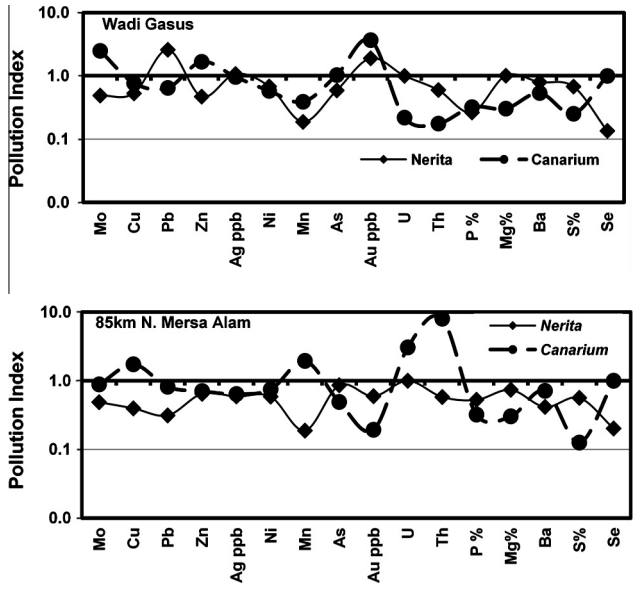

Fig. 11. Distribution of the studied elements in the stations of Wadi Gasus and 85 km North of Mersa Alam.

intertidal and supralittoral zones. Wherever hard substrates are available in the high tide zones, *Nerita* is found there, clinging firmly to either gently sloped or nearly vertical shorelines. The present study indicated that *Nerita* is not only a tolerant for heat

and desiccation but also heavy metals accumulator (for example up to 870 ppm Pb).

The second species *Canarium* is, in contrast, not able to live outside sea water. It is an herbivorous gastropod and lives within shallow sea-grass beds where the sediments are quite fine. The soft sediments are capable of receiving more of the heavy metals and rare earth elements (Bosch et al., 1995).

According to Chester et al. (1985) the index of pollution (IP) can be calculated according to the equation: IP = *conc. E*/*threshold*, where *E* is the concentration of an element. Whenever IP > 1.0 this indicates that additional pollutant input has been introduced to the sample.

3. Conclusions

The Red Sea coast is subjected to natural and anthropogenic sources of trace elements. The natural sources include weathering of rocks, thermal springs, wadi deposits and vegetation. Inputs from anthropogenic sources include tourist activity, smelting, oil spills, industrial and mining operations, waste disposal, agricultural activities, and domestic sewage.

The study area can be subdivided into three zones; the first one is the almost pristine zone which covers the stations: 12 km to the north of Mersa Alam, 43 km to the south of Mersa Alam and 43 km to the north of Berenice, where most elements have IP below unity. The second zone represents the moderately polluted area of Hamrawein and the area from 40 km to the north of Mersa Alam (Fig. 9). This zone shows relative enrichment of Th and sometimes Mo or U. Indeed, there is no straightforward explanation of such sporadic pollution but, however, the shipping of phosphorites ore could be a possible source. The third zone represents the markedly polluted areas that include the area from Abu Darag to 20 km to the south of Hurghada (Fig. 10), which shows high enrichment in many trace elements. The sources of pollution in this zone are frequent, but tourist villages and resorts remain the most influential.

Other areas that show serious degree of pollution (IP > 1) include; Wadi Gassus which recorded high Mo, Pb, Zn, Au, and 85 km to the north of Mersa Alam for high Cu, Mn, U and Th (Fig. 11). However, the two species under consideration do not show the same response to pollutants in the same site. The tourism activity in the above two areas is very limited and cannot be regarded as an effective cause for pollution while mineralization derived from the hinterland can be an adequate source.

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