# Environmental behaviour of strontium in some salt affected soils along the Western North coast of Egypt

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## ABSTRACT

**In the present work, $Sr^{2+}$ contamination in some salt affected soils along the Western North coast of Egypt was investigated. The contamination of $Sr^{2+}$ in different soils samples was evaluated using different risk indices such as enrichment factor (EF), geo-accumulation index ($I_{geo}$), contamination factor (CF), the degree of contamination ($C_d$), modified degree of contamination ($mC_d$ ), pollution load index (PLI), soil pollution index (SPI), and ecological risk assessment (RAC). The concentrations of $Sr^{2+}$ were investigated according to the bioaccumulation (BAC) in different plant species such as tomato (*Solanum lycopersicum*), leek (*Allium ampeloprasum*), barley (*Hordeum vulgare* ), olive (*Olea europaea*) , alfalfa (*Medicago sativa* ), sweet sorghum (*Sorghum vulgare var. sacchratum*), fig ( *Ficus carica*), apple (*Malus domestica*), mountain spinach (*Atriplex hortensis*), onion (*Allium cepa*), eggplant (*Solanum melongena*), camphor (*Cinnamomum camphora* ), faba bean (*Vicia faba*), galawein (*Sonchus oleraceus L.*), and orange (*Citrus Sinensis*). The obtained results showed that, the mean value of EF for $Sr^{2+}$ was the highest (15) among the other associated elements. Although, the highest $I_{geo}$ values was observed with $Zn^{2+}$ followed by $Cd^{2+}$ and $Sr^{2+}$, $Sr^{2+}$ is not belongs to contamination category. According to CF index, $Sr^{2+}$ is classified as low degree of contamination. According to $mC_d$ classification, $Sr^{2+}$ contamination level is belongs to nil to very low degree of contamination class. The SPI presented that $Sr^{2+}$ is considered moderate to highly contamination element. The highest values of BAC was found to be 2.018 in leek, while the lowest BAC value was 0.005 in tomato. To compare the concentration of median Sr in the studied area with its concentrations in the land of the African continent and the world, the median Sr in the western north coast of Egypt (449 mg/kg) appear to be very close to the empirical data value from Africa and higher than the empirical data value globally.**


**Keywords: Strontium; Contamination; Risk indices; Bioaccumulation**

## INTRODUCTION

Strontium ($Sr^{2+}$) pollution is considered a big dilemma nowadays, because of the increases concentration in wastewater and other areas (Abou-Shady, 2017). $Sr^{2+}$ interference with the biological processes that normally involve calcium and eventually skeletal development. The fact that $Sr^{2+}$ is chemically similar to calcium allows it to exchange imperfectly with calcium in bone and other cellular that are enriched in calcium. Also, the function of different enzymes that are calcium dependent will be substituted when $Sr^{2+}$ exists that may modify kinetic parameters. $Sr^{2+}$ can interact with secondary cell messenger systems and transporter systems that normally use calcium (ATSDR, 2004).

At high doses of $Sr^{2+}$, neurotoxic and neuromuscular perturbations may be caused. The total daily intake of $Sr^{2+}$ for adults in many parts of the world is estimated to be up to 4 mg $day^{-1}$. $Sr^{2+}$ occurs naturally in earth's crust (approximately 0.02-0.03%) in mineral forms such as celestite (strontium sulfate) and strontianite (strontium carbonate). However, minor amounts of $Sr^{2+}$ exist in other mineral deposits and close to sedimentary rocks associated with gypsum, anhydrite, rock salt, limestone, and dolomite. $Sr^{2+}$ can also occur in shales, marls, and sandstones (ATSDR, 2004). low concentrations of the $Sr^{2+}$ may be adsorbed on calcium carbonate via electrostatic attraction force as hydrate ions, however at high concentrations $Sr^{2+}$ may be precipitated as strontianite (strontium carbonate) (Parkman *et al*., 1998).

The main objective of the present work was to investigate the environmental behavior of $Sr^{2+}$ in some salt affected soils along Western North coast of Egypt. The transportation of $Sr^{2+}$ from soil to the grown plants was also investigated. The contamination levels of $Sr^{2+}$ concentrations were evaluated using risk indices such as enrichment factor (EF), geo-accumulation index ($I_{geo}$), contamination factor (CF), the degree of contamination ($C_d$), modified degree of contamination ($mC_d$ ), pollution load index (PLI), soil pollution index (SPI), and risk assessment code (RAC). In addition, $Sr^{2+}$ containing plants was investigated using bioaccumulation (BAC).

## MATERIALS AND METHODS

**Soil sampling and analysis:** Soil samples were collected from different locations between latitude 27° 2` E - 29° 55` E and 30° 40` N - 31° 22` N. These areas include different towns such as

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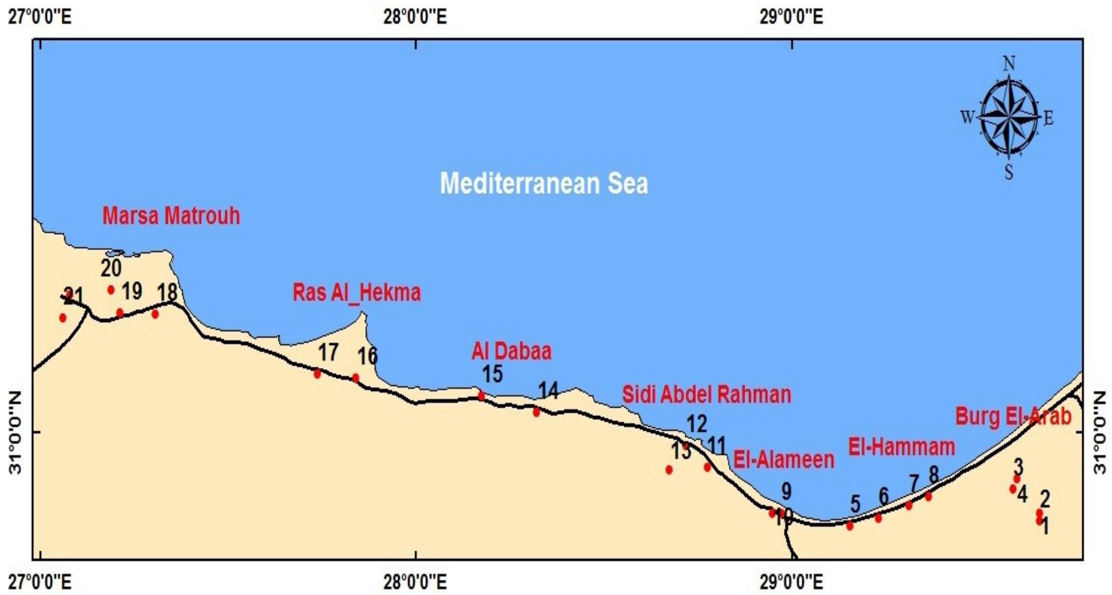


**Fig. 1. A map shows the studied locations along the Western North Coast of Egypt**

Burg El Arab, El Hammam, Al Alameen, Sidi Abdel Rahman, Al Dabaa, Ras Alhekma, and Marsa Matrouh. Forty three surface (0-25) cm and subsurface (25-50) cm soil samples were collected from 22 sites that represented calcareous soils along North Western Coastal Plain (Fig. 1). Sixty plant samples, grown in twenty one locations, representing the different plant species were collected.

Soil texture was determined using international pipette method. Organic matter content was determined according to Walkley and Black method. Soil pH was determined in the soil suspension of 1:2.5. Total soluble salts were determined in soil - water extract (1:2.5). Total carbonate content was determined using Collin's calcimeter method (Jackson, 1973). Heavy metals content was determined using Inductivity Coupled Argon Plasma (ICAP). $Sr^{2+}$ fractions were determined using sequential extraction methods (Kilmer and Alexander, 1949, Piper, 1950, Jackson, 1973, Tessier *et al*., 1979, Jena *et al*., 2013).

**Plant analysis**

Plant samples (aerial parts and roots) were thoroughly washed with distilled water and dried at $70^o$ C. Afterwards, plant samples were digested using the mixture of $H_2O_2$ and $H_2SO_4$ according to Nicholson (1984).

**$Sr^{2+}$ risk indices**

**Enrichment factor (EF) :** The EF was utilized to assess the level of contamination and possible anthropogenic impact of $Sr^{2+}$ in the studied soils along the Western North Coast of Egypt. In the present study, Fe was used as the conservative tracer to differentiate natural components from the anthropogenic samples. The EF was calculated as follows according to Ergin *et al*.(1991), Abrahim and Parker (2008) and Chen *et al*. (2007):

$$EF = \left( \frac{(C_x / C_{Fe})_{sample}}{(Cx / CFe)_{Reference}} \right) \quad (1)$$

where $(C_x/C_{Fe})_{sample}$ is the a ratio content of the element and Fe in the studied sample, and $(C_x/C_{Fe})_{Reference}$ is the same ratio in the earth's crust Rudnick and Gao (2004) and Nadimi-Goki *et al*. (2014).

**Geo-accumulation index ($I_{geo}$):** Another approach to estimate the contamination levels of $Sr^{2+}$ is the geo-accumulation index ($I_{geo}$). This method assesses the degree of metal pollution in terms of seven enrichment classes based on the increasing numerical values of the index and could be calculated as follows according to Muller (1969) and Rudnick and Gao (2004):

$$I_{geo} = Log_2 (C_x / 1.5 b_x) \quad (2)$$

where $C_x$ is the content of the element in the enriched samples, and $b_x$ is the background value of the element.

**Contamination factor (CF):** Contamination factor (CF) is the ratio of metal concentration in soil sample to its concentrations in the background. The CF was calculated using the following equation Hakanson (1980):

$$CF = C_x / C_r \qquad (3)$$

where $C_x$ and $C_r$ are the mean concentrations of the metal contaminants in the soil samples and background reference material, respectively Chen *et al*.(2015).

**The degree of contamination (Cd):** The degree of contamination ($C_d$) is based on the CF of the pollutant and may be calculated according to the following equation (Swarnalatha *et al.(*2015).

$$C_d = \sum_{i=1}^{n} CF \qquad (4)$$

where n is the number of analyzed elements and i is $1^{th}$ element, and CF is the contamination factor.

**Modified degree of contamination (mCd ):** Abrahim and Parker (2008) presented a modified form for the Hakanson (1980) equation. The modified formula is generalized by defining the degree of contamination ($mC_d$) as the sum of all the contamination factors ($C_d$) for a given set of pollutants divided by the number of analyzed pollutants. The modified degree of contamination is given from the following equation:

$$mC_d = \frac{\sum_{i=1}^{i=n} CF}{n} \qquad (5)$$

where n is the number of analyzed elements and CF is the contamination factor.

**Pollution load index :** To estimate the overall pollution status of the studied samples, the pollution load index (PLI) was calculated using the following equation Chen *et al*. (2015) and Qing *et al*. (2015).

$$\text{PLI} = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \times CF_4 ....... \times CF_n} \qquad (6)$$

where CF represents the contamination factor of a metal, and n represents the specific metals contamination factor.

**Soil pollution index:** Soil pollution index (SPI) is a simple well known pollution evaluation tool was used to identify single element contamination indices. SPI was calculated using the following equation:

$$\text{SPI} = \frac{Metal\ content\ in\ soil}{Permissible\ level\ of\ metal\ in\ soil} \qquad (7)$$

The permissible level of metals has been provided by soil quality guideline according to Gowd *et al*. (2010).

**Environmental implications:** The fractionation of metals is of critical issue because of their potential toxicity and mobility Maiz *et al*. (2000). The fractions that are most influenced by human activity include the exchangeable and carbonate-bound fractions, in which metals are weakly adsorbed and can become more bioavailable due to equilibration with the aqueous phase Rath *et al*. (2009). The reactivity of sediments was evaluated via applying the principles of the risk assessment code (RAC). The RAC is a scale that used to assess potential mobility and risk based on the percentage of exchangeable and carbonate-bound metal in the sediment Perin *et al*. (1985); Jain (2004); Ghrefat and Yusuf (2006) and Karak *et al.(*2011).

**Strontium bioaccumulation in plant:** The biological absorption coefficient (BAC) was used to characterize the degree of elements uptake by plants from soil. Nagaraju and Karimulla (2002) have defined the BAC as the ratio of concentration of an element in plant ash to the total metal concentrations in soils. On the other hand, Mountouris *et al*. (2002) and Hassinen *et al*. (2009) have defined the bioconcentration factor or translocation factor as the ratio of metal concentration in the edible part of vegetables such as leaves, seeds, and roots to the total metal concentrations.

**Statistical analysis**

For statistical analysis of the present data, both descriptive and multivariate data analysis was used, such as Cluster analysis, Factor analysis, and Principal Component Analysis. SPSS (SPSS 20.exe) were used to calculate the descriptive statistics (Min., Max., mean, Std. Deviation, median, skewness, kurtosis, factor analysis and Cluster analysis) and assess the elements' correlations with some soil parameters.

## RERSULTS AND DISCUSSION

The present study dealt with environmental behavior of $Sr^{2+}$ in some salt affected soils along the Western North Coast of Egypt. Tables (1a and ab) shows a summary of some physical and chemical properties for the investigated soils. In general, soil pH ranged from 7.0 to 8.9 denoting to the neutral to alkaline soil reaction. EC ranged from 0.20 dS $m^{-1}$ to 12.21 dS $m^{-1}$ indicating non-saline to extremely saline soil. Organic matter content ranged from 0.001% to 1.67%. $CaCO_3$ content ranged from 12.31% to 42.80%. CEC ranged from 1.70 meq $100g^{-1}$ to 18.90 meq $100g^{-1}$. Percentage of sand fraction varied from 46.20% to 95.61% while clay content ranged from 2.68 to 32.80%.

The risk indices were explicit to investigate the contamination degree of $Sr^{2+}$ and other associated elements in the studied soils. The first risk indices was enrichment factor (EF). If the EF is higher than 1, the metal concentration in the soil sample will enrich

**Table 1a. the main physical and chemical properties of the studied soils**

| | $Sr^{2+}$ ($\mu gg^{-1}$) | PH | EC (dS $m^{-1}$) | OM (%) | $CaCO_3$ (%) | Sand (%) | Silt (%) | Clay ( %) | CEC (meq $100g^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Minimum | 159.1 | 7.00 | 0.20 | 0.001 | 12.31 | 46.2 | 1.71 | 2.68 | 1.7 |
| Maximum | 740.0 | 8.91 | 12.21 | 1.67 | 42.8 | 95.61 | 22.4 | 32.8 | 18.9 |
| Mean | 442.9 | 7.80 | 2.88 | 0.47 | 28.08 | 80.31 | 10.02 | 9.66 | 6.2 |
| Median | 449.0 | 7.81 | 1.71 | 0.38 | 26.90 | 83.62 | 10.15 | 6.82 | 4.9 |
| Std.Deviation | 180.7 | 0.54 | 2.83 | 0.42 | 10.67 | 11.80 | 5.98 | 7.23 | 4.3 |
| Skewness | -0.08 | 0.05 | 1.68 | 1.30 | -0.06 | -1.09 | 0.23 | 1.68 | 1.2 |
| Kurtosis | -1.29 | -1.16 | 2.85 | 1.31 | -1.58 | 1.39 | -1.01 | 2.57 | 0.7 |

**Table 1b. the main physical and chemical properties of the studied soils**

| | Fe | Mn | Zn | Cu | Co | Ni | Pb | Cr | Cd | Ca | Mg | Ba |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ( $\mu gg^{-1}$) | | | | | | | | | | | |
| Minimum | 10530.0 | 54.1 | 13.6 | 2.6 | 1.3 | 3.2 | 0.0 | 7.7 | 0.0 | 22570.0 | 5909.0 | 4.3 |
| Maximum | 59230.0 | 1010.0 | 608.1 | 38.1 | 33.2 | 64.2 | 7.6 | 136.1 | 3.1 | 191700.0 | 19680.0 | 40.3 |
| Mean | 16318.6 | 197.7 | 100.0 | 11.0 | 5.9 | 16.5 | 2.5 | 28.9 | 0.2 | 102431.9 | 12229.5 | 17.5 |
| Median | 14925.0 | 145.4 | 52.1 | 9.4 | 4.1 | 14.5 | 1.9 | 22.6 | 0.1 | 97040.0 | 12320.0 | 15.8 |
| Std.Deviation | 7151.3 | 155.7 | 110.4 | 7.0 | 5.4 | 12.2 | 2.1 | 23.1 | 0.5 | 38641.4 | 3019.1 | 9.9 |
| Skewness | 5.4 | 3.6 | 2.7 | 2.1 | 3.3 | 2.2 | 1.3 | 2.9 | 5.7 | 0.2 | 0.2 | 0.5 |
| Kurtosis | 32.4 | 17.4 | 9.8 | 5.4 | 15.2 | 6.0 | 0.9 | 10.8 | 34.5 | -0.3 | 0.4 | -0.7 |

**Table 2. The Enrichment factor (EF) for $Sr^{2+}$ and some associated elements in the studied soils**

| Element | Number of soil samples | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Ba | 43 | 0.019 | 1.426 | 0.392 | 0.327 |
| Sr | 43 | 1.887 | 54.376 | 15.046 | 13.085 |
| Cd | 43 | 0.079 | 5.402 | 1.263 | 2.361 |
| Co | 43 | 0.405 | 2.265 | 1.752 | 0.234 |
| Cr | 43 | 0.905 | 5.831 | 1.396 | 0.778 |
| Cu | 43 | 0.470 | 3.921 | 1.033 | 0.580 |
| Mn | 43 | 0.523 | 2.140 | 1.242 | 0.284 |
| Ni | 43 | 0.480 | 3.690 | 0.946 | 0.622 |
| Pb | 43 | 0.010 | 1.492 | 0.388 | 0.257 |
| Zn | 43 | 1.010 | 15.896 | 4.380 | 3.570 |

**Table 3. Index of geoaccumulation ($I_{geo}$) for contamination levels in soil**

| $I_{geo}$ | Class $I_{geo}$ Value | Contamination Level |
|---|---|---|
| 1 | $0 < I_{geo} < 1$ | Uncontaminated/moderately contaminated |
| 2 | $1 < I_{geo} < 2$ | Moderately contaminated |
| 3 | $2 < I_{geo} < 3$ | Moderately/strongly contaminated |
| 4 | $3 < I_{geo} < 4$ | Strongly contaminated |
| 5 | $4 < I_{geo} < 5$ | Strongly/extremely contaminated |
| 6 | $5 < I_{geo}$ | Extremely contaminated |

Mean values of the $I_{geo}$ for all elements which have been calculated and presented in Fig. 3 and table (4). This mean The $I_{geo}$ value of all elements remains in class '0', so the studied areas considered uncontaminated category.

soil values and the source of the metal in the topsoil is likely to be anthropogenic. On the other hand, when the EF values are less than 1, this indicates that the metal concentration is not enriched and may be related to the natural source. If the EF values are equal to 1, this indicates that metal concentration and its reference relative to the average of continental crust and surface value are the same Swarnalatha *et al*. (2015). The EF values for $Sr^{2+}$ and some associated elements are presented in Table (2). The maximum values of the EF was observed with $Sr^{2+}$ and $Zn^{2}$, respectively compared with that was observed with the other associated elements. This may be owing to the fact that $Sr^{2+}$ is strongly associated with calcium and indicative calcareous rocks. It is clear that there is no enrichment risk for Ba, Co, Cr, Cu, Mn, Ni, and Pb. The lowest values of EF were observed with $Pb^{2+}$ followed by Ba < Cd < Co < Cu < Ni < Mn < Cr < Zn < Sr, Fig. (2).

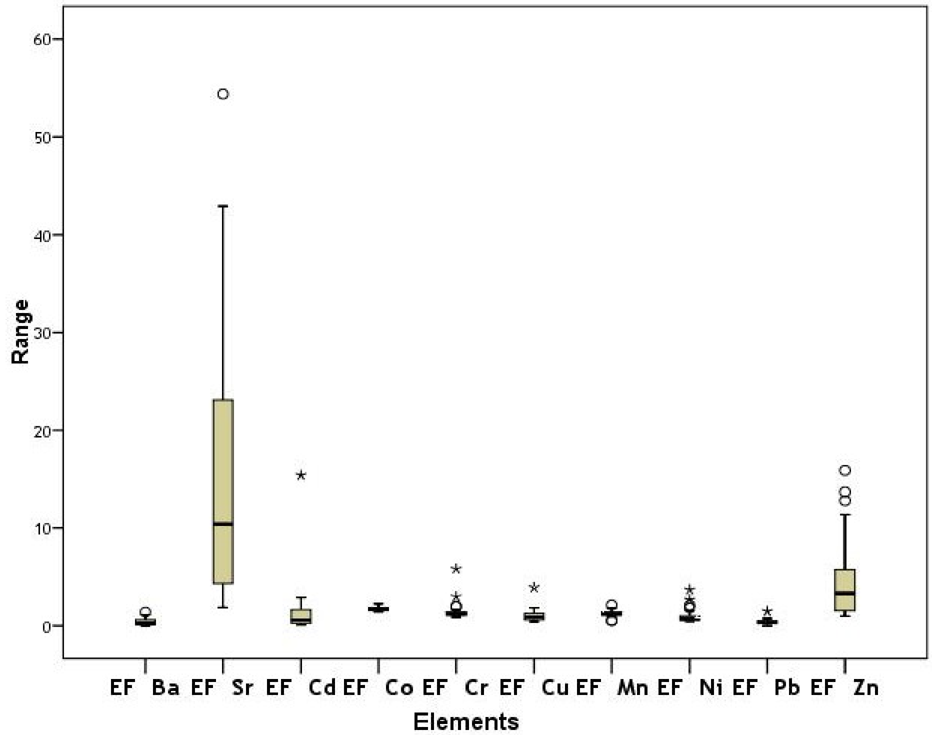


**Fig. 2. Enrichment factors for some element in the studied soils**

**Table 4. Indexes of geo-accumulation (Ig) for some elements concentrations in the studied soils**

| Element | Number of soil samples | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Ba | 43 | -7.31 | -4.08 | -5.55 | 0.92 |
| Sr | 43 | -1.59 | 0.62 | -0.26 | 0.68 |
| Cd | 43 | -7.46 | 0.83 | -4.28 | 1.65 |
| Co | 43 | -4.50 | 0.15 | -2.75 | 1.07 |
| Cr | 43 | -4.77 | -0.64 | -3.17 | 0.89 |
| Cu | 43 | -5.49 | -1.64 | -3.66 | 0.82 |
| Fe | 43 | -3.26 | -0.76 | -2.69 | 0.38 |
| Mn | 43 | -4.88 | -0.65 | -3.28 | 0.85 |
| Ni | 43 | -5.89 | -1.55 | -3.82 | 0.95 |
| Pb | 43 | -10.75 | -3.17 | -5.31 | 1.52 |
| Zn | 43 | -4.10 | 1.39 | -1.84 | 1.32 |

**Table 5. the terminologies used to describe the contamination factor CF (Hakanson *et al*., 1980)**

| CF | $C_d$ | Description |
|---|---|---|
| CF<1 | $C_d$<7 | Low degree of contamination |
| 1<CF<3 | 7<$C_d$<14 | Moderate degree of contamination |
| 3<CF<6 | 14<$C_d$<28 | Considerable degree of contamination |
| CF>6 | $C_d$>28 | Very high degree of contamination |

Mean of all CF values is less than 1 except mean value of CF for Sr is (1.38), which indicated that CF for Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn are low contamination but CF for Sr only is moderate contamination. Value $C_d$ ranged from 1.50 to 11.35 and its mean value is 3.49 i.e. this value less than 7 so its description is low degree of contamination, Table (5 and 6) and Fig. (4).

For the classification and description of the $mC_d$ seven gradations are proposed as shown in Table (7).

$mC_d$ is ranged from 0.14 to 1.03 and its mean equal to 0.317,i.e. this less than 1.5. so the class of modified degree of contamination level is nil to very low degree of contamination, Table (7).

The pollution load index values are used to classify samples as; unpolluted (PLI ≤ 1), moderately polluted (PLI = 1–3), highly polluted (PLI = 3–5) or very highly polluted (PLI > 5) (Qing *et al*., 2015). The pollution load index has been calculated and ranged from 0.06 to 0.54 and its mean is 0.163, i.e. it less than 1,so can classify as unpolluted.

The soil pollution index level of each heavy metal present was classified as low contamination (SPI ≤ 1), moderate contamination (1 < SPI ≤ 3) or high contamination (SPI > 3) (Chen *et al*., 2005). All calculated values of SPI for all elements except SPI of Sr and Zn is less than 1. So the pollution index levels of Ba, Cr, Cu, Pb and Zn are low contamination and while SPI of Sr is moderate contamination, Table (8) and Fig. (5).

**Table 6. Contamination factors for some elements the in studied soils**

| Element | Number of soil samples | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Ba | 43 | 0.009 | 0.088 | 0.038 | 0.022 |
| Sr | 43 | 0.497 | 2.313 | 1.384 | 0.565 |
| Cd | 43 | 0.009 | 2.658 | 0.172 | 0.409 |
| Co | 43 | 0.067 | 1.660 | 0.295 | 0.269 |
| Cr | 43 | 0.055 | 0.965 | 0.205 | 0.164 |
| Cu | 43 | 0.033 | 0.483 | 0.139 | 0.088 |
| Fe | 43 | 0.157 | 0.883 | 0.243 | 0.107 |
| Mn | 43 | 0.051 | 0.953 | 0.186 | 0.147 |
| Ni | 43 | 0.025 | 0.513 | 0.132 | 0.097 |
| Pb | 43 | 0.001 | 0.166 | 0.055 | 0.045 |
| Zn | 43 | 0.088 | 3.923 | 0.645 | 0.712 |

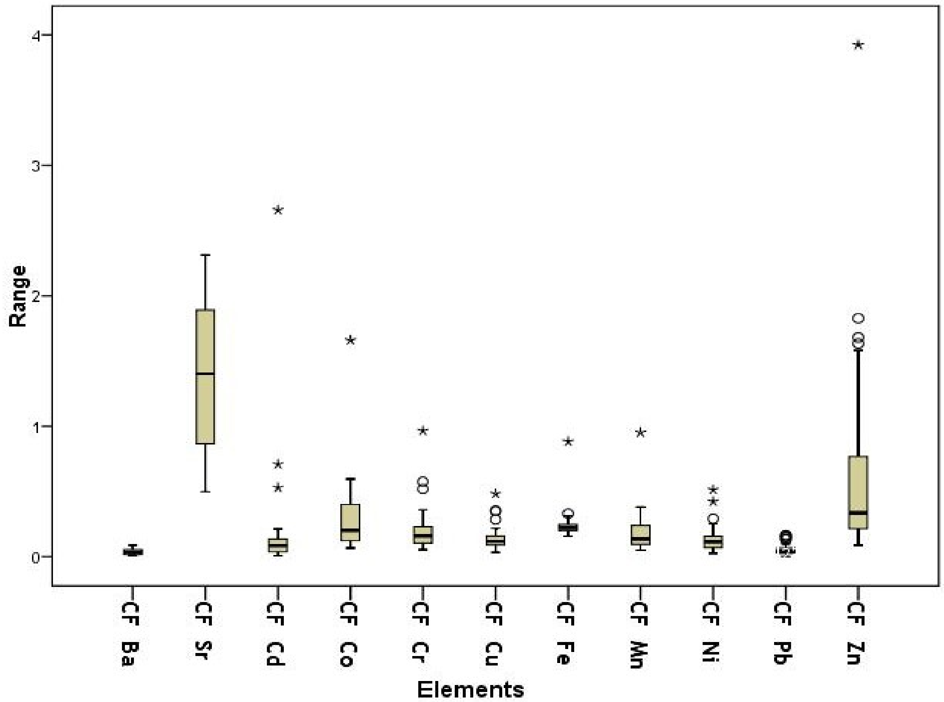


**Fig.4. Contamination factor for metals in the studied soils**

**Table 7. Different modified degree of contamination ($mC_d$) for soil**

| $mC_d$ Class | Modified Degree of Contamination Level |
|---|---|
| $mC_d < 1.5$ | Nil to very low |
| $1.5 \leq mC_d < 2$ | Low |
| $2 \leq mC_d < 4$ | Moderate |
| $4 \leq mC_d < 8$ | High |
| $8 \leq mC_d < 16$ | Very high |
| $mC_d \geq 32$ | Extremely high |
| $16 \leq mC_d < 32$ | Ultra high |

**Correlation analysis:**

Significant correlation was found among trace element concentrations and some physco-chemical properties, especially Sr/Ca (r=0.60) That agree with the fact Sr and Ca have similar ionic radii and other research suggesting that Sr and Ca are associated mostly with the mineral phase in soils, Sr/Ba (r=0.48), Sr/Co (r=-0.35), Sr/pH (r=-0.42), Sr/OM (r=0.37) and Sr /$CaCO_3$ (r=-0.38). Almost trace elements were correlated with Fe and Mn in soils (Table 9 ), These correlation coefficients were the strongest with Mn and Fe, particularly Mn/Fe (r=0.85), Zn/Fe (r=0.73), Cu/Fe (r=0.61), Co/Fe (r=0.84), Ni/Fe (r=0.56), Pb/Fe (r=0.45), Cr/Fe (r=0.79), Mg/Fe (r=0.44), Zn/Mn (r=0.84), Cu/Mn (r=0.77), Co/Mn (r=0.95), Ni/Mn (r=0.58), Pb/Mn (r=0.66), Cr/Mn (r=0.87) and Mg/Mn (r=0.62). This may be suggesting that trace elements are associated with the Fe-Mn oxyhydroxides. The statistical analysis reveals that Zn in soils is highly significant positively correlated with Cu (r = 0.78), Co (r = 0.78), Ni (r = 0.45), Pb (r = 0.69), Cr (r = 0.68) and Mg (r = 0.53). and organic matter is highly significant positively correlated with Fe, Mn, Zn, Cu, Pb, Ca, silt % and CEC while being significant negatively correlated with sand % (r = -0.53). Soil pH is significant positively correlated with clay %, Mn, Cu, Co, Ni, Pb and Mg. Soil salinity is correlated with sand % and CEC,table(9).

**Table 8. Soil pollution index (SPI) for some elements concentratons in studied soils**

| Element | Number of soil samples | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Ba | 43 | 0.009 | 0.081 | 0.035 | 0.020 |
| Sr | 43 | 0.796 | 3.700 | 2.215 | 0.904 |
| Cr | 43 | 0.121 | 2.127 | 0.451 | 0.361 |
| Cu | 43 | 0.042 | 0.605 | 0.175 | 0.111 |
| Pb | 43 | 0.000 | 0.055 | 0.018 | 0.015 |
| Zn | 43 | 0.068 | 3.041 | 0.500 | 0.552 |

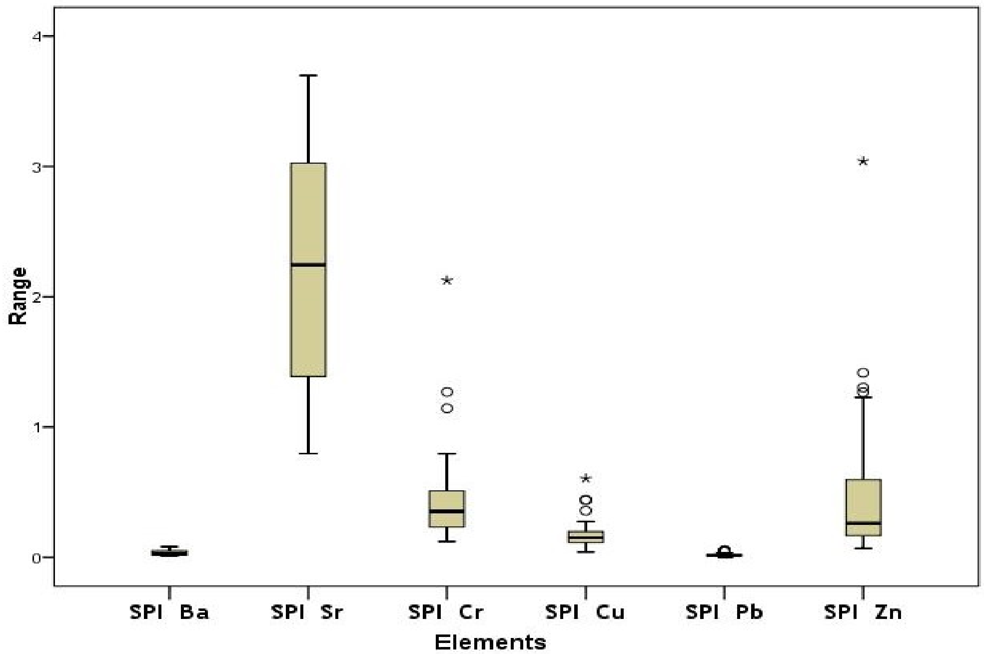


**Fig.5. Soil pollution Indexes for metals in the studied soils**

**Table 9. Pearson correlation coefficient between trace element concentrations and some physical and chemical properties of the studied soils**

| | $Sr^{2+}$ | PH | EC | OM | CaCO3 | Sand | Silt | Clay | CEC | Fe | Mn | Zn | Cu | Co | Ni | Pb | Cr | Cd | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Sr^{2+}$ | 1.00 | | | | | | | | | | | | | | | | | | | |
| PH | -.416-** | 1.00 | | | | | | | | | | | | | | | | | | |
| EC | -0.02 | -0.17 | 1.00 | | | | | | | | | | | | | | | | | |
| OM | .366* | -0.13 | 0.19 | 1.00 | | | | | | | | | | | | | | | | |
| CaCO3 | -.379-* | 0.12 | 0.23 | -0.28 | 1.00 | | | | | | | | | | | | | | | |
| Sand % | -0.11 | 0.05 | -.309-* | -.526-** | -0.01 | 1.00 | | | | | | | | | | | | | | |
| Silt% | 0.24 | -0.25 | 0.22 | .466** | -0.14 | -.870-** | 1.00 | | | | | | | | | | | | | |
| Clay % | 0.05 | .318* | -0.11 | 0.18 | -0.21 | 0.07 | -0.13 | 1.00 | | | | | | | | | | | | |
| CEC | 0.01 | 0.03 | .319* | .381* | 0.12 | -.889-** | .616** | -0.02 | 1.00 | | | | | | | | | | | |
| Fe | -0.02 | 0.06 | -0.02 | .310* | 0.02 | -0.28 | 0.26 | 0.06 | 0.25 | 1.00 | | | | | | | | | | |
| Mn | -0.18 | .385* | -0.02 | .317* | 0.11 | -0.27 | 0.13 | -0.01 | 0.26 | .848** | 1.00 | | | | | | | | | |
| Zn | -0.04 | 0.24 | 0.00 | .502** | -0.02 | -0.29 | 0.18 | -0.07 | 0.22 | .729** | .839** | 1.00 | | | | | | | | |
| Cu | -0.21 | .336* | -0.10 | .393** | 0.08 | -0.18 | 0.03 | -0.05 | 0.22 | .614** | .769** | .781** | 1.00 | | | | | | | |
| Co | -.353-* | .383* | 0.00 | 0.21 | 0.22 | -0.18 | 0.02 | -0.03 | 0.21 | .835** | .945** | .776** | .755** | 1.00 | | | | | | |
| Ni | -0.30 | .334* | -0.02 | 0.01 | 0.14 | -0.15 | 0.06 | -0.05 | 0.25 | .560** | .580** | .448** | .576** | .652** | 1.00 | | | | | |
| Pb | -0.24 | .438** | 0.22 | .428** | 0.08 | -.522-** | .310* | -0.02 | .447** | .454** | .666** | .692** | .570** | .633** | .407** | 1.00 | | | | |
| Cr | -0.23 | 0.27 | -0.02 | 0.22 | 0.24 | -0.17 | 0.04 | -0.04 | 0.21 | .789** | .874** | .676** | .655** | .886** | .533** | .502** | 1.00 | | | |
| Cd | -0.13 | 0.29 | -0.03 | -0.07 | -0.23 | 0.19 | -0.22 | -0.06 | -0.17 | -0.06 | 0.09 | 0.07 | 0.04 | 0.08 | 0.02 | 0.12 | 0.07 | 1.00 | | |
| Ca | .601** | -0.04 | 0.05 | .309* | -0.27 | -0.18 | 0.20 | 0.08 | 0.10 | -0.06 | -0.02 | 0.01 | -0.09 | -0.20 | -0.22 | 0.01 | -0.08 | 0.02 | 1.00 | |
| Mg | -0.21 | .308* | 0.02 | 0.26 | 0.07 | -0.08 | -0.03 | -0.07 | 0.07 | .442** | .617** | .532** | .520** | .611** | .361* | .373* | 0.61** | 0.02 | 0.08 | 1.00 |
| Ba | .481** | -0.06 | -0.11 | 0.25 | -.340-* | -0.21 | 0.21 | 0.13 | 0.12 | -0.15 | -0.10 | -0.05 | -0.12 | -.322-* | -.312-* | 0.00 | -0.26 | -0.07 | .770** | -0.1 |

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

**Table 10. Total variance explained and component matrices for the heavy metals**

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | | Rotation Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 6.379 | 49.073 | 49.073 | 6.379 | 49.073 | 49.073 | 6.186 | 47.588 | 47.588 |
| 2 | 2.243 | 17.255 | 66.328 | 2.243 | 17.255 | 66.328 | 2.422 | 18.632 | 66.220 |
| 3 | 1.071 | 8.242 | 74.570 | 1.071 | 8.242 | 74.570 | 1.086 | 8.350 | 74.570 |
| 4 | 0.738 | 5.679 | 80.248 | | | | | | |
| 5 | 0.705 | 5.420 | 85.668 | | | | | | |
| 6 | 0.555 | 4.267 | 89.935 | | | | | | |
| 7 | 0.429 | 3.297 | 93.232 | | | | | | |
| 8 | 0.344 | 2.644 | 95.876 | | | | | | |
| 9 | 0.212 | 1.628 | 97.504 | | | | | | |
| 10 | 0.126 | .972 | 98.476 | | | | | | |
| 11 | 0.102 | .786 | 99.262 | | | | | | |
| 12 | 0.074 | .572 | 99.834 | | | | | | |
| 13 | 0.022 | .166 | 100.000 | | | | | | |

| | Component Matrixa | | | Rotated Component Matrixa | | |
|---|---|---|---|---|---|---|
| | Component | | | Component | | |
| | PC1 | PC2 | PC3 | PC1 | PC2 | PC3 |
| Co | 0.970 | -0.059 | -0.015 | 0.968 | -0.029 | 0.048 |
| Mn | 0.954 | 0.174 | | 0.935 | -0.262 | 0.035 |
| Cr | 0.886 | 0.035 | -0.055 | 0.886 | 0.075 | 0.067 |
| Zn | 0.853 | 0.258 | 0.034 | 0.874 | -0.154 | -0.012 |
| Fe | 0.837 | 0.152 | -0.243 | 0.860 | -0.037 | -0.206 |
| Cu | 0.834 | 0.089 | | 0.833 | -0.087 | 0.041 |
| Pb | 0.698 | 0.149 | 0.264 | 0.702 | 0.011 | 0.292 |
| Ni | 0.694 | -0.193 | -0.097 | 0.675 | -0.015 | 0.048 |
| Mg | 0.665 | 0.126 | 0.020 | 0.641 | -0.337 | -0.057 |
| Ca | -0.166 | 0.901 | 0.127 | 0.023 | 0.921 | 0.088 |
| Ba | -0.278 | 0.834 | 0.091 | -0.099 | 0.877 | 0.050 |
| Sr | -0.315 | 0.722 | -0.218 | -0.146 | 0.762 | -0.257 |
| Cd | 0.082 | -0.071 | 0.926 | 0.027 | -0.047 | 0.931 |

Factor analysis to reduce the number of variables, a factor analysis was applied to the available data set by using Principal Component Analysis (PCA) and cluster analysis (CA) were used to distinguish the different groups of heavy metals. PCA with varimax rotation was performed with respected factor loadings were calculated using eigen values >1. The factor loadings may be classified as ‘strong’, ‘moderate’ and ‘week’ considering their significant influence in the geochemical processes corresponding to absolute loading values of > 0.70, 0.70–0.50 and 0.50–0.40, respectively (Liu *et al*., 2003; Panda *et al*., 2006). In the current study factor analysis separate the soil analysis data into three factors, which describe the distribution of elements in the studied soils. These factors explain 74.5% of the variance using 13 variables in the analysis .The results of PCA for heavy metal contents are listed in Table (10).

According to these results, Sr, Ca, Ba, Co, Mn, Cr, Zn, Fe, Cu, Pb, and Ni. Mg and Cd concentrations could be grouped into a three component model, the first principal component (PC1) was correlated with Co, Mn, Cr, Zn, Fe, Cu, Pb, Ni and Mg. The second principal component (PC2) includes Sr, Ca and Ba. While Cd was only isolated in the third component (PC3). The result of CA analysis is illustrated in the dendrogram (Fig.6). Three distinct clusters can be identified Cluster I contained Sr, Ca and Ba. While the long distance between Cd and the other heavy metals may suggest that this cluster can be further divided into two sub clusters Cluster II contained Sr, Ca and Ba. The results of PCA agreed well with that of the CA. Therefore, it is suggested from the PCA and CA that the analysed elements may be classified into three groups.

**Ecological risk assessment:**

The exchangeable and carbonate bound metals easily mobile and thereby make themselves more readily bio-available (Singh *et al*., 2005). The criteria of risk assessment code (RAC) as given below indicates that the soil that can release <1 % of the total metal in exchangeable and carbonate fractions is considered safe, i.e. in no risk category while that release >50 % of the total metal in the same fraction is considered to be under very high risk category. Low risk is there when the release is 1–10 %, medium risk is there when the release is 11–30%, high risk is there when the release is 31–50% and very high risk (>50%) (Perin *et al.*, 1985). Mean of RAC is 69.237, 69.889, 70.606, 67.289, 72.021, 71.970 and 68.680 in Burg El Arab, El Hammam, Al Alameen, Sidi Abdl Rahman, Al Dabaa, Ras Alhekma, and Marsa Matrouh area respectively, indicating their significant bio-availability which may pose significant ecological risk, (RAC> 50%). Strontium content ratio of F1-soluble fraction is ranged from 0.155 to 0.367, its ratio of F2-exchangeable fractionis ranged from 9.88 to 20.03, its ratio of F3-carbonate fraction is ranged from 47.06 to 63.452, its ratio of F4-bound to Fe-Mn oxyhydroxides (Fe-Mn-) ranged from 18.54 to 33.80, its ratio of F5-bound to organic matter (OM-) ranged from 0.954 to 4.953 and its content ratio of F6-residual (Res-) ranged from 0.953 to 3.673, Table (11)

**Bioaccumulation of strontium (BAC):**

The BAC has a wide range (0.001–100), which could be classified into five groups; Nagaraju and Karimulla (2002), very weak absorption 0.001–0.01; weak absorption 0.01–0.1; intermediate absorption 0.1–1; strong absorption 1–10; intensive absorption 10–100. The BAC of strontium in study area was calculated and the results were shown in Table (12), the classification of BAC could be ordered as follows: very weak absorption (1.66%), weak absorption (16.66%), intermediate absorption (76.66%) and strong absorption (5%), The variation of BAC was not remarkable in different districts, which due to the bio-available contents of strontium were similar in different districts. Furthermore, the highest BAC (2.018) was occurred in Leek (*Allium ampeloprasum*) and the lowest BAC (0.005) was occurred in tomato (*Solanum lycopersicum*). The highest Sr/Ca (0.257) was occurred in Sweet sorghum (*Sorghum vulgare var. sacchratum*) and the lowest Sr/Ca (0.006) was occurred in Olive (*Olea europaea*). Although the concentration of Sr is considered value but its absorption by all the plants was significantly limited that due to their specific absorption comparing to their Ca absorption.

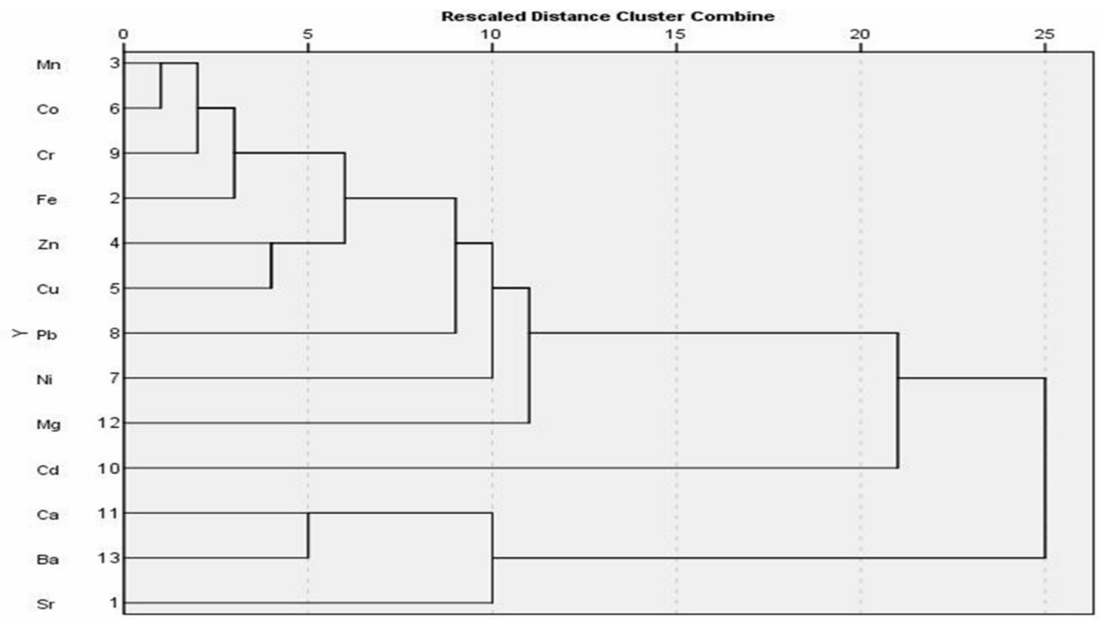


**Fig.6. Dendrogram depicting the hierachical clustering of the heavy metals**

**Table 11. Ratio of Sr in different fractions and RAC in the studied areas**

| Location | | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Burg EL Arab | F1 % | 0.161 | 1.302 | 0.531 | 0.390 |
| | F2 % | 12.548 | 17.664 | 14.675 | 1.671 |
| | F3 % | 48.251 | 59.456 | 54.562 | 5.161 |
| | F4 % | 18.960 | 33.414 | 25.642 | 6.575 |
| | F5 % | 1.524 | 4.754 | 2.892 | 1.523 |
| | F6 % | 1.061 | 2.379 | 1.698 | 0.589 |
| | RAC | 60.799 | 75.783 | 69.237 | 6.512 |
| El-Hammam | F1 % | 0.166 | 0.720 | 0.363 | 0.218 |
| | F2 % | 11.361 | 20.038 | 16.529 | 3.286 |
| | F3 % | 47.060 | 56.821 | 53.361 | 3.592 |
| | F4 % | 21.451 | 29.075 | 25.210 | 2.437 |
| | F5 % | 1.375 | 4.943 | 2.439 | 1.367 |
| | F6 % | 1.509 | 2.721 | 2.098 | 0.391 |
| | RAC | 66.443 | 74.276 | 69.889 | 2.411 |
| Al-Alameen | F % | 0.294 | 0.983 | 0.534 | 0.309 |
| | F2 % | 12.574 | 16.178 | 14.560 | 1.746 |
| | F3 % | 49.103 | 60.509 | 56.046 | 5.486 |
| | F4 % | 19.123 | 33.055 | 25.178 | 5.907 |
| | F5 % | 1.011 | 2.105 | 1.543 | 0.482 |
| | F6 % | 1.901 | 2.424 | 2.139 | 0.215 |
| | RAC | 62.727 | 76.374 | 70.606 | 5.799 |
| Sidi AbdlRahman | F1 % | 0.179 | 0.835 | 0.532 | 0.232 |
| | F2 % | 11.464 | 17.972 | 13.680 | 2.682 |
| | F3 % | 47.650 | 62.214 | 53.610 | 6.559 |
| | F4 % | 21.978 | 33.854 | 27.388 | 4.683 |
| | F5 % | 1.742 | 4.478 | 3.202 | 1.182 |
| | F6 % | 0.953 | 2.213 | 1.589 | 0.501 |
| | RAC | 59.624 | 74.656 | 67.289 | 5.397 |
| AlDabaa | F1 % | 0.181 | 0.610 | 0.341 | 0.189 |
| | F2 % | 10.865 | 17.376 | 13.821 | 3.050 |
| | F3 % | 54.486 | 59.867 | 58.201 | 2.534 |
| | F4 % | 18.547 | 24.858 | 22.753 | 2.861 |
| | F5 % | 2.047 | 2.470 | 2.325 | 0.194 |
| | F6 % | 1.456 | 3.272 | 2.560 | 0.844 |
| | RAC | 69.790 | 76.061 | 72.022 | 2.793 |
| Ras Alhekma | F1 % | 0.154 | 0.367 | 0.274 | 0.109 |
| | F2 % | 11.157 | 16.917 | 12.953 | 2.671 |
| | F3 % | 53.576 | 63.452 | 59.022 | 4.859 |
| | F4 % | 19.910 | 26.317 | 23.002 | 2.789 |
| | F5 % | 1.927 | 2.814 | 2.236 | 0.415 |
| | F6 % | 2.059 | 3.673 | 2.514 | 0.779 |
| | RAC | 67.912 | 75.565 | 71.975 | 3.436 |
| Marsa Matrouh | F1 % | 0.209 | 0.590 | 0.402 | 0.119 |
| | F2 % | 9.886 | 15.920 | 11.691 | 2.198 |

**Table 11. Continued**

| Location | | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| | F3 % | 49.872 | 62.615 | 56.991 | 4.351 |
| | F4 % | 21.723 | 33.800 | 26.870 | 4.585 |
| | F5 % | 0.954 | 4.953 | 2.149 | 1.086 |
| | F6 % | 1.048 | 2.266 | 1.897 | 0.361 |
| | RAC | 59.758 | 73.482 | 68.682 | 4.560 |

Strontium content in F1-soluble fraction, F2-exchangeable fraction,F3-carbonate fraction, F4-bound to Fe-Mn oxyhydroxides (Fe-Mn-), F5-bound to organic matter (OM-), and F6-residual (Res-)

**Table 12. Strontium content (ppm) in plants and calculated BAC in study areas**

| profile No. | Location | Weighted mean of Sr in soil ppm | Sr in plant ppm | plant species | Sr/Ca plant | BAC | Classification of BAC |
|---|---|---|---|---|---|---|---|
| 1 | Burg El-Arab | 237.8 | 56.8 | tomato (*Solanum lycopersicum*) | 0.050 | 0.239 | intermediate absorption |
| | | | 25.2 | Leek (*Allium ampeloprasum)* | 0.033 | 0.106 | intermediate absorption |
| | | | 30.9 | Barley (*Hordeum vulgare* ) | 0.043 | 0.130 | intermediate absorption |
| | | | 69.5 | Olive (*Olea europaea)* | 0.072 | 0.292 | intermediate absorption |
| | | | 55.6 | Alfalfa (*Medicago sativa )* | 0.046 | 0.234 | intermediate absorption |
| | | | 35.3 | Sweet sorghum (*Sorghum vulgare var. sacchratum)* | 0.134 | 0.091 | weak absorption |
| 2 | | 387.3 | 298.2 | Alfalfa (*Medicago sativa )* | 0.015 | 0.770 | intermediate absorption |
| | | | 205.8 | Barley (*Hordeum vulgare )* | 0.009 | 0.531 | intermediate absorption |
| 3 | | 422.9 | 127.0 | Alfalfa (Medicago sativa ) | 0.007 | 0.328 | intermediate absorption |
| | | | 349.9 | tomato (*Solanum lycopersicum)* | 0.041 | 0.827 | intermediate absorption |
| | | | 339.0 | Sweet sorghum *(Sorghum vulgare var. sacchratum)* | 0.033 | 0.802 | intermediate absorption |
| 5 | El-Hammam | 380.0 | 2.0 | tomato (*Solanum lycopersicum)* | 0.035 | 0.005 | very weak absorption |
| | | | 28.9 | fig ( *Ficus carica)* | 0.033 | 0.076 | weak absorption |
| | | | 33.3 | Faba Beab (*Vicia faba)* | 0.026 | 0.088 | weak absorption |
| | | | 366.3 | Apple (*Malus domestica)* | 0.057 | 0.964 | intermediate absorption |
| | | | 99.4 | Eggplant (*Solanum melongena)* | 0.045 | 0.262 | intermediate absorption |
| | | | 25.8 | Mountain spinach (*Atriplex hortensis)* | 0.015 | 0.068 | weak absorption |
| | | | 125.7 | Olive (*Olea europaea)* | 0.030 | 0.331 | intermediate absorption |
| | | | 34.7 | Alfalfa (*Medicago sativa* ) | 0.038 | 0.091 | weak absorption |

**Table 12. Continued**

| profile No. | Location | Weighted mean of Sr in soil ppm | Sr in plant ppm | plant species | Sr/Ca plant | BAC | Classification of BAC |
|---|---|---|---|---|---|---|---|
| 6 | | 182.0 | 48.9 | Barley (*Hordeum vulgare* ) | 0.096 | 0.129 | intermediate absorption |
| | | | 66.4 | Sweet sorghum (*Sorghum vulgare var. sacchratum)* | 0.257 | 0.175 | intermediate absorption |
| | | | 198.8 | onion *(Allium cepa)* | 0.043 | 0.523 | intermediate absorption |
| | | | 155.3 | Eggplant *(Solanum melongena)* | 0.032 | 0.853 | intermediate absorption |
| | | | 19.6 | camphor (*Cinnamomum camphora )* | 0.049 | 0.108 | intermediate absorption |
| | | | 173.9 | Faba Beab *(Vicia faba)* | 0.038 | 0.955 | intermediate absorption |
| | | | 69.0 | Barley *(Hordeum vulgare )* | 0.215 | 0.379 | intermediate absorption |
| | | | 61.0 | Olive *(Olea europaea)* | 0.006 | 0.335 | intermediate absorption |
| | | | 286.6 | Orange *(Citrus Sinensis)* | 0.036 | 1.574 | strong absorption |
| | | | 286.6 | Galawein *(Sonchus oleraceus L.)* | 0.036 | 1.574 | strong absorption |
| 7 | | 283.9 | 137.3 | fig ( *Ficus carica)* | 0.010 | 0.754 | intermediate absorption |
| | | | 177.7 | Eggplant *(Solanum melongena*) | 0.017 | 0.626 | intermediate absorption |
| | | | 232.5 | Orange (*Citrus Sinensis)* | 0.015 | 0.819 | intermediate absorption |
| | | | 198.2 | Alfalfa (*Medicago sativa* ) | 0.010 | 0.698 | intermediate absorption |
| | | | 197.6 | Olive *(Olea europaea)* | 0.012 | 0.696 | intermediate absorption |
| 8 | | 318.9 | 120.2 | fig ( *Ficus carica)* | 0.063 | 0.424 | intermediate absorption |
| | | | 643.5 | Leek *(Allium ampeloprasum)* | 0.050 | 2.018 | strong absorption |
| | | | 54.7 | Galawein (*Sonchus oleraceus L.)* | 0.009 | 0.171 | intermediate absorption |
| 9 | Al-Alameen | 424.1 | 22.3 | Olive *(Olea europaea)* | 0.015 | 0.052 | weak absorption |
| | | | 53.9 | fig *( Ficus carica)* | 0.081 | 0.127 | intermediate absorption |
| | | | 24.7 | Leek (Allium ampeloprasum) | 0.019 | 0.058 | weak absorption |
| 10 | | 473.6 | 185.5 | Galawein *(Sonchus oleraceus L.)* | 0.014 | 0.392 | intermediate absorption |
| | | | 57.4 | fig ( *Ficus carica)* | 0.010 | 0.121 | intermediate absorption |
| 11 | Sidi AbdlRahma | 391.4 | 93.6 | fig ( *Ficus carica)* | 0.053 | 0.239 | intermediate absorption |

n

**Table 12. Continued**

| profile No. | Location | Weighted mean of Sr in soil ppm | Sr in plant ppm | plant species | Sr/Ca plant | BAC | Classification of BAC |
|---|---|---|---|---|---|---|---|
| 12 | AlDabaa | 273.6 | 161.5 | Barley *(Hordeum vulgare )* | 0.016 | 0.413 | intermediate absorption |
| | | | 244.9 | fig ( *Ficus carica)* | 0.497 | 0.895 | intermediate absorption |
| | | | 237.3 | Eggplant (Solanum melongena) | 0.011 | 0.867 | intermediate absorption |
| 13 | | 448.5 | 216.9 | Olive *(Olea europaea)* | 0.054 | 0.484 | intermediate absorption |
| | | | 62.0 | fig ( *Ficus carica)* | 0.146 | 0.138 | intermediate absorption |
| 14 | | 629.5 | 235.6 | almonds (*Prunus dulcis)* | 0.072 | 0.525 | intermediate absorption |
| | | | 41.8 | Mountain spinach (*Atriplex hortensis)* | 0.011 | 0.066 | weak absorption |
| | | | 184.5 | Apple (*Malus domestica)* | 0.043 | 0.293 | intermediate absorption |
| | | | 292.6 | fig ( *Ficus carica)* | 0.037 | 0.465 | intermediate absorption |
| 15 | Ras Alhekma | 376.5 | 167.1 | fig ( *Ficus carica)* | 0.053 | 0.444 | intermediate absorption |
| 16 | | 488.0 | 20.9 | Olive *(Olea europaea)* | 0.050 | 0.043 | weak absorption |
| 17 | Marsa Matrouh | 494.0 | 84.5 | Barley (*Hordeum vulgare )* | 0.140 | 0.171 | intermediate absorption |
| 18 | | 637.9 | 131.7 | Mountain spinach (*Atriplex hortensis)* | 0.048 | 0.206 | intermediate absorption |
| 19 | | 508.0 | 25.3 | tomato *(Solanum lycopersicum)* | 0.041 | 0.050 | weak absorption |
| 20 | | 697.5 | 88.7 | Olive *(Olea europaea)* | 0.026 | 0.127 | intermediate absorption |
| 21 | | 685.5 | 131.6 | Eggplant (*Solanum melongena)* | 0.011 | 0.192 | intermediate absorption |
| 22 | | 636.5 | 219.4 | Mountain spinach (*Atriplex hortensis)* | 0.011 | 0.345 | intermediate absorption |

And to compare the concentration of median Sr in the studied area with its concentrations in the land of the African continent and the world, table (13)

The median Sr in the western north coast of Egypt (449 mg/kg) appear to be significantly above empirical data from both Nile Delta (263 mg/kg) and soil Egyptian central Nile Valley (307 mg/kg) and value is very close to the value of Aswan-Sohag (400 mg/kg), Aswan-Asyut valley (214 mg/kg) and Africa (47 mg/kg). The median Sr in the western north coast of Egypt was less than its value globally, England and Wales (27 mg/kg), North Germany (9 mg/kg), North Europe (15 mg/kg), Whole Europe (89 mg/kg), Congo river (52 mg/kg), Japan soils (125 or 98 mg/kg), North American (142 mg/kg).

## CONCLUSIONS

$Sr^{2+}$ contamination in some salt affected soils along the Western North coast of Egypt was investigated. The contamination of $Sr^{2+}$ in different soils samples was evaluated using different risk indices such as EF, $I_{geo}$, CF, $C_d$, $mC_d$, PLI, SPI, and RAC. The concentrations of $Sr^{2+}$ in deferent plant species were also investigated according to the bioaccumulation (BAC) for different plant species such as tomato, leek, barley, olive, alfalfa, sweet sorghum, fig, apple, mountain spinach, onion, eggplant, camphor, faba bean, galawein, and orange. The obtained results showed that, the mean value of EF

**Table 13. Comparison of $Sr^{2+}$ median values (mg $kg^{-1}$) in the present work and the obtained data from other relevant literature**

| Median (mg/kg) | Location | Reference |
|---|---|---|
| 449 | the western north coast of Egypt | The present study |
| 263 | Nile Delta | Arafa *et al*., (2015) |
| 307 | soil Egyptian central Nile Valley | Badawy *et al*., (2017) |
| 214 | Aswan-Asyut vally | Arafa *et al*., (2015) |
| 400 | Aswan-Sohag | Dekov *et al*. (1997) |
| 47 | Africa | Towett *et al*., (2015) |
| 27 | England and Wales | Mc Grath and Loveland (1992). |
| 9 | North Germany | Reimann *et al.* (2003). |
| 15 | North Europe | Reimann *et al.* (2003). |
| 89 | Whole Europe | Salminen (2005). |
| 73.7 | Central Catalonia | Tume *et al*., (2011) |
| 375 | Crustal Average | Kabata-Pendias and Mukherjee (2007). |
| 147 | various soils | Kabata-Pendias and Mukherjee (2007). |
| 52 | Congo river | Dupre *et al*., (1996) |
| 125 | Agricultural soils in Japan | Yanai *et al*., (2012) |
| 98 | Japan soils | Takeda (2004) |
| 32-1000 | Reported worldwide range | Kabata-Pendias and Mukherjee (2007). |
| 117 | Upper Niger | Picouet *et al*., (2002) |
| 350 | Upper continental crust | Rudnick and Gao, (2004), |
| 175 | various soils | Gromet *et al*., (1984) |
| 187 | various soils | Viers *et al*. (2009) |
| 142 | North American Shale Composite (NASC) | Earthref, (2013) |
| 175 | world average soil (WAS | Kabata-Pendias (2011) |
| 250 | Soil of the world | Bowen (1979) |

for $Sr^{2+}$ was the highest (15) among the other associated elements. Although, the highest $I_{geo}$ values was observed with $Zn^{2+}$ followed by $Cd^{2+}$ and $Sr^{2+}$, $Sr^{2+}$ is not belongs to contamination category. According to CF index, $Sr^{2+}$ is classified as low degree of contamination. According to $mC_d$ classification, $Sr^{2+}$ contamination level is belongs to nil to very low degree of contamination class. The SPI presented that $Sr^{2+}$ is considered moderate to highly contamination element. The highest values of BAC was found to be 2.018 in Leek, while the lowest BAC value was 0.005 in tomato.

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## الملخص العربي

# السلوك البيئى لعنصر الاسترنشيوم فى بعض الاراضى المتاثرة بالاملاح عبر الساحل الشمالى الغربى بمصر

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اجريت دراسة لتقييم مدى تلوث الاراضى المتاخمة للساحل الشمالى الغربى- مصر بالاسترانشيوم. من خلال دراسة موشرات المخاطر مثل عامل التخصيب ( EF) ومؤشر التراكم الجغرافي ($I_{geo}$) وعامل التلوث (CF) ودرجة التلوث ($C_d$) ودرجة التلوث المعدلة ($mC_d$) ومؤشر تلوث التربة، بالاضافة الى تقييم المخاطر الإيكولوجية (RAC). كما تم دراسة مدى التلوث فى النباتات النامية فى مناطق الدراسة من خلال تقدير معدل التراكم البيولوجي (BAC) للاسترانشيوم فى الطماطم والكراث والشعير والزيتون والبرسيم والذرة الرفيعة والتفاح والسبانخ والبصل والباذنجان والكافور والفول والجلاوين والبرتقال. وقد اوضحت النتائج المتحصل عليها ان قيمة عامل التخصيب للاسترانشيوم وصلت لاعلى القيم بالمقارنة بالعناصر الاخرى الموجودة و على الرغم من ان اعلى قيم لمعامل التراكم الجغرافى قد تم الحصول عليه مع عنصر الزنك والكادميوم والاسترانشيوم، فان عنصر الاسترانشيوم لا يمكن ضمة ضمن فئة العناصر الملوثة. طبقا لعامل التلوث تم تصنف الاسترانشيوم ضمن درجة العناصر ذات معدل التلوث الضعيف. طبقا لدرجة التلوث المعدلة فان تركيزات عنصر الاسترانشيوم لا يمكن ادراجها ضمن العناصر الملوثة، ويمكن اعتبارة ايضا من العناصر ذات التلوث القليل. وبالنسبة لدليل تلوث الاراضى فان الاسترانشيوم يمكن اعتبارة من العناصر ذات مستوى التلوث المتوسط. وقد سجلت اعلى درجات معدل التركم البيولوجى ( ٢,٠١٨) مع نبات الكراث، بينما اقل درجات معدل التراكم البولوجى سجلت مع نبات الطماطم.