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# Mineral pollution of goat, ewe, and camel's milk in different desert regions of Egypt

**K. A. Soryal**
kamalsoryal49@yahoo.com
Desert Research Center
**A. H. Ibrahim**
Desert Research Center
**Samah M. Elshafei**
Desert Research Center
**E. M.M. Abdeen**
Desert Research Center

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## Abstract

In this study, levels of contamination by heavy metals in goat, camel, and ewe's milk, water, and animal diet were evaluated all through four Egyptian desert regions: Ras Sidr, Matrouh, Sidi Barani, and Halayeb & Shalateen.

Camel's milk samples of Ras Sidr showed the highest values of Silver, Boron, Aluminum, Chromium, Lead, Manganese, Molybdenum, Zinc and Thallium. Halayeb & Shelatin region showed the highest values of magnesium and Cupper in milk samples while Sedi Barani region showed highest values of Lithium, calcium and Vanadium.

Goat's milk samples of Ras Sidr region showed the highest values of Boron, Barium, Bismuth, Cobalt, Molybdenum, Silicon, Strontium, Cadmium, Lead and Thallium also, highest values of Silver, Lithium, and Aluminum were recorded at Matrouh region. Sedi Barani region recorded higher values of Aluminum and Vanadium while Halayeb & Shelatin region recorded highest values of Manganese and Chromium in goat's milk samples.

Ewe's milk samples of Ras Sidr region showed the highest values of Silver, Boron, Lithium, Nickel, Silicon, Strontium, Zinc, Cadmium and Lead. Matrouh region milk samples recorded highest values of Iron, Manganese and Molybdenum, while Sedi Barani region recorded higher values of Magnesium.
From the public health point of view, monitoring the levels of heavy metals in milk, water, and animal feed can help draw attention to environmental pollution that affects the growth and health of both humans and animals. Sustainable development and health of the society are the final goal of our objectives to reflect welfare and pleasure of families and desert communities.


## Introduction

Milk and dairy products have always been acknowledged as an important part of the human diet both in developing and developed nations of the world. In underdeveloped nations, goat, ewe and camel**'s** milk production are effective in combating malnutrition, particularly among infants 1. Goat milk is becoming increasingly popular, not only to feed the poor and rural populations with small landholdings but also as a “super” dairy food with unique medicinal, nutritional, urological, and biological properties 2. Goat milk and its processed products are useful as functional foods, maintaining nourishment and health of young and elders, especially those who have an allergy to cow milk. Goat milk can be used to prepare a wide variety of dairy products such as butter, ice cream, cheese, buttermilk, condensed milk, yogurt, flavored milk, sweets, and candies 3. Camels are majorly reared for milk production as they produce milk for extended periods compared to cattle, especially in dry areas 4. Camel milk provides nutrients and medicinal benefits to consumers 5. Camel milk is documented to possess properties that fight various diseases, including cancer, diabetes, autism, hypertension, and skin diseases 6-8. Ewe milk is mainly processed into traditional fine cheeses for gourmet and export markets, as well as yogurt and ricotta 9, 10.

Heavy metal contamination is a serious threat because of its toxicity, bio-magnification, and bioaccumulation in the food chain. The deficiency of some of these metal elements leads to the impairment of vital biological processes but when they are present in excess, they become toxic 11. Trace heavy metals such as Cr (III), Ni (II), Cd (II), Zn (II), Pb (II), and Cu (II) are hazardous pollutants and are rich in areas with high anthropogenic activities 12. Several elements in milk like iron (Fe), zinc (Zn), and copper (Cu) are essential for the human body and play a crucial role in metabolism. These elements are considered as co-factors in many enzymatic reactions showing a variety of biochemical functions in the living organism. Nevertheless, the levels of these components above the sanitary recommendations may become toxic to human health 13-14. Industrial and agricultural activities, drinking water, animal feeds are the most common sources of pollutants entering the milk production processes in food chain.

From the public health point of view, monitoring the levels of heavy metals in milk, water, and animal feed can help draw attention to environmental pollution that affects the growth and health of both humans and animals. Sustainable development and health of the society is the final goal of our objectives to reflect welfare and pleasure of families and desert communities.

Hence, the present study aimed to determine the heavy metals concentrations in milks of (goat, camel, and ewe) water, and animal feed from four different locations i.e Ras Sidr, Matrouh, Sedi Barani, and (Halayeb&Shalatin) regions of Egypt. Water and animal feed samples were analyzed to investigate the relationship between heavy metal concentrations in milk and that of the dairy food chain at the field level.

## Materials and methods

**Chemical Properties**

**Milk Sample Collection**

A total of 36 raw camel, goat, and ewes milk samples was collected during lactation periods from each animal milk type located in four different desert regions: Ras Sedr (located in the south of Sinai), Matrouh, Sedi Barani (located in the northwest coast), and Halayeb & Shalatin (located in the south of Egypt). Samples were collected in sterile containers, immediately cooled to 4 ± 1°C, and delivered to the lab for analysis using a Lactoscan milk analyzer (Model Lactoscan SL, Milkotronic Ltd., Bulgaria) to determine the chemical content of each sample. The chemical composition of milk samples is illustrated in Table 1.

Milk samples preparation: Milk samples (10 ml) were digested utilizing microwave-assisted acid digestion (2-5 min) which included ultra-pure nitric acid (65%) volume and 1 ml of hydrogen peroxide (35%) and the sample. The digests were then filtered and diluted up to 20 ml with deionized water before examination 15. Animal feed sample preparation: The forage samples were taken from the same site and collected during the lactation and before milk sampling were collected, and stored in plastic bags for chemical analyses. Concentration forage plus (pasture and berseem hay) samples from each region were washed properly with distilled water and then with deionized water to remove soil or any other surface contaminants. Forage samples were cut into small size pieces and after drying, acid digestion was performed by a wet procedure described by 16 and prepared for the metals analyses. For Animal diet and raw material samples prepared and analyzed, Association of Official Analytical Chemists AOAC 17 methods were used. The concentrate mixture had an average chemical composition and nutritional value of 94.5% dry matter (DM g/kg wet material), 91.0% organic matter (OM), 17.38% crude protein (CP), 2.26% ether extract (EE), 47.5% neutral detergent fiber (NDF),14.5% acid detergent fiber (ADF), 5.62% acid detergent lignin (ADL), and 1.08% acid insoluble ash (AIA). Drinking water for animals: samples were collected from four different desert regions: Ras Sidr and Matrouh depend on tap water, while Sedi Barani and Halayeb & Shalatin depend on shallow and deep wells groundwater and all samples were stored in glass bottles at 4 ºC until metals analyses measurement.

**Detection metals using the ICP-OES method**

All the samples were the macro-elements; Calcium (Ca), Magnesium (Mg) and trace elements; Silver (Ag), Boron (B), Barium (Ba), Bismuth(Bi), Cobalt (Co), Copper (Cu), Iron (Fe), Lithium (Li), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Silicon (Si), Strontium (Sr), Zinc (Zn)as well as the toxic metals; Aluminum (Al), Cadmium (Cd), Chromium (Cr), Vanadium (V), Lead (Pb), Thallium (Tl) using inductively coupled plasma optical emission spectrometry ICP-OES (PERKINS ELMER OPTIMA 5300 DV MODEL-USA) inductively coupled plasma-optical emission spectrometry device. The ICP-OES system was equipped with a cyclonic spray chamber and a GemTip cross-flow nebulizer. The operating parameters of determination of elements by ICP-OES are as follows: The nebulizer argon gas flow rate, the auxiliary argon gas flow rate, and the plasma argon gas flow rate were 0.7 L min−1, 0.6 L min−1, and 13 L min−1, respectively. Sample aspiration at a flow rate of 2.0 mL min−1 and the sample pump rate (rpm) 25. The radiofrequency incident power was 1450 W and the radiofrequency generator was working at 40 MHz. The ICP-OES method in all samples was validated in terms of linearity, limits of detection (LOD) 6 limits of quantification (LOQ), accuracy, and precision. The LODs and LOQs of the method were calculated by analyzing ten separate blank solutions that were independently prepared. Based on the guidelines of the International Union of Pure and Applied Chemistry (IUPAC 1997), The following instrument's emission lines operational state for each element is described in Table 2.

**Calculated the Transfer factors (TFs)**

Transfer factors (TF1): The transfer factor is the ratio of the concentration of metals in water to their concentration in milk. The transfer factors (TF1) for each metal were computed as described by Cui et al. 18.

$$TF1 = \frac{\text{Mean concentration of metal in water}}{\text{Mean concentration of metal in milk}}$$

Transfer factors (TF2): the transfer factor is the ratio of the concentration of metals from forage to milk by following the formula as described by Houpert et al., 19 and Leeman et al., 20:

$$TF2 = \frac{\text{Mean concentration of metal in forage}}{\text{Mean concentration of metal in milk}}$$

where the metal content in milk and water (ppm (ww: wet weight)), and the metal content in forage (ppm: dry weight).

**Statistical analysis**

Triplicate analysis was carried out for each forage, drinking water, and milk samples. Data is reported as Mean ± SD. SPSS 21 statistics 27.0 software (version 27.0; IBM Corporation, Armonk, NY, USA) was used to analyze the significance of the differences to assess the effects of the treatment. A probability level ($P<0.05$) was considered to differ statistically.

## Results and discussion

**Levels of macro elements in camel, ewe and goats' milk**

Data shown in (Table, 3) represents the Mean values ± SD of the macro elements (Ca and Mg) values in camel, ewe and goats' milk of the four different regions. Results showed that calcium recorded higher values in camel's milk at Sidi Barani region, 1351.0 ± 96.0 ppm while lower values were recorded at Ras Sidr region, 1033.3 ± 76.4 ppm. Generally, camel milk samples showed higher values of calcium than those in ewe's milk while, goat's milk showed the lowest values. Results agreed with the higher values of calcium in drinking water in Sedi Barani region and the lower values at Ras Sidr region (Table, 6). The lower values of calcium in the diet at Ras Sidr region and the higher values at Halayeb & Shalatin region supported the results (Table, 7).

Magnesium (Table, 3) showed higher values in ewe's milk samples of Sedi Barani region (101.7 ±12.7 ppm) followed by camel milk in Halayeb & Shalatin region (95.3 ±19.2 ppm) while showed lower values in goats' milk at Ras Sidr and Matrouh regions being, 73.7 ±9.6 ppm and 71.3 ±16.9 ppm, respectively despite the higher values of Tf1 and Tf2. All sample values are within optimal limits according to 22-25.

**Levels of trace-elements in camel, ewe and goats' milk**

Data shown in (Table, 4) represents the Mean values ± SD of the trace elements (Ag, B, Ba, Bi, Co, Cu, Fe, Li, Mn, Mo, Ni, Si, Sr and Zn) values in camel, ewe and goats' milk of the four different regions. The concentration of silver (Ag) recorded highest values (4.00 ± 0.63 ppb) in goat's milk sample located at Matrouh region followed by the goat's milk sample (2.33 ± 0.21 ppb) located in Ras Sidr region. Except the higher values in camel and ewe milk samples at Ras Sidr region, 0.67±0.06 and 0.67±0.06 ppb, respectively there was no significant difference among other samples in the rest of the regions. Although the higher concentrations of Ag in the in the drinking tap water (Table, 6), animal diet (Table, 7) and the TF1 (Table, 8), the concentration of Ag in the milk recorded lowest values in camel milk at Matrouh and Ras Sidr regions. The concentrations of Ag in camel, ewe and goats' milk samples collected from the four locations in the present study were higher than the residue limit (0.25- 0.286 ppb) according to Şanal et al., 26. The highest concentrations of boron (B) were recorded in camel, goat and ewes milk samples at Ras Sidr region followed by Halaib and Shalatin regions in goat and ewe milk samples. The higher values of (B) in the milk samples were related to the higher content of (B) in the drinking water and in the animal diet (Table, 6 and 7). The concentrations of (B) of ewe and goats' milk samples collected from the four locations are higher than the residue limit (80.9- 77.1 ppb) according to Şanal et al., 26, while the camel milk sample has no limitations. The milk samples of Ras Sidr region recorded highest values of Barium (Ba) compared to other regions especially goat milk, 30.5+23.9 ppb which was related to the higher content of (Ba) in the drinking water and animal diet (2.7±0.2) and (16.47±0.77) ppb, respectively (Table, 6 and 7). Values in the present study were higher than the residue limit as explained by 25, 26, 27.

Ewe milk samples showed higher values of Bismuth (Bi) at Ras Sidr region, 3.33±0.29 ppb compared to that of goat and camel milk samples while camel milk samples showed the lowest value of (Bi), 1.0±0.10 ppb. at Ras Sidr region. Milk samples of camels and ewes at Matrouh region recorded relatively high concentrations of (Bi) compared to that of other regions and was related to the higher values in of (Bi) in drinking water and animal feed (Table, 6 and 7). In the current study, the concentration of (Bi) in ewe milk samples in all studied regions was higher than the limits mentioned by Al-Naemi 28 while in goat milk samples, (Bi) concentration was higher than the limits found by Pennington 29 in cow's milk and noticed that camel milk samples didn't have limits.

Goat milk samples recorded the highest value of (Co) at Ras Sidr region, 4.0 ±0.26 PPb, while camel milk samples recorded slightly lower values in the four regions especially at Sedi Barani region, 1.67 ± 0.21 PPb. Ewe milk samples recorded the lowest value at Halayeb & Shalatin region, 2.67±0.06 PPb. Goat milk samples recorded higher values than the limits mentioned by 27, 30, 31 except that collected from Matrouh which recoded lower value than the limit found by Miedico et al. 31. Ewe milk samples recorded higher values than the limits found by 27, 31, while recorded lower values than the limits found by Miedico et al., (2016) who reported that camel milk samples didn't have limits. Milk samples of Halayeb&Shalatin region recorded higher values of cupper (cu) in camel and goat milk samples and slightly higher in ewe milk samples, while lower values of (cu) were recorded at Matrouh region. Camels milk samples recorded highest values than the limits found by 27, 32, 33 while were lower than the limits mentioned by 23, 24, 34. Regarding to goat milk samples, the concentration of cu showed lower values than those limits mentioned by 31, 35. On the other hand, the concentration of Cu in goat milk samples was higher than limits recorded by Coni et al., 27. Ewe milk samples collected from Halayeb & Shalatin, Ras Sidr and Sedi Barani recorded higher values of 0.63±0.03, 0.53±0.01 and 0.50±0.03 ppm than the limits found by Coni et al., 27. while Halayeb & Shalatin and Sedi Barani recorded higher values than the limits illustrated by Khan, et al . 30, Miedico et al . 31, and Raynal-Ljutovac et al. 36. It was noticed that Codex Commission Regulation (EU) 37 and Egyptian standard 38 mentioned that maximum residues limit for Cu milk is 0.5 ppm. Concentrations of iron (Fe) were slightly higher in camel milk samples at Sidi Barani and Halayeb & Shalatin regions than that at Ras Sidr and Matrouh regions and recorded higher values than limits found by Abba et al. 35 and Meldebekova et al. 39. Also, camel milk samples showed higher values of Fe than those in milk samples of goats and ewes in the four regions. Goat milk samples collected from Ras Sidr

region recorded slightly lower values of Fe than those of other regions, the four studied locations showed lower values of Fe than the limits found by Coni et al. 27, Raynal-Ljutovac et al., 36, Elhardallou & El-Naggar, 34 and Abba et al., 35. The present study showed slightly lower values of Fe in ewe's milk samples than those limits reported by Coni et al. 27, Khan, et al . 30, Raynal-Ljutovac et al., 36 and Licata et al., 40. Codex Commission Regulation 37 and Egyptian standard 38 mentioned that maximum residues limit for Fe in milk is 2.6 pp. The milk samples collected from Ras Sidr region showed slightly higher values of Lithium (Li) compared to other regions especially in ewe's milk samples, while those of Halayeb&Shalatin region showed lower values which reflected the lower values of (Li) in the animal diet of this region. The average concentration of (Li) in goat's milk samples was lower than that reported by Bilandžić et al., 41, approx. 14 ppb.

Camel's milk samples recorded lower values of Manganese (Mn) at the four studied regions compared to those of goat's and ewe's milk samples also, contained a lower concentration of Mn than that mentioned by Mehaia et al., 24, Diacono et al., 33 and Meldebekova et al., 39. Camel's milk samples contained a lower concentration of Mn than those mentioned by Mehaia et al., 24, Diacono et al., 33 and Meldebekova et al., 39. The higher concentrations of Mn were recorded in milk samples of Ras Sidr region and the lowest value at Matrouh region in camel's and goat's milk samples. In the present study the values of Mn in goat milk samples recorded higher values than the limits found by Bilandžić et al., 41, Elhardallou and El-Naggar, 34 and Antunović et al., 42. Ewe's milk samples recorded lowest value of Mn concentration than limits mentioned by Khan et al., 30, Raynal-Ljutovac et al., 36, Licata et al., 40, and Miedico et al., 31. Codex Commission Regulation 43 mentioned that maximum residues limit for MN milk is 50 ppb. The molybdenum (Mo) concentration of milk samples in Ras Sidr region was higher than those in other regions while the lower concentration was recorded in Sedi Barani region. The average (Mo) concentration in camel milk samples of the present study was lower than those limits reported by Mostafidi et al., 25, approx. 100 .0 ppb while, the concentration of (Mo) in goats milk samples recorded higher value than limits found by Bilandžić et al., 41, Miedico et al., 31, and Antunović et al., 42. Ewe milk samples recorded lower value than limits found by Miedico et al., 31. Milk samples from Ras Sidr region showed relatively higher values of Nickel (Ni) concentrations in camels and ewes while Halayeb & Shalatin region showed higher values in goat's milk. Matrouh region showed lower values in (Ni) concentrations in goat's and ewe's milk samples. Ewe's milk samples showed highest value of Ni at Ras Sidr region while camel's milk samples recorded lowest value at Sidi Barani region which was matching with the Ni concentration in animal drinking water, animal diet and the TF1 value. The concentration of (Ni) in camel's milk samples of the present study showed lower values than the limits indicated by Abba et al. 35, while the camel's milk samples collected from Ras Sidr region were within the stated limits. The concentration of (Ni) in goat's milk samples in the present study was significantly higher than the limits found by Coni et al., 27, Aslam et al 44, Şanal et al., 26, and Abba et al., 35, while ewe's milk samples showed lower values than those limits mentioned by Coni et al., 27, Şanal et al., 26, Licata et al., 40, and Miedico et al., 31. Maximum concentration values of Silicon (Si) were recorded at Ras Sidr region in camel's, goat's and ewe's milk samples, while minimum values were recorded in the three types of milk samples at Matrouh region, accompanied with relatively higher values of (Si) concentration at Ras Sidr region and lower values at Matrouh region in drinking water and significant higher values at Ras Sidr region and lower values at Matrouh region in animal diets. Results were in agreement with the values of TF2.Camel's, goat's and ewe's milk samples of the present study showed higher values of (Si) concentration than those limits of Miedico et al., 31 and Ahmed et al., 45.

Goat's milk samples recorded higher values of strontium (Sr) except for Sidi Barani region, while camel's milk showed the lowest values in the four regions. Ras Sidr region recorded higher values of (Sr) concentration in milk samples, while Sedi Barani recorded the lowest values which agreed with the with the higher values of (Sr) in drinking water and animal feed at Ras Sidr region and the lower values at Sedi Barani region.In the present study, a remarkable decrease in the concentration of (Sr) in camel milk samples compared to the limits indicated by Elhardallou and El-Naggar 34. Goat's milk samples recorded higher values in the concentration of (Sr) than the limits found by Coni et al., 27, Elhardallou and El-Naggar 34, and Miedico et al., 31. Ewe milk samples showed higher values in the concentration of (Sr) than limits of Coni et al., 27.

Camel's, goat's and ewe's milk recorded highest values of Zinc (Zn) at Ras Sidr region and lower values at Matrouh region. Results were in agreements with concentration of Zn in drinking water, relatively higher values at Ras Sidr region (0.66 ppm) and lower values at Matrouh region (0.60 ppm) and in animal diet, 76.67ppm and 52.33 ppm in the two regions, respectively. A slight increase of Zn concentration in Camel's milk samples of the present study was observed than limits reported by Mehaia et al., 31, Al-awadi and Srikumar 32, Diacono et al. 33, Meldebekova et al. 37, Elhardallou and El-Naggar 34. While Zn concentrations in ewe's and goat's milk samples were clearly higher compared to those reported by to Khan et al., 30, Raynal-Ljutovac et al., 36, Bilandžić et al., 39, Elhardallou and El-Naggar 34, Antunović et al., 40, and Abba et al., 35. Codex Commission Regulation 37 and Egyptian standard 38 mentioned that maximum residues limit for Zn in milk is 5.0 ppm.

**Levels of Toxic Metals in camel, ewe and goats' milk**

Data from Table, 5 illustrated the Mean values ± SD of the toxic metals (Al, Cd, Cr, V, pb and Tl) values in camel, ewe and goats' milk of the four different regions. The least concentration of (Al) was recorded in camel milk samples while the highest concentration was recorded in

goat milk samples. Ras Sidr and Halayeb & Shalatin regions represented the highest concentration of (Al) in milk samples while, Matrouh region showed the least concentration of (Al) in milk sample. Results agreed with the relative increase of (Al) concentration in drinking water especially at Halayeb & Shalatin region ($p< 0.05$) same as the relative increase of (Al) concentration in animal feed. It was apparent that the concentrations of (Al) in the present study recorded lower values in camel milk sample than the limits according to Mostafidi et al. 25. Also, Goat milk samples recorded higher values than the limits found by Coni et al 27 and Miedico et al., 25. A noticeable decreased of (Al) concentration in ewe milk samples of the present study compared to the limits reported by Coni et al. 27, Khan et al., 30, and Mostafidi et al., 25 was recorded.

Ras Sidr region recorded highest values of (cd) in milk samples compared to other regions especially in goat milk samples which recorded lowest values at Sidi Barani region. Results agreed with the highest concentration of (cd) in the animal diet and the lowest concentration at Sedi Barani region. Results of the present study showed higher values in concentration of (Cd) in camel milk samples than limits according to Aludatt et al., 23 and Mostafidi et al., 25. Also, the present study showed higher values in concentration of (Cd) in goat's milk samples than limits found by Coni et al., 27, Miedico et al., 31, and Abba et al., 35. A slight increase of (Cd) concentration in ewe milk samples of the present study compared to the limits according to Coni et al., 27, Şanal et al., 26, and Miedico et al., 31 was observed. Codex Alimentarius Commission 46 and Egyptian standard 38 mentioned that maximum residues limit for Cd milk is 50. 0ppb.The goat milk samples recorded the highest values of chromium (Cr) at Halayeb & Shalatin region and the lowest values at Matrouh region, while camel milk showed the highest values at Ras Sidr region and the lowest value at Matrouh region. Results were explained by the higher concentrations of (Cr) in drinking water and animal feed in these regions (Table, 6 and 7). The concentrations of (Cr) in camel milk samples were lower than those limits reported by Elhardallou and El-Naggar 34. Goat and ewe milk samples of the present study showed lower concentration values of (Cr) than those limits reported by Aslam et al., 41, Licata et al., 40, Bilandžić et al., 41, Elhardallou & El-Naggar 34, and Al-Naemi., 28. The milk samples of Matrouh region recorded the lowest values of vanadium (v) concentration compared to that of other regions in camel, goat and ewes milk samples. Ewe milk samples recorded lower values of (v) concentration compared to that of other animals in the four regions. In the present study, Camel milk samples showed higher concentration of (V) in the four studied regions than the limits recorded by Mostafidi et al., 25. Lower concentrations of (V) were observed in the present study for ewe and goat's milk samples than the limits recorded by Şanal et al., 26 and Miedico et al., 31. The higher concentrations of (pb) in milk samples in different animals were recorded at Ras Sidr region while, the lowest concentrations were recorded at Matrouh region. Ras Sidr region recorded slightly lower values of (pb) in camel milk compared to other animals while, goat and ewe milk showed higher values. Results were matching with the higher values of (pb) recorded in the drinking water and animal feed at Ras Sidr region and the lower values at Matrouh and Sedi Barani regions.

Camel and goat's milk samples of the present study showed higher concentrations of (pb) than those found by Diacono et al., 33, Aslam et al., 44, and Elhardallou and El-Naggar. 34 while, concentration of (pb) in ewe milk samples was lower than the limits mentioned by Coni et al., 27, Licata et al., 40, Miedico et al., 31 and Al-Naemi., 28. Codex Commission Regulation (EU) 37 and Egyptian standard 38 mentioned that maximum residues limit for pb milk is 20.0 ppb.

Ras Sidr region showed the highest concentration of (Tl) in the milk of animals except for ewe milk in Sidi Barani and Halayeb&Shalatin region compared to other regions. Ewe milk samples recorded higher values of (Tl) compared to that of other milks which agreed with the higher values of (Tl) in drinking water at Halayeb&Shalatin region. Concentrations of (Tl) in camel, ewe and goat's milk samples in the present study were lower than those mentioned by Şanal et al., 26, Mostafidi et al., 25, and Miedico et al., 31.

## Conclusion

Camel milk samples of Ras Sidr showed the highest values of Silver (Ag), Boron (B), Aluminum (Al), Chromium (Cr), Lead (Pb), Manganese (Mn) Molybdenum (Mo), Zinc (Zn) and Thallium (Tl) while recorded the lowest values of calcium and magnesium. Halayeb & Shelatin region showed the highest values of magnesium and Cupper (cu) in milk samples while Sedi Barani region showed highest values of Lithium (Li), calcium and Vanadium (V). Goat milk samples of Ras Sidr region showed the highest values of Boron (B), Barium (B), Bismuth (Bi), Cobalt (Co), Molybdenum (Mo), Silicon (Si), Strontium (Sr), Cadmium (Cd), Lead (Pb) and Thallium (Tl) also, highest values of Silver (Ag), Lithium (Li), and Aluminum (Al) were recorded at Matrouh region. Sedi Barani region recorded higher values of Aluminum (Al) and Vanadium (V) while Halayeb & Shelatin region recorded highest values of Manganese (Mn) and Chromium (Cr) in goat milk samples. Ewes milk samples of Ras Sidr region showed the highest values of Silver (Ag), Boron (B), Lithium (Li), Nickel (Ni), Silicon (Si), Strontium (Sr), Zinc (Zn), Cadmium (Cd) and Lead (Pb). Matrouh region milk samples recorded highest values of Iron (Fe), Manganese (Mn) and Molybdenum (Mo), while Sedi Barani region recorded higher values of Magnesium (Mg) and in Halayeb & Shelatin higher values of Vanadium (V) were recorded.

## Abbreviations

Ca Calcium

Mg Magnesium

Ag Silver

B Boron

Ba Barium

Bi Bismuth

Co Cobalt

Cu Copper

Fe Iron

Li Lithium

Mn Manganese

Mo Molybdenum

Ni Nickel

Si Silicon

Sr Strontium

Zn Zinc

Al Aluminum

Cd Cadmium

Cr Chromium

V Vanadium

pb Lead

Tl Thallium

## Declarations

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**Ethical Approval**

This study was approved by the Institutional Animal Care and Use Committee of Desert Research Center, protocol No. (.....). All protocols follow the ARRIVE guidelines for reporting animal research (https://arriveguidelines.org).

**Data Availability Statement**

All the data supporting this article are available from the corresponding author upon request. 326

**Author contributions**

K. A. Soryal conceptualized the experimental design. A. H. Ibrahim and E.M.M. Abdeen coordinated the study. K. A. Soryal discussed the results and gave important contributions to the writing. A. H. Ibrahim and E.M.M. Abdeen. performed the feeding trials, performed

molecular work in the laboratory, and compiled the results. Samah M.S. El-Shafei and A. H. Ibrahim did the statistical analyses and compiled the draft version of the manuscript. K. A. Soryal and Samah M.S. El-Shafei supervised the work. All authors formatted and edited the final manuscript version.

**Conflict of Interests**

The authors declare that they have no conflict of interest.

**Consent for publication**

Not applicable.

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## Tables

Table 1: chemical composition of raw camel, goat, and ewe's milk in different regions of Egypt.

| Chemical Composition (%) | Milk samples | Regions | | | |
|---|---|---|---|---|---|
| | | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin |
| **Fat** | **Camel** | 4.23±0.28 | 3.34±0.26 | 3.53±0.22 | 3.40±0.21 |
| | **Goat** | 4.00±0.37 | 3.93±0.23 | 3.72±0.14 | 3.34±0.21 |
| | **Ewe** | 7.28±0.15 | 5.00±0.34 | 5.27±0.11 | 6.82±0.31 |
| **Protein** | **Camel** | 3.42±0.24 | 3.25±0.24 | 3.38±0.25 | 2.81±0.14 |
| | **Goat** | 3.70±0.33 | 3.79±0.14 | 3.52±0.21 | 3.37±0.22 |
| | **Ewe** | 5.66±0.31 | 4.98±0.12 | 5.63±0.34 | 5.79±0.15 |
| **Lactose** | **Camel** | 3.75±0.12 | 4.38±0.11 | 4.49±0.13 | 4.40±0.24 |
| | **Goat** | 4.42±0.27 | 4.47±0.23 | 4.50±0.23 | 4.32±0.33 |
| | **Ewe** | 3.43±0.31 | 3.60±0.28 | 3.92±0.25 | 3.24±0.31 |
| **Total solids** | **Camel** | 13.10±0.34 | 11.59±0.42 | 12.76±0.43 | 11.69±0.52 |
| | **Goat** | 12.60±0.45 | 12.80±0.42 | 12.57±0.54 | 11.91±034 |
| | **Ewe** | 15.78±0.46 | 13.01±0.62 | 13.70±0.53 | 16.43±0.43 |

Table 2. Analytical quality and control parameters of the ICP-OES spectrometer method in terms of *LOD, and *LOQ.

| Mineral/Heavy Metal | Units | LOD limit of detection | LOQ limit of quantification | Accuracy (%) | Wavelengths |
|---|---|---|---|---|---|
| Macro-element | | | | | |
| Calcium (Ca) | ($mg/L^{-1}$) | 30 | 1500.0 | 98 | 4152.61 |
| Magnesium (Mg) | ($mg/L^{-1}$) | 0.05 | 1000.0 | 97 | 279.45 |
| Trace Elements | ($\mu g/L^{-1}$) | 0.011 | 100.0 | 96 | 339.24 |
| Silver (Ag) | | | | | |
| Boron (B) | ($\mu g/L^{-1}$) | 0.40 | 200.0 | 96 | 249.83 |
| Barium (Ba) | ($\mu g/L^{-1}$) | 0.25 | 80.0 | 98 | 233.55 |
| Bismuth(Bi) | ($\mu g/L^{-1}$) | 0.23 | 80.0 | 100 | 341.63 |
| Cobalt (Co) | ($\mu g/L^{-1}$) | 0.60 | 50.0 | 97 | 257.98 |
| Copper (Cu) | ($mg/L^{-1}$) | 0.16 | 47.0 | 101 | 233.56 |
| Iron (Fe) | ($mg/L^{-1}$) | 0.13 | 120.0 | 95 | 247.45 |
| Lithium (Li) | ($\mu g/L^{-1}$) | 0.12 | 74.0 | 99 | 231.89 |
| Manganese (Mn) | ($mg/L^{-1}$) | 0.021 | 89.0 | 97 | 249.61 |
| Molybdenum (Mo) | ($mg/L^{-1}$) | 0.028 | 4.54 | 103 | 242.96 |
| Nickel (Ni) | ($mg/L^{-1}$) | 0.017 | 1.03 | 100 | 226.43 |
| Silicon (Si) | ($mg/L^{-1}$) | 0.018 | 0.99 | 97 | 261.89 |
| Strontium (Sr) | ($mg/L^{-1}$) | 0.014 | 0.95 | 96 | 424.69 |
| Zinc (Zn) | ($mg/L^{-1}$) | 0.54 | 150.8 | 104 | 223.24 |
| Toxic Elements | ($\mu g/L^{-1}$) | 0.013 | 1.55 | 95 | 394.76 |
| Aluminum (Al) | | | | | |
| Cadmium (Cd) | ($\mu g/L^{-1}$) | 1.0 | 30.0 | 99 | 228.80 |
| Chromium (Cr) | ($\mu g/L^{-1}$) | 1.5 | 938.0 | 101 | 255.46 |
| Vanadium (V) | ($mg/L^{-1}$) | 0.013 | 0.96 | 100 | 234.58 |
| Lead (Pb) | ($mg/L^{-1}$) | 0.015 | 0.75 | 95 | 280.40 |
| Thallium (Tl) | ($mg/L^{-1}$) | 0.020 | 5.0 | 98 | 243.54 |

*LOD=limit of detection, and LOQ=limit of quantification.

Table, 3: The mean values ± SD of the macro elements (Ca and Mg) values in camel, ewe and goats' milk of the four different regions.

| Elements | Units | Milk samples | Region | | | |
|---|---|---|---|---|---|---|
| | | | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin |
| Macroelement Calcium (Ca) | ppm | Camel | $1033.3^{Bab}$±76.4 | $1201.7^{Aa}$ ±88.1 | $1351.0^{Aa}$ ±96.0 | $1098.3^{Bab}$±102.5 |
| | | Goat | $980.7^{Ab}$±23.2 | $1042.3^{Ab}$ ±80.0 | $978.7^{Ab}$ ±59.1 | $1033.7^{Ab}$±33.5 |
| | | Ewe | $1114.2^{Aa}$±64.6 | $1280.3^{Aa}$ ±15.6 | $1250.3^{Aa}$ ±31.3 | $1139.3^{Aa}$±46.7 |
| Magnesium (Mg) | ppm | Camel | $75.8^{Bb}$±24.3 | $76.0^{Aba}$ ±9.8 | $86.3^{ABab}$±8.6 | $95.3^{Aa}$±19.2 |
| | | Goat | $73.7^{Ab}$±9.6 | $71.3^{Aa}$ ±16.9 | $76.7^{Aab}$ ±10.0 | $82.3^{Aa}$±27.4 |
| | | Ewe | $93.7^{Ba}$±6.7 | $78.0^{Ba}$ ±12.3 | $101.7^{Aa}$ ±12.7 | $90.0^{Ba}$±19.5 |

**(mg/kg) ppm, µg/L (ppb), n: number of samples taken,** the mean values are presented as the mean ± standard deviation, abc… Vertically different small letters are significantly different ($p<0.05$). ABC… Horizontally different capital letters are significantly different ($p<0.05$).

Table, 4: The Mean values ± SD of the trace elements (Ag, B, Ba, Bi, Co, Cu, Fe, Li, Mn, Mo, Ni, Si, Sr and Zn) values in camel's, ewe's and goat's milk of the four different regions.

| Elements | Units | Milk samples | Region | | | |
|---|---|---|---|---|---|---|
| | | | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin |
| Trace elements Silver (Ag) | Ppb | Camel | $0.67^{Ab}$±0.06 | $0.33^{Ba}$±0.06 | $0.33^{Ba}$±0.06 | $0.33^{Ba}$±0.06 |
| | | Goat | $2.33^{Ba}$±0.21 | $4.00^{Aa}$±0.36 | $0.33^{Ca}$±0.06 | $0.33^{Ca}$±0.06 |
| | | Ewe | $0.67^{Ab}$±0.06 | $0.33^{Ba}$±0.06 | $0.33^{Ba}$±0.06 | $0.33^{Ba}$±0.06 |
| Boron (B) | Ppb | Camel | $143.7^{Aa}$±6.9 | $104.2^{Ba}$±13.1 | $105.4^{Ba}$±8.1 | $122.7^{Aa}$±44.5 |
| | | Goat | $154.0^{Aa}$±38.6 | $111.7^{Ba}$±28.9 | $119.7^{ABa}$±12.5 | $144.0^{Aa}$±25.2 |
| | | Ewe | $146.0^{Aa}$±14.8 | $109.7^{ABa}$±31.4 | $119.3^{Ba}$±26.3 | $135.3^{ABa}$±25.7 |
| Barium (Ba) | Ppb | Camel | $23.0^{Aab}$±0.80 | $19.8^{Aa}$±1.14 | $21.3^{Aa}$±2.10 | $18.8^{Aa}$±1.10 |
| | | Goat | $30.5^{Aa}$±23.9 | $20.0^{Ba}$±1.50 | $20.2^{Ba}$±1.46 | $23.4^{Ba}$±1.95 |
| | | Ewe | $22.0^{Aab}$±15.0 | $17.0^{Aa}$±2.51 | $16.0^{Aa}$±1.44 | $22.4^{Aa}$±2.40 |
| Bismuth (Bi) | Ppb | Camel | $1.00^{Ac}$±0.10 | $2.33^{Aa}$±0.12 | $2.00^{Aa}$±0.20 | $2.00^{Aa}$±0.17 |
| | | Goat | $2.33^{Ab}$±0.21 | $2.00^{Aa}$±0.20 | $2.00^{Aa}$±0.20 | $2.33^{Aa}$±0.40 |
| | | Ewe | $3.33^{Aa}$±0.29 | $3.00^{Aa}$±0.36 | $2.67^{Aa}$±0.12 | $2.33^{Aa}$±0.32 |
| Cobalt (Co) | Ppb | Camel | $2.67^{Ab}$±0.25 | $2.00^{Aa}$±0.10 | $1.67^{Aa}$±0.21 | $2.00^{Aa}$±0.17 |
| | | Goat | $4.00^{Aa}$±0.26 | $2.33^{Ba}$±0.21 | $3.00^{Aa}$±0.17 | $3.33^{Aa}$±0.31 |
| | | Ewe | $3.33^{Ab}$±0.23 | $3.67^{Aa}$±0.35 | $3.67^{Aa}$±0.12 | $2.67^{Ba}$±0.06 |
| Copper (Cu) | Ppm | Camel | $0.50^{Ba}$±0.04 | $0.37^{Bb}$±0.02 | $0.57^{Bb}$±0.03 | $0.63^{Ab}$±0.03 |
| | | Goat | $0.60^{Aa}$±0.01 | $0.50^{Aa}$±0.02 | $0.70^{Aa}$±0.01 | $0.73^{Aa}$±0.02 |
| | | Ewe | $0.53^{Aa}$±0.01 | $0.43^{Aab}$±0.03 | $0.50^{Ab}$±0.03 | $0.63^{Ab}$±0.03 |
| Iron (Fe) | Ppm | Camel | $1.87^{Aa}$±0.35 | $1.97^{Aa}$±0.38 | $2.07^{Aa}$±0.51 | $2.03^{Aa}$±0.51 |
| | | Goat | $0.29^{Ab}$±0.22 | $0.36^{Ab}$±0.14 | $0.35^{Ab}$±0.16 | $0.33^{Ab}$±0.10 |
| | | Ewe | $0.30^{Bb}$±0.10 | $0.47^{Ab}$±0.06 | $0.37^{ABb}$±0.12 | $0.27^{Bb}$±0.12 |
| Lithium (Li) | Ppb | Camel | $3.0^{Aa}$±0.52 | $2.3A^{Bb}$±0.21 | $3.3^{Aa}$±0.49 | $1.7^{Ba}$±0.21 |
| | | Goat | $3.0^{Aa}$±0.30 | $3.4^{Aa}$±0.36 | 3.3Aa±0.21 | $2.3^{Ba}$±0.32 |
| | | Ewe | $4.7^{Aa}$±0.42 | $4.0^{Aa}$±0.20 | $2.0^{Ba}$±0.17 | $3.0^{Ba}$±0.36 |
| Manganese (Mn) | Ppb | Camel | $48.7^{Aa}$±3.59 | $32.0^{Bb}$±9.5 | $35.7^{Bb}$±6.4 | $34.0^{Bb}$±21.1 |
| | | Goat | $60.7^{Aa}$±9.30 | $41.0^{Bb}$±12.5 | $55.3^{Aa}$±24.7 | $61.3^{Aa}$±29.9 |
| | | Ewe | $62.7^{Aa}$±23.2 | $77.0^{Aa}$±17.3 | $46.3^{Ba}$±15.3 | $53.3^{Ba}$±29.2 |
| Molybdenum (Mo) | ppb | Camel | $49.3^{Aa}$±18.9 | $36.7^{Bb}$±7.2 | $35.0^{Ba}$±14.7 | $43.0^{Aa}$±10.5 |
| | | Goat | $49.3^{Aa}$±26.5 | $40.7^{Ab}$±11.7 | $34.3^{Ba}$±20.6 | $40.7^{Aa}$±11.6 |
| | | Ewe | $47.7^{Aa}$±15.5 | 50.0Aa±15.4 | $32.3^{Ba}$±0.6 | $39.7^{Aa}$±15.3 |
| Nickel (Ni) | Ppb | Camel | $22.0^{Aa}$±2.11 | $18.5^{Aa}$±2.17 | $16.7^{Aa}$±1.65 | $19.2^{Aa}$±1.36 |
| | | Goat | $21.3^{Aa}$±1.91 | $19.8^{Aa}$±1.24 | $21.4^{Aa}$±2.91 | $23.3^{Aa}$±2.08 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Ewe | 25.$^{Aa}$±0.29 | 18.7$^{Ba}$±1.74 | 20.3$^{Aa}$±1.80 | 19.3$^{Aa}$±0.45 |
| Silicon (Si) | Ppb | Camel | 39.0$^{Ab}$±24.2 | 30.3$^{Ab}$±6.4 | 37.3$^{Ab}$±14.7 | 37.0$^{Ab}$±25.1 |
| | | Goat | 54.3$^{Aa}$±18.6 | 42.0$^{Ba}$±17.7 | 46.0$^{Aa}$±30.0 | 43.3$^{Bab}$±23.7 |
| | | Ewe | 55.7$^{Aa}$±19.3 | 41.0$^{Ba}$±6.1 | 47.3$^{Aa}$±24.0 | 53.3$^{Aa}$±18.0 |
| Strontium (Sr) | Ppb | Camel | 42.7$^{Ab}$±8.5 | 34.3$^{Aa}$±6.9 | 34.7$^{ABa}$±6.9 | 39.3$^{Ab}$±7.9 |
| | | Goat | 56.3$^{Aa}$±11.3 | 39.3$^{Ba}$±7.9 | 37.7$^{Ba}$±7.5 | 54.7$^{Aa}$±10.9 |
| | | Ewe | 46.0$^{Ab}$±9.2 | 34.7$^{Ba}$±6.9 | 42.3Ba±8.5 | 42.0$^{Bab}$±8.4 |
| Zinc (Zn) | Ppm | Camel | 7.52$^{Aa}$±1.98 | 3.49$^{Bb}$±0.86 | 3.90$^{Bb}$±0.58 | 4.10$^{Bb}$±1.00 |
| | | Goat | 8.89$^{Aa}$±1.51 | 7.55$^{Aa}$±0.83 | 7.69$^{Aa}$±1.19 | 7.79$^{Aa}$±2.85 |
| | | Ewe | 8.19$^{Aa}$±3.00 | 4.16$^{Bb}$±1.04 | 6.23$^{ABa}$±3.02 | 7.43$^{Aa}$±3.49 |

**(mg/kg) ppm, µg/L (ppb), n: number of samples taken,** the mean values are presented as the mean ± standard deviation, abc… Vertically different small letters are significantly different ($p<0.05$). ABC… Horizontally different capital letters are significantly different ($p<0.05$).

Table 5: The mean values ± SD of the of the toxic Metals (Al, Cd, Cr, V, pb and Tl) in camel, ewe and goats' milk of the four different regions.

| **Elements** | **Units** | **Milk samples** | **Region** | | | |
|---|---|---|---|---|---|---|
| | | | **Ras Sidr** | **Matrouh** | **Sedi Barani** | **Halayeb & Shelatin** |
| Toxic metals Aluminum (Al) | ppb | Camel | 3.7$^{Aa}$±0.73 | 1.7$^{Ba}$±0.33 | 2.3$^{Ba}$±0.47 | 3.3$^{Aa}$±0.67 |
| | | Goat | 3.0$^{Ba}$±0.60 | 4.7$^{Aa}$±0.93 | 4.7$^{Aa}$±0.93 | 3.3$^{Ba}$±0.67 |
| | | Ewe | 3.7$^{Aa}$±0.73 | 3.3$^{Aa}$±0.67 | 3.3$^{Aa}$±6.60 | 3.0$^{Aa}$±0.60 |
| Cadmium (Cd) | ppb | Camel | 52.7$^{Aa}$±15.0 | 40.7$^{Aa}$±15.3 | 48.0$^{Aa}$±39.0 | 51.0$^{Aa}$±20.4 |
| | | Goat | 74.3$^{Aa}$±17.0 | 57.7$^{Aa}$±19.9 | 34.3$^{Bb}$±35.2 | 56.3$^{Aa}$±9.1 |
| | | Ewe | 60.7$^{Ab}$±4.5 | 42.0$^{Ba}$±9.5 | 45.0$^{Ba}$±14.0 | 44.3$^{Bab}$±19.0 |
| Chromium (Cr) | ppb | Camel | 48.7$^{Aa}$±25.5 | 32.3$^{Ba}$±5.7 | 38.0$^{Aa}$±15.4 | 48.0$^{Aa}$±20.4 |
| | | Goat | 51.3$^{Aa}$±20.3 | 41.3$^{ABa}$±20.8 | 52.7$^{Aa}$±7.5 | 54.3$^{Aa}$±19.5 |
| | | Ewe | 49.0$^{Aa}$±5.3 | 43.0$^{ABa}$±16.5 | 51.3$^{Aa}$±13.7 | 52.3$^{Aa}$±19.6 |
| Vanadium (V) | ppb | Camel | 60.9$^{Aa}$±6.1 | 50.7$^{Ba}$±5.1 | 66.5$^{Aa}$±6.7 | 65.3$^{Aa}$±6.5 |
| | | Goat | 65.0$^{Ab}$±6.5 | 55.0$^{ABa}$±5.5 | 67.7$^{Aa}$±6.8 | 63.1$^{Aa}$±6.3 |
| | | Ewe | 51.6$^{Bb}$±5.2 | 45.3$^{Ba}$±4.5 | 50.9$^{Bb}$±5.1 | 60.3$^{Aa}$±6.0 |
| Lead (Pb) | ppb | Camel | 39.3$^{Aa}$±14.2 | 23.0$^{Ba}$±9.2 | 30.0$^{Aa}$±6.1 | 30.0$^{Aa}$±9.5 |
| | | Goat | 45.7$^{Aa}$±29.2 | 25.3$^{Ba}$±16.9 | 34.3$^{ABa}$±10.0 | 38.7$^{Aa}$±21.2 |
| | | Ewe | 45.3$^{Aa}$±11.5 | 28.0$^{Ba}$±20.9 | 24.7$^{Bab}$±10.2 | 39.7$^{Aa}$±23.1 |
| Thallium (Tl) | ppb | Camel | 47.3$^{Aa}$±7.6 | 29.3$^{Bb}$±11.0 | 38.3$^{Aa}$±7.1 | 41.3$^{Ab}$±22.8 |
| | | Goat | 53.7$^{Aa}$±16.2 | 30.3$^{Bb}$±4.6 | 39.7$^{Aa}$±14.4 | 33.3$^{Bb}$±1.5 |
| | | Ewe | 46.3$^{Aa}$±20.8 | 42.3$^{Aa}$±18.2 | 59.7$^{Aa}$±15.0 | 58.3$^{Aa}$±23.5 |

**(mg/kg) ppm, µg/L (ppb), n: number of samples taken,** the mean values are presented as the mean ± standard deviation, abc… Vertically different small letters are significantly different ($p<0.05$). ABC… Horizontally different capital letters are significantly different ($p<0.05$).

Table 6. Levels of trace and toxic element content in animal drinking water across four regions of Egypt.

| Elements | Units | Regions | | | | Range | | % of Positive Samples (n = 36) |
|---|---|---|---|---|---|---|---|---|
| | | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin | Minimum | Maximum | |
| Trace Elements Silver (Ag) | ppb | $2.33^{b}\pm0.32$ | $4.0^{a}\pm0.36$ | $3.33^{ab}\pm0.58$ | $3.33^{ab}\pm0.58$ | <LOD | 7.0 | 50 |
| Boron (B) | ppb | $6.0^{b}\pm0.36$ | $7.0^{b}\pm0.25$ | $4.0^{c}\pm0.25$ | $12.0^{a}\pm0.25$ | 2.0 | 15.0 | 100 |
| Barium (Ba) | ppb | $2.7^{a}\pm0.2$ | $1.7^{b}\pm0.1$ | $2.7^{a}\pm0.2$ | $2.4^{a}\pm0.2$ | <LOD | 5.0 | 91.6 |
| Bismuth (Bi) | ppb | $2.0^{b}\pm0.2$ | $4.0^{a}\pm0.4$ | $2.0^{b}\pm0.1$ | $2.0^{b}\pm0.3$ | <LOD | 8.0 | 75 |
| Cobalt (Co) | ppb | $1.0^{b}\pm.0.06$ | $0.667^{b}\pm0.06$ | $1.333^{a}\pm0.06$ | $0.667^{b}\pm0.06$ | <LOD | 2.0 | 83.3 |
| Copper (Cu) | ppm | $13.33^{a}\pm0.04$ | $7.66^{b}\pm0.07$ | $9.33^{b}\pm0.08$ | $12.0^{a}\pm0.07$ | <LOD | 17.0 | 83.3 |
| Iron (Fe) | ppm | $0.366^{a}\pm0.23$ | $0.366^{a}\pm0.21$ | $0.300^{ab}\pm0.10$ | $0.233^{b}\pm0.152$ | 0.1 | 0.6 | 100 |
| Lithium (Li) | ppb | $2.0^{a}\pm0.17$ | $1.33^{b}\pm0.15$ | $1.33^{b}\pm0.15$ | $1.33^{b}\pm0.12$ | <LOD | 4.4 | 75 |
| Manganese (Mn) | ppm | $0.603^{a}\pm0.250$ | $0.516^{a}\pm0.142$ | $0.660^{a}\pm0.173$ | $0.683^{a}\pm0.277$ | 0.36 | 0.99 | 100 |
| Molybdenum (Mo) | ppm | $0.082^{a}\pm0.010$ | $0.074^{a}\pm0.020$ | $0.080^{a}\pm0.021$ | $0.061^{ab}\pm0.014$ | 0.048 | 0.097 | 100 |
| Nickel (Ni) | ppm | $0.028^{a}\pm0.039$ | $0.024^{a}\pm0.035$ | $0.021^{ab}\pm0.03$ | $0.025^{a}\pm0.017$ | 0.0023 | 0.074 | 100 |
| Silicon (Si) | ppm | $0.064^{a}\pm0.037$ | $0.060^{a}\pm0.033$ | $0.066^{a}\pm0.037$ | $0.066^{a}\pm0.022$ | 0.023 | 0.098 | 100 |
| Strontium (Sr) | ppm | $0.063^{a}\pm0.015$ | $0.047^{b}\pm0.015$ | $0.052^{ab}\pm0.019$ | $0.057^{ab}\pm0.015$ | 0.033 | 0.077 | 100 |
| Zinc (Zn) | ppm | $0.66^{a}\pm0.50$ | $0.60^{a}\pm0.44$ | $0.45^{b}\pm0.46$ | $0.63^{a}\pm0.51$ | 0.064 | 1.1 | 100 |
| Toxic Metals Aluminum (Al) | ppb | $2.3^{b}\pm0.32$ | $2.0^{b}\pm0.26$ | $2.0^{b}\pm0.34$ | $4.0^{a}\pm0.36$ | <LOD | 7.0 | 58.3 |
| Cadmium (Cd) | ppb | $4.68^{a}\pm0.25$ | $5.33^{a}\pm0.25$ | $5.00^{a}\pm0.20$ | $5.33^{a}\pm0.35$ | 2.0 | 9.0 | 100 |
| Chromium (Cr) ppm | ppm | $0.079^{a}\pm0.02$ | $0.066^{b}\pm0.01$ | $0.064^{b}\pm0.019$ | $0.078^{a}\pm0.03$ | 0.043 | 0.096 | 100 |
| Vanadium (V) | ppm | $0.046^{a}\pm0.040$ | $0.044^{a}\pm0.044$ | $0.043^{a}\pm0.036$ | $0.043^{a}\pm0.030$ | 0.002 | 0.09 | 100 |
| Lead (Pb) | ppm | $0.026^{a}\pm0.01$ | $0.017^{b}\pm0.003$ | $0.017^{b}\pm0.01$ | $0.025^{a}\pm0.01$ | 0.011 | 0.039 | 100 |
| Thallium (Tl) | ppm | $0.034^{a}\pm0.02$ | $0.029^{ab}\pm0.02$ | $0.031^{ab}\pm0.02$ | $0.037^{a}\pm0.007$ | 0.012 | 0.053 | 100 |

LOD = limit of detection. Tap water: Ras Seder, Matrouh Groundwater: shallow and deep wells Sedi Barani, Halayeb & Shelatin.

Table 7. Levels of trace and toxic element content in animal diet across four regions of Egypt.

| Elements | Units | Region | | | | Range | | % of Positive samples (n = 36) |
|---|---|---|---|---|---|---|---|---|
| | | Raas Sedr | Matrouh | Sedi Barani | Halayeb & Shelatin | Minimum | Maximum | |
| Macroelement Calcium (Ca) | ppm | 273.0$^{b}$±11.1 | 307.67$^{a}$±7.3 | 328.33$^{a}$±10.9 | 350.06$^{a}$±10.7 | 166.0 | 456.2 | 100 |
| Magnesium (Mg) | ppm | 672.33$^{a}$±8.87 | 417.67$^{b}$±19.08 | 387.33$^{c}$±13.9 | 428.0$^{b}$±23.3 | 233.0 | 765.0 | 100 |
| Trace elements<br>Silver (Ag) | ppb | 2.333$^{b}$±0.25 | 5.333$^{a}$±0.46 | 0.667$^{c}$±0.06 | 0.333$^{c}$±0.06 | <LOD | 8.0 | 58.3 |
| Boron (B) | ppb | 69.33$^{a}$±2.35 | 57.33$^{b}$±2.61 | 48.33$^{c}$±1.56 | 76.0$^{a}$±1.15 | 33.0 | 95.0 | 100 |
| Barium (Ba) | ppb | 16.47$^{a}$±0.77 | 12.67$^{ab}$±1.21 | 16.13$^{a}$±1.59 | 15.67$^{a}$±1.55 | <LOD | 33.0 | 83.3 |
| Bismuth(Bi) | ppb | 8.33$^{b}$±0.72 | 13.00$^{a}$±0.20 | 7.67$^{b}$±0.67 | 8.33$^{b}$±0.74 | <LOD | 15.0 | 75 |
| Cobalt (Co) | ppb | 7.67$^{b}$±0.67 | 8.67$^{b}$±0.76 | 11.67$^{a}$±0.58 | 11.67$^{a}$±0.58 | <LOD | 14.0 | 83.3 |
| Copper (Cu) | ppm | 10.19$^{a}$±1.59 | 8.43$^{a}$±3.77 | 8.23$^{a}$±3.12 | 9.30$^{a}$±2.23 | 4.56 | 12.11 | 100 |
| Iron (Fe) | ppm | 81.96$^{ab}$±4.25 | 90.60$^{a}$±6.56 | 82.93$^{ab}$±13.34 | 76.03$^{b}$±11.16 | 65.2 | 95.3 | 100 |
| Lithium (Li) | ppb | 10.0$^{c}$±0.1 | 40.0$^{a}$±0.30 | 30.0$^{ab}$±0.17 | 23.33$^{b}$±0.15 | 10.0 | 70.0 | 100 |
| Manganese (Mn) | ppm | 13.53$^{ab}$±2.95 | 12.46$^{ab}$±4.01 | 15.63$^{a}$±3.78 | 16.30$^{a}$±3.46 | 10.1 | 18.3 | 100 |
| Molybdenum (Mo) | ppm | 0.93$^{a}$±0.09 | 0.92$^{a}$±0.10 | 0.74$^{ab}$±0.57 | 0.83$^{a}$±0.51 | 0.20 | 1.42 | 100 |
| Nickel (Ni) | ppm | 0.044$^{a}$±0.023 | 0.033$^{b}$±0.022 | 0.037$^{ab}$±0.042 | 0.038$^{ab}$±0.017 | 0.011 | 0.086 | 100 |
| Silicon (Si) | ppm | 0.083$^{a}$±0.012 | 0.052$^{ab}$±0.02 | 0.059$^{ab}$±0.01 | 0.055$^{ab}$±0.01 | 0.033 | 0.09 | 100 |
| Strontium (Sr) | ppm | 0.082$^{a}$±0.01 | 0.046$^{b}$±0.01 | 0.046$^{b}$±0.01 | 0.050$^{b}$±0.023 | 0.037 | 0.094 | 100 |
| Zinc (Zn) | ppm | 76.67$^{a}$±22.55 | 52.33$^{b}$±24.54248 | 63.66$^{a}$±9.51 | 69.33$^{a}$±24.79 | 24.0 | 100.0 | 100 |
| Toxic metals<br>Aluminum (Al) | ppb | 2.33$^{ab}$±0.25 | 3.03$^{a}$±0.43 | 2.01$^{b}$±0.20 | 1.67$^{c}$±0.15 | <LOD | 8.0 | 75 |
| Cadmium (Cd) | ppb | 83.33$^{a}$±1.1547 | 53.33$^{c}$±2.5166 | 30.0$^{d}$±1.7321 | 76.67$^{b}$±2.30 | 20.0 | 90.0 | 100 |
| Chromium (Cr) | ppm | 0.61$^{a}$±0.15 | 0.53$^{a}$±0.17 | 0.59$^{a}$±0.14 | 0.57$^{a}$±0.12 | 0.37 | 0.77 | 100 |
| Vanadium (V) | ppm | 0.083$^{a}$±0.016 | 0.060$^{a}$±0.02 | 0.058$^{a}$±0.02 | 0.072$^{a}$±0.03 | 0.036 | 0.094 | 100 |
| Lead (Pb) | ppm | 2.267$^{a}$±0.86 | 1.86$^{b}$±0.73 | 2.02$^{ab}$±0.88 | 2.13$^{ab}$±0.49 | 1.27 | 3.03 | 100 |
| Thallium (Tl) | ppm | 0.48$^{a}$±0.43 | 0.29$^{b}$±0.21 | 0.30$^{b}$±0.40 | 0.39$^{b}$±0.46 | 0.04 | 0.94 | 100 |

LOD= limit of detection

Table 8. Transfer factors of 22 elements from animal drinking water and feed to camel, goat, and ewe's milk Across Four Regions of Egypt.

| Minerals and Heavy Metals | Types of milk | Transfer factors: TF1 | | | | Transfer factors: TF2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Region | | | | Region | | | |
| | | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin | Ras Sidr | Matrouh | Sedi Barani | Halayeb & Shelatin |
| Macroelement Calcium (Ca) | Camel | 0.10 | 0.14 | 0.12 | 0.16 | 0.26 | 0.26 | 0.24 | 0.32 |
| | Goat | 0.11 | 0.16 | 0.17 | 0.17 | 0.28 | 0.30 | 0.34 | 0.34 |
| | Ewe | 0.10 | 0.13 | 0.13 | 0.15 | 0.25 | 0.24 | 0.26 | 0.31 |
| Magnesium (Mg) | Camel | 0.79 | 0.84 | 0.65 | 0.61 | 8.88 | 5.50 | 4.49 | 4.49 |
| | Goat | 0.81 | 0.90 | 0.73 | 0.70 | 9.13 | 5.86 | 5.05 | 5.20 |
| | Ewe | 0.64 | 0.82 | 0.55 | 0.64 | 7.18 | 5.35 | 3.81 | 4.76 |
| Trace elements | Camel | 3.50 | 12.00 | 1.00 | 1.00 | 3.50 | 16.00 | 2.00 | 1.00 |
| Silver (Ag) | Goat | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.30 | 2.00 | 1.00 |
| | Ewe | 3.50 | 12.00 | 1.00 | 1.00 | 3.50 | 16.00 | 2.00 | 1.00 |
| Boron (B) | Camel | 0.04 | 0.06 | 0.04 | 0.10 | 0.48 | 0.55 | 0.46 | 0.62 |
| | Goat | 0.04 | 0.06 | 0.04 | 0.09 | 0.45 | 0.51 | 0.40 | 0.53 |
| | Ewe | 0.04 | 0.06 | 0.04 | 0.09 | 0.48 | 0.52 | 0.41 | 0.56 |
| Barium (Ba) | Camel | 0.12 | 0.08 | 0.13 | 0.13 | 0.72 | 0.64 | 0.76 | 0.10 |
| | Goat | 0.09 | 0.08 | 0.14 | 0.10 | 0.54 | 0.63 | 0.80 | 0.10 |
| | Ewe | 0.12 | 0.10 | 0.17 | 0.11 | 0.75 | 0.75 | 1.01 | 0.10 |
| Bismuth (Bi) | Camel | 2.00 | 1.57 | 1.17 | 1.17 | 8.33 | 5.57 | 3.83 | 4.17 |
| | Goat | 0.86 | 1.83 | 1.17 | 1.00 | 3.57 | 6.50 | 3.83 | 3.57 |
| | Ewe | 0.60 | 1.22 | 0.88 | 1.00 | 2.50 | 4.33 | 2.88 | 3.57 |
| Cobalt (Co) | Camel | 0.38 | 0.33 | 0.80 | 0.33 | 2.88 | 4.33 | 7.00 | 5.83 |
| | Goat | 0.25 | 0.29 | 0.44 | 0.20 | 1.92 | 3.71 | 3.89 | 3.50 |
| | Ewe | 0.30 | 0.18 | 0.36 | 0.25 | 2.30 | 2.36 | 3.18 | 4.38 |
| Copper (Cu) | Camel | 0.03 | 0.02 | 0.02 | 0.02 | 20.38 | 22.99 | 14.52 | 14.69 |
| | Goat | 0.02 | 0.02 | 0.01 | 0.02 | 16.98 | 16.86 | 11.75 | 12.69 |
| | Ewe | 0.03 | 0.02 | 0.02 | 0.02 | 19.11 | 19.45 | 16.45 | 14.69 |
| Iron (Fe) | Camel | 0.20 | 0.19 | 0.15 | 0.11 | 43.91 | 46.07 | 40.13 | 37.39 |
| | Goat | 1.25 | 1.01 | 0.86 | 0.71 | 279.43 | 249.36 | 236.95 | 230.40 |
| | Ewe | 1.22 | 0.79 | 0.82 | 0.88 | 273.22 | 194.14 | 226.18 | 285.13 |
| Lithium (Li) | Camel | 0.67 | 0.57 | 0.40 | 0.80 | 3.33 | 17.14 | 9.00 | 14.00 |
| | Goat | 0.67 | 0.40 | 0.40 | 0.57 | 3.33 | 11.88 | 9.00 | 10.00 |
| | Ewe | 0.43 | 0.33 | 0.67 | 0.44 | 2.14 | 10.00 | 15.00 | 7.78 |
| Manganese (Mn) | Camel | 12.40 | 16.15 | 18.50 | 20.10 | 278.08 | 389.58 | 438.32 | 479.41 |
| | Goat | 9.95 | 12.40 | 11.93 | 11.14 | 223.08 | 299.20 | 282.53 | 265.76 |
| | Ewe | 9.63 | 6.71 | 14.24 | 12.81 | 215.96 | 161.90 | 337.41 | 305.63 |
| Molybdenum (Mo) | Camel | 1.67 | 2.03 | 2.30 | 1.41 | 18.92 | 25.18 | 21.24 | 19.38 |
| | Goat | 1.67 | 1.83 | 2.34 | 1.49 | 18.92 | 22.70 | 21.65 | 20.49 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ewe | 1.73 | 1.49 | 2.48 | 1.53 | 19.58 | 18.47 | 22.99 | 21.01 |
| Nickel (Ni) | Camel | 1.29 | 1.29 | 1.24 | 1.31 | 2.03 | 1.80 | 2.22 | 1.99 |
| | Goat | 1.33 | 1.21 | 0.96 | 1.08 | 2.09 | 1.68 | 1.73 | 1.64 |
| | Ewe | 1.10 | 1.27 | 1.01 | 1.31 | 1.74 | 1.78 | 1.82 | 1.98 |
| Silicon (Si) | Camel | 1.64 | 1.97 | 1.78 | 1.77 | 2.14 | 1.73 | 1.57 | 1.48 |
| | Goat | 1.18 | 1.42 | 1.44 | 1.52 | 1.53 | 1.25 | 1.28 | 1.26 |
| | Ewe | 1.15 | 1.46 | 1.40 | 1.23 | 1.50 | 1.28 | 1.24 | 1.03 |
| Strontium (Sr) | Camel | 1.47 | 1.36 | 1.51 | 1.45 | 1.92 | 1.35 | 1.32 | 1.28 |
| | Goat | 1.11 | 1.19 | 1.39 | 1.04 | 1.46 | 1.18 | 1.21 | 0.92 |
| | Ewe | 1.36 | 1.35 | 1.24 | 1.36 | 1.78 | 1.34 | 1.08 | 1.20 |
| Zinc (Zn) | Camel | 0.09 | 0.17 | 0.12 | 0.15 | 10.20 | 15.00 | 16.34 | 16.92 |
| | Goat | 0.07 | 0.08 | 0.06 | 0.08 | 8.62 | 6.93 | 8.28 | 8.90 |
| | Ewe | 0.08 | 0.14 | 0.07 | 0.08 | 9.36 | 12.59 | 10.22 | 9.33 |
| Toxic metals | Camel | 0.64 | 1.20 | 0.86 | 1.20 | 0.64 | 18.20 | 0.86 | 0.50 |
| Aluminum (Al) | Goat | 0.78 | 0.43 | 0.43 | 1.20 | 0.78 | 6.50 | 0.43 | 0.50 |
| | Ewe | 0.64 | 0.60 | 0.06 | 1.33 | 0.64 | 9.10 | 0.06 | 0.56 |
| Cadmium (Cd) | Camel | 0.09 | 0.13 | 0.10 | 0.10 | 1.58 | 1.31 | 0.63 | 1.50 |
| | Goat | 0.06 | 0.09 | 0.15 | 0.09 | 1.12 | 0.92 | 0.87 | 1.36 |
| | Ewe | 0.08 | 0.13 | 0.11 | 0.12 | 1.37 | 1.27 | 0.67 | 1.73 |
| Chromium (Cr) | Camel | 1.62 | 2.04 | 1.69 | 1.63 | 12.53 | 16.29 | 15.53 | 12.01 |
| | Goat | 1.53 | 1.60 | 1.22 | 1.44 | 11.88 | 12.74 | 11.20 | 10.61 |
| | Ewe | 1.61 | 1.53 | 1.25 | 1.50 | 12.45 | 12.25 | 11.49 | 11.02 |
| Vanadium (V) | Camel | 0.76 | 0.87 | 0.64 | 0.65 | 1.37 | 1.18 | 0.87 | 1.11 |
| | Goat | 0.71 | 0.80 | 0.63 | 0.68 | 1.28 | 1.08 | 0.86 | 1.15 |
| | Ewe | 0.90 | 0.97 | 0.84 | 0.71 | 1.61 | 1.32 | 1.14 | 1.21 |
| Lead (Pb) | Camel | 0.66 | 0.72 | 0.56 | 0.84 | 57.63 | 80.87 | 67.33 | 71.00 |
| | Goat | 0.57 | 0.66 | 0.49 | 0.66 | 49.64 | 73.42 | 58.83 | 55.09 |
| | Ewe | 0.57 | 0.60 | 0.68 | 0.64 | 50.00 | 66.43 | 81.89 | 53.70 |
| Thallium (Tl) | Camel | 0.73 | 1.00 | 0.82 | 0.90 | 10.21 | 9.90 | 7.83 | 9.35 |
| | Goat | 0.64 | 0.97 | 0.79 | 1.12 | 9.01 | 9.57 | 7.57 | 11.60 |
| | Ewe | 0.74 | 0.69 | 0.53 | 0.64 | 10.43 | 6.86 | 5.03 | 6.63 |