Advances in Geological and Geotechnical Engineering Research
https://ojs.bilpublishing.com/index.php/agger

REVIEW

Investigation of Environmental and Biological Effects of Rare Earth Elements (REEs) with a Special Focus on Industrial and Mining Pollutions in Iran: A Review

Aref Shirazi[1] Adel Shirazy[1] Amin Beiranvand Pour[2*] Ardeshir Hezarkhani[1] Shayan Khakmardan[1]

1. Department of Mining and Metallurgy Engineering Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
2. Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu (UMT), Malaysia

ARTICLE INFO

Article history
Received: 16 November 2021
Revised: 13 December 2021
Accepted: 20 December 2021
Published Online: 01 January 2022

Keywords:
Environment
Rare earth elements
Pollution
Disease
Kor river
Choghart mine
Life cycle

ABSTRACT

The present article is a review study on the types of rare earth elements (REEs), environmental and biological effects as well as the sources of emission of these elements as pollution in nature. The purpose of this study is to provide a vision in environmental planning and control of pollution caused by REEs. The evaluation of rare earth elements was studied in human life and its environmental and biological effects, which have particular importance and are entering the life cycle through industrial and mining pollution sources. Since mining activities intensify the dispersion of these elements in the environment and the existence of industrial factories located around urban drainage system plays a unique role in creating and spreading pollution caused by rare earth elements; As a result, two case studies were conducted on two mining and industrial areas. The first case is the Choghart mine in Yazd province as an example of mining pollution, and the second case study is performed on the Kor river as an example of industrial pollution which is caused by industrial activities around it, Then the results are well explained to show both two environments of litho and hydro. Due to this fact that produced environmental pollution can cause exchange pollutant compounds with the surrounding environment besides its long-lasting destructive effects; It can cause irreversible biological effects on living organisms. By targeting this evaluation, several techniques can be proposed to prevent the entry and dispersal of rare earth elements from pollution sources besides methods to reduce the damage of these elements to the ecosystem.

1. Introduction

Rare earth elements include 15 lanthanide elements in Group IIIA of the periodic table of elements. These elements are divided into two groups of light or cerium group (7 elements from atomic number 57 to 63 including lanthanum, cerium, praseodymium, neodymium, promethium, samarium, and europium) and heavy or yttrium group (8 elements from atomic number 64 to 71

*Corresponding Author:
Amin Beiranvand Pour,
Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu (UMT), Malaysia;
Email: beiranvand.amin80@gmail.com

DOI: https://doi.org/10.30564/agger.v4i1.4290

Includes gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium) [1]. Yttrium and scandium are also considered in the rare earth elements group due to their chemical similarity, with atomic numbers 39 and 21, respectively [1-3]. The objectives of this review study are divided into three general sections: first, study of rare earth elements in minerals (economic geology); second, investigation of the destructive effect of these elements on human health (biological effects); third, investigation of the destructive effect of rare earth elements on Environmental cycle.

1.1 The Abundance of Rare Earth Elements

Most of the rare earth elements are similar to chromium, nickel, copper, zinc, molybdenum, tin, tungsten and lead in terms of accumulation in the crust. In contrast to a joint base and precious metals, these elements have a slight tendency to accumulate in extractable deposits. Therefore, most of the global amount of these elements comes from several sources. Cerium is the most abundant rare earth element with an average content of 60 grams per ton in the Earth's crust, more than lead, copper and tin. Cerium does not form a specific mineral, and as a result, it does not concentrate in the form of principal mine ore. Yttrium and neodymium are also more abundant than lead. The rarest rare earth elements, Lutetium and Thulium, are about 125 times more abundant than gold. Lutetium is even more abundant than mercury and iodine. The only element among rare earth elements that are not found in nature and is artificially made is promethium. Although these elements are abundant in nature, just found in traceable amounts or, in other words, very low grades ores and as a by-product to other mineral commodities [4].

The abundancy differences among rare earth elements in the Earth's upper continental crust are influenced by two factors of nucleic and geochemical parameters. Rare earth elements with even atomic numbers (Ce-58, Nd-60) have more abundancy than rare earth elements with odd atomic numbers (La-57, Pr-59). Light rare earth elements are very incompatible compared to the heavy rare earth elements due to their large ion radius; And as a result, they (Light REEs) are more concentrated in the continental crust [5].

1.2 Rare Earth Elements from an Economic Geology Point of View

Igneous rocks host the first place of rare earth elements, and their amount in basalt (basic) rocks is more than acidic rocks [6]. China and the United States have the most considerable resources of rare earth elements in the world. Bastanzite, monazite and xenotime are the three most important economic minerals of these elements [7].

The geochemical behaviour [8-10] of these elements is similar to each other so that almost no geological process is known that can focus on just one of these elements. Bastansite and monazite are the main minerals for light rare elements, and Xenotime and Alanite are the main minerals for the heavy rare elements. Bastenazite is found primarily on calcined silicate rocks associated with alkaline internal igneous rock assemblages and to a minor degree in quartz veins, epithermal fluorite veins, and breccia fillers [11].

Monazite and xenotime are present as minor minerals in granitoid rocks and low calcium pegmatites. Continued weathering in these types of rocks causes them to concentrate on heavy minerals of placer deposits. Xenotime is usually associated with zircon due to its resistance to chemical changes and its high specific gravity [12]. Other sources of rare earth elements are apatite, clay minerals, and various minerals such as churchite. Rare elements that come with iron ores, especially those with a magmatic or metasomatic origin, hosting rare earth elements and, to a more significant extent, phosphorus, titanium and vanadium are present in them. The geochemical behaviours of rare earth elements during specific geological processes have made them particularly desirable for detecting the origin of igneous rocks.

The number of minerals containing rare earth elements is over 300 different minerals. As mentioned earlier, the main minerals of these elements include bastnasite, monazite, xenotime and allanite [13].

1.3 Medical Geology

Medical geology is a discipline of geology that is less concerned with environmental contamination and more concerned with the research and study of rare and trace elements in the environment and their link to health and illness in people, animals, and plants. These studies include discovering biological effects, exposure to various elements, and their dispersion in the environment. Although the chemical abnormalities that affect human health do not naturally exist in the environment, humans are still affected by adverse changes, such as the release of pollutants, Improper use of various chemical fertilizers and generating chemical wastes [14,15].

2. Rare Earth Elements and the Environment

2.1 Rare Earth Elements Distributed in the Environment

Nowadays, Rare earth elements are widely used in modern technologies so that they have a special place in most high-tech devices and accessories. Due to similar properties, rare earth elements are used in groups or a combination of several elements [16]. Applications of rare earth elements are divided into five groups according to their properties: chemical, metallurgical, optical, magnetic and nuclear. As mentioned earlier, Earth is the source of all rare earth elements, so before any application or dispersal of these elements in the environment by humans, they are naturally dispersed and distributed by geological and geochemical processes. Human activities have no role in this dispersion type, known as primary dispersion [17].

The mining process is the first stage of the impact of human activities on the artificial dispersion (distribution) of rare earth elements in the environment [18,19]. Extraction and processing of these elements from the Earth mean disturbing their geochemical balance, created in the Earth's cycle for millions of years. These elements strongly desire to regain equilibrium when exposed to natural factors beyond their geochemical and geological equilibrium. Therefore, rare earth elements that exist along with various deposits (such as iron, phosphate) and are considered waste are accumulated in some places. These accumulations containing rare earth elements enter the ecosystem cycle due to weathering factors such as wind and rain gradually; besides human and animal activities, they leave their effects on various organisms [20].

Another group of mining activities is related to the extraction and processing of rare earth elements from the deposits containing them, in which case, after the extraction of these elements, mine tailings such as acidic effluents and secondary tailings are created, which have far more risks and speed of dispersal than the previous type. This group of dispersions caused by mining primarily causes water, air and soil pollution, which causes biological effects on living organisms [17,21].

Nowadays, with the widespread use of these elements in various industries, the relationship between living organisms, especially humans, and the pollution caused by them has increased exponentially; around large cities, there are many industrial towns in which factories use these elements in their products. In addition, various high-tech devices that are directly and indirectly related to our daily lives (such as cell phones, laptops, electronic kits) are not well disposed of and recycled after their lifetime, and they can quickly enter the biological cycle and create irreversible effects [22].

Several applications of rare earth elements are more closely related to the life cycle of living organisms, including [23]:

• Mobile phone industry
• T.V. industry
• Medical radiography
• Cast iron industry
• Alloy industry
• Advanced technology industries
• Battery industry

2.2 Environmental and Biological Effects of Rare Earth Elements

The most significant environmental parameter concerning rare earth elements is that they are often associated with radioactive materials, and it is vital to observe their environmental issues. Rare earth elements are dispersed in the environment in various ways, mainly due to the oil-producing industries. Also, by the disposal of waste electrical and electronic equipment, these elements enter the environment and gradually accumulate in the soil. Ultimately, their concentration in the human body, animals, and soil particles increases, although these elements also have a natural origin. In aquatic animals, rare earth elements cause damage to cell membranes, which negatively affects reproduction and nervous system function. These elements in the workplace, especially if inhaled for a long time, is dangerous and causes lung blockage. Most of these elements cause cancer and liver problems. Rare earth elements are toxic and Absorb through the skin, and causes poisoning and death. The environmental and biological effects of some of these elements are as follows [24]:

Cerium (Ce): Cerium, like all rare earth metals, has mild to moderate toxicity. This element is a potent reducing agent and burns spontaneously in air at a 65-80 °C temperature. The cerium reaction with zinc can be explosive, and also it has a highly calorific reaction with bismuth and antimony. Generated Smoke from the burning of cerium is toxic. Water should not be used to prevent cerium from burning, as cerium reacts with water to produce hydrogen gas. Workers dealing with cerium have experienced itching, heat sensitivity, and bodily harm. Animals that have been injected with large amounts of cerium have died of heart and venous lesions. Cerium oxide (IV) is a solid oxidizing agent at high temperatures and reacts with combustible organic matter. Cerium has no known biological application.

Lanthanum (La): One of the causes of respiratory diseases in mines and factories is the high concentration of lanthanum. Lanthanum has a mild to moderate level of toxicity and should be used with caution. Injections of lanthanum solutions in animals cause glycemia, hypotension, splenic lesions, and liver changes. No biological role has been identified for lanthanum. This element is not absorbed through eating and disappears if injected very slowly. The use of lanthanum carbonate to absorb excess phosphate in the final stages of kidney injury is under investigation. Some rare earth chlorides, such as lanthanum chloride ($LaCl_3$), have anticoagulant properties.

Neodymium (Nd): All neodymium compounds should be considered highly toxic. Neodymium compounds also cause eye and skin damage. Neodymium dust poses a risk of explosion and fire. High concentrations of neodymium in the mine increase the risk of pulmonary embolism and cancer.

Samarium (Sm): Samarium compounds are highly toxic, and this metal dust is flammable and explosive. Soluble samarium salts cause eye and skin irritation.

Europium (Eu): Europium particles in the environment cause fires and explosions.

Terbium (Tb): Prolonged exposure to high levels of terbium can cause lung cancer and lung obstruction in mine-workers and miners. All terbium compounds are highly toxic. The compounds of this element irritate the eyes and skin. Terbium dust poses a risk of explosion and fire.

Dysprosium (Dy): High levels of dysprosium in people cause lung obstruction and cancer. All compounds of dysprosium should be considered slightly to be semi-toxic. This metal carries the risk of explosion and fire. No biological properties have been reported for dysprosium.

Lutetium (Lu): Lutetium has a low degree of toxicity; however, in any case with this metal and especially its compounds should be treated very carefully. The metal dust of this element poses a risk of fire and explosion. Lutetium has no biological role in the human body but may help increase metabolism. In aquatic animals, lutetium causes damage to cell membranes, which has a negative effect on reproduction and nervous system function.

Ytterbium (Yb): Although it is generally stable, it should be stored in a tight container to avoid contact with air and moisture. All ytterbium compounds are very toxic; ytterbium compounds cause skin and eye disorders. High concentrations of ytterbium, in the long run, can lead to skin and eye discomfort.

Promethium (Pm): It has high radioactivity, so great care is needed when working with this element because promethium can emit X-rays during the beta reduction process. It has a considerably shorter half-life than 239 plutonium. Promethium has no biological effect.

Thulium (Tm): Thulium has a mild to moderate toxicity and should be used with caution. Thulium metal powder is dangerous in terms of explosion and ignition. The presence of thulium in the workplace is dangerous, and its prolonged inhalation with air obstructs the lungs.

Holmium (Ho): It has low toxicity. This element does not have any biological role in humans, but it can activate metabolism.

Gadolinium (Gd): Gadolinium compounds have mild to moderate toxicity, although their toxicity is not specified in detail. Gadolinium has no biological role but may increase metabolism.

Erbium (Er): Erbium compounds have low to moderate toxicity, although details of their toxicity have not been fully disclosed.

3. Case Studies of Rare Earth Elements Contaminant Sources Distribution

3.1 Lithogeochemical Studies in Choghart Iron Ore Mine, Bafgh

3.1.1 Geographical Location of the Study Area

The Choghart iron mine is located about 12 kilometres northeast of Bafgh, on the outskirts of Iran's central desert. This area is part of Central Iran in terms of geological and structural divisions of Iran. The presence of rare earth elements in this mine has already been proven. Due to the importance of environmental issues of rare earth elements, the amount of elements in the Choghart mine has been studied in this study [25-28].

3.1.2 Sampling Method and Analysis

The studied samples include 25 stone samples selectively from different parts of the mine. Concentrations of rare earth elements were measured by the active neutron capture (NAA) method. Lu, Yb, Tm, La, Dy, Tb, Eu, Sm, Nd and Ce are the Rare earth elements measured in the Choghart mine by the active neutron capture method. According to the results, the highest amount of rare earth elements in the samples is Ce. After the element Ce, the highest value in the samples belongs to the element La, and the lowest is the element Tm.

In general, based on the findings of the investigations, it can be said [1]:

1) When compared to the typical grade of these elements in the Earth's crust, the average quantity of rare earth elements in Choghart mine samples reveals enrichment. Most of the enrichment belongs to the sample prepared from the tectonic block northeast of the mine, related to the presence of minerals such as apatite, sphene and zircon, in the region.

2) Comparing the average values of light rare earth

elements (LREEs) with the average values of heavy rare earth elements (HREEs) in Choghart mine samples, it can be seen that in these samples, light rare earth elements are more than heavy rare earth elements. Show enrichment.

3.1.3 Data Analysis and Interpretation of Rare Earth Elements

In this study, the range of changes in the concentration of each rare earth element in the samples and also their Clark values along with the average amount of these elements are summarized in Table 1, and their concentration contrast with the field (Figure 2 left) and the field concentration with Clark. Figure 1 right is given.

According to Table 2 and also the comparative diagrams of Figure 2, it can be said that the amount of all ten rare earth elements that have been identified in the Choghart iron ore mine is more than their background and Clark. Among the rare earth elements in the mine, the elements of samarium, terbium, neodymium, cerium, lanthanum, lutetium, europium, ytterbium, dysprosium, thulium, respectively, can be named concerning the amount of ground limit and then to the amount of Clark of the elements in descending order.

According to the results of studies, on average, rare earth elements in Choghart mine are 19 times more than the amount of Clark of these elements in the Earth's crust and seven times more than the amount of background of these elements in the study area, which indicates its economic and environmental importance [29]. The elements cerium, lanthanum, and neodymium have the highest concentrations, respectively, and according to environmental and biological effects of rare earth elements given in 2.2, the risk of cardiovascular disease, respiratory, injury Eyes and skin, as well as pulmonary embolism and cancer, increase in areas containing contamination caused by these elements [5].

3.2 Investigation of Geochemical Distribution of Rare Earth Elements and Their Environmental Effects in the Sediments of the Kor Riverbed

3.2.1 Geographical Location of the Study Area

The study area in this research is a part of Kor River which is located in Fars province in the south

Table 1. Changes in the concentration of rare earth elements in the samples and Clark and the mean

Mean/Baground	Mean/Clark	Mean (ppm)	Concentration (ppm)	Baground (ppm)	Clark (ppm)	Symbol	Elements
5	25	744.88	8.86 - 2800	145	30	La	Lanthanum
7	23	1481.7	6.68 - 5700	203	64	Ce	Serium
9	25	658.36	3.01 - 2600	75	26	Nd	Neodymium
18	21	96.41	0.57 - 375	5.4	4.5	Sm	Samarium
4	15	12.85	0.17 - 48	3.3	0.88	Eu	Europium
9	27	17.38	0.54 - 67.1	1.93	0.64	Tb	Terbium
3	23	81.66	0.88 - 288	28.82	3.5	Dy	Dysprosium
3	7	2.36	0.16 - 7.59	0.8	0.33	Tm	Tulium
4	13	29.26	1.45 - 113	6.85	2.2	Yb	Ytterbium
5	10	3.15	0.23 - 11.3	0.61	0.32	Lu	Lutectium

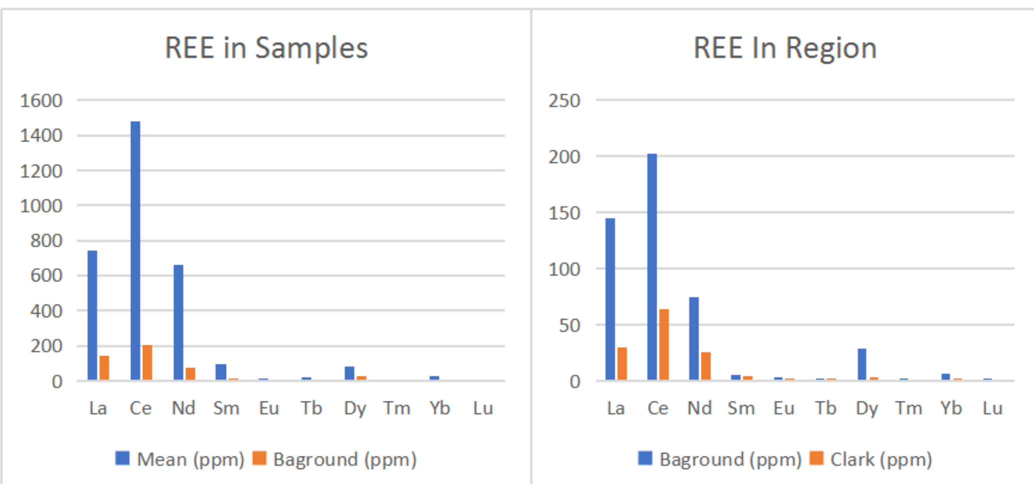

Figure 1. Comparative diagrams of field-Clark (left) and field-concentration of samples (right)

of Marvdasht city between latitudes (29°, 49', 52")and (29°, 56', 25")and longitudes (52°, 43', 42")and (52°,47', 43"). According to the industries located alongside the Kor River, evaluation of the environmental effects of these elements is essential. The Kor River is one of the Fars province's principal surface water resources, which provides water for thousands of farmers in the region, and as a result, their living relies on it. Also, it provides a large proportion of drinking water to Shiraz, Marvdasht, and the villages along the route. In addition, it supplies water to industries and factories along the river [30,6].

3.2.2 Sampling Method and Analysis

Sediments are an essential part of the lithosphere in environmental geochemistry because they are the final accumulation of potentially toxic elements in the aquatic environment. Under certain conditions, sediments can act as a source of pollution in water. Rivers are also important from an environmental point of view because they act as a drain for all incoming water to the catchment area and transport it out of the catchment area. Fine-grained particles, especially particles in the range of silt and clay, are chemically highly-active. In addition, these particles are the most mobile sedimentary part of rivers. In general, due to their high adsorption capacity, fine-grained particles are themselves a factor for the adsorption and accumulation of potentially toxic elements in river bed sediments [8].

In order to investigate the distribution of rare earth elements and the factors affecting them in the Kor River, sampling of 14 stations along the Kor River was performed, and fine-grained sediment samples, particles smaller than 63 microns, were analyzed by ICP-MS experiment. Since most of the pollution of the Kor River is caused by urban and industrial activities, the focus of sampling was done near the city of Marvdasht. The satellite image shows the position of the sampling points in the image below (Figure 2).

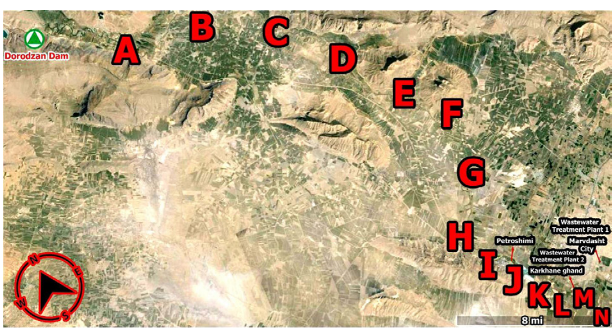

Figure 2. Satellite image of the Location of sampling points

By Comparing the analysis results of samples with local background samples and the average sediments of the region, it is indicated that the concentration of rare earth elements is high in most studied stations. In order to estimate the severity of pollution in the region and also to separate the effect of human factors (anthropogenic) from natural factors (geogenic), the pollution index (P.I.) and the percentage of anthropogenic factors (An) have been used.

3.2.3 Studies

In this study, four elements Ce, La, Sc and Y, have been studied, and Al has been selected as the reference element. A summary of the results of the sample analysis is given in Table 2 and Figure 3.

According to the above diagrams:

Cerium: The element Ce has the highest concentration in the vicinity of Marvdasht municipal and sugar factory water treatment facilities, which shows an increase concerning the local field (B.G station) and the average sediments of the region. At the points of the Dorodzan checkpoint, Abraj and the railway bridge, a decrease in concentration can be seen compared to the region's local background and average sediments.

Lanthanum: The element La has the highest concentration in the vicinity of Marvdasht municipal and sugar factory water treatment facilities, which shows an increase in concentration compared to the local background and the average sediments of the region. A decrease in concentration can be seen at the Dorodzan checkpoint, Abraj and the railway bridge, compared to the local background and the average sediments of the region.

Scandium: Sc element in the vicinity of Marvdasht municipal and sugar factory water treatment facilities shows the highest amount, higher than the Dorodzan dam (local context) and the average sediment in the area. At Dorodzan checkpoint station, there is a decrease in concentration compared to the local background and the average sediments in the area. At Abarj station, the concentration of this element is equal to the local field, and in other places, it shows an increase in concentration compared to the local field.

Yttrium: The element Y in the points of Abraj, Dorodzan checkpoint, and railway bridge shows a decrease in concentration compared to the local field, and in other places, it increases the concentration relative to the local field, which is peaked in the vicinity of Marvdasht municipal and sugar factory water treatment facilities.

Table 2. Results of sample analysis

Sampling stations		Reference element (ppm)	Rare earth elements (ppm)			
Station	Sampling location	Al	Ce	La	Sc	Y
Mean	-	31957.6	28.01533	14.70467	8	8.516667
Baground	Dorodzan Dam (local context)	13876	19.9	11.16	5	6.7
A	Dorodzan checkpoint	14703	17.86	10.08	4	6.19
B	Abraj	14124	17.98	10.13	5	6.29
C	Tashnian	20039	22.44	11.99	6	6.94
D	Hashem Abad	34816	32.02	16.94	8	9.13
E	Talaghani Town	30059	29.26	15.12	8	8.43
F	Esfandaran	41930	35.01	17.96	10	9.47
G	Fakhr Abad	40268	31.41	16.22	10	8.93
H	Ali Abad	45215	31.63	16.11	10	9.27
I	Cargo terminal	37614	33.61	17.44	9	9.43
J	Petroshimi	23557	23.97	12.69	7	7.57
K	Rahahan bridge	24748	18.09	9.31	6	6.07
L	Khan bridge	36324	28.49	14.73	9	9.99
M	Karkhane ghand wastewater	52066	38.34	19.33	11	11.19
N	Marvdasht city wastewater	50025	40.22	21.36	12	12.15

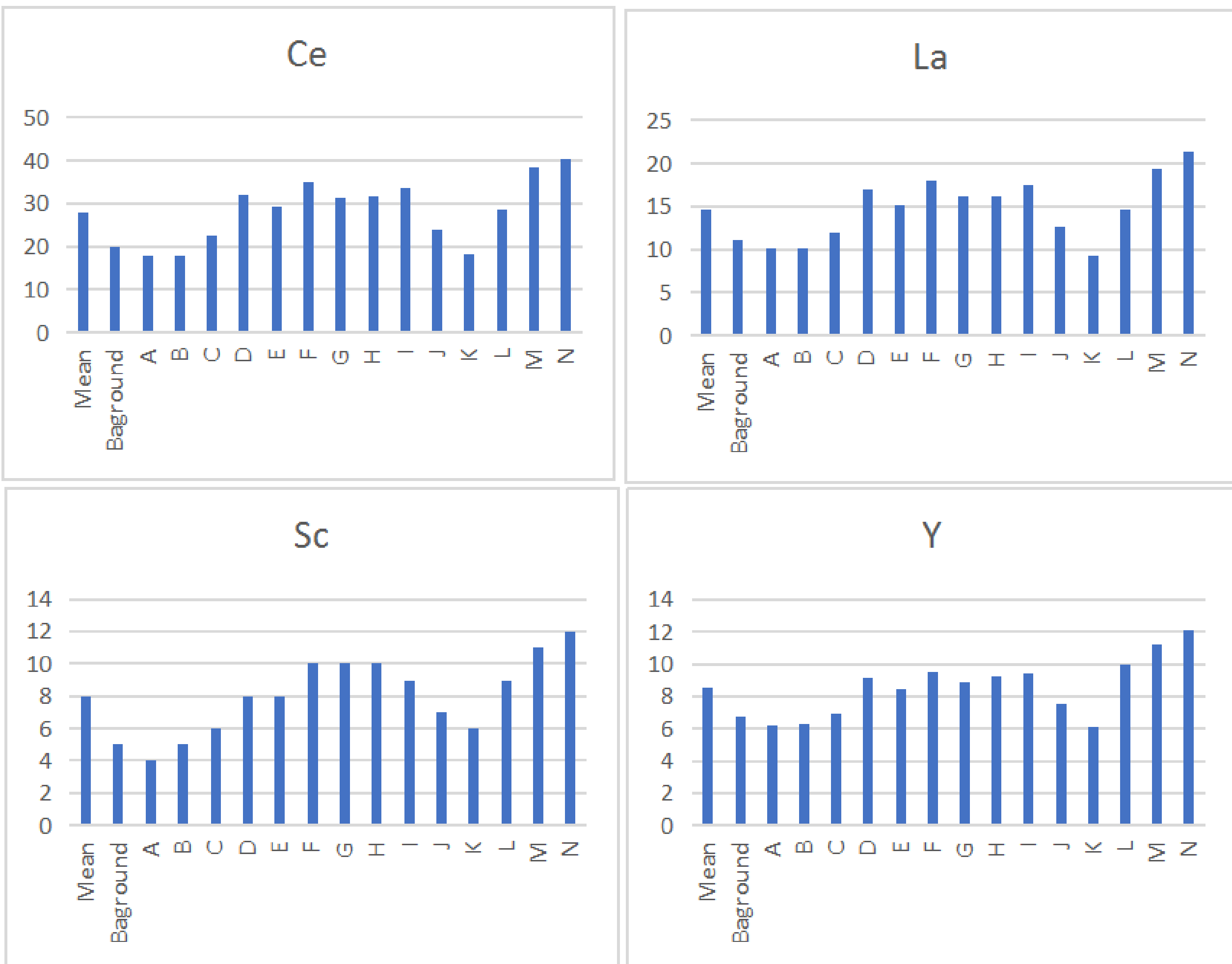

Figure 3. Concentration of analyzed elements (in ppm)

3.2.4 The Correlation Coefficient of Rare Earth Elements Studied in the Sediments of the Kor River

Recognizing the relationships and interrelationships between different elements can help to assess environmental impacts more accurately. Understanding these relationships can help identify the element's source and transport in the aquatic environment [31]. In this research, Pearson correlation coefficients have been used to determine the relationships between different elements (Table 3).

Table 3. Pearson correlation coefficients

Pearson correlation coefficient				
Ce	La	Sc	Y	
1	1	0.96	0.96	Ce
	1	0.94	0.96	La
		1	0.95	Sc
			1	Y

The correlation coefficients obtained between the rare earth elements studied in this study show that these elements have a high and positive correlation due to the exact origin, release, and similar deposition under surface conditions along the river.

Pollution Index (P.I.): Pollution Index (Pollution Index) is also used to estimate the nature of an environment. The Pollution index is expressed as the ratio of the concentration of an element in the sediment samples of the study area. Based on the pollution index, three categories of pollution are observed, low (P.I.> 1), medium (1>P.I.> 3), and high (P.I. <3) [26]. This index is calculated for the studied elements of each station (Table 4).

Percentage of Anthropogenic Factors (An): The percentage of anthropogenic factors of a particular element in a sample shows the percentage of humans entering this element into the sample or field. The anthropogenic factor is one of the essential factors in environmental analysis after enrichment coefficient for assessing the concentration of elements under the influence of anthropogenic and natural factors, the formula of this factor is shown in Formula 1 [32].

$$An(\%) = \frac{Mt - [M's + (\frac{Mr}{M'r})]}{Mt} \times 100 \qquad (1)$$

An: Anthropogenic factors, Mt: The amount of element in the sample, M's: The amount of reference element in the sample, Mr: The amount of element in the reference medium, M'r: The amount of reference element in the reference medium

In the study area, element Al was selected as the reference element due to its geochemical nature, small changes, and low mobility in the geochemical environment. According to the values obtained from the results of chemical analysis of sediment samples in the Kor River, the percentage of anthropogenic factors in each sample has been determined separately.

Table 4. Pollution index and anthropogenic factors

Sampling stations		Pollution Index (PI)				Percentage of anthropogenic factors (An)			
Station	Sampling location	Ce	La	Sc	Y	Ce	La	Sc	Y
A	Dorodzan checkpoint	0.9	0.9	0.8	0.92	-11.4	-10.7	-25	-8.2
B	Abraj	0.9	0.91	1	0.94	-10.7	-10.2	0	-6.5
C	Tashnian	1.13	1.07	1.2	1.04	11.3	6.9	16.7	3.5
D	Hashem Abad	1.61	1.52	1.6	1.36	37.9	34.1	37.5	26.6
E	Talaghani Town	1.47	1.35	1.6	1.26	32	26.2	37.5	20.5
F	Esfandaran	1.76	1.61	2	1.41	43.2	37.9	50	29.3
G	Fakhr Abad	1.58	1.45	2	1.33	36.6	31.2	50	25
H	Ali Abad	1.59	1.44	2	1.38	37.1	30.7	50	27.7
I	Cargo terminal	1.69	1.56	1.8	1.41	40.8	36	44.4	29
J	Petroshimi	1.2	1.14	1.4	1.13	17	12.1	28.6	11.5
K	Rahahan bridge	0.91	0.83	1.2	0.91	-10	-19.9	16.7	-10.4
L	Khan bridge	1.43	1.32	1.8	1.49	30.2	24.2	44.4	32.9
M	Karkhane ghand wastewater	1.93	1.73	2.2	1.67	48.1	42.3	54.5	40.1
N	Marvdasht city wastewater	2.02	1.91	2.4	1.81	50.5	47.8	58.3	44.9

According to the calculated indices of P.I. and An in Table 4, it can be seen that the increase in the concentration of studied rare elements in most sampling points is due to the involvement of anthropogenic factors in the pollution of the Kor River. Also, according to the region's Geology, a small percentage of pollution is related to natural factors (geogenic).

Accordingly, for Ce element, except for Abarj, Dorodzan checkpoint and railway bridge stations, it shows moderate pollution in other places, with a minimum percentage of anthropogenic factors of 11.3% in Tashnian and a maximum of 50.5% in the marvdasht sewage site. On average, 23.5% of the total pollution in the region is related to anthropogenic factors.

For element La, except for Abarj, Dorodzan checkpoint and railway bridge stations, it shows a moderate degree of pollution in other parts, with a minimum percentage of anthropogenic factors of 6.9% in Tashnian and a maximum of 47.8% in Marvdasht sewage site. Moreover, on average, 19.24% of the total pollution in the region is related to anthropogenic factors.

Except for Abarj and Dorodzan checkpoint stations, the Sc element shows a moderate degree of pollution in other places, where the minimum percentage of anthropogenic factors is 16.7% in Tashnian, and the maximum is 58.3% in the sewerage site of Marvdasht city. An average of 30.91% of the total pollution in the region is related to anthropogenic factors.

For element Y, except for Abraj, Dorodzan checkpoint and railway bridge stations, it shows a moderate degree of pollution in other places, where the percentage of anthropogenic factors is 3.5% in Tashnian and up to 44.9% in Marvdasht sewage site. Moreover, on average, 17.72% of the total pollution in the region is related to anthropogenic factors.

The pattern of element concentration variations in the Kor River is mainly influenced by the distance of pollution source from the monitoring stations, and then it is controlled by geological units like fine rocks forming this catchment area in the riverbed. In addition, the correlation coefficient calculated in the sediments of the Kor River indicates the release, transfer and deposition of the same rare earth elements in relatively similar conditions along the river route.

Metal enrichment show a significant increase after the entry of various effluents from factories and the Marvdasht Petrochemical plant; especially the most severe pollution is observed at the entrance of effluents of Marvdasht municipal and sugar factory water treatment facilities into the river.

The findings from the analysis of the obtained samples, besides the results of the P.I. and An indices calculation, show that the average pollution for all the studied elements in the Esfandaran region can result from the entry of effluent Charmineh tanning factory and Fars meat complex into the Kor River. In the vicinity of the petrochemical plant, a moderate pollution is observed for these rare elements, resulting from petrochemical effluents entry into the Kor River. At the site of Pol-e Khan, moderate pollution is observed for these elements, which can be the result of the Sivand River entry into the Kor River. All these pollutions indicate the involvement of anthropogenic factors in the pollution of the Kor River, and according to the geology of the region, a small percentage of the pollutants are related to natural (geogenic) factors.

The exchange of toxic elements in sediments is much higher than in aquatic environments. Due to the long shelf life of these materials, it is not easy to release contaminated sediments from the contaminants; cleaning the river sediments and removing the contaminants can take hundreds and maybe thousands of years.

4. Conclusions and Recommendations

Some rare earth elements with diverse applications in industry and advanced technologies can cause fire or explosions under some circumstances. In addition to the adverse environmental effects of these elements that cause poisoning and several diseases, these elements can also play beneficial biological roles for the human body.

Rare earth elements have been in balance on Earth for millions of years, but Mining and industrial activities enter them into the ecosystem, which causes environmental pollution. Industrial pollution sources located around urban drainage systems are hazardous and play an adverse and vital role in spreading widely of these pollution factors into the ecosystem.

For reducing the damages caused by the pollution of these rare elements into the ecosystem, a logical solution is needed to control and prevent the entry of toxic elements into the environment and life cycle. This goal requires special management programs and further study in this area.

References

[1] Wall, F., 2014. Rare earth elements. Critical metals handbook. pp. 312-339.

[2] Humphries, M., 2010. Rare earth elements: the global supply chain. Diane Publishing.

[3] Martin, W., Zalubas, R., Hagan, L., 1978. Atomic energy levels-the rare earth elements.(the spectra of lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium).[66 atoms and ions]. Manchester Coll. of Science and Technology (UK). Dept. of Chemistry.

[4] Henderson, P., 1984. General geochemical properties and abundances of the rare earth elements, in Developments in geochemistry. Elsevier. pp. 1-32.

[5] Schmitt, R., et al., 1963. Abundances of the fourteen rare-earth elements, scandium, and yttrium in meteoritic and terrestrial matter. Geochimica et Cosmochimica Acta. 27(6), 577-622.

[6] Shirazi, A., et al., 2018. Remote sensing studies for mapping of iron oxide regions, South of Kerman, Iran. International Journal of Science and Engineering Applications. 7(4), 45-51.

[7] Lehmann, B., 2014. Economic geology of rare earth elements in 2014: a global perspective. European Geologist. 37, 21-24.

[8] Shirazy, A., et al., 2019. Geochemical and geostatistical studies for estimating gold grade in tarq prospect area by k-means clustering method. Open Journal of Geology. 9(6), 306-326.

[9] Shirazy, A., Shirazi, A., Hezarkhani, A., 2018. Predicting gold grade in Tarq 1: 100000 geochemical map using the behavior of gold, Arsenic and Antimony by K-means method. Journal of Mineral Resources Engineering. 2(4), 11-23.

[10] Shirazy, A., Ziaii, M., Hezarkhani, A., 2020. Geochemical Behavior Investigation Based on K-means and Artificial Neural Network Prediction for Copper, in Kivi region, Ardabil province, IRAN. Iranian Journal of Mining Engineering. 14(45), 96-112.

[11] Mariano, A.N., 2018. Economic geology of rare earth elements. Geochemistry and mineralogy of rare earth elements. 309-338.

[12] Shirazy, A., et al., 2021. Geophysical study: Estimation of deposit depth using gravimetric data and Euler method (Jalalabad iron mine, kerman province of IRAN). Open Journal of Geology.

[13] Long, K.R., et al., 2012. The principal rare earth elements deposits of the United States: A summary of domestic deposits and a global perspective, in Non-renewable resource issues. Springer. pp. 131-155.

[14] Rokade, V. Medical Geology: Integrated Study of Geochemistry and Health.

[15] Panichev, A., 2015. Rare earth elements: review of medical and biological properties and their abundance in the rock materials and mineralized spring waters in the context of animal and human geophagia reasons evaluation. Achievements in the life sciences. 9(2), 95-103.

[16] Mackizadeh, M.A., Taghipour, B., 2011. Geology, geochemistry and behavior of rare earth element in the hydrothermal alteration zones, Karkas Mountain North of Isfahan. Iranian Journal of Petrology. 2(8), 55-68.

[17] Liang, T., Li, K., Wang, L., 2014. State of rare earth elements in different environmental components in mining areas of China. Environmental monitoring and assessment. 186(3), 1499-1513.

[18] Shirazi, A., et al., 2018. Exploration Geochemistry Data-Application for Cu Anomaly Separation Based On Classical and Modern Statistical Methods in South Khorasan, Iran. International Journal of Science and Engineering Applications. 7, 39-44.

[19] Shirazy, A., et al., 2020. Geostatistical and remote sensing studies to identify high metallogenic potential regions in the Kivi area of Iran. Minerals. 10(10), 869.

[20] Haque, N., et al., 2014. Rare earth elements: Overview of mining, mineralogy, uses, sustainability and environmental impact. Resources. 3(4), 614-635.

[21] Reid, S., et al., 2017. Technospheric mining of rare earth elements from bauxite residue (red mud): Process optimization, kinetic investigation, and microwave pretreatment. Scientific reports. 7(1), 1-9.

[22] Pagano, G., et al., 2015. Rare earth elements in human and animal health: state of art and research priorities. Environmental research. 142, 215-220.

[23] Haxel, G., 2002. Rare earth elements: critical resources for high technology. US Department of the Interior, US Geological Survey. Vol. 87.

[24] Li, X., et al., 2013. A human health risk assessment of rare earth elements in soil and vegetables from a mining area in Fujian Province, Southeast China. Chemosphere. 93(6), 1240-1246.

[25] Majidi, S., et al., 2018. Investigation on the genesis of the iron oxide-apatite±REE deposits of the Bafgh-Saghand district (Central Iran), based on oxygen isotope studies. Journal of Geoscience. 28(109), 237-244.

[26] Pazand, K., 2018. Controls on the distribution of arsenic and rare earth elements in groundwaters of the Bafgh city area, central Iran. Water Science and Technology: Water Supply. 18(5), 1590-1597.

[27] Eslamizadeh, A., 2022. Geological setting of iron oxide-apatite deposits in theBafq district, central Iran with an emphasis on mineralogical, petrographic, and geochemical study of the Sechahun deposit. Iranian Journal of Earth Sciences. 8(2), 147-163.

[28] Nabilou, M., et al., 2018. Determination of relationship between basement faults and alteration zones in Bafq-Esfordi region, central Iran. Episodes Journal of International Geoscience. 41(3), 143-159.

[29] Esmaeily, D., Afshooni, S., Valizadeh, M., 2009. The study of the mineralogy and Rare Earth Elements (REE) behavior in the hydrothermal alteration zones of the Astaneh granitoid massif (SW Arak, Markazi province, Iran).

[30] Sheykhi, V., Moore, F., 2013. Evaluation of potentially toxic metals pollution in the sediments of the Kor river, southwest Iran. Environmental monitoring and assessment. 185(4), 3219-3232.

[31] Förstner, U., 2004. Sediment dynamics and pollutant mobility in rivers: an interdisciplinary approach. Lakes & Reservoirs: Research & Management. 9(1), 25-40.

[32] Lu, X., et al., 2009. Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. Journal of hazardous materials. 161(2-3), 1058-1062.