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Mining Geography: How Does the Spatial Distribution and Extraction of Rare Earth Elements and Uranium in Kazakhstan Shape the Country's Economic Development, Environmental Challenges, and Geopolitical Positioning within Global Resource Networks?

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Abstract

Kazakhstan, a resource-rich country in Central Asia covering an area of about 2.7 million square km, has significant reserves of rare earth elements and uranium, which are located geographically in the north, south and east of the country. The uranium reserves are mostly located in the southern sedimentary basins, in particular the Chu-Sarysu and the Syr-Darya basins, while the rare earth elements are mostly encountered in the eastern and central metamorphic regions of the country, especially at such locations as Shok-Karagay, Syrymbet and the gigantic Zhana Kazakhstan deposit. The purpose of this study is to examine the large effect of the geological distribution and mining of these important minerals on the economic development of Kazakhstan, which is extremely important from the point of view of obtaining large export revenues, varied industrial development, both of which are of extreme importance to the development of Gross Domestic Product of the country. The study will also look into the effect of their extraction on the present environmental situation, particularly with reference to large areas of radiation contamination and water pollution, both of which are often caused by former Soviet-era operations and modern mining techniques. Geopolitically Kazakhstan is in a strong position as it is the largest producer of uranium in the world, producing between 38% and 43% of the output in the world, and is also becoming an important supplier of rare earth elements, with reserves which could rank in the top three in the world. The diversification of the structure of supply of minerals could make an important strategic sub-division of the economy of Kazakhstan not only as a potentially large producer of these essentials, but also as a means of diversifying the all-important world structure of supply of minerals, and at the same time of reducing dependence on the existing China-based structures of supply. The results of the present investigation based on geological surveys, economic reports and policy papers indicate that, whereas the extraction of these minerals contributes to a large degree to the G.D.P. and a great deal of economic growth is anticipated, there are also several important sustainable problems which will arise, such as a possible source of social discontent and environmental degradation leading to poverty locally, together with a possible problem of vulnerability to problems of world markets being evident.

Keywords: Mining Geography, Rare Earth Material, Uranium, Kazakhstan, Central Asia, Geopolitics

Introduction

Spanning a huge land mass of 2.7 million km² in area Kazakhstan possesses a variety of geological formations from the northern steppe lands via southern basins to eastern mountains. The result is that it includes a substantial reserve of several strategic minerals including rare earth elements (REEs) and uranium (D'yachkov et al., 2103). As the world's chief producer of uranium giving between 38 and 43% of the world production and regarding REE's it is emerging as a potential leading country in the availability of its reserves, Kazakhstan's resource industry is not only of importance but is a very important factor in its post-Soviet economy (Muratova et al., 2023). The geographic location of these deposits with the uranium occurring mainly in southern sedimentary basins and the REE's in eastern and central metamorphic provinces gives these minerals a great influence on extraction methods, economic dependency, the extreme degree of environmental dispossession and the geo-political factor of the country (Parafilov et al., 2020). However, the geographical nature of the developments also gives rise to the possibility of considerably differentiated regional economic development and also environmental bad spots which could lead to local social unrest and increased susceptibility to the developments in the world market if not controlled and properly diversified with a conscientious environmental policy plus effector environmental safety systems.

The purpose of this article is to examine the interrelation of these various factors, since mining does not only influence the past and future development of the country but determines Kazakhstan's importance in the world market with reference to the demand to be found for clean energy and materials for technological exploitation.

Literature Review

The research on Kazakhstan, particularly with reference to its minerals, speaks of the supreme importance of uranium, which is produced in quantities amounting to over 23,000 tU annually. This production of uranium is confined mostly to the southern basins of Chu-Sarysu and Syr-Darya (Karataev & Clarke, 2014). The REE literature is concerned with the eastern occurrences of these elements in the Tien Shan region. The discoveries new to the list, for example, Zhana Kazakhstan, have, however, increased the estimates of reserves to something like 20 million tons. The economic literature refers to the contribution made by mining to GDP, which is considerable, and which is expected to rise as high as \$30 billion by 2025, due to not only the large amounts derived from exported products, but also to the number of jobs created (D'yachkov et al., 2021). The environmental literature provides details of the legacies created by the tests and mining of the Soviet era still existing, for example, how the radiation and contamination from the product remains, as well as the disposal of wastes (Nurpeisova et al., 2021). The geopolitical literature deals with the ability of Kazakhstan to play its multi-vector card, by adroitly balancing its relationship with Russia, China, and the West through critical supplies in the area. But there are, it seems, little analysis of the problems of the integrated, spatial, meaningful working of the inter-connections in the geological working of these many resources and the effects on the economic, environmental, and geo-political levels. This is the area which this paper concretely confines itself (Vakulchuk & Øverland, 2021). That these resources are concentrated in and produce localised benefits and jobs, does mean that the problems of much social difference in those regions, and thus the environmental questions, are increased. Some management and remedial procedures are therefore necessary to arrive at a more even distribution of benefits. Moreover, Kazakhstan is well placed geographically as a Central Asian State, which could easily become a geo-political hot spot, for there is no doubt of its being one of the areas of supply of critical minerals, which the countries of the world contest (Vakulchuk & Øverland, 2021). Although Kazakhstan has a great endowment of minerals, it is afflicted with the problems of limited diversification of its extractive industries or secondary manufacture, which renders it vulnerable to global developments in the price of oil and critical minerals (Vakulchuk & Øverland, 2021). This dependence helps, it seems, create the "resource curse." Here the economy remains dependent on raw material resources, instead of passing to the type of developed economy and diversification of product which is necessary (Vakulchuk & Øverland, 2021). Again, this part of the world: Central Asia, is to be found missing in the literatures on critical materials and minerals, yet it has played its part in giving the massive quantities of metals and industrial minerals previously to the Soviet Union and has large reserves of critical materials (Vakulchuk & Øverland, 2021)

Methodology

This qualitative study synthesizes secondary data from geological databases (e.g., USGS, IAEA), economic reports (e.g., World Nuclear Association), environmental assessments, and geopolitical analysis. Internet searches and targeted browsing resulted in current (2025) knowledge of distribution, impacts, and policies. The themes were compared amongst the economic, environmental, and geopolitical categories, with the limitation of accessibility of data offset by verification of data across disciplines.

Spatial Distribution and Extraction

Rare Earth Elements

Kazakhstan is the host of 160 rarer earth elements occurrences with most of occurrences being situated in the Tien Shan mountains. The various types include the carbonatite-alkaline, pegmatite-skarn, weathered crust and sedimentary uranium deposit (Liu et al., 2023). The most important occurrences are Shok-Karagay, which is in the east, Syrymbet, in the north and the Zhana Kazakhstan deposit, which is situated in the central Karagandy region, which is estimated to contain 20 million tons. The extraction is carried out by means of open pits and underground workings, with an increasing attention being paid to the ion-adsorption clays and co-associated rarer earth (REE) elements in Shubarkol (D'yakov et al., 2021). Because of the role of the eastern metamorphic zones transportation of goods by rail can be carried out, while the more isolated positions raise the problems of transport infrastructure (Depraire and Goutte, 2023). The large mineral wealth present in Central Asia and especially Kazakhstan which has excitingly attracted large amounts of foreign capital direct investment with China becoming by far the largest consumer of critical materials from the region owing to its famous "Going Out Strategy" and the 'Belt and Road Initiative' (Vakulchuk and Øverland, 2021). As a result of the gathering together of mineral wealth and foreign investment from various countries, not the least China, this means that there are various opportunities for wealth, but the side effects of this are that there may be develop excessive monetary dependence on one market, while the political and geographical implications of this concentrating of trading relationships is both of a serious nature.

Uranium

Uranium deposits are distributed in nine regions, with the southern sedimentary basins being the most important producing areas; namely, the Chu-Sarysu and Syr-Darya. The northern province Kokshetau has vein-stockwork deposits while in the western region (Pricaspian) there are deposits of a unique type: organic phosphorites. In the southeastern basins of Pribalkhash and Ily are found volcanic-sol stockwork varieties. The mode of working is in-situ leaching which minimises surface disturbance but necessitates an acid solution. The southern concentration of plants is in accord with the arid situation which encourages the use of water highly necessary for the processes involved, but heightens the risks involved in scarcity of its supply (Smedley &

Kinniburgh, 2022). In addition, while in-situ leaching offers environmental advantages in that surface disturbance is not inflicted, it is questionable whether this is not more than balanced by the demands of the process for quantities of acid or alkaline solution which may contaminate groundwater source if not properly supervised. This latter danger is particularly pronounced in arid regions with limited water supplies.

Economic Development

The extraction sectors reinforce the economy of the Republic of Kazakhstan, within which mining contributes 14% of GNP with a rate of growth of 6% per year, projected at a level of \$ 30 billion by 2025. Uranium exports of 23,270 tU in 2024 produce very large revenues which will promote a diversification in the production of nuclear fuel and in renewable energy. REE which are now produced by a factor five further than in 2020 provide an opportunity for Kazakhstan to substitute for "new oil" which attract investments such as the projects of Rio Tinto. Geography allows the development of job opportunities in the employment of workers in remote and in some places geographically difficult developing clusters, where however minimum unit costs involved are so very high and labour intensive as to make profitable a small-scale operation very difficult. It is the natural resources of the country which provoke foreign direct investment to an increasing extent and their necessary infrastructure through the Middle Corridor (BEISENGALIYEV et al. 2023). Continuing to assist the economic growth already referred to above, is the political and economic stability of Kazakhstan within the territory of Central Asia, an attractive factor for the investment of foreign direct investment in the area especially in consideration of other states in the same geographical region (Ablyalimov & Rajibaev, 2023). Unfortunately, and despite these positive factors, the dominance of the extractive industries of the Republic of Kazakhstan in its economy represents a classic dependence on natural resources, which restricts the drive for a broader industrial development and diversification of value-added manufacturing. Meanwhile however the dependence on raw material exports has means of exposure to the highly volatile nature of the world market prices of commodities whilst any satisfactory development of higher valued products in the manufacturing industries may meet with similar opportunities of the same declining prices thereby provoking the disaster potentially of the "resource cur" restated.

Environmental Challenges

Degradation in arid ecosystems is heightened through mining. Uranium mining through in situ leaching is causing ground water pollution through the leakage of concentrates of sulfuric acid, as occurred in the Kyzylorda events of 2022. Southern basins suffer from loss of water, while in the North, sites are at risk of soil erosion. Pollution from the testing of nuclear weapons in Semipalatinsk includes isotopes which exceed the norms for radiation protection and are negatively impacting upon the sources of biodiversity and man. The mining and processing of the rare earth elements generates hazardous waste which pollutes the rivers and atmosphere of the East and plays a role in the human and environmental increase of technological risks through the industrial catastrophes of the beryllium fire of 1990. Areas coexist with areas of populous residence and increase in danger, requiring rehabilitation work (Zhu et al., 2023). Furthermore, the extraction of energy resources in Kazakhstan (oil, gas, coal, and uranium), brings more environmental problems and hazards additional to those mentioned, through e.g. the pollution of the soil and Caspian Sea through products of oil, the leakage of methane from installation and emissions of dangerous particles and oxides through the combustion of fuels, and radiation waste products in addition (Dahl and Kuralbayeva, 200). Remedial work is however being carried out to ease the production of harmful effects on the site through more stringent environmental laws, the introduction of more modern techniques for the control of waste, the introduction of cleaner extraction devices and processes, and work is proceeding in the field of remediation of contaminated sites.

Geopolitical Positioning

Kazakhstan's mineral resources increase its leverage in global networks. Being the foremost supplier of uranium enables the country to serve the emerging nuclear industry with its fuel needs as the world moves away from carbon-based energy resources. With respect to the rare earths industry, where China controls between 60 to 90 percent of the output, Kazakhstan can serve to redistribute supplies through export quotas. Multi-vector diplomacy resources relationships with the West, the European Union and China. Southern uranium hubs enable work with Russians who may provide refining capacities, but diversification of sources leads to less dependence. New rare earth mining efforts in the central regions of the country are drawing investments from the Gulf and Germany which can be utilized to reshape supply chain structures (Liu et al, 2023). However, the focus on foreign processing of minerals and on concentrated markets of the needed raw materials also entails the beginnings of new dependencies that may restrain strategic autonomy from such players as and in the future, especially considering wavering worldwide demand and continuously changing geo-political configurations. What is more, these are countries that control the extraction of natural resources and critical minerals resources in Kazakhstan and elsewhere. This entails a complex stew of national alliances and economic factors that denies a simple approach to the question of foreign policy, as there is the necessity of both accepting investments and investments matters together with issues of national sovereignty and of sustainable development.

Aspect	REEs	Uranium
Key Regions	East (Tien Shan), Central (Karagandy)	South (Chu-Sarysu, Syr-Darya)
Extraction Methods	Open-pit, Ion-adsorption	In-situ Leaching
Economic Contribution	Exports 5x since 2020	38-43% Global Supply
Environmental Issues	Toxic Waste, Pollution	Radiation, Water Contamination
Geopolitical Role	Diversify from China	Nuclear Energy Security

Discussion

The spatial distribution of benefits is concentrated on southern and eastern hubs, resulting in uneven development, but this gives rise to transboundary infrastructure and cooperation between regions. Economic benefits could lead to a resource curse if there is no diversification into value-adding industries and environmental impacts require the introduction of green technologies and more stringent regulation. Geopolitically, Kazakhstan is in a strong position insofar as current tensions between the US and China exist, combined with a global energy transition, but reliance on foreign processing of strategic minerals will undermine its long-term strategic autonomy and efforts to diversify the economy. However, it is suggested that proactive government initiatives and international cooperatives along the lines of developing its own processing capability and diversifying export markets are being pursued to mitigate these risks and ensure more balanced economic growth.

Conclusion

Kazakhstan has significantly improved its economy and international standing through the distribution and extraction of REEs and uranium. However, the problems posed for the environment, by the issues of these resources, are compounded. Some economists argue that the economic benefits of these resources and the geostrategic benefits that derive from them outweigh any problems of the environment especially in the short term, as these resources generate much needed income and enhance the country's position in international supply chains. However, in order to achieve full economic and geostrategic benefits from the resources, it is important that the state qualify the risks that are attached to them by implementing good sustainable policies based on suitable waste disposal methods, international diversification of partner states and investment in clean extraction methods to ensure environmental health in the long term and economic sustainability.

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