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Landscape-geochemical Differentiation of the Yertis River Basin within the East Kazakhstan

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Abstract

The purpose of the study is to carry out landscape-geochemical differentiation of the Yertis River basin within the East Kazakhstan. In this work 12 geochemical landscapes of the Yertis River basin within the East Kazakhstan region are highlighted and shown on the map. The structural analysis of the geochemical landscapes of dry steppes, sub-boreal Kazakh deserts, and mountain-meadow landscapes of the river basin territory was carried out. The classification of A. I. Perelman was taken as the basis for the allocation of geochemical landscapes of the Yertis River basin, methods of analysis and synthesis, landscape-geographical and cartographic methods were used. The initial basis of the study was: a series of branch physical and geographical maps, landscape maps, topographic maps, literary materials. This study reflects the landscape-geochemical differentiation of the geosystems of the Yertis River basin within the East Kazakhstan region. The peculiarities of geochemical conditions of the geosystems of the Yertis River basin are influenced by various interactions of components, such as the biological cycle, relief, geological formations, migration of chemical elements.

Keywords: eochemistry; River basin; Geochemical landscape; Migration of elements; Biological cycle

1. Introduction

The study of the geochemical structure of landscapes plays one of the leading roles in the landscape-geographical sphere since the theoretical provisions of landscape geochemistry find practical application in many areas. The study of the geochemical composition of natural landscapes is of great application and fundamental importance since data on the concentrations of elements and substances in the environment are necessary to understand their impact on natural landscapes. In recent years, the increased impact of economic activity on the landscapes of the river basin, associated with water abstraction and its pollution by industrial and municipal wastewater, has had a significant impact on the processes of migration of chemical elements, the nature of their distribution, accumulation and concentration, the rate of chemical reactions, and in general on the geochemical conditions of the region under consideration.

2. Materials and Methods

The territory under consideration has a complex geological structure. Paleozoic, Mesozoic, and Cenozoic deposits participate in the surface structure of the described territory. The relief of the basin is diverse and is represented by all kinds of plains, as well as high mountains in the northeastern part of the region. The climate in the basin is sharply continental. The complex relief, the variety of climatic features cause the variegated composition of the soils in the territory under consideration. Paleozoic, Mesozoic, and

Cenozoic deposits participate in the surface structure of the described territory. The relief of the basin is diverse and is represented by all kinds of plains, as well as high mountains in the northeastern part of the region. The climate in the basin is sharply continental. The complex relief, the variety of climatic features cause the variegated composition of the soils in the territory under consideration (Vilesov, 2009).

Geochemistry of landscapes studies the patterns of migration of chemical elements in the geographical envelope of the Earth. Polynov, who is considered the founder of landscape geochemistry, understood the geochemical landscape as a paragenetic association of conjugated elementary landscapes interconnected by the migration of elements (Polynov, 1952). An elementary landscape, in turn, in a typical manifestation should represent one specific type of relief, composed of one rock or sediment, and covered at every moment of its existence by a certain plant community. Such scientists as Perelman (1975) and Glazovskaya (2002) also studied this direction. Nechaeva and Davydova (2010) and Ostaszewska (2010) highlight the functional role of landscape geochemistry in complex physical geography. The classification of A. I. Perelman was taken as the basis for the allocation of geochemical landscapes of the Yertis River basin, methods of analysis and synthesis, landscape-geographical and cartographic methods were used. The initial basis of the study was: a series of branch physical and geographical maps (National Atlas of the Republic of Kazakhstan, 2010), landscape maps (Landscape map of the Kazakh SSR, 1978), topographic maps, literary materials.

3. Results and Discussion

Geochemical landscapes can be classified, as types, families, classes, genera, and species. All taxa of geochemical landscape taxonomy in the basin can be attributed to the group of the steppe, desert, and meadow landscapes. In the study area, in the group of geochemical landscapes, there are types of landscapes that have been classified as dry steppes, desert sub-boreal, and mountain meadows.

The territory of the **steppe zone** of the basin belongs to the southern light chestnut soil family of dry steppes. Biomass in the steppes on the territory under consideration ranges from 100 to 350 c/ha, most of it is concentrated in the roots (70 - 90%). The annual production of П is 13-50 c/ha, 30 - 50% of the biomass; $К = \frac{\lg П}{\lg Б}$ in the chestnut steppes, it ranges from 0.77 - 0.88. Thus, the bik (biological cycle of atoms) in the steppes is progressive. In wet years, “waves of life” are observed: biomass and the number of species are increasing, fauna is rapidly developing. In dry years, B (biomass) decreases, species diversity decreases, the landscape acquires a more desert appearance. The above-ground plant mass in wet years is sometimes 10 times more than in dry years.

The dry steppes in the basin are characterized by the complexity of the soil and vegetation cover: chestnut soils are characterized by widespread distribution in combination with salt marshes, salt marshes are found in some areas. Along with the usual salt marshes, saline chestnut soils are also found. The complexity is especially great on flat undrained plains. The southern dry steppes are characterized by an arid climate and, accordingly, a lower intensity of biological accumulation, a lower accumulation of humus, a weaker runoff, and a wide development of light chestnut soils. This subzone is characterized by the greatest development of the saline process. Common salt marshes are common here, almost all light chestnut soils are saline. On steppe eluvial soils, biogenic accumulation is strong, and leaching is weaker, which is explained by an alkaline environment less favorable for the migration of most metals (there is no acid leaching), as well as weak soaking in a dry climate. A distinctive feature of steppe soils within the basin is the accumulation of humus with a decrease in its content as it deepens. Biogenically, P, S, K and Ca accumulate in the upper part of the soil (Bogdanova, 2016). In the steppes formed on rocks, under the humus horizon there is a clastic horizon with calcite crusts on the surface of the debris. Often there is so much calcite that all the crushed rock of the bedrock is covered with a white crust. In the cliffs of the plateau, in artificial recesses,

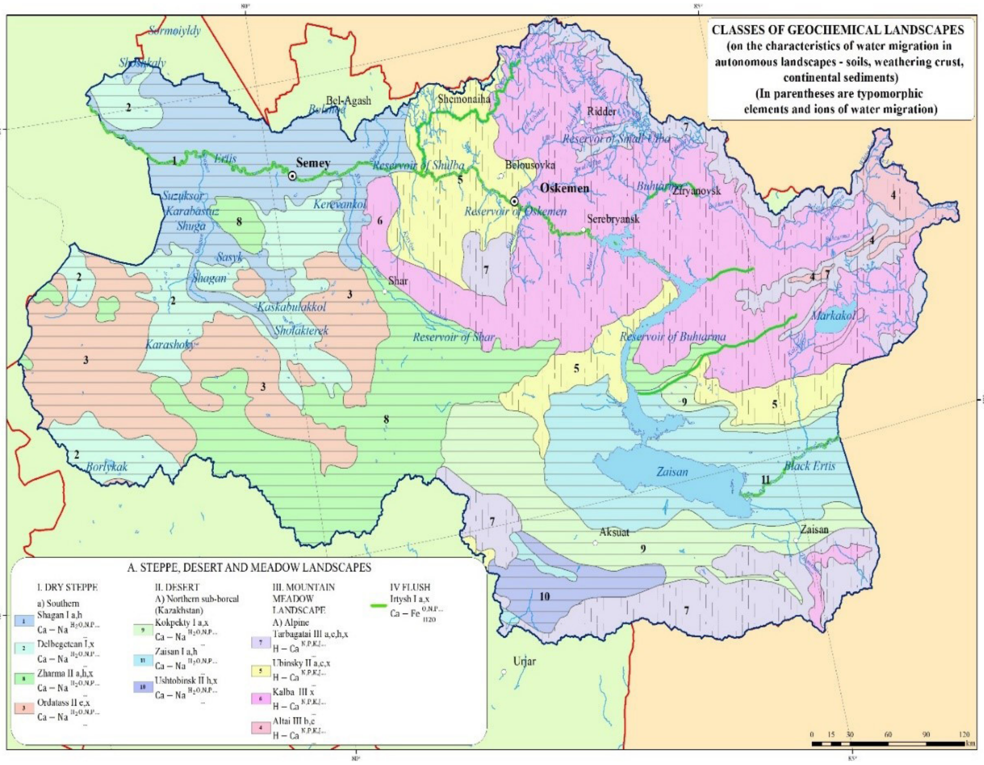

Figure 1. Map of geochemical landscapes of the Yertis River basin within the East Kazakhstan (compiled by the authors)

Continuation of the legend to the map

Classes of geochemical landscapes (on the characteristics of water migration in autonomous landscapes - soils, weathering crust, continental sediments)

(In parentheses are typomorphic elements and ions of water migration)

Carbonate gley (Ca^{2+}- Fe^{2+})-Bicarbonate-calcium weakly and moderately mineralized often hard waters

Transitional from acidic to calcium (H^{+} - Ca^{2+}), sometimes in complex with acidic (H^{+}) calcium (Ca^{2+}) - Weakly and moderately mineralized bicarbonate-calcium waters

Calcium-sodium (Ca2+, Na+) - Medium and highly mineralized waters, hydrocarbonate and chloride-sulfate

I $\frac{O,N,P,K,Ca...}{H2O,H...}$ Geochemical landscape formula

H-Fe Typomorphic elements and ions

O,N,P,K,Ca Elements scarce in the landscape

H_2O, H Connections and elements redundant in the landscape

Types of geochemical landscapes (according to the intensity of water exchange, the ratio of chemical and mechanical denudation, the contrast between autonomous and fixed landscapes)

III Vigorous water exchange, mechanical denudation prevails over chemical denudation in places, a sharp boundary and significant differences between autonomous and subordinate landscapes (mountainous strongly dissected relief).

II Average water exchange, the ratio between mechanical and chemical denudation is different, a sharp boundary between autonomous and subordinate landscapes (hilly relief, dissected uplands)

I Slow water exchange, chemical denudation often prevails over mechanical, the boundary between autonomous and subordinate landscapes is gradual, the differences are insignificant in places (flat relief)

Types (and Groups of species) of geochemical Landscapes (by geological formations)

a Clay and loamy alluvial deposits (not loessial)

b Glacial deposits of various compositions (boulder loams, sands with boulders, etc.)

c Fluvioglacial and alluvial sands, predominantly quartz

d Polymictic desert sands

i Loesses and loess-like rocks

f Quaternary deposits of various genesis

g Red color formation

h Platform sedimentary formations (limestones, clays, etc.)

x Geosynclinal formations (igneous, metamorphic, sedimentary)

e Granitoids and shield formations

t Traps

the carbonate horizon is traced in the form of a white stripe parallel to the earth's surface.

The chestnut soils of the steppes are characterized by two main geochemical barriers: 1) biogeochemical barrier in the upper part of the humus horizon, where P, S, K, Ca, Mg, Na, Sr, Mn, Cu, Zn, Mo, Co, As, Ag, Ba, Pb, and other trace elements accumulate due to biogenic accumulation; 2) alkaline and thermodynamic barriers in the lower parts of the humus horizon and the upper part of the carbonate horizon, where CaCO3 accumulates. In chestnut soils, oxidative conditions prevail, as indicated by the immobility of Fe, the absence of gluing (Shogelova *et al.,* 2021).

The steppes in the basin are characterized by families of cereals, complex-colored, to a lesser extent cruciferous, legumes, etc. The chemistry of flora is primarily determined by the systematic position of plants and to a lesser extent by modern geochemical conditions (Glazovskaya *et al.,*1989). Therefore, in the same elementary landscape, cereals contain more Than wormwood, the letter contains more Ca and Na, etc. According to the mineral composition, Rodin and Basilevich (Rodin, 1965) divide all steppe grasses into three groups: 1) cereals with a high Si content of low N; 2) legumes with a significant accumulation of K, Ca, and N; 3) herbs occupying an intermediate position. There are also differences in the distribution of elements by plant organ: Ca, Si, Fe and Al mainly accumulate in the roots, and Na and K - in aboveground organs. Similar patterns are observed for trace elements.

The waters of the dry steppes in the territory under consideration are medium and highly mineralized, bicarbonate and chloride-sulfate. There are almost no organic substances and mineral colloids in them. They are saturated not only with an element such as Ca but sometimes also with Ma, Na, S, Cl, N (Vinogradov, 1962). When water evaporates, minerals of these elements are formed. Since the waters are poor in organic compounds, they are poor in free energy, they are not aggressive (neutral and slightly alkaline), often saturated solutions have almost no dissolving or decomposing ability. Consequently, the impact of groundwater on rocks is small. The steppes are characterized by families of cereals, complex-colored, to a lesser extent cruciferous, legumes, etc. (Perelman et al., 1999).

In the subtype of the southern steppes, landscapes of the Ca-Na class belonging to the landscapes of the I and II kind are common. The landscapes of the first kind include the Shulba and Shagan landscapes in which slow water exchange, chemical denudation often prevails over mechanical, the boundary between autonomous and subordinate landscapes is gradual, differences in places are insignificant (flat terrain).

Shagan landscapes can be attributed to several types of geochemical landscapes - on clay, loamy alluvial deposits, platform sedimentary formations (limestones, clays, etc.). In the areas of the villages of Ondiris, Karabash, the landscapes of the first kind are represented by accumulative poorly divided mid-quaternary-modern plains with oatmeal-sand-and-sand-and-sand-and-sand vegetation on chestnut, saline soils on sandy loam, and sandy soil-forming rocks. On the territories of the city of Semey, the village of Dolon, the relief is flat accumulative medium-quaternary with pine forests and aspen-birch forests combined with oatmeal-sand-and-dust steppes on the soils of boreal sands, salt flats on sandy loam and sandy rocks. Within the territory of the lakes Karabastuz, Terenkol, Shuga, Susukkor, Balyktykol, the landscapes of the first kind are represented by accumulative alluvial-proluvial early quaternary plains with marshallowsoil-tyrsa with complexes of sagebrush-turf-grasses, sagebrush and in places black-wormwood-kokpek plant communities on light-clay soils on loamy, sandy loam and sandy rocks. In the areas of the village of Zhazyk, the relief is plain accumulative diluvial-proluvial, in the area of the Myrzabek River, plain denudation on a folded basis, weakly wavy pre-Eocene peneplains with Marshall-wormwood-tyrsa vegetation on light chestnut soils on loamy and light loamy rocks are common. On the territory of the village of Novaya Shulba, the relief is represented by accumulative alluvial-proluvial middle-Late quaternary plains with arable lands in place of rich grass-grass and arable lands in place of dry tipchak and kovylkov steppes on foothill chestnut soils.

In the Delbegetean landscapes, there are several types of geochemical landscapes such as clay, loamy alluvial deposits, platform sedimentary formations (limestones, clays, etc.). Within the banks of the Saryozen River, the landscapes of the first kind of Delbegetean landscapes are represented here by accumulative diluvial-proluvial plains in combination with denudation wavy peneplains on a folded basis with Karaganovo-cold wormwood-thyrs vegetation on chestnut soils on dense crystalline rocks. In the area of the Shagan river, the relief is flat, accumulative alluvial-proluvial in combination with denudation plains with a folded base, wavy foam with psammophytic grass-tyrsovo-variegated and tyrsovaya, seropolynno-kovylkova in combination with brittle grate, Karaganovo-cold wormwood-tyrsovaya, turf-black-wormwood vegetation on light chestnut soils. On the territory of Borlykak and Aktobekol lakes, landscapes of the first kind are represented by denudation wavy peneplains with Karaganov-cold wormwood-tyrsa and xerophytic-grass-tipchak-kovylkov vegetation on chestnut soils on gravelly soil-forming rocks.

Ordatass landscapes belong to the second genus with an average water exchange, here the ratio between mechanical and chemical denudation is different, there is a sharp boundary between autonomous and subordinate landscapes (hilly relief, dissected hills). Several types of geochemical landscapes such as granitoid and shield formations and geosynclinal formations are common here. In the areas of Borli Mountain and Karashoka wintering, the landscapes of the second kind are represented here by hilly denudation-heeled relief of pre-Eocene age with Karaganov-cold wormwood-tyrsa vegetation on chestnut and dark-brown soils on dense crystalline rocks. On the territory of the Itayak River, the relief is hilly tectonically-denudational withered with Karaganov-cold wormwood-tyrsa, petrophytic-grass-shrub-turf-grass vegetation on chestnut and low-mountain chestnut soils. On the territory of Mount Karaadyr, the relief is represented by tectonically-denudation-heeled hills with sagebrush-feather grass: subleasing a sagebrush-fescue and kyrgyz feather grass vegetation on low-mountain light brown soils. On the territory of the Kayrakty mountain, the villages of Arshaly, Akshoky, the relief is denudation mane hilly.

In the Zharma landscapes, the landscapes of the second kind in the area of Mount Karakus are represented by tectonically-denudation ridge hills with wormwood, sublessingian, wormwood-fescue and kyrgyz feather grass vegetation on low-mountain chestnut soils on dense crystalline rocks. On the territory of the Karasu River, the relief is represented by denudation heeled hills with wormwood-grass vegetation on light-clay soils on light-loamy soil-forming rocks. In the areas of the Saryshoky mountains, the village of Kyzyltas, Zhurekadyr, the landscapes of the second kind are represented by ridge hills with shrubby-grass-turf-grasses: petrophytic-grass-red-grass vegetation on low-mountain chestnut soils.

(1) The territory of the semi-desert zone of the basin belongs to the desert type. Biomass in the desert is usually 10-15 c/ha, but in some landscapes it reaches 300 c/ha. Annual production most often ranges from 5-15 c/ha. The ratio between B and N varies enormously. The species diversity in the desert territories is almost half that in the steppes.

In autonomous and transeluvial positions, primitive brown and gray-brown soils are formed on the calcified alluvium. In the eluvial-accumulative landscapes of the foothill plains and the lower parts of the slopes of the hills, carbonate gravelly proluvium and diluvium are formed, on which full-profile, sometimes saline, brown, and gray-brown soils are developed (Kasimov, 1988). For autonomous and transit-accumulative landscapes with a deep groundwater level, calcium and calcium-sodium migration classes are characteristic. The alkaline oxidizing environment of soils, a small amount of organic matter in them, and extremely weak moisture determine the low intensity of migration of most elements. Gray-brown soils are confined to eluvial landscapes. The soil profile is differentiated into horizons. Iron accumulates in the illuvial horizon, clay partially accumulates. Clay minerals are not oriented horizontally, which indicates their formation from the surrounding rock and the lack of movement along with the soil profile. Hydrosluidic and chlorite minerals predominate. In comparison with the soil-forming rock, Si, Mn, Fe, Al, P, Ti, K, Na accumulate in the soil. The humus content is insignificant (0.15 - 0.54%), so the biogenic accumulation in the hummus horizon is not pronounced. Humus is firmly fixed by the mineral part of the soil.

Wormwood associations are characteristic of the deserts of the studied territory. The desert flora in the basin is characterized by intensive biogenic accumulation of Na, Cl, S, as well as K and P, with the first three elements concentrated in aboveground organs, and P and K – underground. The total ash content is higher than in steppe plants. Si, Fe, and Al have low coefficients of biological absorption, their content in ash is very small (A 2 = 0.0-0.5). Alkaline and alkaline-earth metals are involved in the bik more vigorously than in the steppes. In the sharply oxidizing environment of deserts, the decomposition of plant residues proceeds intensively, organic substances are rapidly mineralized and humus almost does not accumulate. This is how the deserts of the basin differ from the steppes. Wood residues, on the contrary, persist for a long time, being preserved in a dry climate (but not being humified). According to Bazilevich and Rodin, the nitrogen type of chemistry (N > Ca) prevails in the bik of the desert with significant participation of Cl and S. Thus, in the desert, bik flows quickly, the green organic mass is small, organic substances are mineralized or preserved, but almost not humified. The predominant part of living matter is concentrated underground.

The waters of the desert territory of the basin are medium and highly mineralized, bicarbonate and chloride-sulfate, the chemical composition of fractured groundwater is formed mainly due to atmospheric salts, interaction with rocks, and calcified weathering crust.

The territory of the semi-desert zone of the basin belongs to the northern sub-boreal (Kazakhstan) family. These are temperate deserts with grey-brown soils, frosty winters, cold dry spring, and hot summers - the main period of the biological cycle. Landscapes of the I and II kind are common. Calcium-sodium class landscapes are common in this subzone.

The landscapes of the first kind include the Kokpekty and Zaisan landscapes. Within the Kokpekty landscapes, several types of geochemical landscapes are distinguished. Landscapes of the first kind are represented here by accumulative alluvial-proluvial late quaternary plains with thin-tufted vegetation on meadow-chestnut, meadow soils, chestnut, loamy rocks.

The Zaisan landscapes on the shores of Lake Zaisan are represented by accumulative alluvial-proluvial late Quaternary-modern plains with thin-wormwood-tyrsikov, wormwood-tipchak-tyrsova, tyrsikovo-subleasing an-wormwood and lichen-tasbyurgun-grass-wormwood and cattail-reed with thickets of hydrophytes in lagoons on the meadow, foothill-light-brown, gray-brown, meadow-brown in combination with saline and takyrovid soils on loamy rocks.

In the Ushtobinsk landscapes in the areas of the village of Ushtobe, the Bazar river landscapes of the second kind, the relief is represented by tectonically-denudation ridge hills with fescue - feather grass: caragan-cold wormwood-tyrsovo-ovsets vegetation on mountain chestnut soils on loamy, sandy-pebble and gravelly rocks.

(2) **The mountainous** high-altitude zone of the basin territory belongs to the type of mountain-meadow landscapes. In terms of values B, N, and K, mountain meadows are closest to meadow chernozem steppes. The biomass here is 250 c/ha, and the annual production is 120 c/ha. Decomposition of organic substances proceeds slower than in the steppes, acidic compounds prevail over the main ones in decomposition products, less oxidative conditions are developed in soils, and a different redox zonality. They are formed on carbonate rocks - limestones, dolomites, marls, etc. Strong evaporation, sharp changes in temperature during the day, significant heating of the soil compared to air, heavy snow cover, and long winters have a great influence on the bik. Relatively frequent thunderstorms increase the ozone content in the atmosphere and thereby enhance oxidative reactions.

Their mountain meadow soils usually contain fragments of carbonate rocks, around with a local neutral microenvironment is created. However, in general, the soil fine-grained is acidic, the bik is stronger than the influence of the rock, an extremely variegated, sharply no equilibrium alkaline-acidic environment occurs in the soil (both acidic and neutral environments are developed in the same horizon). $CaCO_3$ is unstable, and bicarbonate solutions leave the soil, the illuvial carbonate horizon does not form. However, these landscapes are richer in calcium than acidic ones, the pH of the soil is higher here, organisms are better provided with calcium, there are more calcifies among grasses.

The biomass of alpine meadows is dominated by higher plants – monocotyledonous and dicotyledonous perennial grasses, moss, and lichens are few. The rocks are usually covered with scale lichens, which here are the first visible agents of weathering and soil formation. The conquest of rocks by lichens is probably slow.

Fractured groundwater is formed in carbonate rocks, calcite and dolomite dissolution processes play an important role in the formation of their composition. The waters are more mineralized than in the acidic class, bicarbonate-calcium. However, they are also not saturated with $CaCO_3$, and therefore there are no secondary accumulations of lime carbonate.

Mountain-meadow landscapes belong to the Alpine family of the transition from acidic to calcium (H^+- Ca^{2+}) class, sometimes in combination with acidic H^+ calcium Ca^{2+}. The waters there are weakly and strongly mineralized bicarbonate-calcium. There are widespread landscapes of the III kind with vigorous water exchange, mechanical denudation prevails over chemical in places, a sharp border prevails and significant differences between autonomous and subordinate landscapes (mountainous, highly dissected relief). On the territory of the Tarbagatai landscapes, the relief is high-altitude tectonically-denudation with thin-wormwood-tyrsikov, shrubby thickets in combination with meadow and rich grass steppes: kalofachniki, almonds, spiracles, shrubs in combination with petrophytic steppes on foothill light chestnut soils and low-mountain chernozems of ordinary dense crystalline rocks, sand-pebble and gravelly rocks.

In the Ubinsky landscapes in the area of the city of Shemonaiha, village altar, Ubinka river landscapes of the III kind are represented by tectonically-denudation ridge hills with sagebrush- fescue -tyrsovaya, aspen-birch-willow thickets, sedge-grass grass swamps, and grass-grass meadow plants on the foothill chernozems of ordinary and southern and mountain-steppe xeromorphic soils. In the areas of the rivers Derevyanka, Zhartas, Kuyula, the relief is hilly ridge modern with shrubby thickets; wormwood-covy in combination with brittle grate; shrubby-mixed-grass-red-covy vegetation on mountain chestnut soils on loamy soil-forming rocks. In the areas of the villages of Egindibulak, Sarykamys, the relief is mountainous, and in the areas of the Kalzhir River, the relief is a hilly ridge with grassy-wormwood tyrsikovo-subleasing an-wormwood and lichen-tasbyurgun vegetation on mountain chestnut soils on densely crystalline rocks.

The landscapes of the III kind in the Kalba landscapes are represented by high-altitude tectonic-denudation relief with pine and birch-pine forests; shrub-herbaceous communities, shrubby thickets in combination with meadow and rich grass steppes: rose gardens, spire, Karagiannis in combination with sedge, offsets and krasnokovylny steppes on mountain-steppe xeromorphic and mountain-forest chernozem - like soils.

Altai landscapes of the III kind are represented by high-altitude tectonic-denudation relief with high-altitude moss-lichen, grass-lichen and ermine, high-altitude low-grass meadows, birch woodlands, and cedar-larch woodlands on mountain-meadow alpine and subalpine soils on dense crystalline soil-forming rocks.

In the flood plains on the territory of the basin, the relief is an accumulative alluvial-proluvial plain with fescue, sand-and-dust and shrub vegetation on meadow soils.

4. Conclusion

As a result of the classification, 12 geochemical landscapes were identified within the basin. In the dry steppes, plains and hilly genera of geochemical landscapes are more common, were, respectively, slow and medium water exchange. In sub-boreal deserts, flat landscapes with slow water exchange are more common, where chemical denudation often prevails over mechanical, and the boundary between autonomous and subordinate landscapes is gradual and the differences between them are insignificant in places. In mountain-meadow landscapes, mountainous terrain is widespread on a larger territory, where water exchange is vigorous, mechanical denudation in places prevails over chemical, there is a sharp boundary and significant differences between autonomous and subordinate landscapes. In the soils of dry steppes, chemical elements accumulate biogenically, and the chemistry of flora is primarily determined by the systematic position of plants, as well as there are differences in the distribution of elements by plant organs: Ca, Si, Fe, and Al mainly accumulate in the roots, and Na and In the above-ground organs. In the soils of deserts in the basin, biogenic accumulation is weakly expressed, since the humus content is insignificant here, the nitrogen type of chemistry is characteristic for plants, the flora in the basin is characterized by intensive biogenic accumulation of Na, Cl, S, as well as K and P, and the first three elements are concentrated in aboveground organs and P and K – underground. Within the dry steppes, plains and hilly genera of geochemical landscapes are more common, where water exchange is slow and medium. In sub-boreal deserts, flat landscapes with slow water exchange are more common, chemical denudation often prevails over mechanical, and the boundary between autonomous and subordinate landscapes is gradual, differences in places are insignificant. In mountain-meadow landscapes, mountainous terrain is widespread on a larger territory, where water exchange is vigorous, mechanical denudation in places prevails over chemical, there is a sharp boundary and significant differences between autonomous and subordinate landscapes.

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