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MORPHOGENETIC INDICATORS AND DIAGNOSTIC CRITERIA OF ALLUVIAL-MEADOW SOILS ON THE NORTHEASTERN SLOPE OF THE LESSER CAUCASUS, AZERBAIJAN

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SUMMARY

This study comprised a comprehensive evaluation of the morphogenetic characteristics, diagnostic features, and classification of alluvial-hydromorphic soils formed within river basins of the northeastern slope of the Lesser Caucasus, Azerbaijan. However, these soils developed under complex geomorphological conditions, heterogeneous microrelief, and periodic seasonal flooding, resulting in dynamic pedogenic processes, stratified profiles, and variable clay formation intensity. The subsequent research aimed to identify the key morphogenetic and diagnostic indicators of soil types and subtypes within the Kura River basin. It also sought to define their classification based on principles of the World Reference Base (WRB) for soil resources and assess the rational use of conditionally unsuitable stony alluvial soils. Field investigations transpired from 2015 to 2025, including detailed surveys, laboratory analyses, statistical evaluations, and large-scale soil mapping. The results revealed humid subtropical soils exhibited intensive carbonate leaching, higher humus content, and the formation of active clay, whereas dry subtropical soils showed a surface carbonate accumulation, salinization tendencies, and lower humus reserves. Clay formation intensity had a close association with moisture regime, redox potential (Eh), and mobile iron oxides, contributing to improved soil classification and sustainable land use.

Keywords: Alluvial-hydromorphic soils, morphogenetic diagnostics, soil classification, clay formation process, river floodplains, WRB system, soil mapping, bioclimatic zones

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Key findings: The results provided a scientific basis for the improved diagnosis, mapping, and passporting of alluvial-hydromorphic soils, support for the development of soil-related GIS databases, and a contribution to the sustainable and efficient use of these soils in agricultural systems.

INTRODUCTION

Alluvial-meadow soils are the widely distributed type within the floodplains of the Kura River and Araz River, the Ganikh-Ayrichay Valley, the Guba-Khachmaz Massif, and the Lankaran Lowland. Likewise, these are dominant on floodplains, young terraces, and alluvial cones of mountain rivers in both the Greater Caucasus and Lesser Caucasus. However, these soils typically formed under well-developed meadow-grass vegetation and represent a major component of floodplain landscapes in Azerbaijan (Hasanov, 2015; Huseynov *et al.,* 2026a).

The alluvial-meadow soil's genesis and morphogenetic development had the management primarily by shallow groundwater occurrence (0.8–2.5 m), seasonal river flooding, especially during spring and autumn, and the deposition of clay-loamy and sandy-loamy sediments periodically. As a result, these soils commonly exhibit pronounced profile stratification and buried humus horizons, which serve as key diagnostic indicators of alluvial-hydromorphic formation (Arinushkina, 1961; Sadigov and Mustafayev, 2024).

Soil diagnostics and classification constitute the methodological foundation of soil science, which is evidently crucial for soil mapping, resource assessment, sustainable land use, and the development of soil-based geographic information systems (GIS). In recent decades, greater emphasis has progressed on harmonizing national soil classifications with internationally recognized frameworks, particularly the World Reference Base (WRB) for soil resources, to formulate standardized soil databases, unified soil passporting, and improved international comparability (Krasilnikov *et al.,* 2009; FAO, 2015; IUSS Working Group WRB, 2022).

In this context, correlating Azerbaijan's national soil classification system with international standards has become a viable scientific priority. Such types of harmonization help in the integration of national soil data into global soil information systems that eventually improve the consistency of comparative studies (Hasanov, 2018; IUSS Working Group WRB, 2022).

For alluvial-hydromorphic soils, the development of a refined morphogenetic diagnostic framework with an updated classification scheme among the less comprehensively studied soil groups of Azerbaijan necessitates an urgent research task. Special emphasis should take place on the clay formation processes, which demonstrate key diagnostic indicators of alluvial-hydromorphic soil profiles under humid and dry subtropical conditions. Long-term dynamic observations of these soil processes are of significant practical importance for improving concepts of soil genesis and classification (Hasanov, 2015; Mammadov *et al.,* 2025).

Comparative geographical studies enunciated the diversity of natural and ecological conditions across river basins leads to pronounced zonal differentiation in soil-forming processes and various diagnostic characteristics (Sadigov and Mustafayev, 2024). Alluvial-hydromorphic soils of the Kura River basin, formed under dry steppe and semi-desert subtropical conditions, revealed distinctions from carbonate accumulation, occasional salinization and sodicity, surface marling, relatively thick accumulative-sedimentary horizons, and generally low humus content. However, considerable variations in groundwater mineralization further exert a decisive influence on their morphogenetic and hydromorphic properties (Hasanov, 2015). This promising study aimed to recognize the key morphogenetic and diagnostic features and classification of alluvial-hydromorphic soils formed within river basins of the northeastern slope of the Lesser Caucasus, Azerbaijan.

MATERIALS AND METHODS

Extensive field investigations proceeded in river valleys on the northeastern slope of the Lesser Caucasus, Azerbaijan, including transects from riverbeds to ancient terraces, to examine evolutionary stages of alluvial-hydromorphic soils under varying geomorphological and hydrological conditions (Figure 1).

Laboratory analyses

The standardized methods followed sought to assess humus and total nitrogen (I.V. Tyurin), exchangeable Ca^{2+} and Mg^{2+} (D.V. Ivanov), Na^{+} (K.K. Gedroits), pH potentiometrically, carbonates by Scheibler calcimeter, and soluble salts after E.V. Arinushkina. The study also determined hygroscopic moisture, granulometric composition (N.A. Kachinsky), bulk density, and stoniness (A.I. Petrov). Fractional humus composition (V.V. Ponomaryova and T.A. Plotnikova) and gross chemical analyses ensued. River turbidity measurement used the GGI bathometer method (Arinushkina, 1961; Tyurin, 1965; Kashinsky, 1970; Dospekhov, 1984; Hasanov, 2015, 2018; Interstate standard, 2019; Mammadov *et al*., 2025).

The vegetation influence on soil formation received an assessment over the five years in the Kura River basin through aboveground and root biomass measurements. Long-term stationary studies evaluated seasonal dynamics of moisture, redox potential (Eh), mobile iron oxides, water-soluble humus, groundwater levels, and temperature to 1.5 m depth. Using statistical correlation and regression analyses helped interpret the relationship between soil properties and environmental regimes.

RESULTS AND DISCUSSION

The results revealed the studied subtypes of alluvial-meadow soils enunciated pronounced variations for morphogenetic profile structure, diagnostic characteristics, and spatial distribution across river valleys representing distinct bioclimatic zones. Accordingly, the presented study also classified the alluvial-meadow soils commonly occurring in river valleys of the region into three subtypes: a) primitive alluvial-meadow soils, b) layered alluvial-meadow soils, and c) typical alluvial-meadow soils (Figure 2).

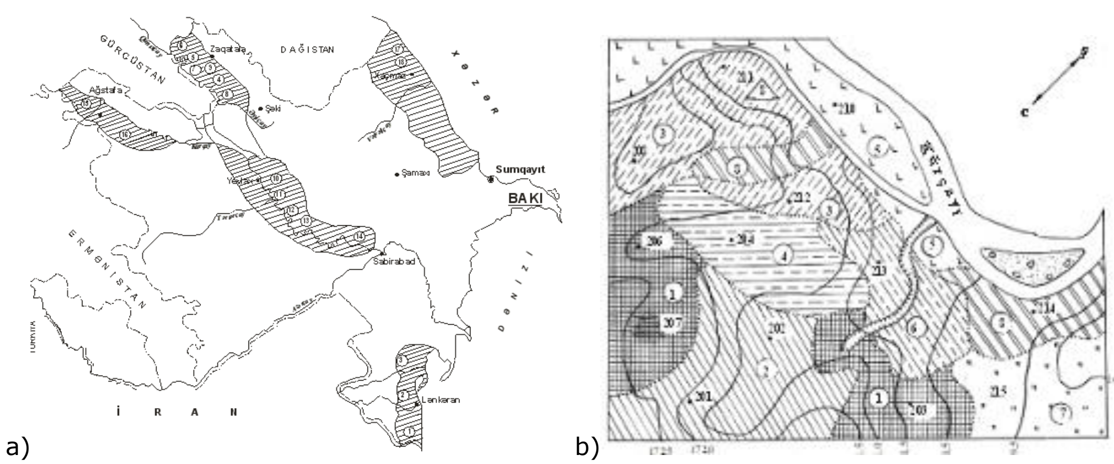

Figure 1. a) Location of alluvıal-hydromorphıc soıls of Azerbaıjan, and b) scheme of location of research areas in the village of Gadirli.

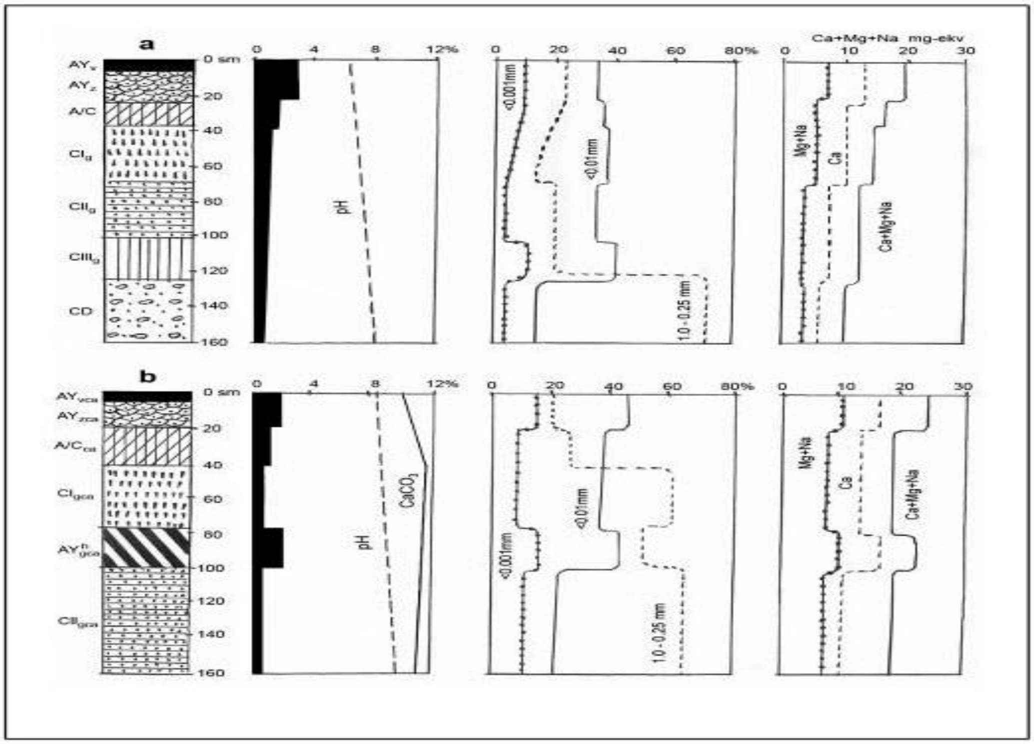

Figure 2. a) Morphogenetic indicators of washed, and b) carbonated primary alluvial-meadow soil profiles.

In high-mountain areas, primary soil formation occurs under pioneer (lithophile) vegetation on weathered rocks with constant conditions of leaching, erosion, and transport of weathering products. In river valleys, by contrast, the mechanical, chemical, and biological sediments, along with soil-forming materials, underwent continuous deposition due to the floodplain regime. These alluvial sediments also gained enrichment with plant residues, seeds, and both organic and mineral nutrients. The shaping of primary soils occurred through initial soil formation processes and an impact of mountain rocks and environmental factors on newly deposited alluvial sediments in river floodplains (Kovda, 1973). As a result, grasses, shrubs, and trees can develop on young alluvial deposits within 2–3 years, giving a boost to the creation of primary alluvial-meadow soils. Mammadov (2025) and Sadigov and Mustafayev (2024) also corroborated these observations, showing that nutrient-rich alluvial sediments accelerate the vegetation colonization and humus accumulation, facilitating rapid primary soil development in floodplains.

The distribution of primary alluvial-meadow soils typically appears in interfluve sections of river floodplains, developing locally on young and lightly lithified alluvial deposits. The flood regimes, particularly during spring and autumn, hinder the stable development of the soil cover, with fresh alluvial sediments periodically deposited on the soil surface. In these areas, the groundwater incurs weak mineralization (0.8–2.0 g), exhibiting dynamic seasonal fluctuations, with depths ranging from 1.5 to 3.5 m. The mineralization level of groundwater received considerable influences from seasonal floods and infiltration from river waters (Krasilnikov *et al.,* 2009; Hasanov, 2015). Arinushkina's (1961) and Khalilov *et al.*'s (2023) findings showed that weakly mineralized and seasonally fluctuating groundwater promotes the stratified profile formation in young alluvial soils, supporting

Table 1. Main physicochemical indicators of primary alluvial-meadow soils.

Section No.	Genetic layers and depth (cm)	Humus (%)	Nitrogen (%)	C:N	$CaCO_3$(%)	pH	Absorption capacity in aqueous solution (mg-eq.)	Granulometric composition (%)		Density (g/cm^3)
								<0.001 mm	<0.01 mm	
	Carbonate primary alluvial meadow (Salahlı)									
1	AYv 0-5	1.84	0.14	7.6	11.3	8.0	19.0	12.8	45.4	1.24
	AYz 5-20	1.73	0.13	7.7	11.5	8.1	17.9	8.4	36.5	1.25
	A/Cca 20-42	0.81	0.07	6.0	12.6	8.2	19.8	10.7	41.8	1.28
	CIgca 42-78	0.70	Not.an	-	11.4	8.2	17.2	8.7	32.6	1.36
	A^{h}gca 78-120	2.04	«-»	-	10.1	8.1	21.4	15.7	41.8	1.29
	CIIgca 120-155	0.82	«-»	-	11.5	8.3	18.5	9.7	21.7	Not.an
	Irrigated carbonate primary alluvial meadow (Gadirli)									
2	AY'aca 0-20	2.07	0.17	7.2	10.5	8.1	21.4	19.2	44.3	1.18
	AY''aca 20-38	1.84	0.15	7.4	10.7	8.2	24.7	22.0	50.2	1.35
	A/C 38-75	1.53	0.12	7.2	12.5	8.2	22.5	25.5	48.4	1.32
	Cıgca 75-103	0.75	Not.an	-	13.5	8.3	19.3	17.6	33.4	1.27
	CIIgca 103-132	0.58	«-»	-	13.2	8.3	22.8	23.4	57.2	Not.an
	CIIIgca 132-170	0.67	«-»	-	13.1	8.4	20.4	19.7	47.1	-

rapid soil genesis under floodplain conditions. These past findings further reinforce the presented study observations that seasonal floods play a decisive role in managing soil formation and nutrient distribution.

Vegetation on primary alluvial-meadow soils mostly comprises sparse grass-meadow communities, including *Poa pratensis*, *Bromus japonicus*, and *Folium riditum*, forming a poorly developed soft turf layer (AYv = 6 ± 1.0 cm) on the soil surface. Beneath the upper accumulative horizon (AYz = 18 ± 1.7 cm), the soil profile contains monotonous sandy-clayey alluvial deposits. Weak clay formation process, observed seasonally, was primarily evident in deeper layers (CIIg = 120–150 cm), often associated with buried humus horizons (AUhg) and silty-clayey lithological material. Main physicochemical indicators of primary alluvial-meadow soils appear in Table 1 (Hasanov, 2018; Mammadov *et al*., 2025). Research by Kovda (1973) and Arinushkina (1961) enunciated that sparse pioneer vegetation and weak clay formation in young alluvial deposits were typical early-stage soil characteristics, facilitating gradual humus accumulation and profile stratification. These past findings further support the current observations of seasonal clay development and buried humus horizons in the studied soils.

The primary alluvial-meadow soil profile expressed characteristics of poorly developed horizons, which can have a representation of AYv-Ayz-CI-CIIg, and in carbonate-rich variants, AYvca-AYzca-CIca-CIIg. This subtype of alluvial-meadow soils has a wider distribution on young river terraces, where the effects of the flood regime appear relatively weak, and at mountain rivers' feet. The landscape had the dominance of plain and micro-concave relief types. These soils were typically existent in the partially flood-protected areas, where the zonal climatic and vegetation factors influence was more pronounced (Gumbatov *et al.,* 2024; Sadigov *et al.,* 2025). Kovda (1973) and Arinushkina (1961) reported that young alluvial-meadow soils on protected terraces often exhibited less developed horizons and enhanced influence of climatic and vegetative factors, supporting the patterns observed in this present study. These findings provide additional evidence that microrelief and partial protection from flooding critically manage the development of soil profiles.

Soil formation occurs under subtropical climatic conditions, characterized by mild winters and hot summers. However, considerable variability revealed in the bioclimatic parameters influences soil

Table 2. Main physicochemical indicators of alluvial-meadow soils.

Section No.	Genetic layers and depth (cm)	Humus (%)	Nitrogen (%)	C:N	$CaCO_3$ (%)	pH	Absorption capacity in aqueous solution (mg-eq.)	Granulometric composition (%)		Density (g/cm^3)
								<0.001 mm	<0.01 mm	
	Carbonate alluvial-meadow (Salahlı)									
3	AUvca 0-10	3.70	0.39	8.4	5.8	7.5	39.8	26.7	62.7	1.12
	AUzca 10-24	3.24	0.27	7.0	8.6	7.6	34.9	21.4	51.4	1.24
	A/Bca 24-48	1.97	0.09	5.8	15.0	7.9	27.9	23.0	62.2	1.31
	Bgca 48-76	0.96	Not.an	-	14.1	7.9	35.3	20.7	59.2	1.38
	B/Cca 76-122	0.75	«-»	-	14.8	8.3	26.1	20.1	51.2	1.35
	Cgca 122-158	0.53	«-»	-	12.1	8.3	17.4	10.7	26.6	«-»
	Marly alluvial meadow (Gadirli)									
4	AUv 0-14	4.78	0.29	12.3	23.7	8.2	42.0	18.7	54.2	0.86
	Auml 14-35	4.93	0.27	11.2	30.6	8.5	39.2	22.2	63.4	1.18
	A/Bml 35-58	2.34	0.19	9.1	25.5	8.7	32.7	28.9	68.5	1.42
	Bmlg 58-86	1.82	0.14	7.4	27.9	8.9	24.6	30.2	70.2	1.50
	CImlg 86-115	0.78	Not.an	-	33.4	9.2	24.7	28.8	71.7	1.52
	CIImlg 115-165	0.42	«-»	-	24.1	9.3	19.9	14.8	46.8	Not.an

development. In the Kura River floodplain, dry conditions prevail, with average annual precipitation (275–440 mm), potential evaporation between 950 and 1200 mm, and a humidity coefficient of 0.3–0.5. In this region, the groundwater was generally occurring at depths of 1.5–3.0 m, with mineralization (5.0–8.5 g), which could be due to the saline and clay-silty alluvial deposits (Hasanov, 2015; Mammadov *et al.,* 2025). Kovda's (1973) and Sadigov and Mustafayev's (2024) findings revealed that low precipitation and high evaporation rates in subtropical floodplains considerably influenced soil moisture and salinity accumulation. The presented observations gained support from past findings that groundwater mineralization and the arid climate received recognition as key factors controlling soil formation and the distribution of alluvial-meadow soils in the Kura River basin.

The normally developed profile of the said alluvial-meadow soil subtype revealed a well-defined system of genetic horizons, which can have the following representation as:
Auv-Auz-A/Bg-Bg-B/Cg-Cg
or, in carbonate-enriched variants:
Auvca-Auzca-A/Bgca-Bgca-B/Cgca-Cgcas

The analysis of the genetic profile of alluvial-meadow soils showed that these soils possess a clayey-heavy loamy granulometric composition and weakly expressed stratification. In the accumulative humus horizon (AUvz), the physical clay (< 0.01 mm) was 58% ± 4.5%, while the silt fraction (< 0.001 mm) was 21% ± 3.4%. In the lower horizons (Bg–Cg), a gradual textural lightening was visible, with physical clay and silt contents of 39% ± 3.7% and 18% ± 4.6%, respectively. Similar to the zonal soils of the Lankaran lowland formed under humid subtropical conditions, the middle illuvial layer of these alluvial-meadow soils revealed an enhancement in physical clay (77.8%) and silt fraction (39.4%), whereas the upper layers remain relatively lighter (< 0.01 mm = 58.4%; < 0.001 mm = 20.9%) (Table 2). Kovda (1973) and Arinushkina (1961) reported that in alluvial-meadow soils, the accumulation of clay and silt acquired a significant influence from depositional dynamics and local relief. These previous findings further supported the present observations of increased clay content in middle illuvial layers and textural stratification, confirming the viable role of sediment deposition and pedogenic processes in soil profile development.

Alluvial-meadow soils emerged to be highly enriched in humus. In the accumulative turf-sludge horizon (AUv), humus content

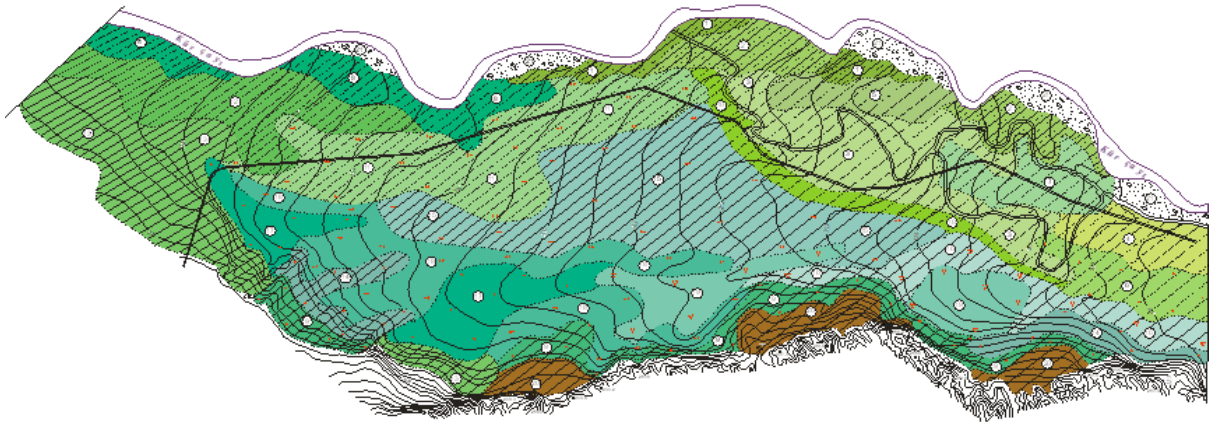

Figure 3. Soil map of Salahli swamp (1:10 000) (Prepared by Prof. Vilayat Hasanov) (Hasanov, 2018)

averages 4.9% ± 0.5% and gradually decreases with depth, even at 80–100 cm (1.0%–1.2%). However, in certain soil sections, the humus content rose to 5.7%. The absence of a buried humus horizon (AUhg) revealed the stable formation of these soils under the flood regime of rivers in the elevated microrelief forms and on young terraces (Amanova *et al*., 2024a,b). Arinushkina (1961) and Kovda (1973) reported that in floodplain soils, the stable humus accumulation displayed a considerable association with elevated microrelief and reduced sediment deposition. These findings further support the latest observations that the highest humus content in AUv reflects the limited flood disturbance and the stable development of alluvial-meadow soils on young terraces (Mehdiyeva *et al.,* 2026).

In the soil profile, the humus reserves further confirmed its highest content, ranging from 78 to 110 t/ha (in the 0–20 cm layer), 135–213 t/ha (in the 0–50 cm), and 216–324 t/ha (in the 0–100 cm depth). In upper horizons, the total nitrogen content ranges from 0.27% to 0.39%, with reserves of 9–17 t/ha (in the 0–50 cm layer). The C:N ratio varies between 8.4 and 11.5, indicating a relatively high nitrogen supply in these soils (Table 2, Figure 3). The genetic profile of marly alluvial-meadow soils showed a distinction from other variants by their extremely high carbonate content (25%–33%). Regional geographical and soil ameliorative studies conducted by V.R. Volobuyev occurred in the Karabakh Plain of the Kur-Araz lowland, particularly within the Tartar River catchment area. According to the said study, the intensive accumulation of carbonates in marly meadow soils had the primary control of highly mineralized hydrocarbonate groundwater near the soil surface (Shukurov *et al.,* 2025; Huseynov *et al.,* 2026a; Sadigov *et al.,* 2026b).

In the studied areas, the results confirmed that groundwater mineralization ranged from 8.9 to 11.6 g. The concentration of carbonate ions (CO_3^{2-}) reaches 0.072 g, bicarbonate ions (HCO_3^-) increased to 1.045 g, while chloride anions vary between 0.25 and 1.83 g. Soils occupy smooth and weakly dissected micro-depositional parts of terrace depressions. The shallow groundwater table (1.0–1.5 m) developed the conditions of excessive and relatively stable moisture supply, which further promoted the intensive development of grass-herb vegetation. As a result, a thick and dense sod layer formation occurred in the soil profile (AUv = 12–15 cm), accompanied by the accumulation of substantial aboveground and root biomass, reaching 39.5 t/ha. Arinushkina's (1961) and Kovda's (1973) findings revealed that shallow groundwater with moderate mineralization fosters the development of dense turf and enhances the above-ground and root biomass in floodplain soils. These past findings supported this study's observations that stable moisture conditions and nutrient availability directly influence the vegetation productivity and sod formation in alluvial-meadow soils.

Consequently, in the upper soil layer (0.5 m), the humus content significantly rose. The said soil layer has a dark gray shade, and when moist, it almost becomes black, a well-developed accumulative horizon (AUvml = 35–40 cm), where humus content varies between 5.9% and 10.4%, and the total nitrogen content reaches 0.31%–0.49%. The C: N ratio was relatively wide, ranging from 9.1 to 12.3. The middle and lower horizons of the soil profile (Bgml-Cgml) displayed bluish-green coloration under moist conditions and whitish-gray tones with ochre-brown and rusty mottles when dry, reflecting pronounced clay formation processes. These horizons exhibited the highest clay content. Under the prolonged excessive moisture conditions, substantial amounts of carbonates ($CaCO_3$ = 25%–33%) entailed incorporation into the soil organic–mineral complex, with the said feature obviously expressed in the soil morphology. Earlier studies by Arinushkina (1961) and Kovda (1973) revealed that bluish-green coloration and mottling in floodplain soils were the diagnostic features of clay illuviation and carbonate accumulation.

The marly alluvial-meadow soils possess a relatively high cation exchange capacity, ranging from 33 to 42 cmol (+)/kg, as characterized by a robust alkaline reaction of the soil solution (pH 8.2–9.3) (Table 2). Marly alluvial-meadow soils were characteristically of a heavy granulometric composition. In the upper soil horizons (AUv + AUz, 35–40 cm), the physical clay reaches 54.2%–63.4%; in the middle illuvial horizon (Bg, 50–80 cm), the said value increases to 70.2%–71.7%, and the silt fraction proportion rises to 28.9%–30.2%. Correspondingly, bulk density exhibited an apparent vertical differentiation: in the humus-accumulative horizon, it ranges from 0.9 to 1.2 g cm^{-3}, whereas in the middle horizons, it increases to 1.5 g/cm (Khalilov *et al*., 2023). The heavy granulometric composition and vertical increases in clay content were the typical signs of floodplain soils undergoing active illuviation (Arinushkina, 1961; Kovda, 1973). Present observations of this study also received support from these past findings on vertical textural differentiation and bulk density variations, highlighting the influence of pedogenic processes on soil structure and mechanical properties in marly alluvial-meadow soils.

The described soil ecological conditions contribute to varying degrees of salinization in marly alluvial meadow soils. The total soluble salt content, expressed as dry residue, fluctuates between 0.35% and 1.58%. The highest concentrations of water-soluble salts were notable in the upper horizons of the soil profile. Salinity has the primary domination of sodium bicarbonate and calcium sulfate salts. This has further evidence with the increased accumulation of gypsum ($CaSO_4 \cdot 2H_2O$), where the content reaches 3.8%–5.8% in the soil profile (Figure 4).

Salahli research area

The Salahli research area, covering around 1588.2 ha, has a location on the right bank of the Kura River valley within the Agstafa Region, with an elevation from 207 to 230 m above sea level. This territory corresponds to the Asaghi-Salahli floodplain depression, commonly referred to as a 'swamp area.' The study area has borders from the high Kura River terraces (25–30 m) dissected by ravines and gullies to the southeast and by the active river channel to the northwest.

From a geomorphological perspective, the said area's characteristics comprise a complex relief structure, subdivided into three main geomorphic units: a) a contact terrace depression, b) a riverbed zone, and c) micro-depressions of the low terrace. Groundwater levels within the terrace depressions range from 0.5 to 1.0 m, and during spring and autumn, they may rise to the soil surface, developing prolonged waterlogging conditions. In these zones, the groundwater relatively exhibited the highest mineralization (5.6 and 9.0 g). However, the mineral composition resulted from mineralized 'black waters' (3.4–5.1 g), emerging as springs from terrace depressions (Sadigov and Macnunlu, 2023).

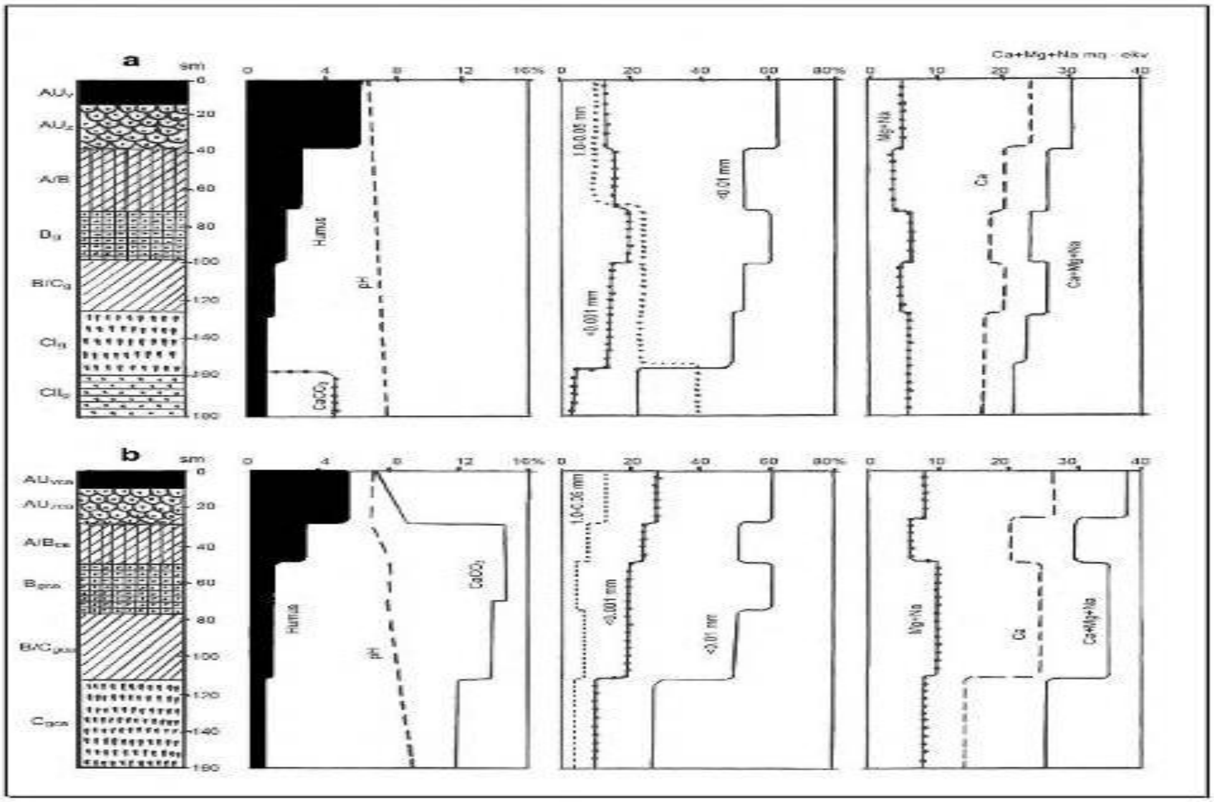

Figure 4. a) Morphogenetic indicators of washed, and b) carbonated alluvial-meadow soil profiles.

Soil-forming parent materials in the terrace depression comprised predominantly of robust carbonated alluvial deposits ($CaCO_3$ content of 15.8%–24.2%) with a silty-clayey texture (< 0.01 mm fraction, 61.8%–86.5%). The vegetation cover was dominantly with meadow-swamp phytocenoses, including reed (*Phragmites* spp.), sedge (*Carex* spp.), rush, broom, and various meadow grasses. Within this geomorphic unit, marlized, saline, sodic, and gleyed swamp soils were widespread, primarily covered by carbonate alluvial-swamp and carbonate alluvial-meadow-swamp soil types (Sadigov *et al.,* 2026a).

In the riverbed zone and low-terrace micro-elevations, groundwater depth fluctuates between 1.5 and 2.5 m, periodically rising to 0.8–1.0 m during spring-autumn floods. Given the infiltration from river waters, in these areas, the groundwater incurred weak mineralization, with total dissolved solids ranging from 0.9 to 2.3 g. Soil-forming materials comprised weakly carbonated alluvial sediments ($CaCO_3$ content of 1.5%–4.9%) with sandy-clayey textures (< 0.01 mm fraction of 4.8%–42.7%) and sandy-gravelly river deposits (Sadigov *et al.,* 2025).

In these zones, the vegetation feature has sparse tugai forests dominated by poplar (*Populus* spp.), elm (*Ulmus* spp.), and willow (*Salix* spp.), accompanied by shrubs, such as hawthorn, blackthorn, tamarisk (*Tamarix* spp.), and blackberry. A well-developed meadow-herbaceous layer was evident in the understory. Under these conditions, carbonate alluvial-meadow-forest and carbonate alluvial-meadow soils have predominantly formed. On the higher terraces of the Kura River, meadow gray-brown (chestnut) soils occurred as isolated patches. An establishment of a stationary observation site (Site 10) surfaced within an area of marly gleyed carbonate alluvial-meadow-swamp soils to conduct detailed regime and morphogenetic studies (Figure 3).

Gadirli research area

The Gadirli research area, encompassing 168.2 ha, sits within the right bank floodplain of the Kura River valley at an elevation of 184–190 m above sea level. The study site lies approximately 9–10 km southeast of the Gadirli Village in the Tovuz Region. The said area exhibited characteristic floodplain relief, including well-defined bedrock and central morphological forms. The plain gently inclined toward the southeast, with a significant dissection of small tributary channels of the Akhmaz type (Sadigov *et al.,* 2024; Ayubov *et al.,* 2025; Sadigov *et al.,* 2026c, 2026d).

In the said area, the groundwater has weak mineralization, with total dissolved solids ranging from 1.6 to 2.1 g. The water table depth varies between 1.5 and 2.3 m, based on the Kura River's hydrological regimes. During the spring and autumn flood seasons, groundwater levels may temporarily rise to 0.8–1.3 m, contributing to periodic soil waterlogging. Soil-forming materials comprised weakly carbonated alluvial deposits ($CaCO_3$ = 1.6%–4.5%) with a layered structure. The sediments were predominantly clayey-silty (< 0.01 mm fraction of 25.6%–50.8%) with a subordinate sandy-riverstone material (< 0.01 mm fraction of 1.6%–9.5%).

Vegetation cover's primary composition was of shrub-liana communities, including *Elaeagnus* spp., blackthorn (*Prunus spinosa*), blackberry (*Rubus* spp.), tamarisk (*Tamarix* spp.), and wild grapes (*Vitis* spp.), as well as tugai forests dominated by poplar (*Populus* spp.), elm (*Ulmus* spp.), willow (*Salix* spp.), and oak (*Quercus* spp.). Open glade areas feature well-developed herbaceous and grass cover (Amanova *et al.,* 2024b; Hajiyeva and Jafarova, 2024). In this area, the soil profiles had qualities of sharp horizon differentiation and the presence of a buried humus layer (AUgh) at depths of 0.8–1.2 m. Carbonate alluvial-meadow-forest and carbonate alluvial-meadow soils had a wide distribution, reflecting the combined effects of fluvial deposition, groundwater influence, and vegetation cover.

CONCLUSIONS

Alluvial-meadow soils represent a highly heterogeneous and dynamic component of soil cover, formed under the combined influence of fluvial sedimentation, groundwater regime, bioclimatic conditions, and vegetation in the northeastern slope of the Lesser Caucasus, Azerbaijan. The Kura River floodplain soils exhibited pronounced spatial and vertical variability, expressed through profile stratification, buried humus horizons, gleying intensity, and carbonate distribution. Differences between humid and dry subtropical zones were reflections from contrasting soil-forming processes, particularly humus accumulation, clay formation, carbonate migration, and salinization. Three diagnostically substantiated subtypes—primitive, layered, and typical alluvial-meadow soils—were identifiable, reflecting varying degrees of profile stability and pedogenic development. Marly alluvial-meadow soils were distinguishable with the highest carbonate content, alkalinity, and groundwater-controlled genesis. The correlation of national soil units with the WRB system confirmed the applicability of international diagnostic criteria, supporting improved soil classification, mapping, and sustainable floodplain land-use strategies.

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