Hydrogeological systems of landslides in central part of the Volga-Ural region

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Abstract. The study of landslide massifs made it possible to identify two types of hydrogeological systems that differ by feeding area structure and transit zone. In landslide bodies of Urzhuminan stage, composed by dolomites and marls, hydrogeological systems are simple stratal. The aquifers are localized in fractured marls, which, under the influence of infiltration water seeping through them, have turned into a poorly structured gruss-rock cover, which lies on dense dolomites - water-resistant. The inclined bedding of dolomite layers creates the prerequisites for directed filtration of groundwater towards natural lowering. Here forming areas of ground water discharge as low-water springs. In landslides composed of the Upper Jurassic series clays and marls, hydrogeological systems are distinguished by the prevailing vertical groundwater infiltration in transit zone. Their’s water source is shallow lakes formed on the surfaces of landslide terraces. Under water pressure influence of in the lake basins and gravity, infiltration groundwaters leaking through the systems of cracks in clays penetrate to a more dense clay layers which are fluid trap. Here, directly under the lake basin, a dome of groundwater is formed. The flow of groundwater from the dome towards inclined depressions leads to creation of unloading areas. They are presented by permanently wet land (flarks) or low-water infiltration springs that come to the surface at the same hypsometric level.

1. Introduction

Assessment of natural slopes stability of the Volga Upland is main tasks when conducting engineering and geological surveys within boundaries of settlements adjacent to right bank of the Kuybyshev reservoir in the Tatarstan territory [1, 2, 3, 4, 5]. The systematic destroyed of coastal edge and landslides observed here over the course of decades have necessitated hydrogeological monitoring of coastal sections of the Volga River. As part of this task, a study of landslide slopes in the areas of most intense manifestation of landslide processes was carried out. The result of research was identification of some peculiar hydrogeological systems developing in landslide massifs that determine stability of landslides to further destruction.

The complex geological structure of right bank of the Volga River territory of Tatarstan, expressed in lateral change of carbonate, carbonate-terrigenous and terrigenous rocks at coastline sections [6], predetermined formation of landslide massifs various forms along right bank of the Kuybyshev reservoir.
In the upper, northern part of right bank of the Volga River, from the side of the Volga River valley, dense, pelitomorphic dolomites of the Kazanian stage are exposed. Due to the dense structure and petrophysical properties, rocks are relatively resistant to external factors exposure. Here, only insignificant collapses of slopes over wave-breaking niches prevail. Landslide processes are poorly developed, mainly on edge of ravines, the mouths of which extend to water edge of the Kuibyshev reservoir. Downstream, dolomites of the Kazanian stage are replaced by less durable dolomite marls of the Urzhumian stage. Clay material presence in rocks leads to lower stability of the edges, resulting in appearance of landslide massifs along coastline. The largest landslides were recorded in areas of the village "Dolgaya polyana" and the Tetyushi city. Near the village “Proley kasha” marls plunge below water edge of the Kuibyshev reservoir. Below, up to the Ulyanovsk region, the coastline is composed of greenish-gray clays with the Middle and Upper Jurassic series sandstones-siltstones interlayers. The presence of potentially aquifers within clay strata creates conditions for slope processes activation. As a result of this, almost entire coast, composed of bed Jurassic sediments, is complicated by extensive landslide massifs [7, 8]. Often, later landslides develop along some landslides. According to previous studies, in all cases, the activation of landslide processes was associated with changes in water regime of groundwater on coastal sections of the Kuibyshev reservoir [9, 10, 11].

Soil genetic features of landslide massif led to development of hydrogeological systems various types in them. A common feature of landslide hydrogeological systems is their lack of hydrodynamic connection with groundwater of bedrock and implementation of a complete hydrogeological cycle of infiltration water within the landslide body. The hydrodynamic separateness of landslide massifs is emphasized by shine rupture and wetweather rills in their rear part, reaching the Volga River abrasion terrace, which is a landslide bed. The absence of a relationship between landslide bodies and bedrock, presence of sections with different filtration properties soils, and relatively large water drainage area of terraces contributed to development of some water systems in landslides. Within each water system, localized within the boundaries of structurally isolated landslide body, one can distinguish: distribution area of groundwater, their catchment area, discharge area, and piezometric surface of aquifers. Below, we consider hydrogeological systems formed in landslides composed of carbonate-clay rocks of the Urzhumian stage and clay rocks of the Jurassic system.

2. Results and Discussion

Among the landslide bodies composed of Urzhumian stage rocks is landslide near the pier of Tetyushi turned out to be the most accessible for hydrogeological studies. Its descent occurred in the spring of 2012. By the mechanism of rock displacement, the landslide refers to shear slide, consequent subtype. The slope was moved as a result of the penetration of melt snow water into deep tension cracks, previously formed in several tens of meters along the edge of a steep cliff of the right bank of the Volga River. Due to the water saturation of dolomite marls, a large landslide block was moved along slip plane on contact with bedrocks. As a result, a landslide body about 500 m long, 60 m wide and 80 m high was formed. The displacement of the block did not lead to significant deformations composing its rocks of the Urzhumian stage. The order of light gray layers of dense pelitomorphic dolomites and red-brown marls interlayering in the landslide body completely corresponded to their analogues in the bedrock. Over the following years, due to the processes of wave abrasion and erosion of block sole, the landslide body changed its position. As a result of this, the horizontal bedding of rocks it changed to inclined. Seasonal rainfall and melt snow water, in turn, contributed to destruction of integrity of marl layers in the roof of the displaced block, turning them into an unstructured clay-gruss-rock eluvium. During the period of the landslide's existence, was its complete separation from the root slope by wide rain rill; due to denudation. The surface acquired a hilly relief with clearly expressed depressions to the periphery. An exception was front part of the landslide facing the Volga River. Due to the constant destruction by waves, it currently represents a steep slope with a height of 4.5 m in middle part and 1.0-1.5 m at edges.
In outcrops of slope it is seen that the landslide massif is separated into two parts (figure 1). The lower part is composed of unchanged, dense red-brown marls and light gray dolomites, forming weakly inclined, monoclinic layers with a fall to the southern edge of the landslide at an angle of 5-8°. The upper part is represented by a loose, integumentary eluvium, consisting of clay with inclusions of rotten stone consisting of marl and dolomite. Eluvial deposits formed from the destroyed rocks of the Urzhumian stage, which was move in the zone of intensive infiltration of precipitation. The sole for eluvium serves dense, impermeable layer of pelitomorphic dolomites. Obviously, the presence of this dolomite layer prevented destruction of underlying bedrock, creating the prerequisites for development of a local water system.

![Figure 1. A schematic section of landslide massif near the Tetyushi town, in which hydrogeological system is developing: 1 – eluvial clay; 2 – eluvial detritus rubbish and rotted rock of marls and dolomites; 3 – marl; 4 – dolomite; 5 – groundwater level; 6 – water saturated rocks.](image)

The hydrogeological system developed in the landslide massif is of a simple type. In it there is only one aquifer sustained in area, representing in hydrodynamic terms a single whole. The aquifers are disintegrated gruss-gravely dolomite marls and dolomites that lie in subface of stratum of integumentary eluvium. The thickness of the aquifer is inconsistent, according to manual drilling, it is from 0.3 to 1.0 m, from subface of stratum it is limited by dolomite waterproof rocks, from edges by compacted clays of eluvial cover without inclusions of gruss. The upper boundary is free surface of groundwater, the position of which depends on season of the year and climatic factors. The waters here are stratal, infiltration by origin, hydrocarbon-calcium type by chemical composition, with total salinity of 552 mg/l, medium hardness 6.8 mg * equiv/l. Their pH = 7.71, temperature 7.5-8.0°. Groundwater catchment area coincides with their distribution area. Discharge is carried out in the southern slope of the landslide massif, where dense dolomites of obliquely lying waterproof rocks, come to the surface from under the eluvial cover. Moving on an inclined surface under the action of gravity, groundwater comes out from under the soil in the form of a descending spring with a flow rate of 0.3 l/s. Despite the relatively small size of hydrogeological system, the spring functions for most of the year, freezing only during winter periods, when ice formed on the Volga River.

In the north-west of the Tatarstan and the Ulyanovsk region, the right bank of the Volga River is composed of clay-ttigenous deposits of the Middle and Upper Jurassic series with a thickness of up to 45.0 m. In sections, greenish-gray and black clays with interlayers of sandstones, siltstones and oil-shales prevail everywhere [12, 13]. A low degree of rock resistance to wave abrasion leads to the
development of landslide processes along steep slopes. Often, on the early large-block landslides, activation of new, smaller landslides is observed. As a result of this, on segment of the right bank of the Kuibyshev Reservoir, where Jurassic deposits occur, the slopes are heavily terraced by landslide bodies of different ages.

Field studies of coastal slopes showed that landslides are activated not only under influence of abrasion, but also with the participation of local hydrogeological systems which formed within the landslide bodies. Moreover, the landslide blocks themselves act as peculiar hydrogeological structures. It should be noted that the prevailing lithological type of rocks in the Middle and Upper Jurassic series sedimentary complexes does not contribute to the formation of aquifers in them. Clay strata under conditions of natural occurrence hinder the downward filtration of precipitation into the landslide massifs. Therefore, most of rain and melt snow water flows from surface of terraces into the Kuibyshev reservoir as a surface runoff. A smaller part of atmospheric precipitation is absorbed into clay soils, increasing their natural humidity. The thickness of the impregnation zone is relatively small (up to 0.5 m). In addition, it does not exist for more than two months. Due to the evaporation of moisture from the near-surface of landslide terraces, the moisture content of the surface clay strata gradually decreases. Such hydrogeological conditions have little effect on changes in physicomechanical properties of clay soils composing landslides. Only in the near-surface part of the terraces does some clay structure changes occur with their periodic transition to a visco-plastic state.

An exception is landslide slopes composed of highly fractured clays. As a rule, these are rocks composing the upper parts of steep slopes sections. During the Quaternary glaciation, although territory of the Ulyanovsk and the Tatarstan lay beyond the edge of the glaciers, the Mesozoic deposits underwent periodic freezing and thawing [14]. As a result of this, frost cracks formed in clay strata close to the surface of the Earth. Their presence is well recorded in outcrops by yellowish earthy masses of jarosite, which performing cavities of faulting in the hypergenesis zone [15]. In some parts, the density of cracks reaches 25-40 pieces per square meter. Here, the clay stratum is actually fractured by cross exogenic fissures to large polygonal bocks, along the walls of which infiltration waters ooze.

During the destruction of rocks of the main bedrock and they displacement, fractured clays compose the upper terraces of landslide massifs. As a result of this, the largest blocks adjacent to rear seam of the landslide in the upper part have relatively good drainage properties. This feature of clay rocks served as the basis for the formation of local hydrogeological systems in them with an infiltration type of supply. The most well-similar systems were studied in sections at the Tarhanovskaya pier in the western part of the Tatarstan and at the settlement Gorodishche in the eastern part of the Ulyanovsk region.

Both of these systems are localized within one upper block of landslide bodies. The approximate length of monolithic blocks terraces is 80-90 m, the width is 20-35 m. Terraces adjoin rear seams of the landslide; their edges rise above the lower terrace, forming steep ledges 5-7 m high, facing the Kuibyshev reservoir. The upper landslide blocks are separated from slope and from smaller lower blocks by rupture cracks, which are currently fully colmatage by clay mass without any structure. There are no hydrodynamic connections between blocks of landslide massifs and adjacent to them bedrocks slopes. This is indicated on the one hand by dry rocks of slopes and lower-bedding blocks, and on the other, by groundwater outcrops observed only in the lower part of the upper block bench. That is, local aquifers are spatially associated only to individual landslide morphostructural elements isolated from the surrounding geological environment.

The study of aquifers showed presence catchment areas in each of them, accumulation and discharge, not exceeding the boundaries of the upper blocks of landslides, which are a kind of hydrogeological structures (figure 2). Water recharge areas are located in lower part of terrace. They are small, relatively isometric in outline lakes with a diameter of up to 5.0-10.0 m. Their depth, after snow and heavy rainfall,
is 0.6 m. In the dry period, the height of water column does not exceed 0.3 m. The bottom is silty, muddy, capable of suction water to a depth of 1.2 m. Below the flooded clay mass are denser structured clay rocks. Water-saturated silt sediment serves as a waterproof layer, preventing intensive filtration of water from lake basins through underlying fractured clay rocks. Basins are characterized by atmospheric type of supply. Falling rainwater flows into pot hole, periodically replenishing them with water supplies. Part of the water goes to evaporation from mirror of lakes, part - to supply of underground runoff. From the bottom of lakes there is a constant downward filtration of water under the influence of gravitational forces and the pressure of the water column of closed reservoirs on underlying rocks. As a result of this, under the bottom of the lake basins in the fractured clay soils, inverse pumping depression of the ingress of infiltration water are formed, expanding to down. The funnels base is dense waterproof clay layers, not affected by exogenous fractured processes. Having reached waterproof rocks, infiltration waters change the direction of movement from vertical to lateral. Gradually, spreading in a horizontal plane, groundwater forms aquifers up to 1.0 m thick. The slight slope of landslide blocks in direction of the Kuibyshev reservoir created prerequisites for the predominant movement of stratalfissured waters in this direction. As a result of such migration, discharge zones in form of descending marginal producer springs were formed in the lower parts of the upper landslide terraces ledges. In the places of groundwater outcrops to the surface at the base of ledges, mud avalanche arise. Over time, this phenomenon causes a loss of static stability of the slopes and immediately flowing the liquefied soil to down. Thus, the relief of landslide massifs is gradually smoothing.

![Figure 2](image-url)

**Figure 2.** A schematic section of landslide massif near the Gorodishe village of the Ulyanovsk region, in which hydrogeological system is developing: 1 – clay; 2 – marl; 3 – water-saturated rocks.

It should be said that such hydrogeological systems are not durable. Over time, fractured filtration channels become clogged with very fine clay particles, which reduce their throughput. There is a migration of water, bypassing the already colmatation areas with the formation new outlets of groundwater. In dry periods, the springs completely dry out, because their low water supply areas are not able to provide a constant flow of moisture into the aquifers of landslide blocks.

A study of the groundwater composition of landslide hydrogeological systems showed that all of them belong to hydrocarbonate-sulfate calcium-magnesium type. By total mineralization water is fresh 0.3-0.4 g/l, with pH = 6.6-6.8. The temperature is relatively small ~ 7.3°C. Such a hydrochemical type of
groundwater is caused, on the one hand, by atmospheric precipitation, where hydrocarbon-ion predominates, and on the other, by clay rocks mineral composition. Sulfate-ions enter the solution as a result of pyrite oxidation and gypsum dissolution. Ca$^{2+}$ cations are products of gypsum and calcite dissolution, Mg$^{2+}$ ions enter groundwater mainly due to ion-exchange reactions in the clay-water system. Judging by the presence of red-brown earthy masses near dried springs, the underground waters of landslide blocks are enriched with migration-capable iron compounds. As follows from the infiltration waters composition, in local hydrogeological systems development areas, the processes of clay mineral skeleton dissolution with the removal of ions part from the landslide massif are very active. Obviously, over time this will contribute to weakening of structural bonds between the mineral grains of clay rocks, the activation of suffusion processes and the reduction of static stability of landslide terraces slopes and bench.

3. Conclusions

Given the above, the following conclusions can be drawn:

1. The presence of fractured clays in the upper terraces of landslide massifs composed of Mesozoic terrigenous-clay sedimentary rocks of the territory of the Tatarstan Republic and the Ulyanovsk region, can serve as a place for the formation of local hydrogeological systems.

2. Hydrogeological systems in landslide terraces are characterized by the presence of water supply, accumulation and discharge areas concentrated within the boundaries of the upper landslide blocks, which are hydrogeological structures.

3. According to water supply type hydrogeological systems of landslide are infiltration. On the conditions of aquifer occurrence of and nature of the water-saturated rocks, groundwater is classified as non-artesian water, fractured-stratal water with a free piezometric surface. The hydrochemical type of water is hydrocarbonate-sulfate calcium-magnesium, by total mineralization - fresh.

4. Landslide hydrogeological systems are active participants in the destruction of landslide massifs. The filtration deformations of terraces benches, the clay minerals dissolution and the activation of suffusion are associated with them. As a result of this, the static stability of landslide blocks decreases, which is expressed in smoothing of the boundaries between the morphostructural elements of landslide massifs.

Acknowledgments

This study was performed in the context of the Russian Government Program of Competitive Growth of Kazan Federal University.

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