Evolutive interpretation of the landslides from the Miron Căproiu Street Scarp (Eternităţii Street – V. Alecsandri Street) – Breaza Town

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Cuvinte cheie: oraşul Breaza, versantul terasei II, alunecări, modelul digital al altitudinilor, monitorizare, modele evolutive

Key words: Breaza town, II-nd terrace scarp, landslide, elevation model, monitoring, evolution patterns

Landslides are amongst the most damaging natural hazards in the Subcarpathian Prahova Valley, especially in the context of a higher increase of the dwellers' number after 1990. The great variety of landslide types mirrors the diversity of local conditions and the particular combination of factors that render the slopes unstable.

The landslides of the Breaza scarp belong to the period of occasional reactivations, with periods of relative stability, marked by creep processes on the active escarpments and appearance of cross cracks parallel to the scarps or within the mass slide.

Mass movements have various forms and dimensions, less profound landslides being the most frequent; they are recent or reactivated in the body or lateral scarps of the masses that were previously moved.

In this paper we systematized the results of field investigations spread over five years. Field mapping and computer-based analysis using the location of landslides, as well as morphographic aspects, geology, soil, forest and land-use databases allowed us to identify some evolutionary patterns.

The topographical survey of the landslide named Miron Căproiu – A1 was accomplished with a Leica TC 805 Total Station, at a scale of 1:5000, in 2003, and with a Total Station, model SOKKIA SET610, in 2005. The surface was not covered with a rectangular grid, but with profiles traced along thalwegs and micro-depressions. On an area of 29,521 sq. meters, with a length of the sliding mass of 369 meters, over 6,000 points were determined.

1. Introduction

Field surveys executed during the last five years along the Prahova Valley scarp of Breaza locality permitted the mapping of several landslide categories. These landslides are characteristic for a 7–15° dip of the scarp, occurring in the proximity of built-in areas and leading to a wavy aspect of the landscape. Several stages of the landslide development were documented:

- Development of fissures, cracks, sometimes filled with freatic water, before the mass rupture in the rock;
- Appearance of break and falling/sliding of the material until reaches a final equilibrium state;
- Occasional reactivations of the major breaking surface and/or minor surfaces within the slided rock mass, with seasonal variation.

The studied landslides, called here the „*Miron Căproiu Street landslides*” (between the Eternităţii Street, at the cemetery and the Morii Street), had completely destroyed six houses placed on the margin and edge of the terrace, while numerous rudimentary repairs were undertaken at the other houses of the area (these houses, all 50-70 years old, are considered light buildings, without foundation, with a wooden structure covered by clay). Shallow to medium deep landslides, both new and reactivated, dominate in this area. Reactivations are located in the lateral crevices of the older landslides. Some of the landslides are naturally stabilized, especially through the gardens located as an extension of the built-in area; naturally grown grasslands or planted orchards occupy the wavy landslide surfaces, leading to a popular perception that landslides do not represent a natural hazard.

The raise of interest for real state developments in this urban area after 1990 was not accompanied by corresponding access route systematization. Thus, for example in M. Căproiu Street problems related to the traffic intensity and load, as well as those related to water drainage (including household waste water) were completely overlooked.

After 1990–1992 new building constructions took place — large scale weekend houses with one or two floors and the ground floor partially dug into the substrate. These „cuts” into the slope, as well as digs executed to construct foundations and lay underground cables and pipes – represent probably the immediate anthropic cause that led to the landslides of 1997, ad after them to those from the fall of 2005.

The field studies carried out during a period of five years along an extended sector of the Prahova Valley, allowed understanding the wide picture of the landslide processes, as well as the identification and description of the local lithological and structural setting. The studies included direct field observation and geological, geomorphological and pedogeographical mapping, shallow excavations, trenches and boreholes; over 50 samples for geotechnical analyses were collected. The Miron Căproiu Street – Eternităţii Street landslides was periodically mapped with total station (between 2003 and 2005) and the development of the landslide monitories through witness marks.

2. The M. Căproiu Street landslides (between the Eternităţii and V. Alecsandri Streets)

2.1. Local lithological features

Downstream from the confluence between the Prahova and Belia valleys, the outcropping deposits belong to the post-tectonic cover (fig. 1). From Breaza de Sus – Plaiu Cornului towards the Doftana valley there is the *Breaza – Buciumeni syncline*, with a west – to – east orientation; it has the greatest development and the deepest descent in this direction. This syncline has equally developed flanks and is axially faulted. The southern compartment of the structure s uplifted along the Breaza fault. The axis of the syncline passes through the center of the town and continues in the left bank of the river to Frăsinet; from here, it is translated towards south along some transverse faults, until it reaches a position south of Lunca Mare, in the Doftana valley.

In the flanks of the Breaza – Buciumeni syncline (and leading to a prominent landscape especially in its southern flank) Lower Miocene deposits are present.

Centimeter to decimeter thick, bedded sedimentary formations build up the landslide area. These are represented by marls, mudstones, compacted sands and gipsiferous marls. The sands are extremely permeable, with a consistency index similar to *hard rocks*. The characteristic fingerprint is represented by a mudstone at the „very active” boundary. The mudstones are „contractile mudstones”. The geotechnical features suggest the presence of clay minerals capable of expansion — *illite* and *montmorillonite* — that increase their size when in contact with water. When wetted, their shearing resistance drops severely and this rock type represents the sliding surface along which the landslides are initiated. At least at two different levels gypsum occurs as 0,80–1,20 m thick beds or decimeter – to – meter thick blocks. The gypsum beds formlines of relief that supports and guides the slided rock mass.

The gypsum ($CaSO_4 2H_2O$), a soft rock made up of only one type of mineral, decomposes in the presence of water. This process develops at a gradually increasing pace and results in a soft, highly plastic, saturated bed with essentially no shearing resistance. The deposits overlying these gypsum beds slide gravitationally, even at low dips (Legget and Hatheway, 1988). The gypsum beds overlay a succession starting with decimeter thick medium to fine grained sandstones with carbonate or gypsum cement and chaotically arranged gypsum or anhydrite-filled fissures. These are followed by centimeter-thick grey-blue marls with shaly sandy marl intercalations. The dissolution process is promoted by the infiltrated rainwater, either drained along the street drainage network or redirected by *anthropic constructions: foundations, wells, septic fosses, canals* etc. When the critical value of stability is reached, the in-mass slide of meter-thick successions is initiated, involving also the levels whose stability was lowered by gypsum dissolution; this phenomenon was documented following the rainy season of September 2005.

In the edge of the Breaza terrace, tuffs were identified at the middle of the escarpment, under the house nr. 66, within an outcrop developing into a new landslide. The upper part of this slide (monitored along 3 years) is obviously advancing.

The field studies show that the landslides are generally medium deep, affecting the soil and only the superficial level of the underlying rocks; they have a thickness of 1,5–2 m, rarely exceeding 3–5 m. The landslides are consequences of rainwater infiltration through the terrace sediments down to the described lithological levels; this causality is perceived correctly by the local population, as shown by the polls (see Armaş et al., 2003). Rainwater infiltrates through the gravel beds and re-appears in the side of the terrace as springs. Due to them landslides develop at the edge of the terrace, continuously undermining it (as seen in the case of nr. 66 Miron Căproiu Street).

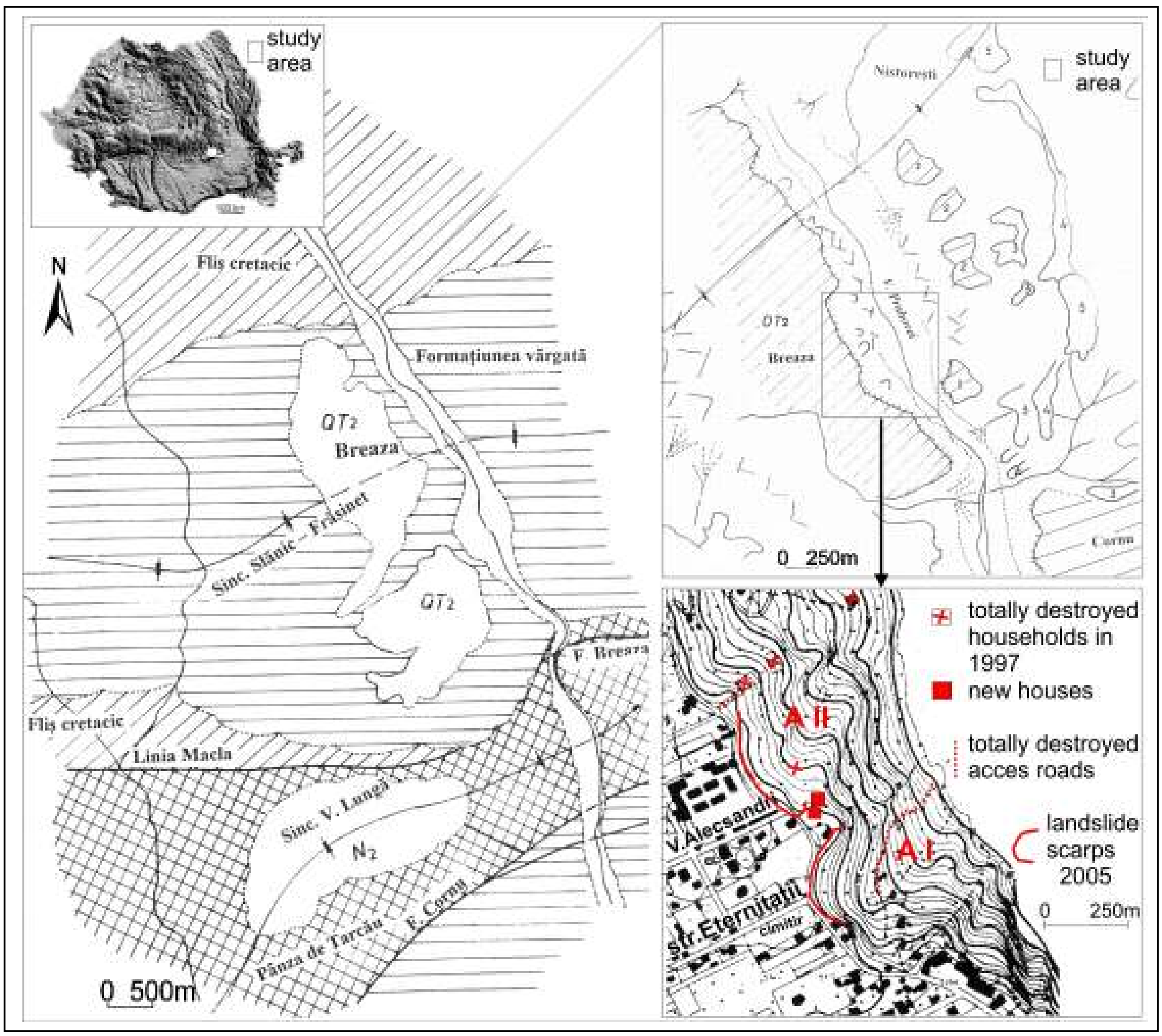

Fig. 1 **Geological and geomorphological background**

2.2. Geomorphological and instability features of the Miron Căproiu – A1 landslide

The steep slopes of terrace II (in the Miron Căproiu – A1 area) is shaped by a complex series of adventive, active landslides, centered on the main landslide (photo 1). The slope is fragmented by amphitheatre-shaped slide crevices, 10–15 m high. The slided material forms forested waves, covered by willow. Reactivations and slow movements appear especially in rainy years, affecting the street network. In the slope up to 5 m high secondary breaking crevices appeared, with a regressive development. As a consequence, the width of the street is reduced, locally to less than 2 m. In certain sectors, flowing slides or even mudflows also occur.

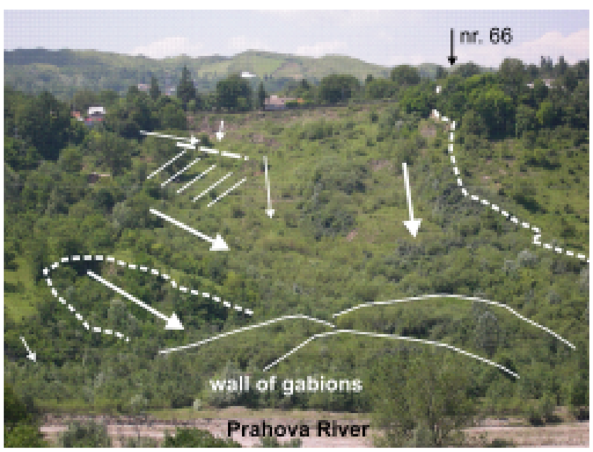

Photo 1 **The A1 landslide in July 2005, seen from the left bank of the Prahova** (arrows show the main directions of movement, cross-hatching represents the T1 surface, continuous lines mark the contour of the main slide waves from the slope base)

The morpho-dynamical analysis shows a continuous retreat of the breaking crevices during the study period, especially in the central area, along the motorway. This process is countered by filling and consolidation of the motorway. The filling material breaks down in a ladder-like pattern, especially during the rainy seasons, when the surface drainage along the Eternităţii Street is accompanied by a subterranean drainage (suffusion type). The drainage is following the axis of the route. The gravitational process starts as falls, developing into rotational slides.

The slided rock mass overstepped the structural ledge (shown as interrupted line in the photo) during the spring-summer of 2005, oriented by the gypsum levels. In the ledge a secondary breaking crevice developed.

The steps made up of the slided filling material falling periodically from the central breaking crevice accumulate at the base of the slope, being renewed during the rainy seasons. In the upper half of the landslide, the material moves along a direction controlled by the gypsum levels, then is reoriented to the Prahova Valley; there is a relative stopping period on terrace, at 30 m relative altitude. Field observations during the study period showed a removal of the material from the slide waves of the breaking crevice through drainage on the structural surface. A central, very active drainage alignment is obvious, being continuously supplied from the breaking crevice. The secondary landslide below house nr. 66 is less active.

In the body of the main landslide there is a drainage that presents opportunities for stabilization and regularization, placed in the southern extremity. This drainage presently supplies ponds and small swamps, having numerous course changes especially due to fact that the area is a grazing land.

The analysis of the spatial and morphological features, as well as that of the flow directions and the stability of the slided masses, led to the identification of several genetical, morphological and morpho-dinamic models of the landslide. At the edge of the terrace, on the Miron Căproiu Street intersection with the Eternităţii Street, the studied landslide can be included in the model ***M-A1*** separated by the authors (Miron Căproiu – A1 landslide; fig. 1 and 2, see also Armaş et al., 2003).

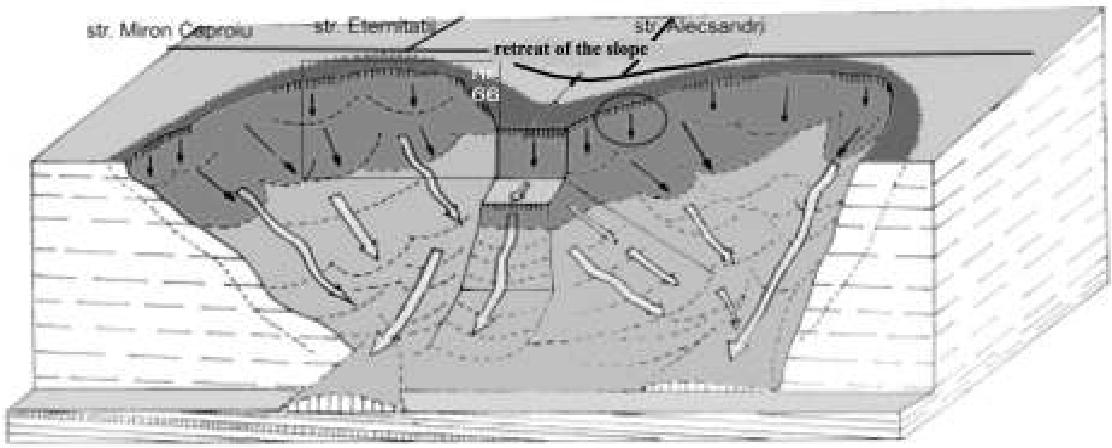

Fig. 2 **Model of evacuation of the deluvial mass, M-A1, as specific to the syncline flank**

A2 landslide, September 2005, from the cooperation

The A1 landslide and the secondary landslide from nr. 66 M. Căproiu Street

Examples of this type of landslide occur, at a smaller scale, on the southern edge of the syncline and, somewhat larger, in the axial part. These led to the „opening" of „small bays" in the slope, with a uniform frontline. The landslide is made on the bed surfaces and probably interferes with „moments" of fall from the edge of the undermined terrace or even from intermediate steps. Through area extension, the break crevices might fuse, leading to the development of embayment's that cut deeply in terrace II.

2.3. The M. Căproiu – V. Alecsandri streets landslide (in front of the cooperation), Miron Căproiu – A2 landslide

The evolution of the slope and development of the landslide during September 2005 was conformable to that proposed in the model developed (Armaş et al., 2003). Following heavy rains, a sudden collapse involving filling material occurred, leading to the destruction of the motorway, fall-out of an electric pole, destruction of a well and unearthing water pipes and electrical cables (photo 2).

This landslide is deep, and was initially directed, in the shape of partially stabilized waves. The presence of active lateral crevices led soon to the development of a rotational landslide, controlled by the bedding plane, towards the fold axis.

The slided surface overlays an area with interbedded sandstones, shales and marls, covered by gravely-sandy terrace deposits.

The presence of steps and grooves, oriented transversally, was noted – these represent natural crevices and small valleys, existing before the development of the present motorway. This suggest that during the development (widening) of the motorway, several crests were cut, unearthing the rocky underground, while small valleys and depressions were filled in. As a result, the motorway is underlaid by a feebly compactized, high permeability infrastructure.

The vulnerability of this area is augmented by the lack of drainage systems to collect rainwater as well as surface waters flowing along the street (that is slightly dipping from the direction of the city center).

During warm, arid time periods, the eastern exposure of the slope lead to increasing dryness of the sliding surfaces and apparent stability; this is however, reversed during rainy periods. It is during these moments (showed statistically as being *perceived as such by the local inhabitants*) that the landslides initiate, controlled also by geological factors (dip of the strata, the particular syncline structure, attendances of permeable and impermeable beds.

The wetting of the sandy beds, due to rainwater, reaches the level of the sand-mudstone boundaries. The amount of the supplied water is increased by the free-flowing groundwater from under the terrace gravels, by the household waste waters (due to defectuous waste water management). This process is continuous and represents the main and constant element of instability. As soon as the critical level is reached, the wetted rock mass is set in motion, through decollment and sliding of the rocks along the bedding planes, in a north-eastern direction.

Photo 2 **The landslide at the margin of the Alecsandri Street** (September 2005); **the paths of the pipes and electric cables that led to slope instability; in the right side, the cobbles of a well felt into the breaking crevice**

The lithology, geological setting and field observations made the second day after the initialization of the September 2005 landslide (small, wet breaking crevices, sliding slopes, free-flowing water) suggest the presence of a process that threatens the stability of the foundation for an electric pole and transform station from the side of the road.

Moreover, the position of this electric pole is further weakened by local instability factors due to constructions: almost horizontal leveling – without possibility of water discharge and covering with concrete of the courtyards, construction of transverse support walls; all these led to the build-up of a system that stories water under pressure (nr. 68 M. Căproiu Street). This water is partly discharging towards north (the plea of the landslide). The presence and fluctuations of this water volume are demonstrated by the existence of a spring within the courtyard of nr. 68 M. Căproiu Street (shown by arrow in photo 2). The excess water storage leads to instability of the area extending to the the Miron Căproiu Street. The landslide is very active and develops regressively within the terrace. Up to the fall of 2006, no security measures were taken to protect the area, except for a sidewalk fence.

The landslide started with a fall of the material from the edge of the terrace and its reorganization at the base, pushing and covering material resulting from a previous fall. Within the body of the fall, there is a previously destroyed building; the pushing effect of the fall affected (through rotation and rolling over) the remnants of this building.

The „widely open embayment” contour, representing a level of relative equilibrium, is currently being remodeled by a new contour “invasion”. It is probable that this new, minor arc-shaped structure will continue its northward development. Some fissures evident in the motorway are already suggesting this trend (see fig. 3).

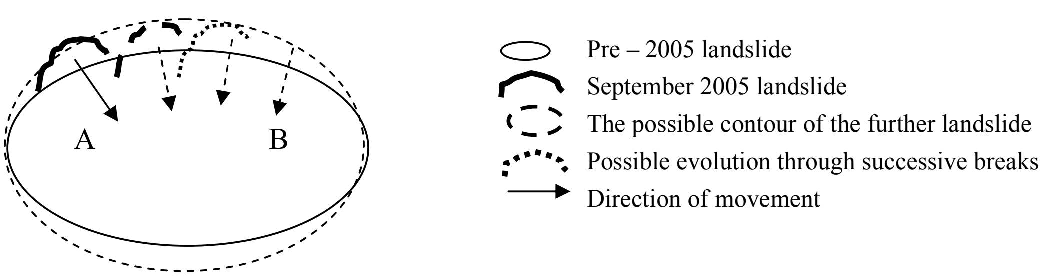

Fig. 3 **Probable evolution for the September 2005 landslide**

From A to B (fig. 3), the arrow A shows the direction of the already started slide towards the distal part of the *breaking crevice arc, practically aligned with the axis of the road*.

In the present, the landslide developed locally superimposed sectors, with steps and waves of different generations. It will be supplied at its upper part by continuous processes of creep and fall from the retreating terasse edge, which is currently open and steep. A major impact is that of the suffusion process, the water discharging from under the terrace gravels as springs, with increased water supply during rainy seasons. *In the possibility of the presence of some gypsum levels suggests that these will reorient the sliding mass as soon as they will be reached* (similarly to the case of landslide A1).

The movement of the material is done along the steepest dip of the slope. Direction changes occur on bed surfaces, and the slided body shows several stacked waves, with increased thickness towards the base of the slope. The speed of the landslide was initially high, due to the lithology and the occurrence of heavy rains, leading to increased fluidity. During the 23–25.09.2005 time period, the amount of fallen rainwater, measured at the Prahova S. H., totaled at 39,5 mm (out of which 20,1 mm during the 23rd of September). At the Câmpina station, 24,2 mm water column was measured on the 24th of September. Due to this rainfall values, the flood along the Prahova Valley reached peak values of 53,8 m^3/s on 24.09.2005, 18.00 hours, and 55,9 m^3/s on 25.09.2005, 12.00 hours (Prahova S.H., Poiana Ţapului).

The drainage of the water that accumulates in the terrace material, as well as that originating from peripherical infiltration along the edges of the exposed beds is converging towards the central, axial part of the syncline. The landslide started as a fall in the morning of 25th September. The direction of the slide was (and continues to be) controlled by a slight eastward dip of the syncline; since the dip angle is slightly less than that of the topographical surface, water outsource and pounding occur within the body of the slided material.

3. Conclusions

In the present, the chances of natural stabilization of the slope are small. The continuous expansion of the built-in areas leads to the development of high-vulnerability sectors; these, although restricted in surface, represent major local risk factors.

The major vulnerability to mass transport are present in the case of deep, flowing or waved landslides, showing recent instability, as well as those being active under wooded areas, or those representing breaking surfaces developed upon older landslide bodies in pasture areas.

The exploitation of the Miron Căproiu Street is developing in a wrong manner and without restrictions, regardless its constructive quality and setting. It represents a non-standardized road from dimensional point of view, without infrastructure, without lateral or transverse (at the intersection with perpendicular streets descending from the city centre) drainage system and periodical traffic with heavily loaded trucks.

The road is intimately influenced by a series of old-fashioned active wells (with a diameter of about 1,20/0,80 m), some not used as water supply, with a fluctuating, active hydrostatic level (the water level, as measured in June, is less than 2 meters from the surface, at a water depth of 2,55 m).

Recently, along the road – within the range of the access road – several interventions took place: digs for foundations of electric poles of different dimensions, installation of water pipes and electric cables, and probably also for other reasons as well.

The road itself, as morphological surface, represents a local base for water infiltration and drainage; the material and mode of building makes it a drainage way for water from under the terrace gravels. All these contribute to the development of landslides in the upper part of the slope. In the lower half of the slope, the material presents locally a higher fluidity, leading to the development of large fans into the Prahova floodplain. Several geotechnical works within the floodplain, built to protect the motorway, railway or pipelines, permit the development of pounded areas with in-excess humidity.

The building activities and extension of the anthropically modified surface within the area led to further effects that promote landslide formation. These effects include affecting the natural stability of the area, especially through in-excess introduction of water in the underground. This is done through water works for household supply constructed in an unprotected and uncontrolled manner; the lack of monitoring in the waste water disposal, through drainage systems either not constructed to meet the current needs or constructed for other reasons, in many cases used, flawed and with many shortcomings. Moreover, since household water is mostly supplied by wells, building of a large number of new houses led to several new wells perforating in an unplanned manner the groundwater table. These effects are supplemented by the significant water losses from the „industrial systems".

In the meanwhile, the lack of an adequate canal network for water supply and disposal in this part of the city, on the edge of the Prahova terrace, in concurrence with the aim of assuring comfortable living conditions, led to compromises that affect adversely both the traditional local community and the environment.

As a general conclusion, we underline that the studied sector is highly instable and vulnerable; any kind of anthropic activity, not taking into account the local conditions, will only led to further degradation of the local conditions.

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