

Geological and hydrogeological characterization of the landfill areas located around Bucharest city in the context of environmental management

Alexandru Balint^{1*}

¹University of Bucharest, Doctoral School of Geology, 6 Traian Vuia, Bucharest, Romania

Abstract. The process of risk assessment and investigation of potentially contaminated soil and groundwater is highly dependent on a proper understanding of the geological and hydrogeological conditions of the investigated site. The current paper aims at identifying the general geological and hydrogeological conditions of the landfill areas around Bucharest city based on interpretations of the data available in research articles, books, public reports, and geological and hydrogeological maps. Several soil samples were collected, and laboratory analyses were conducted to validate the initial expectations in terms of physical properties of the underlying strata. Results were presented as cross-sections and piezometric maps suitable for developing tridimensional models, conceptual site models and contaminant fate and transport modeling with sufficient accuracy for environmental urban planning. The research provides a quick method which may be used when assessing the general geological and hydrogeological conditions of various sites in environmental studies. The vulnerability of the Romanian legislation in data management and decision-making was also highlighted, therefore a series of recommendations to improve the data availability and quality were provided.

1 Introduction

The Romanian regulation dealing with the investigation of contaminated sites is the Ministry Order no. 1423/3687/2020 approving the Methodology for the investigation of potentially contaminated and contaminated sites, approved by the Ministry of Environment, Waters and Forests and the Ministry of Public Works, Development and Administration. All sites are classified initially as potentially contaminated sites based on a list of activities included in Annex no. 1 of the methodology. The list does not include landfilling sites which are widely seen as activities controlled by other specific regulations.

* Corresponding author: joan.alexandru.balint@drd.unibuc.ro

Prior to conducting any public risk or exposure assessment, a desk review to understand the local geology and hydrogeology is mandatory for planning purposes and for developing the initial conceptual site model. In the current article, the author attempted to describe the general geology and hydrogeology based on available Romanian documents developed by public authorities and research institutes, highlighting the key points and drawbacks for three landfilling sites located near Bucharest city.

2 General information

2.1 Bucharest location

Bucharest is located in the southeast part of Romania, in the Wallachian Plain. Bucharest sits on three plains as follows [1]: Otopeni Plain located north of the Colentina river, Colentina Plain in the centre of Bucharest between Dambovită river in south and Colentina river in north and Cotroceni Plain in the south, between Dambovită river in north and Sabar river in south.

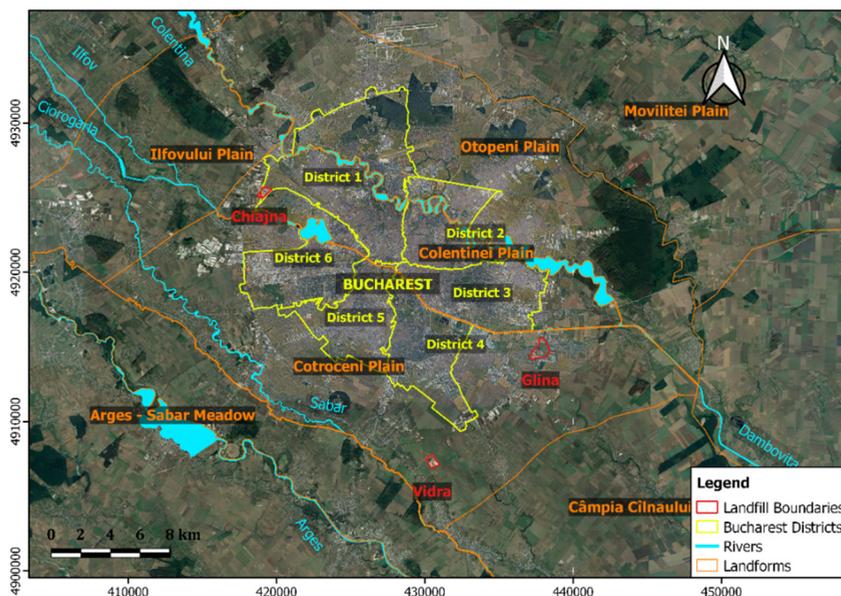


Fig. 1. Aerial view of Bucharest city, landforms, main rivers and the three operational landfills.

From a hydrological standpoint, Bucharest is located in the drainage basin Argeș-Vedea. The main rivers crossing Bucharest city are Dambovită and its tributary, Colentina. Dambovită river crosses the centre of Bucharest city with a NW to SE flow direction, while Colentina crosses the northern part of Bucharest, also with a NW to SE flow direction. The confluence of the two rivers is located in the eastern part of Bucharest city, at approximately 5 km east of the Glina landfill. Dambovită is a tributary of Argeș river, which is the most important river in the drainage basin. Argeș river flows on a NW to SE direction, at approximately 9 km Southwest of Bucharest, along with its tributary Sabar. Sabar and Dambovită are connected through the Ciorogarla channel, which collects the overflow of the Dambovită river.

The three landfills are Chiajna located in the northwest part, Glina in the southeast part and Vidra in the southern part of Bucharest city. The boundaries of Bucharest city, the landforms, rivers and the three landfills were depicted in Figure 1.

2.2 Chiajna Landfill

Chiajna landfill is in the north-western part of Bucharest, in a mixed industrial and residential area. Based on the historical map scale 1:25.000, sheet L-35-124-D-b, the landfill was constructed on a wetland of approximately 1 m in depth, which was in the southern part of the current landfill [2]. Based on the site report developed for obtaining the integrated environmental permit [3], uncontrolled landfilling began with construction debris resulted after the earthquake of 7.4 magnitude on the Richter scale in March 4, 1977. Uncontrolled landfilling continued with municipal and industrial waste.

The design and construction of new landfilling cells with appropriate waterproof lining was started in 1999 and landfilling began approximately in 2001. The highest point of the landfill based on aerial imagery from Google Earth is approximately 123 m AMSL, thus the maximum height is approximately 34 m.

2.3 Glina Landfill

Glina landfill is in the south-eastern part of Bucharest, in a mixed industrial and residential area. Based on the topographic military map scale 1:25.000, sheet L-35-125-C-d, the landfill was constructed on a wetland named Balta Ochiu Boului of approximately 1 m in depth, which occupied most of the site [4]. Based on the site report developed for obtaining the integrated environmental permit, uncontrolled landfilling began with construction debris resulted after the earthquake of 7.4 magnitude on the Richter scale on March 4, 1977. Uncontrolled landfilling continued with municipal and industrial waste until December 2001 when controlled landfilling began. [5]

The design and construction of new landfilling cells with appropriate waterproof lining was started in 1999 and landfilling began approximately in 2001. The site has 2 compartments, both functional in the southern part of the site. The old landfill where waste was stored uncontrolled is located in the center of the site.

The highest point of the landfill based on aerial imagery from Google Earth is approximately 75 m AMSL, thus the maximum height of the landfill is approximately 15 m.

2.4 Vidra Landfill

Vidra landfill is in the southern part of Bucharest, in a mixed agricultural and residential area. Based on the topographic military maps scale 1:25.000, sheets L-35-137-A-a and L-35-137-A-b, the landfill was constructed on an agricultural land [6, 7]. Based on the site report developed for obtaining the integrated environmental permit [8], the baseline studies were conducted in 2000, so it is presumed that landfilling began approximately in 2001.

The landfill has 8 compartments as follows: compartments 1-4 located in the northern half of the site (closed), compartments 5-6 located in the southwestern corner of the site (both functional) and compartments 7-8 located in the southeastern corner of the site.

The highest point of the landfill based on the site layout is approximately 108.5 m AMSL in the area separating compartments 1-4, thus the maximum height of the landfill is approximately 44.5 m.

3 Materials and methods

The sites were analyzed from a geological and hydrogeological point of view as follows:

- The general geology of the sites was identified based on the existing geological maps of Romania, scale 1:200,000 and various authors.
- The general hydrogeology of the sites was identified based on the existing hydrogeological maps of Romania, scale 1:100,000.
- Geological cross sections were generated starting from the existing cross sections in the geological maps. The stratigraphy was approximated based on outcrops, topography and descriptions provided by various authors.
- One borehole was drilled through manual techniques at each site to check the presumed lithology.
- Soil samples were collected to characterize the soils based on the particle size distribution, moisture content, relative density and porosity.

To identify the general lithology around each landfill, the following cross sections were generated:

- 1H and 2V: general horizontal (W-E direction) and vertical (N-S direction) cross sections; profile 2V was generated based on the geological map of Romania and profile 1H was generated based on the observed stratigraphy and outcrops which were correlated based on the digital elevation model [9] with profile 2V.
- 11H and 12V: horizontal (W-E direction) and vertical (N-S direction) cross sections generated for Chiajna landfill.
- 21H and 22V: horizontal (W-E direction) and vertical (N-S direction) cross sections generated for Glina landfill.
- 31H and 32V: horizontal (W-E direction) and vertical (N-S direction) cross sections generated for Vidra landfill.

All cross sections were correlated between themselves, starting from the known cross section 2V, all being depicted in Figure 2.

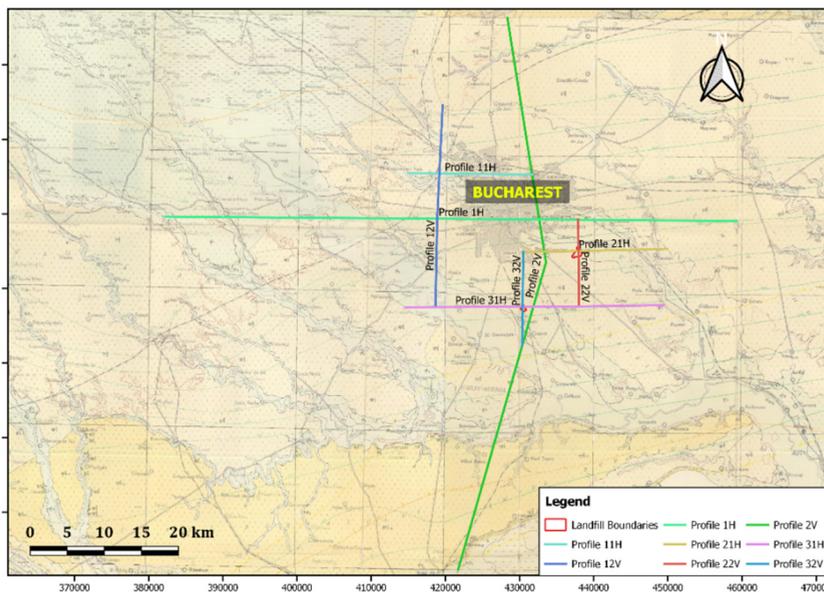


Fig. 2. Position of the geological cross sections [10].

Additionally, three boreholes were executed through auger manual drilling, one borehole around each landfill. Undisturbed and disturbed soil samples were collected from each borehole and analyses were conducted in the geotechnical laboratory of the University of Petrosani.

Analyses were conducted in accordance with the following standards:

- Grain size distribution: determined in accordance with the Romanian standard STAS 1913/5-85 Grain size determination, interpretation in accordance with the standard ISO 14688:2005 Geotechnical investigation and testing. Identification and classification of soil. Part 2: Principles for classification. [11]
- Water content: Romanian standard STAS 1913/1-82 Water content determination. [12]
- Specific gravity: Romanian standard STAS 1913/2-76 Foundation ground. Specific weight determination. [13]
- Volumetric weight: Romanian standard STAS 1913/15-75 Foundation ground. Field determination of volumetric weight. [14]
- Porosity: calculated after water saturation of undisturbed soil samples, considering the water density at 20 °C ($998 \text{ kg}\cdot\text{m}^{-3}$).

The location of each borehole is described in Table 1.

Table 1. Location of manual boreholes and soil samples collected.

Borehole	Location [UTM]	Date	Final depth	Sample type	Sample depth	Sample ID
-	[m]	-	[m]	-	[m]	-
Chiajna	N 4924739 m E 420565 m	July 21, 2020	2.35	Disturbed	0.9-1.0	CHI 0.9-1.0
				Disturbed	1.6-1.7	CHI 1.6-1.7
				Disturbed	1.7-1.8	CHI 1.7-1.8
				Disturbed	2.3-2.35	CHI 2.3-2.35
				Undisturbed	1.0-1.2	CHI 1.0-1.2
Glina	N 4915299 m E 438367 m	July 15, 2020	3.3	Disturbed	0.5-0.6	GLI 0.5-0.6
				Disturbed	2.3-2.4	GLI 2.3-2.4
				Disturbed	3.2-3.3	GLI 3.2-3.3
				Undisturbed	1.6-1.8	GLI 1.6-1.8
				Undisturbed	2.4-2.6	GLI 2.4-2.6
Vidra	N 4906392 m E 430300 m	July 14, 2020	6.1	Disturbed	0.5-0.6	VID 0.5-0.6
				Disturbed	1.5-1.6	VID 1.5-1.6
				Disturbed	3.0-3.1	VID 3.0-3.1
				Disturbed	6.0-6.1	VID 6.0-6.1
				Undisturbed	2.5-2.7	VID 2.5-2.7
				Undisturbed	4.6-4.8	VID 4.6-4.8

4 Results

4.1 Geology

The Quaternary period in Bucharest city consists of the following lithology [10]:

- Lower Pleistocene (qp_1^2) - gravel, sand and clay, with a thickness between 15 and 150 m (known as Fratesti Strata).

- Middle Pleistocene (qp_2^1) - marl complex consisting of marl and clay with sand intercalations, with a thickness between 100 and 120 m.
 - Middle Pleistocene (qp_2^2) - loess deposits with a thickness between 15 and 25 m.
 - Upper Pleistocene (qp_3^1) - sand, with a thickness between 8 and 20 m (known as Mostistea Sands).
 - Upper Pleistocene (qp_3^2) - gravel of the old river terrace, with a thickness between 10 and 30 m (known as Colentina Gravels).
 - Upper Pleistocene (qp_3^3) - gravel and sands of the old river terrace, as well as loess deposits, with a thickness between 10 and 20 m.
 - Lower Holocene (qh_1) - gravel and sands of the new river terrace, as well as loess deposits, with a thickness between 5 and 15 m.
 - Upper Holocene (qh_2) - clayey sands, gravel and sands of the river floodplain, as well as loess deposits, with a thickness between 5 and 20 m.
- Since the current research focuses on the upper layers, the cross sections were generated until the base of the upper Pleistocene qp_3^2 . The profiles are included in Figures 3-5 below.

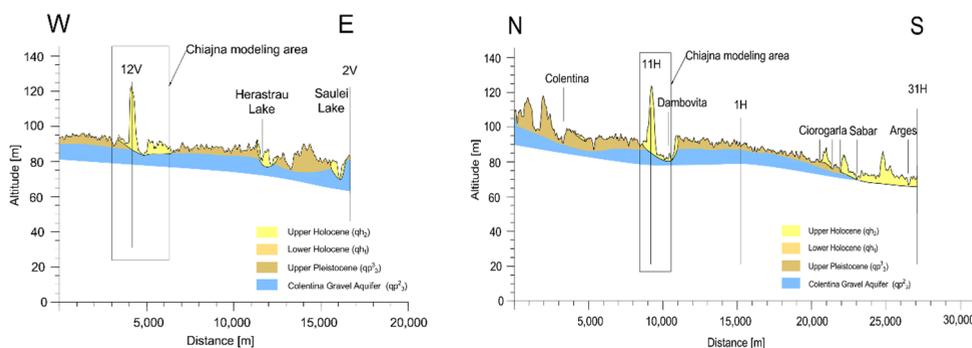


Fig. 3. Cross sections for Chiajna landfill – profiles 11H (left) and 12V (right).

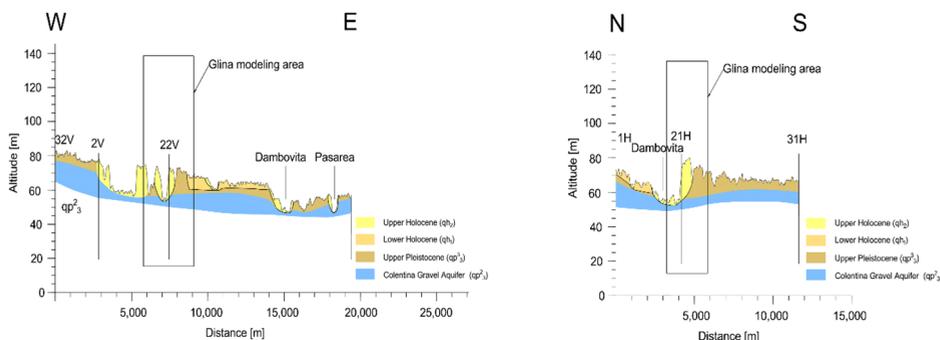


Fig. 4. Cross sections for Glina landfill – profiles 21H (left) and 22V (right).

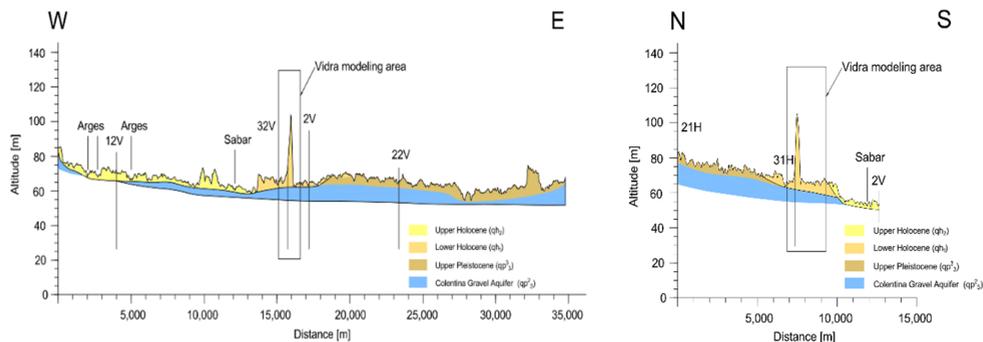


Fig. 5. Cross sections for Vidra landfill – profiles 31H (left) and 32V (right).

The laboratory test results are included in Table 2.

Table 2. Physical properties of the collected soil samples.

Sample ID	Sample type	Soil classification	Water content	Specific gravity	Volumetric weight	Porosity
-	-	-	[%]	[g·cm ⁻³]	[kN·m ⁻³]	[%]
CHI 0.9-1.0	D	Silt	12.14	2.529	-	-
CHI 1.6-1.7	D	Sandy silt	9.02	2.560	-	-
CHI 1.7-1.8	D	Sandy gravel	1.31	2.635	-	-
CHI 2.3-2.35	D	Sandy gravel	1.68	2.658	-	-
CHI 1.0-1.2	U	-	12.51	-	16.93	30.8
GLI 0.5-0.6	D	Sandy silt	16.43	2.605	-	-
GLI 2.3-2.4	D	Sandy clayey silt	23.18	2.587	-	-
GLI 3.2-3.3	D	Sandy silt	25.04	2.539	-	-
GLI 1.6-1.8	U	-	16.11	-	20.36	32.1
GLI 2.4-2.6	U	-	18.22	-	19.57	33.8
VID 0.5-0.6	D	Silt	17.50	2.561	-	-
VID 1.5-1.6	D	Clayey silt	21.19	2.568	-	-
VID 3.0-3.1	D	Clayey silt	18.92	2.645	-	-
VID 6.0-6.1	D	Gravelly sand	-	2.707	-	-
VID 2.5-2.7	U	-	15.48	-	18.77	30.6
VID 4.6-4.8	U	-	18.29	-	19.51	34.6

The laboratory test results indicate that the local lithology consists mostly of silty soils to various depths of 1.7 m near Chiajna landfill, >2.3 m near Glina landfill and 6.0 m near Vidra landfill.

The depth to the base of the upper Pleistocene (qp_3^3) or Holocene estimated through the cross-sections are 2.3 m near Chiajna landfill, 5.4 m near Glina landfill and 5.9 m near Vidra landfill. Presuming that the upper Pleistocene consists mostly of silty soils, the differences between the depths to which cohesive soils were encountered in comparison with the estimation from the geological map are significantly smaller in comparison with the total area investigated to generate the cross sections. It is presumed that errors may have resulted since the upper Pleistocene may also consist of sands and gravels and not only cohesive soils.

4.2 Hydrogeology

The hydrogeology of all the three landfills was approximated based on the hydrogeological maps developed by the Geological Institute of Romania, scale 1:100000, sheets 43b Domnesti, 44a Bucharest and 44c Vidra [15 - 17]. The aquifer located immediately beneath all the three landfills is the Colentina Gravels unconfined aquifer, code ROAG03, with a total area of 1859 km². Based on the Management Plan for the Arges-Vedea Drainage Basin, the groundwater extracted from the ROAG03 aquifer is used for supplying the population (999,110 m³/year), industry (2,099,770 m³/year) and agriculture (456,300 m³/year) [18].

Chiajna landfill is located between the groundwater contours of 86 and 87 m AMSL. The groundwater is drained by the Dambovita river, with a local flow from northwest towards southeast. Based on the local topography, it is estimated that the groundwater is located at approximately 2-3 meters below ground level (bgl.) in Giulesti neighbourhood located east of the landfill.

The hydraulic gradient of the groundwater is approximately 1.8×10^{-3} in the area of Chiajna landfill and approximately 3×10^{-3} in the area of Giulesti neighbourhood.

The piezometric surface of the Colentina Gravels aquifer in the area of Chiajna landfill and a hydrogeological cross section are depicted in Figure 6 below.

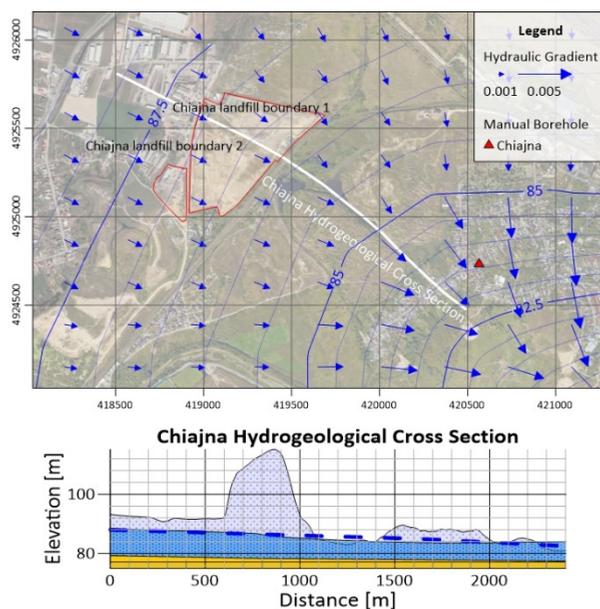


Fig. 6. Piezometric map and hydrogeological cross section for Chiajna landfill.

Based on the local groundwater flow and aerial imagery of Google Earth, a wetland area is in the southeastern part of the modeled area, which is fitted with multiple drains suggesting a hydraulic connection with the Colentina aquifer. Based on the estimation from the hydrogeological map, the groundwater is located at approximately 3.6 m below ground level in the area of the manual borehole. Actual water level measurement indicated that groundwater is located at approximately 4.5 m below ground level suggesting that either local disturbances are caused by existing foundations or the water well was not designed properly.

Glina landfill is located between the groundwater contours of 57 and 59.5 m AMSL. The groundwater is drained by the Dambovita river, with a local flow from southwest

towards northeast. Based on the local topography, it is estimated that the groundwater is located at approximately 2-3 meters bgl. in the northern part of Glina town, close to the boundary with the Glina wastewater treatment plant and approximately 15 m bgl.

The hydraulic gradient of the groundwater is approximately 1.9×10^{-3} and it has small local variations throughout the area of interest.

The piezometric surface of the Colentina Gravels aquifer in the area of Glina landfill and a hydrogeological cross section are depicted in Figure 7 below.

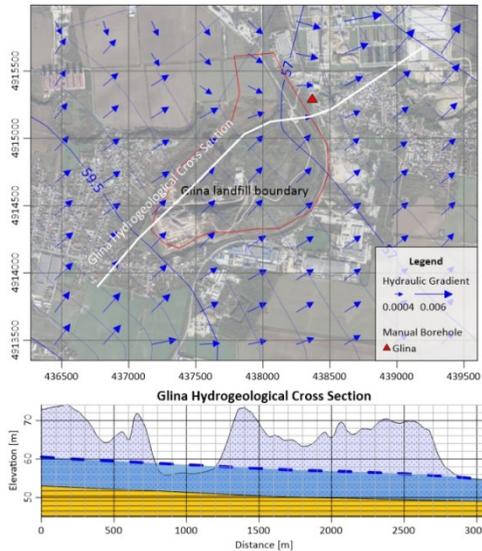


Fig. 7. Piezometric map and hydrogeological cross section for Glina landfill.

Based on the local groundwater flow and aerial imagery of Google Earth, a wetland area is in the southern and southwestern part of the modeled area, which is a drain for the Colentina aquifer surrounding the landfill. Based on the estimation from the hydrogeological map, the groundwater is located at approximately 4.3 m below ground level around the manual borehole and approximately 5.3 m below ground level in the northern part of Glina town. Actual water level measurement indicated that groundwater is located at approximately 2.5 m below ground level near the manual borehole and at approximately 7.2 m below ground level in the northern part of Glina town. Differences may have resulted through grid generation based on the digital elevation model near the manual borehole, especially given the fact that the measuring point was located near the steep slope surrounding Glina town. The difference between the estimated and measured groundwater level in the northern part of Glina town is presumed to be a consequence of the fact that the site was developed recently and made ground material may have been used during site levelling as seen on historical aerial imagery of Google Earth.

During the execution of the manual borehole and through laboratory analyses, it was observed that the silty layers have a higher water content. It is presumed that the aquifer is partially confined in the area of the manual borehole near Glina landfill.

Vidra landfill is located between the groundwater contours of 60 and 62 m AMSL. The groundwater is drained by the Sabar river and by a series of small water bodies located southeast of the landfill, which include Vadu lui Moș, Berceni lake etc. As a result, the groundwater has a divergent flow from north towards southwest and southeast.

Based on the local topography, it is estimated that the groundwater is located at approximately 5-6 meters bgl. in Sintești inhabited area neighbourhood located south of the landfill.

The hydraulic gradient of the groundwater is approximately 2×10^{-3} .

The piezometric surface of the Colentina Gravels aquifer in the area of Vidra landfill and a hydrogeological cross section are depicted in Figure 8.

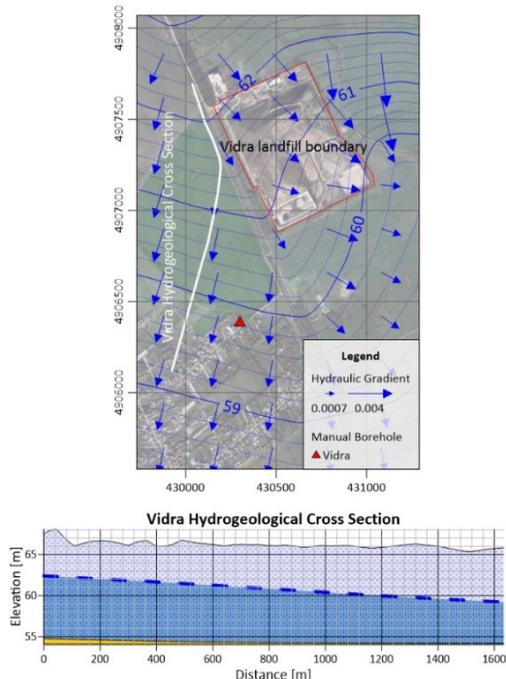


Fig. 8. Piezometric map and hydrogeological cross section for Vidra landfill.

Based on the estimation from the hydrogeological map, the groundwater is located at approximately 6.1 m below ground level around the manual borehole, fact confirmed during manual augering. Actual water level measurements were not possible because all investigated wells were covered for sanitary protection since groundwater is used for household activities and food preparation.

5 Conclusions

The methodology applied in the current article for assessing the geological and hydrogeological conditions of the landfills located around Bucharest city is suitable for high-level environmental assessments which envisage risks and exposure of public to contaminated soil and groundwater, especially when access to the potential sources of contamination is not provided. Although the method does not provide information on lithology, groundwater and contaminant fate and transport with high accuracy, the low costs required and the necessity to research the geology and hydrogeology on a wider area makes it suitable for the development of public risk maps and exposure assessments.

Several drawbacks were identified during the application of the methodology related to the data availability which include the following:

- Unlike the topographical map for which the National Agency for Cadastre and Land Registration (ANCPPI) which has published the digital elevation model (DEM) with an open license and is working towards developing updated topographical maps (e.g. through the Land Administration Knowledge Improvement projects LAKI and LAKI II), there are no

readily available open licenses of geological and hydrogeological maps for the entire surface of Romania.

- The geological and hydrogeological conditions in the urban areas were significantly modified since the geological and hydrogeological maps were first developed as new construction works have been carried out including excavating geological materials and backfilling with made ground, which makes it difficult to approximate the regional conditions. As an example, the geological and hydrogeological maps for Bucharest area do not include Lacul Morii located at approximately 3 km southeast of Chiajna landfill, a hydrotechnical dam constructed approximately in 1985 and which is presumed to have a significant impact on the regional hydrogeology.

- Unlike the Order of Architects in Romania who receive a copy of all projects which are signed by authorized architects, there are no legal entities in Romania entitled to receive copies of the geotechnical studies although there are sufficient public authorities and professional associations which may take on this task with the purpose of creating a public database.

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