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Geological-genetic structure of Irpin city, the role of lithological factors during engineering-geological zoning and construction assessment

Geološko-genetska zgradba mesta Irpin, vloga litoloških dejavnikov pri inženirsko-geološkem določanju con in oceni gradnje

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Key words: engineering-geological zoning, engineering-geological units, geological-genetic structure, engineering-geological map, construction assessment

Ključne besede: inženirsko-geološka rajonizacija, inženirsko-geološke enote, geološko-genetska zgradba, inženirsko-litološka karta, gradbena ocena

Abstract

The scheme of engineering-construction assessment created based on engineering-geological zoning of the city's territory is desirable among additional graphic materials in the design of master plans projects as determined by building regulations. Engineering-geological zoning provides for different ranks' selection of engineering-geological units (EG units), which have a particular range of common engineering-geological conditions that ultimately determine the construction sites' affiliation to a specific suitability category. Geological-genetic structure of Irpin city of Kyiv region (Ukraine) is explored in this article. A variant of the creation of a large-scale engineering-geological map and corresponding geological-lithological sections by supporting boreholes in the borders of the city based on the engineering-geological survey conducted is presented. The obtained result allowed the selection of engineering geological zoning units – engineering geological districts by general conditions of geological development and subdistricts by engineering-geological complexes of Quaternary rocks' thickness. The analysis of soils' geomechanical properties (engineering-geological elements) lays the foundations for the selection of engineering-geological sites based on the comparison of this information with geomorphological, hydrogeological and geodynamic data. Accounting of geological-lithological factors in the preparation of the construction assessment scheme in the project of Irpin city's master plan has become the ultimate result.

Izvleček

Shema inženirsko-gradbene presoje, ki je ustvarjena na podlagi inženirsko-geološkega razvrščanja mestnega ozemlja, je zaželena informacija, ki bi bila na voljo projektantom pri izdelavi gradbenega projekta. Inženirsko geološko razvrščanje predvideva različno rangiranje inženirsko geoloških enot (EGE), ki imajo skupne nekatere osnovne inženirsko-geološke lastnosti, ki vplivajo na gradnjo objektov. V tem članku je raziskana inženirsko-geološka sestava tal mesta Irpin v Kijevski regiji (Ukrajina). Predstavljena je varianta izdelave obsežne geološko-litološke karte in ustreznih geoloških litoloških prerezov z vključenimi podatki iz raziskovalnih vrtin, izvedenimi za inženirsko-geološke raziskave različnih predelov mesta. Dobljeni rezultat je omogočil rangiranje tal glede na inženirsko-geološke zahteve glede temeljenja objektov. V naslednjem koraku se tla rangirajo še na debelino kvartarnih plasti. Analiza geotehničnih lastnosti zemljin (inženirsko-geoloških elementov) postavlja osnovo za izbiro primernih lokacij za gradnjo na osnovi inženirsko-geoloških podatkov pridobljenih z geomorfološkimi, hidrogeološkimi in geosezmičnimi podatki. Končni rezultat raziskave je ocena tal glede na primernost gradnje v mestu Irpin.

Introduction

In the design of projects' master plans building regulations determine that among some additional town-planning documentation the engineering construction assessment scheme is desirable and that scheme takes into account natural and anthropogenic factors that define construction sites' suitability for urban development (Building regulations B.1.1-15:2012, 2012). Estimated natural and technogenic factors (geological processes triggered by civil engineering activity that harm building structures: technogenic waterlogging, eutrophication, technogenic landslides, water erosion, ground subsidence, etc. (Shnyukov et al., 1993) of engineering-construction assessment should include geomorphological characteristics, geologic-lithological structure, geomechanical properties of rocks, hydrogeological circumstances, microseismic circumstances, etc. (Zhyrnov et al., 2019).

Engineering-geological maps are a generalized image on a topographic base of a complex of geological parameters, the interaction of which determines the engineering-geological conditions, the specifics of surveys, construction and operation of engineering structures. The most important of engineering-geological conditions in the maps are the basis for the engineering construction scheme's elaboration, namely the geological structure of the territory, lithological composition, hydrogeological conditions and current natural and technogenic geological processes. Engineering-geological zoning maps have particular importance among engineering-geological maps for engineering construction assessment. They are drawn up as a result of identification in the space based on theoretical positions' combination and methodological procedures of objectively existing territorial elements that have common engineering-geological features of their delineation from territories that haven't such features, their mapping and description. Different-order engineering-geological units are allocated during the regional type of engineering-geological zoning and each next unit is allocated from the previous (larger) by dividing it into separate parts based on specific classification features (Trofimov & Krasilova, 2008).

A significant role belongs to EG units that are allocated by geological-genetic and lithological features during engineering-geological zoning. Geological-genetic and lithological structure of the territory plays the main and crucial role in the engineering-geological substantiation of construction projects, determination of the type of buildings' foundations, planning the features of building operation and their reverse impact on the ecological state of the geological environment (Bell, 2007). Therefore, there is an urgent need to characterize the geological-genetic and lithological structure of the deposits used for construction.

Identification of engineering-geological districts and subdistricts, as well as preconditions for the selection of engineering-geological sites based on detailed geomorphological, geological-genetic and lithological characteristics using the example of Irpin city, Kyiv region (Ukraine) is the purpose of this article. Determination of the place of lithological factors in the structure of engineering-geological zoning and complexity categories of geologic-lithological conditions for construction assessment are also the objectives of this article.

Attempts of engineering-geological zoning detailing with geologic-lithological features' accounting have been implemented in Tunis city, (El May et al., 2010) Split city (Šestanović et al., 2012) Moscow city, (Osipov et al., 2012) Velopolja region, (Muceku, 2010) Fortaleza region, (Zuquette et al., 2004). We took into account the scientific experience of the predecessors and offer our opinion on the consideration of geologic-lithological factors in the engineering-geological zoning for urban planning.

One of the previous articles (Zhyrnov & Solomakha, 2022) provides an example of a completed engineering-geological zoning of the Irpin city. However, in this study, there is not enough information about the geomechanical properties of engineering-geological elements, there are no recommendations for choosing the types of foundations for buildings and structures, and protective measures for buildings located in areas with a high level of groundwater are not introduced. In previous work is no accounting for the category of complexity of geological-lithological conditions for engineering-construction assessment. In addition, here we will dwell in more detail on the principles for selection such important engineering-geological units as districts and subdistricts. The current article aims to fill these important gaps.

Study area

Irpin city administratively is situated in the central part of the Kyiv region at a distance of 7 km northwest of Kyiv, which is Ukraine's capital (Fig. 1).

Irpin city is situated in the southwest part of the East European Plain in the limits of Kyiv Polesia as a part of the Polesian Lowland. According

Fig. 1. Irpin city in the central part of Kyiv region, Ukraine.
Sl. 1. Mesto Irpin v osrednjem delu Kijevske regije, Ukrajina.

to the geomorphological map (scale 1: 55 000) of Ukraine, the investigated territory corresponds to Makariv moraine fluvioglacial wavy slightly dissected plain between Irpin's, Buchanka's, Teteriv's and Zdvyzh's River valleys. Knowing the physical-geographical and administrative location of the city, it is easy to identify that according to principles of engineering and geological classification, Irpin is situated in the limits of East-European Craton, the north-east slope of Ukrainian Shield province, Kyiv Polesia subprovince, engineering geological region of Makariv moraine fluvioglacial wavy slightly dissected plain (Paton et al., 2007). There are such engineering geological districts in the limits of Irpin according to engineering geomorphological zoning of Kyiv city district's map: erodible and depositional alluvial plain and denudation-depositional watershed moraine and fluvioglacial plain (Barshchevsky et al., 1989).

Upper- and Holocene Quaternary Q_{III}-Q_{IV} erodible and depositional alluvial plain with absolute altitudes of 107–118 m. Middle Quaternary Q_{II} denudation-depositional watershed moraine fluvioglacial plain with absolute altitudes of 120–160 m. In the borders of the erodible and depositional alluvial plain are allocated: 1) Alluvial floodplain flat inundated terrace of Buchanka and Irpin Rivers of Holocene age with swamped areas and peat depressions of Holocene age; 2) Alluvial upper Holocene, slightly dissected first above-flood terrace of Buchanka and Irpin Rivers. In the borders of the denudation-depositional watershed moraine, fluvioglacial plain is allocated: 1) Plateau and highland of moraine fluvioglacial wavy and slightly dissected plain of Dnipro age with corresponding absolute altitudes of 135–160 m; 2) Lowland part of moraine fluvioglacial wavy and slightly dissected plain of Dnipro age with absolute altitudes of 120–135 m; 3) Arroyos' bottoms and detrital cones of Holocene age; 4) Sites with artificially modified relief (Tsybko, 2020).

Flooding in the Buchanka and Irpin Rivers' floodplains, waterlogging in the borders of the floodplain and the first terrace of the Buchanka and Irpin Rivers are part of the dangerous hazards in the Irpin. Waterlogging is connected with a naturally high level of groundwater, floodplain flooding during spring and also the unloading of aquifers in permanent and temporary watercourses. Eutrophication occurs in the Buchanka and Irpin Rivers' floodplain and is connected with spring floods and unloading of aquifer related to Middle-Quaternary fluvioglacial deposits of dividing range. River erosion is generally weak along the Irpin and Buchanka Rivers and occurs at local sites during spring. Eolian sand deflation is observed on some sites of the floodplain and first terraces of the Irpin and Buchanka Rivers (northeast and northwest city outskirts) (Tsybko, 2020).

Significant hydration of Quaternary deposits and high groundwater level, which provokes flooding, waterlogging and eutrophication are the main obstacles to urban development (Rudenko et al., 1971).

Comparison of data on the territory's morphogenetic structure and areas of development of natural hazards made it possible to build a geomorphological map of Irpin city (Zhyrnov & Solomakha, 2022) (Fig. 2).

The morphogenetic and morphological structure of the relief lays the foundations for the selection of engineering-geological districts and subdistricts, but it is necessary to distinguish corresponding geological-genetic complexes of Quaternary sediments within the erosion-accumulative alluvial plain and the denudation-accumulative watershed moraine water-glacial plain and determine the lithological composition of the mentioned Quaternary deposits for the relief's morphological elements.

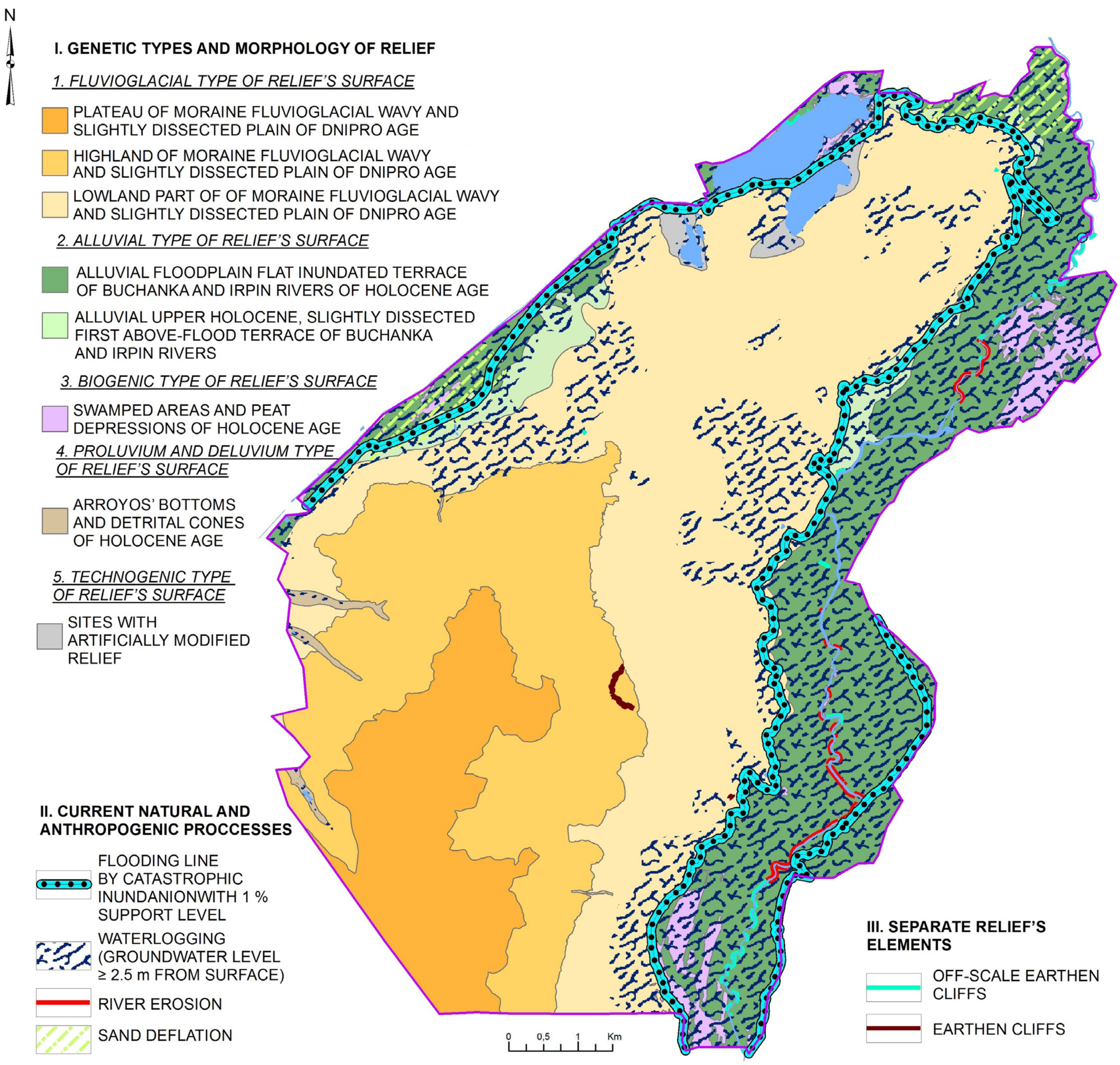


Fig. 2. Geomorphological map of Irpin city (Zhyrnov & Solomakha, 2022).
Sl. 2. Geomorfološka karta mesta Irpin (Zhyrnov & Solomakha, 2022).

Materials and methods

There are such initial data for engineering-geological mapping: a topographic survey of Irpin city on a scale of 1: 5000, a geological map on a scale of 1: 50 000 on sheets of Kyiv region, (Solovytsky & Vozgryn, 1990) project of the master plan of Irpin city (Gubenko et al., 2017), state geological map of Ukraine – 200 (Ivanenko, 2020), a geological map of Ukraine (Panchenko, 2019), materials of engineering-geological investigations between 1990 and 2020 years under construction for residential and public buildings that have been made by different design organization and companies. 154 geotechnical reports were analyzed, and those materials were collected and systematized at SE "Ukrainian Institute of Engineering Technical Exploration for Construction" (UKRIINTR) (Tsybko, 2020).

The principles of engineering-geological zoning were most fully developed by Ivan Popov, who proposed to distinguish engineering-geological regions, oblasts, districts and subdistricts of various orders as independent taxonomic units.

Engineering-geological regions are distinguished by structural-tectonic features. The engineering-geological region of the first order is the largest taxonomic unit. The second-order region, namely the engineering-geological province, is distinguished by its morphostructure and hydrogeological structure. The region of the third order (subprovince) is distinguished based on the morphogenetic type of the territory of the first order (Popov, 1951).

Popov proposed to distinguish engineering-geological areas within one region based on geomorphological features. With this approach, the geomorphological features of the territory are a consequence of the history of its geological development, mainly in recent times. We can say that engineering-geological regions are territories that are distinguished by geostructural features as a result of the analysis of the history of the geological development of this territory for the entire time available to us, and engineering-geological oblasts are parts of regions that have had different development in recent times, which was reflected in their geomorphological features (Popov, 1951). So, engineering-geological oblasts are distinguished based on the IInd order morphogenetic type.

Engineering-geological districts in the engineering-geological oblasts are distinguished on the territory of which the uniformity of the geological structure is noted, which is expressed in the same sequence of rocks' occurrence, their thickness and petrographic composition. Such relatively small territories can be formed under the conditions that they experienced tectonic movements of the same sign and intensity over their entire area and were in the same paleoclimatic conditions throughout their development history, which goes beyond the latest stage of the Earth's geological development (Popov, 1951). Therefore, engineering-geological districts are distinguished based on the common conditions of geological development.

Engineering-geological subdistricts can be allocated within one engineering-geological district according to a different state of rocks, and the manifestation of modern and ancient geological processes, if necessary (Popov, 1951). For example, within one engineering-geological area, there may be different strata of rocks located in a stratigraphic sequence and characterized by similarity or natural variability of engineering-geological characteristics. So, engineering-geological subdistricts are distinguished based on engineering-geological complexes of rocks of a certain age geological layer.

Engineering-geological sites are allocated within subdistricts during a large-scale engineering-geological study of the territory, within which engineering-geological subsites can be allocated as well. As a rule, engineering-geological sites are distinguished according to the conditions of construction, that is, according to the assessment of a complex of natural and technogenic factors (Popov, 1951) (Fig. 3).

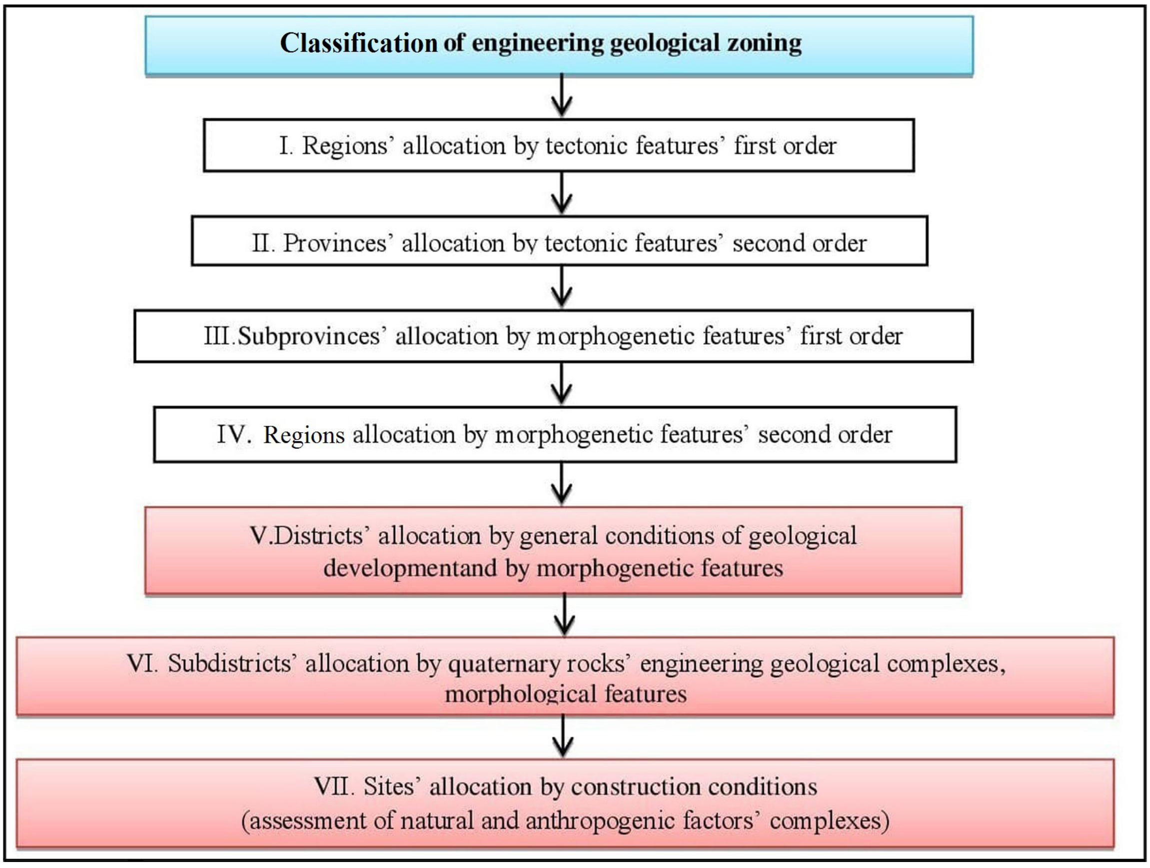


Fig. 3. Procedure of engineering-geological zoning (adapted after Zhyrnov & Solomakha, 2022).
Sl. 3. Postopek inženirsko-geološkega razvrščanja (prirejeno po Zhyrnov & Solomakha, 2022).

The following methods were used in the current research: field engineering-geological researches (geomorphological, geological and hydrogeological survey, identification of natural hazards) methods of interpretation of remote sensing data (analysis of satellite images Sentinel-2 (scale 1: 40 000, period - 2017–2020 years) of the study area in order to fix natural hazards) methods of mining and drilling operations: 72 wells were drilled by percussion-rope method with a depth of 1.6 to 94 m, 9 points of cone penetration test were made (studying the geological structure, indication of tectonic processes and rock fracturing, conducting field experimental work, sampling rocks with an undisturbed structure and water samples, organization of observations of the regime of groundwater and exogenous geological processes) hydrogeological research (research of state of rocks, depth of groundwater level and the level of soils' permeability) methods of engineering-geomorphological (engineering-geomorphological maps are narrow-purpose maps that serve engineering purposes in construction, reflect the structural and geomorphological characteristics, dynamics and stability of the relief, its qualitative and quantitative features and development forecast elements (Palienko, 1978) and engineering-geological mapping (creation of engineering-geomorphological (scale 1: 55 000) and engineering-geological maps (scale 1: 55 000) for the purposes of urban planning) laboratory methods for obtaining data on the geomechanical properties of soils (selection of engineering-geological elements, research of granulometric composition, description of strength, deformation properties, compressibility indicators, etc.) as well as the method of conjugated cartographic analysis (complex comparison of cartographic data into a single multicomponent synthetic map) (Fig. 4).

Results

As noted earlier borders of genetic types and relief morphology were delineated during the engineering-geological survey using GPS equipment, made relief's morphologic description, research of natural hazards and made a detailed description

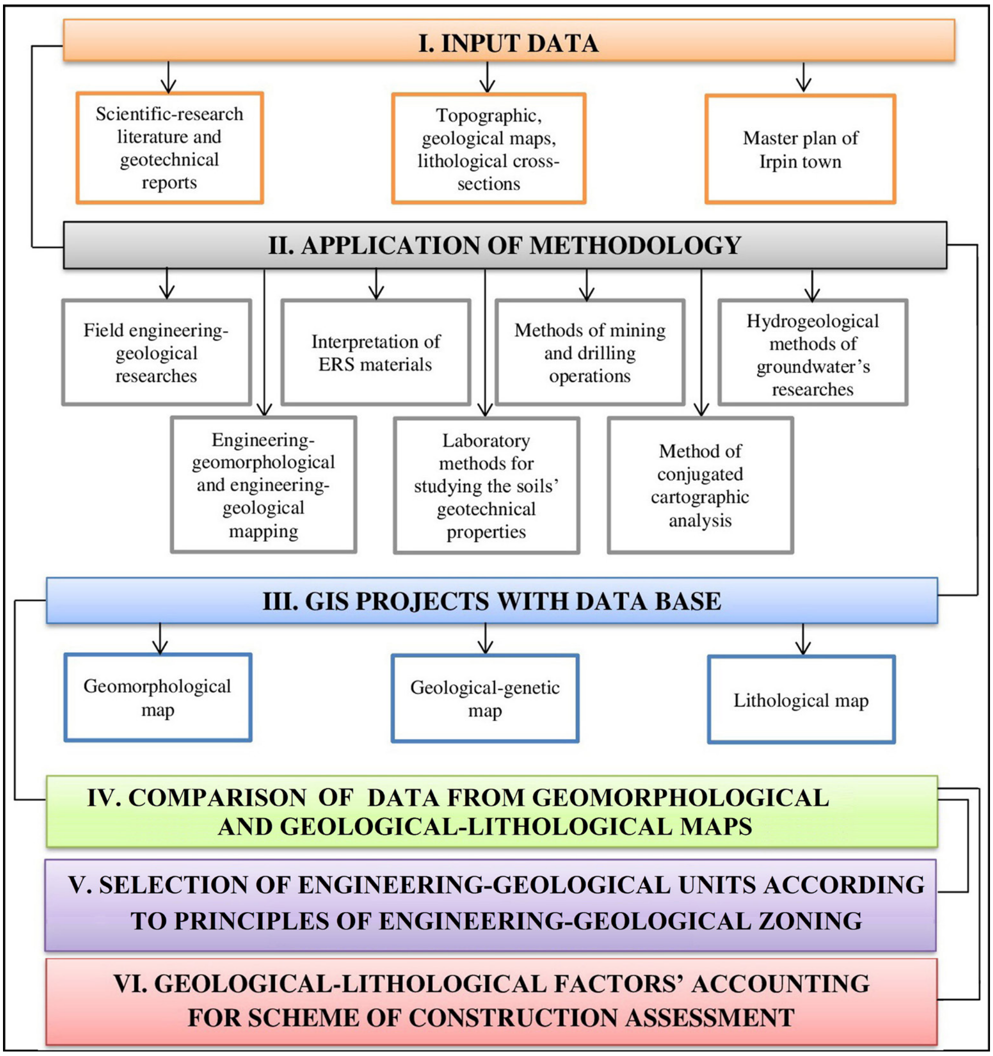


Fig. 4. Data and methodology of current research (adapted after Zhyrnov & Solomakha, 2022).

Sl. 4. Podatki in metodologija trenutne raziskave (prirejeno po Zhyrnov & Solomakha, 2022).

of sediments, that are involved in construction, selected soil samples for determination of their geomechanical properties in the geotechnical laboratory. All this information was exported from GPS equipment and referenced to the existing topographic survey. Geotechnical reports' analysis allowed to specify Quaternary deposits' lithological composition and correct the areas of hydrological and hydrogeological hazards' manifestation in particular flooding, waterlogging and eutrophication (Tsybko, 2020).

Irpin is situated on the borders of the Ukrainian Shield's northern-east slope in geostructural terms, which gradually dips in a north-easterly direction to the side of the Dnieper-Donets Rift. The sediments of the Cretaceous, Paleogene and Quaternary systems lie on the eroded surface of the Precambrian basement. Deposits of the Cenomanian layer, represented by sands and sandstones on siliceous cement are the oldest sedimentary formations exposed in the territory of Irpin. The sand is greenish-gray, fine- and medium-grained, quartz-glauconite. Deposits of the Upper Cretaceous are on the rocks of the Cenomanian layer represented by white, light gray chalk with an average thickness of 9.0 m. The Kaniv, Bucha, Kyiv and Kharkiv suites are established as part of the Paleogene sediments. Rocks of the Kaniv Formation (P_2kn) lie on chalk rocks and are represented by shallow marine formations: dark gray fine- and fine-grained glauconite-quartz, micaceous sand with underlying layers of aleurites and clays, and sometimes sandstones. The thickness of the Kaniv suite varies from 20.4 to 30.5 m with an average thickness of 25 m.

The sediments of the Bucha suite (P_2bc) lie on the Kaniv sediments and are overlain by clays and marls of the Kyiv suite, they are represented by shallow marine formations: greenish-gray, fine- and fine-grained sands of quartz-glauconite composition and dark green and greenish-gray clays with thickness from 8.0 to 20.0 m.

Deposits of the Kyiv suite (P_2kv) are represented by a layer of greenish-gray clayey marls, which pass into marly clays with a thickness of 4.0-30.0 m. A significant change in the capacities of the Kyiv suite is due to its erosion in the Irpin and Buchanka Rivers' riverine zones for which the Kyiv suite's deposits are a water-resistant layer. Deposits of the Kharkiv suites (P_3ch) are limitedly distributed on the territory of the city's south-western part, where they are confined to the most mountainous part of the watershed between the Irpin and Buchanka Rivers, they are blurred in the rest of the area in Quaternary time. The sediments of the Kharkiv suite are gray, greenish-gray, shallow- and fine-grained sands of quartz-glauconite composition with a thickness of 4.5-5.0 m.

Quaternary sediments completely cover pre-Quaternary formations. They are represented by the following genetic types: water-glacial, glacial, alluvial, marsh and technogenic. Quaternary deposits in terms of age are represented by Middle Quaternary, Upper Quaternary and modern sediments.

Mid-Quaternary water-glacial submarine sediments ($f_{II}dn_1$) lie on formations of the Kharkiv and Kyiv suites. They are widely distributed on the city's territory and consist of the highlands between the Irpin and Buchanka Rivers. They are represented by yellow-gray, gray, ochreous, fine- and medium-grained, quartz sands with admixtures of feldspars with layers and lenses of clays. They overlap with moraine and water-glacial moraine sands with a capacity of 12 m.

Mid-Quaternary glacial (moraine) deposits ($g_{II}dn_2$) are represented by glacial deposits with red-brown loams and clays, sometimes greenish-gray with ochre spots of ferrugination with inclusions of gravel and pebbles of crystalline rocks. Coarse-grained material is represented by granites, gneisses, limestones and sandstones. Moraine sediments were not widely distributed, they were preserved only in upland watershed areas and remnant mounds. The moraine deposits are covered everywhere by fluvioglacial deposits, their thickness ranges from 3.0 to 11.5 m.

Mid-Quaternary water-glacial over-moraine deposits ($f_{II}dn_3$) are the most widely distributed on the city's territory, they are the basis for the foundations of most buildings and structures. They are represented by light-gray, brown-yellow and yellow-gray quartz sands. Sands are multi-grained, medium-grained prevail. Sandstone layers and lenses are often found in gravel-pebble material with a thickness of 0.2–2.7 m, including boulders of crystalline rocks. The total thickness of fluvioglacial deposits varies from 5 to 20 m with an average thickness of 10 m.

Alluvial Upper Quaternary a_{III} deposits are represented by alluvial formations of the Irpin and Buchanka Rivers' floodplain terraces – quartz, fine-grained, light-gray and yellow-gray sands with a thickness of 8–12 m with interlayers and lenses of sands with a thickness of 0.2–0.5 m. Alluvial deposits lie on the washed-out surface of Kyiv suite's marls.

Modern Quaternary alluvial a_{IV} and biogenic deposits b_{IV} consist of the floodplain of the Irpin and Buchanka Rivers. They are represented by fine-grained light-yellow and gray-yellow quartz sands with a thickness of 10–16 m with lenses and interlayers of sandy loams and silts with a thickness of 0.13–0.9 m. Biogenic deposits are represented by peat with a thickness of 0.3-5.0 m, which covers alluvial deposits in most of the flood-

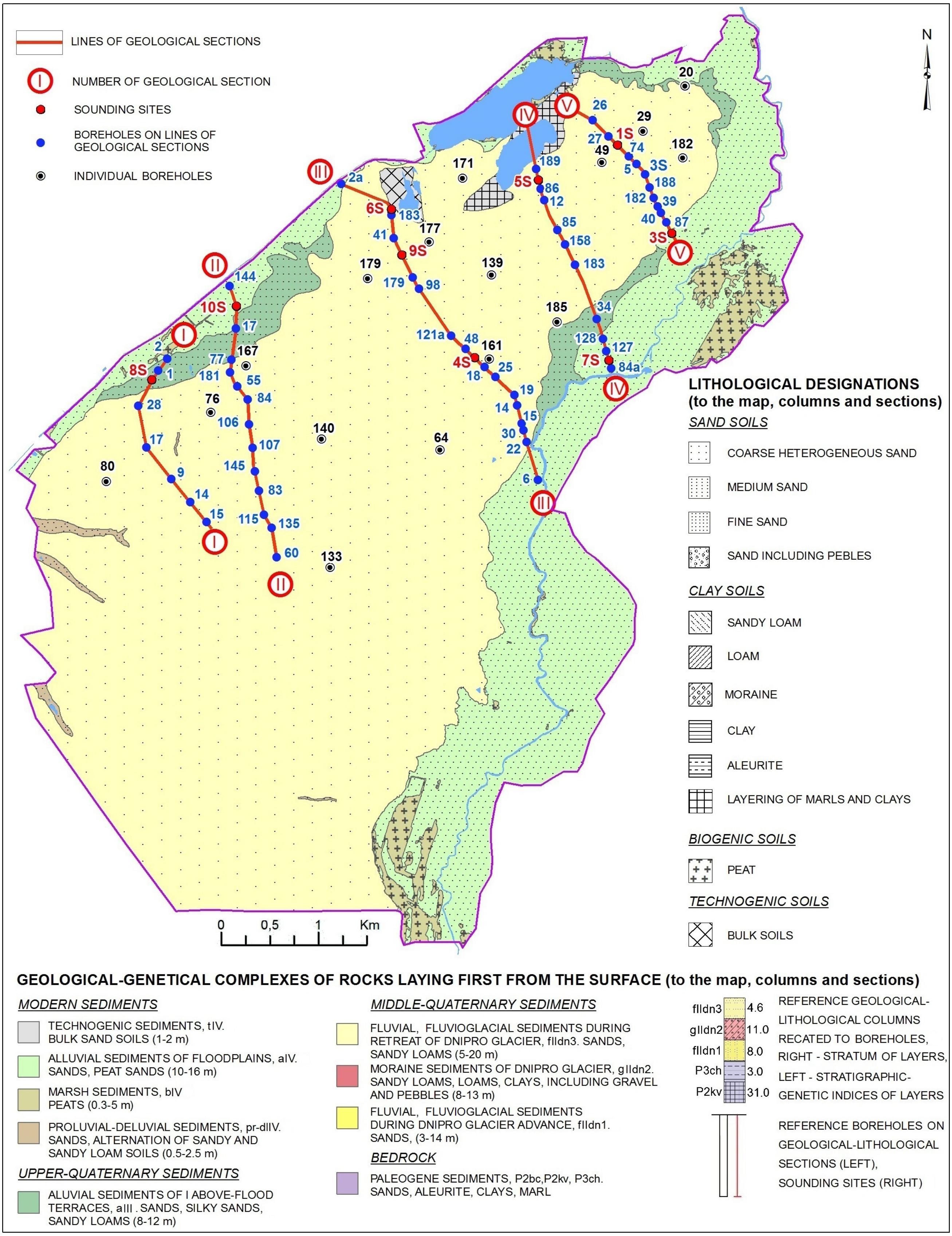


Fig. 5. Geological-lithological map of Irpin city (Zhyrnov & Solomakha, 2022).
Sl. 5. Geološko-litološka karta mesta Irpin (Zhyrnov & Solomakha, 2022).

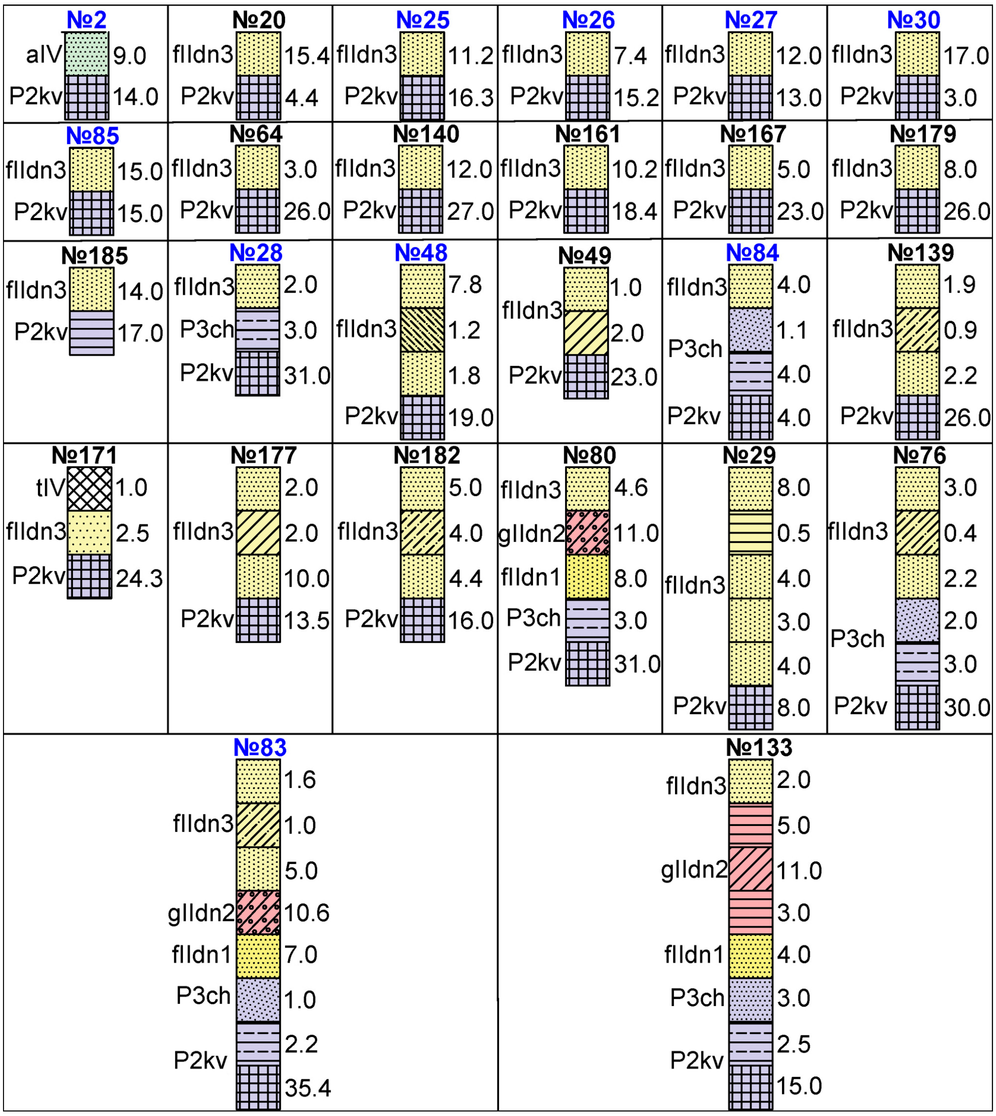


Fig. 6. Geological-lithological columns by boreholes on lines of geological sections and by individual boreholes (Zhyrnov & Solomakha, 2022).

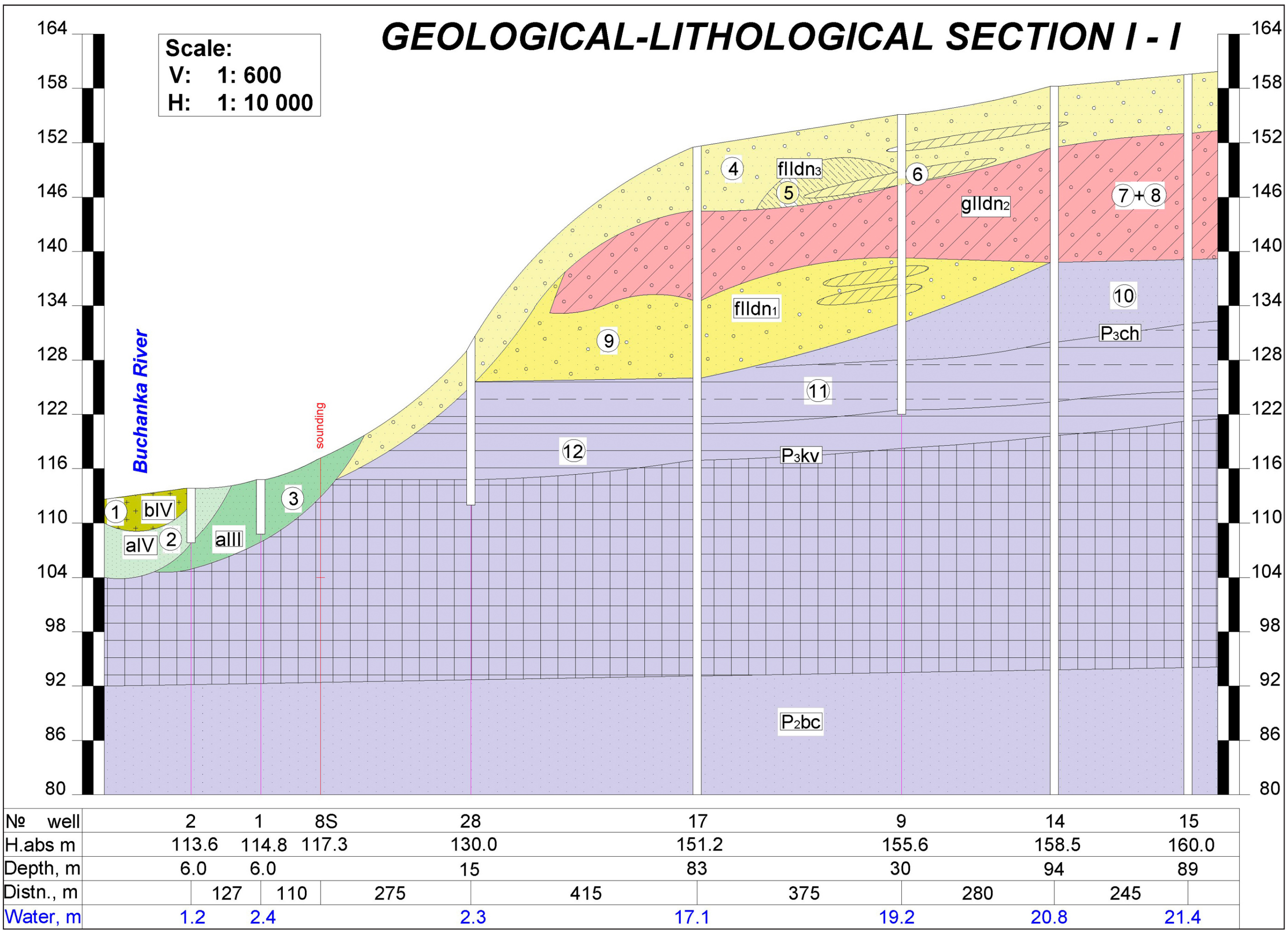
Sl. 6. Geološko-litološki popisi vrtin na linijah geoloških prerezov in po posameznih vrtinah (Zhyrnov & Solomakha, 2022).

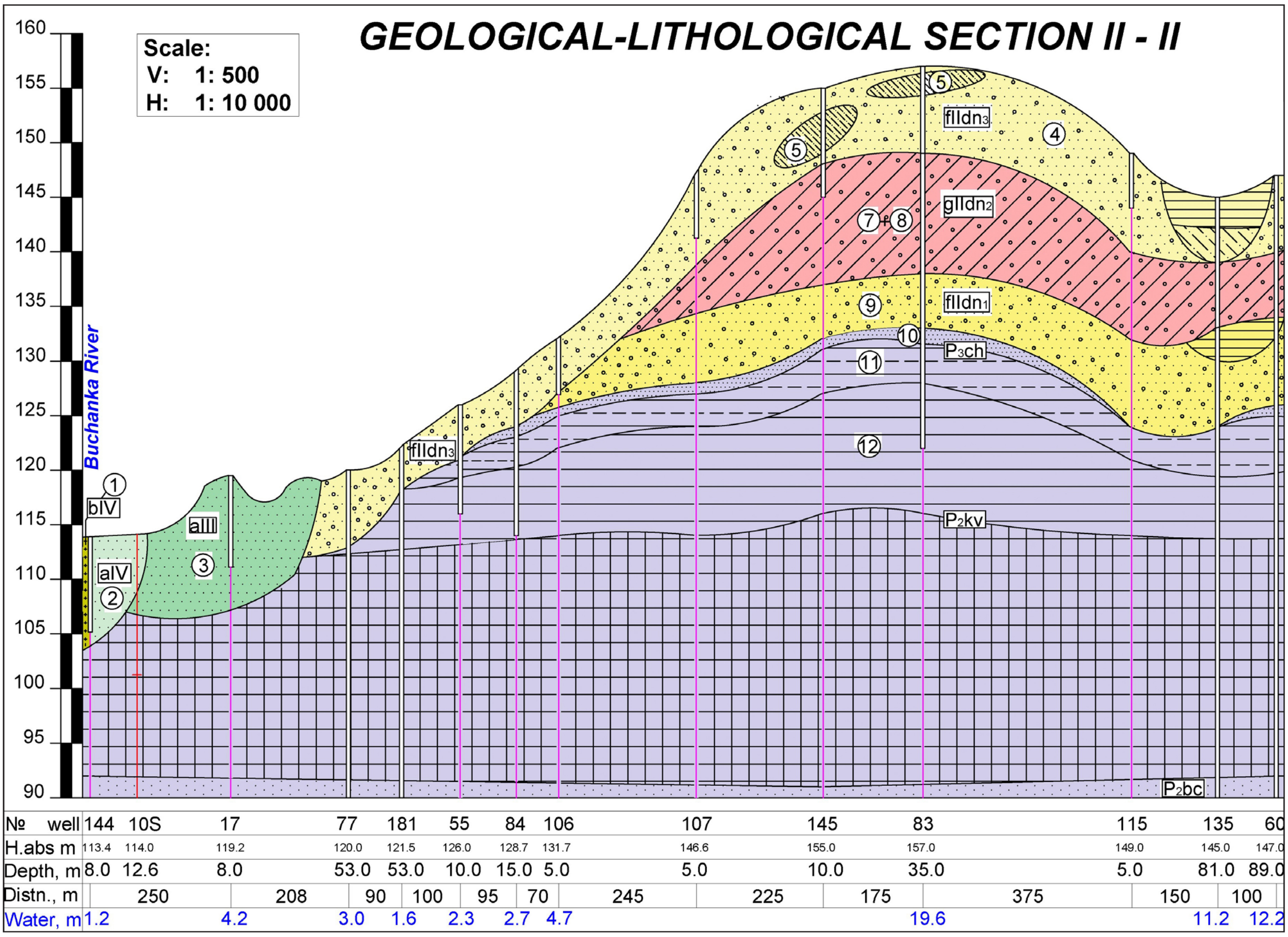
plain. Peat is mainly poorly decomposed, brown and brownish-brown in colour. The composition of peat is dominated by reed material. Peat is often sandy, which is the result of washing out the organic component from its mass (Tsybko, 2020; Veklych, 1958; Zhyrnov & Solomakha, 2022).

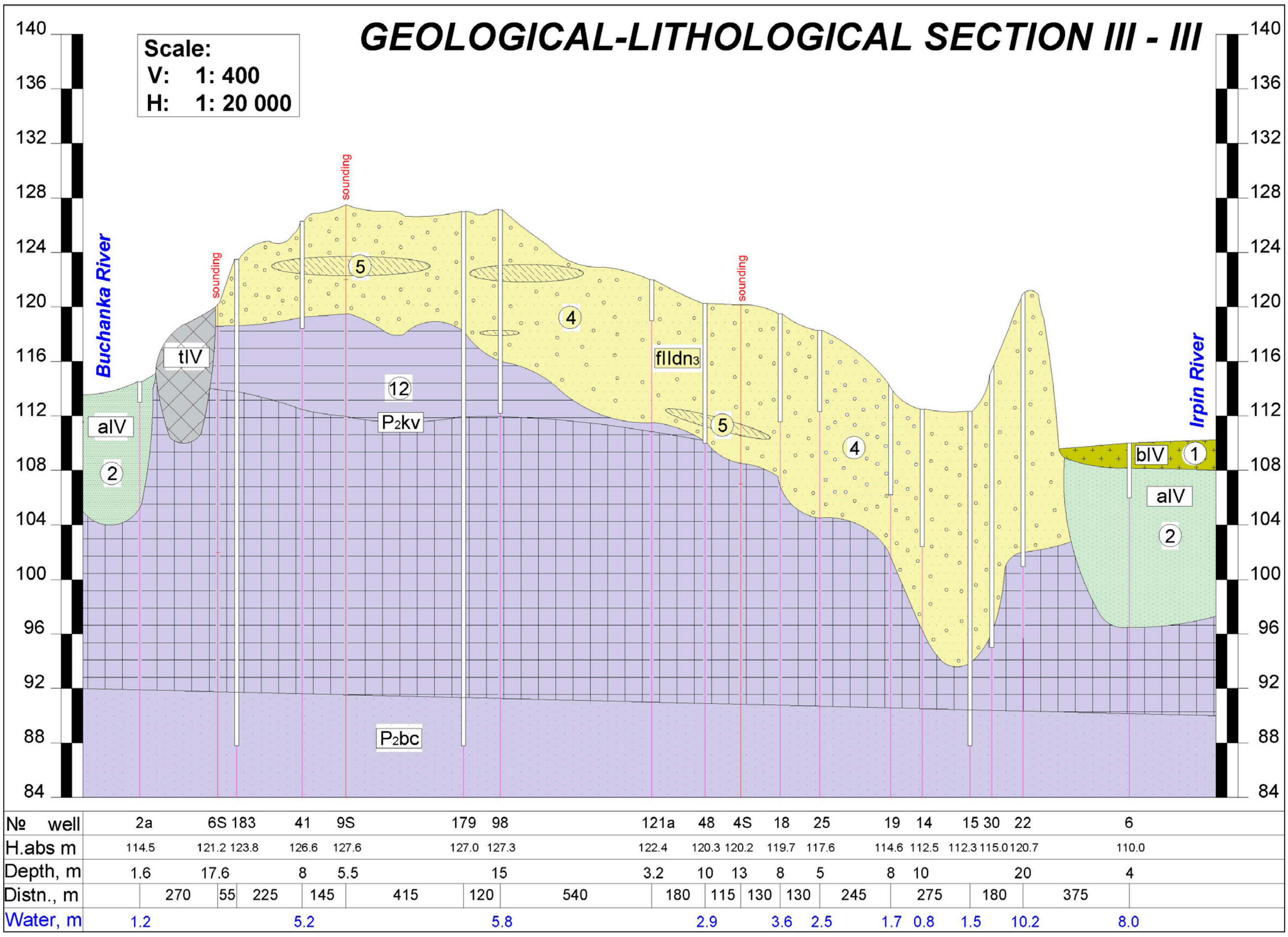
Therefore, the analysis of the territory's geomorphological features and geological structure made it possible to distinguish four geological-geneti crock complexes on the territories of Irpin's city.

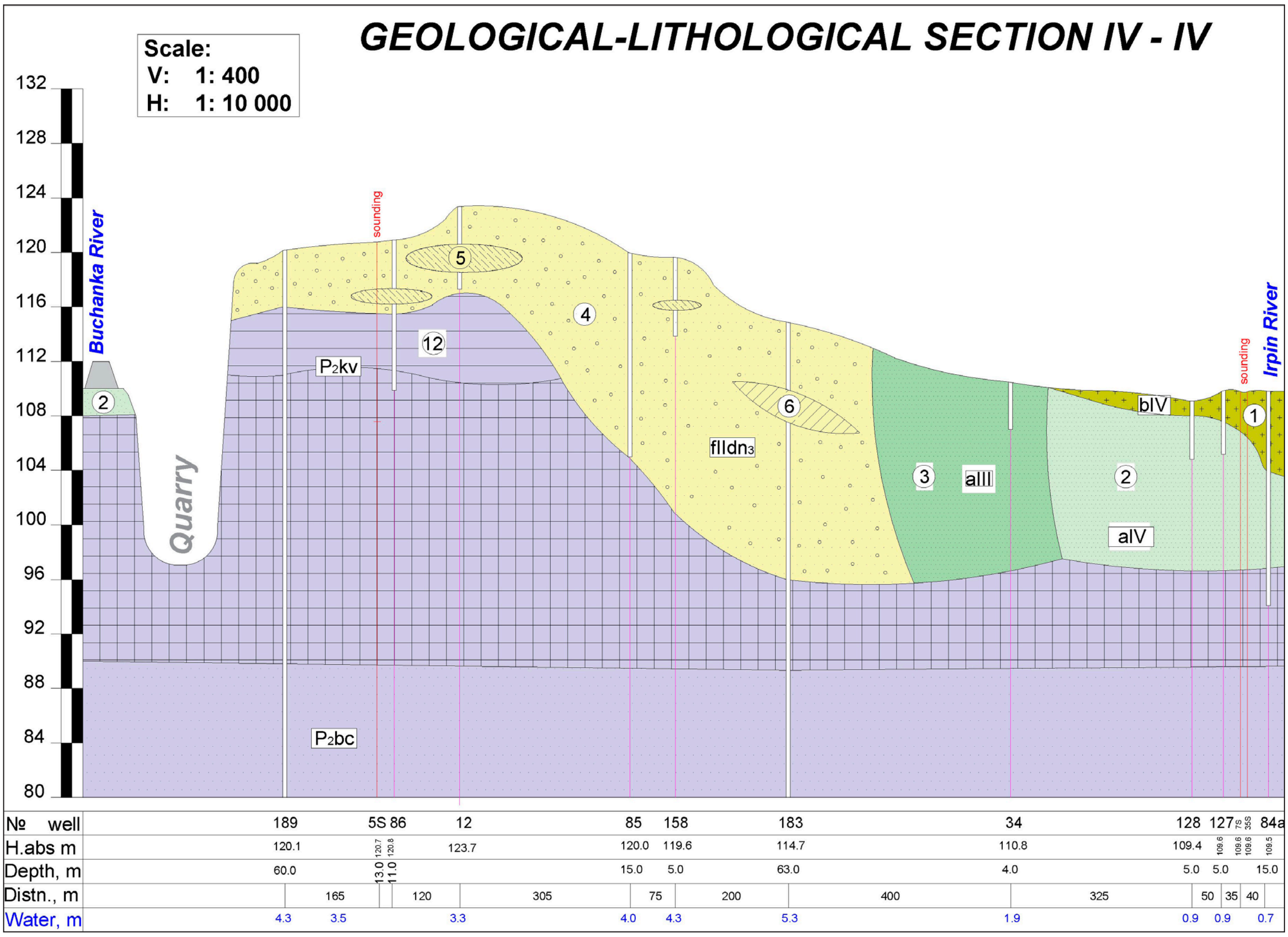
1. A complex of modern alluvial sandy-clay deposits (a_{IV}) with a thickness of 10–16 m represented by fine-grained quartz sands of light yellow and gray-yellow colour with lenses and interlayers of sandy loams and loams with a thickness of 0.3–0.9 m;
2. A complex of Upper Quaternary alluvial sandy-clay deposits (a_{III}) with a thickness of 8–12 m, represented by quartz medium-grained sands of light gray and yellow-gray colour with lenses and layers of sand with a thickness of 0.2–0.5 m;
3. A complex of Upper Quaternary water-glacial sand-clay deposits ($f_{II}dn$) with a thickness of 5–20 m represented by granular quartz sands of a light gray colour with lenses and interlayers of sands, loams and clays with a thickness of 0.2–2.7 m with the inclusion of gravel and weakly rolled pebbles of crystalline rocks;
4. A complex of Upper Quaternary moraine deposits ($g_{II}dn$) with a thickness of 8–13 m, represented by boulder loams and clays, in places with layers of sand (Figs. 5, 6).

The analysis of the geomechanical properties of the soils according to SSU B V.2.1-2-96 made it possible to divide the selected complexes into 12 engineering-geological elements (EGE) which are presented in the geological-lithological sections (Fig. 7).


GEOLOGICAL-LITHOLOGICAL SECTION I - I
Scale:
V: 1: 600
H: 1: 10 000
Buchanka River
sounding
bIV
aIV
aIII
fIIdn3
gIIdn2
fIIdn1
P3ch
P3kv
P2bc
№ well 2 1 8S 28 17 9 14 15
H.abs m 113.6 114.8 117.3 130.0 151.2 155.6 158.5 160.0
Depth, m 6.0 6.0 15 83 30 94 89
Distn., m 127 110 275 415 375 280 245
Water, m 1.2 2.4 2.3 17.1 19.2 20.8 21.4


GEOLOGICAL-LITHOLOGICAL SECTION II - II
Scale:
V: 1: 500
H: 1: 10 000
Buchanka River
bIV
aIV
aIII
fIIdn3
gIIdn2
fIIdn1
P3ch
P2kv
P2bc
№ well 144 10S 17 77 181 55 84 106 107 145 83 115 135 60
H.abs m 113.4 114.0 119.2 120.0 121.5 126.0 128.7 131.7 146.6 155.0 157.0 149.0 145.0 147.0
Depth, m 8.0 12.6 8.0 53.0 53.0 10.0 15.0 5.0 5.0 10.0 35.0 5.0 81.0 89.0
Distn., m 250 208 90 100 95 70 245 225 175 375 150 100
Water, m 1.2 4.2 3.0 1.6 2.3 2.7 4.7 19.6 11.2 12.2


GEOLOGICAL-LITHOLOGICAL SECTION III - III
Scale:
V: 1: 400
H: 1: 20 000
Buchanka River
Irpin River
sounding
tIV
alV
blV
fIIdn3
P2kv
P2bc
№ well: 2a 6S 183 41 9S 179 98 121a 48 4S 18 25 19 14 15 30 22 6
H.abs m: 114.5 121.2 123.8 126.6 127.6 127.0 127.3 122.4 120.3 120.2 119.7 117.6 114.6 112.5 112.3 115.0 120.7 110.0
Depth, m: 1.6 17.6 8 5.5 15 3.2 10 13 8 5 8 10 20 4
Distn., m: 270 55 225 145 415 120 540 180 115 130 130 245 275 180 375
Water, m: 1.2 5.2 5.8 2.9 3.6 2.5 1.7 0.8 1.5 10.2 8.0


GEOLOGICAL-LITHOLOGICAL SECTION IV - IV
Scale:
V: 1: 400
H: 1: 10 000
Buchanka River
Irpin River
Quarry
sounding
P2kv
P2bc
fIIdn3
aIII
alV
blV
№ well: 189 5S 86 12 85 158 183 34 128 127 84a
H.abs m: 120.1 123.7 120.0 119.6 114.7 110.8 109.4
Depth, m: 60.0 13.0 11.0 15.0 5.0 63.0 4.0 5.0 5.0 15.0
Distn., m: 165 120 305 75 200 400 325 50 35 40
Water, m: 4.3 3.5 3.3 4.0 4.3 5.3 1.9 0.9 0.9 0.7

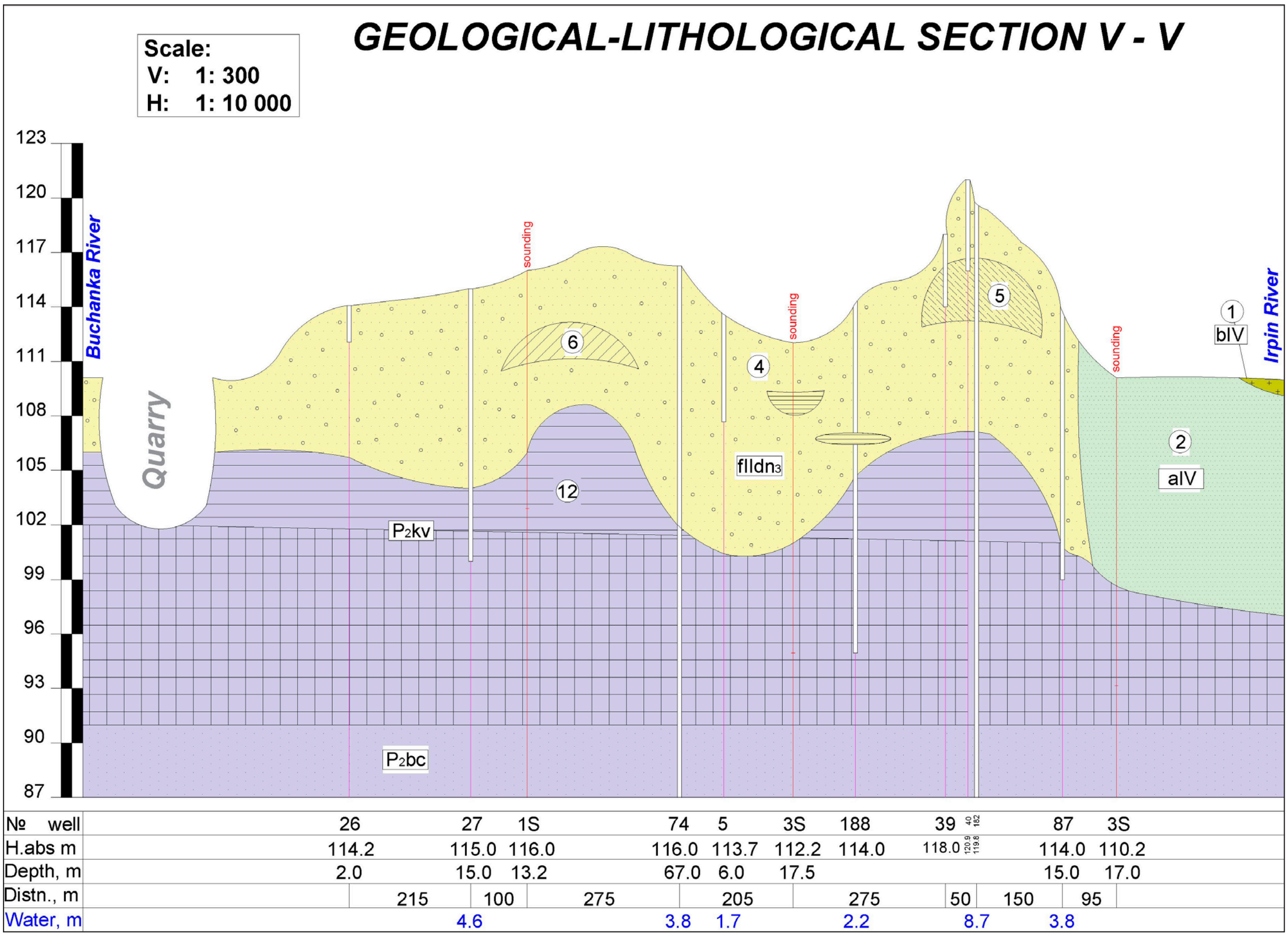


Fig. 7. Geological-lithological sections I-V on Irpin city's territory along conditional lines (Zhyrnov & Solomakha, 2022).
Sl. 7. Geološko-litološki profili I-V na območju mesta Irpin (Zhyrnov & Solomakha, 2022).

Table 1. Engineering-geological elements (EGE) are presented in the geological-lithological sections.
Tabela 1. Inženirsko-geološki elementi (IGE), ki so predstavljeni na geološko-litoloških profilih.

№ EGE	Description
1	Peat, mainly finely decomposed, brown and brownish-brown in colour. Reed material is present in the composition of peat, and sedge material plays a secondary role. Peat is often sandy, which is the result of the washing-out of organic components from its mass. The peat is medium ashy, strongly moist, plasticity and very compressible. Peat is characterised by poor geomechanical properties and cannot be the basis for buildings and structures.
2	Quartz sand with the inclusion of weakly rounded quartz grains. Lenses and layers of sandy loam, loam and silt are found at various depths. The sand is heterogeneous, of poor density, fine and fine-grained, horizontally layered, low water permeability, medium deformability, compressibility and strength.
3	Medium-grained quartz sand of light gray and yellow-gray colour, with lenses and layers of sand 0.2–0.5 m thick. Sand is heterogeneous, poorly compacted, medium permeable, medium deformability, compressibility and strength.
4	Light-gray multi-grained quartz sands with brown and red-brown layers and spots of ferruginization. The sand is layered with the inclusion of weakly rounded quartz grains with separate inclusions of gravel and pebbles, as well as with layers of gravel-pebble material with a thickness of 5 to 25 cm. The sand is homogeneous, with a low degree of compactibility, high permeable, medium deformability, compressibility and strength.
5	Light-yellow and brown-yellow sandy loam. The soil is thin-layered, sometimes with layers of sand, loam and clay. Statistical processing of the granulometric composition gave the following content of fractions: sand – 64 %, dust – 28 %, clay – 8 %. Sandy loam is solid, dense, weakly compressible and medium deformability.
6	Moraine loam of light composition. Loam is dense, stiff, low water permeability, weakly compressible and medium deformability.
7	Moraine clay of dark brown colour with inclusions of pebbles and boulders. Clay is dense, stiff, impermeable, weakly compressible and medium deformability.
8	Moraine loam. Loam is dense, stiff, low water permeability, weakly compressible and slightly deformable.
9	Quartz sand. The sand is homogeneous, with a high permeable, medium deformability, compressibility and strength.
10	Quartz sand. Sand is heterogeneous, poorly compacted, medium permeable, medium deformability, compressibility and strength.
11	Sandy aleurite, thinly laminated, of low strength, medium-deformable.
12	Marl.

Table 2. Geomechanical properties of biogenic soils.
Tabela 2. Geomechanske lastnosti biogenih tal.

№	Indicators of geomechanical properties	EGE-1
1	Degree of soil decomposition, R (%)	> 20
2	Soil ash content, %	24
3	Weighted soil moisture, w (%)	390
4	Plasticity index	143
5	Density of wet peat γ_o (g/cm^3)	1.01
6	Density of dry peat, γ_d (g/cm^3)	0.22
7	Solid particles density, γ_s (g/cm^3)	1.57
8	Porosity, e	19
9	Volume shrinkage, ε_{shV}	34
10	Specific adhesion, C (KPa)	0.33
11	Modulus of deformation, E_o (MPa)	2.6

Table. 3. Geomechanical properties of sandy soils.
Tabela. 3. Geomechanske lastnosti peščenih tal.

№	Indicators of geomechanical properties	EGE-2	EGE-3	EGE-4	EGE-9	EGE-10
1	Coefficient of non-uniformity, Cu	1.7	2.1	3.4	4.0	1.9
2	Compaction coefficient, Cc (%)	7–15	8–12	8–12	-	7–10
3	Density, γ_o (g/cm^3)	2.02	2.00	2.00	1.99	1.97
4	Bulk density, γ_c (g/cm^3)	1.70	1.70	1.72	1.66	1.68
5	Natural slope's angle dry (°)	33	32	33	-	29
6	Natural slope's angle underwater (°)	25	25	29	-	23
7	Internal friction's angle, φ (°)	34	37	27	33	33
8	Specific adhesion, C (KPa)	2.94	0.98	1.96	2.94	0.98
9	Modulus of deformation, E_o (MPa)	23.5	27.5	31.4	22.6	23.5

Table. 4. Geomechanical properties of clayey soils.
Tabela. 4. Geomehanske lastnosti glinenih tal.

№	Indicators of geomechanical properties	EGE-5	EGE-6	EGE-7	EGE-8	EGE-11	EGE-12
1	Moisture content, w (%)	16	13	22	14	29	31
2	The upper limit of plasticity, w_l (%)	22	26	44	35	50	34
3	Plasticity index, P_I	4	10	22	14	18	25
4	Density, γ_o (g/cm^3)	1.92	2.14	1.99	2.08	1.91	1.89
5	Bulk density, γ_c (g/cm^3)	1.69	1.89	1.63	1.80	1.48	1.44
6	Porosity, e	0.58	0.43	0.67	0.51	0.84	0.90
7	Internal friction's angle, φ (°)	27	23	18	22	20	18
8	Specific adhesion, C (KPa)	15.7	25.9	49.0	32.4	42.2	72.6
9	Modulus of deformation, E_o (MPa)	29.4	45.1	34.3	53.9	23.5	25.5

Engineering-geological districts and subdistricts can be distinguished based on the geomorphological and engineering-geological maps' comparison (Figs. 2, 5) by the procedure of engineering-geological zoning. Geomechanical properties of engineering-geological elements are the basis for the selection of engineering-geological sites, however, hydrogeological data are needed for this, so the selection of engineering-geological sites is not possible yet. However, the soils' geomechanical characteristics determine the lithological component of Irpin city's construction assessment, which will be discussed later.

So, the I district is represented by Upper- and Holocene Quaternary Q_{III}-Q_{IV} erodible and depositional alluvial plain with absolute altitudes of 107–118 m. Alluvial deposits with a thickness of 8–16 m lie on the Kyiv suite's marls, which are a water-resistant layer for this area. Two engineering-geological subdistricts are allocated in the first district: 1) Alluvial floodplain inundated flat terrace with swamped areas and peaty depressions of Holocene age that composed modern alluvial deposits a_{IV} with a capacity of 10–16 m, that covered by modern organogenic formations (silt, peat) b_{IV} with a capacity of 0.3–5.0 m. Alluvial deposits are represented by quarts of fine-grained sands of light yellow and grey-yellow colours with a layer of sandy loams and loam with a capacity of 0.3–0.9 m. The alluvial complex lies on the washed-out surface of the Kyiv suite's marls P_2kv; 2) Alluvial Upper Holocene slightly dissected first above-flood terrace that composed by alluvial sandy and clayey deposits a_{III} with a capacity of 8–12 m, that represented by alluvial quarts fine-grained sands of light grey and yellow-grey colours with lens and layers of sandy loams with a capacity of 0.2–0.5 m. The alluvial complex lies on the washed-out surface of the Kyiv suite's marls P_2kv.

The II district is represented by the Middle Quaternary Q_{II} denudation-depositional watershed moraine fluvioglacial plain with absolute altitudes of 120–160 m. Fluvioglacial and glacial deposits with a thickness of 5 to 23 m lie on the marls of the Kyiv suite, which is a regional water-resistance layer for this area. Two engineering-geological subdistricts are allocated in the II district: 1) Lowland part of moraine fluvioglacial wavy and slightly dissected plain of Dnipro age with absolute altitudes of 120–135 m. Subdistrict composed of complex of Middle Quaternary fluvioglacial sandy-clayey deposits ($f_{II}dn_3$) with a capacity of 5–20 m at 10 m medium capacity. The complex is represented by middle-grained quarts of sands of light grey colour with lens and layers of sandy loams, loams and clays with a capacity of 0.5–2.7 m with the inclusion of crystal rocks' gravel

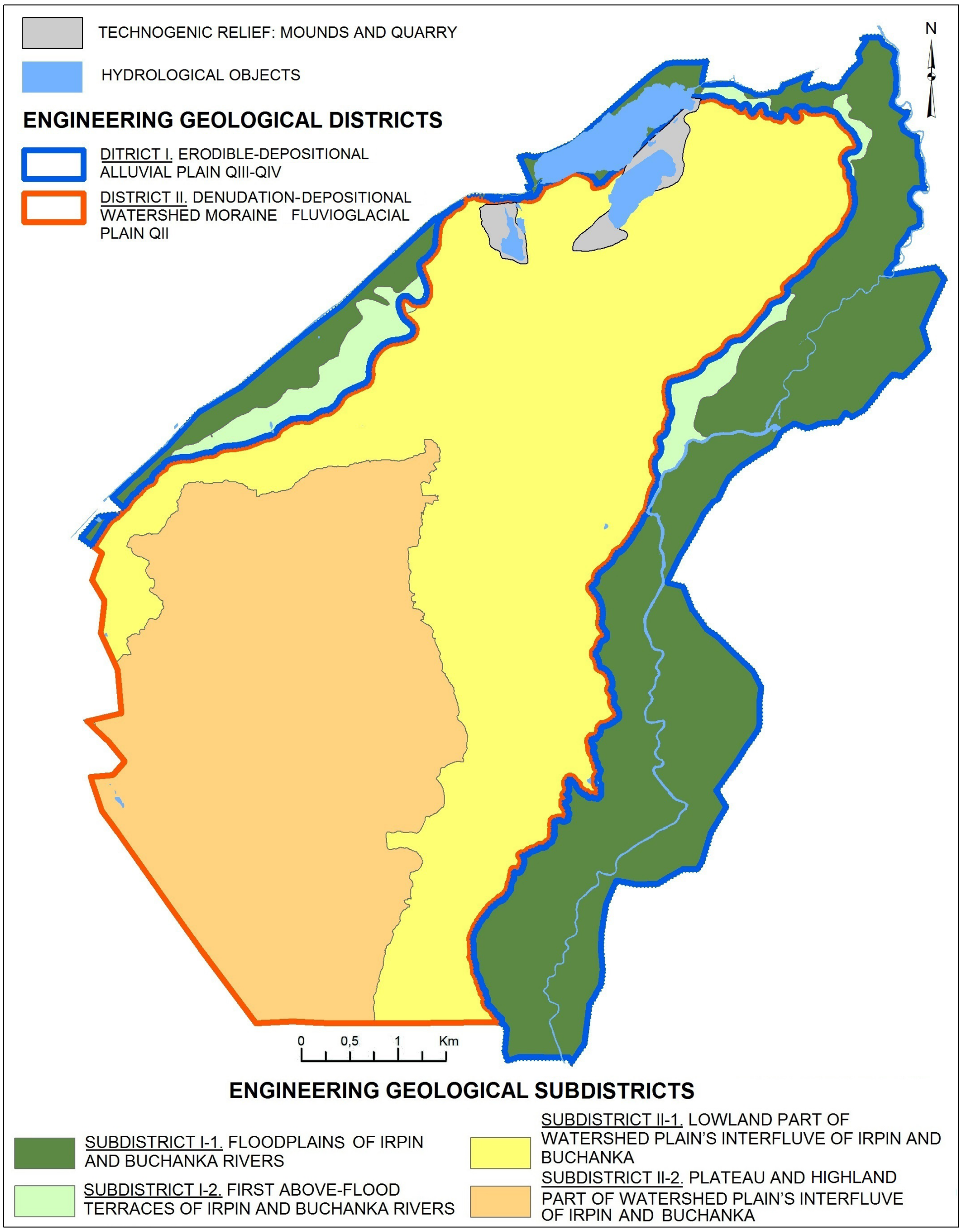


Fig. 8. Engineering-geological districts and subdistricts of Irpin city.

Sl. 8. Inženirsko-geološka okrožja in podokrožja mesta Irpin.

and pebble. Sometimes the gravel-pebble material is collected in the form of lenses and layers; 2) Plateau and elevated portion of moraine fluvioglacial wavy and slightly dissected plain of Dnipro age with absolute altitudes of 135–160 m. Subdistrict consists of moraine complexes ($g_{II}dn_2$) with a capacity of 8–13 m, which cover and underlie with fluvioglacial sandy-clayey deposits of advance and retreat of Dnipro glacier ($f_{II}dn_1$ and $f_{II}dn_3$). Moraine deposits are represented by loams and clays with the inclusion of pebbles and boulders, fluvioglacial deposits are represented by average-grained quarts sands with layers of sandy loams and loams including gravel and pebbles. (Fig. 8) (Tsybko, 2020; Zhyrnov & Solomakha, 2022).

Sites with artificially modified relief and arroyo's bottoms and detrital cones of the Holocene age will relate to engineering-geological sites due to the small size and local spread.

Discussion

The conducted research on the geological-genetic structure map of Irpin city allows us to determine two topics for discussion:

- Disadvantages of studying soil properties (engineering-geological elements) within Irpin city;
- Geological-lithological factors' accounting for drawing up schemes of construction assessment in the project of the master plan of Irpin city.

1. Disadvantages of studying soil properties (engineering-geological elements) within Irpin city;

The main disadvantages in the determination of soils' geomechanical properties (engineering-geological elements) within Irpin city are the absence of the following studies: a) determination of chemical soils' properties, in particular, missing data on solubility, acid-base properties and soils' chemical aggressiveness; b) determination of soils' physical properties, in particular, missing information on thermophysical (thermal capacity, soils' frost resistance) and electrical properties (electrical conductivity, soils' corrosive activity); c) determination of soils' biotic properties (biological activity, bioaggressiveness and biocorrosion in soils);d) determination of certain geomechanical properties of soils (rheological properties: creep, relaxation of stresses in soils, soils' long-term strength; dynamic properties: soils' behavior under vibration and impulsive effects, soils' liquefaction)(Trofimov et al., 2005). The categories of soils according to seismic properties according to the construction sites' normative seismicity are not defined (Building regulations B.1.1-12:2014, 2014). It is worth noting that the construction of geological-lithological sections and the determination of soils' geomechanical properties took place only in the high-density area and most developed northern, north-eastern and north-western city's parts, while the rest of Irpin's territory has not been explored, which is a significant disadvantage for the urban development in the distant future.

2. Geological-lithological factors' accounting for drawing up schemes of construction assessment in the project of the master plan of Irpin city. The compiled geological-lithological map and sections can be used to determine the territory with different degrees of geological conditions' complexity for the city's construction assessment at this stage. (tab. 5; Building regulations A.2.1-1-2008, 2008).

The study of the geological-lithological structure of Irpin city allows us to conclude that the engineering-geological conditions for the development of the city's territory are simple and the soils that consist of the Quaternary and Paleogene rock strata suitable for their use by their geomechanical properties as a natural base for laying foundations, except the peat layer, which must be removed or which must be excluded during construction development (Amaryan, 1990).

Table 5. Category of geological-lithological conditions' complexity for construction assessment.
Tabela 5. Kategorija zahtevnosti inženirsko-litoloških razmer za oceno gradnje.

Factors	I (easy)	II (average)	III (difficult)
Geological-lithological	No more than four different geological-lithologicalunitsof rocks with horizontal laying lithological layers. Soil characteristics by plan or by depth with natural changes. Absence of soils with poor geomechanical properties.	No more than six different geological-lithological units of rocks with sloping laying lithological layers. Soil characteristics as per plan or according to depth with natural changes. Absence of soils with poor geomechanical properties.	More than six different geological-lithological units of rocks. Capacity suddenly changed, lens' soil laying. There are a high diversity index's soil characteristic, which vary with out-of-specification changes. Presence of soils with poor geomechanical properties (peak, silt).

Conclusion

1. Qualitative engineering-construction assessment as part of the project of the urban master plan should be based on the engineering-geological zoning of the territory with the determination of engineering-geological units. Consideration of geological-lithological estimated factors in engineering construction assessment is the basis for the selection of engineering-geological units (districts and subdistricts) and also sets the preconditions for the selection of engineering-geological sites based on the geomechanical properties of engineering-geological elements (EGE).
2. The morphogenetic and morphological structure of the relief forms a basis for engineering-geological districts and subdistricts selection. It is necessary to distinguish the geological-genetic complexes of Quaternary deposits, that constitute them, while relief's morphological elements determine the lithological composition of the mentioned Quaternary deposits.
3. The analysis of the territory's geomorphological features and their geological structure made it possible to distinguish four geological-genetic rocks' complexes on the territories of Irpin's city: 1) complex of modern alluvial sandy-clayey deposits (a_{IV}) with a thickness of 10–16 m (sands with lenses and layers of sandy loams, loams); 2) complex of Upper Quaternary alluvial sandy-clay deposits (a_{III}) with a thickness of 8–12 m (sands with lenses and layers of sandy loams); 3) complex of Upper Quaternary water-glacial sand-clay deposits ($f_{II}dn_1$) with a thickness of 5–20 m (sands with lenses and layers of sandy loams, loams and clays with inclusion of gravel, boulders, pebbles); 4) complex of Upper Quaternary moraine deposits ($g_{II}dn_2$) with a thickness of 8–13 m (boulder loams, clays and clays with layers of sand).
4. The analysis of the soils' geomechanical properties made it possible to divide the selected complexes into 12 engineering-geological elements (EGE) with appropriate geomechanical properties, of which only EGE-1 (peat) is unsatisfactory as a natural basis for laying foundations. The peat layer must be removed during construction.
5. There are engineering-geological districts according to morphogenetic features and common conditions of geological development and engineering-geological subdistricts according to morphological features and engineering-geological complexes of Quaternary rocks based on the conjugate cartographic analysis' method of geomorphological and engineering-geological maps. So, the first district is represented by an erodible-depositional alluvial plain with two engineering-geological subdistricts: floodplain terraces of the Irpin and Buchanka rivers with swamped areas and peat depressions with alluvial (sands, sandy loams, loam) and biogenic (peat) deposits and first above-flood terraces of mentioned rivers with alluvial deposits (sands, sandy loam. The second district is represented by a denudation-depositional watershed moraine water-glacial plain with two engineering-geological subdistricts: lowland part, highland part and plateau of moraine fluvioglacial plain with fluvioglacial and glacial deposits, (sands, sandy loams, loam with inclusion of gravel, pebbles and boulders).
6. Geological-lithological estimated factors of Irpin city are simple in complexity and soils, in general, are suitable for use as a natural basis for laying foundations. Engineering-geological elements (EGE) 3, 4, 7, 8, 9, 11, 12 can serve as a natural basis for laying foundations. The development of the floodplains of the Buchanka and Irpin Rivers is not recommended for environmental reasons, therefore EGE-2 is excluded from use. A deep strip foundation is recommended for low-rise buildings, taking into account the geomechanical properties of soils. The best type of foundation is the pile type for multi-storey buildings. It is necessary to use waterproofing materials, when arranging foundations. It is necessary to equip horizontal drainage and rainwater drainage for areas with a high level of groundwater, for aggressive waters appropriate grades of concrete and anti-corrosion protection for underground metal reinforcement should be used. (Building regulations B.2.1-10:2018, 2018).

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