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Adaptation of Engineering-Geological Database for Very Shallow Geothermal Potential Mapping of the Urban Areas. Case study: Warsaw

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ABSTRACT

The development of the Smart City is determined by the use of information technology to increase the efficiency of the urban infrastructure and improve the inhabitants' quality of life. An important element of the Smart City is sustainable economic development, which can be achieved, among other things, through the efficient use of the ground-rock medium for clean energy and the infrastructural development of the underground space. Thermal parameters of the ground-rock medium (subsoil), such as thermal conductivity, resistivity, and specific heat capacity are crucial for determining the very shallow geothermal potential (vSGP) of urbanised areas. Without this information, it would be impossible to correctly design thermoactive building components such as geothermal energy piles, thermoactive foundations or energy tunnels, as well as to estimate the performance of heat pump systems based on ground-source exchangers. In addition, information on the thermal properties of soils (compressive strength Rc<=600 kPa, according to ISO 14689) is essential in the design and prediction of the operating conditions of transmission infrastructures in the fields of energy, heat supply, fresh water, wastewater, etc.

The Engineering-Geological Database (BDGI) is the country's largest and unique collection of digital data on engineering geology and geotechnical conditions in Poland. The database contains nearly 500,000 boreholes entered between 1998 and 2023, of which more than 35,000 are located in the area concerning this paper. The information gathered in the BDGI, i.e. borehole lithological profiles, groundwater depth, density and sample water content supported by additional field and laboratory studies, made it possible to semi-automatically generate maps of thermal properties of subsurface "at" and "to" the given depths of 2, 5, 10, 15, 20, 25 and 30 m BSL. The results of the studies and database analyses were presented in the form of tables, charts and sample maps for Warsaw.

1. INTRODUCTION

Meeting existing national, EU and other international climate change and energy balance regulations and requirements means a significant increase in the share of RES in Poland's total energy mix. Low-temperature geothermal perfectly fits into the strategy of gradual reduction of CO_2 emissions. Thermal energy obtained through ground-source heat pumps is an efficient and stable source for heating, cooling, seasonal storage, and thermal energy recovery. It contributes to reducing low emissions and improving air quality and positively impacts the environment and human health. Cities possess significant and diverse motivations to transition their energy sectors towards a model with low carbon emissions. However, they frequently face various challenges in implementing such a transformation. One notable obstacle is that, despite urban areas exhibiting the highest energy demand density, cities often grapple with space limitations that hinder the installation of additional energy generation and/or long-duration energy storage systems (Goetzl et. al, 2023).

The growing demand for new transport infrastructure and additional office, retail and residential space is stimulating new construction projects. These projects, due to the ever-increasing demand for floor space, are significantly extending the underground floors, thereby increasing the area of structural and foundation elements in direct contact with the ground. These projects and their underground parts could have great potential to function as a source of shallow geothermal energy if their foundation elements (slabs, diaphragm walls and foundation piles) were equipped with heat exchangers attached to the reinforcement. The vast majority of high-rise buildings and underground urban infrastructure (e.g. underground car parks, underground tunnels, metro stations) have extensive foundations that can be thermally activated for heating and cooling purposes. Energy foundations are particularly attractive for urbanized areas, where space for classical borehole heat exchangers is very limited. The use of heat exchangers in foundations is common in European countries such as Austria, Germany, Switzerland and the UK. In Poland, it is still a new technology that is at an early stage of market development. This is due to the existence of several psychological, informational, educational and economic barriers.

The factor that allows the use of thermally active foundation element technology is the relatively constant temperature of the ground and its thermal properties such as thermal conductivity or heat capacity. In the exchanger, a closed-circuit plastic tube inserted into the foundation, a working medium (water or a water/propylene glycol mixture) circulates, which transports the thermal energy received from the surrounding ground-rock mass to the heat pump. Depending on the current demand, the foundation can extract heat energy from the ground during the heating season, or give back the surplus created during the air-conditioning/cooling of the facility. The economic viability of the system is determined by the thermal properties of the foundation (which affect the total metric area of the borehole heat exchangers) and the heat pump's coefficient of energy efficiency (COP), which describes the ratio of the amount of energy that can be extracted through the exchanger to the amount of energy required to power the unit - pump efficiency (Loveridge et. al, 2020). The most common types of thermally efficient structures include foundation geothermal energy piles, slurry walls, foundation slabs and tunnel lining elements including prefabricated tunnel segments excavated using TBM (tunnel boring machine) technology (Figure 1.)

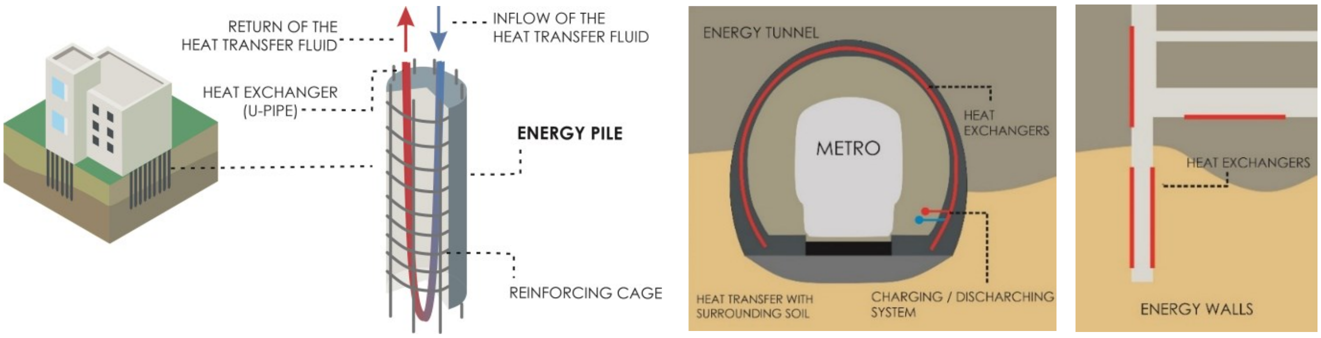

Figure 1: Examples of thermoactive construction elements (energy foundations).

Geothermal energy piles most often include large-diameter foundation piles. They are used primarily in the foundation of office buildings, but also residential buildings, where the energy demand for heating and cooling is exceptionally high. Additionally, geothermal energy piles are used to heat the surface of bridge structures, thanks to which it is possible to maintain this type of structure in winter without any maintenance (Bogusz, 2017). Surface de-icing takes place without the involvement of service teams. Diaphragm walls and foundation slabs constitute another important category of thermoactive structures. Compared to geothermal energy piles, they have a much larger contact surface with the soil and rock medium, which allows for better exchange and obtaining very large amounts of thermal energy. They are used in facilities such as underground garages and underground metro and railway stations. In the case of structures using thermoactive tunnel casings, the exchanger, as in the case of diaphragm walls, is embedded in the tunnel lining. A very large heat exchange surface enables effective cooling of the tunnel as well as cooling and heating of underground stations and facilities located in the immediate vicinity of the installation (Baralis et. al, 2018).

Thermoactive building foundation elements have an advantage over classic borehole heat exchangers (BHE). The financial outlays related to the use of technology are relatively lower than those necessary to produce classic vertical exchangers. Integrating heat exchangers into building foundations is much cheaper than drilling new boreholes. Additionally, the specific thermal efficiency obtained by using thermoactive structures is higher. This is due to a much larger contact surface of energy foundations with the ground compared to classic BHEs. The concept of zero-emission buildings forces designers to use available renewable energy resources by designing facilities equipped with thermoactive foundation elements (Bourne-Webb et al., 2016).

Due to the possibility of selecting technologies with different spatial dimensions, it is necessary to know the thermal parameters of the ground at different depths and levels to select the most advantageous way of extracting thermal energy from the ground. In highly urbanized centers, this allows the optimal selection of the technology with the most suitable performance with limited land use possibilities caused by existing structures and other underground utilities. Thermal conductivity, thermal resistivity and specific heat capacity parameters to a depth of 30 meters below ground level are essential information for the selection and design of very shallow geothermal technologies in urban areas. This applies primarily to thermoactive geostructures (foundation piles, energy walls or energy tunnels), but also to horizontal, spiral and very shallow vertical heat exchangers.

The task of parameterization of the thermal parameters of the building substrate was performed using information collected in the Engineering and Geological Database (BDGI). 35,000 boreholes from Warsaw were parameterized in terms of thermal properties. The results of the work indicate that the algorithm can be used in areas for which data stored in BDGI has been collected. For the purpose of parameterization, a Python algorithm was created enabling the conversion of lithological profiles into the point value of the thermal parameter of the soil and rock medium (thermal conductivity, resistivity, specific heat). Thermal parameters were taken from Soil and Rock Parameters Database, that gathers results from in situ and laboratory tests. After parameterization, Euclidean allocation was used to create maps of the thermal parameters of the shallow substrate (up to 30 m b.g.l.). The subsurface soil (compressive strength Rc<=600 kPa, according to ISO 14689) to this depth is well-identified and contains key information for the utilization of underground space in urban agglomerations for shallow geothermal purposes.

2. MATERIALS AND METHODS

Warsaw is situated in the Vistula River valley within the central part of the Warsaw trough, formed during the Quaternary period. The left-bank section of the city lies within the boundaries of the glacial upland—an elevated, flat area carved by the Vistula River along its eastern edge, descending sharply to the river valley. The valley itself comprises two flood-plain terraces and three over-flood terraces (Ryżyński & Bogusz, 2016).

The stratigraphic profile of Quaternary deposits in Warsaw consists of fluvioglacial, glacial, and ice-dammed lake sediments from glaciation periods, as well as fluvial and organic deposits from interglacial periods. Throughout the Holocene, the Vistula River accumulated a sedimentary complex with a thickness of 1.5 meters, comprising fine-grained sands interspersed with silty and sandy-mud layers. Oxbows in the region experienced the formation of peat and peaty aggradations exceeding 2 meters in thickness. During the Dryas period, dune formations occurred, as well as Vistula accumulation of deposits, 5 meters thick, consisting of variously grained sands and gravels. Terrace areas were covered with compact clayey mud. During the Pleistocene-Holocene time, glacial uplands were covered with loess-like silts and sandy eluvial deposits. Beneath these sediments, are Pliocene deposits, mostly in the form of clay with a thickness of up to 100-140 meters. The roof of the Pliocene deposits was influenced by glacitectonic processes. Miocene sediments are made out of sand, silt and clay with lignite seams (tens of meters thickness). Older deposits consist of marine clastic sediments from the Oligocene (sand, silt, and clays, 50 to 80 meters thick), forming a continuous cover on the roof of the Cretaceous formations. The oldest known sedimentary series in Warsaw comprises Cretaceous marly sediments, including rocks such as marls and sandy marls. The roof of this series in the central Warsaw Trough is situated at depths ranging between 260 and 290 meters below ground level (Frankowski & Wysokiński, 2000).

While analyzing Warsaw ground parameters for urban planning and shallow geothermal exploration, only soil (compressive strength Rc<=600 kPa, according to ISO 14689) deposits are taken into consideration, as rock sediments lay far too deep to have influence on the case.

2.1 Data Source – Engineering-Geological Database (BDGI)

Engineering-Geological Database is the largest unique collection of digital data for biggest Polish urban agglomerations, containing geological, geotechnical, hydrogeological reports as well as borehole profiles. These atlases have been developed for the largest Polish agglomerations (Figure 2), and the dataset for each city consists of 15 000-50 000 shallow (about 3-10 m deep) geological boreholes. These boreholes form the basis of thematic maps. They allow assessment of geo-engineering conditions of agglomeration areas, e.g. in spatial planning or preparation of forecasts and economic aspects of investments (Frankowski et al., 2018)

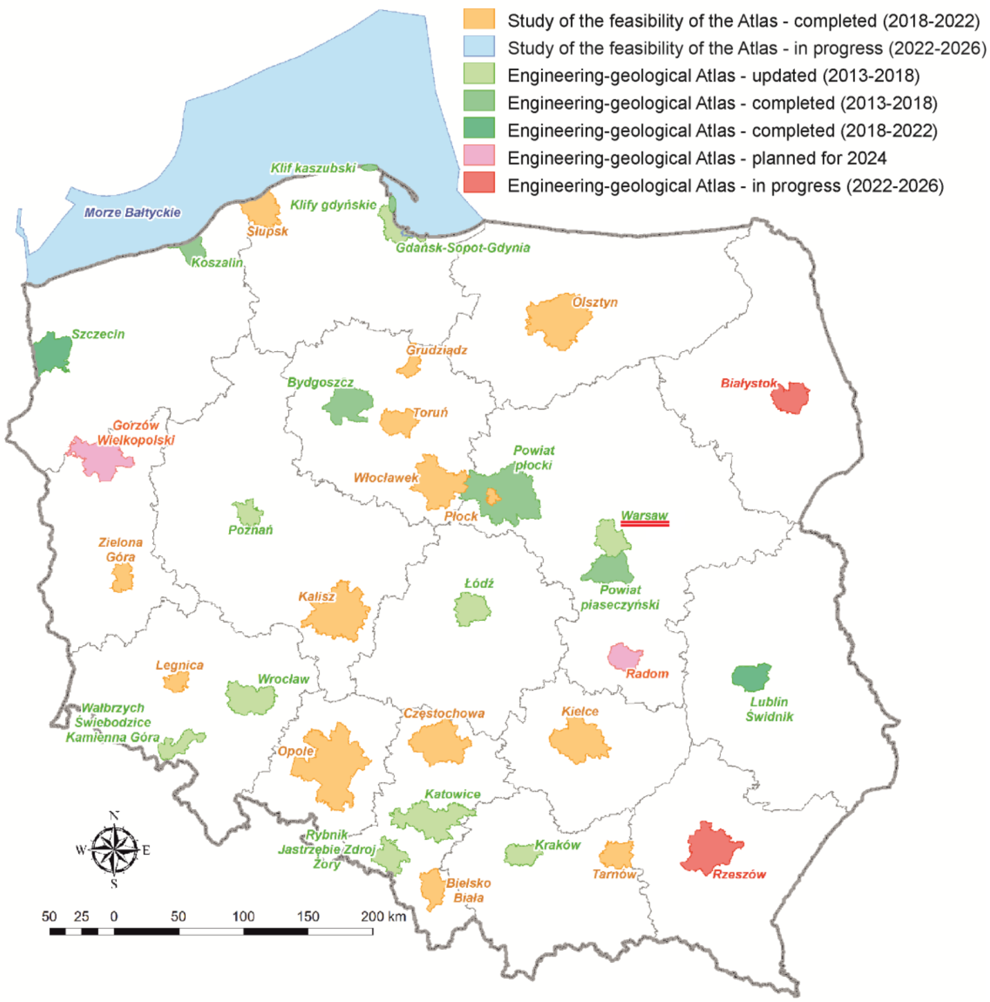

Figure 2: Status of works in development of Engineering-geological Atlases in 1 : 10 000 scale (https://geoportal.pgi.gov.pl/atlasy_gi/projekt/realizacja)

Borehole data, along with dynamic and hydrogeological soundings, are stored in the GeoSTAR software database and used to create profiles, cross-sections, statistics, models, etc. GeoSTAR software is widely used as an unofficial standard for collecting and managing geotechnical and geo-engineering borehole data. In Poland alone, it is used by more than 400 public and private entities such as universities, research institutes and geotechnical and geological companies and consultants. Its structure is a set of related tables, shown as a simplified diagram in Figure 3. Despite the evolution of the software, the main tables and fields have remained unchanged over the years (GS_Borehole tables - contains information on location, depth, contractor, drilling date, drilling method, etc. and GS_Profile log - contains lithostratigraphic profile, layer genesis and reclassification of the borehole profile to geological-engineering, parameterised units). This makes it possible to use archival database records from both private and public companies as well as geological authorities. The dictionaries used in GeoSTAR software were developed following Polish Standards for the classification of soils and rocks and EU ISO/Eurocode standards (Ryżyński & Nałęcz, 2016).

The geological-engineering database (BDGI), based on the GeoSTAR database, makes it possible to collect various types of geological and geotechnical information together with laboratory test results. These data are the basis for regional subsoil characterisation in urban areas and its modelling, as well as for the preparation of geological-engineering atlases. The prepared database serves as a reference material for analysis in GIS technology, including precise quantitative and qualitative geostatistical analyses of lithology, stratigraphy, genesis and soil and rock parameters. By creating and combining various digital layers, thematic maps are generated. These present and synthesise the regional geological and geotechnical information stored in the database, enabling the presentation of factors influencing construction conditions in the subsurface. The methodology and procedures for the digital production of geological and engineering atlases are presented in the document 'Geological and engineering atlases of urban agglomerations at a scale of 1:10,000 - instructional document', available at http://atlasy.pgi.gov.pl. This document serves as a comprehensive guide, providing insight into the steps involved in producing these valuable atlases (Judkowiak et al., 2021).

All created data are available in spatial data viewers and can be accessed through the GIS browser GEOLOG (adopted for both desktop and mobile devices), that allows for downloading borehole profiles and PDF versions of engineering-geological and cross-sections. The Engineering Geological Database has significant use in preliminary investigation of the subsoil/soil prior to in situ testing, planning and interpretation of in situ and laboratory tests, reporting of the data and increased understanding of the importance of city subsurface (Frankowski et al., 2021).

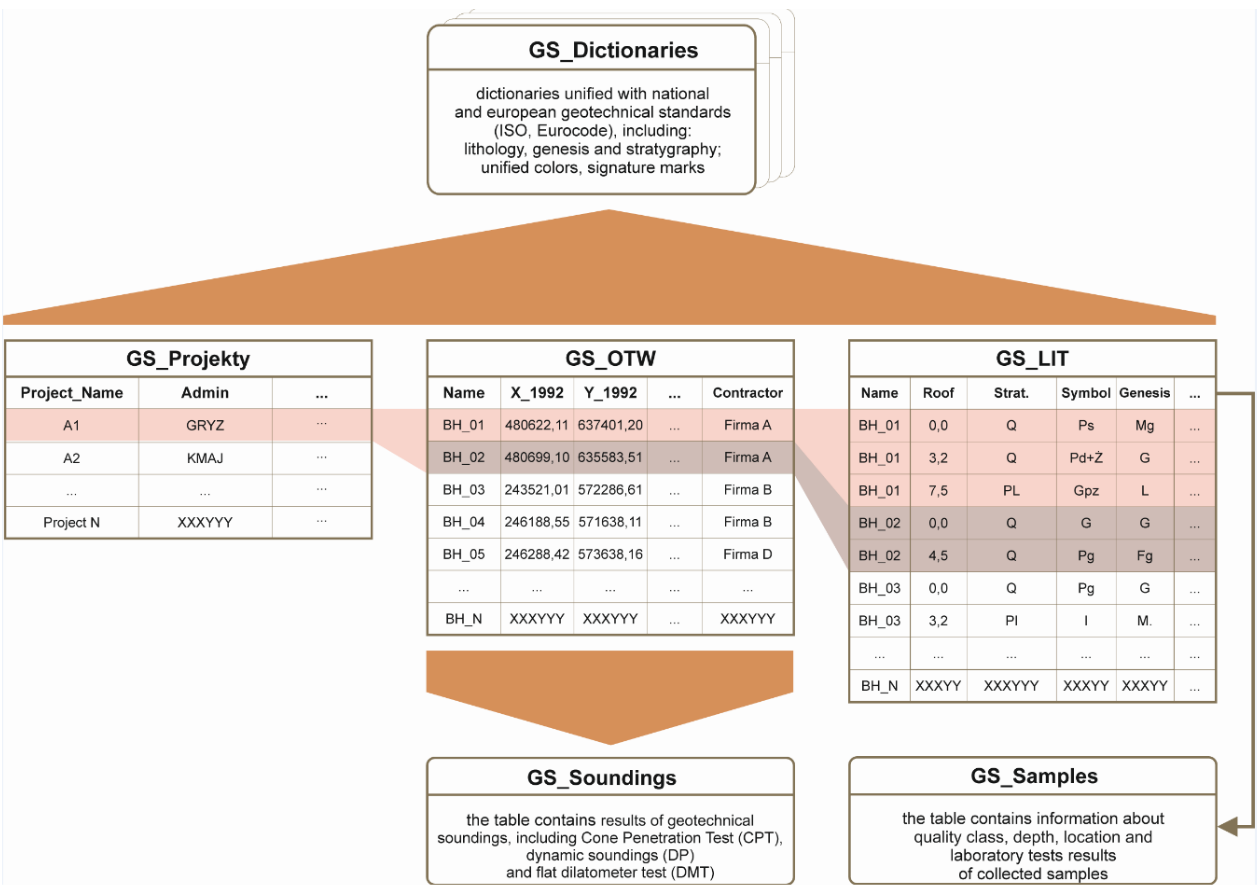

Figure 3: The simplified scheme of GEOSTAR Borehole Data Base structure (Ryżyński & Nałęcz, 2016).

2.2 Data Source – Soil and Rock Thermal Properties Database

Measurements of effective thermal conductivity are performed on mineral soils samples with various water content and bulk density. Details of the testing procedure are described in the paper "Serial Laboratory Effective Thermal Conductivity Measurements of

Cohesive and Non-cohesive Soils for the Purpose of Shallow Geothermal Potential Mapping and Databases — Methodology and Testing Procedure Recommendations" by Łukawska et al., 2020.

Thermal parameters obtained during laboratory tests on over 360 samples of cohesive and non-cohesive soils from various regions of Poland were compiled in a database. Thermal conductivity measurements were performed for 5 ranges of water content for non-cohesive soils and 5 ranges of liquidity index according to national soil classification standard PN-B-02480:1986. Each sample has been tested on three subsamples. In total over 5400 unique measurements of λ parameter were performed. In addition to measurements of thermal properties, the database contains information on physical properties (water content, bulk density, porosity, grain size and consistency parameters), organic matter and carbonate content, simplified mineral composition, genesis and stratigraphy, and coordinates of the sample collection point.

In the case of all measured non-cohesive soil type samples, the rise of effective thermal conductivity values is observed as the water content is increasing. The most dynamic increase in thermal conductivity values occurs in the water content class between 0 to 5% (see Table 1). As the porous space of non-cohesive soils gradually saturates with water, the increase in effective thermal conductivity value becomes slower. The highest values of thermal conductivity are observed in non-cohesive soils that are fully saturated with water (2-phase media). From the scope of analyzed non-cohesive soil types the lowest thermal conductivity values were measured for gravels (Ż) – from 0.22 W/m·K in water content range 0-5% to 2.80 W/m·K for water content >20%. The highest thermal conductivity values were measured for sandy gravels + cobble (Po) – from 0.42 W/m·K in water content range 0-5% to 3.21 W/m·K for water content >20%.

Table 1: Values of effective thermal conductivity (λ) for non-cohesive soils samples according to water content (Łukawska et al., 2021a).

Soil classification according to PN-B-02480:1986	Water content [%]														
	0 - 5			5 - 10			10 - 15			15 - 20			> 20		
	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ
Pπ Piasek pylasty	0.28	1.80	1.06	1.66	2.11	1.86	1.82	2.25	2.14	2.23	2.67	2.54	2.60	2.88	2.76
Pd Piasek drobny	0.24	1.81	1.08	1.70	2.16	1.90	1.87	2.42	2.17	2.39	2.75	2.66	2.63	2.90	2.77
Ps Piasek średni	0.28	1.86	1.11	1.72	2.21	1.95	1.93	2.45	2.20	2.41	2.90	2.73	2.88	3.12	3.03
Pr Piasek gruby	0.25	1.89	1.12	1.74	2.25	2.00	1.98	2.46	2.27	2.39	2.83	2.70	2.71	3.01	2.85
Po Pospółka	0.42	2.01	1.26	1.82	2.31	2.19	2.10	2.56	2.33	2.55	2.92	2.62	2.81	3.21	3.05
Ż Żwir	0.22	1.76	1.03	1.61	2.00	1.84	1.95	2.37	2.15	2.27	2.61	2.30	2.54	2.80	2.67

Symbol description: λ min – lowest measured effective thermal conductivity value [W/m·K]; λ max – highest measured effective thermal conductivity value [W/m·K]; x̄ λ – arithmetic mean value of effective thermal conductivity for certain soil type [W/m·K].

Soil classification based on particle size distribution according to PN-B-02480:1986:
***Pπ**: 0.05 – 2.00 mm: 68 ÷ 90 %; 0.002 – 0.05 mm: 10 ÷ 30 %; <0.002 mm: 0 ÷ 2 %;*
***Pd**: > 2 mm: < 10 %; > 0.5 mm: < 50 %; >0.25 mm: < 50 %;*
***Ps**: > 2 mm: < 10 %; > 0.5 mm: < 50 %; >0.25 mm: > 50 %;*
***Pr**: > 2 mm: < 10 %; > 0.5 mm: > 50 %;*
***Po**: < 0.002 mm: < 2 %; > 2 mm: 10 - 50 %;*
***Ż**: < 0.002 mm: < 2 %; > 2 mm: > 50 %.*

The measured values of effective thermal conductivity for cohesive soils are initially increasing as the water content (saturation) increases, but in the later phase, the λ values are decreasing (see Table 2). For all types of tested cohesive soils highest values of thermal conductivity are for the liquidity index range 0 < IL ≤ 0.25. From the scope of analyzed cohesive soil types the highest thermal conductivity values were measured for sandy clays (Pg) – up to 3.31 W/m·K for the liquidity index range 0 < IL ≤ 0.25. Lowest values were measured for clays (I) – from 0.61 W/m·K in IL < 0 range to 1.50 W/m·K for the liquidity index range 0 < IL ≤ 0.25. All cohesive soil types show a decrease in effective thermal conductivity values in IL ranges exceeding 0.25.

Table 2: Values of effective thermal conductivity (λ) for cohesive soils samples according to liquidity index classes (IL) (Łukawska et al., 2021a).

Soil classification according to PN-B-02480:1986	Liquidity index IL [-]														
	IL < 0			IL ≤ 0			0 < IL ≤ 0,25			0,25 < IL ≤ 0,50			0,50 < IL ≤ 1,00		
	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ	λ min	λ max	x̄ λ
π Pył	0.61	1.40	1.25	1.10	1.91	1.71	1.80	2.31	2.10	1.60	2.10	1.90	1.41	1.91	1.71
Pg Piasek gliniasty	0.71	1.61	1.45	2.10	2.86	2.71	2.41	3.31	3.06	2.00	2.80	2.56	1.91	2.51	2.31
Gp Glina piaszczysta	1.01	2.10	1.90	2.01	2.61	2.46	2.41	2.90	2.76	2.00	2.61	2.31	1.71	2.31	1.80
G Glina	0.91	1.81	1.41	1.51	2.41	2.21	1.80	2.60	2.34	1.70	2.20	1.85	1.41	1.91	1.70
Gπ Glina pylasta	0.81	1.41	1.20	1.21	2.01	1.86	1.60	2.41	2.21	1.41	2.00	1.70	1.21	1.60	1.46
I Ił	0.61	1.01	0.86	0.61	1.26	1.11	1.11	1.50	1.36	0.90	1.31	1.10	0.75	1.16	1.01

Symbol description: λ min – lowest measured effective thermal conductivity value [W/m·K]; λ max – highest measured effective thermal conductivity value [W/m·K]; x̄ λ – arithmetic mean value of effective thermal conductivity for certain soil type [W/m·K].

Soil classification based on particle size distribution according to PN-B-02480:1986:
***Π** - 0.05 - 2.00 mm: 0 ÷ 30 %; 0.002 – 0.05 mm: 60 ÷ 100 %; <0.002 mm: 0 ÷ 10 %;*
***Pg** - 0.05 - 2.00 mm: 60 ÷ 98 % 0.002 – 0.05 mm: 0 ÷ 30 %; <0.002 mm: 2 ÷ 10 %;*
***Gp** - 0.05 - 2.00 mm: 50 ÷ 90 %; 0.002 – 0.05 mm: 0 ÷ 30 %; <0.002 mm: 10 ÷ 20 %;*
***G** - 0.05 - 2.00 mm: 30 ÷ 60 %; 0.002 – 0.05 mm: 30 ÷ 60 %; <0.002 mm: 10 ÷ 20 %;*
***Gπ** - 0.05 - 2.00 mm: 0 ÷ 30 %; 0.002 – 0.05 mm: 50 ÷ 90 %; <0.002 mm: 10 ÷ 20 %;*
***I** - 0.05 - 2.00 mm: 0 ÷ 50 %; 0.002 – 0.05 mm: 0 ÷ 50 %; <0.002 mm: 30 ÷ 100 %.*

Results of thermal conductivity measurements are stored in a Soil and Rock Thermal Properties Database along with the information about the water content, density and lithology of measured samples. This database is the basis for thermal parameterization of geological layers.

2.3 Parameterization Process

To achieve the final result, that is, geothermal potential maps for the shallowest ground layers, i.e. up to 30 meters below the ground surface, the algorithm was created, the structure of which is shown in Figure 4.

The parameterization process begins with a data query (step 1) from the Engineering-Geological Database (BDGI). Two relational tables GS_OTW and GS_LIT were selected from the database (step 2). Table GS_OTW contains information on the documentation point (borehole) such as: coordinates with ordinate, depth of the documentation point, date of drilling, contractor's data and where the documentation is stored. Table GS_LIT contains information on lithology, genesis and stratigraphy of each borehole, depth of each borehole groundwater level (AGI_GLW_POW), results of field and laboratory determinations of physical and mechanical properties of borehole soils and rocks. The research area has 35,000 documented boreholes, which translates into almost 166,000 unique geological combinations that had to be assigned thermal parameter values.

Step 3 involves querying the soil and rock thermal properties database. Thermal parameters of soil occurring in the GS_LIT table are assigned to each lithological layer based on lithology, genesis and stratigraphy (step 4). Then the obtained value is modified depending on the each individual lithological layer's water content, density and compaction. If the parameterized lithological layer contains admixtures or interbeddings the total value of the thermal parameter is a combination of both lithologies modified with a predefined parameter considering the type of relation (admixture, interlayer).

In the next step (5), the algorithm, based on data regarding the occurrence of the groundwater table, assigns the value of thermal parameters in fully saturated conditions for non-cohesive soils located below the water table. The occurrence of the water table is crucial for determination of vSGP (Rammler et al., 2023). If the water table occurs within a layer of non-cohesive soil, the layer is divided into a saturated and an unsaturated zone. After this step, the weighted average conductivity of the lithological profile is calculated down to defined depths. The algorithm used for the calculations is described in more detail by Ryżyński et al., 2020 and Kłonowski et al., 2020. The process of calculating the weighted average value of thermal parameter is repeated for each given depth. In the case of "at-depth" maps, the algorithm reads the parameter value assigned to the lithological layer located at a given depth (step 6). As a result, point layers are created (a borehole location with a thermal parameter value) which is the basis for creating polygons.

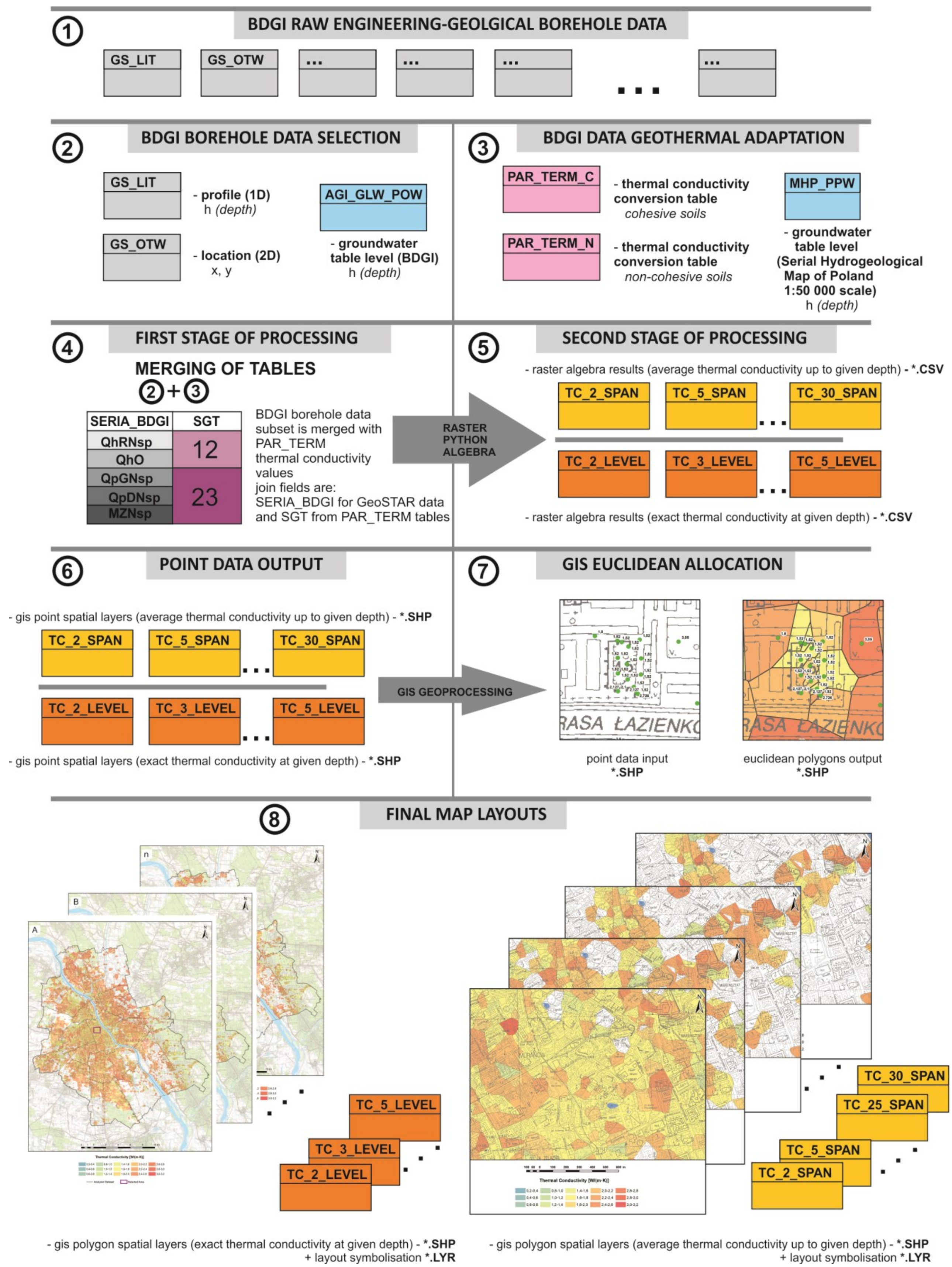

Figure 4: Parameterization process.

The resulting polygon layers were generated based on geoprocessing of the point layers using the geostatistical analysis method - Euclidean allocation (step 7). The Euclidean distance (distance in a straight line) is measured between the existing boreholes. The polygon boundary is placed exactly halfway through. Only the subset of boreholes exceeding 2 meters in depth was used as the geometric basis to generate Euclidean polygons. Below a certain depth where the resolution of the data decreases, i.e. there is no information on the geological layer, or the borehole was shallower than the depth of calculations, the use of Euclidean allocation allowed to exclude such a polygon. Then, the polygons were aggregated based on the defined classes of 0.2 W/m*K ranges of thermal parameter values (in this case, thermal conductivity). The use of a geostatistical algorithm eliminates the stage of interpreting the maps resulting from interpolation. It should be noted that the algorithm is intended to enable quick preliminary analyses and the analysed dataset is very heterogenic in means of its quality and certainty. The reliable design of a system using vSGE (very shallow geothermal energy) requires in-situ testing the planned installation subsurface.

The last step of the entire process is to generate maps using GIS software, resulting in maps of the thermal parameter values "at the given depths" and "up to the given depth" (step 8).

3. RESULTS

The resultant maps made to depths of successively: 5, 10, 15, and 20 m for the Warsaw region are shown in Figure 5. A decrease in polygon coverage can be seen as the depth increases. Less information is due to the lack of deeper boreholes. The polygon coverage in the case of the analysis to a depth of 2 m was 100%, whereas, in the case of a map made to 30 meters depth, the coverage dropped to only 1.5% (the available data was located mainly along the 1st and 2nd lines of the Warsaw metro). Coverage for the remaining depths is presented in Figure 6.

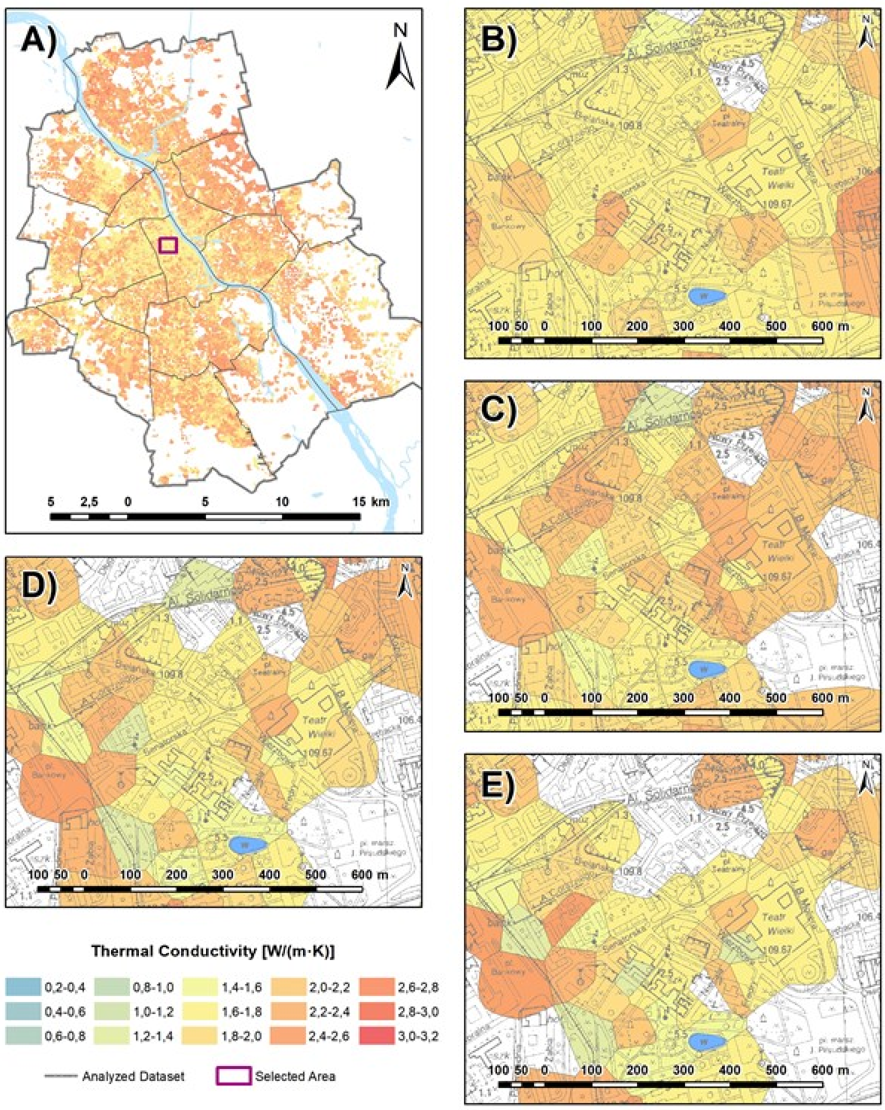

Figure 5: The resultant maps made to depths of successively: A) 5 m, B) 5 m detailed, C) 10 m detailed, D) 15 m detailed and E) 20 m detailed.

The average thermal conductivity of shallow soil in Warsaw shows favourable conditions, and quite high values of the parameter, which can allow obtaining significant amounts of energy. The value in thermal conductivity classes increases with depth which is due to the depth of the groundwater table - the value of the parameter increases with water saturation and soil compaction. Only in places where Pliocene clays occur, the value of thermal conductivity decreases with depth. This is because clays have lower thermal conductivity due to their lower quartz content than the non-cohesive soils lying on them.

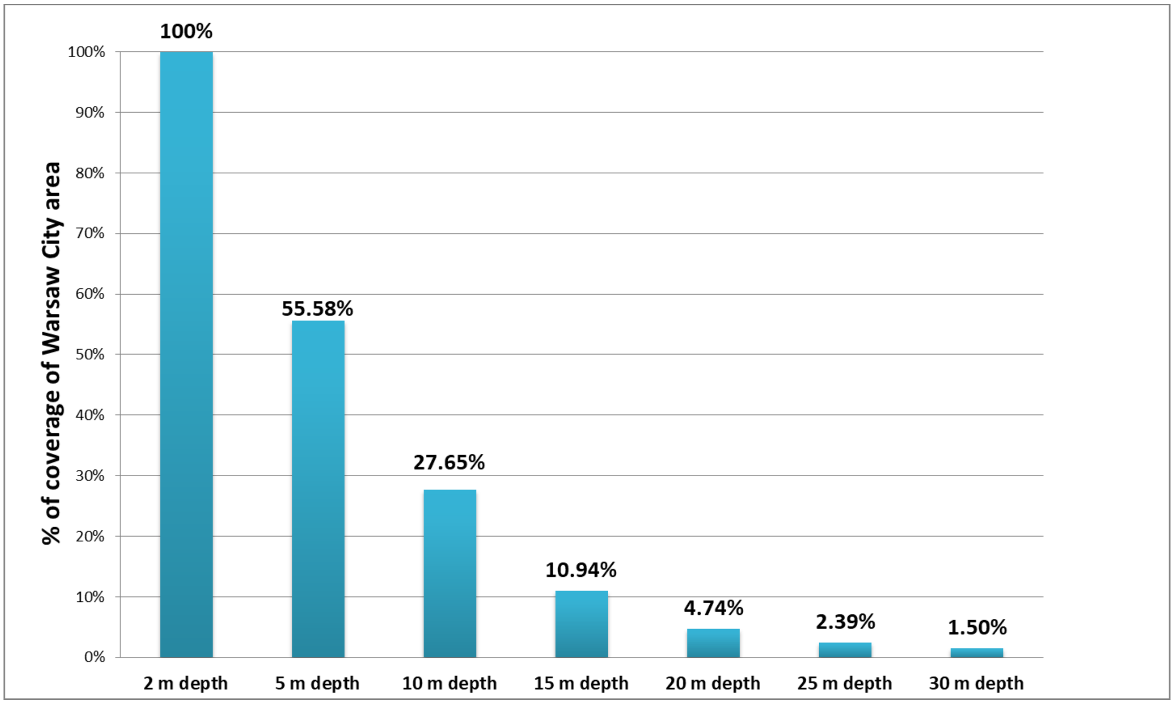

Figure 6: Warsaw city area coverage by polygons at different depths.

4. CONCLUSIONS AND FURTHER RESEARCH

The approach presented in the paper is an example of an iterative database processing workflow. According to the planning and design needs for vSGE systems numerous subsets can be processed on a loop presented in Figure 4. The process should be started with the borehole subsetting criterion from the lowest acceptable depth (2 meters) and be consecutively iterated with progressive depth increments. As the initial (resulting from the selected borehole subset) Euclidean polygon shape are used for all steps of the algorithm (from step 7), all depth levels from step 8 will inherit the initial Euclidean polygon shape. As a result, the coverage for deeper layers will increase but with a significant loss of geological and geothermal conditions prognostic certainty. By comparison of algorithm workflow processing subsets (with increasing depth criterion) it is possible to incorporate the geological uncertainty (due to unequal borehole depth and location distribution in the urban area) into feasibility studies stages of vSGE systems planning and design.

The proposed approach should be considered as a GIS tool to assist designers and planers of vSGE systems and the maps generated with the proposed iterative algorithm should be considered as a 2D visualisation of borehole database content. Application fo Euclidean allocation algorithm is intentional due to its simplicity and transparency. Lack of subjective interpetation in case of publication of the results (especialy those comunicating poor geothermal conditions) simplifies the legal bases interaction with third parties and general public.

Thanks to the unification of the data schema for urban agglomerations collected in BDGI, it is possible to use the computational algorithm on all urban areas of Poland presented in Figure 2. The only additional activity will be to supplement the Soil and Rock Thermal Properties Database with parameter values for lithological unique specimen occurring in a given area. It is also possible to prepare maps of different thermal parameters such as thermal resistivity, specific heat capacity and thermal diffusivity if the values of these parameters are collected in the database.

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