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Analysis of Atterberg limits of clayey soils exposed to pollutants

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Abstract

The issue of soil pollution has become a global concern due to the extensive and accelerated industrial development since the Industrial Revolution. Various anthropogenic activities, including industrial processes and agricultural practices, introduce pollutants into the soil. These pollutants vary widely in type and concentration, and they pose significant risks to both the soil ecosystem and the surrounding environment. This study is part of an extensive series of laboratory investigations aimed at examining how different pollutants—specifically hydrocarbons, detergents, and pesticides—affect the geotechnical properties of clayey soils in Hungary. The primary focus of this research is to analyze the changes in the Atterberg limits of these soils when exposed to different pollutants. The laboratory tests were conducted in strict accordance with Eurocode standards to ensure the reproducibility of the results and consistency in the experimental procedures. The findings elucidate the distinct impacts of various pollutants on the Atterberg limits across different types of clay. The insight gained from this research can significantly enhance the efficiency, safety, and cost-effectiveness of geotechnical engineering projects.

Keywords:
Atterberg limits; clay; geotechnics; soil; pollution

1. Introduction

In the investigation of soil contamination, the initial step is to distinguish between “contamination” and “pollution”. While these terms are frequently used interchangeably in everyday language and media, scientific usage differentiates them. “Contamination” refers to the presence of a chemical in a sample without any evidence of harm, whereas “pollution” describes situations where the chemical’s presence is causing environmental damage (Harrison, 2001). For this reason, the paper employs the term “pollution”, given that later sections will illustrate how the natural properties of polluted soils have been negatively impacted and altered.

Soil pollution is a critical environmental issue caused by the introduction of harmful substances into the soil, which adversely affect plant growth, animal health, and human well-being (**Poczok et al., 2019**). The main sources of soil pollution include industrial activities, agricultural practices, improper waste disposal, and accidental spills of hazardous materials (**Phiri et al., 2024**). **Zhang (2019)** highlights the complexity of soil pollution, which stems from the diverse and uneven nature of soils, the tendency of contaminants to bind to clay minerals and organic matter, and the wide array of pollutants involved. This complexity makes soil pollution an inconspicuous hazard that cannot be directly assessed or visually observed. It’s a significant aspect of land degradation and one of the most pressing environmental issues. It can occur through various means, with different materials acting as pollutants, including hydrocarbons, heavy metals, herbicides, and pesticides (**Calabrese et al., 2005; Fang and Daniels, 2006; Pascucci, 2011**). The impact of soil pollution is particularly notable because soil plays a fundamental role in human life. Its importance has been increasingly highlighted by the accelerating pace of industrialization, which, while essential, has intensified the risk of soil pollution (**Liu et al., 2014**).

The severity of soil contamination is significantly influenced by the nature of the contaminants, which can be broadly classified into two categories: macro-pollutants and micro-pollutants. Macro-pollutants are typically present in substantial concentrations within soil matrices, whereas micro-pollutants are found in much lower concentrations. Examples of macro-pollutants include substances such as acid-rain deposits and fertilizers, while micro-pollutants include both organic and inorganic compounds, such as heavy metals, pesticides, non-pesticidal chemicals, and hydrocarbons (**Mirsal, 2004**).

This study investigated the impact of three distinct pollutants on various clayey soils. The pollutants were select-

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ed to represent a range of chemical compositions, facilitating a clear differentiation of their respective mechanisms of action. The three pollutant groups under examination were hydrocarbons, detergents, and pesticides.

Hydrocarbon soil pollution involves the contamination of soil by hydrocarbons, which are organic compounds primarily composed of carbon and hydrogen. This type of pollution often arises from the spillage or improper disposal of petroleum products, such as crude oil, gasoline, diesel, and lubricants (**Ossai, et al., 2020; Shah et al., 2003; Székely et al., 2018**). Detergent pollution in soil refers to the introduction of synthetic cleaning agents, which often contain surfactants, phosphates, and various chemical additives, into the soil environment (**Djukic et al., 2006; Sharo et al., 2020; Kogawa et al., 2017**). Pesticide soil pollution refers to the contamination of soil by synthetic chemicals used for pest management, including herbicides, insecticides, and fungicides (**Mesquita et al., 2019**).

Pollution has substantial effects on the geotechnical properties of soils, which can critically impact their behavior, stability, and suitability for construction and agricultural purposes. Soil response to environmental conditions is influenced by several key factors: soil structure, geochemical parameters, and soil-water interactions (**Zhang et al., 2023**). Soil structure encompasses the arrangement and aggregation of soil particles, while geochemical parameters refer to the soil's mineral composition and chemical properties. Soil-water interactions involve the dynamics between soil and water, including water retention, permeability, and the impact of water on soil chemical and physical properties (**Liu et al., 2022**). The sensitivity of soil to environmental factors is contingent not only on the local environmental conditions but also significantly influenced by its mineralogical structure, including parameters such as particle size, interparticle bonding characteristics, and ion exchange capacity. Soils with finer particle sizes exhibit a heightened ability to interact with environmental variables. Soils characterized by weaker inter-particle bonding energies or elevated cation exchange capacities exhibit increased environmental sensitivity. For instance, due to its distinct mineralogical properties, montmorillonite demonstrates a higher potential for environmental sensitivity compared to illite and kaolinite (**Szabó and Tóth, 2019**).

Understanding and mitigating the geotechnical impacts of soil pollution are essential for ensuring the stability and safety of constructions and maintaining soil health. This requires comprehensive site assessments, soil testing, and the implementation of effective remediation strategies. The Atterberg limits, comprising the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI), are fundamental parameters used to characterize the consistency and plasticity of fine-grained soils, particularly clays (**Knapett and Craig, 2012**). These limits provide insight into soil behavior under varying moisture conditions and are essential in geotechnical and soil science applications. Soil pollution can significantly influence the Atterberg limits by altering the soil's ability to retain water, its structural properties, and its texture. These changes can have profound effects on soil behavior, stability, and suitability for engineering and agricultural applications. An accurate assessment of these impacts is crucial for effective soil management and remediation strategies, necessitating a thorough understanding of how various pollutants affect soil properties.

The impact of pollutants on clay soils has been a long-standing issue, first studied in Hungary by **Járay and Bidló (1962)** and internationally by **Sullivan and Graham (1938)**. Sullivan's research demonstrated that changes in soil plasticity could be attributed to the so-called Hofmeister series (**Hofmeister, 1888**). According to Hofmeister, "the chemical nature and hydration of ions significantly influence the electrokinetic potential and surface conductivity of soil colloids."

Less hydrated ions adsorb to the surface at a higher rate compared to hydrated ions, leading to increased accumulation in the Stern layer (the double-diffuse layer of the soil colloid). This accumulation can result in a decrease in the electrokinetic potential and surface conductivity of the particles (**Manilo et al., 2020; Kang et al., 2020; Mazzini and Craig, 2017**). The lyotropic series (**Voet, 1937**) essentially dictates that the amount of ions adsorbed on the surface of soil colloids is significantly influenced by the concentration of the soil solution. According to the series, ions that adsorb a thin viscous water film (whose thickness increases as the chemical value of the cation decreases) play a crucial role. Consequently, it has been found that clays containing Na and Li ions exhibit high plasticity and reduced shear strength due to the enlargement caused by the formation of the water film layer.

It was determined that an increase in ionic value results in a decrease in the Liquid Limit, and the Liquid Limit further decreases with an increase in the concentration of the pore fluid. Additionally, it is noteworthy that an increase in the dielectric constant of the pore fluid can enhance the Liquid Limit of highly plastic clays. Furthermore, it is pertinent to note that an increase in the dielectric constant of the pore fluid may lead to an enhancement in the Liquid Limit of highly plastic clays (**Szabó and Tóth, 2019**). The presence of contaminants leads to an increase in the thickness of the diffuse double layer of soil colloids, which reduces electrical attraction and enhances repulsive forces. Conversely, a decrease in the thickness of this diffuse layer can reverse the effect, with Van der Waals forces dominating the colloidal structure. If repulsive forces diminish, the Liquid Limit of the soil decreases. Conversely, an increase in repulsive forces results in an elevated Liquid Limit. These principles are not solely applicable to the Liquid Limit; they also manifest in the Plasticity Index results.

2. Methods

The objective of this study is to evaluate the impact of various pollutants on the Atterberg limits of different clay

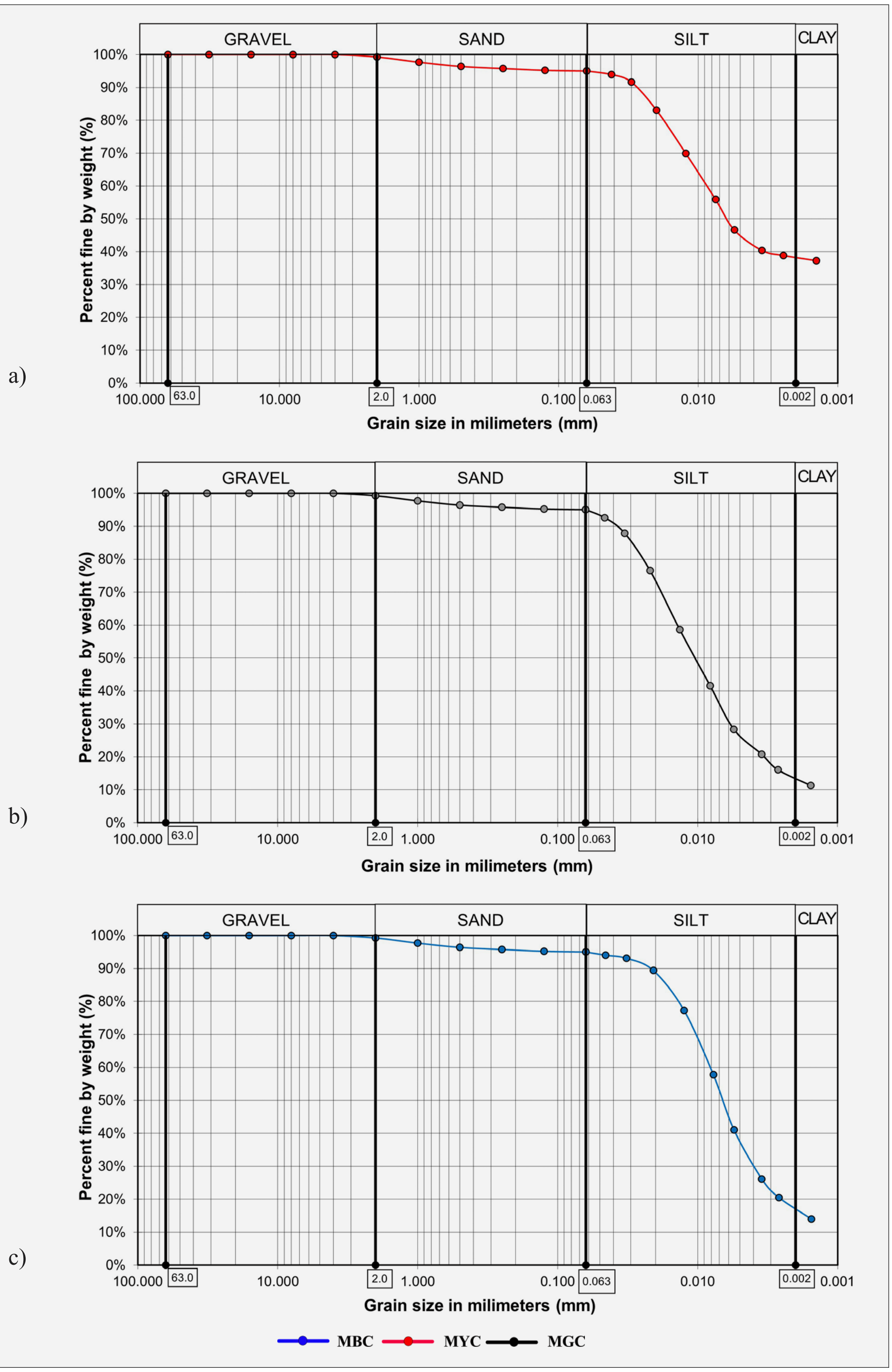

Figure 1: Grain size distribution for the soil samples

types. The hypothesis is that distinct clay mineral assemblages will exhibit differential changes in their Atterberg limits when subjected to pollution. Samples were collected from a clay quarry located near Mályi, Hungary. This site provided a range of clay types, allowing for a comparative analysis of their responses to pollutants. Three distinct clay assemblages were identified and sampled from the quarry. These samples represent a variety of mineralogical compositions typical of the region.

2.1. Basic properties of the soil samples

Initially, the three samples are categorized and uniquely identified based on their origin and color, designated as mályi blue clay (MBC), mályi yellow clay (MYC), and mályi grey clay (MGC), to streamline the identification process. In the subsequent stages of the study, these samples are consistently referred to by their respective identifiers. The samples were prepared uni-

Table 1: Organic content of the soil samples

Sample ID	Organic content (%)	Description
MBC	2.55	Slightly organic
MYC	2.02	Slightly organic
MGC	2.70	Slightly organic

formly, dried to a constant weight, and subsequently reduced to a uniform particle size using a hammer mill.

Sieve analysis was executed on the soil samples following the guidelines outlined in the MSZ EN ISO 14688 and MSZ EN ISO 14689 series for soil classification, and specifically in accordance with the MSZ EN ISO 17892-4 standard, which governs particle-size analysis procedures (**ECS, 2007; Orr, 2012**). The sieve analysis conducted on the soil samples demonstrated that the majority of the samples were predominantly composed of fine clay fractions, specifically particles smaller than 0.063 mm in diameter. Analysis of 100-gram soil samples indicated that less than 10% of the material consisted of particles larger than 0.063 mm. This distribution of particle sizes (see **Figure 1**) underscored the necessity for a more detailed analysis of the finer fractions. Due to the predominance of clay-sized particles in the soil samples, a hydrometer test was employed to accurately determine the particle size distribution of the finer soil fractions (**ECS, 2007; Lopez et al., 2021**). The test was performed in accordance with MSZ EN ISO 17892-4, adhering to a methodology comparable to that employed for sieve analysis. Based on the analysis of particle size distribution, the samples were classified as, clayey-silt (MBC), clay (MYC), and clayey-silt (MGC).

Table 1 summarizes the organic matter content of the samples. The analysis was performed following the methodologies outlined in the referenced standards. In the loss-on-ignition method, the organic matter content of the soil is quantified by the weight reduction observed during the annealing process. The weight loss, referred to as the loss on ignition, is expressed as a percentage of the soil's dry weight (**Stevens et al., 2008; Hoogsteen, 2015**).

Water uptake capacity refers to the ability of a material, such as soil, to absorb and retain water (see **Figure 2**). This property is critical for understanding the material's behavior in various environmental and agricultural contexts. The Enslin-Neff method is employed to determine the water-uptake capacity of a solid, such as clay, when in direct contact with liquid water. It is commonly used in civil engineering (**Kaufhold and Dohrmann, 2008; Kaufhold et al., 2010**). The investigation of water absorption capacity is a crucial aspect of geotechnical practice, as the results provide insight into the propensity of a given clay soil to undergo swelling. In practical applications, such swelling behavior can significantly impact soil bearing capacity and may lead to stability issues. Based on the measurement results, the water absorption capacity of all three soil samples is nearly identical, ranging between 50-60%. These findings indicate that the soils exhibit low susceptibility to swelling. This conclusion is further substantiated by X-ray Diffraction measurements, which confirmed the mineral composition of the samples.

X-ray diffraction (XRD) analysis was performed to ascertain the mineralogical composition of the soil samples. XRD measurements provide a detailed and accurate assessment of the mineralogical composition of soil samples (**Adams, 2005; Zhou et al., 2018**). This technique is essential for predicting soil behaviour, and assessing geotechnical stability. In conjunction with various predefined safety factors, it ensures the structural integrity and reliability of buildings.

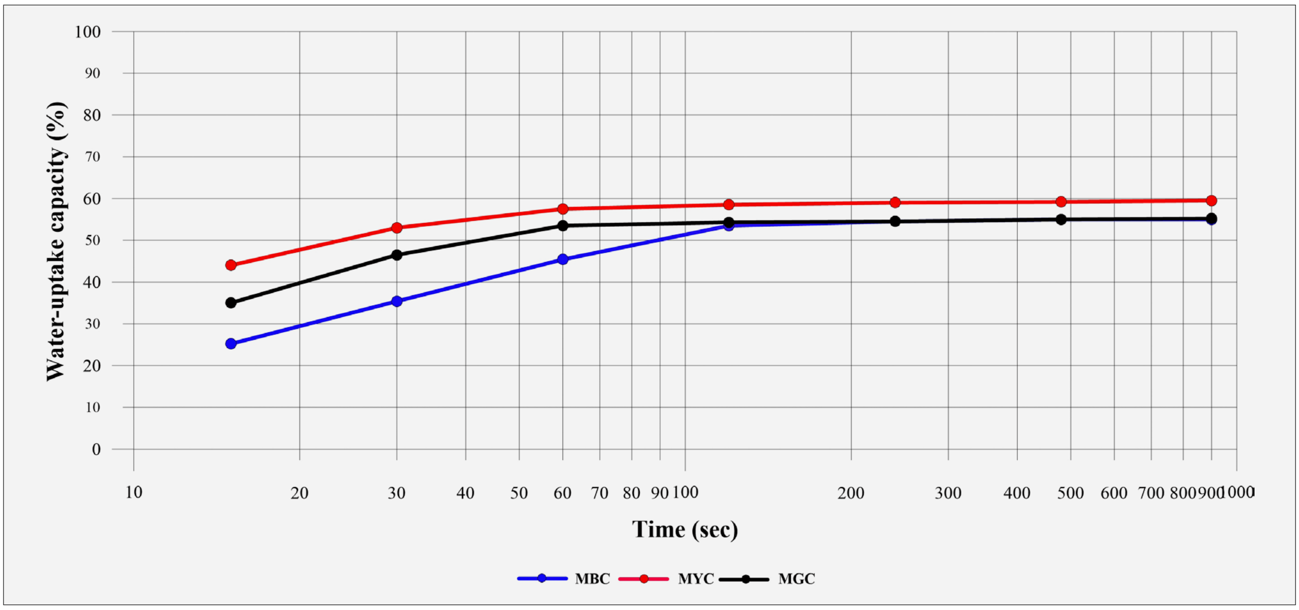

Figure 2: Water uptake capacity of the samples

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Table 2: Primary mineralogical constituents of the samples

	Mineralogical composition (wt%)							
Sample ID	**Quartz**	**Muscovite**	**Chlorite**	**Calcite-magnesium**	**Dolomite**	**Halite**	**Albite**	**Illite**
MBC	32.01	14.29	2.86	4.36	3.22	1.39	4.45	24.47
MYC	36.30	11.38	2.49	3.84	2.46	-	6.87	19.45
MGC	39.49	12.43	1.71	3.02	2.83	0.75	8.19	19.29

During the analysis, diffraction peaks are resolved using a reference database integrated into the instrument's software package. This database facilitates the identification and differentiation of distinct mineral phases based on their characteristic diffraction patterns. Once the diffraction peaks are resolved, the weight percentage distribution of each constituent phase can be quantified. It is important to note that for these measurements, a maximum error margin of approximately 10% is expected, depending on factors such as sample preparation, instrument calibration, and data processing conditions. **Table 2** presents only the primary mineral components identified in the samples. Quartz exhibits the highest concentration across all three samples, followed by the clay mineral illite. Illite is particularly significant for these measurements, as it is less susceptible to swelling compared to minerals such as montmorillonite. This characteristic is expected to influence several key geotechnical properties of the samples.

2.2 Basic properties of the pollutants

Three distinct types of pollutants were employed for the laboratory measurements (see **Table 3**). These pollutants were selected to represent the most common environmental pollutants and were chosen to ensure safety under laboratory conditions.

Table 3: Technical specifications of the pollutants used for the laboratory tests

Pollutant	**Technical specifications**				
	pH	**Kinematic viscosity at 100 °C (mm^2/s)**	**Boiling point (°C)**	**Density at 20°C (g/cm^3):**	**Solubility in water (at 20°C):**
Hydrocarbon (Brake fluid)	7.69	2.16	269.0	1.069	fully miscible with water
Pesticide (Copper sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$))	~ 4 (as a solution)	N/A	650.0	2.284	highly soluble
Detergent	~ 7 to 9	N/A	N/A	1.03	fully miscible

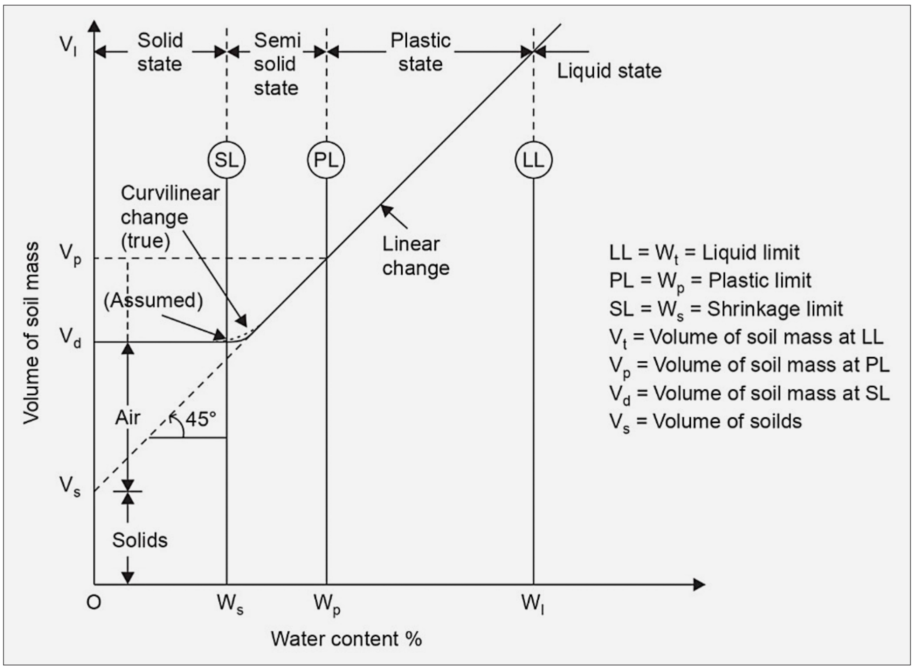


Figure 3: The Liquid Limit, Plastic Limit, and Shrinkage Limit of soils (**Venkatramaiah, 2006**)

Table 4: Summary table of the Atterberg limit test results. (LL=Liquid Limit, PL=Plastic Limit, Ip= Plasticity Index)

Pollutant		**Mályi Yellow Clay (MYC)**			**Mályi Blue Clay (MBC)**			**Mályi Grey Clay (MGC)**		
Hydrocarbon	Concentration (wt%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)	LL (%)	PL (%)	PI (%)
	0	55.2	25.5	31.65	40.5	22.5	17.99	46.2	28.4	17.69
	2	53.9	23.7	30.63	37.4	19.6	17.87	55.3	27	28.32
	4	54.9	23.6	31.63	37.0	18.9	18.51	56.0	26.2	28.51
	8	55.1	23.2	31.87	37.3	17.5	19.75	56.9	23.6	33.17
	12	56.5	22.3	34.24	37.5	17.4	20.28	58.8	24.2	34.98
	16	57.4	23.8	32.96	38.6	16.9	22.19	60.2	25.8	34.82
	20	58.5	25.2	33.74	39.4	18.4	21.02	61.0	24.6	36.24
Pesticide	0	55.2	25.5	31.65	40.5	22.5	17.99	46.2	28.4	17.69
	2	57.5	25.6	32.02	36.9	18.3	18.54	50.4	24.6	24.09
	4	58.7	24.3	34.37	38.4	20.3	19.5	53.6	29.0	24.53
	8	54.9	22.7	32.2	39.1	20.9	18.2	54.7	30.6	24.93
	12	55.8	25.9	29.87	39.8	19.4	20.99	55.4	27.1	27.92
	16	55.3	26.2	29.26	41.6	19.6	21.76	57.1	14.0	29.2
	20	52.3	23.8	28.43	38.6	19.5	19.7	54.6	26.0	28.62
Detergent	0	55.2	25.5	31.65	40.5	22.5	17.99	46.2	28.4	17.69
	2	59.6	26.6	33.04	42.3	19.4	22.88	60.2	30.6	30.57
	4	58.7	26.0	32.68	43.5	19.6	23.85	62.4	32.3	29.29
	8	60.5	27.8	32.73	43.5	19.6	22.77	63.0	34.2	28.53
	12	61.6	27.7	33.52	43.9	23.0	20.94	60.7	33.0	28.77
	16	59.4	27.8	31.64	56.6	24.9	30.29	64.3	33.9	30.21
	20	59.1	28.8	30.29	45.0	25.5	26.61	62.2	34.4	27.92

2.3 Atterberg-limit tests

The Atterberg limits test is a standardized procedure used to determine the critical moisture contents of fine-grained soils, particularly clays (see **Figure 3**). These limits classify soil and predict its behaviour under varying moisture conditions. (**Kaliakin, 2017; Jiménez and Guerrero, 2017; Andrade et al., 2011**). The tests were conducted in accordance with the MSZE CEN ISO/TS 17892-12:2006 standard, which outlines the procedures for determining the Atterberg limits of soil. The test involves measuring distinct moisture contents, Liquid Limit (LL), and Plastic Limit (PL) tests.

Depending on the moisture content, soil can exist in one of four states: solid, semi-solid, plastic, or liquid. The Liquid Limit, Plastic Limit, and Shrinkage Limit of soils, which define these states, are determined using established methods as specified in the relevant standard. For Liquid Limit tests the Casagrande apparatus were used (**Haigh, 2015**). The liquid limit is defined as the water content at which 25 blows are necessary to close the groove in the soil sample.

The plastic limit is determined by rolling a clay sample into a cylindrical shape with a diameter of 3 mm. As rolling continues, the clay progressively loses moisture and begins to crack. The water content at which these cracks first become visible is identified as the plastic limit (**Rajapakse, 2016; Netinger Grubeša, et al., 2016**). The preceding two data points can be utilized to calculate the so-called Plasticity Index (PI), which is a measure of the range of moisture content within which the soil remains plastic (Das, 2014). The plasticity index is a key parameter used to evaluate the water sensitivity of clay soils, providing insight into the soil's grain-water interaction. By comparing the current water content of a clay to its consistency limits, its present state can be assessed. Atterberg Limits are fundamental in the preliminary phases of geotechnical design, ensuring that the soil will behave as anticipated under varying conditions. Significant volumetric changes due to moisture fluctuations can lead to differential settlement or heaving, potentially compromising the structural integrity of foundations.

The Atterberg limit tests were performed in accordance with the specified measurement methodologies and standards. All three sample groups were artificially contaminated under controlled laboratory conditions. Pollutant solutions were introduced to the soil samples at varying concentrations of 0 wt%, 2 wt%, 4 wt%, 8 wt%, 12 wt%, 16 wt%, and 20 wt%.

During sample preparation, the objective was to ensure reproducibility and consistency across all specimens. Upon receipt, the samples were oven-dried to a constant weight (at 105°C) and subsequently ground to a

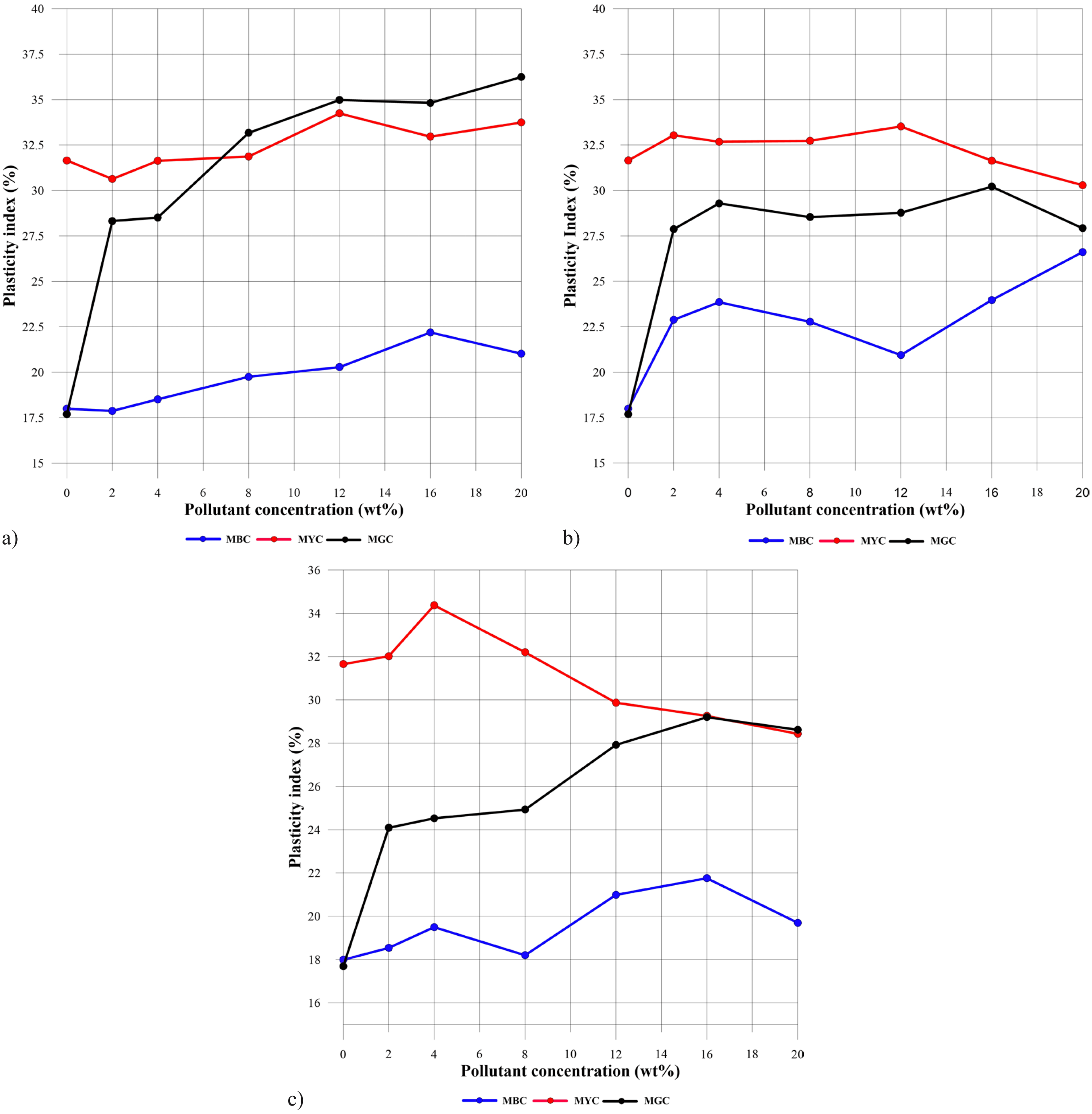
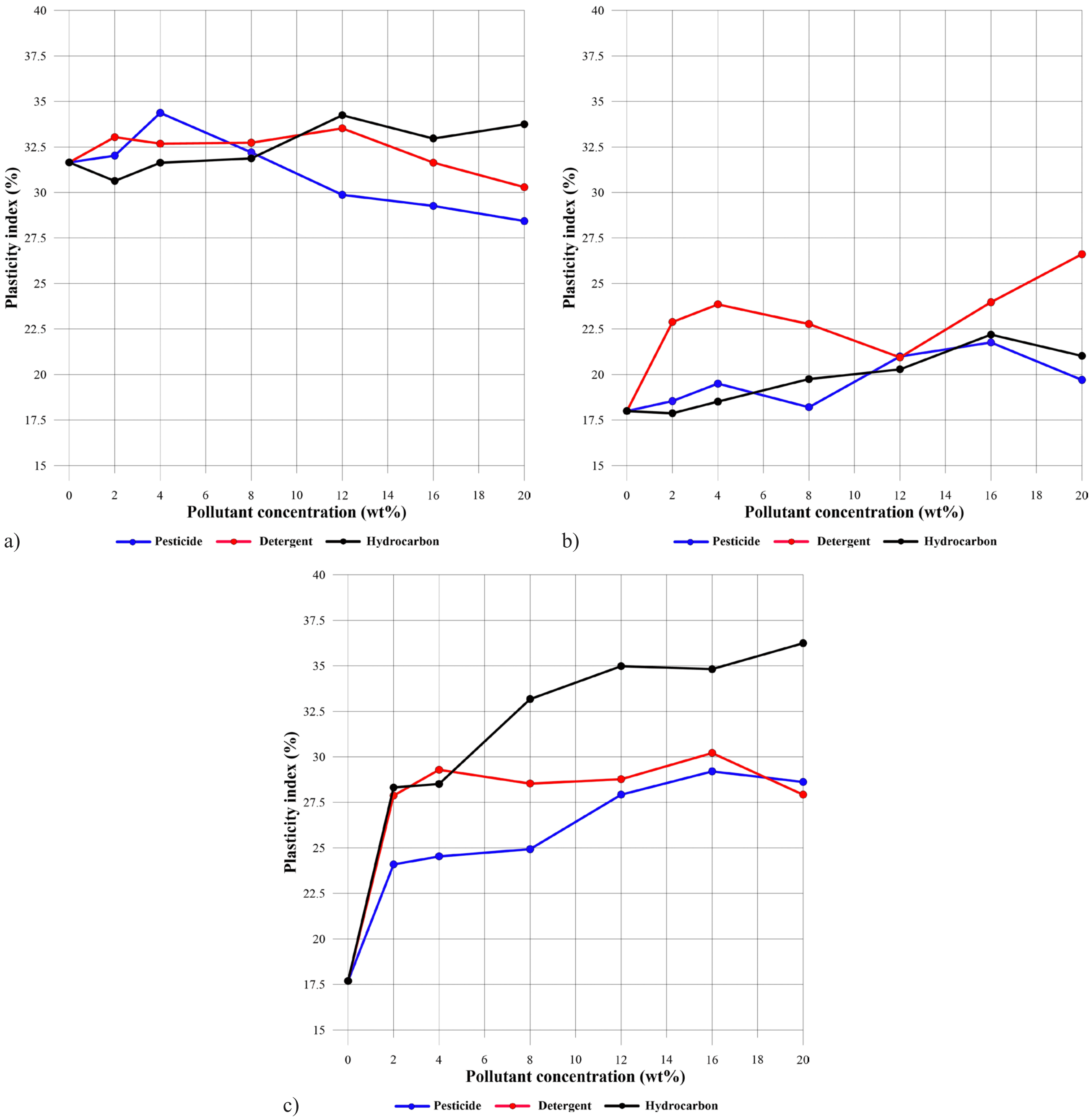


Figure 4: Changes in the Plasticity Index (Ip) as a result of various pollutants are evaluated as follows: a) Hydrocarbon b) Pesticide c) Detergent

particle size of 2 mm using a hammer mill. This step was essential to facilitate uniform preparation and thorough homogenization of the soil with the contaminants during testing. The pollutants were then introduced into the samples at the specified concentrations. To enhance the reliability of the results, three replicates of each sample type were prepared, enabling repeated measurements for improved accuracy. The polluted samples were allowed to equilibrate in hermetically sealed containers for 24 hours. Following this period, Atterberg limit tests were conducted to assess the soil's properties Preliminary identification tests indicated that the blue and yellow clays were nearly identical. Consequently, we decided to add sand to the blue clay to introduce a slight variation in the test results. Consequently, three distinct soil groups were delineated: the fat clayey Mályi Yellow Clay (MYC), the sandy-clay Mályi Blue Clay (MBC), and the silty-clay Mályi Grey Clay (MGC).

3. Results and discussion

The results of the Atterberg-limit tests are summarized in **Table 4** below. To facilitate interpretation and ensure clarity, the table presents the median values of these measurements for each set of samples. Subsequently, the results are plotted and compared based on the Plasticity



a) b) c)

Figure 5: Variations in plasticity index (Ip) values across different soil groups as a function of the presence and type of pollutants. a) Mályi Yellow Clay b) Mályi Blue Sandy-Clay c) Mályi Grey Clay.

Index (Ip) values, in accordance with the Eurocode standard for the classification of various fine-grained soils. Prior to conducting the Atterberg limit measurements on the contaminated samples, the tests were first performed on the three uncontaminated samples. Based on the plasticity index values, sample MYC is classified as high-plasticity clay, whereas samples MBC and MGC are categorized as medium-plasticity clays.

In the context of hydrocarbon pollutants, it is observed that the table indicates that, for the yellow clay and blue sandy-clay samples, there is minimal increase in the plasticity index values, with changes of only 2-3% between uncontaminated samples and those contaminated at a 20 wt% concentration. However, for the grey silt-clay samples, there is an observed increase of approximately 9% in the plasticity index value.

The pesticides exhibit less uniform changes, with a decreasing trend in the plasticity index for MYC and an increasing trend for the other two samples, similar to the pattern observed with the previous pollutant. The most significant change is again observed in MGC, with a difference of over 10% between the uncontaminated and the most heavily contaminated samples.

For detergent pollutants, unlike the previous two cases, the MBC soil sample exhibits a notable increase in the plasticity index, showing an 8% change. The most significant difference remains with the MGC sample.

Trend changes are evident for all three contaminants, with MYC exhibiting the smallest variations of only 2-3%. The most substantial percentage difference in plasticity index is consistently observed in the MGC samples across all three cases. In **Figure 4**, the variation in the plasticity index is plotted as a function of the pollutant concentration.

An effective approach to presenting the results could involve separating the different soil types and independently analyzing the changes in plasticity index values induced by the pollutants. This method would allow for a more detailed assessment of how each soil type responds to pollutant exposure, providing clearer insight into the specific impact of pollutants on soil plasticity.

Based on the measurement results obtained, as well as previous research and literature, the foundational hypothesis is that the variations in the behavior of the samples can be attributed to differences in their crystalline composition and their interactions with the contaminants (**Safehian et al, 2018; Karkush and Kareem, 2017**). The results should be interpreted in the context of previous research and based on a review of the literature.

4. Conclusions

In this study, the effects of various pollutants, hydrocarbon, pesticide and detergent, on the Atterberg-limits of three distinct clayey soils were investigated. The findings are consistent with previous literature, demonstrating that consistency limits are significantly altered by contamination. The measurements were conducted under the pertinent European standards. Conclusions and hypotheses derived from previous studies and literature reviews highlight correlations, causal factors, and relationships between the measurement results and the chemical and crystallographic properties of the samples. More definitive conclusions can be obtained through further investigation, such as Scanning Electron Microscope (SEM) analysis, to directly observe surface morphology and potential alterations on the surface of the grains.

Although the Atterberg limit test results do not fully elucidate the underlying processes at the crystalline level, such as alterations in grain surface properties, insight from prior research and literature examples can assist in formulating the following hypotheses:

(1) For all three soil types, a noticeable change is observed between the contaminated and uncontaminated samples.

(2) In the plasticity index values used as a basis for comparison, the greatest variation was observed for all three pollutants, for the Mályi Grey Clay (MGC) samples.

(3) Conversely, the smallest difference in plasticity index was observed in the Mályi Yellow Clay (MYC) samples for all three pollutants.

(4) Among the pollutants, detergent induced the most substantial change. This can be attributed to its highly lubricative nature, forming a film layer that coats the soil particles. This coating reduces the attractive forces between particles, thereby affecting the Atterberg limits.

(5) It is hypothesized that the observed changes are presumably primarily influenced by two factors: the crystalline properties of the soils and their interactions with the pollutants. An increase in the dielectric constant of the pore fluid can enhance the repulsive forces between soil particles, thereby increasing the thickness of the diffuse double layer. This phenomenon can lead to an upward trend in the observed measurements.

(6) For clays with lattice structures that exhibit minimal swelling, the Liquid Limit is predominantly governed by intergranular resistance, leading to a reduction in it. Conversely, in clays with highly swelling lattice structures, the reduction in Liquid Limit attributable to changes in intergranular resistance is significantly more pronounced than the reduction resulting from alterations in the diffuse double-layer thickness.

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SAŽETAK

Analiza Atterbergovih granica glinovitih tala izloženih zagađenju

Izazov onečišćenja tla postao je globalno zanimljiv zbog opsežnoga i ubrzanoga industrijskog razvoja nakon industrijske revolucije. Razne antropogene aktivnosti, poput industrijskih procesa i poljoprivrednih aktivnosti, unose onečišćivače u tlo. Ti se zagađivači uvelike razlikuju po vrsti i koncentraciji te predstavljaju znatne rizike za ekosustav tla i okoliš. Ova je studija dio niza opsežnih laboratorijskih istraživanja čiji je cilj ispitati kako različiti zagađivači, posebno ugljikovodici, deterdženti i pesticidi, utječu na geotehnička svojstva glinovitih tala u Mađarskoj. Primarni je fokus ovoga istraživanja analiza promjena Atterbergovih granica tala kada su izložena različitim onečišćivačima. Laboratorijska ispitivanja provedena su strogo u skladu s normama Eurokod kako bi se osigurala ponovljivost rezultata i dosljednost u ispitivačkim postupcima. Zaključci objašnjavaju utjecaje različitih zagađivača na Atterbergove granice kod različitih vrsta gline. Rezultati dobiveni ovim istraživanjem mogu znatno poboljšati učinkovitost, sigurnost i isplativost projekata geotehničkoga inženjerstva.

Ključne riječi:
Atterbergove granice, glina, geotehnika, tlo, onečišćenje

Author’s contribution

Noémi Szász (1) (PhD student) provided the raw materials preparation, performed the laboratory work, and the presentation of the results. **Andrea Tóth (2)** (Associate professor) provided the evaluation of the experimental results and the presentation of the results.