Development of an Engineering Geological Zoning Map of Iraq Based on the Reclassification of an Existing Geological Map

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Abstract

This study presents the development of a nationwide engineering geological zoning map of Iraq through the reclassification of an existing geological map. The aim is to extend the available engineering geological information for Iraq and provide a regional-scale framework applicable to land-use planning, foundation engineering, infrastructure development, and other engineering activities. The geological formations exposed at the surface were analysed according to their lithological characteristics and subsequently classified into engineering geological zones using ArcGIS Pro. The engineering geological zoning system applied in the Czech Republic was used as the methodological basis and modified to account for geological conditions specific to Iraq. Several additional zones were therefore introduced for lithological units not adequately represented in the original classification. As a result, an engineering geological zoning map comprising 17 zones was developed, and the area and percentage representation of each zone were calculated. A comparison with the engineering geological zoning of the Czech Republic was also performed to identify major similarities and differences between the two geological environments. The resulting map provides a regional overview of engineering geological conditions that can support preliminary assessment and planning of construction and infrastructure projects. Its level of detail is limited by the scale of the source geological map (1:1,000,000). Future refinement should incorporate higher-resolution geological data, field-based lithological observations, weathering information, and physical and mechanical properties of soils and rocks.

Keywords: *Engineering-geological mapping, Engineering-geological zoning, Foundation engineering, Iraq, GIS.*

1. Introduction

The primary objective of this study is to classify the exposed geology of Iraq into engineering geological zones and represent the resulting classification spatially. The study is based on the reclassification and engineering geological interpretation of an existing geological map rather than on independent geological mapping. Engineering geological zoning is important for land-use planning and for the preliminary assessment of geological and geotechnical conditions relevant to construction. At a regional scale, such information can support the planning of foundations, transport infrastructure, water-management structures, and other engineering projects [1-3].

In addition to the primary objective of developing an engineering geological map for Iraq, the study addresses the following objectives:

- distinguishing Quaternary and pre-Quaternary geological units.
- characterizing the mapped units as soils or rocks according to their dominant lithological properties.
- calculating the area and percentage representation of each engineering geological zone.
- presenting the resulting engineering geological information in a form accessible to both engineering geologists and other professionals involved in construction and spatial planning.
- providing a regional framework for future, more detailed engineering geological investigations in Iraq.

ArcGIS Pro was used as the primary software for georeferencing, digitization, spatial analysis, and preparation of the engineering geological map. The geological formations and units from Iraq were described based on published sources, primarily [4] and supplemented by [5], and subsequently analyzed based on their lithological types. Iraq's surface geology was then categorized into various engineering geological zones. To establish a consistent engineering geological classification, an appropriate existing zoning system was required as a methodological basis. Consequently, the Czech Engineering Geological classification was chosen for this purpose, and corresponding zones were established. However, additional zones were required to represent lithological conditions specific to the exposed soils and rocks of Iraq. Ultimately, a total of 17 zones were created.

The principal limitations of the study arise from its nationwide scale and the spatial resolution of the available source data. The geological map used has a scale of 1:1,000,000, which does not permit detailed site-specific engineering geological assessment. Furthermore, detailed field descriptions, weathering-zone data, and physical and mechanical properties of the mapped geological units were not consistently available. Consequently, the resulting map should be regarded as a regional engineering geological framework rather than a substitute for site-specific engineering geological and geotechnical investigations.

2. Methodology

The primary spatial dataset used in this study was the geological map of Iraq published by the Iraqi Geological Survey [6], which was provided in raster format. The map was georeferenced and digitized using ArcGIS Pro. Each geological formation or unit was digitized as a polygon and subsequently assigned to an engineering geological zone based primarily on its dominant lithological characteristics. This study uses the engineering geological zone classification of the Czech Republic as a basis, but it also introduces new zones to account for significant geological differences between Iraq and the Czech Republic. In addition to the created map, graphical representations were generated to illustrate the properties and areas of each engineering geological zone.

In geo-referencing, it is essential to use a map of high resolution and suitable scale that corresponds with the project's needs to minimize errors during processing. Although the resolution and scale of the source map are not optimal for detailed engineering geological analysis, the dataset provides nationwide coverage suitable for the regional-scale objectives of this study. Control points were selected from the raster data and linked with control points from the target data, resulting in the map being shifted and rotated based on the alignment and linkage between the points. Having many control points does not necessarily guarantee a better outcome. Instead, their arrangement and distribution are crucial for obtaining the best results. Additionally, a more significant overlap between the raster dataset and the target data leads to a better-aligned map. Multiple options are available for transforming the raster dataset to match the target data and its coordinates. Each type can help determine the accurate map coordinate location for every cell within the raster. These transformation ways enable accurate alignment and integration of the raster data with the desired map coordinate system and ensure accurate spatial analysis. However, georeferencing maps using known coordinates corresponding to the map-sheet corners is a recommended approach for rectification [7].

In digitization, features were generated. The standard georeferenced image of the map was converted to a digital version. The features here were described in an attribute table and provided different information. In our study, features like polygons represented geological formations or groups of formations. In some cases, it is possible to perform automatic digitization, where the created features of polygons, lines, and points are added directly to the raster map. Automatic digitization was not considered sufficiently reliable because of the spatial resolution and graphical characteristics of the source raster; therefore, the geological units were digitized manually.

Tab. 1. Engineering geological (EG) zones in the Czech Republic, according to the Czech Geological Survey [8].

Symbol of EG zones	EG regions name for Quaternary soils	Symbol of EG zones	EG regions name for Pre-Quaternary rocks
An	Anthropogenic deposits	**Nk**	Alternating fine-grained, sandy and gravelly sed.
Or	Organic soils (min. 5% organic admixtures)	**Ng**	Gravelly sediments
Fn	Alluvium of lowland streams including fluviolacustrine sediments	**Nj**	Clay-dusty sediments
Ft	Pleistocene fluvial sediments (terraces)	**Np**	Sandy sediments
D	Diluvial (slope) and diluviofluvial (flush) sed.	**Mn**	Low metamorphic rocks
Dk	Diluvial (slope) stony to blocky sediments	**Mv**	Highly metamorphosed (isotropic) rocks
P	Alluvial cone region	**Vl**	Compact solid volcanic rocks
Ep	Eolian (blown) sands	**Sj**	Clay and siltstone rocks
Es	Loess and loess clay region	**Ss**	Sandstone and conglomerate rocks
Gg	Glaciogenic (glaciolacustrine, glacifluvial) sed.	**Sv**	Limestone and dolomite rocks
		Sf	Flysch (significantly anisotropic) rocks
		Ih	Igneous intrusive rocks
		Vk	Volcaniclastic rocks

[a] Several zones defined in the Czech engineering geological classification are not applicable to the exposed geological conditions of Iraq and were therefore not included in the Iraqi zoning scheme.

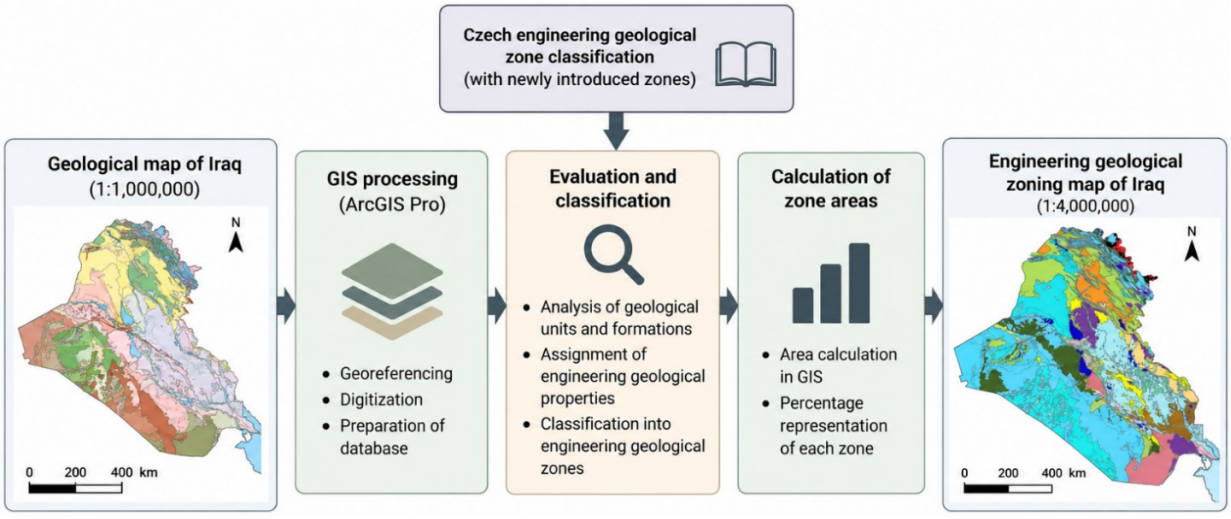


Fig. 1. Workflow of the study.

The lithological characteristics used for the classification were primarily derived from [4] and supplemented by data from [5]. The classification of the Iraqi geological formations according to the proposed engineering geological zoning scheme is presented in Table 2.

Tab. 2a. Classification of Iraqi geological formations according to the proposed engineering geological zoning scheme

Geological formation/unit	Age	Main lithology	EG Zones
Active Marsh	Quaternary	Organic soil, mainly sandy or clayey silt.	Or
Aeolian	Quaternary	Sand, silt dust.	Ep
Akashat	Paleocene	Limestones with phosphatic intraclasts, micritic limestone, and mudstone.	Sv
Al-Fatha Fan Conglomerate	Quaternary	Conglomerate	P
Alluvial Fan	Quaternary	Rock fragments, gravels and conglomerate, sand, silt and mud.	P
Amij	Liassic	Quarzitic sandstone, siltstone, dolomite and dolomitic limestone.	Ss
Avroman Limestone	Upper Triassic	Limestone, rarely dolomitized.	Sv
Azkand Anah	Upper Oligocene	Dolomitic and recrystallized limestones- coralline limestone.	Sv
Bai Hassan	Pliocene-Pleistocene	Conglomerates, sandstone, siltstone and claystone.	Ss
Balambo, Dokan, Gulneri and Kometan	Cretaceous (Valanginian - Turonian)	Limestone, green marls, blue shales. - limestones-calcareous shale. - thin bedded limestones, chert concretions.	Sv
Balambo-Aqra	Lower – Upper Cretaceous	Limestone, green marls, blue shales. -massive and bedded dolostone and limestone	Sv
Balambo-Shiranish	Lower – Upper Cretaceous	Limestone, green marls, blue shales. - marl, marly limestone and limestone	Sv
Baluti, Kurra Chine, Geli Khana, Beduh	Lower - Upper Triassic	Shale, dolostone and limestone- black limestone and dolomite. - dolomite with black chert, dolomitic limestones. shale with intercalation of limestone. bedded limestones and shale. - shales and marls, some silty limestones.	Sj
Chia Gara-Sargelu	Middle Jurassic-Cretaceous (Tithonian - Berriasian)	Limestone, shale and marly limestone - bituminous limestones, shales, black chert.	Sv
Chia Gara-Serki	Jurassic (Lower Liassic) - Jurassic - Cretaceous (Tithonian - Berriasian)	Limestone, shale and marly limestone- massive dolostone and limestone.	Sv
Chia Zairi	Upper Permian	Dark blue limestones, organic detrital massive limestone with chert nodules, dolomites and breccia.	Sv
Crevasse Splay	Quaternary	Sand and silt.	Ft
Dammam (Late)	Eocene	Dolomitized limestone. These limestones are sometimes chalky.	Sv
Dammam (Middle)	Eocene	Dolomitized limestone. These limestones are sometimes chalky.	Sv
Depression Fill	Quaternary	Silt and clay.	Fn
Dhiban Serikagni	Lower Miocene	Gypsum and recrystallized limestone - chalky limestones.	Gc
Dibdibba	Upper Miocene–Pliocene–Lower Pleistocene	Mainly sand and gravel of igneous rocks, and white quartz pebbles.	Ih
Digma	Cretaceous (Upper Senonian)	Phosphatic-glauconitic and silicified marls.	Sj
Dry Marsh	Quaternary	Organic soil, mainly sandy or clayey silt.	Or
Estuarine Sabkha	Quaternary	Silty clay with coarse crystalline gypsum and clayey silt.	Cm
Euphrates	Lower Miocene	Limestone, dolostone and marl.	Sv
Fatha	Middle Miocene	Anhydrite, gypsum and salt, interbedded with limestone and marl.	Gc
Fatha (Lower Member)	Middle Miocene	Marl, limestone and gypsum.	Gc
Fatha (Upper Member)	Middle Miocene	Red claystone, marl, limestone, gypsum and siltstone.	Gc
Flood Plain	Quaternary	Sand, silt and silty clay.	Fn
Ga'ara	Middle Triassic	Coarse - grained sandstone, band of sandy marl, silty marl.	Ss
Ghar	Middle Miocene	Sands and gravels, rare sandy limestone, rare clay and anhydrite.	Nk
Ghar-Euphrates	Middle Miocene- Lower Miocene	Sands and gravels, rare sandy limestone, rare clay and anhydrite. - limestone, dolostone and marl.	Nk
Gypcrete	Quaternary	Gypsiferous soil	Gy
Habbariyah Gravels	Quaternary	Gravels	Fn
Hartha	Cretaceous (Maastrichtian - Upper Campanian)	Organic detrital glauconitic limestone, marls and shale.	Sv
Horan Gravels	Quaternary	Gravels	Fn
Hussainiyat	Jurassic (Upper Liassic)	Mudstones, Sandstones, carbonate part (dolostone and limestone).	Sj
Injana	Upper Miocene	Sandstone, siltstone and claystone	Ss
Inland Sabkha	Quaternary	Silty clay with powdered gypsum layers.	Cm
Intrusive Complex	Cretaceous	Intrusive igneous rocks like gabbro and granite.	Ih
Jaddala-Avanah	Middle-Upper Eocene	Marly and chalky limestones and marls- dolomitized and recrystallized limestone.	Sv
Jill	Lower Eocene	Predominantly anhydrite with some limestones, shale and marl.	Gc
Kata Rash Series	Cretaceous	Predominantly calc-alkaline volcanics of andesite and rhyolite, phyllite, intruded by granodiorite, granite and diorite.	V
Khabour	Ordovician	Fine grained sandstones, quartzite and silty micaceous shale.	Ss
Khurmala-Gercus	Paleocene - Eocene	Dolostone and limestone- red clastic.	Sv
Kolosh-Sinjar-Khurmala-Gercus-avanah-pilaspi	Paleocene - Eocene	Black and dark green clastics-limestone with algal reefal and shoal facies-dolostone and limestone- red clastic-dolomitized and recrystallized limestone-bituminous limestone, chalky limestone and marly limestone.	Sv
Marbat	Upper Cretaceous. (Campanian-Maastrichtian)	Mainly pebbly sandstone, sandy dolostone, conglomerate, silty claystone, claystone.	Ss
Mauddud	Cretaceous (Albian)	Limestone with chert nodules shale streaks.	Sv
Msad	Cretaceous (Cenomanian)	Limestones, reef limestones, breccias, chalky limestones, marls, sandy marls and sands.	Sv
Muhaiwir	Jurassic (Bathonian)	Limestone, marly limestone, sandstone, soft marl.	Sv
Mukdadiyah	Pliocene	Pebbly sandstone, siltstone and red mudstone.	Ss
Mulussa	Upper Triassic	Sandy limestones intercalated with marls and marly limestones.	Sv

Tab. 2b. Classification of Iraqi geological formations according to the proposed engineering geological zoning scheme

Nahr Umer	**Cretaceous -Albian**	**Black shales, fine-grained sands and sandstones.**	**Sj**
Najma	Upper Jurassic	Recrystallized limestone, dolomites and thin anhydrites.	Sv
Naopurdan Series	Lower-Middle Eocene	Shale, greywacke, volcanics; andesite, coralline limestone.	Mx
Nfayil	Middle Miocene	Marl and limestone.	Sj
Pilaspi-Avanah	Middle-Upper Eocene	Bedded dolostone and limestone - Nummulitic and marly limestone.	Sv
Piran Limestone	Paleocene	Massive fossiliferous limestone, marly limestone.	Sv
Pirispiki, Chalki, Ora and Harur	Ordovician-Lower Carboniferous	Cross-bedded quartzites, marls and sandstones, and with lenticular intercalations of conglomerates- olivine basalts, bright red ash-containing, soft siltstones and shales-calcareous shale, silty marls, detrital limestones and fine-grained sandstones- organic detrital limestone, with intercalations of shale.	Mx
Polygenetic	Quaternary	Gravel, rock fragments and mixture of gravel and clay	Es
Qandil Series	Lower Cretaceous	Mainly limestones, phyllites, massive metamorphosed limestones, serpentine intrusions, calcareous schist, basalts, meta basalts, diabase, amphibolite and granodiorite.	Mx
Qulqula Series	Cretaceous	Limestone, radiolarian limestone, chert, conglomerate and shale.	Sv
Ratga (Early, Late, Middle)	Eocene	Marine chalk, nummulitic limestone and phosphorites.	Sv
Red Bed Series	Paleocene-Eocene	Red clastics.	Sj
River Terraces	Quaternary	Pebbles, sand, silt and some gypsiferous sand.	Fn
Rutbah	Cretaceous	Coarse to fine sands and sandstones.	Ss
Sanam Plag	Infra-Cambrian Salt	Evaporates and carbonates and igneous fragments.	Gc
Sarki-Sehkaniyan	Jurassic (Lower Liassic-Upper Liassic)	Massive dolostone and limestone- dark dolomite, dolomitic limestone, chert, organic and pellety limestone.	Sv
Shalair Series	Cretaceous	Mainly metamorphic rocks, basic volcanics, and coralline limestone.	Mx
Sheet Run Off	Quaternary	Sand, silt and clay.	Sr
Sheikh Alas, Shurau	Lower Oligocene	Dolomitic and recrystallized limestones. -limestone.	Sv
Shiranish	Upper Cretaceous	Marl, marly limestone and limestone.	Sj
Sinjar-Aaliji	Paleocene-Eocene	limestone with algal reefal and shoal facies. - shale, marly limestone and marl.	Sv
Tanjero-Shiranish	Upper Cretaceous	Silty marls, siltstones, sandstones, conglomerates and detrital limestones. - marl, marly limestone and limestone.	Sj
Tarjil, Baba, Bajwan	Middle Oligocene	Dolomitized and marly limestone. - porous dolomitized limestone - dolomitized limestone and coral fragments.	Sv
Tayarat	Upper Cretaceous	Chalky limestone and dolomitized limestone.	Sv
Tidal Flat	Quaternary	Sandy clay, silt, sand and clay loam.	Cm
Ubaid	Jurassic (Liassic)	Dolomitized and recrystallized limestones, marl and chert nodules.	Sv
Umm Er Radhuma (Early, Late)	Paleocene - Eocene	Anhydritic and dolomitic limestone, chert.	Gc
Walash Series	Paleocene - Eocene	Mainly volcanics, basalt and andesite flows, red mudstones.	V
Zahra	Middle Miocene	Limestones, sandy marls, calcareous sands.	Sv
Zor Hauran	Upper Triassic	Gypsiferous marls and shales, marly limestones, and dolomitized limestones.	Gc

Note: Engineering geological zones were assigned according to the dominant lithology of each geological unit. Mixed zones represent lithologically heterogeneous units that could not be further subdivided at the scale and resolution of the source geological map. The assignments reflect the regional-scale interpretation adopted in this study and may require refinement when higher-resolution lithological data become available.

3. Results and discussion

As discussed above, the geology of Iraq differs from that of the Czech Republic in several respects, making it necessary to introduce additional engineering geological zones appropriate to Iraq's exposed geological units and rock types. The zones used to classify the exposed geological units of Iraq are presented in Table 3.

Tab. 3. The designated engineering geological zones for Iraq based on the Czech classification.

Symbol	**Group type**	**Engineering geological regions name**	**Typical rocks**
Gy	Quaternary soils	Zone of gypsiferous soil.	Gypsiferous soils
Cm	Quaternary soils	Zone of silty clay with gypsum layers.	Clay, silt and sand.
Sr	Quaternary soils	Zone of sheet run off.	Sand, silt and clay.
Or	Quaternary soils	Region of organic soils (min. 5% organic admixtures).	peats, bogs and coal.
Fn	Quaternary soils	Alluvium region of lowland streams including fluviolacustrine sediments.	clastic sediments created by the activity of Quaternary flows - clays, loams, sands, gravels and flood clays.
Ft	Quaternary soils	Region of Pleistocene fluvial sediments (terraces)	sediments created by the accumulation activity of river flows in the Pleistocene.
P	Quaternary soils	Alluvial cone region	deposits of watercourses at their mouths in the main valley, gravels, sands, clays and their combinations.
Ep	Quaternary soils	Region of eolian (blown) sands	Wind-deposited sands.
Es	Quaternary soils	Loess and loess clay region	loess, loess clays.
Nk	pre-Quaternary rocks	A region of alternating fine-grained, sandy and gravelly sediments	alternating positions of clays, sands and gravels
Sj	pre-Quaternary rocks	Region of clay and siltstone rocks	claystone, siltstone and shale
Ss	pre-Quaternary rocks	Region of sandstone and conglomerate rocks	sandstone, conglomerate, chert, and arkose.
Sv	pre-Quaternary rocks	A region of limestone and dolomite rocks	limestone, dolomite and crystalline limestone.
Ih	pre-Quaternary rocks	A region of igneous intrusive rocks	granodiorites, granites, diorites, gabbro, porphyries, pegmatites
V	pre-Quaternary rocks	Zone of volcanic rocks	Andesite, Rhyolite and basalt.
Mx	pre-Quaternary rocks	Zone of mixed rock types	Basalt, quartzite, sandstone and limestone.
Gc	pre-Quaternary rocks	Zone of carbonate rocks and evaporites.	limestone, dolomite, gypsum and anhydrite.

After defining the zoning scheme, all geological units and formations exposed in Iraq and shown on the geological map published by GEOSURV [6] were evaluated according to their lithology and assigned to the corresponding engineering geological zones.

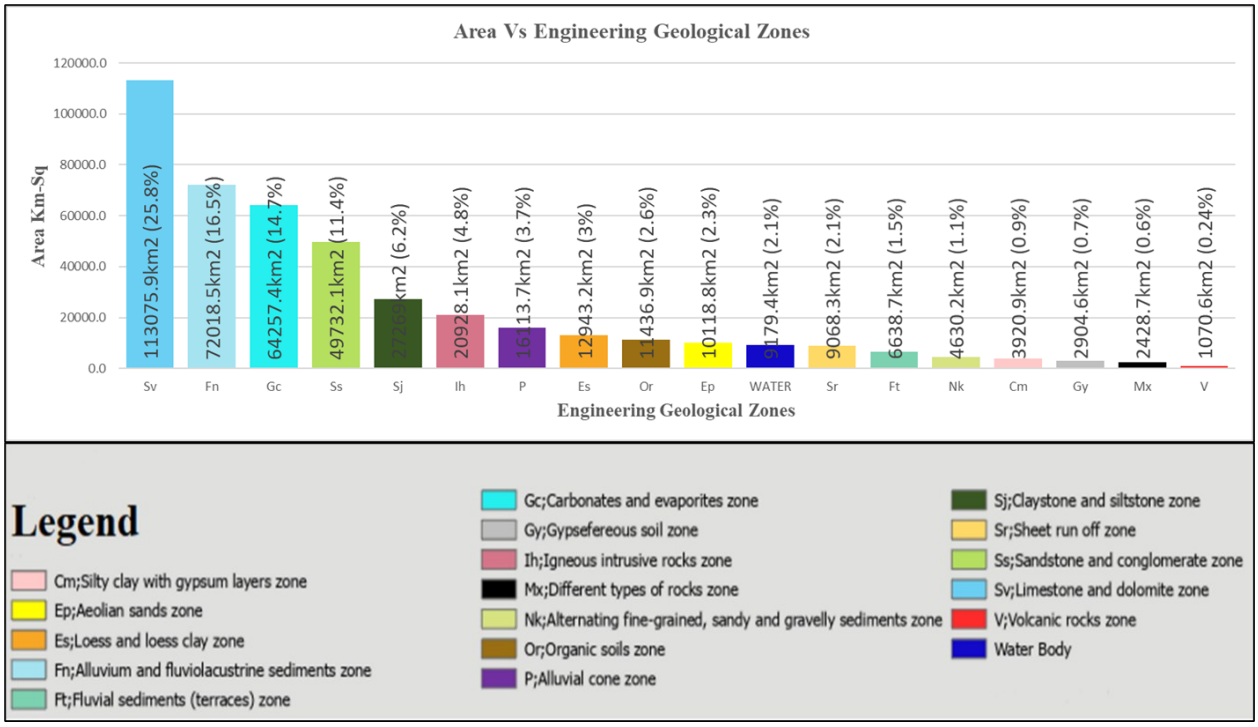


Fig. 2. Area of engineering geological zones in Iraq (km²).

Based on the geological map used in this study, some geological units comprise combinations of igneous, metamorphic, and sedimentary rocks that cannot be separated at the scale of the source data. This required the introduction of the Mx zone for mixed rock types. Additional zones were introduced to represent geological conditions specific to Iraq: Gc for carbonate rocks associated with evaporites, Cm for sabkha and tidal-flat sediments consisting mainly of silty and sandy clay with gypsum layers, Sr for Quaternary sheet-runoff sediments, which cover approximately 9,068.34 km², and Gy for gypsiferous soils such as gypcrete, covering approximately 2,904.61 km².

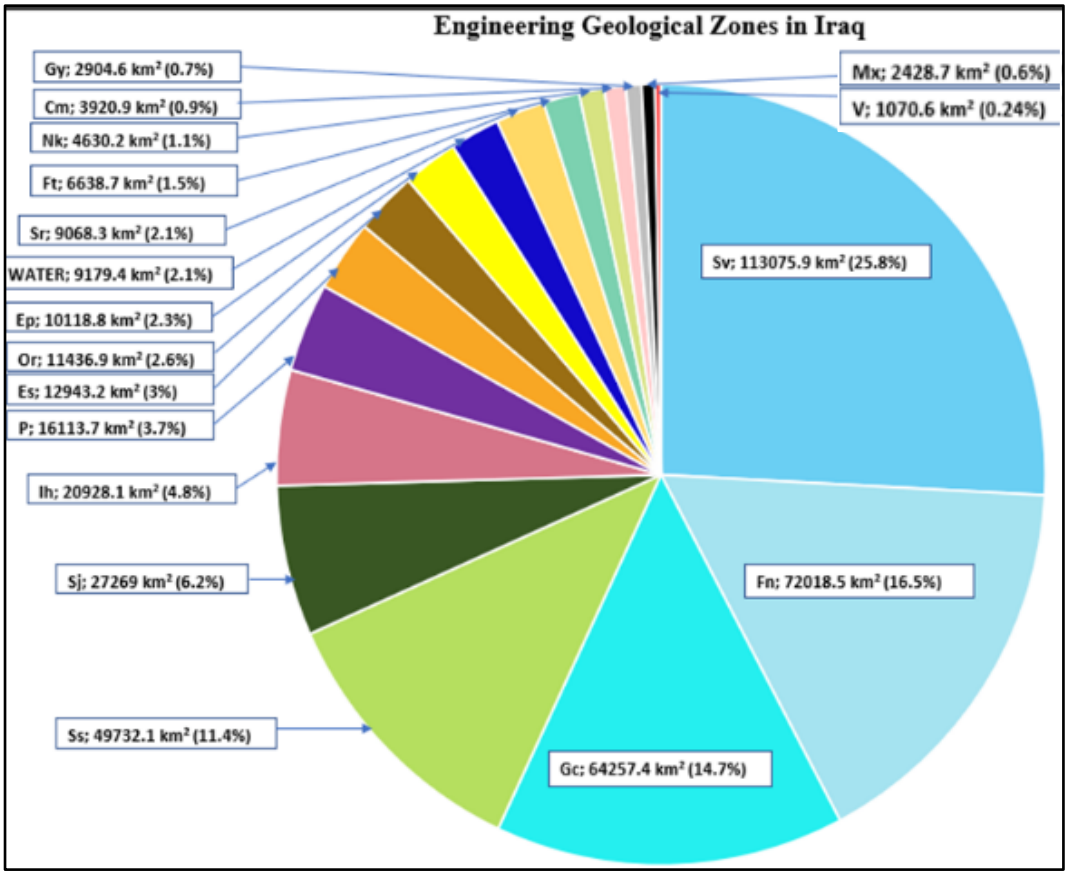
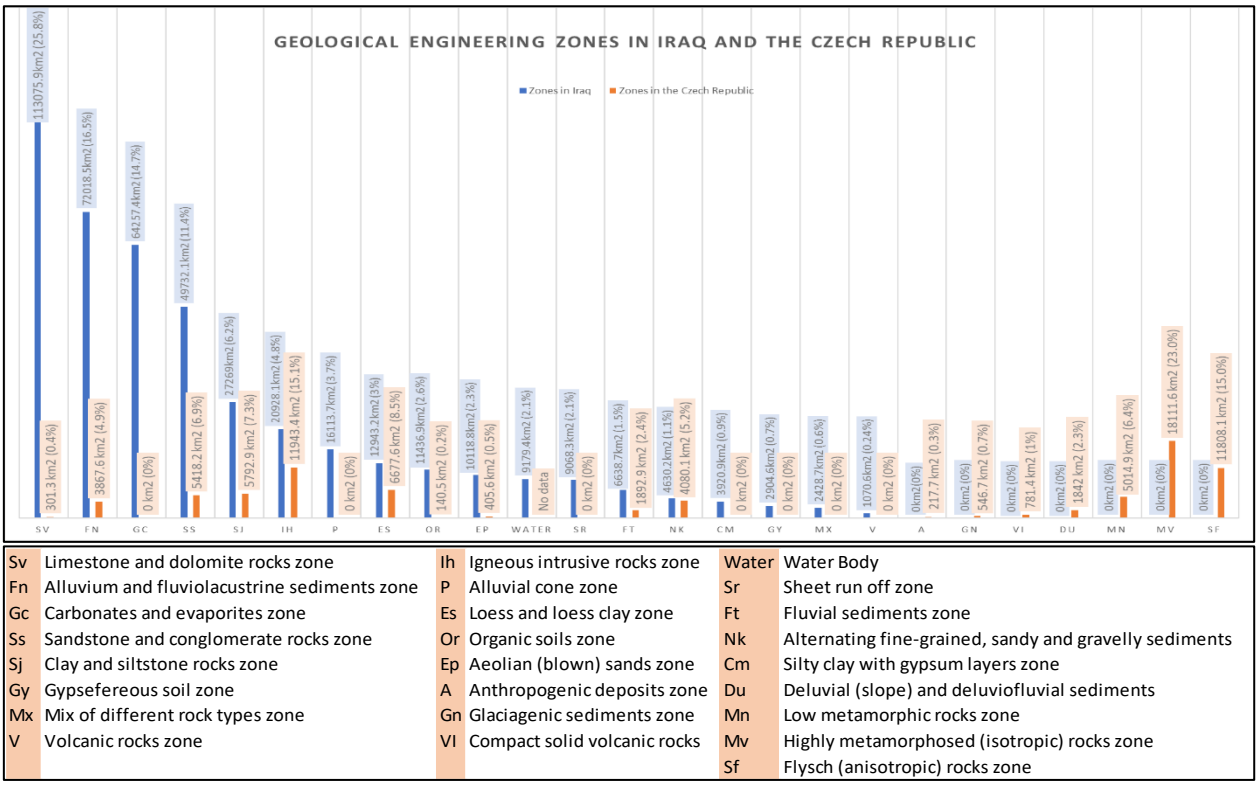


Fig. 3. Pie chart for the engineering geological zones in Iraq.

In Iraq we can see from the illustrated pie chart of the Iraqi engineering geological zones in (Figure 3), they are comprised of four big categories (Sv, the biggest—almost 26 % of Iraq's area; Fn, the second most extensive zone, nearly 17%; Gc, the third most significant zone, about 15%, and then Ss, the fourth, more than 11%). This means that more than a quarter of the Iraqi land is mainly covered by limestone and dolomitic rocks. Iraq's land is historically known as Mesopotamia, which translates to "the land between the two rivers" (Tigris and the Euphrates) that is expressed geologically by the geological deposits from the river's floodplains and terraces where gravel, sand, and silt were deposited in significant amounts from the north part to the south part of Iraq. Ss and Sj are made of clastic rocks like (sandstones, conglomerates, claystones, and siltstones) together, they make up around 18%, which is a significant amount of the Iraqi land surface geology. Therefore, they are both essential zones in this study.

We can also divide the engineering geological zones in the Czech Republic [1] into five main zones (Mv, the biggest, which has 23% of Czechia's area; Ih, the second of 15.1%; Sf, the third of 15.0%, Es and Sj fourth and the fifth respectively of both making up around 16%). This tells us that almost a quarter of the Czech Republic's exposed geology is made of high-grade metamorphosed rocks. In contrast, the exposed geology of Iraq is predominantly sedimentary, whereas igneous and metamorphic rocks occur only to a limited extent, mainly in the northern and northeastern parts of the country. Also, it is essential to point out the Ih zone, which expresses a significant amount of intrusive rocks; Sf comprises almost the same percentage as Ih in Czechia, but it is for the flysch rocks. Es and Sj both add up to around 16% of Czechia. They have an essential presence in this classification as they show the deposits of loess and loess loams for Es and claystone and siltstones for Sj. We must mention Ss, about 7% of Czech Republic zones. This adds up to more than 14% of clastic rocks together with the Sj zone; this could be worth mentioning in comparison with Iraq's zones, as we saw it had a coverage of about 18% of clastic rocks.



Sv	Limestone and dolomite rocks zone	Ih	Igneous intrusive rocks zone	Water	Water Body
Fn	Alluvium and fluviolacustrine sediments zone	P	Alluvial cone zone	Sr	Sheet run off zone
Gc	Carbonates and evaporites zone	Es	Loess and loess clay zone	Ft	Fluvial sediments zone
Ss	Sandstone and conglomerate rocks zone	Or	Organic soils zone	Nk	Alternating fine-grained, sandy and gravelly sediments
Sj	Clay and siltstone rocks zone	Ep	Aeolian (blown) sands zone	Cm	Silty clay with gypsum layers zone
Gy	Gypsefereous soil zone	A	Anthropogenic deposits zone	Du	Deluvial (slope) and deluviofluvial sediments
Mx	Mix of different rock types zone	Gn	Glaciagenic sediments zone	Mn	Low metamorphic rocks zone
V	Volcanic rocks zone	Vl	Compact solid volcanic rocks	Mv	Highly metamorphosed (isotropic) rocks zone
				Sf	Flysch (anisotropic) rocks zone

Fig. 4. A comparison between the engineering geological zones in Iraq and the Czech Republic.

Figure 4 will be more apparent to make the comparison as each zone is compared with its same type in Iraq and Czechia. However, we have to mention that Iraq's area is five times more than the Czech Republic's area; this explains how huge the difference in the zones. For example, the Sv carbonate zone occupies approximately 113,076 km² in Iraq, compared with about 301 km² in the Czech Republic. This substantial difference reflects both the contrasting geological conditions and the markedly different sizes of the two countries. Iraq is mostly of sedimentary rocks, while Czechia has all three types of rocks. For this reason, we can find some zones in both countries had zero values; for example, the Czech Republic had zero value in (Gc; Carbonate and evaporite zone, P; Alluvial cone zone, Sr; Sheet run-off zone, Cm; Silty clay and gypsum layers zone, Mx; a mix of different rock types in one unit or series, V; volcanic rock zone, however, the volcanic rocks in Czechia are classified in different zones like Vl (Effusive rocks, compacts hard volcanic rocks).

The comparison also shows that several zones represented in the Czech classification are absent from the Iraqi zoning scheme, including the anthropogenic, glaciogenic, slope-deposit, volcanic, metamorphic and flysch categories. This does not necessarily indicate the complete absence of the corresponding rock or sediment types in Iraq. In several cases, these geological units were assigned to other zones according to their dominant lithological characteristics. For example, metamorphic rocks occurring within heterogeneous geological units were included in the Mx zone, while flysch-related units were classified according to their prevailing lithology. The resulting spatial distribution of the classified engineering geological zones is presented in Figure 5.

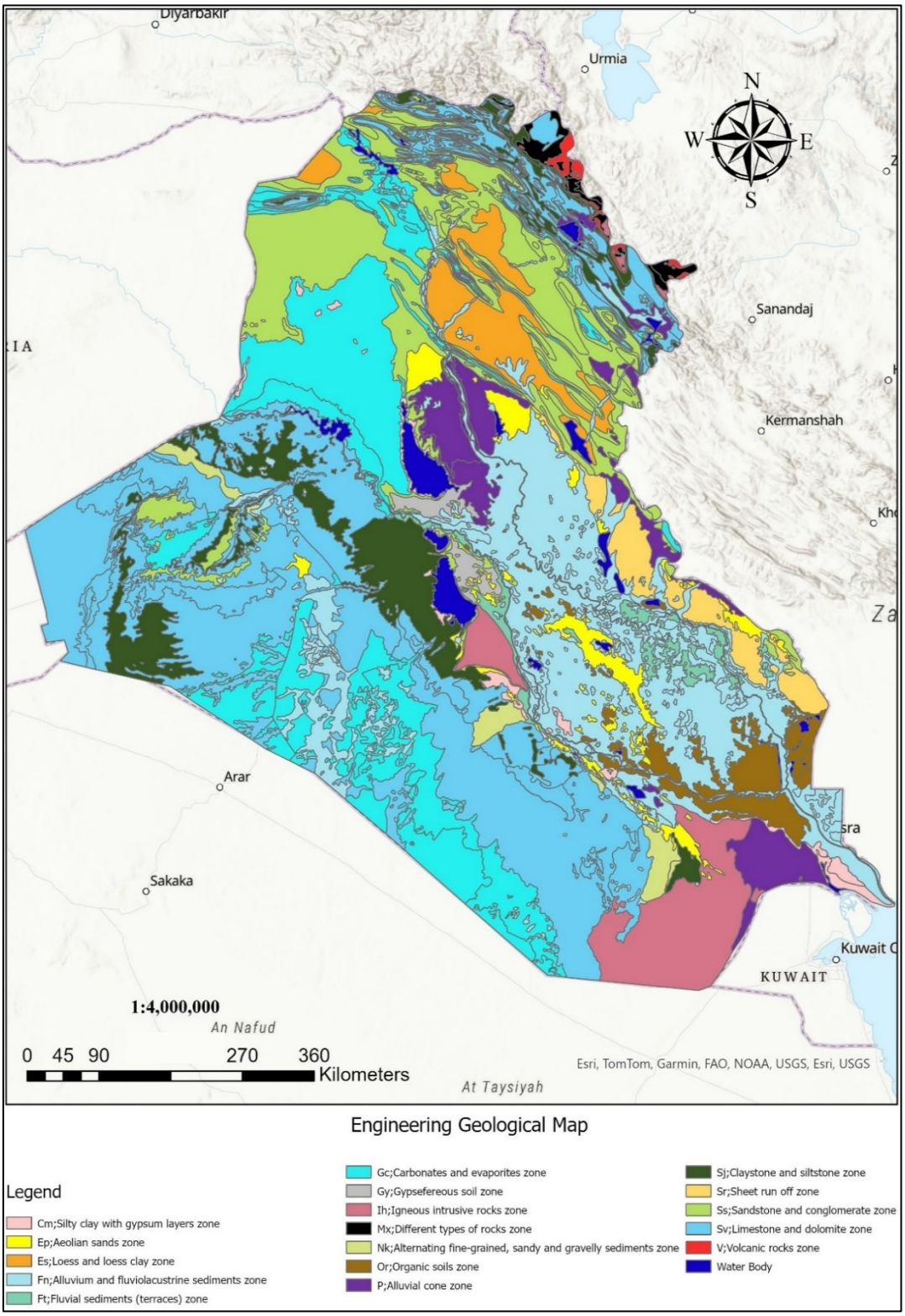


Fig. 5. Engineering geological zoning map of Iraq based on the modified Czech classification.

4. Conclusion

The engineering geological zoning map developed in this study comprises 17 zones derived from the lithological evaluation and reclassification of geological formations and units exposed at the surface of Iraq. The modified zoning system provides a regional framework for interpreting geological conditions relevant to construction, foundation engineering, infrastructure planning, and other engineering applications.

Most of the zones correspond to the Czech engineering geological classification; however, five additional zones were introduced to represent geological conditions characteristic of Iraq:

1. Mx- mixed rock types zone. This zone is added to describe the units of mixed types of rocks, Igneous, Metamorphic, and Sedimentary, precisely in the Kurdistan region. This zone is a new zone for the map. The Mx zone represents a regional-

scale simplification because the available source data do not allow lithologically heterogeneous units to be subdivided according to their physical and mechanical properties.

2. Gc- Carbonates and evaporites zone is found in many areas in Iraq, and examples of that are the Fat'ha and Jill formations.
3. Cm- described Sabkhas and Tidal flat sediments like silty clay, sandy clay, and gypsum layers.
4. Sr- The sheet runoff zone is very important and comprises a great area of 9068.3 km^2.
5. Gy- describes Iraq's gypsiferous soil like gypcrete with a significant area of 2904.6 km^2.

Four zones dominate the engineering geological zoning of Iraq:

- Sv, the largest zone – about 26 % of Iraq's area, huge carbonate rocks of limestone and dolomite of 113075.9 km^2.
- Fn, the second most extensive zone of around 17 %, fluvial deposits are abundant in Iraq due to the abundance of rivers and streams, in addition to the two great rivers of Tigris and the Euphrates that flow from the north to the south of Iraq, which explains the great amount of these deposits. The area comprised is 72018.5 km^2.
- Gc, the third most significant zone of about 15 % carbonates and evaporite formations, comprises an area of 64257.4 km^2.
- Ss, the fourth of 11.4% sandstones and conglomerate zones, comprises 49732.1 km^2 of the Iraqi exposed geology.
- The Ss and Sj zones together account for approximately 18% of the mapped area; other clastic sediments are represented by additional zones.

The resulting map is intended for regional-scale assessment and preliminary planning. It can support the identification of areas requiring more detailed engineering geological and geotechnical investigation prior to construction; however, it does not replace site-specific investigation required for engineering design.

Although the resulting map provides a regional engineering geological framework for Iraq, its future refinement should incorporate:

- higher-resolution geological mapping.
- systematic field-based lithological observations.
- physical and mechanical properties of soils and rocks.
- integrated Quaternary and bedrock geological information.
- regional weathering-zone data.
- information on the thickness of geological units and weathering profiles.

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