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A Comprehensive Review on Gypsisols: Characteristics, Genesis, and Environmental Implications

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Abstract
Gypsisols, a distinct soil order recognized by the presence of gypsum as a primary soil-forming mineral, play a crucial role in shaping terrestrial ecosystems and influencing environmental processes. This research review provides a comprehensive examination of Gypsisols, encompassing their key characteristics, genesis, and the broader environmental implications associated with their presence. The paper delves into the unique physicochemical properties of Gypsisols, exploring the impact of gypsum on soil structure, fertility, and water retention. The genesis of Gypsisols is explored, considering factors such as climate, parent material, and biological processes that contribute to the formation of these specialized soils. Additionally, the review investigates the distribution of Gypsisols globally, highlighting regions where they are prevalent and the ecological significance of their presence.
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1. Introduction

Soil classification is one of the most important stages in natural resources assessment. There are a number of theoretical soil forming processes that determine the prevailing soil types. Soil patterns can be understood using soil-landscape models that provide a key to establish or predict soil type occurrences using different soil environmental attributes (Vargas and Alim, 2007). In other words, each soil formation factor, i.e. geology, geomorphology (landform, exposure and elevation), vegetation, land use and time, determines the different stages and paths of soil development. Moreover, soil classification can present a basis for soil-related agro-technology transfer (Braimoh, 2002; Buol and Denton, 1984). According to Shi et al. (2005), systematic soil classification connects research findings and their useful extension to field applications. The significance of soil classification and mapping as a foundation for agricultural planning and the adoption of environmentally friendly land use techniques.

There is no single system for classifying soils that is approved worldwide yet. However, the Soil Taxonomy (ST, Soil Survey Staff, 1992) and the World Reference Base for Soil Resources (FAO/ISRIC/ISSS, 1998) are more commonly used on a global scale (Shi et al., 2005). Weathering forces act on parent material that has been deposited by geologic agencies to create soil (Jenny, 1941).

There are five main factors that affect the type of soil that develops. They include the type of parent material, the environment in which it has existed, the presence of organisms, the terrain, and the amount of time that the forces of soil formation have had an impact on the parent material (Brady and Weil, 1999). By its very nature, soil development involves a complex process of weathering that affects the content of one or more components in a specific horizon (Breemen and Buuman, 2002).

The factors that make up soil are interdependent; one affects the others' effects in different ways. Each of the aforementioned factors has an impact on how a soil develops, however depending on the location; one factor may be dominant and account for the majority of the soil's features. In some locations, a change in any one of the five criteria causes the creation of a different type of soil.

Gypsisols are soils with significant secondary gypsum buildup. These soils are located in the driest regions of the arid climate zone, which helps to explain why many of them were classified by the leading soil classification systems as desert soils (in the former Soviet Union) and yermosols or xerosols (FAO–UNESCO, 1971–1981). They are referred to as Gypsids by the US Soil Taxonomy. (WRB, 2006)

This review was aimed to investigate and understand the genesis and mineralogy, characteristics, geographical distribution and management of Gypsisols.

History, connotation and correlation

The name Gypsisol comes from L. gypsum and refers to soils with substantial accumulation of calcium sulphate. In the FAO 1974 legend of the Soil Map of the World, Gypsisols were classified under the Yermosols and under the Xerosols. As of 1988 Gypsisols were taken up to the highest hierarchical level in the FAO Legend. In Soil Taxonomy, Gypsisols key out under the Aridisols as Gypsiorthids. In the USSR Gypsisols were called Desert soils. Common soil units:

Petric*, Hypergypsic*, Leptic*, Vertic*, Endosalic*, Duric*, Calcic*, Luvic*, Takyric*, Yermic*, Aridic*, Hyperochric*, Skeletic*, Sodic*, Arzic*, Haplic*. (FAO, 2001)

2. Genesis and Mineralogy of Gypsisols

The majority of gypsisols were created when dissolved gypsum from gypsiferous source materials moved through the soil with soil moisture and precipitated in an accumulation layer. Gypsic or petrogypsic horizons are found at a shallower depth than a layer with lime accumulation when soil moisture tends to flow upward (i.e., when a net evaporation surplus exists for a sustained period of time each year) (if present).

During the wet winter months, gypsum is leached from the soil's top layer. Gypsum ($CaSO_4.2H_2O$) dehydrates in hot, dry summers in arid places, becoming a loose, powdery hemihydrate ($CaSO_4.0.5H_2O$), which then transforms back into gypsum in the moist winter. Gypsum crystals that have been created in this way can group together to form compact layers or surface crusts that can grow to be tens of centimeters thick.

Gypsum can form as fine, white, powdery crystals in previous root pathways (known as "gypsum pseudomycelium") or pockets, or it can form as coarse, crystalline "gypsum sand" or in heavily cemented petrogypsic layers in the soil body. Under stones and pebbles or rosettes (sometimes known as "desert roses"), it sometimes creates pendants. There are also instances where the collected gypsum is generated in place. Sites with sulfate-rich groundwater at shallow depths have been observed to produce "intrazonal" gypsisols, which are generated under the dominant effect of local material or relief.

Another example was recorded from regions in southwest Siberia with pyritic sediments where sulphate ions, created when sulphides oxidized during forced drainage of the land, precipitated as gypsum at depths of 20 to 150 cm. In the Republic of Georgia, it was discovered that gypsum formed when saline, seepage water containing Na_2SO_4 came into contact with dolomite weathering. Gypsum in Gypsisols, however, typically comes from evaporites from the Triassic, Jurassic, and Cretaceous eras or (most commonly) from Miocene gypsum deposits. (FAO, 2001)

3. Characteristics of Gypsisols

3.1. Morphological characteristics

The typical gypsisol is built of a 20–40 cm thick, yellowish brown, loamy or clayey A–horizon overlain by a B–horizon that is pale brown and features prominent pockets of white gypsum and/or pseudomycelium. With little organic matter and a weak, subangular blocky structure, the surface layer is made up of severely de-gypsified weathering leftovers. The gypsic horizon is most obviously formed in the lower B-horizon or somewhat deeper and can range in consistency from a soft, powdery, highly porous mixture of gypsum, lime, and clay to a hard, huge layer of practically pure, coarse gypsum crystals. (FAO, 2001).

3.2. Hydrological characteristics

Gypsisols have hydraulic qualities that can vary greatly. Infiltration of surface water is nearly minimal in some encrusted soils, whereas very substantial percolation losses happen in soils where gypsum dissolving has widened fissures, holes, and cracks to interconnected subterranean caverns. Saturated hydraulic conductivity values ranges from 5 to >500 cm/d. The valuable topsoil becomes even shallower as the voids are filled with surface soil particles, necessitating annual land surface leveling. (FAO, 2001)

3.3. Physical characteristics

The majorities of de-gypsified surface layers include 40% or more clay and have a 25–40% volume water retention capacity. Gypsum-containing surface soils hardly ever contain more than 15% clay, and they retain no more than 25% of the "available" soil moisture. Despite having just 200 to 450 mm of annual rainfall, loamy surface soils readily slake to a coarsely platy surface crust that prevents rainwater infiltration and encourages sheet wash and gully erosion to the point where deep (petro) gypsic layers are revealed.

The presence of gypsum frequently affects the color of the soil. Gypsum-rich soils (which make up around 90% of all soils) are white in color.

They differ in texture often as a result of the sedimentary environment in which they are found. The gravel component can be significant, particularly on river terraces.

Normally, soil structure is not well formed, but when the gypsum level exceeds 20%, it usually develops into a massive structure. Capillary rise could introduce salts into the profile if the water table is close to the surface. The amount and kind of ions introduced into the system have a bearing on this aspect of salinity. (FAO, 1988)

3.4. Chemical characteristics

Gypsum in trace amounts has no negative effects on plants; but, gypsum levels of more than 25%, as seen in many gypsiferous subsoils, disturb plant nutrient uptake and reduce the availability of phosphorus, potassium, and magnesium. Gypsisol surface horizons have total element levels of less than 2500 mg N/kg, less than 1000 mg

P_2O_5/kg (of which less than 60 mg/kg is considered "available"), and less than 2000 mg K_2O/kg. This means that considerable fertilization is required for acceptable yields. In general, the cation exchange capacity is between 20 and 10 cmol(+)/kg in the surface soil and declines as the gypsum content of the soil material increases. The base is then almost fully saturated. (FAO, 2001)

4. Geographical Distribution of Gypsisols

Gypsisols are found only in dry areas; their global extent is most likely in the range of 100 million ha. Large occurrences can be found in Mesopotamia, the Libyan and Namib deserts, southeast and central Australia, the southwest of the USA, desert regions of the Near East and neighboring Central Asian republics. (FAO, 2001)
Only arid environments, flat or hilly land and depression areas have gypsisols (e.g. former inland lakes). Gypsisols cover around 1 million km^2 of the planet. Gypsisols contain a significant secondary gypsum accumulation in the soil.

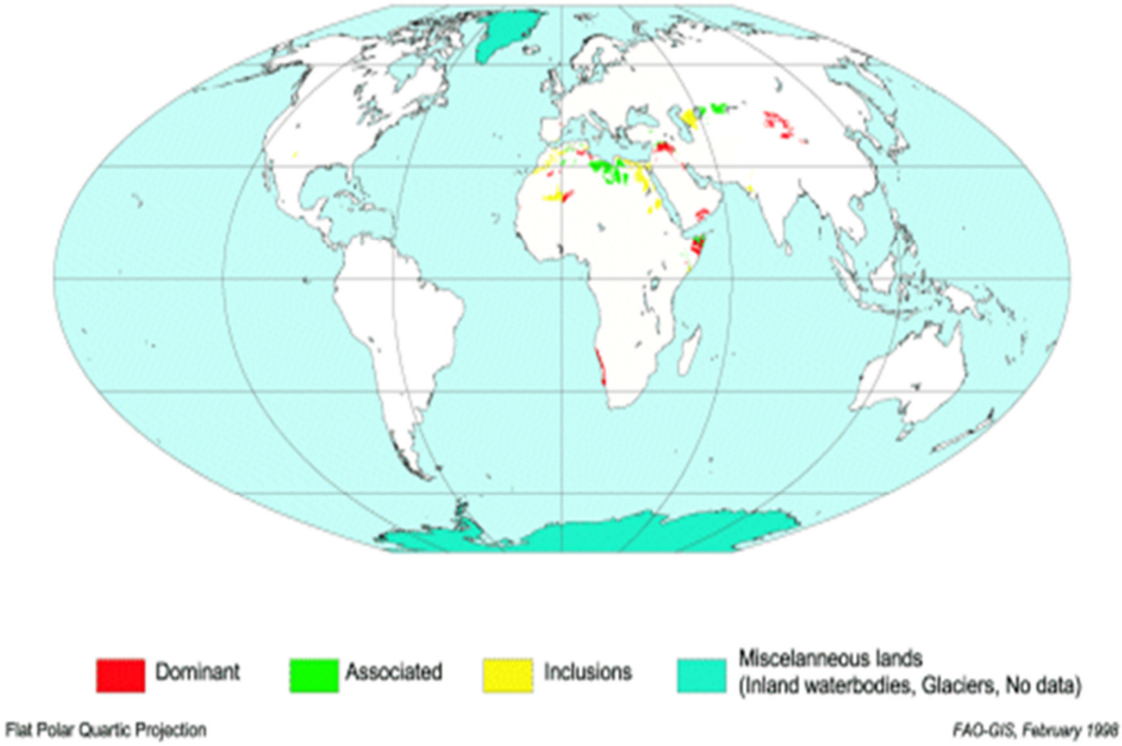

Figure1. Distribution of gypsisols in the world

They make a significant portion of the rangelands. Most of the time, precise information about their distribution is lacking. As a result, it is challenging to get a precise or even rough number for the percentage of area covered by these soils globally. The spatial distribution of these soils is greatly influenced by their closeness to water sources. Examples include Syria, where Gypsisols predominate on all river terraces of the Euphrates, Khabour, and Balikh rivers (Ilaiwi, 1983). In Iraq, the Mesopotamian lowlands between and near the Tigris and Euphrates rivers are largely covered by gypsisols.

They can be found in the driest regions of arid climate zones, and in Africa, the northern Desert is where they are most common. A lot of gypsisols are found in depressions and are reflections of ancient lake beds that have evaporated and dried up. Gypsum precipitation processes resemble those of calcisols. Gypcrete is the name for gypsum that hardens into a solid pan. Ephemeral grasses or xerophytic bushes predominate in the scant natural vegetation (Gergely Tóth *et al.*, 2008).

In Ethiopia, Gypsisols with a high concentration of gypsum ($CaSO_4.2H_2O$) are almost exclusively found in the Somali region (Ogaden plain) and on the alluvial and colluvial deposits of the Wabishebele River. (Eyasu Elias, 2016)

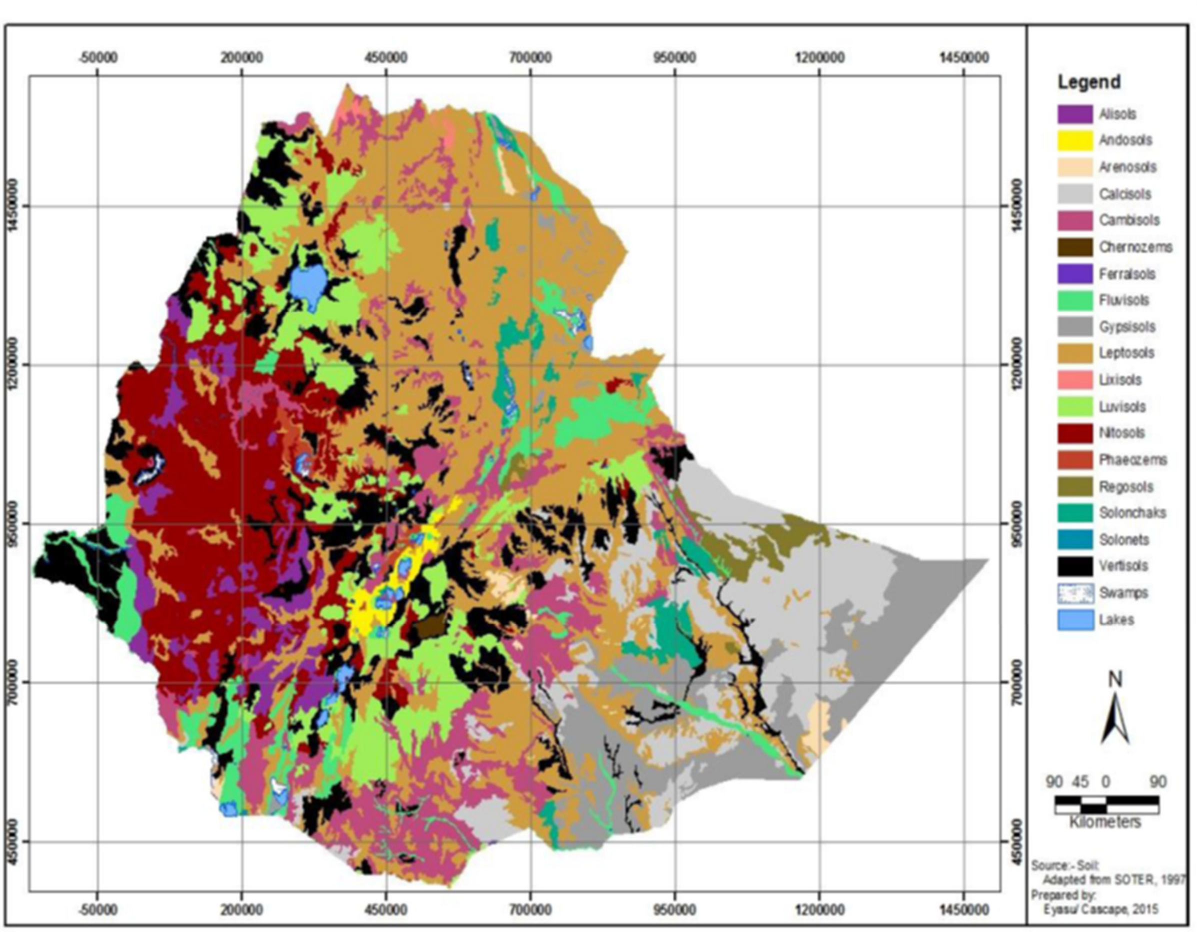

Figure2. SOTER Map of Ethiopia (FAO, 1998). (Eyasu Elias, 2016).

Table1. Reference Soil Group (Gypsisols) according to the SOTER map of Ethiopia.

ReferenceSoil Groups	Soil units and mapping codes	Area (Km^2)	% of total landmass
Gypsisols(GY)	Haplic Gypsisols (GYh)	46591.37	4.12
	Petric Gypsisols (GYp)	39700.21	3.51
	Total Gypsisols	86291.58	7.63

(Eyasu Elias, 2016)

5. Management and Use of Gypsisols

Gypsisols are suitable for small grains, cotton, and alfalfa if the gypsum content in the top 30 cm is not more than a few percent. Crops including wheat, maize, apricots, and dates can all be produced with irrigation in soils that contain 25% or more gypsum. Gypsum that dissolves quickly may lead to issues including concrete building corrosion, canal wall caving, and land subsidence.

There is comparatively little gypsum in many Gypsisols in (young) alluvial and colluvial deposits. If properly irrigated, such soils can be quite productive. Even soils with 25 percent or more of powdered gypsum may nevertheless offer excellent yields of alfalfa hay (10 tons per hectare), wheat, apricots, dates, maize, and grapes if irrigation was applied at high rates in conjunction with forced drainage. The rapid dissolution of soil gypsum in irrigated agriculture on gypsisols causes irregular subsidence of the ground surface, cave-ins in canal walls, and corrosion of concrete structures.

Gypsum dissolution may also shallow a petrogypsic horizon to the point where a hard pan impedes root development, water availability to the crop, and/or soil drainage. Gypsisols are used to cover large regions that are extensively grazed. (FAO, 2001)

Linkages

Gypsic horizons may occur in other reference soil groups, e.g. in Vertisols, Solonchaks, Solonetz and Kastanozems, but these soils are also characterized by the presence of other diagnostic horizons or properties which are absent in the Gypsisols.

The lateral linkage of the different forms of gypsic layers with non-gypsic horizons is a function of the following factors:

- **Topography**

Petrogypsic horizons occupy the summits in areas with dominant gypsic formations whereas gypsic horizons occur on slopes. Calcic horizons are found in the lower parts and in depressions. If both gypsum formation and calcification has taken place in old geomorphic surfaces, summits are usually occupied by petrocalcic horizons while gypsic and petrogypsic horizons occur at lower levels.

- **Age**

The degree of expression of the gypsic horizons is influenced by time. The volume of gypsum crystals in recent quaternary saline depressions and valleys does not only reflect the rate of salinization, but also the age of the salinization process. As gypsic horizons age, they have a tendency to petrify. Water plays a key role in transporting and redistributing gypsum. For example, where gypsiferous rocks are exposed in semi-arid hilly or mountainous regions, gypsum is transported by run-off and deposited in lower lying areas over quite far distances. (ISRIC, 2001)

6. SUMMARY

Gypsisols are soils with substantial secondary accumulation of gypsum (CaSO4.2H2O). They are found in the driest parts of the arid climate zone, which explains why leading soil classification systems labeled them 'Desert soils' (USSR), Aridisols (USDA Soil Taxonomy), Yermosols or Xerosols (FAO, 1974). Gypsisols are also defined as soils having a gypsic or petrogypsic horizon within 100 cm from the soil surface; and having no diagnostic horizons other than an ochric or cambic horizon, an argic horizon permeated with gypsum or calcium carbonate, a vertic horizon or a calcic or petrocalcic horizon underlying the gypsic or petrogypsic horizon.

Gypsisols are exclusive to arid regions; their worldwide extent is probably of the order of 100 million hectares. Gypsisols are found in the same climatic zone as Calcisols. Note that the presence of a gypsic or petrogypsic horizon is diagnostic for Gypsisols but that accumulation of gypsum occurs also in other Reference Soils. Vertisols, Solonchaks, Gleysols or Kastanozems with clear signs of gypsum accumulation intergrade with the Gypsisol Reference Group but do not key out as Gypsisols because of diagnostic properties other than a gypsic or petrogypsic horizon.

Gypsisols formed when gypsum, dissolved from gypsiferous parent materials, moved through the soil with the soil moisture and precipitated in an accumulation layer. Gypsisol has 20 to 40 cm of yellowish brown, loamy or clayey surface soil over a pale brown subsurface soil with distinct white gypsum pockets and/or pseudo-mycelium. Surface soils with more than 15 percent gypsum have seldom more than 15 percent clay and their retention of 'available' soil moisture does not exceed 25 volume percent. The total element contents of Gypsisol surface horizons are typically less than 2500 mg N/kg, 1000 mg P_2O_5/kg (of which less than 60 mg/kg is considered 'available'), and 2000 mg K2O/kg: application of fertilizers is required for good yields.

Connotation: soils with substantial secondary accumulation of calcium sulphate; from L. gypsum, gypsum.

Parent material: mostly unconsolidated alluvial, colluvial or aeolian deposits of base-rich weathering material.

Environment: predominantly level to hilly land and depression areas (e.g. former inland lakes) in arid regions. The natural vegetation is sparse and dominated by xerophytic shrubs and trees and/or ephemeral grasses.

Profile development: AB(t) C profiles with a yellowish brown ochric surface horizon over a pale brown or whitish cambic or argic subsurface horizon. Accumulation of calcium sulphate, with or without carbonates, is concentrated in and below the B-horizon.

Use: Deep Gypsisols located close to water resources can be planted to a wide range of crops. Yields are severely depressed where a petrogypsic horizon occurs at shallow depth. Nutrient imbalance, stoniness, and uneven subsidence of the land surface upon dissolution of gypsum in percolating (irrigation) water are further limitations. Irrigation canals must be lined to prevent canal walls from caving in. Large areas of Gypsisols are in use for low volume grazing. (FAO, 2001)

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