

A New Hydrothermal Coupling Model for Predicting Temperature Profiles: Impact of Porosity, Density and Meteorological Factors

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Abstract: Accurately predicting soil temperature variation plays a crucial role in the design and optimization of geothermal applications, as it directly impacts the efficiency and performance of geothermal energy systems. The study of the hydrothermal behavior of soil systems lacks accurate simulations of the effects of atmospheric conditions on water transfer processes and thermal changes in unsaturated soil media. Therefore, a 3D coupled numerical model was developed in this paper, incorporating both soil-atmosphere interactions and the specific characteristics of unsaturated soils, to provide a more comprehensive understanding of the behavior of soil systems under varying conditions. Based on this model, the changes in the thermal profile within soil, as a function of depth and time, were analyzed. Two soil types (clay and sand) were investigated, considering different porosities and specific densities. Furthermore, the developed model accounts for real meteorological conditions in the Oran region (Algeria). The results indicate that clayey soil with low porosity ($n = 0.4$) and high density, is particularly well-suited for retaining heat and reducing heat loss. Its properties allow it to efficiently store thermal energy, making it an ideal medium for geothermal applications where heat retention is important. This model can be adapted to other regions by adjusting local data, offering a methodology for optimizing geothermal systems in various climatic and geological contexts.

Keywords: Atmospheric conditions; Hydrothermal model; Porosity; Specific soil density; Soil temperature.

1. INTRODUCTION

In recent decades, global temperatures have risen significantly worldwide. As a critical environmental parameter, soil temperature plays a fundamental role in numerous environmental studies and is particularly vital for various Earth science applications. This includes its essential contribution to geothermal systems used for building heating and cooling [1]. Soil temperature (ST) which describes the thermal conditions of the ground at a specific location and depth, serves as a reliable indicator of climate change, as soil temperature shows a quick and sensitive response to changes in environmental and climatic conditions [2]. Soil acts as a prominent heat reservoir, capturing energy during the day and providing heat to the surface at night. Moreover, throughout the warm season, the soil stores energy and during the colder season, releases it [3, 4]. Soil temperature is considered a function of the soil's internal energy. Additionally, it depends on the heat flux in the soil and the exchange of heat between the soil and the atmosphere [3, 5]. Researchers reported that ground temperatures at depths of up to 1 meter are considered to be affected by daily temperature changes. Moreover, seasonal fluctuations can reach depths of 9 to 15 meters [6].

Various studies have been performed to assess the ground temperature profiles [7, 8]; however, the experimental measurements of ST variations are usually restricted to specific research sites and are available for limited period of time [1]. Thus, developing modelling approaches to predict soil temperature fluctuations at various depths would be crucial in many research fields [1,9]. Several mathematical models have been formulated to describe the periodic fluctuations in soil temperature at given depths and times, and analytical solutions were developed for heat transfer considering thermal conduction and convection process in porous media [10, 11] However, most of these analytical solutions are valuable for 1D heat transfer in saturated soil, and invariant temperature boundaries are applied. More recently, researchers carried out numerical investigations on ST variations considering many factors, such as organic matter content, vegetative cover, soil color, urbanization effect and thermal conductivity calculations [2, 12]. Other studies state that solar radiation and air temperature represents the main factors affecting ST; and the secondary factors include soil moisture content, bulk density and soil texture [1, 13].

ST combines the effects of hydrothermal processes and the interactions occurring near the ground surface and within the soil. Moreover, a positive feedback relationship is observed between ST and atmospheric conditions at shallow depth. Understanding the full significance of this involves assessing meteorological patterns and seasonal fluctuations in assessing ground temperature variations.

In recent years, geothermal energy has emerged as a clean, cost-effective, and sustainable renewable energy source, particularly in an era of increasing global energy demand. It presents a highly advantageous alternative to fossil fuels for heating and cooling applications. The underlying principle involves harnessing the Earth's thermal energy and utilizing it for diverse applications, including electricity generation, as well as providing thermal energy for heating and cooling residential and commercial buildings, greenhouses, and industrial processes. Researchers carried out experimental and numerical investigations to assess the thermal efficiency of shallow heat exchanger systems [4, 14-17]. They reported that time-varying ground temperatures involving atmospheric temperatures affect the performance of geothermal systems, a consideration that is often neglected in numerical simulations. Furthermore, the majority of these investigations consider the soil as a saturated porous media and heat transfer occurs exclusively through thermal conduction [18, 19].

This research focuses on developing a numerical hydrothermal model incorporating soil-atmospheric interaction for two different types of soil: clay and sand. The effects of soil porosity and density variations were investigated for assessing ST variations, since it represents a key indicator for geothermal application and allows to optimize the energetic performance of ground heat exchangers. Given the shallow installation depth of geothermal systems, atmosphere-soil interactions are crucial in driving ground temperature variations. This work considers weather patterns of the studied region, mainly solar radiation, precipitation and evaporation, in order to predict the fluctuation of ground temperature over time. The 3D hydrothermal developed model considers the effects of moisture changes in unsaturated clayey and sandy soils. Moreover, this study highlights the significance of soil porosity and density with regard to ST variation.

2. MATHEMATICAL FORMULATION

2.1 Atmosphere-soil Interactions at the Ground Surface

The ground surface energy budget is governed by the interplay of multiple energy fluxes, primarily driven by meteorological conditions. As illustrated in Figure 1, these fluxes form part of a complex, coupled hydrothermal system that connects the atmosphere, soil, and water in both natural and engineered environments. Solar radiation acts as the primary driver, heating the ground, water, and air, while precipitation plays a critical role in recharging surface and subsurface water reservoirs. Subsurface flow dynamics and land surface features, such as vegetation, further modulate these energy and mass exchanges. In accordance with energy conservation principles, the heat transfer at the soil-atmosphere interface can be mathematically formulated to represent these interactions, as [20]:

$$R_n + H - LE = G \quad (1)$$

where G represents the ground heat flux; R_n and H are respectively the net radiation heat and the sensible heat; and LE symbolizes the latent heat flux. All the parameters of the previous equation are measured in W/m^2 .

According to [21], the sensible heat flux (H) is calculated by evaluating the temperature difference between the ground surface and the surrounding ambient air; hence driving the heat exchange from the surface to the atmosphere or vice versa. As a result, the thermal transfer that occurs due to this temperature gradient can be expressed by the following equation:

$$H = \frac{\rho_a C_{pa} (T_a - T_s)}{r_a} \quad (2)$$

where the air density $\rho_a = 1.2 \text{ kg/m}^3$; the air heat capacity $C_{pa} = 1004.7 \text{ J/(kg}\cdot\text{K)}$; T_a and T_s represent the air and ground temperatures; and r_a is the aerodynamic resistance to heat transfer determined by the Penman-Monteith method [4,15].

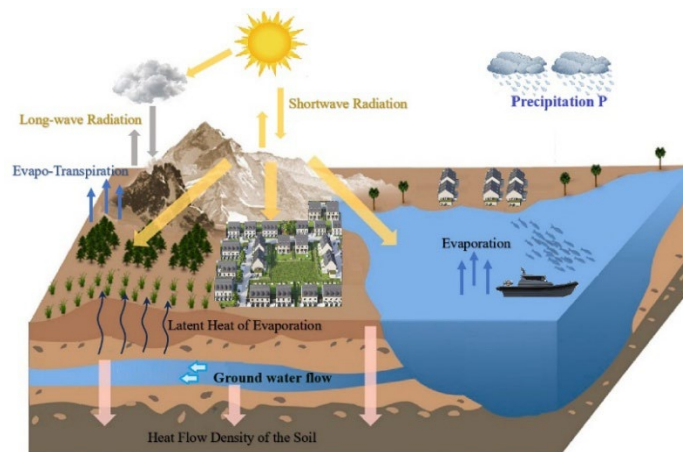


Figure 1. Schematic representation of the hydrothermal processes considering energy budget at the ground surface.

The net radiation R_n at the ground surface, defines the balance of incoming and outgoing long-wave radiation R_a , combined with the short-wave radiations R_s , that are absorbed at the earth surface. R_n is calculated as follows:

$$R_n = (1 - a_l)R_s + (R_a - \varepsilon\sigma T_s^4) \quad (3)$$

where a_l is the surface albedo; ε expresses the emissivity; $\sigma = 5.67 \times 10^{-8} \text{ W}/(\text{m}^2 \cdot \text{K}^4)$ designates Stephan-Boltzman constant.

Latent heat flux (LE) represents the energy transfer associated with phase changes of water, primarily through evaporation and transpiration processes, without causing temperature variation. The balance between evaporation potential (EP) and precipitation rate (P) can be expressed as:

$$E = P \times \left[1 + \left(\frac{EP}{P} \right)^{-2} \right]^{-\frac{1}{2}} \quad (4)$$

2.2 Hydrothermal Transfer in Unsaturated Soil

Partial Differential Equations (PDEs) are widely employed in science and engineering to model diverse phenomena, including heat transfer and fluid dynamics. In this study, the governing equations for water flow are derived from mass conservation principles, whereas the heat transfer equations are based on energy conservation and surface energy balance theories. Consequently, the hydraulic flow process in unsaturated soils is described by the Richards equation:

$$C(h) \frac{\partial h}{\partial t} - \nabla K(h) \nabla h - \frac{\partial K}{\partial z} = 0 \quad (5)$$

where $C(h)$ represents the specific moisture capacity (m^{-1}). $K(h)$ denotes the hydraulic conductivity ($\text{m} \cdot \text{s}^{-1}$) and h is the soil suction (m). In order to calculate the hydraulic conductivity, the formula of Mualem was applied [21], such as:

$$K(h) = K_s S_e^l \left[1 - (1 - S_e^{l/m})^m \right]^2 \quad (6)$$

where K_s denotes the saturation hydraulic conductivity ($\text{m} \cdot \text{s}^{-1}$), S_e is the effective degree of saturation; m and l are variables that represent the shape parameters of the soil water characteristic curve.

The relationship between water content θ and suction is defined by the van Genuchten formulation [22–24]:

$$\theta(h) = \theta_r + (\theta_s - \theta_r) [1 + (\alpha h)^{n_1}]^{-m} \quad (7)$$

where θ denotes the volumetric soil water content (m^3/m^3), θ_s and θ_r represent the saturated and residual water content (m^3/m^3), respectively. The parameter α (m^{-1}) is a fitting coefficient related to the inverse of the air entry pressure, while n_1 is a dimensionless fitting parameter that governs the shape of the soil water retention curve [25].

The energy conservation equation in the soil is expressed as follow [17]

$$\rho_s c_{ps} \frac{\partial T_s}{\partial t} = \nabla (\lambda_g \nabla T_s) + \nabla (\rho_w c_{pw} u_w T_s) + Q_g \quad (8)$$

Here, ρ and c_p denote the density (kg/m^3) and specific heat capacity ($\text{J}/(\text{kg} \cdot \text{K})$), respectively, where the subscripts s and w correspond to soil and water. The term u_w represents the fluid velocity in the soil (m/s); λ_g represents the soil's thermal conductivity; and Q_g stands for the ground heat source (W/m^3).

The volumetric heat capacities of the soil were calculated applying the equation developed by [26], such as:

$$C_v = \rho_d c_{ps} + \rho_w c_{pw} \theta \quad (9)$$

where ρ_d represent the dry density of soil (kg/m^3). The ground thermal conductivity was evaluated using the empirical formulation derived by Chung and Horton [27]:

$$\lambda_g = b_1 + b_2 \theta + b_3 \theta^{1/2} \quad (10)$$

where b_1 , b_2 and b_3 are empirical parameters.

3. NUMERICAL AND PHYSICAL SPECIFICS

3.1 Representation of the Numerical Model

The coupled partial differential equations (PDEs) presented in the previous section were solved numerically with the time-dependent solver COMSOL Multiphysics. The domain of the hydrothermal transfer problem is divided into a grid of finite elements in the COMSOL software [28]. These elements are interconnected to generate a mesh network. The solution of the governing equations is calculated in each element by the finite element method [29]. In order to assess the grid independency of the result, various configurations of finite element mesh were tested. The computational domain has dimensions of 20 m

depth and 10 m in both length and width, discretized into 3148 triangular elements. The model's boundary conditions are implemented as follows: The upper boundary employs Neumann conditions for both hydraulic and thermal domains. For thermal analysis, this incorporates the three primary energy fluxes (R_n , H and LE) to represent key heat transfer mechanisms. The hydraulic component applies a flux boundary condition based on annual precipitation patterns to accurately capture atmosphere-surface interactions (Figure 2). Lateral boundaries are modeled as adiabatic (zero-flux) for both mass and energy transport. The lower boundary utilizes Dirichlet conditions, with a prescribed pressure head for hydraulic analysis and a fixed geothermal temperature for thermal analysis, ensuring physically realistic boundary representations.

3.2 Representation of the Physical Model

The investigated site is located in Oran region (northwestern Algeria). According to the data from the Meteorological agency, the average ambient temperatures T_a and shortwave radiation R_s versus time are roughly modeled as cosine functions [4,17,29], such as:

$$T_a = 292.353 + 7.938 \sin\left(\frac{\pi(t - 118.317)}{195.547}\right) \quad (11)$$

$$R_s = 124.65 + 54.57 \sin\left(\frac{\pi(t - 87.84)}{168}\right) \quad (12)$$

The study was carried out on two types of soil: sandy and clayey soils, with different porosities and densities, as represented in Figure 3. The hydro-thermal parameters are provided in table 1. The hottest and the coldest days in July and January, respectively, were analyzed in the numerical simulation subsequently.

Research revealed that the soil porosity depends on soil type and flow velocity [10]. In this study, the effects of variations in soil porosity and density were thoroughly investigated to understand how these changes influence hydrothermal transfer in both clayey and sandy soils, as well as the interactions between the soil and atmosphere.

Table 1. The hydro-thermal properties of clayey and sandy soils (Oran).

Soil type	l	$\alpha(1/m)$	θ_s	θ_r	K_s (m/s)	C_{ps} (J/kg/K)
Clay	0.5	0.43	0.52	0.03	0.2×10^{-5}	1350
Sand	0.5	3.28	0.44	0.0	2.5×10^{-5}	910

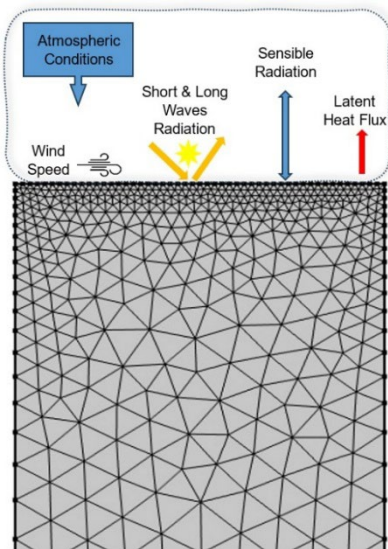


Figure 2. Meshing domain including ground-atmosphere interactions [30].

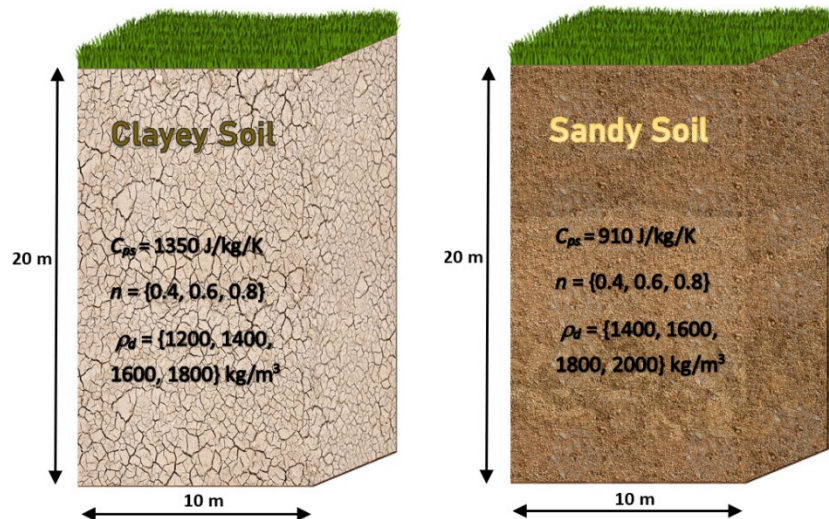


Figure 3. Soil profiles of the study area.

4. RESULTS AND DISCUSSION

4.1 Temperature Profile for Clayey and Sandy Soils Considering Meteorological Conditions

This study analyzed data collected throughout 2023, with focused examination of representative thermal profiles from a cold January day and a hot July day (Figure 4). The left panel demonstrates pronounced diurnal surface temperature variations between seasons, with these differences attenuating with depth and becoming negligible below approximately 4 meters, consistent with the known thermal stability of clay soils at shallow depths. The middle panel presents the January temperature profile, showing minimum temperatures at the surface that progressively increase with depth, reflecting reduced winter heat penetration. Conversely, the right panel displays the July distribution, characterized by elevated surface temperatures and a well-defined thermal gradient extending downward, resulting from combined seasonal heating and thermal diffusion processes.

Figure 5 shows the 2023 temperature distribution profiles in sandy soil during seasonal extremes - the coldest January day and hottest July day. The left graph reveals significant surface temperature differences between winter and summer conditions, with these variations gradually diminishing with depth until reaching thermal stability below approximately 6 meters. The middle panel represents January's temperature profile, where surface temperatures are lower and increase gradually with depth due to limited heat transfer. The right panel depicts July's distribution, with higher surface temperatures and a noticeable gradient as depth increases, indicating the influence of summer heat and thermal diffusion.

4.2 Effect of Soil Porosity on the Hydrothermal Behavior

The porosity of clayey and sandy soils was varied based on the literature review [31] in order to analyze the effect of soil porosity on the thermal behavior of the studied soils, including the atmospheric-soil interaction in the numerical simulation. Figure 6 depicts the variation of pressure head with depth for two soil types, clay and sand, with different porosity values ($n = 0.4; 0.6; 0.8$).

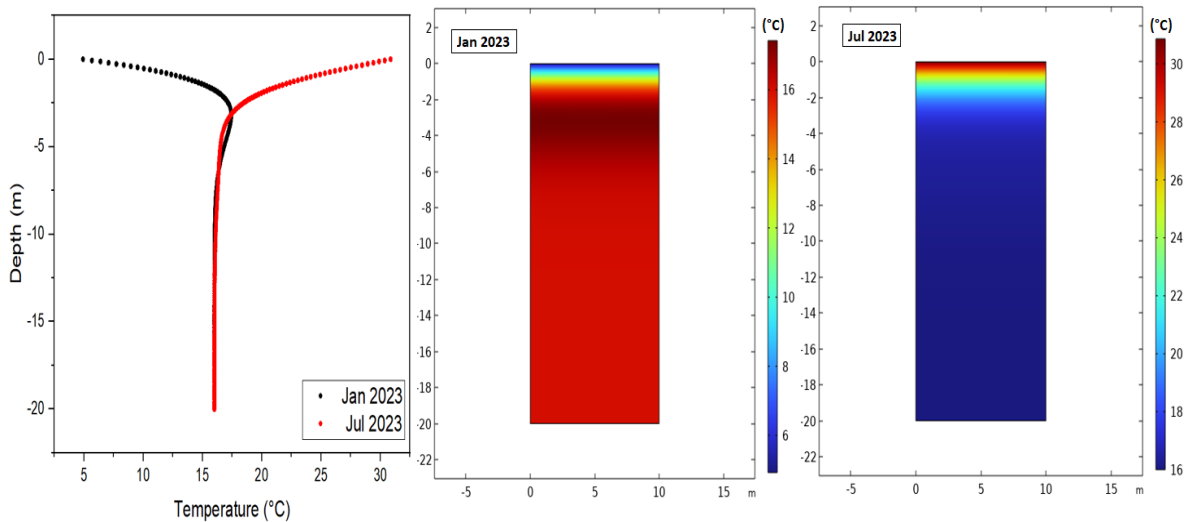


Figure 4. Temperature profiles and distributions of clayey soil for the coldest day in January and the hottest day in July 2023.

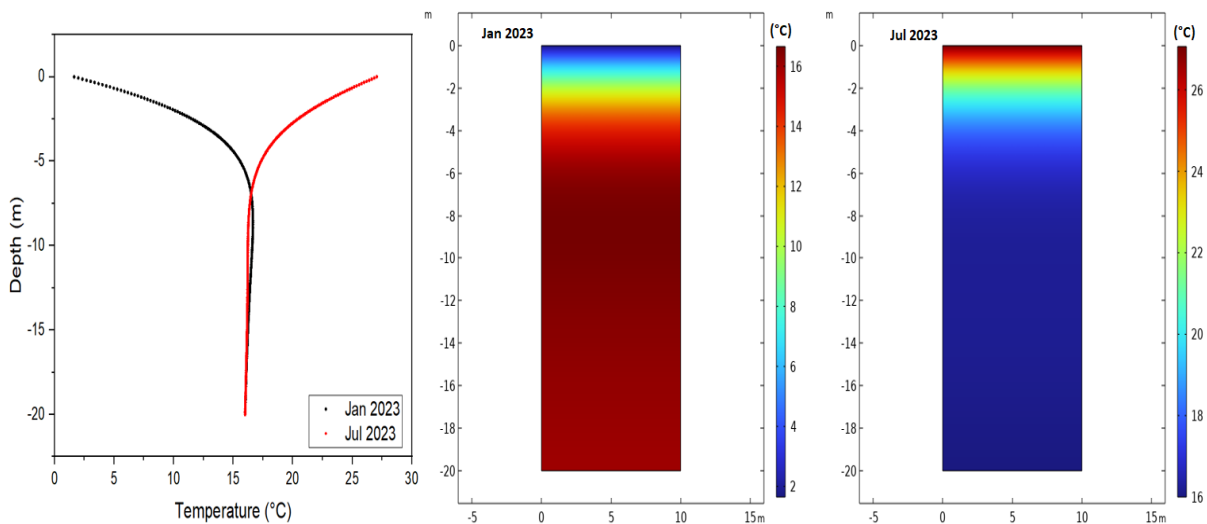


Figure 5. Temperature profiles and distributions of sand soil for the coldest day in January and the hottest day in July 2023.

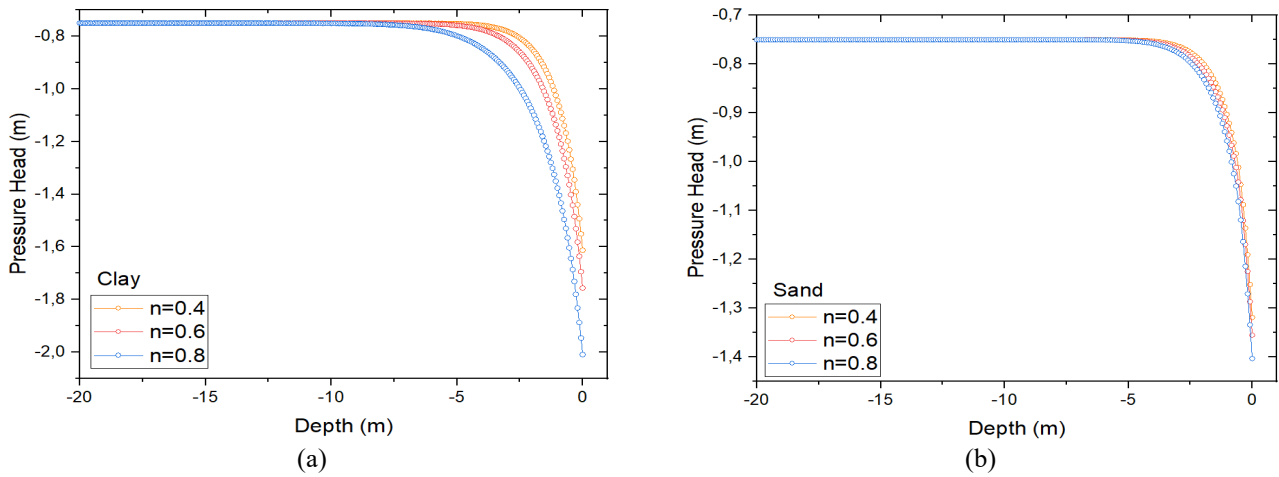


Figure 6. Effect of porosity on pressure head variation with depth for: (a) clay (b) sand.

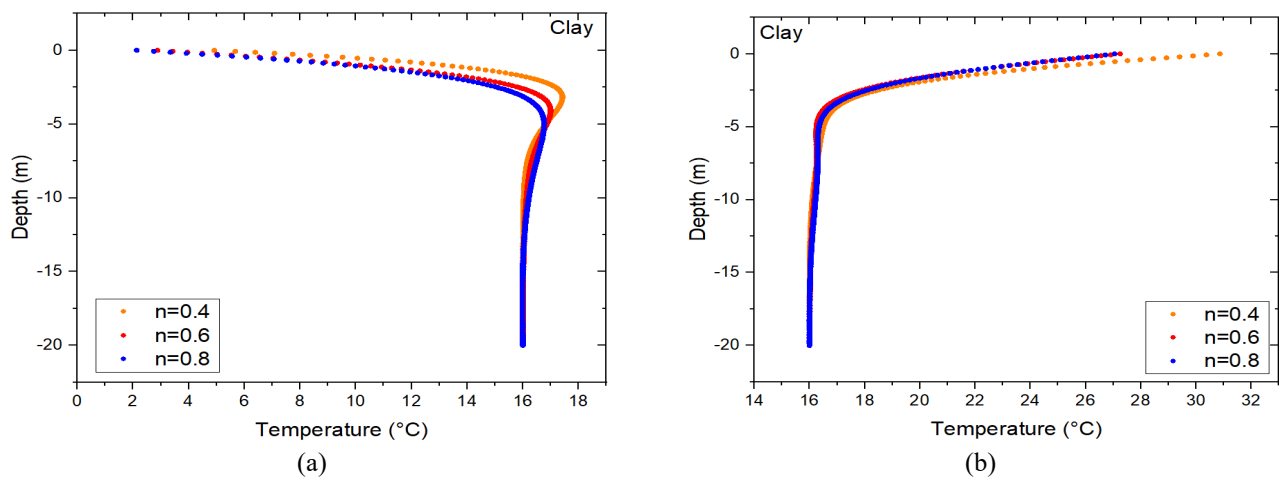


Figure 7. Effect of porosity on temperature distribution with depth in clay for: (a) January 2023, (b) July 2023.

The pressure head profiles reveal distinct water retention characteristics between soil types. Clayey soil demonstrates high water retention capacity, particularly at low porosity ($n = 0.4$), evidenced by its gradual pressure head decrease with depth. This behavior suggests clay's suitability for closed geothermal systems, where reduced porosity limits void space, promotes thermal stability, and minimizes convective heat losses. In contrast, sandy soil exhibits a rapid pressure head decline, reflecting its inherently lower water retention and faster drainage properties. While reduced porosity ($n = 0.4$) improves sand's performance by moderating excessive drainage, its overall efficiency remains inferior to clay. These findings indicate that low-porosity clay is optimal for geothermal applications requiring maximal thermal energy conservation, whereas sandy soil may serve as a secondary option in scenarios where higher permeability is advantageous.

Figure 7(a) depicts the relationship between temperature of a cold day and depth in clayey soil, emphasizing the effect variation porosity (0.4; 0.6; 0.8) on thermal behavior. It can be seen from this figure that as depth increases, the temperature rises due to the geothermal gradient, with heat transfer determined by the material's thermal properties. Low-porosity clay ($n = 0.4$) has a higher temperature gradient, indicating greater thermal conductivity and efficient heat transfer, as fewer voids allow heat to move more effectively. In contrast, higher porosity values ($n = 0.6$ and $n = 0.8$) result in flatter curves, reflecting reduced thermal conductivity caused by increased void spaces that disrupt heat conduction. Low-porosity clay is best suited for geothermal applications as it easily transfers heat, improving the performance of geothermal systems, whereas larger porosity materials are less effective due to their limited heat transfer capacity.

Figure 7(b) presents the temperature-depth profiles for clayey soil at varying porosity levels during July 2023. The observed thermal gradients demonstrate two key phenomena: (1) a consistent temperature increase with depth following the natural geothermal gradient, and (2) porosity-dependent variations in thermal behavior. Specifically, the low-porosity case ($n = 0.4$) exhibits the steepest thermal gradient, indicating enhanced heat transfer efficiency attributable to reduced void fraction and consequent improvement in thermal conduction. Conversely, higher porosity conditions ($n = 0.6$ and 0.8) display attenuated thermal gradients, reflecting the insulating effect of increased pore volume on heat propagation. These results quantitatively confirm that reduced porosity clay soils offer superior performance for geothermal energy applications due to their favorable thermal transport characteristics.

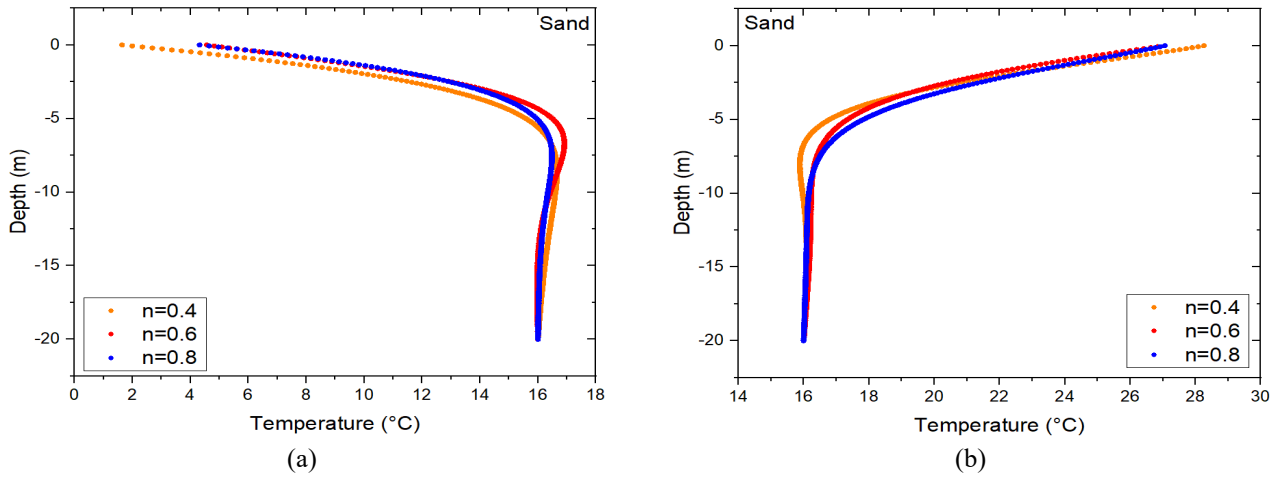


Figure 8. Effect of porosity on temperature distribution with depth in sand for: (a) January 2023, (b) July 2023.

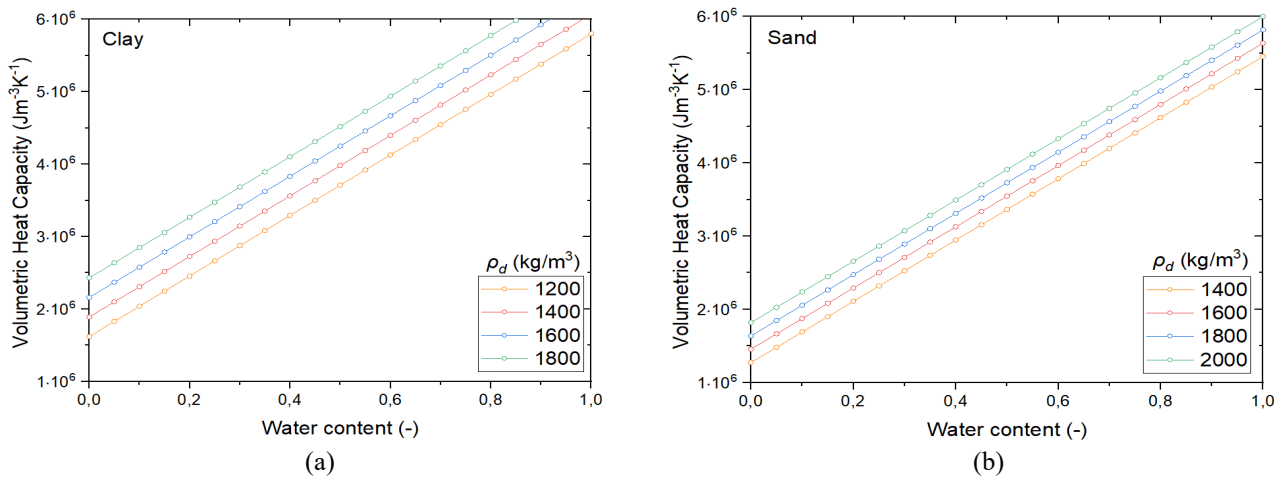


Figure 9. Variation in volumetric heat capacity as a function of water content and soil density of: (a) Clay, (b) Sand.

The temperature profiles in sand reveal a less pronounced temperature rise with depth, as shown in Figure 8(a). For all porosity values, the geothermal gradient is evident, but the differences in temperature distribution due to porosity are less distinct. Lower porosity ($n = 0.4$) shows a slightly sharper temperature increase, which can be attributed to better thermal conductivity due to reduced void spaces. However, the higher porosity values (0.6 and 0.8) exhibit a more gradual temperature rise, indicating that increased voids slightly hinder heat conduction but not as significantly as in clay. Overall, the thermal behavior of sand appears less sensitive to changes in porosity compared to clay, suggesting that porosity has a less dominant effect on heat transfer in sandy soils. This could be due to sand's intrinsic properties, such as larger grain size and reduced water retention, which already influence its thermal conductivity.

In summer, the temperature increases more steeply with depth at lower porosity levels ($n = 0.4$), indicating better heat conservation at lower levels (Figure 8(b)). Conversely, high porosity ($n = 0.8$) shows a more gradual temperature transition, indicating that soil with high porosity dissipates more heat, probably due to greater water or air circulation in the pores. Reduced porosity soil is better at retaining and transferring heat at depth, which may make it more suitable for geothermal applications in comparable circumstances.

4.3 Effect of Soil Density Variation on the Hydrothermal Behavior

According to the literature, the density of the two types of soil was varied as follows [32]:

- Clayey soil: $\rho_d = 1200, 1400, 1600, 1800 \text{ kg/m}^3$
- Sandy soil: $\rho_d = 1400, 1600, 1800, 2000 \text{ kg/m}^3$

Figure 9 illustrates the volumetric heat capacity ($\text{Jm}^{-3}\text{K}^{-1}$) as a function of water content for the two types of soil, at different densities (ρ_d). From this figure, the volumetric heat capacity of clayey soil increases linearly with increasing water content; dense soils ($\rho_d = 1600, 1800 \text{ kg/m}^3$) have higher values. This is explained by higher density corresponding to more mass per unit volume, thus increasing heat storage capacity. Sand behaves similarly, showing higher values for higher densities ($\rho_d = 1800, 2000 \text{ kg/m}^3$) and a linear increase in volumetric heat capacity as a function of water content. However, for equivalent densities, the value observed for sand remain lower than those for clay due to the coarser texture of sand, which limits its ability to retain water and, consequently, store heat. In thermal applications such as geothermal systems, clay performs better than sand due to its fine structure and superior water retention.

Figure 10(a) shows how temperature changes with depth in clay soil of different densities during January. While surface temperatures vary with the seasons, they stabilize at about 16°C below a certain depth. The effect of soil density is most

apparent near the surface, less dense soils show a more gradual temperature change, while denser soils display a sharper transition to stable temperatures and faster heat transfer. At greater depths, all soil types reach the same stable temperature, proving that density only matters in the upper layers affected by seasonal changes. These results demonstrate that while density significantly affects heat distribution near the surface, it doesn't influence the stable temperatures reached at depth.

In July, the temperatures in the surface layers rapidly decrease to about 5 meters, where the influence of surface heat is most noticeable, before stabilizing at deeper depths (Figure 10(b)). The high heat capacity of denser clays ($\rho_d = 1800 \text{ kg/m}^3$) results in slower heat dissipation at depth and better heat retention near the surface. In contrast, less dense clays ($\rho_d = 1200 \text{ kg/m}^3$) lose heat more rapidly with depth, reflecting a lower thermal capacity. Near the surface, low-density clay soils reach higher temperatures due to their greater sensitivity to atmospheric variations. Denser soils distribute heat more evenly and reach slightly lower maximum temperatures. According to this analysis, density is a significant factor in the vertical distribution of heat in clay soils. Dense soils are better at storing and holding onto heat, which makes them ideal for thermal applications like geothermal systems.

For sandy soil (Figure 11(a)), it was observed that at the surface layers of the soil (down to about 8 m), where the impact of winter weather conditions is most noticeable, temperatures drop quickly. At depth, however, they gradually stabilize, suggesting a zone unaffected by seasonal fluctuations. Because of their larger heat capacity, denser soils ($\rho_d = 2000 \text{ kg/m}^3$) retain higher temperatures at depth, whereas less dense soils ($\rho_d = 1400 \text{ kg/m}^3$) show lower temperatures, reflecting faster heat dissipation. These findings demonstrate the significance of density in sandy soil thermal distribution, which is especially important for geothermal and thermal applications.

Furthermore, as shown in Figure 11(b), it appears that at approximately 8 meters below the surface, temperatures increase rapidly before gradually decreasing and stabilizing at deeper levels. While the deeper layers maintain a nearly constant temperature, the superficial layers are impacted by summer heat, as seen in this distribution. Dense soils ($\rho_d = 2000 \text{ kg/m}^3$) retain higher temperatures at depth due to their greater thermal capacity, enabling them to store and retain heat more effectively. However, less dense soils ($\rho_d = 1400 \text{ kg/m}^3$) exhibit lower temperatures at depth, indicative of a lower capacity to store heat and a faster heat dissipation rate. Near the surface, low-density soil heat up faster but do not retain heat effectively at depth, unlike denser soils, which distribute heat better. Given that dense soils perform better in heat storage and retention, a critical component of thermal and geothermal applications, these findings highlight the significance of density in the thermal distribution of sandy soils.

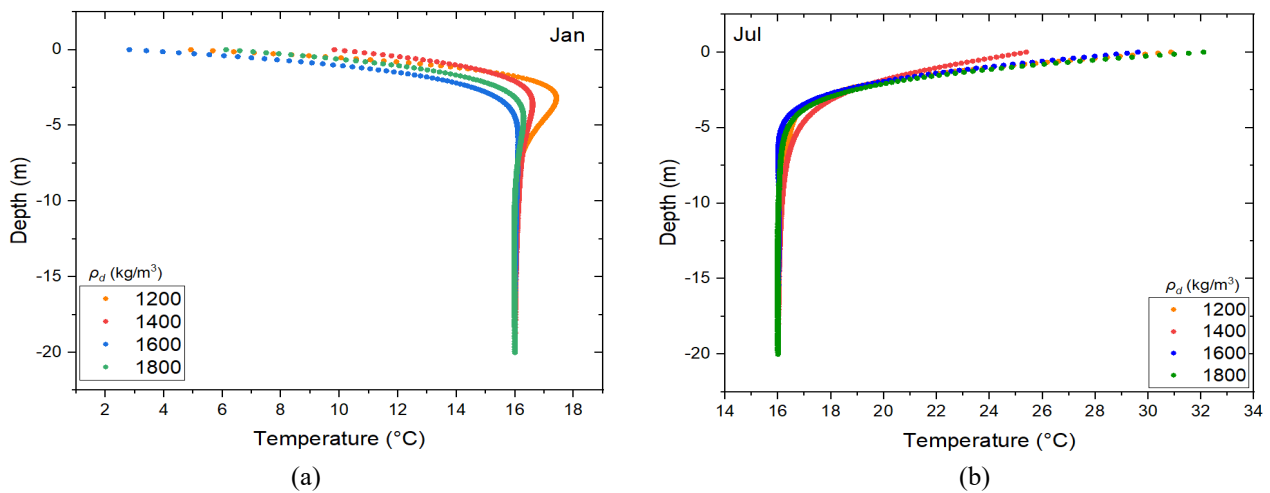


Figure 10. Impact of clay density on depth-dependent temperature variation of: (a) January 2023, (b) July 2023.

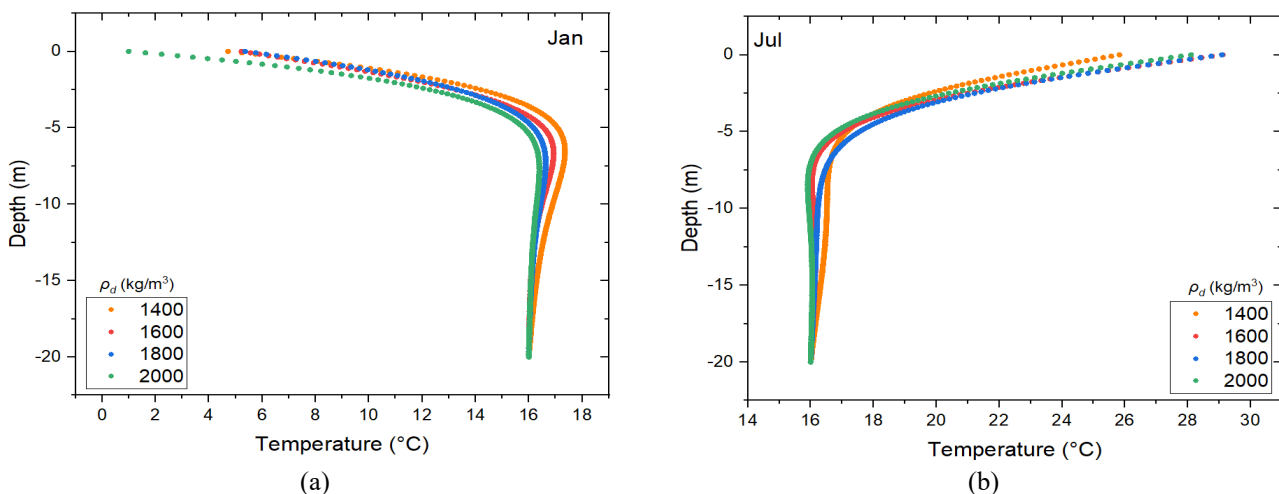


Figure 11. Impact of sand density on depth-dependent temperature variation of: (a) January 2023, (b) July 2023.

5. CONCLUSIONS

Soil temperature determination is crucial for successful geothermal system implementation, as these values directly inform heat exchanger design parameters. To address this need, we developed a numerical hydrothermal model capable of predicting soil temperature variations while accounting for coupled moisture transfer in unsaturated porous media and seasonal hydrothermal fluctuations. The study focuses on two soil types (clay and sand) under actual atmospheric conditions of the Oran region, Algeria. Furthermore, we analyzed how variations in key unsaturated soil properties - particularly porosity and specific density - influence hydrothermal behavior under extreme climatic conditions (specifically the peak summer day in July and coldest day in January 2023).

The finding revealed that clayey soil with low porosity ($n = 0.4$) and high density ($\rho_d = 1800 \text{ kg/m}^3$) demonstrated high thermal retention and minimized heat loss, making it the optimal material for geothermal applications. However, sandy soil, while less efficient in retaining heat, showed improved performance at higher densities. Climatic variations further confirmed that clay consistently maintained optimal thermal stability across all scenarios, particularly at shallow depths, highlighting its economic advantages in geothermal applications. Overall, low porosity, high density, and clay-type soils are the most favorable parameters for geothermal systems, ensuring maximum thermal retention and economic efficiency. Furthermore, the developed hydrothermal model can be adapted to other regions by adjusting local data, offering a methodology for optimizing geothermal applications in various climatic and geological contexts.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research and publication of this article.

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