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# Effect of acid rain on soil infiltration in various land aspects using rain simulation

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**Abstract**

Infiltration refers to the movement of water from the surface into the subsurface. This process varies across different soil types, making the infiltration characteristics distinct for diverse soils. Acid rain significantly impacts infiltration, affecting both the physical and chemical properties of the soil. This study aims to identify the key factors influencing soil infiltration, specifically comparing them to the impact of acid rainfall on the primary land aspects of the Aghajari marl formation in the Margha watershed of Izeh City, covering an area of 1609 hectares. To assess the relationship between infiltration rate and various soil properties, including gravel, clay, silt, sand percentages, acidity, electrical conductivity, moisture, calcium carbonate, organic matter, and sodium, rainfall simulations were conducted on different slopes and aspects of the Aghajari marl formation. Eight sampling points with three replications each were established on the northern, southern, eastern, and western slopes, subject to varying rainfall intensities of 1 and 1.25 mm per minute, as well as simulated rainfall environments with pH levels of 4 and 5. Soil samples were collected at the 20-0 cm layer to study the factors influencing infiltration rate. Multivariate regression analysis identified the most significant factors affecting infiltration. Overall, in the primary aspects of the study area and under rainfall intensities of 1 and 1.25 mm/min, 15 soil physical properties and 25 soil chemical characteristics demonstrated both positive and negative roles in soil infiltration. As precipitation increased towards pH 5, 16 soil physical properties and 24 soil chemical properties exhibited varying impacts on soil infiltration. Conversely, with precipitation impact on pH towards pH 4, 15 soil physical properties and 20 soil chemical properties played crucial roles in influencing soil infiltration. In summary, in the Aghajari marl formation, during precipitation with distilled water and pH levels of 4 and 5, soil chemical characteristics emerged as essential factors contributing to both the enhancement and reduction of infiltration.

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## Introduction

Acid rain is recognized as a global environmental challenge attributable to the rapid growth of the economy and increased energy consumption. Its deleterious effects extend to the acidification of water bodies, forest destruction, harm to aquatic life, and a reduction in forest productivity. Some studies even suggest that highly acidic rain may trigger landslides (Krug and Frink, 1983; Zhang and McSaveney, 2018).

The internal structure of most soils exhibits various alterations in the fissures and pores within the aggregates. These changes can significantly impact water movement within the soil, leading to varied flow velocities (Gerke and Van Genuchten, 1993). Rainfall infiltration, the process through which water permeates the soil, increases overall moisture content, influencing water distribution and hydrological responses, thereby altering erosion development and frequency (Lu et al., 2016; Shakesby et al., 2000; Walker et al., 2007).

Several factors influencing water infiltration intensity in soils have been identified. Some researchers have explored the role of soil physical and chemical characteristics in infiltration. The initial particle size distribution is a crucial physical property that Hwang et al. (2002) described as a fundamental characteristic determining water movement, moisture, and infiltration curves. Soils with limited infiltration capacity retain a smaller portion of rainfall, resulting in increased runoff and sediment production (Mandal et al., 2007).

Rainfall infiltration is controlled by numerous factors, including geomorphology, rainfall or climatic conditions, surface roughness, soil porosity or density, organic carbon content, aggregate size and stability, and soil hydraulic properties (Mohamadi & Kavian, 2015; Morbidelli, Saltalippi, Flammini & Govindaraju, 2018). Lado et al. (2004) argued that the presence of coarse and stable aggregates enhances water diffusivity and soil infiltration intensity. However, these effects diminish under conditions of organic matter and aggregates due to Sodium dispersion. In this regard, the particular weight of the factors affecting infiltration depends on the type of tillage operation, the amount of organic material, particle size distribution, and soil density. Assouline (2006) stated that the increase in the specific mass in a particular activity through the blocking of soil pores caused a significant decrease in infiltration. The research results of Bormann and Klassen (2008) showed that, as a result of the degradation of rangelands, the bulk of the soil is increased, which will eventually reduce the hydraulic conductivity and water infiltration into the soil. Ghorbani Dashtaki et al. (2010) conducted a study to examine the influence of land-use change on the mineralogical properties of water that infiltrates the soil. They found that the average cumulative water infiltration into the soil and water saturation conductivity in natural pasture exceeded those in degraded areas. This disparity was attributed to tillage and pasture operations. Bakhshipour et al. (2016) investigated the effect of acid rain on the geotechnical properties of soil. In this study, different levels of acid rain acidity for different coatings equal to 1 to 20 years were investigated. The results of this study demonstrated that the low acidity of rain reduces the resistance and maximum specific gravity of dry soil and reduces the infiltration coefficient in soil samples. Lamus et al. (2018) investigated the effect of acidification in urban and industrial areas. According to the results of their study, the presence of acidic contaminants has a long-term negative effect on the properties of soil and causes soil mutagenicity. Wei et al. (2019) investigated the effect of acid rain on acid reactions in three types of agricultural soils. Their results showed that acid rain with certain acidity will not cause the same acid reactions in different soil samples as acid reaction in each soil varies according to the structure and contents of the soil. Researchers have found out that acid rain causes great changes in soil chemical and biological properties as the soil is the ultimate recipient of acid rain (Wang et al., 2010; Lv et al., 2014; Liu et al., 2017). Soil pH decreases considerably with acid rain as more $H^+$ inputs the soil system (Liu et al., 2018, Wang et al., 2010). The Aghajari marl formation is among the most erodible in

Iran. Aghajari marl formation, by Bakhtiari conglomerate, is located in Mishan marl formation generated between the Pliocene and Miocene. it is composed of gray and brown calcareous sandstone, gypsum red marl, and siltstone. Its main section spreads from Omidiyeh to the Aghajari oil field and it has a thickness of 2965 meters. The Aghajari marl formation is apt to different kinds of erosions, especially surface erosion, rill erosion, badland, and mass movement (Ahmadi, 2007). The Aghajari marl formation is surrounded by oil industries that emit thousands of tons of sulfur and carbon dioxide chemicals into the air yearly, which can cause acid rainfall. Thus, investigating the role of acid rainfall on soil infiltration in these areas is necessary, and considering that the acidity of rainwater in the study area was recorded to be 5.76, so this study is focused on predicting more hazardous acid rain in acidity levels 4 and 5 in the future.

## Materials and Methods

Aghajari marl formation (Margha watershed) is located in Izeh, Khuzestan Province, Iran, and covers an area of 1609 hectares. It is situated between longitudes 49º 30 ´ 9″ to 49 º 35´ east and latitudes 31º 55´ to 31 º 58´ north (Figure 1). To do this research, we used a topographical map at a scale 1: 50000, maps of geology, land use, slope, and rainfall data.

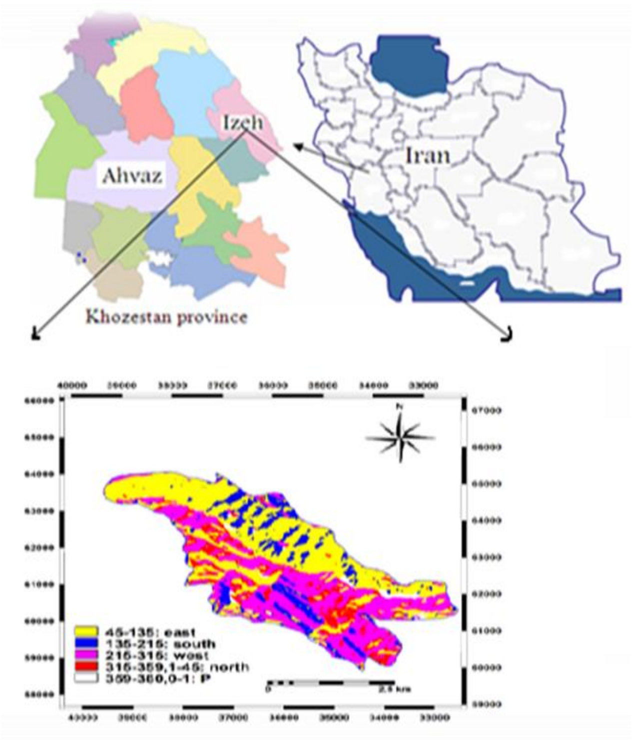


**Figure 1.** The study area in Iran and Khuzestan Province

In this investigation, 14 rainwater specimens were sampled in the study area. The acidity of rainwater in 12 sampling cases varied between 6 and 7 and in 1 case the acidity of rainwater was 8.03 and in 1 other case it was 5.76. The geology of the study area is composed of the deposits of the Aghajari Marl Formation and includes limestone sandstone to gray, gypsy red marls, and siltstone. The Aghajari Marl Formation in the Zagros Mountains is characterized by two faces. The first face is sand and the second face is the Aghajari Marl, which is the majority of the formation of the Formation as red marls. The amount of infiltration was measured in plots located in four main aspects (northern, southern, eastern, and western) and we simulated precipitation with water measuring in acitiy as pH=4 and pH=5 (containing sulfuric acid and nitric acid to portion 2:1) in the intensity 1, 1.25 mm in min, utilizing the Kamphorst rainfall simulator. This standardized, easily portable rainfall simulator was designed to cover a plot area of 625 cm2. The tool was used to determine the properties of soil, erosion, and water infiltration (Kamphorst, 1987). The experimental plot area of 625 $cm^2$ with a smooth gradient was selected. The plot area was representative of the main aspects. Meanwhile, the Kamphorst rainfall simulator was installed at the height of 200 cm to reach a raindrop boundary velocity. After preparing the testing area and installing the rainfall simulator, precipitation began, and timing was recorded by a chronometer. In the 10-minute time interval, the amounts of infiltration over the plot with acid water were collected and each was stored in numbered containers (Morady and saidian, 2010). Considering how costly and time-consuming the process is, the rainfall simulator was used at four main aspects (4 levels) and two formations (2 levels) and at each level, three replications were used for which infiltration sampling was performed. Tests were conducted with pH=4 and pH=5 acid water. Samples of topsoil (0 to 20 centimeters) in the vicinity of the plot were taken and transferred to the laboratory in order to analyze their physicochemical properties (Barthes and Roose, 2002). The soil physicochemical parameters, including the percentage of clay, silt, sand, gravel, moisture, pH, organic materials, EC, sodium rate, and Calcium Carbonate were measured using various methods in the laboratory (Zarinkafsh, 1994). SPSS 17 and Excel 2007 software packages were used to apply all statistical analyses and then for final models we used multi-regressions for every aspect along and we also determined the most important factor in the process. The regression models were applied using the removal method. In the analysis, if the beta coefficient (regression effective coefficient) becomes more in relation to a soil parameter, it shows a higher effect than other parameters.

## Results

The purpose of this study was to determine the most important factors involved in the infiltration in Aghajari marl Formation and the effect of acid rainfall on a part of Margha watershed in Khuzestan Province. The findings are illustrated in Table 1 to Table 12.

**Table 1.** Relation between infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation under precipitation with distilled water

| Models | Aspects |
|---|---|
| In = 1576.06-2.88Cly – 28.2Wm + 3388.3Na – 24.1Cac + 167.03Om | Northern |
| In = 596.9-1.59Cly + 6.19Sa – 1130.25Ec – 2770.5Na + 37.7Om | Southern |
| In = 740.26+0.43Slt – 5.36Gra + 20.98pH + 15.54Wm – 145.1Om | Eastern |
| In = 2325.3-0.43Sa – 49.13pH – 495.4 Na – 32.9Cac – 74.91Om | Western |

Infiltration (In), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 2.** The Beta coefficient of infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with distilled water

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope Aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.79 | - | -0.34 | -1.06 | - | - | 0.78 | - | -0.33 | - | Northern |
| 0.00 | - | 0.00 | 0.00 | - | - | 0.00 | - | 0.00 | - | Sig |
| -0.40 | - | - | - | - | -0.65 | 0.42 | - | -1.03 | 0.63 | Southern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | - | 0.00 | 0.00 | Sig |
| - | -1.12 | - | 1.14 | 0.04 | - | -1.68 | 0.06 | - | - | Eastern |
| - | 0.00 | - | 0.00 | 0.00 | - | 0.00 | 0.00 | - | - | Sig |
| -0.41 | - | -0.80 | - | -0.13 | - | -1.12 | - | - | -0.05 | Western |
| 0.00 | - | 0.00 | - | 0.00 | - | 0.00 | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 3.** Relation between infiltration with intensity 1.25 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with distilled water

| Models | Slope aspects |
|---|---|
| In = 1077.08-2.46Cly – 8.01Slt – 954.7Ec – 2628.04Na + 200.8Om | Northern |
| In = 458.9+2.6Cly+6.69Sa – 508.14Ec – 4858.4Na + 9.26 Om | Southern |
| In = 11041.69-32.3Slt + 3.79Gra – 901.63pH – 6016.34Ec – 61.34Om | Eastern |
| In = 77.46+1.33Sa + 31pH + 815.4Ec + 734.8Na + 74.76Om | Western |

Infiltration (In), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 4.** The Beta coefficient of infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with distilled water

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope Aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| -0.51 | - | - | - | - | -0.75 | 0.78 | -1.09 | -0.23 | - | Northern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | Sig |
| -0.96 | - | - | - | - | -0.39 | 0.13 | - | 0.22 | 0.92 | Southern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | - | 0.00 | 0.00 | Sig |
| - | 0.18 | - | - | -0.52 | -0.74 | -0.18 | -1.2 | - | - | Eastern |
| - | 0.00 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | - | Sig |
| 0.53 | - | - | - | 0.07 | 0.88 | 0.99 | - | - | 0.15 | Western |
| 0.00 | - | - | - | 0.00 | 0.00 | 0.00 | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 5.** Relation between infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=5

| Models | Slope Aspects |
|---|---|
| In =512.1+1.44Cly – 2.16Slt – 210.9Ec+719.6Na + 36.98Om | Northern |
| In = 907.3 + 2.44Cly – 9.96Sa – 49.9Ec – 39.5Wm – 127.3Om | Southern |
| In = 24353.68-48.82Slt + 8.64Gra – 2230.26 pH – 12456.84Ec – 252.69Om | Eastern |
| In = 2228.2+0.88Sa – 270.9pH – 20.19Wm + 61.28Na + 18.09Cac | Western |

Infiltration (In), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 6.** The Beta coefficient of infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=5

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.52 | - | - | - | - | -0.61 | 0.53 | -1.09 | 0.51 | - | Northern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | Sig |
| - | - | - | -1.31 | - | -0.039 | 1.92 | - | 0.21 | -1.37 | Southern |
| - | - | - | 0.00 | - | 0.00 | 0.00 | - | 0.00 | 0.00 | Sig |
| - | 0.26 | - | - | -0.80 | -0.95 | -0.46 | -1.12 | - | - | Eastern |
| - | 0.00 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | - | Sig |
| 0.04 | - | 0.38 | -0.90 | -0.62 | - | - | - | - | 0.10 | Western |
| 0.00 | - | 0.00 | 0.00 | 0.00 | - | - | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 7.** Relation between infiltration with intensity 1.25 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=5

| Models | Slope aspects |
|---|---|
| In = 340.8-4.03Cly + 4.42Slt + 433.8Ec + 2375.5Na – 138Om | Northern |
| In = 626.47-2.75 Cly + 0.45Sa –344.3Ec + 371.76Na + 43.4Om | Southern |
| In = -13495.1+30.15Slt + 5.65Gra + 1183.8pH + 8258.83Ec + 185.78Om | Eastern |
| In = 1472.05+19.36Sa – 46.7pH – 3068.2Ec-562.02Na + 98.8Om | Western |

Infiltration (In), Regression coefficient (R), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity (pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 8**. The Beta coefficient of infiltration with intensity 1.25 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=5

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.98 | - | - | - | - | 0.72 | -1.14 | 1.27 | -0.81 | - | Northern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | Sig |
| 0.10 | - | - | - | - | -0.38 | 0.92 | - | -0.34 | 0.089 | Southern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | - | 0.00 | 0.00 | Sig |
| - | 0.31 | - | - | 0.78 | 1.16 | 0.62 | 1.28 | - | - | Eastern |
| - | 0.00 | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | - | Sig |
| -0.14 | - | - | - | -0.03 | -1.14 | 0.44 | - | - | 0.77 | Western |
| 0.00 | - | - | - | 0.00 | 0.00 | 0.00 | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 9.** Relation between infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=4

| Models | Slope aspects |
|---|---|
| In = -112.3+3.61Cly + 8.24 Slt + 1289.9Ec – 1413.8Na – 229.3Om | Northern |
| In = 1003.7-10.76Cly – 6.97Slt – 452.9Ec + 29.24Wm – 2012.1Na | Southern |
| No Model | Eastern |
| In = -2084-2.24Sa + 256.4pH + 19.2Wm – 16.74Na + 9.7Cac | Western |

Infiltration (In), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 10**. The Beta coefficient of infiltration with intensity 1 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=4

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| -0.35 | - | - | - | - | 1.3 | -1.14 | 1.43 | 0.44 | - | Northern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | Sig |
| -0.41 | - | - | 1.01 | - | -0.37 | | -0.97 | -0.98 | - | Southern |
| 0.00 | - | - | 0.00 | - | 0.00 | | 0.00 | 0.00 | - | Sig |
| - | - | - | - | - | - | - | - | - | - | Eastern |
| - | - | - | - | - | - | - | - | - | - | Sig |
| -0.01 | | 0.17 | 0.73 | 0.50 | - | - | - | - | -0.21 | Western |
| 0.00 | | 0.00 | 0.00 | 0.00 | - | - | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 11.** Relation between infiltration with intensity 1.25 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=4

| Models | Slope Aspects |
|---|---|
| In = 266.4 + 4.4Cly + 1.11Slt + 273.3Ec + 296.3Na – 113.6Om | Northern |
| In = 514.4 + 6.67Cly – 2.52Sa – 362.7Ec + 2139.6Na + 23.58 Om | Southern |
| In = 4717.17-7.98Slt + 2.3Gra – 457.49pH – 47.81Wm + 158.13Om | Eastern |
| In = 2925.4+7.84Sa – 252.2pH – 1102.5Ec – 910.1Na + 15.47Om | Western |

Infiltration (In), Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

**Table 12.** The Beta coefficient of infiltration with intensity 1.25 mm per minute and soil physicochemical characteristics in Aghajari marl formation in precipitation with pH=4

| Na | Gra | Cac | Wm | pH | EC | Om | Slt | Cly | Sa | Slope aspects |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.18 | - | - | - | - | 0.70 | -1.44 | 0.49 | 1.36 | - | Northern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | 0.00 | 0.00 | - | Sig |
| 0.71 | - | - | - | - | -0.48 | 0.60 | - | 0.98 | -0.58 | Southern |
| 0.00 | - | - | - | - | 0.00 | 0.00 | - | 0.00 | 0.00 | Sig |
| - | 0.15 | - | -1.2 | -0.36 | - | 0.62 | -0.40 | - | - | Eastern |
| - | 0.00 | - | 0.00 | 0.00 | - | 0.00 | 0.00 | - | - | Sig |
| -0.62 | - | - | - | -0.55 | -1.12 | 0.19 | - | - | 0.85 | Western |
| 0.00 | - | - | - | 0.00 | 0.00 | 0.00 | - | - | 0.00 | Sig |

Gravel (Gra), Silt (Slt), Clay (Cly), Sand (Sa), Soil acidity( pH), Electric conductivity(Ec), Weighted moisture (Wm), Calcium carbonate (Cac), Organic matter (Om), Sodium (Na)

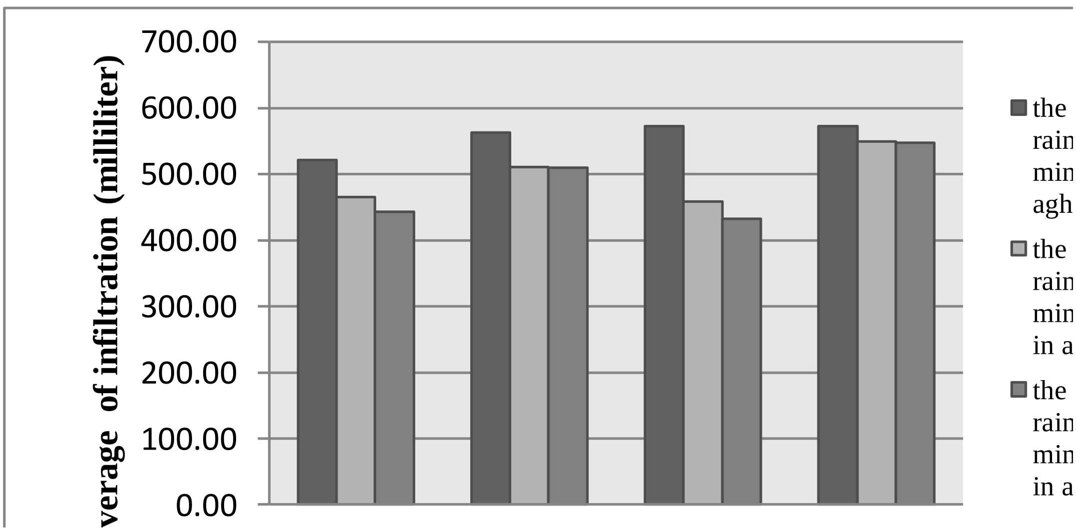


**Figure 2.** The average infiltration with an intensity 1 mm per minute in Aghajari marl formation

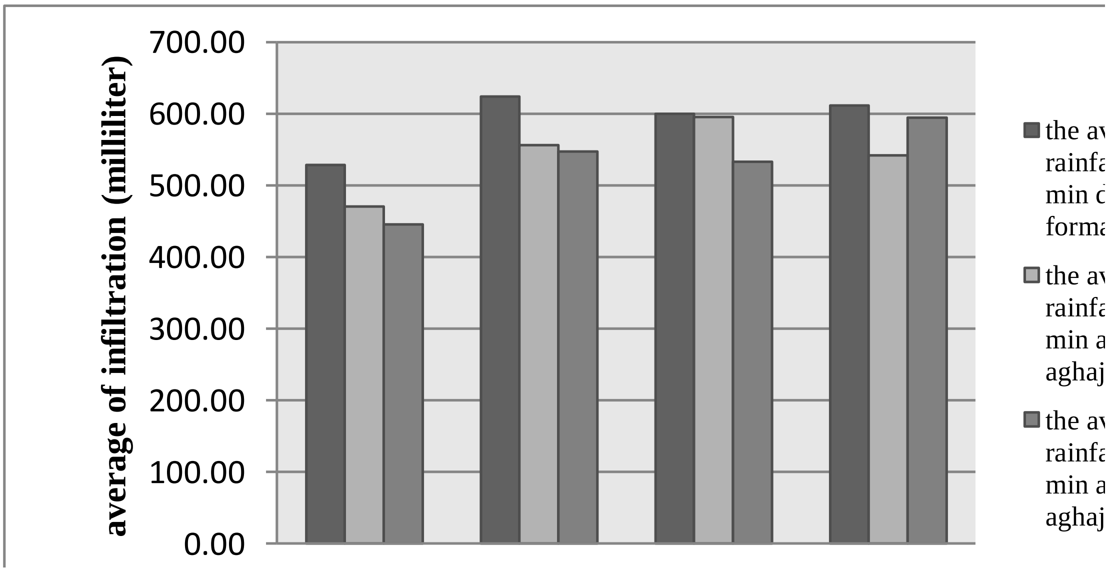


**Figure 3.** The average infiltration with an intensity 1.25 mm per minute in Aghajari marl formation

**Discussion**

One approach to identifying the most significant infiltration parameter is to establish multivariate regression relationships between infiltration and its influencing factors. In this study, regression relationships were examined between infiltration and various parameters, including the percentage of gravel (Gra), silt percentage (Slt), clay percentage (Cly), sand percentage (Sa), electrical conductivity (Ec), acidity (pH), weight humidity percentage (Wn), calcium carbonate percentage (Cac), and organic matter percentage (Om). The SPSS software was employed to determine the best models, considering a high correlation coefficient.

On the northern slopes, under a rainfall intensity of 1 mm per minute with distilled water, organic matter and sodium played the most crucial role in increasing infiltration, while moisture content had the highest impact in decreasing infiltration. At a rainfall intensity of 1.25 mm per minute, organic matter exhibited the most significant influence on increased infiltration, whereas silt had the greatest role in reducing soil infiltration (see Figure 2, 3). In acid precipitation with a pH of 5 at an intensity of 1 mm per minute, the presence of organic matter and sodium played a key role in increasing infiltration, while silt played the primary role in reducing infiltration. With an increase in rainfall intensity to 1.25 mm per minute, soil clay had the most significant impact on increasing infiltration, while soil organic matter had the greatest effect in reducing infiltration (see Figure 2, 3). In acid precipitation with a pH of 4 and a rainfall intensity of 1 mm per minute, soil silt had the greatest influence on increasing infiltration, and soil organic matter had the most substantial impact on reducing infiltration. As the rainfall intensity increased to 1.25 mm per minute, soil clay had the most pronounced effect on increasing infiltration, whereas soil organic matter had the greatest impact on reducing infiltration.

Generally, on the northern slopes of the Aghajari marl formation, soil physical characteristics such as silt and clay played the most significant role in increasing infiltration compared to acid precipitation. Conversely, organic matter had the greatest impact on reducing infiltration compared to acid precipitation. It is noteworthy that this finding contradicts the results of some researchers, such as Franzluebbers et al. (2001) and Nemes et al. (2005). Lado et al. (2004) highlighted the negative relationship between organic matter and infiltration intensity, attributing it to scattered particles in the presence of low or high amounts of organic matter in the presence of sodium. Due to the relatively wide range of soils studied, this discrepancy could be expected, as sodium soils generally exhibit higher density and reduced infiltration (Mzezewa et al., 2003).

On the southern slopes, under a rainfall intensity of 1 mm per minute with distilled water, organic matter played the most crucial role in increasing infiltration, while the clay content had the highest impact in reducing infiltration. At an intensity of 1.25 mm per minute, soil sand had the most significant role in increasing infiltration, while soil sodium played the greatest role in reducing infiltration. Sodium has detrimental effects on soil infiltration by influencing surface development and particle distribution, ultimately reducing water infiltration in the soil (Mandal et al., 2007). In acid precipitation with a pH of 5 and an intensity of 1 mm per minute, soil organic matter played the most important role in increasing infiltration, while sand had the most significant impact on reducing infiltration. With an increase in rainfall intensity to 1.25 mm per minute, soil organic matter had the most prominent role in increasing infiltration, while soil salinity played the most significant role in reducing infiltration (see Figure 2, 3). In acid precipitation with a pH of 4 and an intensity of 1 mm per minute, soil moisture had the greatest impact on increasing infiltration, and soil clay had the most substantial impact on reducing infiltration. With an increase in rainfall intensity to 1.25 mm per minute, soil clay had the most pronounced effect on increasing infiltration, while soil sand had the most significant influence on reducing infiltration (see Figure 2, 3).

In general, on the southern slopes of the Aghajari marl formation, organic matter played the most significant role in increasing infiltration compared to acid precipitation, while clay and sand had the most substantial impact on reducing infiltration compared to acid precipitation.

On the eastern slope, under a rainfall intensity of 1 mm per minute with distilled water, soil moisture played the most crucial role in increasing infiltration, while organic matter had the most significant impact in reducing infiltration. At an intensity of 1.25 mm per minute, soil gravel had the most significant role in increasing infiltration, while silt played the most crucial role in reducing soil infiltration. In acid precipitation with a pH of 5 and a rainfall intensity of 1 mm per minute, soil gravel played the most important role in increasing infiltration, while soil silt played the most significant role in reducing infiltration. With an increase in rainfall intensity to 1.25 mm per minute, soil silt had the most prominent role in increasing infiltration. In acid precipitation with a pH of 4 and a rainfall intensity of 1 mm per minute, the model was not constructed. With an increase in rainfall intensity to 1.25 mm per minute, soil organic matter had the most significant impact on increasing infiltration, while soil moisture had the most substantial impact on reducing infiltration. Increased saturated moisture can reduce water infiltration in the soil. Some researchers have attributed this to the effect of clay on moisture increase on one hand and its role in reducing infiltration, aligning with the results of research by Liu et al. (1994) and Lin et al. (1998).

In general, on the eastern slopes of the Aghajari marl formation, gravel, silt, and organic matter had the most significant role in increasing infiltration compared to acid precipitation, while silt and moisture played the most crucial role in reducing infiltration compared to acid precipitation.

On the western slope, under a rainfall intensity of 1 mm per minute with distilled water, soil organic matter had the most substantial impact on reducing infiltration, and at an intensity of 1.25 mm per minute, soil organic matter continued to have the most significant role in increasing infiltration. In acid precipitation with a pH of 5 and a rainfall intensity of 1 mm per minute, soil calcium carbonate played the most important role in increasing infiltration, aligning with the results of Halliwell et al. (2001) and Ajwa and Trout (2006), who suggested that calcium in lime contributes to particle aggregation and, consequently, increased soil infiltration. However, this finding contradicts the results of research by Merzouk and Black (1991), who reported a negative effect of lime on water infiltration in the soil. In acid precipitation with a pH of 4 and an intensity of 1 mm per minute, soil moisture played the greatest role in increasing infiltration, while sand had the most substantial impact on reducing infiltration. With an increase in rainfall intensity to 1.25 mm per minute, soil sand had the most significant impact on increasing infiltration, while soil salinity had the most substantial influence on reducing infiltration.

In general, in the western range of the Aghajari marl formation, soil physical characteristics such as sand and moisture played the most significant role in increasing infiltration compared to acid precipitation, while soil salinity had the most substantial impact on reducing infiltration compared to acid precipitation.

In the Aghajari Marl Formation soil, physical properties exhibited the highest proportions of clay, silt, sand, and gravel at 52.33%, 40.33%, 39.67%, and 74.16%, respectively, on western, eastern, southern, and western slope aspects. Regarding soil chemical properties, the highest values of pH, electrical conductivity (Ec), soil moisture, sodium content, lime, and organic matter, respectively, were measured on the western, eastern, northern, eastern, northern, and southern slope aspects, with values of 8.40, 0.32 ds/m, 6.75%, 0.029 g/l, 40.11%, and 1.13%.

The slope aspect plays a complex role in soil physical and chemical properties in the Aghajari Marl Formation, influencing solar energy absorption, soil production, vegetation, and erosion rates, consequently affecting soil physical and chemical properties. Therefore, soil infiltration is heavily influenced by these factors. Acid rainfalls exhibited different effects due to changes in soil physical and chemical properties, as well as vegetation, across different slope aspects of the Aghajari Marl Formation.

## Conclusions

Water infiltration into the soil constitutes a critical component of the natural water cycle. This soil property represents the foremost hydraulic characteristic that can undergo significant alterations, particularly in response to acid rainfall, as explored in this study. In general, across the primary slope aspects of the investigated area and at rainfall intensities of 1 and 1.25 mm/min, soil physical properties exhibited both positive and negative effects in 15 cases, while soil chemical characteristics demonstrated such roles in 25 cases, influencing soil infiltration. As the precipitation concentration increased to a pH of 5, soil physical properties in 16 cases and soil chemical properties in 24 cases played positive and negative roles in soil infiltration. Similarly, with an escalation in precipitation concentration to a pH of 4, soil physical properties in 15 cases and soil chemical properties in 20 cases exhibited positive and negative impacts on soil infiltration.

Overall, within the Aghajari marl formation, when exposed to precipitation with distilled water, soil chemical characteristics play a vital role in both augmenting and diminishing infiltration. Furthermore, under precipitation with acidity at pH 5, soil chemical characteristics emerge as the most influential factors in increasing and decreasing infiltration levels. Moreover, as the acidity concentration increases to pH 4, soil chemical characteristics take on the paramount role in influencing both the increase and decrease of infiltration levels. This research underscores the intricate and significant role of slope aspects in determining the infiltration level.

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