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Effect of acidic rainfalls on soil erosion in gypsum formation

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One of the most important effects of acidic rainfall is on the soil. It can affect other environments such as surface water and groundwater, plants and animals. In this study, to investigate the sensitivity of the runoff and sediment production of Gachsaran Gypsum Formation to acidic rainfalls and its density change, parts of Gypsum Mountain watershed the area in Izeh Township in Khuzestan province was selected with the area of 1202 ha. This investigation in order to determine the productivity of runoff and sediment in 8 points and with 3 replicates in Gachsaran Gypsum Formation in intensity 1 mm in a minute and the densities of distilled water, pH=4 and pH=5 in four slope aspects (northern, southern, eastern, western) with using of Kamphorst rainfall simulator, was done. In this investigation also, in order to determine the relationship between the sediment and runoff produced by rainfall simulator and some soil physic-chemical characteristics, like percent of gravel, sand, clay, silt, pH, EC, soil moisture, calcium carbonate, organic materials and sodium rate in slope, different aspects in Gachsaran Gypsum formations were done. To analyze data, SPSS and EXCEL packages was used. Summarily, in Gachsaran Gypsum Formation, soil chemical properties had the most important role in runoff production in precipitation with distilled water, soil physical properties had the most important role in sediment production in precipitation with distilled water; however, in acidic rainfall, soil chemical properties had the most important role.

Key words: Acidic rainfall, Gachsaran Gypsum Formation, soil erosion, Kamphorst rain simulator.

INTRODUCTION

Soil conservation and combating with erosion are the most essential measures that each country should be especially involve in. Soil erosion has always existed in human living, but in recent years it has intensified with

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increase in population and technology (Pimentel and Kounang, 1998; Pimentel and Harvey, 1999). Due to the measurement of runoff and sediment under rainfall, natural condition is time-consuming and expensive (Rienks et al., 1999). Using a rain simulator can solve this difficulty, however, important differences exist between the characteristics of natural rainfall and those of simulated rainfall, such as droplet size distribution, drop velocity, etc (Mingguo et al., 2007). For creating rainfall, natural condition are limited in a small plot (Jordan and Martinez-Zavala, 2008; Arnaez et al., 2007). But simulating rainfall can be a useful tool to compare and quantify runoff and soil erosion processes. This method can be used for the graduating and validating of physical models on the base of rainfall and for comparing erosion purposes (Foster et al., 2000). Utilizing of rainfall simulator for the above-mentioned advantages of research in various aspects of erosion and sediment production is common in the world (Seeger, 2007). However, actually in the world, one of the most important environmental problems is air pollution discussion. This issue, especially in large and overpopulated cities, has assumed the form of a dilemma. Each year, many deaths directly or indirectly occurs due to air pollution around the world. In 1872, Robert Angus Smith, for the first time, used the term ‘acidic rainfall’ to explain and describe the kind of rainfall that occurs in Manchester city. Generally, acidic rainfall is characterized by a value of pH lower than 5.6 (Cowgil, 1990; Manahan, 2005; Neill, 1993; Welburn, 1990). Although rain is one of the purest sources during precipitation, it absorbs carbon dioxide in the atmosphere and becomes impure. Therefore, carbonic acid is formed and it decreases water pH to 5.6. If water pH becomes lower than 5.6, it may be attributed to acid rain. The most important suspended particles of pollutants are represented by sulfates and nitrates. Most of these are secondary pollutants that form in the air and from the air as natural reactions of sulfur dioxide and oxides of nitrogen. These reactions, especially by a viewpoint of the production of sulfuric and nitric acids in the air, are important (Botkin and Keller, 2003). Sulfuric acid is the major component of acidic rainfall and nitric acid has a smaller share but will show a growing portion in acid rainfall in the near future. The environmental effects of acidic rainfall consist in the destruction of buildings and some human means (Yokom and Bear, 1983; Kanazu et al., 2001), in degradation and forest reduction (Driscoll et al., 2001; Tomlinson, 2003), in creating an acidic aquatic environment (Botkin and Keller, 2003), in the destruction of crops (Ferenbaugh, 1976; Pell et al., 1987), etc. One of the most important effects of acid rainfall is on the soil. It can affect other environments such as surface water and groundwater, plants, and animals. In erodibility and sediment yield with using of rainfall simulator, researches of authors such as Rienks et al. (1999) and Duiker et al. (2001) showed that very tiny sand sodium exchange percent are the most important soil parameters. Commandeur (1992) studied the variability of infiltration rates and soil erosion on forest lands using a rainfall simulator. The results showed that the infiltration rate decreases with increasing bulk density and rubble thickness. It also showed that the rate of soil erosion had a positive correlation with runoff volume and is found to be affecting other variables like soil texture, slope, and soil surface. Casermeiro et al. (2004) used rainfall simulator to calculate erodibility. The results showed that measured soil variables had a low correlation with the erosion rate. But the type of vegetation and soil organic matter were introduced as the main factors in controlling erosion. Foltz et al. (2009) determined runoff, infiltration, sediment concentrations and erosion in two forest roads with high and low traffics in North America, by using rain simulator. The results showed that runoff and sediment concentration on two forest roads with high traffic due to reducing vegetation cover and changing in soil physical properties is higher. One of the most erodibility of Iran occurs in Gachsaran Gypsum Formation which has oil industries that yearly pour into the air thousands of tons of sulfur and carbon dioxide acidic rainfall. Thus, investigating the role of acidic rainfall on soil erosion and sediment production in these areas is necessary. Gachsaran Gypsum Formation has a thickness of about 1600 m. From a geological point of view, the lithotypes are represented by salt, anhydrite, colorful lime and some shale. Gachsaran Gypsum Formation age is lower Miocene (Ahmadi, 2007).

MATERIALS AND METHODS

Gachsaran Gypsum Formation is located in Izeh Township in Khuzestan, Iran, a province that spans an area of 1202 ha. Gypsum Mountain watershed (Gachsaran Gypsum Formation) is located in the realm of longitude 49º 45´ 27˝ to 49º 47´ 09˝ eastern and of latitude 31º 50´ 27˝ to 31 º 53´ 32˝ northern (Figure 1). To do this research, several maps were needed such as topographical map at a scale 1: 50000; also, the maps of geology, land use, slope and rainfall data were prepared.

In this investigation, runoff amount and sediment to method testing plots in main aspects of four slopes (northern, southern, eastern, and western), simulated precipitation with distilled water and acidic water with pH=4 and pH=5 (that had contained sulfuric acid and nitric acid at a ratio of 2:1) in intensity 1 mm / min were measured. The study of the field from the Kamphorst rainfall simulator was performed. This rainfall simulator was designed to be fully standardized and easily portable to plot size of 625 cm^2. In addition, this tool was used to determine the characteristics of soil, erosion, water infiltration and is also suitable for soil research (Kamphorst, 1987). The experimental plot area of 625 cm^2 and a smooth gradient was selected as representative of the slope main aspects. Meanwhile, the Kamphorst rainfall simulator was installed at a height of 200 cm to attain raindrop boundary velocity. After preparing the testing area and installing and setting the rainfall simulator, precipitation was started along with a chronometer. In the 10-min time interval, the amount of runoff and sediment from plot coverage with distilled water and acidic water was collected. Also,

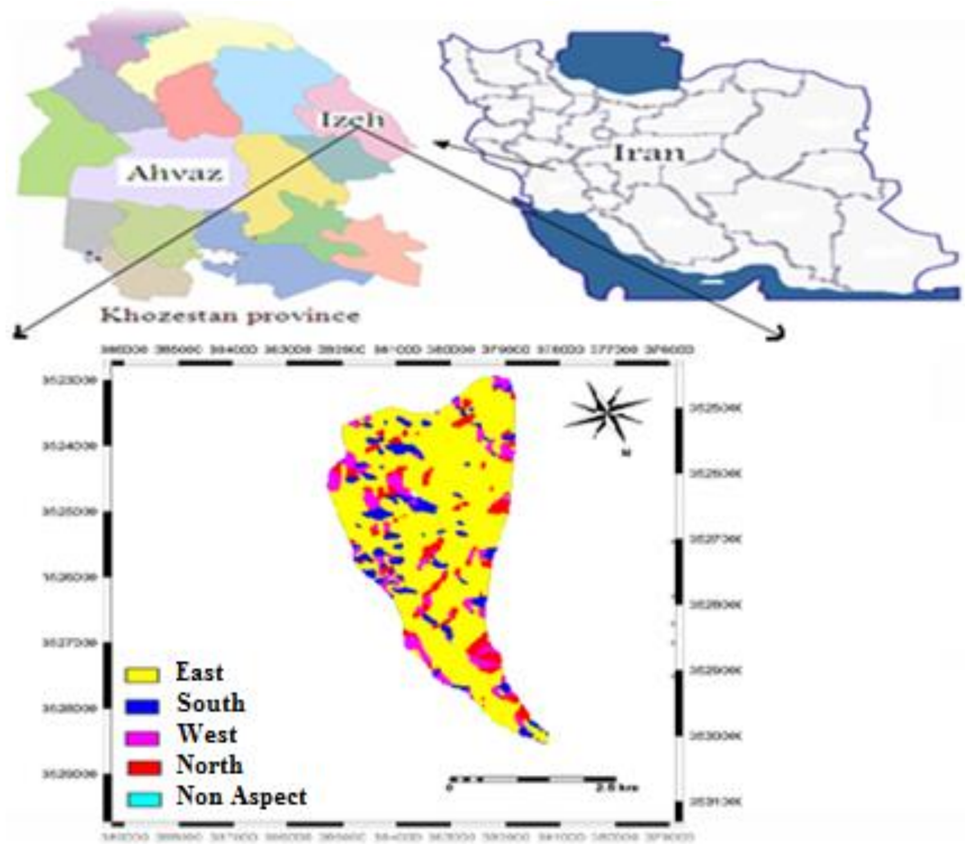

Figure 1. The position of the study area on Iran map and Khuzestan province.

samples in numbered containers were individually stored (Morady and Saidian, 2010). Thereafter, the same work was carried out with acidic water. At the end of the tests, samples were transported to the laboratory and the sediment deposited. As soon as it is dried in the oven at 105°C of temperature, it was measured. Also, the runoff volume of the plot was measured using a calibrated container. Thus, the amount of sediment and runoff at the appropriate time interval for each experiment was obtained (Raisian, 2005). In addition to the amount of runoff and sediment, infiltration and runoff threshold were also obtained. Focusing on cost and time, at least 8 levels (in each main aspect is two-level) and for each level, 3 replicates for using the rainfall simulator in Gachsaran Gypsum Formation were determined and also sediment sampling was performed. Further, another level 8 was done with 3 replicates for using rainfall simulator with pH=4 acidic water and another level 8 with 3 replicates with pH=5 acidic water in Gachsaran Gypsum Formation. In every testing done in the vicinity of every plot, sample of topsoil (0 to 20 cm) was collected in order to test for physicochemical properties and then transferred to the laboratory for assessment and analyses (Barthes and Roose, 2002). Soil physicochemical parameters including percent of clay, silt, sand, gravel, moisture, pH, organic materials, EC, sodium rate and calcium carbonate, under various methods were measured in the laboratory (Table 1). Soil textures including clay, sand and silt percent were determined by using hydrometric method (Zarin, 1994). Gravel percent was measured by sieve instrument; percent of organic materials was calculated by burning method, while EC and pH of saturated water extract was calculated by EC and pH digital meters. Percent of soil calcium carbonate was calculated by the calorimetric method, whereas moisture percent was achieved by weighting method, before and after soil drying with oven instrument at a temperature of 105°C. The sodium rate was determined by the photometric method with the atomic absorption apparatus. To perform all statistical analyses, SPSS 17 and Excel 2007 software packages were used, thereafter final models were determined with multi-regression for every slope aspect along with the most important factor in acidic rainfall. It is necessary to explain that in this investigation, the use of multi regressions with regard to sediment amount and runoff using rainfall simulator in precipitation, various intensities and densities of acidic water were obtained as dependent parameters and another parameter (physical and chemical) was considered in every slope aspect as independent parameter. Meanwhile, in this investigation, regression models using stepwise, removal and backward methods were determined. Achieved models in the different slope aspects of Gachsaran Gypsum Formation are presented in the study findings. In this analysis, if beta coefficient (regression effective coefficient) becomes more in relation to a soil parameter, it will show a higher effect than other parameters.

RESULTS

The purpose of this study is to determine the most important soil factors in erodibility of Gachsaran

Table 1. Relation between productivity of runoff with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with distilled water.

Slope aspect	Model	R	RE%	RMSE
Northern	Ro = 0.315 - 0.047 Ec - 0.006 Sa	0.975	6.33	0.003
Southern	Ro = 0.109 + 0.002 Cly	0.974	4.06	0.002
Eastern	Ro = - 0.022 +0.006 cac	0.936	17.31	0.007
Western	-	-	-	-

Runoff (Ro), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Clay (Cly), Sand (Sa), Electric conductivity (Ec), calcium carbonate (cac).

Formation deposits due to acidic rainfall in a part of the Gachsaran Gypsum Mountain watershed in Khuzestan province. To achieve this, an aspect map was prepared. In each of the slope, the main aspects were performed by conducting rain simulation experiments to determine the runoff and sediment yield.

DISCUSSION

One way to determine the most important soil parameters in runoff and sediment production is that of adopting multi regression relationships between runoff and sediment production along with important soil parameters. The most important soil parameter in runoff production in the northern slope aspects under precipitation with intensity 1 mm / min and precipitation with distilled water is soil salinity which has a negative effect. With the leaching of salts from the soil by rainfall, the values of electrical conductivity decreases. Therefore, soil aggregates were broken and disrupted; hence, infiltration increases and surface runoff reduces. In southern slopes and with the same intensity, soil clay had the most important and positive effect on runoff production. In this slope, the amount of soil clay was lesser than 10%. High evaporation and concreting of soil in this slope caused increase in the runoff. In the eastern slopes of the same intensity, calcium carbonate had the most important positive effect in runoff production. The amount of calcium carbonate was known as a stable factor in soil and the role that the erosion-resistant element played in soil (De Meester and Jungerius, 1978). Thus, it has made the soil particles stick together more tightly, resulting to increased runoff. In the western as well as northern slopes and with the same intensity, due to having no significant differences, a suitable model was not found (Table 1, 2). As regards the most important soil parameters in runoff production in northern slope aspects, with precipitation intensity of 1 mm / min and precipitation with pH = 5, due to having no significant differences, a suitable model was not found. In southern slopes and with the same intensity, calcium carbonate had the most important positive effect on runoff production. In the eastern slopes, and with the same intensity, soil salinity had the most important negative effect on runoff production. In western slopes and with the same intensity, soil moisture percent had the most important negative effect on runoff production. In this slopes, humidity was more than 7%, hence reducing runoff can lead to creation of suitable vegetation cover (Table 5, 6). With regard to the most important soil parameters in runoff production in northern slope aspects with precipitation intensity of 1 mm/min and precipitation with pH = 4, soil silt had the most important positive effect in runoff production. In this slope, the amount of silt is more than 40%. Dissolving of soil particles by acidic rain has therefore caused increase in runoff and sediment. In southern slopes and with the same intensity, soil moisture had the most important negative effect on runoff production. In the southern slope and with the same intensity, due to having no significant differences, a suitable model was not found. In the eastern slopes and with the same intensity, soil salinity had the most important negative effect on runoff production. In the western slopes and with the same intensity, due to having no significant differences, a suitable model was not found (Table 9, 10). Among the most important soil parameters in sediment production in northern slope aspects with precipitation intensity of 1 mm/min and precipitation with distilled water, soil clay had the most important positive effect in runoff production. In this slope, soil clay is about 30% and it can be caused by its composition of tight soil aggregates. Therefore, erodibility and sediment production will increase, especially in the soil that has high clay rates. Small soil aggregates were created and therefore eroded easily. In the southern slope and with the same intensity, soil acidity had the most important negative effects in sediment production. The relation between soil pH and erodibility depends on soil structure and the amount of silt. If soil structure becomes coarse grain or cubic, with increasing soil pH, erodibilty will decrease (Wischmeier and Mannering, 1969). In the southern slopes, in Gachsaran Gypsum Formation, due to high silt quantity, with proliferating soil acidity, erodibility will increase. In the eastern slopes and with the same intensity, soil salinity had the most

Table 2. Beta coefficient of productivity of runoff with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation distilled water.

Slope aspect \ Soil properties	Sa	Cly	Ec	Cac
Northern	- 0.722	-	-1.34	-
t	-3.98	-	-7.42	-
Sig	0.028	-	0.005	-
Southern	-	0.974	-	-
t	-	8.66	-	-
Sig	-	0.001	-	-
Eastern	-	-	-	0.936
t	-	-	-	5.32
Sig	-	-	-	0.006

Clay (Cly), Sand (Sa), Electric conductivity (Ec), calcium carbonate (cac).

Table 3. The relation between productivity of sediment in intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with distilled water.

Slope aspect	Model	R	RE%	RMSE
Northern	Sy = 11.662 - 0.187 Cly	0.908	11.42	0.223
Southern	Sy = 57.074 - 6.24 pH	0.955	6.77	0.192
Eastern	Sy = 10.963 - 3.388 Ec + 223.02 Na	0.991	6.39	0.205
Western	Sy = -74.12+ 294.22 Na + 12.75 pH + 4.12 Om - 0.343 Gra	1	0.47	0.013

Sediment yield (Sy), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Gravel (Gra), Clay (Cly), Soil acidity(pH), Electric conductivity (Ec), Organic matter (Om), Sodium (Na).

important negative effect whereas soil sodium had the most important positive effect in sediment production. With the leaching of salts from the soil by rainfall, the values of electrical conductivity decreases and was caused by soil aggregates that were broken and disrupted; thus, runoff and sediment reduction plus leaching of salts from the soil in low precipitation intensity can be caused by reducing runoff and sediment. In the western slopes and with the same intensity, the organic matter had the most important positive effect and soil gravel had the most important negative effect in sediment production. The western slopes due to having high quantity of organic matter and salinity were altogether affected, and may be caused by increasing of sediment (Table 3, 4). As regards the most important soil parameter in sediment production in northern slope aspects, with precipitation intensity of 1 mm/min and precipitation of acidic water with pH = 5, due to having no significant differences, a suitable model was not found. In the southern slope and with the same intensity, along with no significant differences, a suitable model was not found. In the eastern slope and with the same intensity, soil moisture had the most important negative effect on sediment production. In the western slopes and with the same intensity, calcium carbonate had the most important positive effect and soil sand had the most important negative effect in sediment production. Acidic rainfall was caused by solving the soil's physical and chemical particles. Thus, silt-sized calcium carbonate particles were generated by sealing and filling soil pores and have caused weakening of soil aggregates and increase in erosion (Table 7, 8). With regards to the most important soil parameter with sediment production in northern slope aspects under precipitation intensity 1 mm/min and precipitation with pH = 4 acidic water due to having no significant differences, a suitable model was not found. In the southern slopes and with the same intensity, due to having no significant differences, a suitable model was not found. In the eastern slope and with the same intensity, calcium carbonate had the most important positive effect and soil sodium had the most important negative effect in sediment production. In the western slopes and with the same intensity, soil sand had the most important negative effect in sediment production. The negative correlation of soil sand with sediment production was consistent with research results

Table 4. Beta coefficient of productivity of sediment with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation with distilled water.

Slope aspect \ Soil properties	Cly	Om	Ec	pH	Gra	Na
Northern	-0.908	-	-	-	-	-
t	-4.33	-	-	-	-	-
Sig	0.012	-	-	-	-	-
Southern	-	-	-	-0.955	-	-
t	-	-	-	-6.43	-	-
Sig	-	-	-	0.003	-	-
Eastern	-	-	-0.964	-	-	0.396
t	-	-	-12.3	-	-	5.05
Sig	-	-	0.001	-	-	0.015
Western	-	0/716	-	0.412	-0.759	0.15
t	-	120/7	-	65.43	-117.9	24.96
Sig	-	0/005	-	0/010	0/005	0/025

Gravel (Gra), Clay (Cly), Soil acidity (pH), Electric conductivity (Ec), Organic matter (Om), Sodium (Na).

Table 5. Relation between productivity of runoff with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with pH = 5 acidic water.

Slope aspect	Model	R	RE%	RMSE
Northern	-	-	-	-
Southern	Ro = - 0.301 + 0.015 cac	0.939	14.38	0.009
Eastern	Ro = 0.208 - 0.045 Ec	0.918	12.92	0.007
Western	Ro= 0.305 - 0.026 Wm	0.834	7.18	0.003

Runoff (Ro), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Electric conductivity (Ec), Weighted moisture (Wm), calcium carbonate (Cac).

by Duiker et al. (2001) and Parysow et al. (2002). In the western slopes, soil gravel had the most important positive effect while soil acidity had the most important negative effect in sediment production due to high silt percent. Therefore, the pores of gravel particles are filled by silt tiny particles. Thus, it can be said that gravel plays a positive role in erosion. When soil pH increase, percent of saturated aluminum and alkali cations also increase; and in soil with low electrical conductivity, it led to distribution in soil particles (Table 11, 12). However, in Gachsaran Gypsum Formation due to high electric conductivity, dispersing soil particles was lower. Thus, soil acidity had a negative role in sediment production. In Gachsaran Gypsum Formation, sediment rate in pH = 5 precipitation and with precipitation intensity 1 mm/min was 1.43 times larger than precipitation with distilled water and with pH = 4 precipitation, was 1.62 times larger than distilled water (Figure 2). However, productivity runoff rate in pH = 5 precipitation and with precipitation intensity 1 mm/min was 1.29 times larger than precipitation with distilled water, whereas in pH = 4 precipitation, it was 1.39 times larger than distilled water (Figure 3).

Summarily, in Gachsaran Gypsum formation, soil chemical properties had the most important role in runoff production in precipitation with distilled water while soil physical properties had the most important role in sediment production in precipitation with distilled water. But in acidic rainfall, soil chemical properties had the most important role. Its reason was acid reactions in soil, especially on chemical properties. Therefore, calcium carbonate had the most important role in acidic rainfall, due to having a buffering position in the soil. Acidic rainfall has an immediate role in erosion and sediment

Table 6. Beta coefficient of productivity of runoff in intensity 1mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation with pH= 5 acidic water.

Soil properties / Slope aspect	Ec	Wm	cac
Southern	-	-	0.939
t	-	-	5.47
Sig	-	-	0.005
Eastern	-0.918	-	-
t	-4.63	-	-
Sig	0.010	-	-
Western	-	-0.834	-
t	-	-3.02	-
Sig	-	0.039	-

Electric conductivity (Ec), Weighted moisture (Wm), calcium carbonate (cac).

Table 7. Relation between productivity of sediment in intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with pH = 5 acidic water.

Slope aspect	Models	R	RE%	RMSE
Northern	-	-	-	-
Southern	-	-	-	-
Eastern	Sy = 28.115 – 2.319 Wm	0.936	6.41	0.402
Western	Sy = 11.765 – 0.315 Sa + 0.142 Gra	0.992	2.21	0.087

Sediment yield (Sy), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Gravel (Gra), Sand (Sa), Weighted moisture (Wm).

Table 8. Beta coefficient of productivity of sediment with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation with pH= 5 acidic water.

Soil properties / Slope aspect	Sa	Wm	Gra
Eastern	-	-0.936	-
t	-	0.006	-
Sig	-	-5.3	-
Western	-0/984	-	0.351
t	-13/07	-	4/67
Sig	0/001	-	0/019

Gravel (Gra), Sand (Sa), Soil acidity (pH), Weighted moisture (Wm).

yield as indicated in this investigation. Of course, changing soil physicochemical properties in different slope aspects has caused different runoff and sediment rates in both acidic rainfall and distilled water (Table 2). Gachsaran Gypsum Formation was composed of salt, anhydride, coloreds and some shale. So, sensitivity to acidic precipitation will increase due to dissolving Gachsaran Gypsum in this Formation and decomposition

Table 9. Relation between productivity of runoff with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with pH = 4 acidic water.

Slope aspect	Models	R	RE%	RMSE
Northern	Ro = -0.302 + 0.011 Slt	0.918	0.109	0.001
Southern	-	-	-	-
Eastern	Ro = 0.240 – 0.052 Ec	0.990	5.15	0.003
Western	-	-	-	-

Runoff (Ro), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Silt (Slt), Electric conductivity (Ec).

Table 10. Beta coefficient productivity of runoff in intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation with pH= 4 acidic water.

Soil properties / Slope aspect	Slt	Ec
Northern	0.918	-
t	4.63	-
Sig	0.010	-
Eastern	-	-0.990
t	-	-14.15
Sig	-	0.000

Silt (Slt), Electric conductivity (Ec).

Table 11. Relation between productivity of sediment with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Gypsum Formation in precipitation with pH = 4 acidic water.

Slope aspect	Model	R	RE%	RMSE
Northern	-	-	-	-
Southern	-	-	-	-
Eastern	Sy = 9.761 + 0.289 cac – 152.65 Na	0.996	1.62	0.086
Western	Sy = 26.09 – 0.395 Sa	0.846	7.83	0.430

Sediment yield (Sy), Correlation coefficient (R), Relative Error (RE), Root Mean Square Error (RMSE), Sand (Sa), calcium carbonate (cac), Sodium (Na).

of materials in the soil, leading to reduction in soil properties, soil loose particles and washing off of soil. In this study, increase in H^+ concentration in soil solution is mainly due to effects of acidic rainfall, that is, some H^+ were absorbed on colloids surface and replaced by other cations into the soil solution. In precipitation with pH = 4, rapid dissolving of Gypsum was caused by acidic rainfall. Thus, soil pores were blocked. Therefore, permeability reduces as caused by increasing erosion and runoff and sediment production in this Formation. Acidicprecipitation had an immediate effect on soil; however, if there was no continuous acidic rainfall, it is because the presence of lime buffering mode in soil has not caused a change in soil texture. In eastern slope aspects, in two mentioned precipitation intensities in Gachsaran Gypsum Formation, runoff and sediment rates increase. Due to they are under effect shadow. Shadow creates sparse and poor vegetation in this formation, hence the soil becomes soft and transferable. Another reason forincreasing sediment and runoff is soil high acidity in the soil of eastern slopes. In Gachsaran Gypsum Formation due to soil fine structure, erodibility increases with increasing pH. When pH in soil increases, the percentage of aluminum saturation reduces and alkali cations increase. And in

Table 12. Beta coefficient of productivity of sediment with intensity 1 mm/min and soil physicochemical characteristics in Gachsaran Formation in precipitation with pH = 4 acidic water.

Soil properties / Slope aspect	Sa	cac	Na
Eastern	-	0.911	-0.406
t	-	16.85	-7.5
Sig	-	0.000	0.005
Western	-0.846	-	-
t	-3.17	-	-
Sig	0.034	-	-

Sand (Sa), calcium carbonate (cac), Organic matter (Om), Sodium (Na).

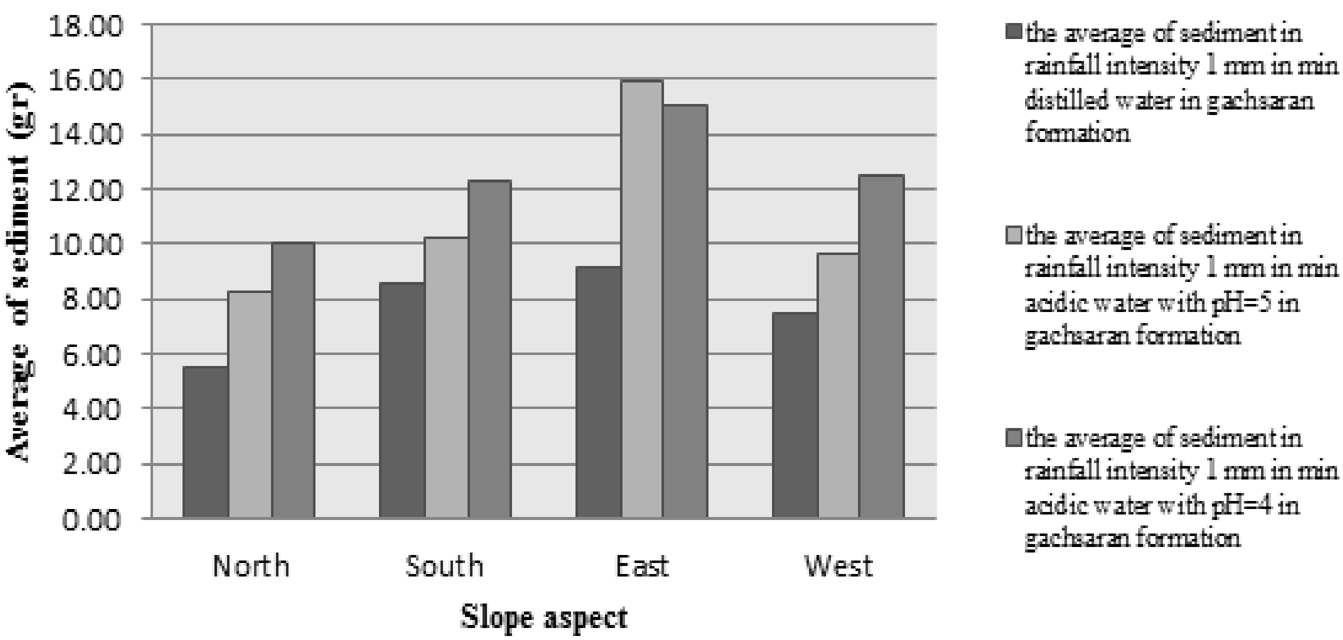

Figure 2. The average of sediment with rainfall intensity 1 mm/min in precipitation various density in Gachsaran Gypsum Formation.

soils with low electrical conductivity, it is caused by dispersing soil particles and increasing erosion. Thus, eastern slopes had high erosion than other slopes. In northern slope aspects, Gypsum bedrock was very near the soil surface and has a high gravel percentage than other slopes. So its soil is made firm and non-transferable and was caused by reducing erodibility. The amount of runoff in southern and northern slopes had greater sensitivity to acidic precipitation. However,they showed almost identical changes but produced more runoff than western and eastern slopes due to Gypsum bedrock near the soil surface. Probably, the main reason for high erodibility in Gachsaran Gypsum Formation was the presence of oil pollutants and air pollution.

Conclusions

This study focuses on investigating the role of acid rainfall on soil erosion and sediment production globally, especially in industrial areas as Gachsaran Gypsum Formations that have nitrate and sulfates. Hence, in Gachsaran Formation, soil chemical properties had the most important role in runoff production in precipitation with distilled water, while soil physical properties had the most important role in sediment production in precipitation

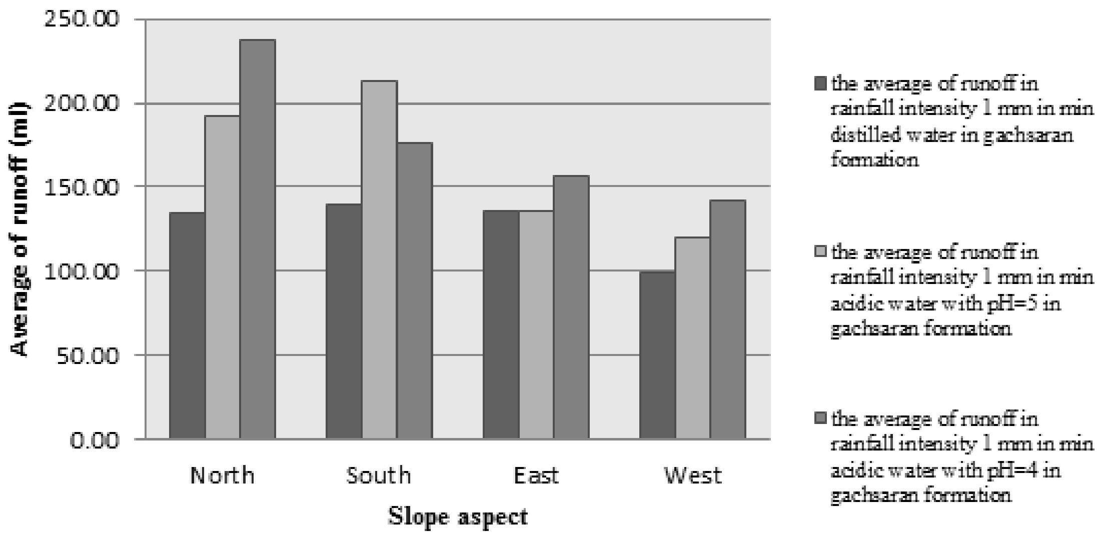

Figure 3. The average of runoff with rainfall intensity 1 mm/min in precipitation various density in Gachsaran Gypsum Formation.

with distilled water. However, in acidic rainfall, soil chemical properties had the most important role. Multi regression models showed that in runoff and sediment production, along with acidic rainfall, different densities, calcium carbonate and Ec had the most important role in runoff hydrological behavior and sediment production to acidic rainfall, due to having a buffering position in the soil.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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