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Application of M5 algorithm of decision tree in simulation and investigation of effective factors of erosion in rangelands and forests

Hatem Ghaleb Maabreh[1]*, Khlood Waheeb[2], Abrar Ryadh[3], Saja Basheer Abdulghani[4], Zainab Jamal Hamoodah[5], Nisreen Yasir Jasim[6], Fakhri Alajeeli[7], Ali H. O. Al Mansor[8], Shlyakhtunov Mikhail Andreevich[9]

1. People's Friendship University of Russia, Moscow, Russia
2. Medical Technical College, Al-Farahidi University, Iraq
3. Medical Laboratory Techniques Department, Al-Mustaqbal University College, 51001 Hillah, Babylon, Iraq
4. Department of Computer Technology Engineering, Al-Hadba University College, Iraq
5. Medical Laboratory Techniques Department, Mazaya University College, Iraq
6.National University of Science and Technology, Dhi Qar, Iraq
7. Al-Hadi University College, Baghdad,10011, Iraq
8. Department of Optical Techniques, Al-Zahrawi University College, Karbala, Iraq
9. Moscow Aviation Institute, Moscow, Russia

** Corresponding author's Email: Hatem.Ghaleb1970@gmail.com*

ABSTRACT
Interrill erosion is the process of soil erosion that occurs on small, un-vegetated areas between ridges or furrows caused by raindrops falling on sloped land. The impact of raindrops can cause the soil to detach and be carried away by runoff. Interrill erosion can be a significant contributor to overall soil erosion and is considered a problem in agricultural areas, construction sites, and other areas with disturbed soil. The aim of this paper was to identify the factors affecting interrill erosion using the M5 algorithm of decision tree in four different regions. The M5 algorithm is considered to be a robust and powerful method for time series forecasting and has been widely used in a variety of applications. To study interrill erosion, 200 soil samples were collected from two rangelands and two forests in Ramadi, Iraq. The soil samples underwent analysis to determine various chemical and physical properties, and the amount of interrill erosion was calculated using the Kamphorst rainfall simulator. The results showed that in the studied areas, the properties of clay, silt, sand, geometric standard deviation and geometric mean particle diameter had the greatest role in interrill erosion. The highest amount of interrill erosion occurred in the disturbed rangeland with a value of 7 tons/hectare and the lowest amount in the protected forest with a value of 3 tons/hectare.

Keywords: Forest, Rangelands, Soil erosion, Decision tree, M5 model tree
Article type: Research Article.

INTRODUCTION
One of the most important resources on earth is soil, which with information from field observations, meteorological statistics and geographical maps shows that more than 75 billion tons of soil is eroded every year on earth. It takes more than 300 years for only 25 mm of topsoil to form (Guimarães *et al.* 2019; Sharifi *et al.* 2021). The existence of soil overshadows human life functions as a renewable resource due to its importance in food production and being a major source for the production of raw materials for human life and agriculture. Therefore, soil erosion and destruction will have irreversible effects on life (Alewell *et al.* 2019). Soil erosion is a physical change and a gradual process of displacement and transfer of the top layer of soil (surface soil) by various factors, especially water, wind and mass movement, which causes its destruction in the long run. In other words, soil erosion is the removal of the most fertile topsoil by excessive water, wind and agriculture (Teng *et al.*

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2019). Soil erosion is the result of unsustainable land use and other disturbances such as fires, mining or intensive agricultural use. Soil loss may have serious effects on the quantity and quality of soil ecosystem services, with serious economic, social and political consequences. In addition to erosion, soil quality is affected by other aspects of agriculture (Pereira da Silva & Lima Rios 2020). These effects include compaction, loss of soil structure, nutrient degradation and soil salinization, which are very real and serious issues (Ricci *et al.* 2020). Soil is the fragile crust of the earth that holds all life on earth. This cover is composed of countless species that create a dynamic and complex ecosystem and is one of the most valuable resources for humans (Sirjani *et al.* 2019). Rising demand for agricultural commodities creates incentives to turn forests and rangelands into farms. The topsoil, which is closest to the earth's surface, contains essential nutrients for crops and is a layer of soil that is endangered by wind and water erosion. Erosion reduces soil fertility, which can negatively affect crop yield. Converting natural soils to agricultural substrates often fails to conserve soil, and many crops such as coffee, cotton, oil palms, soybeans, and wheat may actually increase soil erosion (Zerihun *et al.* 2018). The effects of soil erosion go beyond the loss of fertile land and have led to the increased pollution and sediment in streams and rivers, which have blocked waterways and reduced fish and other species. Damaged soils are also often less able to retain water, which can make floods worse (Saha *et al.* 2019). The main causes of soil erosion include exposure to high winds, copious rain, and moving water. Some human activities, particularly farming and clearing land, make the soil more susceptible to erosion. Erosion, whether by water or wind or by human agriculture, involves three distinct stages of soil separation, movement, and sedimentation (Klik & Rosner 2020). Surface soil with high organic matter, fertility and soil life is transferred to another location. For instance, farmers may expose the soil to erosive factors for weeks or months when they plow the land before or after a growing season and harvest (Rodrigo-Comino 2018). Soil erosion reduces the productivity of farmland and leads to pollution of adjacent waters, wetlands and lakes. Deforestation, particularly logging, which is a common practice in the logging business, is another technique that has disastrous effects on soil health. When trees are destroyed, the ground without roots of plants (a factor that prevents soil sweeping) is exposed to wind and rain (Burzyńska 2019). Erosion is primarily caused by climate change. Extreme temperature swings can make surface soil more prone to erosion, changes in rainfall, then water levels can shift soil, hence protracted droughts can stunt plant development and exacerbate soil erosion. The main causes of soil erosion are either related to natural events or are influenced by the presence of human activities (Berberoglu *et al.* 2020; Gholami *et al.* 2020; Dalir *et al.* 2021). When rain or snowmelt moves soil, erosion occurs. The more water that flows on the ground, the more soil particles move or move away. Water erosion is more likely to occur in areas devoid of vegetation, such as fields that are bare after harvest. Storms and rain create more runoff and erosion since there is no vegetation to absorb water, keep the soil in place, or lessen the force of rainfall (Chalise *et al.* 2019). The effects of water on the farm can be reduced by vegetation, conventional farming methods, and the thoughtful application of cover crops. Through careful farming techniques, agricultural engineers can also lessen soil erosion. Farmers typically cultivate their soil to remove weeds, regulate moisture, and prepare the area for sowing seeds. A less-more strategy may be the best method to reduce soil erosion, according to years of agricultural study. Hence, lessening mechanical disruptions on farms may aid in preserving more soil (Nasir Ahmad *et al.* 2020). Soil erosion occurs in different ways as described below:

- Sheet erosion
- Rill erosion
- Gully erosion
- Bank erosion
- Tunnel erosion
- Interrill erosion

When raindrops and shallow surface water flows interact, the result is sheet erosion, which is the removal of soil in thin, homogeneous layers (sheets). If the soil is not lose to sediment or the damage is not very severe, it can be challenging to detect sheet erosion. The fine soil particles that comprise the majority of the essential nutrients and organic matter are removed by this erosion process. Small, clearly defined canals are created as a result of the erosion known as rill erosion (Novara *et al.* 2019). The canals created by this type of erosion are usually smaller than gully erosion. The latter occurs when water erodes soil by washing soil through deep furrows or canals across an unprotected ground (Lal 2019). This erosion can be used to describe the procedure by which dirt moves through furrows caused by intense rain or to describe soil eroding through drainage systems that were developed artificially. As a temporary fix, farmers typically fill these furrows with fresh soil (Liu *et al.* 2021). Bank soil erosion is caused by cutting, scouring and gradual subsidence of natural rivers and streams as well as artificial drainage canals caused by the intense movement of water. It can exacerbate the problem when landowners remove vegetation or allow ranchers to graze on land beside rivers and riverbanks. This type of erosion poses a serious threat to areas around the world (Batista *et al.* 2019). For instance, clay is particularly prone to erosion during the wet season, as is southwest Bangladesh. Tens of thousands of people are displaced each year by river erosion, which also has a disastrous impact on the area's crops. Tunnel erosion occurs when surface water enters and the soil moves sporadically through the lower parts. Scattered soils are easily eroded when wet because they have a weak structure. Interrill erosion is a type of erosion in which soil particles separated by raindrops can be transported by shallow currents (Pijl *et al.* 2020). The severity of soil erosion is affected by soil properties such as pH, amount of silt, clay and sand as well as the amount of calcium carbonate, etc. which affect the rate of erosion. There are different methods for predicting soil properties in different parts of rangelands and forests. In our study, as a novel strategy, we used a multi-linear model (M5 algorithm of decision tree) to predict soil properties and then compared with the observed values. It should be mentioned that the current study is a case study report which is inspired by a study conducted in Iran by Sharifi *et al.* (2021).

MATERIALS AND METHODS

Two forests and two rangelands in Ramadi, Iraq were selected for sampling. A total of 200 samples were taken, with 50 samples being collected from each region. After removing the organic residues on the soil surface, sampling was performed in the vicinity of the points where rain simulation was performed. Samples were taken using a shovel from a depth of 0 to 10 cm. To determine the bulk density of soil, intact samples were collected using cylinders with a diameter and height of 5 cm. The samples were then transferred to the laboratory, then the disturbed soil samples were dried and prepared for physicochemical experiments. The soil texture was evaluated using a hydrometer after the dried samples had been run through a 2-mm sieve, and the organic carbon content was determined using a wet oxidation method (Du *et al.* 2022). We assessed the soil reaction (pH in saturated soil), electrical conductivity in saturated extract, equivalent calcium carbonate by neutralization method with hydrochloric acid, and organic matter of the particles using thermal removal method (Wen & Zhen 2020). Equations 1 and 2 were used to calculate the geometric mean diameter (dg) and geometric standard deviation (ɓg) of soil particles.

$$\sigma d_g = e^a \ , \ a = 0.01 \sum_{i=1}^{n} f_i \ln M_i \quad \textbf{(1)}$$

$$\sigma_g = e^b \ , \ b^2 = 0.01 \sum_{i=1}^{n} f_i ln^2 M_i - a^2 \quad \textbf{(2)}$$

where f_i is the relative frequency of each soil component (sand, silt and clay) and M_i is the numerical mean diameter of each component. M_i values were calculated according to the USDA classification for three particles of sand, silt and clay (1.025, 0.026 and 0.001 mm) respectively (Rezaei & Vadiati 2020). The Kamphorst rainfall simulator is a device used to measure interrill erosion by simulating the impact of raindrops on soil surfaces. The simulator consists of a tank of water, a pump, and a control system that can adjust the intensity and duration of rainfall. The raindrops are directed onto a soil sample, and the runoff generated by the impact of the raindrops is collected and measured. The amount of interrill erosion can be calculated based on the amount of runoff and the physical properties of the soil. In this study, a Kamphorst rainfall simulator was employed to assess the soil sensitivity to interrill erosion (Panagos & Katsoyiannis 2019). This device is made in a plot size of 0.0625 m^2 and used as a standard method to determine soil surface erodibility, water penetration and soil protection research. This device consists of three parts of sprinkler with pressure regulator to produce standard rainfall, sprinkler base and metal frame in which the vegetation and soil to be tested are placed. In order to measure the rate of interrill erosion, the rain simulator was placed on each of the sampling points. Since high rainfall intensities can better show the soil response to erosion and runoff production, and based on the highest rainfall intensity in the region over the long term, rainfall with intensity of 50 mm h^{-1} was simulated. According to the sources and the recommendation, distilled water was used instead of ordinary water, to prevent the effect of water salts on the separation of soil particles from distilled water.

Modeling M5 model tree

One of the most widely-used data mining algorithms is the decision tree algorithm (Khosravi *et al.* 2022). In data mining, decision tree is a predictive model so that it can be used for both regression and class models. When the tree is used for classification tasks, it is known as a classification tree, and when it is used for regression activities, it is called a regression decision tree (see Fig. 1). The main components of a decision tree are as follows (Nourani & Molajou 2017):

Leaf Nodes: Nodes where successive divisions end. Leaves are identified by a class.
Root Node: The starting node of the tree.
Branches: They are created in each internal node as many as possible answers.

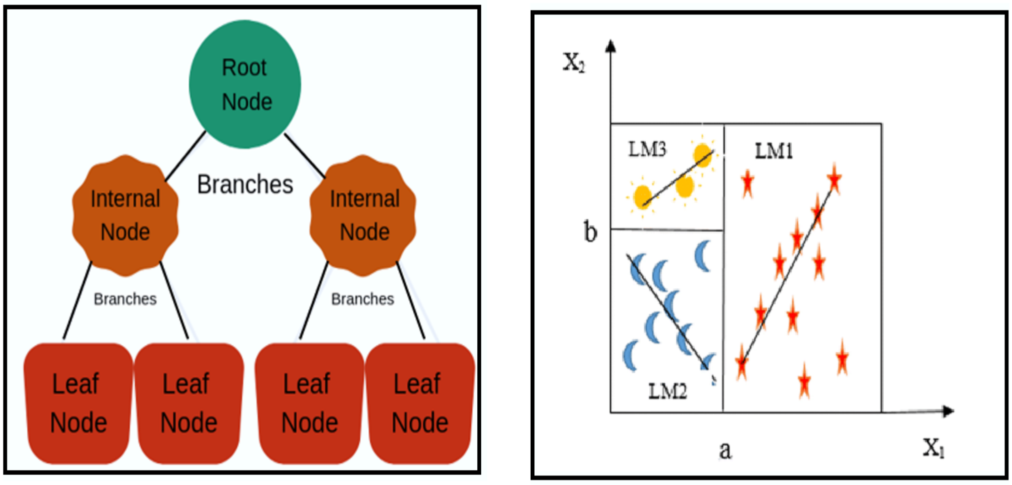

Fig. 1. The schematic of M5 algorithm of decision tree.

In order to model interrill erosion using M5 model tree, 10 soil properties were used in two scenarios. In the second scenario, instead of soil texture components, percentage of sand, silt and clay, the geometric mean diameter of particles (dg) and the geometric standard deviation of soil particles (σg) were used. Using the feed-forward multilayer perceptron network (Ayubi Rad & Ayubirad 2017), modeling process was performed. In this model, 70% of the data were randomly considered as train data, 15% as validation and 15% as test data. Evaluating the efficiency of the model, using the determination coefficient (DC), mean error (ME) and root mean square error (RMSE) were performed as follows (Equations 3 to 5).

$$DC=\frac{\sum_{i=1}^{n}(P_i-m)^2}{\sum_{i=1}^{n}(O_i-m)^2} \quad \textbf{(3)}$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i) \quad \textbf{(4)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)^2]} \quad \textbf{(5)}$$

where P_i is the value predicted by the model, O_i is the actual value of the target variable and m is the average of the actual values (Kumar *et al.* 2021). In general, the closer the value of DC is to one, the more accurate the model used. The best ME value is zero, and if it is positive, the model is overestimated, and if it is negative, it is underestimated. Also, the smaller the RMSE, the higher the modeling accuracy (Nourani *et al.* 2019; Belayneh *et al.* 2019). Sensitivity analysis is a way to determine the importance of the effect of independent input variables on a target or dependent variable. In order to analyze the sensitivity of the model results, the Hill method was used in this study. According to this method, one of the input variables was changed by 10% and then the effect of this change on the target variable was investigated. The more changes the target variable is due to the change of the input variable, the more sensitive that input variable is and the more important it is in modeling (Kidane *et al.* 2019). A statistical analysis of the physical and chemical properties of soil was performed using SPSS software version 23.0. The mean soil properties were compared using a Least Significant Difference (LSD) test in SPSS software at a 5% significance level. Additionally, the M5 decision tree algorithm was implemented using WEKA software.

RESULTS AND DISCUSSION

The lowest and highest coefficients of variation were related to pH and geometric mean particle diameters, respectively. Numbers indicate that most of the studied soils are calcareous. Since they have a pH greater than 7.5, the soil texture was mostly sandy loam. Table 1 presents soil statistical data.

Table 1. Statistical description of soil properties.

Variable	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
Soil bulk density (g cm^{-3})	1.31	1.74	1.54	0.113	0.06
Organic matter (%)	0.15	0.78	0.34	0.161	0.49
pH	7.9	8.5	8.21	0.159	0.02
Clay (%)	7.02	21.11	14.02	3.823	0.26
Silt (%)	3.98	38.21	24.45	8.352	0.34
Sand (%)	40.89	78.38	63.25	11.658	0.18
Calcium carbonate equivalent (%)	1.12	20.11	10.22	5.321	0.53
Particulate organic matter (%)	0.02	0.18	0.08	0.029	0.42
Geometric mean particle diameter (mm)	0.03	0.61	0.21	0.011	0.66
Geometric standard deviation	6.53	15.91	12.25	2.411	0.21

Table 2 shows the efficiency of scenarios 1 and 2 in predicting interrill erosion through evaluation indicators. In fact, these indicators are like RMSE indicate that this type of erosion is most affected by which scenarios and their factors.

Table 2. Comparison of modeling accuracy in scenarios 1 and 2 by M5 model tree.

Model	DC	ME	RMSE
M5 test 1	0.79	-0.175	0.75
M5 train 1	0.85	0.139	1.67
M5 test 2	0.71	0.022	1.12
M5 train 2	0.76	-.0473	1.14
M5 test 1 validation	0.77	-0.169	0.68
M5 test 2 validation	0.74	0.026	1.16

Since the closer the value of DC is to one, the more valid the model is. Due to the DC value of test data and training the first scenario are 0.79 and 0.85, respectively, this scenario is more accurate compared to the second scenario. In terms of RMSE value, because the value of the first scenario test data is closer to zero, it is more accurate. Also in this paper, positive values of ME indicate the overestimation mode and negative values indicate the underestimation mode in modeling. The results of sensitivity analysis to 10 features examined in 2 scenarios are presented in Figs. 2 and 3. It should be noted that the results were consistent with Sharifi *et al.* (2021). The results of sensitivity analysis show that in Scenario one, the most effect is related to the clay variable and then the silt percentage has the greatest effect on the target variable (interrill erosion). On the other hand, in Second scenario, it was observed that the geometric mean diameter and geometric standard deviation of the particles exhibited the highest effect on the model output (interrill erosion). These two variables, which are obtained based on the calculations of texture components, have a broader meaning than soil texture components. This means that soil texture components represent only the relative percentages of sand, silt, and clay. While geometric mean diameter and geometric standard deviation are able to show changes in particle size distribution, thereby creating a stronger association with interrill erosion. In addition, in both scenarios, changes in pH and bulk density had the least effect on interrill erosion because the two did not have much variability in the region. In general, the greater the variability of input variables for modeling in an area and the more it affects the target variable, the more important it becomes in modeling. According to the results of both scenarios, it can be seen that interrill erosion is mainly a function of particle size distribution. Particle cementing agents such as organic matter content, particulate organic matter, calcium carbonate equivalent were of secondary importance. The amount of clay, silt and sand in the four study areas is shown in Fig. 4. In addition, the geometric mean diameter of the particles, geometric standard deviation, and the amount of soil erosion in these areas are presented in Fig. 5.

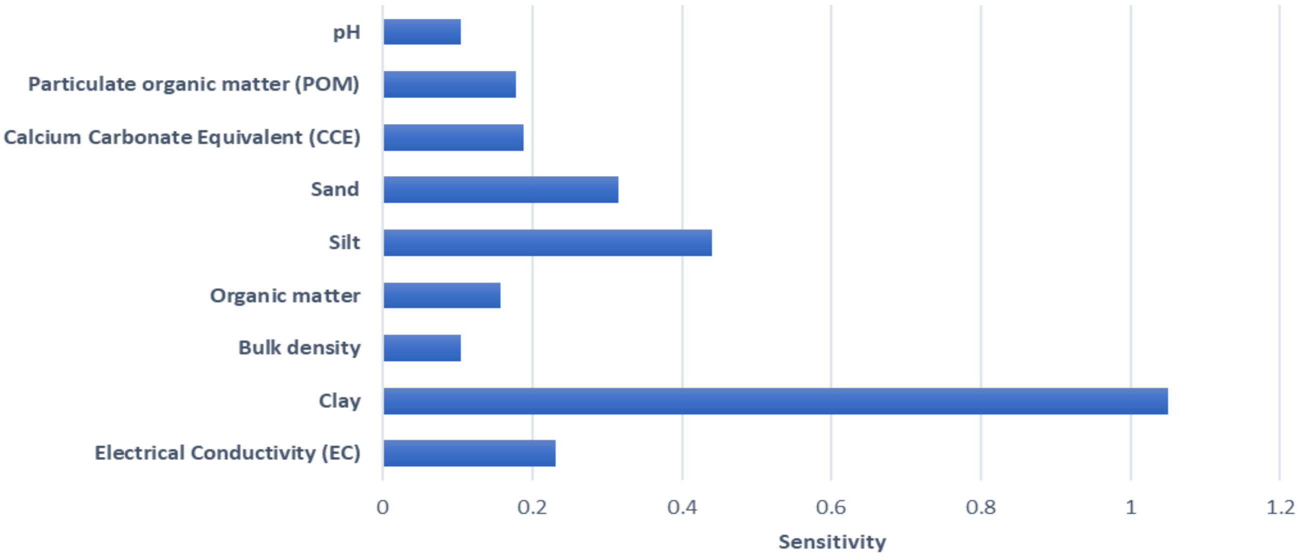

Fig. 2. Sensitivity analysis of input variables in Scenario 1.

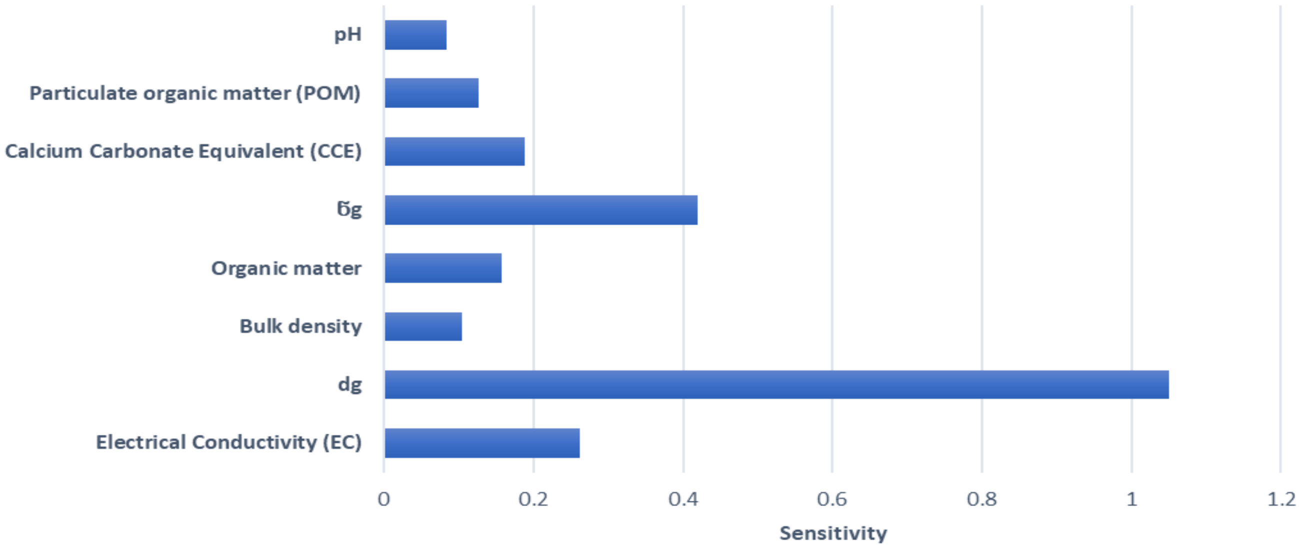

Fig. 3. Sensitivity analysis of input variables in Scenario 2.

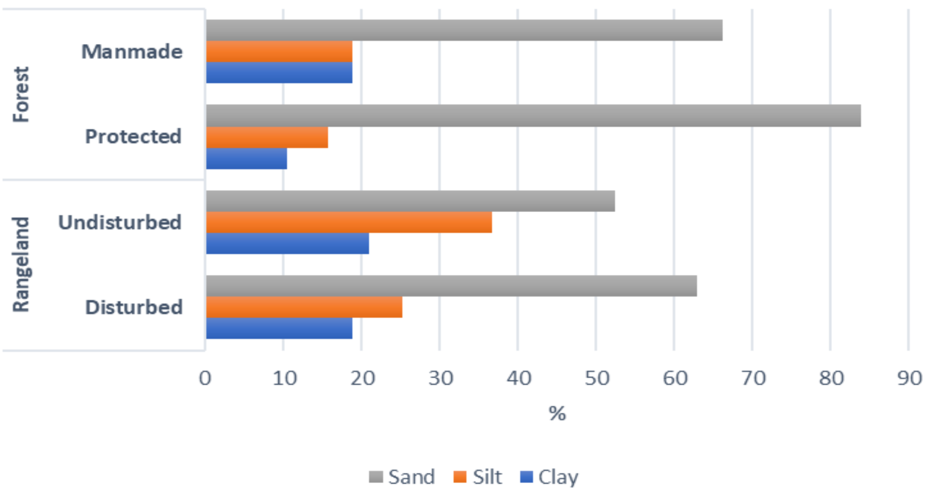

Fig. 4. Amounts of sand, silt and clay in four study areas.

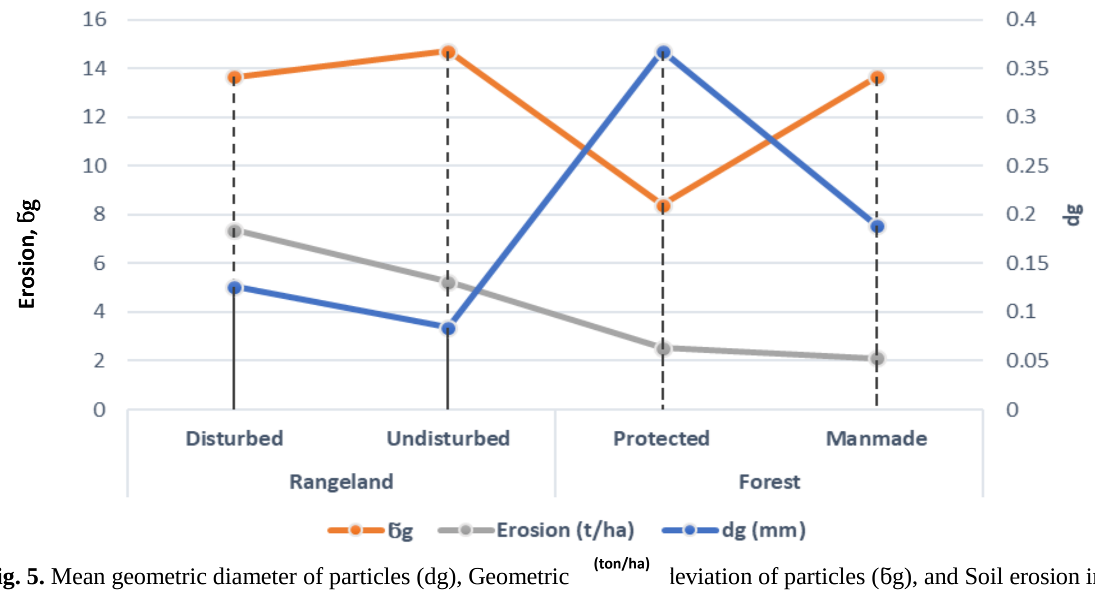

Fig. 5. Mean geometric diameter of particles (dg), Geometric leviation of particles (бg), and Soil erosion in four study areas.

The amount of soil erosion in forests was less than rangelands due to the higher density of vegetation and greater stability in forests. In this study, other cases were assessed in two scenarios. The amount of interrill erosion in the protected forest was 2.5 ton ha^{-1}. Also in this area, the mean geometric diameter of particles and the geometric standard deviation 0.37 mm and 8.4 respectively. The amount of interrill erosion in the disturbed rangeland was 7.35 ton ha^{-1}. Also in this area, the mean geometric diameter of particles and the geometric standard deviation were 0.13 mm and 13.65 respectively. According to the results, the protected forest with the lowest amount of clay, silt and the highest amount of sand exhibited a lower amount of interrill erosion than the rangelands. In addition, in this region, the particles displayed the largest geometric mean diameter and the lowest geometric standard deviation. Therefore, it can be said that the coarseness and fineness of soil particles as well as its distribution are one of the most important factors in the occurrence of interrill erosion. Particle size distribution revealed the greatest effect on modeling and target variables. As silt and sand are very fine, they are sensitive to erosion and increase interrill erosion. In contrast, coarse sand due to weight and clay reduce interrill erosion due to adhesion between its particles.

CONCLUSION

Interrill erosion is a problem in many agricultural areas, construction sites, and other areas with disturbed soil. It can result in reduced soil fertility, decreased crop yields, as well as the increased runoff and sedimentation, which can harm aquatic ecosystems. Interrill erosion can also cause changes in the water balance of an ecosystem, leading to the upraised water use and decline in water availability. In this study, the factors affecting interrill erosion were investigated using two scenarios of M5 algorithm of decision tree with different input variables in 4 regions in Ramadi, Iraq. In Scenario 1, the amount of clay in the soil and in Scenario 2, the geometric mean of the particles, caused the greatest amount of sensitivity to interrill erosion. The highest and lowest amounts of interrill erosion occurred in the disturbed rangeland the protected forest with the values of 7.35 and 2.5 ton ha^{-1} respectively. The mean geometric diameter was the highest in the protected forest. In addition, the standard deviation of the geometric diameter was less than the other 3 regions, which indicates the accuracy of the sensitivity in the scenarios.

Conflict of interests

The authors declare no conflict of interest.

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