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*Full Length Research Paper*

# Factors affecting soil erosion in Beijing mountain forestlands

**Zhenming Zhang[1]*, Siming Song[2], Hailong Wu[2], Xinxiao Yu[2] and Qian Zhang[1]**

[1]College of Nature Conservation, Beijing Forestry University, Beijing 100083, China.
[2]The Key Laboratory of Soil and Water Conservation and Desertification Combating of the Ministry of Education, Beijing Forestry University, Beijing 100083, China.

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**The role of regions, vegetation types and forest stand density in controlling soil erosion were investigated in Beijing mountain forest, China. The main objective was to develop some models to estimate soil erosion under different forest conditions including regions, vegetation type, and stand density as influenced by artificial experiment. Multilevel regression model was used for developing these models. Data used were collected from 23 sampling plots (standard 1 ha units) in the Nature Reserves and State/National Forest in Beijing's mountainous area. This study presents summary data on soil loss as affected by forest condition. The results indicate that region, vegetation types and forest stand density have certain and different degrees of effects on soil erosion of forest land. The present study plays an important role in clarifying forestry management technical processes related to soil erosion, linking these elements to current Chinese forestry issues and bringing new guidance to reducing sediment-related disasters in China.**

**Key words:** Multilevel regression model, forest land, soil erosion, Beijing Mountain.

## INTRODUCTION

The forest soil ecological system assessment is one of the representative methods of understanding forest health. The anti-scouring feature of the forest land soil is considered to be an important part of the assessment as such feature help soil resist from being washed. In the 1960s, Zhu Xianmo defined the anti-scouring feature of forest soil for the very first time in China based on the study of characteristics of erosion at Loess Plateaus. He reported that the anti-scouring features were the key to reveal soil erosion (Zhou, 1993), as well as depositional modes and penetrability of the loess soil (Zhu and Tian, 1993). Following Zhou's study, Li Yong investigated root soil relationship and found that a root density of less than 1 mm in diameter can have a greater impact on the anti-scouring feature (Li, 1991). However, Jiang Dingsheng and others indicated that the vegetation, root distribution and the soil texture altogether are the main factors influencing the anti-scouring feature (Jiang et al., 1995).

Zhou Peihua and Wu Pute also worked out for a number of experiments and developed indices for anti-scouring features of soil (Zhou, 1993; Wu and Zhou, 1993).

Although, prevention of natural disasters has always been recognized as the most important function of forests by the people in China during the recent few decades (Li, 1990a,b; Liu, 1998; Zhang, 1998, 2006; Zhang et al., 2007; Zhou et al., 1997; Zhu and Tian, 1993), problems due to sediment-related disasters are still important threats in China. And there is a limited information available showing the relationship between soil erosion and soil conditions, especially regions, vegetation types and stand density (Razafindrabe, 2004; Razafindrabe et al., 2006 ; Shakesby et al., 2007). In this study, we focused on the assumption that soil erosion is sensitive to forest conditions change, especially on stand density. There-fore, the main objectives of this work were to (1) use multilevel regression model to develop fitted soil erosion model for trees in plot scale of Beijing mountain area and analyze the uncertainty of model parameters, and (2) analyze the effects of regions, vegetation types and stand density on the model and quantify the

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*Corresponding author. E-mail: zhenmingzhang@bjfu.edu.cn.

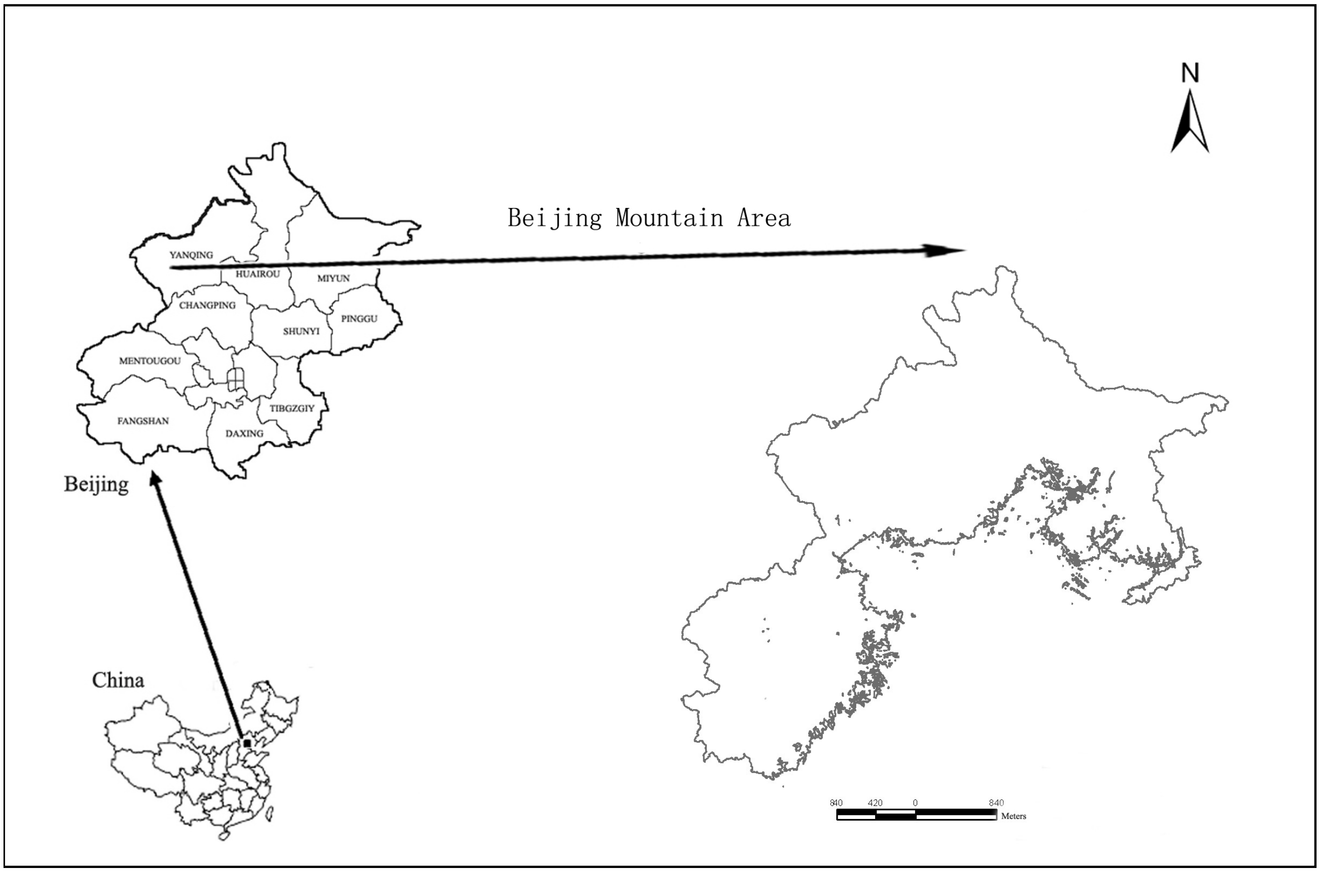

**Figure 1.** Map of research site.

degrees of effects.

## MATERIALS AND METHODS

### Research site

Beijing is situated in North China Plain at 39°28´- 41°05´N, 115°25´-117°30´E (Figure 1). The western part of the city belongs to the Taihang mountain ranges, while the north and east parts belong to the Yanshan mountain ranges. Exposed bedrock in the mountain areas contains the vast majority of rock formations from the Cenozoic Era to Archean Eon and igneous rock in different periods, with a complicated geological structure. In addition, most parts of the plain are covered by quaternary sediments (Huo, 1998). Beijing has complex landform types, a diversity of plants, and obvious vertical differences in climate. Long-term mean annual precipitation of Beijing is 600 mm, and the city belongs to a warm-temperate zone, monsoon-influenced, and semi-humid continent climate (Huo, 1998). The mountain area covers 1.04 million square kilometers and 62% of the city's territory. The forest area is the largest one, which makes up 53.24% of the mountainous forestry land area, and the shrub land area covers 320 974.8 ha (computed based on the rate of woody plant cover: 208 229.2 ha) and 36.44% of the mountainous forestry land area. Other forest land types are relatively less. The main dominant tree species in the Beijing mountain area are *Pinus tabuliformis Carrière, Platycladus orientalis, Larix gmellini, Populus davidiana, Betula sp., Quercus* and other broad-leaved trees.

### Data collection

The study area covers Xishan Forest Farm in Haidian District, Badaling Forest Farm in Yanqing County, Songshan Nature Reserve, Ming Tombs Forest Farm in Changping District, Water-source-nourishing Forest Experimental Workstation, Wulingshan Forest Farm in Mentougou District, etc. Based on the typical representations of forest vegetation types in Beijing mountain area, as well as on-site investigation and comparative analysis, 23 standard plots were established and they were also enclosed and marked by cement piles, wood piles, wire, etc. Main vegetation types in Beijing mountain area comprised by 10 species which include *P. tabuliformis Carrière, P. orientalis, L. gmellini, Cotinus coggygria, Quercus, Betula sp., P. davidiana,* economic forests, shaws and other broad-leaved trees. Tallying was done in 20 m by 20 m plots divided from fixed standard plots and the main survey factors included tree species, distance, DBH, tree height, clear length, crown width, dominance.

### Undisturbed soil sample washing

During the experiment, we used the large undisturbed soil sample washing equipment illustrated in Figure 2. The scouring runoff was 2.0, 3.0, 4.0, 5.0 and 6.0 L min$^{-1}$, the scouring slope was 15° and the time used was for 15 min. During the scouring process we took a water sample for every soil sample every 2 min to measure the erosion amount and analyzed the runoff generation and sediment yield process. The collection tool consists of rectangle cutting rings

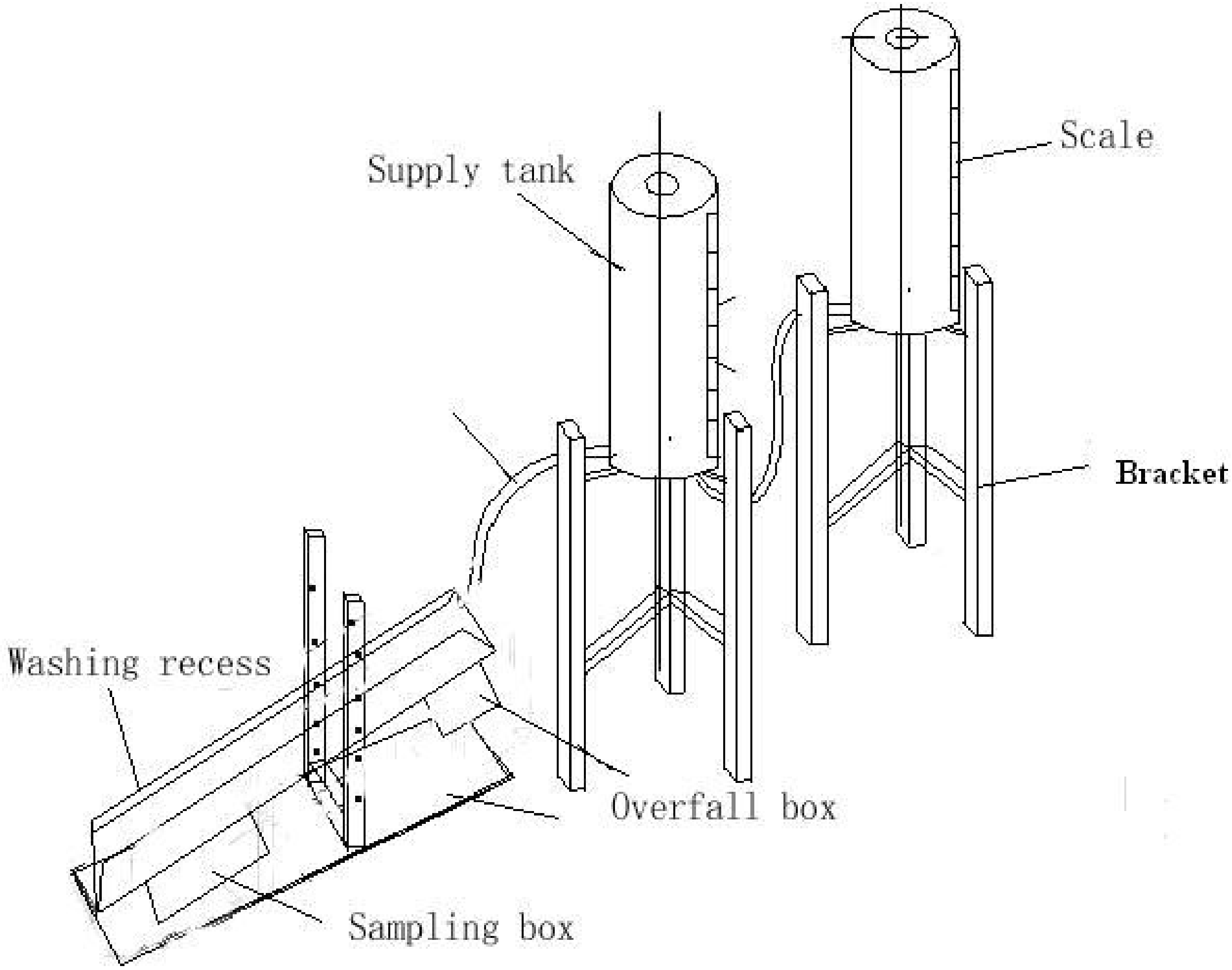

**Figure 2.** Undisturbed soil sample washing equipment.

with a specification of 20 × 10 × 10 cm. Without a seal on their top and bottom, the rectangle cutting rings are 1 cm high at one side and have blade orifices at the bottom.

## RESULTS AND DISCUSSION

### Soil erosion amount and time model

A diagram of the amount of soil erosion, flow capacity, time and fresh root weight was drawn on the basis of the measured data. Figure 3 indicates that the amount of soil erosion has a relationship between flow capacity, time and root fresh weight. With stepwise regression method, we finally fixed the soil erosion model as follows:

$$y_i \sim N(\alpha+\beta_0 x_{1i}+\beta_1 x_{1i}+\beta_2 x_{2i},\varepsilon^2), \qquad for i=1,...,n$$

Where, $y_i = \ln(SD)$ is the logarithm of soil erosion amount, whose unit is g; $x_1 = (T-\overline{T})$ is the value of soil anti-scouring time minus the mean value of anti-scouring time (3.17 min), whose unit is min; $x_2 = (F-\overline{F})$ is the value that soil erosion flow minus the mean value of observed flow data (4.07), whose unit is L min$^{-1}$; $x_3 = (RFW-\overline{RFW})$ equals the root fresh weight in the soil sample minus the root fresh weight in the measured data, the mean value in this study is 19.22 g , while $i$ is the number of samples (I = 1, 2,…,741).

Parameters of this model are finalized after 10000 times of data simulations (Table 1). Following the simulations, all parameters of this model were in their 95% confidence interval and 50% confidence interval respectively, so that the model was as follows:

$$\ln(SD) = -0.31-0.12x_1+0.15x_2 - 0.029x_3$$

$$\varepsilon \sim N(0,1.35^2)$$

The model shows that the soil erosion amount is inversely proportional to the soil anti-scouring time. When

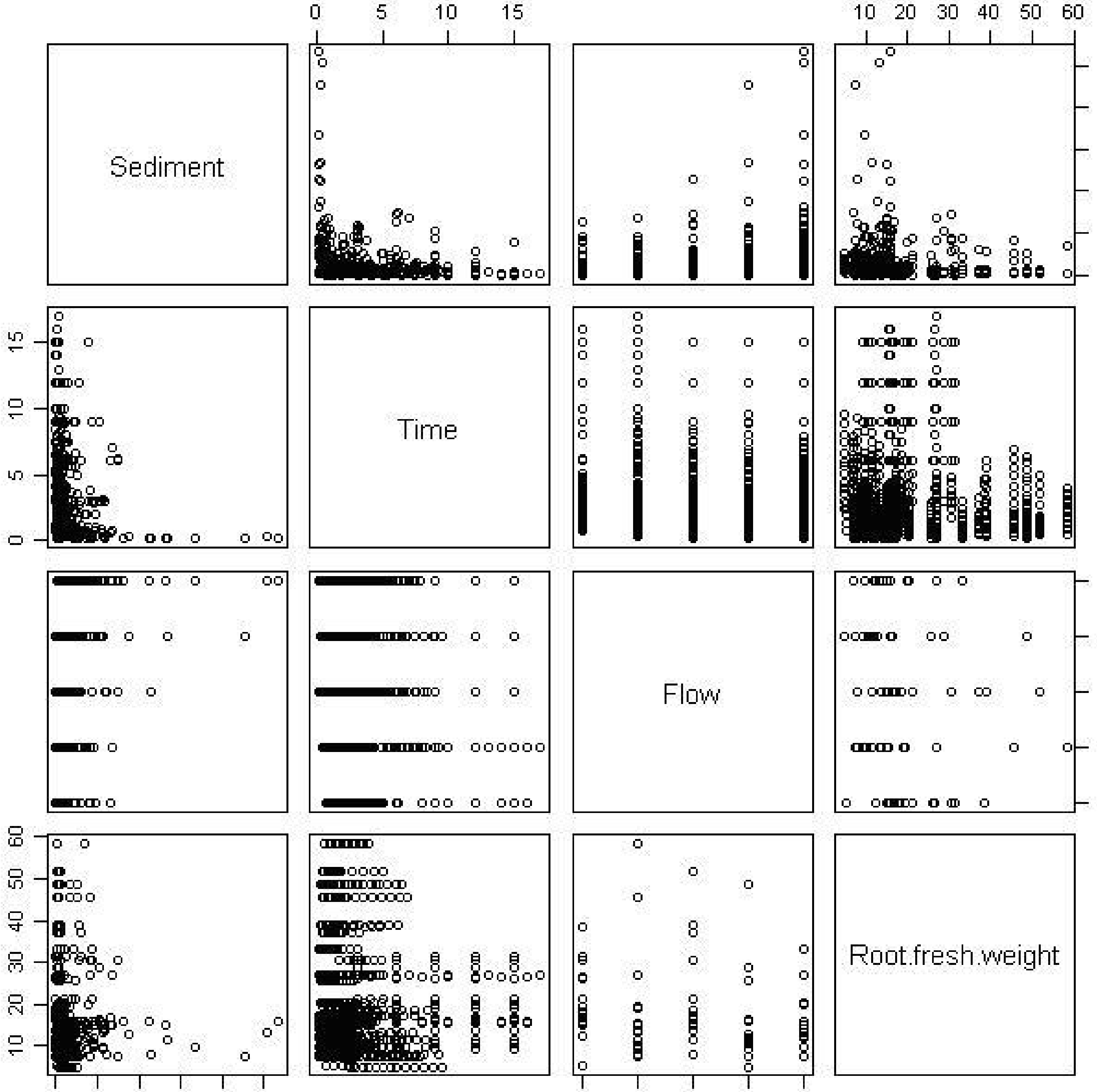

**Figure 3.** Relationship between erosion amount and time model.

the soil anti-scouring time changes by 1 unit, the logarithm of soil erosion amount changed by 12%. Meanwhile, it shows that the soil erosion is proportional to the flow discharge. When the flow discharge changes by 1 unit, the logarithm of soil erosion also changed by 15%. In the mean time, the soil erosion is inversely proportional to the root fresh weight; this is mainly because vegetation roots system can influence the environment of the soil-vegetation ecosystem. Different diameters of root intersperse in the soil constitute the variability in root systems fixing the problems associated with soil and sand erosions (Zhuang et al., 2007). When root fresh weight changes by 1 unit, the logarithm value of soil

**Table 1.** Parameter estimation for erosion amount-time model.

| Parameter estimation | Mean value | Confidence interval (%) | | | |
|---|---|---|---|---|---|
| | | 2.5 | 25 | 75 | 98 |
| $\hat{\alpha}$ | -0.310 | -0.400 | -0.340 | -0.270 | -0.210 |
| $\hat{\beta}_0$ | -0.118 | -0.149 | -0.129 | -0.108 | -0.087 |
| $\hat{\beta}_1$ | 0.146 | 0.083 | 0.124 | 0.166 | 0.206 |
| $\hat{\beta}_2$ | -0.029 | -0.037 | -0.032 | -0.026 | -0.021 |
| $\hat{\sigma}$ | 1.348 | 1.273 | 1.321 | 1.385 | 1.421 |

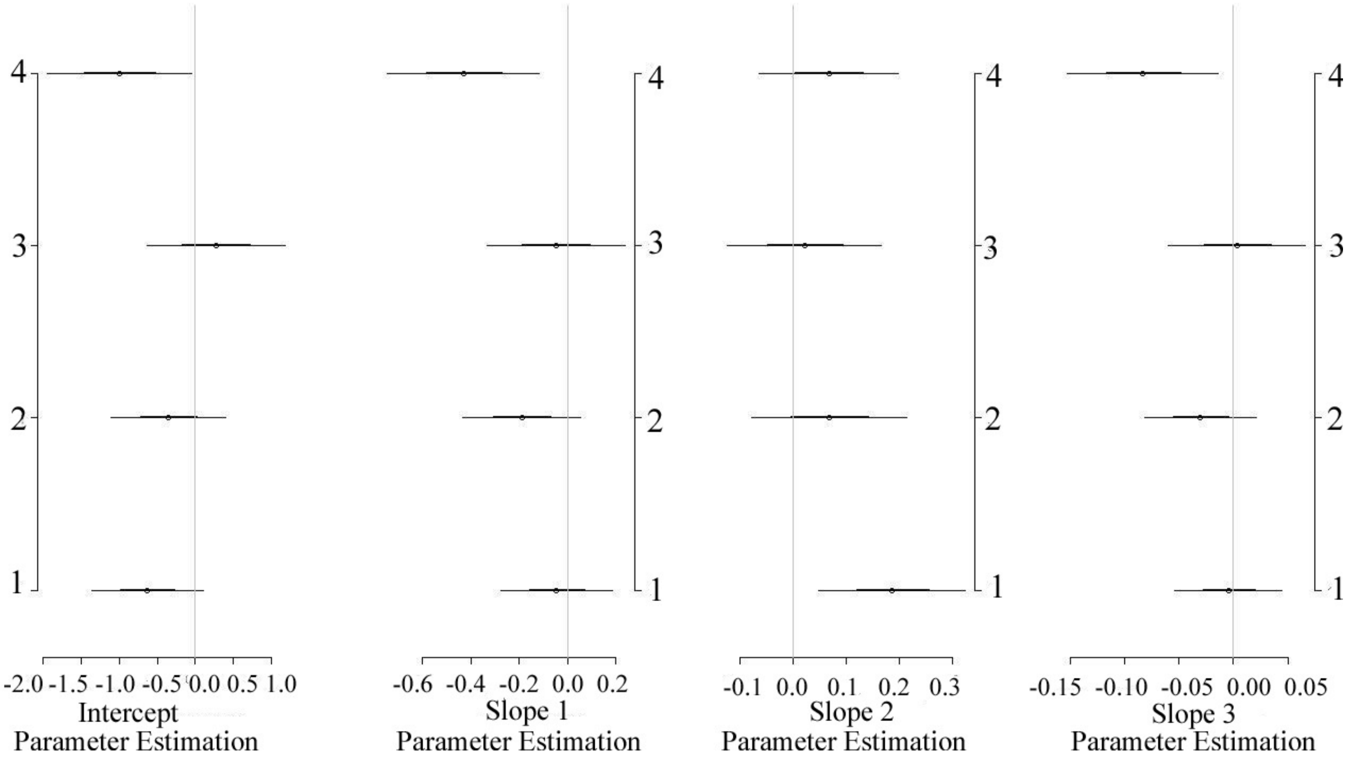

**Figure 4.** Effect of region on erosion amount- time model. 1= Miyun County, 2 = Yanqing County, 3 = Changping District and 4 = Haidian District.

erosion amount changed by 2.9%. Furthermore, when anti-scouring time equals the mean value of the measured data (3.17 min), the flow discharge equals the mean value of the measured data was 4.07 Lmin$^{-1}$, the root fresh weight equals the mean value of the measured data was 19.22 g, and the soil erosion amount equals 0.733 g.

## Region-erosion amount-time model

Figure 4 shows that region influences the amount of soil erosion to a certain extent. Soil erosion amount is inversely proportional to the soil anti-scouring time. When the soil anti-scouring time changes 1 unit, the variations of erosion amount in the 4 regions are 4.6, 19, 4.8 and 43%, respectively and the range in the amount of soil erosion change in the Haidian District was the largest, while Miyun County is the smallest (Figure 4). The amount of soil erosion is proportional to the flow discharge, when the flow discharge changes 1unit, the soil erosion amount in the 4 regions are 18.7%, 6.9%, 2.3%, 6.8%, respectively among them, the soil erosion amount in the Miyun county changes greatly, while the Changping District has relatively a small change (Figure 4). Soil erosion amount is inversely proportional to root fresh weight; when root fresh weight changes 1 unit, the soil erosion amount in the 4 regions are 18.7, 6.9, 2.3

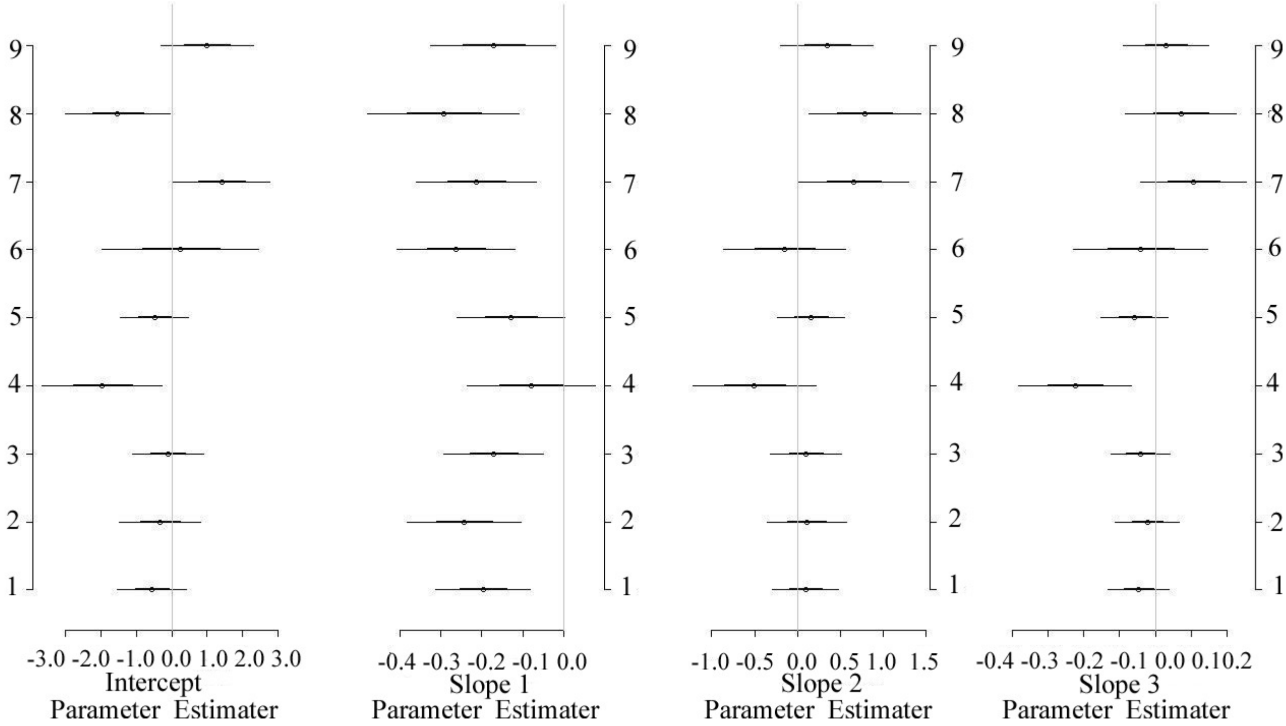

**Figure 5.** Effect of vegetation type- erosion amount- time model. 1 = *Pinus tabuliformis Carrière*, 2= *Betula sp.*, 3= *Platycladus orientalis,* 4 = Cotinus coggygris var., 5 = *Quercus*, 6 = *Larix gmellini*, 7= *Populus davidiana*, 8 = *Robinia pseudoacacia L.*, 9 = economic forests.

and 6.8%, respectively of which the soil erosion amount in the Haidian District changes greatly, while the Changping District had a little change. Moreover, when the anti-souring time equals the mean value of the measured data (3.17 min), flow discharge equals the mean value of the measured data (4.07 Lmin$^{-1}$), root fresh weight equals the mean value of the measured data (19.22 g), while the soil erosion amount in the 4 regions were 0.53, 0.70, 1.31 and 0.37 g, respectively. Among these, the Changping District had experienced a huge change, while the Haidian District had a relatively small change.

## Vegetation type- erosion amount- time model

Figure 5 shows the vegetation types that can impact soil erosion model. Numerous studies (Zhu, 1982; Li et al., 1993; Zhang et al., 1994; Ding et al., 2002) suggest that plant roots, especially the roots whose diameter class is less than 1.0 to 2.0 mm, can stabilize the soil structure. However, roots with diameter class larger than 2 mm with rich organic matter content can add water stable aggregate and create biodynamic properties of the anti-erosion soil. Figure 5 also presented the fine roots' growth distribution for different vegetation types with relative independence and specificity. Soil erosion amount is inversely proportional to soil anti-scouring time and root system, while this is proportional to flow discharge. When anti-scouring time changes 1 unit, the change range of 9 different proportions of vegetation types of the amount of soil erosion included 20, 24, 17, 8, 13, 26, 21, 29 and 17%, respectively. Among these changes, the change range of *Robinia pseudoacacia L.* land soil erosion amount was the largest one, while the *C. coggygris var.* land was the smallest one (Figure 5). Moreover, the soil erosion amount was proportional to flow discharge, when flow discharge changes 1 unit, the change range of 9 different proportions of vegetation types' of the soil erosion amount were 9, 11, 10, 50, 16, 15, 65, 78 and 35%, respectively. Among them, the change range of *R. pseudoacacia L* . land soil erosion amount was the largest one, while *P. tabuliformis Carrière* land was the smallest one (Figure 5).

In addition, the soil erosion amount was inversely proportional to root fresh weight. When root fresh weight changed by 1 unit, the change range of 9 different proportions of the vegetation types' of the soil erosion amount were 5, 2, 4, 22, 6, 4, 0.8, 1.0 and 1.5%, respectively. Among them, the change range of the *C. coggygris var.* land soil erosion amount was the largest, while the *R. pseudoacacia L.* land was the smallest (Figure 5). Also, when the anti-scouring time equaled the mean value of its measured data (3.17 min), the value of flow discharge equals the mean value of its measured data (4.07 L min$^{-1}$), and the root fresh weight equals the

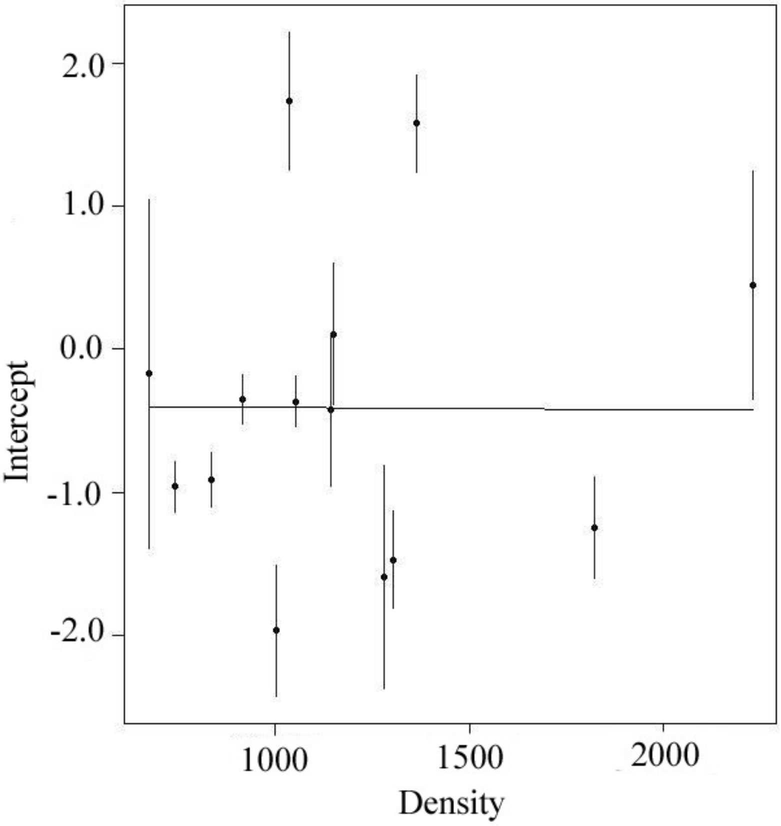

**Figure 6.** Effect of density on soil erosion model.

mean value of its measured data (19.22 g), with the different proportions of the vegetation types' soil erosion being 0.57, 0.72, 0.90, 0.14, 0.61, 1.28, 4.10, 0.22 and 2.69 g, respectively. Among these, the soil erosion amount of the *P. davidiana* land was the largest, while *C. coggygris var.* land was the smallest. Hou et al. (1995) studied the soil anti-erosion properties of the *R. pseudoacacia L.* and *Hippophae rhamnoides Linn.* lands in the loess hilly and gully region. and their study showed that the soil surface anti-erosion properties of *Caragana Korshinskii Kom*. land was the largest, the one of *R. pseudoacacia L.s* land and *Hippophae rhamnoides Linn.* land is in the middle, and the one of wastelands is the smallest. Zhang et al. (1998) also reported that the mixed *P. tabuliformis Carrière* and *R. pseudoacacia L.s* lands had the best anti-erosion properties, which were in the order of *P. tabuliformis Carrière* land >*R. pseudoacacia L.* land > *Ostryopsis davidiana Decaisne* land > *H. rhamnoides Linn.* land >wasteland>maize stubble land >soil street>new clearance land (Zhang et al., 1998).

## Density-erosion amount-time model

Figure 6 shows that that density had very little impact on soil erosion amount. When density, flow, and root fresh weight were included at the same time, the soil erosion amount and soil erosion amount decreases with the increase in the density. The soil density- erosion amount-time model was as follows:

$$y = (-0.39 - 0.00002x_1) + [(-0.32x_2 + 0.53x_3 - 0.023x_4) + (0.00007x_2 - 0.0004x_3 - 0.000008x_4)x_1]$$

Where, $y_i = \ln(SD)$ is the logarithm of the soil erosion amount; $x_1$ is the adjustment value of density; $x_2$ is the adjustment value of soil anti-scouring time; $x_3$ is the adjustment value of soil anti-scouring flow discharge; $x_4$ is the adjustment value of root fresh weight of soil sample and $i$ is the sample number ($i$ =1,2,..., 741).

When the density changes 1 unit, the logarithm of the soil erosion amount changed by 0.002%. Soil erosion amount decreases with the increase in the anti-scouring time, when anti-scouring time changes 1 unit, the logarithm of the soil erosion amount will change by 32% (Figure 6). Soil erosion amount increases with the increase of anti-scouring flow such that when anti-scouring flow changes 1 unit, the logarithm of soil erosion amount will change 53% (Figure 6). Moreover, soil erosion amount decreases with the increase in the root fresh weight; when root fresh weight changes 1 unit, the logarithm of soil erosion amount will change 2.3% (Figure 6). The interaction of density and soil anti-scouring time has positive correlation with soil erosion amount; when the interaction changes 1 unit, the logarithm of soil erosion amount changed by 0.007% (Figure 6). While the interaction of density and anti-scouring flow has negative correlation with soil erosion amount; when the interaction changes 1 unit, the logarithm of soil erosion amount will change 0.0008% (Figure 6). Furthermore, when anti-scouring time equals the mean value of the measured data (3.17 min), the flow discharge equaled the mean value of the measured data (4.07L $\text{min}^{-1}$), the root fresh weight equaled the mean value of the measured data (19.22 g), the density equaled 1182 strains $(\text{ha})^{-1}$, and the soil erosion amount equals 0.68 g.

## Conclusion

A soil erosion model was established: $\ln(SD) = -0.31 - 0.12x_1 + 0.15x_2 \text{ - } 0.029x_3$ . It can be drawn from the model that soil erosion amount decreases with the increase in anti-scouring time and root fresh weight. Region/vegetation type/ density-soil erosion models were established: $y_i \sim N(\alpha_{j[i]} + \beta_{j[i]}, \sigma_y^2)$ . Regions, vegetation types and density all have certain effects on the soil erosion model. The same period sampled data were adopted in this study and there was no time series among the factors input in the model. However, it is often necessary to integrate the extra information to increase the model accuracy and also the correct handling of uncertainty is important for time series. Thus, building Bayesian state-space state model will be our future study direction. Since the study data came from 23 hectare-level plot, with the supplement of data, part of the conclusions need further intensive study. Furthermore, environmental factors such as light, temperature can help our understanding of the structural changes in forest ecosystem. However, these environmental factors were not measured from the standard plots in the present study area. It is hoped that these will be added during the model establishment in future studies.

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