ROAD SEDIMENT PRODUCTION AND DELIVERY IN KHANG NINH COMMUNE, BA BE, BAC KAN

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SUMMARY

This study used three sediment fences to measure sediment production caused by water from three road segments for over one month in the wet season in Khang Ninh Village, Ba Be, Bac Kan, Vietnam. The mean sediment production rate from native surface roads was 0.6023 kg/m². Comparisons among segments showed that recently-graded native surface roads produced more sediment than ungraded native surface roads and of course the number of sediment production depended on the amount of precipitation, slope segments and other external factors. Sediment production on native surface roads was best predicted by the product of road area times road slope (A*S) (Coe D. 2006.). Road sediment production can be reduced by a variation of rocks and vegetation increasing the frequency of road drainage structures, avoiding locations that generate more road surface and ditch runoff, and minimizing grading and traffic. Sediment delivery was assessed by a survey of 8 road segments along 2 km of a forest road. 819 m of the surveyed 2 km of this road are directly connected to the stream. Gully initiation increased with road segment length, side-slope gradients, road designs that concentrate road runoff and infiltration capacity of the soil. Road sediment delivery can be minimized by the construction of a drain-ditch or reducing the amount of runoff processes on the road surface.

Keywords: Ba Be - Bac Kan, runoff, sediment delivery, unpaved road sediment.

I. INTRODUCTION

Unpaved roads can contribute a lot of sediment to streams in each wet season, and accumulated road surface erosion in large storm events can have catastrophic effects, such as filling in pools and reducing habitat complexity. Road erosion can have a major impact on stream health with very big amount of sediment, especially surface erosion from unpaved roads and the adjacent drainage ditches. After heavy rain erosion will occur and then at the end almost all sediment goes to streams causing more turbidity and sediment concentrations, and then it does not only change the morphology of the roads but also changes the size of the rivers or lakes making all of them shallower and narrower. Of course it will have a bad effect on water quality and plants and animals in the water.

Some studies before have identified that unpaved roads can contribute 50% to 80% of the sediment that enters streams (Hagans et al., 1986). The amount of sediment delivered from forests with roads can be more than 300 times greater than from undisturbed forest land (Morrison, 1975). Roads located close to forest land and near rice paddies as well as those leading to rural and suburban parcels may also contribute to sediment problems in a watershed. Data on road erosion and sediment delivery rates are critical for assessing road impacts on aquatic resources, and a sound understanding of road erosion processes is needed to minimize road sediment production (Coe, D., 2006).

Bac Kan is located in the northeast of Vietnam, 240 km from Hanoi. It is a developing region of Vietnam, mostly located in high mountains, and the roads without cover and drainage create big amount of road erosion each year. Especially the steep roads have a lot of sediment production that deposits to the rice fields, farms, and the river, all of it has bad consequences for the farmers. To evaluate the consequences of road erosion it is necessary to make some initial research on road erosion at a specific location. The proposed study is in Khang Ninh Commune - Ba Be – Bac Kan Province, as there is not any study on sediment production and sediment delivery in this region yet. So this thesis will provide information on how important it is to manage road surface erosion and why sediment delivery is harmful to the farmers and the surrounding ecosystem.

II. METHODOLOGY

2.1. Sediment Production

Sediment production rates from three road segments will be measured with sediment fences. Sediment fences are constructed at the drainage point of hill slopes or discrete road segments that have clearly defined contributing areas (Lee, 2007). They are made of sacks stitching together and attached with 4-6 poles that are pounded 0.3-0.5 m into the ground. The leading edge of the sack is attached to the ground with landscape staples to prevent underflow and also a floor of fabric is put on the ground so it is easy to remove the sediment. A shovel and trowel are used to help clean out the fence after collecting data. Measurements are taken during 10 storms and the time is marked to know how long the rain took. Rainfall is measured by using a Vietnamese rain gage. After each rain sediment productions are measured by using a scale (kg). A sample of 0.3 Kg was taken after each rain at each of the sediment fences and spread out in a pan to let it air dry inside a room.

The collected data is the basis for following calculations: wet-soil minus dry-soil and then calculate the percentage of water stored in the wet-soil (Water /300 g) * 100 = % of water). To measure how many percent of sediment are in the water the soil has to be dried in a dry room which is not affected by wind or other activities until the soil is completely dry and can be split easily. Erosion at a segment are calculated by:

1) Length * Width = Area (m^2)

2) Mass / Area = erosion (kg)

2.2. Sediment Delivery

Sediment delivery will be measured at 8 road segments within 2 km^2 in Khang Ninh Commune. The discrete point will be determined and then sediment delivery will be measured from the road to the end of sediment visibility. Tracking runoff and sediment from each drainage point is necessary to see where it goes. Calculation of sediment delivery equals to the total of area which is connected to stream multiplied by the amount of soil (kilogram) that eroded in each rain.

2.3. Characteristics of road segments surface

2.3.1. Diameter of Rocks, Gravel or Sand

The diameter of rocks, gravel or sand covering the road is measured at 50 equally-spaced points in each road segment.

In particular it means that a measuring tape will be used to identify 50 points on the road, each of them has to be 50cm apart from the previous one. At each point a sample of road cover which can either be a rock, gravel or soil will be taken to measure the diameter with a common ruler. This procedure will be performed at all three road segments with a total of 150 measurements to find out which road cover causes the highest rate of erosion

2.3.2. Bulk Density

Bulk density (p) = mass of dried soil/ Total volume: in this research a bamboo tube with the height of 10cm and a ratio of 2.5cm will be used. For each road segment 1 bulk density will be calculated by the following steps:

1. Clean soil surface where the soil sample will be taken.

2. Use the hammer to pound into ground until the bamboo tube is completely filled with

soil. It is important to put a piece of wood on the bamboo tube before hammering. The piece of wood will distribute the pressure equally so that the soil will not be compressed by the hammer.

3. Use the shovel to dig out the bamboo tube and put the soil into a plastic bag and then dry the soil in a dry room to measure the weight.

4. With the mass of dry soil and total volume (V), following calculation will be done: V = π*r2*h (where r is radius and h is height of the bamboo tube).

• Precipitation data will be collected with a Vietnamese rain gage in 10 storms. For each storm the time raining started and stopped will be noted to know how long the rain lasted.

• Use a clinometer to measure the slop segments and measuring tape to measure the length and width of segments.

2.4. Site Description

The study area is a forest road located in Na Kieng Village near Ba Be National Park in Vietnam. Na Kieng Village belongs to Khang Ninh Commune, which is one of seven communes of Ba Be district surrounding Ba Be lake, the largest natural lake in Vietnam.

Elevation of the study site ranges in average from 150 m to 1,535 m (measured from sea level). It is located completely within the South-West Valley of Phiabyior Range with its characteristic peaks of 1,502 m and 1,517 m to 1,525 m.

Ba Be is to be described as a high-lying region in a tropical or sub-tropical forest with a characteristic climate for such regions. Compared to other regions in Vietnam it is rather cool but nevertheless with a high annual average relative humidity of 83%. Throughout the year the average air temperature is approximately 22°C with a monthly average temperature ranging from 14.1°C in winter (January) up to 27.5°C in summer (July). The lowest air temperature ever measured at the study site was 6°C while the highest air temperature amounts to 39°C.

The mean annual precipitation measured with a Vietnamese rain gage in the north of Vietnam ranges between 1,500 and 2,000 mm per year. Summer months from May to September are characterized by frequent and heavy rainfall.

III. RESULTS AND DISCUSSION

3.1. Sediment Production

Ten rainfall events were measured for sediment production at 3 road segments and 8 road segments for sediment delivery in July and early August of 2014. The number of rainfall events and the amount of sediment production considered for each plot is reported in table 1 below:

Table 1. The number of rainfall events and sediment production (Jul. and Aug., 2014)

Storms	Time (minutes)	Date	Precipitation (mm)	Fence 1 (67x3m, 12°, kg)	Fence 2 (77x2,5m, 15°, kg)	Fence 3 (55x3m, 22°, kg)	Note
1	50	7/8/2014	6.9	15	23.5	17	
2	26	12/7/2014	20.5	108	160	120	
3	47	13/7/2014	8.6	17.5	26	19	
4	35	18/7/2014	9.2	25.7	59	25	
5	1500	20/7/2014	148.5	325.5	358.1	340	Big storm
6	30	21/7/2014	17	98	146	100	
7	420	26/7/2014	98	135	178.5	145	

8	240	29/7/2014	60.5	127	155	135
9	38	3/8/2014	32	118	129	115
10	32	5/82014	9.6	28	62.5	30
Total area				201 m^2	192.5 m^2	165 m^2

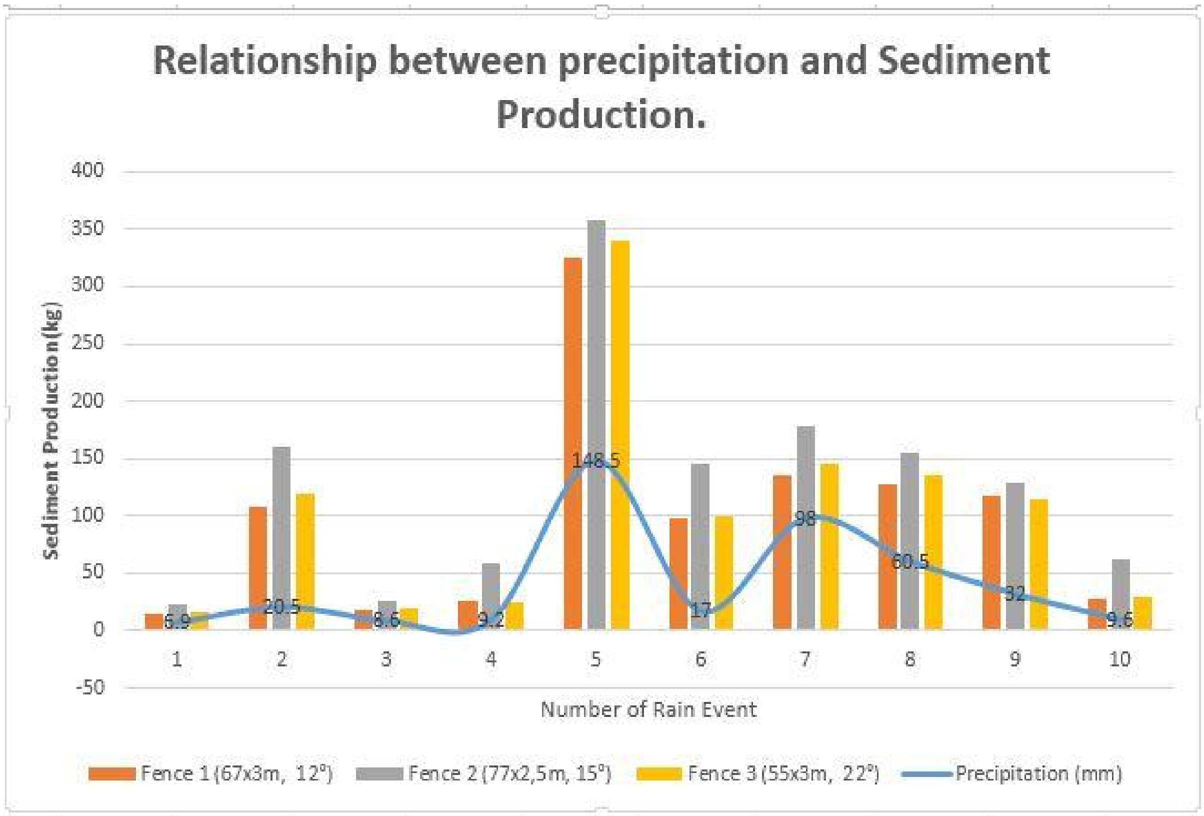


Figure 1. Relationship between precipitation and Sediment Production

From the table 1 and figure 1 above the different characteristics of each road segment and the relationship between precipitation and the amount of sediment production per storm can be seen. We can see that the sediment fence 1 has the largest area: 201 m^2 but the total erosion is the smallest: 997.7 kg because of the lowest slope compared to the other fences: 12° from 3 road segments. With slope 15° in sediment fence 2 more sediment production can be noted. Total area is 192.5 m^2 and the total of sediment is 1297.6 kg. At sediment fence 3 with the highest slope of 22° and a total area of 165 m^2, the smallest area of all 3 sediment fences that have been built produced the largest amount of sediment: 1046 kg. From those numbers it can be said that sediment production depends on precipitation and is most affected by the slope.

Sediment was collected at the 3 sediment fences for ten rains, so after each rain the sediments had to be weighed and from each sediment fence a soil sample of 300 g was taken and put into a plastic bag. Afterwards the soil was dried in a dry room which is neither affected by wind nor rain in order to get the soil dry weight, water content and by that the actual percentage of eroded soil. The results are clearly stated in the table below.

Table 1. percentage of actual eroded soil and water

Storm	Soil samples of sediment fence 1				Soil samples of sediment fence 2				Soil samples of sediment fence 3			
	Wet-soil (g)	Dry-soil(g)	Percent of		Wet-soil(g)	Dry-soil(g)	Percent of		Wet-soil(g)	Dry-soil(g)	Percent of	
			Soil	Water			Soil	Water			Soil	Water
1	300	220	73	27	300	190	63	37	300	210	70	30
2	300	215	72	28	300	200	67	33	300	220	73	27
3	300	215	72	28	300	195	65	35	300	225	75	25
4	300	215	72	28	300	190	63	37	300	195	65	35
5	300	210	70	30	300	190	63	37	300	210	70	30
6	300	210	70	30	300	195	65	35	300	225	75	25
7	300	210	70	30	300	190	63	37	300	210	70	30
8	300	215	72	28	300	195	65	35	300	195	65	35
9	300	220	73	27	300	200	67	33	300	210	70	30
10	300	220	73	27	300	200	67	33	300	210	70	30

Note: Length * Width = Area (m^2) and Mass / Area = erosion (kg) road erosion is calculated per m^2 at 3 sediment fences.

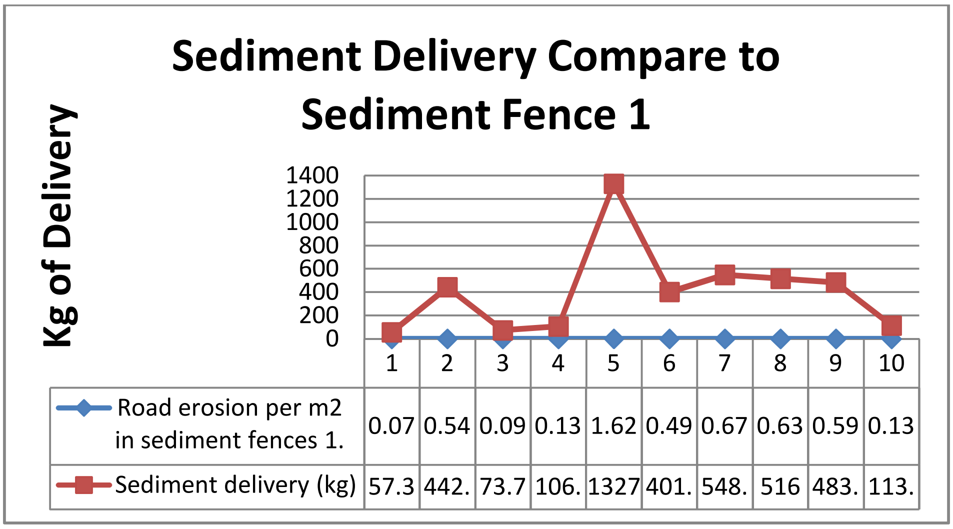
Table 2. Road erosion per m² at three sediment fences

Road erosion per m^2 at 3 sediment fences				
No.	Precipitation (mm)	Total Sediment/ Total are(kg) Sediment fence 1	Total Sediment/ Total are (kg) Sediment fence 2	Total Sediment/ Total are (kg) Sediment fence3
1	6.9	0.07	0.12	0.10
2	20.5	0.54	0.83	0.73
3	8.6	0.09	0.14	0.12
4	9.2	0.13	0.31	0.15
5	148.5	1.62	1.86	2.06
6	17	0.49	0.76	0.61
7	98	0.67	0.93	0.88
8	60.5	0.63	0.81	0.82
9	32	0.59	0.67	0.70
10	9.6	0.139	0.32	0.18

Where: TS is total sediment (kg); TA_i is total area of fence I (m^2).

3.2. Sediment Delivery

Sediment delivery was measured at 8 road segments within 2 km^2, to know where the sediment goes on the investigated forest road between Na Kieng and Na Co villages. The results are shown the table below:



Within the 8 road segments there are 5 segments which are connected directly to the stream with a total area of 273* 3 = 819 m, and 3 road segments with a total area of 147 * 3 = 441 m were leading directly to the rice paddy and pond with very bad consequences for the farmers. The calculation was done in kilogram of sediment for each rain that was connected by: road erosion per m² in the sediment fence 1 times 819 m (total area connected) in order to have sediment delivery in kilogram, shown in the chart above. Example: the highest peak is of rain number 5 with 1.62 kg * 819 m = 1327 kg connected directly to the stream just in a short distance during one rainfall. Those numbers show the big amount of sediment that affects the river, making it shallower and narrower with a bad effect on water quality as well as plants and animals in the water.

3.3. Characteristics of road segments surface

3.3.1. Diameter of Rocks, Gravel, Sand or Soil

Table 4. Road surface at 3 segments

Rock, graveled, sand	Diameter (cm)			Rock, graveled, sand	Diameter (cm)		
	Road segment 1	Road segment 2	Road segment 3		Road segment 1	Road segment 2	Road segment 3
1	0.2	0.25	0.5	26	1	4.5	2.5
2	0.5	0.25	0.5	27	5.5	3	3
3	0.25	0.25	1	28	0.5	1	0.5
4	0.25	0.2	1	29	2	0.5	3.5
5	2	4	0.25	30	2	0.5	0.5
6	3	2	0.1	31	0.2	0.2	2
7	0.2	3	0.5	32	0.5	3	1
8	2	1	0.25	33	4	5.5	0.25
9	2	1	1	34	4	0.5	1
10	4	1	1	35	2	0.5	4
11	0.2	0.5	0.25	36	0.5	1	0.25
12	0.5	0.5	3.5	37	2	1	0.1
13	4.5	0.5	0.25	38	4	3	3
14	4	2	0.5	39	5.5	0.5	3.2
15	0.5	3	1	40	0.5	0.1	5
16	0.2	1	1	41	0.5	2	0.5
17	0.5	0.25	2	42	3.5	0.5	0.5
18	4	0.25	0.5	43	1	2	1
19	3.5	0.25	1	44	1	0.5	4.5
20	4	1	0.5	45	2.5	2	2
21	6	3	2	46	4	1	4.5
22	2	2	0.25	47	1	1	0.25
23	0.5	0.5	3.5	48	6.5	0.5	0.5
24	0.5	0.25	1.5	49	0.5	5	2
25	3	0.2	1	50	4	2.5	3.5
				Average	**2.14**	**1.40**	**1.48**

Road erosion is not only affected by precipitation and slope but it is also affected by the land cover. In the 3 road segment, segment 1 has the highest diameter (2.1 cm). It means if the diameter of rock or gravel are large it will be less sediment production proved by sediment fence 1 in table 1 with a total sediment production of 997.7 kg. In road segment 1 is no vegetation cover. But in road segment 2 there is about 20% grass cover that can make sediment production slower. However the average diameter of rock and gravel is 1.4 cm which can be produce much sediment (1297.6 kg). In road segment 3 there is about 5% vegetation cover and the average diameter of rocks and gravel is 1.5 cm with the total amount of sediment production during 10 storms of 1046 kg.

3.3.2. Bulk Density

Table 5. Bulk density for three segments

Total Volumes 196.2 cm^3			
Weight of dry soil sample in 3 road segment	310g (road segment 1)	280g (road segment 2)	240g (road segment 3)
Bulk Density (mass/volume)	1.58 g/cm^3	1.43 g/cm^3	1.22 g/cm^3

A soil that has a well-developed structure will become less dense as porosity increases; as a result the bulk density of the soil will decrease. Soils which show massive structures and less porosity will show higher bulk densities ranging from 1.6 to 1.7 g/cm^3, water movement will be hindered at this point down the profile. Most soil bulk densities will be found in a range from 1 to 2 g/cm^3, with the density of soil solids (Quartzie), being 2.56g/cm^3 (http://www.usyd.edu.au/agric).

It can be seen that at road segment 1 an elevated bulk density of 1.58 g/cm^3 was measured. This is also affected by the number of vehicles on soil porosity. In road segment 1 it about 432 motorbikes per day are estimated. In road segment 2 bulk density is 1.43 g/cm3.This road is only used by about 3 motorbike per day since it is only used to reach the rice paddy so not many people use it. Finally road segment 3 is very steep, so people just walk on it without any vehicle affecting this segment. In general at all 3 road segments bulk density is normal, not too dense, found in a range from 1 to 2 g/cm^3.

IV. DISCUSSION

4.1. Experimental Setup Performance

The basis of the research was the collection of sediment to identify how much sediment is produced during storms. Normally a sediment fence has to build as U-shape so that as much sediment as possible can be trapped and no sediment can run off the fence. In reality however this method could not be applied at two of the three sediment fences that were constructed at the unpaved road near Na Kieng Village: Although the road is an unpaved road, it still has a drain-ditch next to it. A U-shaped fence at that point would disturb water runoff in the drain-ditch. Furthermore water coming from the other side of the hill slope would cross the road but then would also be hindered to runoff with severe effects on the research results. Building a U-shaped sediment fence behind the drain-ditch was not an option either because most sediment would erode inside the ditch thus could not be caught by the fence. Finally, as a compromise, two of the three fences were built in the shape of a litter bit straight line but surely that two sediment fences still trapped all sediment production.

For measuring sediment delivery the collected data was only compared to the data of sediment fence 1. The reason is that only sediment fence 1 is located on the investigated road. All along the road the physical characteristics are very similar so a comparison of the date was not necessary. Sediment fences 2 and 3 lie on smaller roads which still belong to the investigated road, however they show different characteristics (soil texture, bulk densities and width). So it is hard to compare them in the same way as done with sediment fence 1.

4.2. Data Analysis Performance

Research was done during 10 storms which occurred approximately over one month. The output are numbers that stress the significance of soil erosion management on unpaved roads, however those numbers might not be representative enough for further scientific research: This study was the first of its kind in the area of Ba Be National Park and it only produced data which can be taken as an average for one month. The results show that soil erosion depends on several factors but one of the most significant factors is precipitation. Unlike the South, the North of Vietnam lies in a climatic zone with four seasons making it very hard to predict the climate and weather conditions. Since research has never been done before in Khang Ninh Commune there is also no data on precipitation over long time available yet. With the data collected during one month in a mostly wet season it is impossible to predict yearly precipitation. This leads to the problem that the results of this research cannot or only hardly be compared to previous studies or to the results of the Water Erosion Prediction Model (WEPP). The WEPP is a set of tools developed by researchers at the USDA Forest Service (USFS) to see the differences in rock cover, vegetation and soil texture, length, width, slope etc. in order to estimate erosion from the road. The simulation only works by years, it is not split up into months therefore the results of this current research covering a period of one month cannot adapt to suit the given factors of the WEPP.

4.3. Future Research

A logical resumption of the study would be to extend the period of data collection to one year including all four seasons. The data would be better in terms of quality and could be used for comparison with the WEPP: Road Model as well as previous studies on road erosion. Sediment production should be measured with more sediment fences (up to 10), each constructed at a different slope to get more differentiated data. The same applies to sediment delivery which should be surveyed on more than eight road segments.

In addition it would be useful to measure the velocity on the road surface during heavy rains when runoff processes occur. Velocity can be a driving key factor for the amount of sediment produced during the storm and therefore it should be investigated, however measurements require more time and more specific tools.

V. CONCLUSION

Over a time span of approximately one month in July and early August 2014, sediment production and sediment delivery were measured at an unpaved road in Na Kieng Village, Bac Kan Province, Vietnam. The study area is a high-lying tropical region, Ba Be District n in the North of Vietnam, characterized by comparably lower air temperatures and heavy rainfalls in the summer months from May to September.

The specific objectives of the study were to quantify and determine sediment production at three segments of the investigated unpaved road as well as sediment delivery at eight segments of the same road for at least ten storms in order to achieve representable results. Further objectives were to determine the effects of different surface covers on sediment production and delivery.

The method to determine sediment production was the construction of three sediment fences at three road segments with clearly defined contributing areas. Each fence was built at the drainage point of a road segments with an angle of either 12°, 15° or 22°. Following each storm, the soil at the fence was collected and dried in order to get the exact weight of sediment produced. Sediment delivery was measured at eight road segments within 2 Km^2 by tracking the runoff of sediment from each drainage point down to the farthest point at which sediment was still visible. A single survey was sufficient since runoff distance and direction are not suspect to changes. The effects of surface cover were determined by measuring the diameter of the different cover type's at all three road segments. In addition, bulk density was measured with a bamboo tube of 10cm length and 2.5cm diameter. The tube was used to collect soil samples at each of the three road segments which were dried and weighed in order to calculate the volume.

The results of the study make clear that sediment production does depend on precipitation. After long storms with high rainfall over 350 Kg of sediment could be collected at the fences. Furthermore sediment production depends strongly on the slope and only a little on the area of the fence because the highest amount of sediment was collected at fence 3 (slope 22°) although it had the smallest area compared to the other two fences. The drying of soil samples after each storm in order to get the actual percentage of soil and water eroded did not show great differences between the three fences and the ten storm events: The percentage of eroded soil ranged between 63% (Sediment fence 2) and 75% (Sediment fence 3, storm 3). Recalculating the results in order to get the total erosion in Kg per m^2 of road showed that in most cases far less than 1 Kg sediment/m^2 of road area are eroded; however in cases of long storms with heavy rainfall it is possible that up to 2.06 Kg of sediment erode per m^2 of road. Looking at sediment delivery, most road segments in the surveyed area delivered their sediment to the river with severe effects on plant and animal life. The data was only compared to the sediment produced at fence 1 because it was the only fence laid within the investigated 2 km of forest road. Sediment delivery depends strongly on sediment production thus it can have strong fluctuations. However, calculations showed that during strong rainfall with road erosions of 1,62Kg/m^2 an alerting amount of 1327Kg of sediment were delivered directly into the adjacent stream. The third objective was to analyze the road cover at three different segments. In general a larger diameter of rocks or sand mean less sediment production which was the case at sediment fence 1 and also corresponds to the results of the first objective. Vegetation cover can decrease sediment production but a decrease in diameter of only 0.7cm can reverse this effect and cause high sediment production (fence 2, also proved by survey of sediment fence 3). Bulk density usually ranges from 1-2g/cm^3 which was successfully proved by the investigation of all three road segments. However, soil porosity and bulk density are affected by the way the road is used; frequent passage of motorbikes can increase bulk density from 1,22g/cm^3 (segment 3) up to 1,58g/cm^3 (segment 1).

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SỰ HÌNH THÀNH VÀ PHÂN PHỐI LƯỢNG BỒI LẮNG TRÊN MẶT ĐƯỜNG TẠI XÃ KHANG NINH, HUYỆN BA BỂ, TỈNH BẮC KẠN

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TÓM TẮT

Nghiên cứu này sử dụng ba hàng rào giữ lượng bồi lắng để đo lượng bồi lắng từ ba đoạn đường trong hơn một tháng mùa mưa ở làng Khang Ninh, huyện Ba Bể, tỉnh Bắc Kạn. Tỷ lệ sản xuất bồi lắng trung bình từ mặt đường tại chỗ là 0,6023 kg/m². So sánh giữa các đoạn đường cho thấy, mặt đường mới được phân cấp gần đây đã tạo ra mức bồi lắng nhiều hơn mặt đường chưa được phân cấp và tất nhiên số lượng bồi lắng được sản sinh phụ thuộc vào lượng mưa, phân đoạn dốc và các yếu tố bên ngoài khác. Lượng bồi lắng trên mặt đường đã được ước đoán tốt nhất từ tích số của diện tích đường với độ dốc đường (A * S) (Coe D. 2006.). Lượng bồi lắng được sinh ra có thể giảm nếu có nhiều các loại đá và thảm thực vật, có thể tăng cùng với tần suất các công trình thoát nước trên đường, có thể tránh được các điểm mà có nhiều mặt đường và mương thoát nước hơn, và có thể giảm thiểu sự phân cấp và phương tiện giao thông. Sự phân phối bồi lắng cũng được đánh giá thông qua việc điều tra 8 đoạn đường dọc theo 2 km đường rừng. 819 m trong số 2 km của con đường này được kết nối trực tiếp đến dòng chảy. Sự xuất hiện khe rãnh tăng theo chiều dài đoạn đường, gradient sườn-dốc, và khả năng thấm nước của đất. Sự phân phối lượng bồi lắng trên đường có thể được giảm thiểu bằng việc xây dựng một cống mương hoặc giảm số lượng các quá trình rửa trôi trên bề mặt đường.

Từ khóa: Ba Bể - Bắc Kạn, bồi lắng trên đường trải nhựa phù sa, dòng chảy, phân phối lượng bồi lắng.

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