INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 11, No. 5, p. 415-422, 2017
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Soil erosion analysis in bamboo-planted sites using paired catchment approach

George R. Puno*, Rico A. Marin

College of Forestry and Environmental Science, Central Mindanao University, Musuan, Bukidnon, Philippines

Article published on November 30, 2017

Key words: Regression, Soil Erosion, Bamboo, Catchment, Calibration.

Abstract

The influence of bamboo to deter soil erosion rates has already been widely recognized and accepted. However, analysis of erosion reduction owing to the absence or presence of bamboo in a catchment scale still has yet to be established. This paper examines the variability of soil erosion between two catchments using a paired catchment method. The approach involves two adjacent catchments, one as a control and another as a treatment, which is simultaneously monitored during the calibration and post-calibration or treatment periods. Erosion rates were collected in 2013 to 2015 on a per event basis. Using the analysis of covariance at 5% significance, the study revealed that the erosion mean value within the treated catchment had decreased dramatically by a factor of 6.5 between the calibration and treatment periods. Based on the calibration regression equation using the predicted and observed mean values, an overall 21% reduction in mean erosion was obtained due to the presence of bamboo in the treatment catchment. The findings offer a baseline information on the influence of bamboo to soil erosion using the paired catchment approach although longer observation period is expected to minimize biased estimate of the treatment effects. Nevertheless, the study able to show that the relationship of the considered variable between the control and the treatment catchments has existed. The results suggest that planting of bamboo is as good as best management practice in controlling soil erosion at a catchment-scale particularly in the marginal and sloping landscape.

***Corresponding Author:** George R. Puno ✉ punogeorge@gmail.com

Introduction

Several studies revealed that gully and bank erosion protection using locally available bamboo proved effective with proper design layout (Higaki *et al.*, 2005; Suzaki and Nakatsubo, 2001; Abam, 1993). Lots of studies showed that bamboo possesses the inherent characteristics to hold soil particles from detachment and the subsequent entrainment and deposition (Arguelles-Sanchez, 2012; Ben-Zhi *et al.*, 2005). Because of this, the introduction of bamboo as best management practice (BMP) for soil erosion control intervention was evaluated using paired catchment method. Paired catchment studies are considered as the appropriate for documenting BMP effects within the relatively short time period (Lyon, 2006). The method provides reliable results and is perhaps the most effective for monitoring BMP program which can be implemented in small catchment scale (Lyon, 2006).

The use of paired catchment has been extensively applied as a way of determining impacts of management practices on hydrologic responses (Gomyo and Kuraji, 2016; Ssegane *et al.*, 2013; Som *et al.*, 2012; Prokopy *et al.*, 2011; Jokela *et al.*, 2010; Veum, *et al.*, 2009; Fisher *et al.*, 2008; King, *et al.*, 2008; Ricker *et al.*, 2008; Udawatta, 2002; Loftis *et al.*, 2001). However, impacts of bamboo as BMP to minimize soil erosion and sedimentation at a catchment scale are not well investigated.

The basis of the paired catchment approach is that there is a quantifiable relationship between paired erosion data for the two catchments and that this relationship is valid until a change is made in one of the catchments. At that time, the treatment period, a new relationship will exist. This does not require that the quality of data is statistically the same for the two catchments, but rather that the relationship between paired observations of erosion behavior remains the same over time except for the influence of the change brought by introducing change in the treatment catchment (USEPA 1997).

This study was sought to quantify the extent of bamboo in minimizing soil erosion in sloping areas. There were similar studies conducted in the previous, however, a catchment scale approach is still wanting. It is expected that this study would contribute new information to the body of knowledge so that further analysis comparing bamboos with other vegetation in terms of arresting erosion is motivated. The main objective of this study was to compare the erosion rates of similar catchments with the underlying assumption that the biophysical condition such as soil, vegetation, local climate, topography, erosional processes, management practices, and catchment geomorphometry are homogeneous throughout the observation period. Erosion values are expected to vary only between the control and the treatment catchment due to land cover change in the latter. The existence of bamboo in the treatment catchment was considered as the change in the management.

Materials and methods

Location and selection of the study catchment

The study was conducted within the land occupancy of Central Mindanao University (CMU), Philippines, approximately 1 kilometer northwest of Sayre National Highway (Fig. 1). Geographically, the site is located at 125° 3’ E and 7° 52’ N with an average elevation of 398 meters above sea level. The topography of the area is undulating with an average slope of 10%. Soil textures of the sites are mostly silt loam with observed surface rocks at about 8% of the land area. The site has no pronounced rain period but relatively dry during the months of November to May.

Control and treated catchments

There were two adjacent southeast-facing catchments selected for the study, one for the control and one for the treatment catchment with sizes of 10.40 and 3.07 hectares, respectively. As shown in Fig. 1, two sampling sites with an area of 0.55 and 0.86 hectares, respectively, were established within the control and treatment catchments, correspondingly.

The two catchments were monitored concurrently for two successive periods, the calibration and the post-calibration or treatment periods. The control catchment had no activities conducted during the entire observation period.

On the other hand, the treated catchment had the same status with the control catchment for the first period and may be altered by introducing bamboo as BMP during the second period which is also termed as the treatment period. Ideally, the treated catchment is the same catchment observed during the calibration and the treatment periods. However, the modification is logical based on the similarity of the physical conditions of the adjacent catchments (Loftis *et al.*, 2001). Change in the set up assumes similar observation of erosion variable during the same rainfall event in closer sites. In the same manner, time is also an important limiting factor that has taken into account considering that bamboo rotation needs a longer period to complete the observation within the allowable duration.

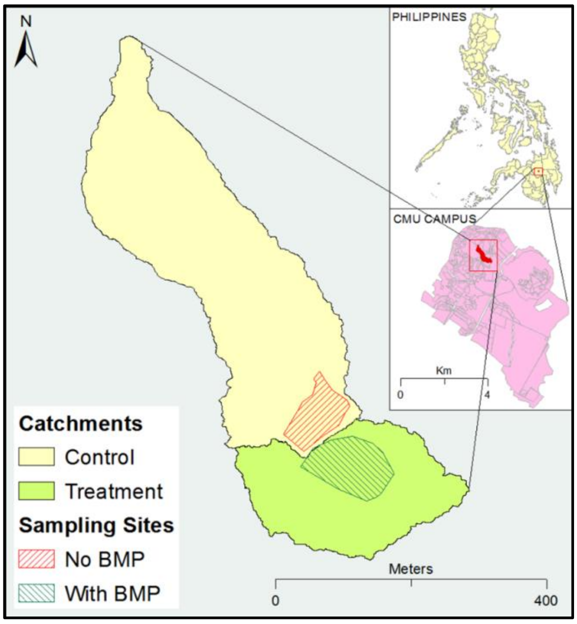

Fig. 1. Location of the study.

The control catchment was initially cultivated for a small-scale corn production. After harvest, the catchment was left undisturbed for the entire period allowing the short grasses and herbs to regenerate and eventually cover the land surface. On the other hand, the treated catchment was selected on the basis of the existing bamboo in the area. The bamboo stand in the treatment was approximately 25 years old with an average spacing of 10 by 10 meters. For the purpose of the study, the two sites were virtually protected from disturbances during the entire period of observation to prevent other factors that might cause large errors of data.

Instrumentation and data collection

The two catchments were instrumented in June 2013 to October 2015. An automatic weather station was installed to monitor the different climate parameters at approximately six hundred meters southeast of the site. A total of thirty erosion monitoring plots were randomly established within the two sampling sites. Each plot has a dimension of 3 by 1.5 meters with the galvanized iron sheets placed at both sides of the plot to prevent the in and out influx of the soil particles. The plots were prepared with vegetation and other objects removed from the ground surface to free the movement of the soil particles during the event. Erosion rates in each plot were measured using a device made of 165 centimeter-long bar with ten equally distributed holes for the ten calibrated erosion pins (Fig. 2).

Fig. 2. Erosion measuring device.

A total of 262 events were monitored for the whole period. Half of the events were allotted for the calibration while the remaining half was for the treatment. The calibration period has ended with the start of the treatment period. The details of the procedures in measuring the erosion rates, soil sample collection, laboratory analysis, and data processing were done following the procedure in the previous studies (Marin and Casas, 2017; Marin and Jamis, 2016). The collated erosion values were used to account the difference of the variables from paired catchment during the calibration and treatment periods.

Calibration and treatment periods

The design of data collection schedule consisted of the two independent periods corresponding to calibration and treatments which were monitored simultaneously (Table 1). Calibration period was different from the treatment period as the latter was altered using bamboo as the introduced BMP. Ideally, treatment period shall be done after the calibration. However, as reported, a reverse schedule is possible for certain BMP's where the treatment period could precede the calibration period (USEPA, 1993). Ideally, the datasets to be used in the analysis for the treatment period should be collected in the same treatment catchment. However, due to the pre-existence of the old bamboo plantation in the latter, datasets collected from an adjacent catchment without bamboo stand were used in the analysis.

Table 1. Schedule of calibration and treatment implementations.

Period	Catchment	
	Control	Treated
Calibration	No bamboo	No bamboo
Treatment	No bamboo	With bamboo

Statistical analysis

The purpose of paired catchment approach is to factor out variables other than the treatment effects that influenced the reduction of erosion rate over time. To accomplish this, analysis of covariance (ANCOVA) of erosion variable was conducted. ANCOVA is appropriate because the comparison of variability between the two periods is precisely accounted for (USEPA, 1997 as cited by Lyon, 2004). The analysis allows the removal of variation due to the covariate, which is the independent variable, that may have added the factors of erosion to take effect into the treated catchment as the dependent variable before the introduction of bamboo was taken into consideration. The equation used in the ANCOVA was expressed by a simple linear regression of the form:

$$C_1 = b_o + b_1C_2 + e$$

Where continuous variable C_2 (the covariate) models the relationship with C_1. For this study, C_2 represents the daily soil erosion rates from the control catchment and C_1 represents the same set of erosion variable from the treatment catchment, b_o and b_1 are regression coefficients representing the intercept and slope, respectively, and e is the residual error.

Results and discussion

Precipitation and erosion patterns

The study sites received the highest daily precipitation of 49.4 mm recorded on August 5, 2015, with an average of 4.81 mm. Fig. 3 shows the rainfall pattern of precipitation and erosion from 2013 to 2015 across the calibration and treatment periods. Similarly, the variations of erosion and deposition values on a per event basis are likewise depicted. The negative and positive numbers on the right side of Fig. 3 represent the erosion and deposition values, respectively. Deposition indicates erosion of soil particles from the upper portion of the plot which was accumulated just below the point where erosion was measured using the erosion pins. During the calibration period, a 16.0 mm of precipitation on October 31, 2013, yielded an erosion amount of 27.26 t/ha from the control catchment while 22.58 t/ha of erosion was measured from the treated catchment. During the treatment period, 8.4 mm of precipitation on March 31, 2015, yielded erosion amount of 11.03 t/ha from the control catchment while 10.15 t/ha of erosion was measured from the treated catchment. In general, the variability of erosion from both catchments has shown similar patterns of responses as affected by the amount of precipitation. However, as depicted in Fig. 3, the occasionally observed less variability of erosion pattern towards the end of the study period indicates the effect of the vegetation thickening which may have lessened the processes of soil erosion. Further, as pointed out by Lauren (2008), the shorter periods of the calibration and treatment may cause biases of estimates owing to the limited array of datasets.

On a monthly basis, the highest cumulative precipitation of 310.7 mm was recorded in September 2015. For this month, a total of 5.33 and 2.40 t/h of erosion were measured from the control and the treatment catchments, respectively.

Lesser variation of these values was expectedly attributed to the vegetation that gradually covered the control catchment towards the end of the study period. Almost the same amount of precipitation (301.7 mm) was recorded in October 2013 with erosion values of 51.32 and 2.21 t/h observed from the control and treatment catchments, respectively. The high amount of erosion during the earlier part of the study suggests that erosion was due to land tilling in the control catchment as it was initially cultivated for corn production. On the other hand, the lower value of erosion during the treatment period highlighted the advantage of using bamboo to control detachment and the subsequent transport of soil particles from one point to another.

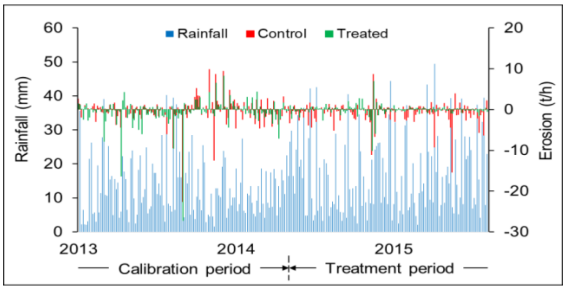

Fig. 3. Rainfall and erosion values of the control and treated catchments during the calibration and treatment periods.

Regression and analysis of covariance

The regressions between the control and treated catchments for the calibration and treatment periods were found significant based on the analysis of variance presented in Tables 2 and 3, respectively. The result also shows the difference between the intercept and slope values although the model fails to meet the assumption of regression homogeneity. The coefficient of determinations (R^2) values as depicted in Fig. 4 and 5, for the two regression models corresponding to the calibration and treatment periods respectively, showed that 56% and 32% of the variation of mean erosion values of the treated catchment were due to the variability of the same in the control catchment. The combined regressions for the calibration and treatment periods (Fig. 6) was also significant based on the analysis of covariance (ANCOVA) with 46% of the variation was accounted for by the model (Table 4).

Table 2. Analysis of variance for regression of calibration period.

Sources	DF	SS	MS	F	Sig.
Regression	1	923.71	923.71	162.58	0.00
Residual	129	732.90	5.68		
Total	130	1656.61			

Table 3. Analysis of variance for regression of treatment period.

Sources	DF	SS	MS	F	Sig.
Regression	1	87.65	87.65	60.38	0.00
Residual	129	187.26	1.45		
Total	130	274.92			

Table 4. Analysis of covariance for comparing calibration and treatment regressions.

Source	DF	MS	F	Sig.
Model	2	452.01	111.29	0.00
Intercept	1	0.654	0.16	0.68
Control	1	879.60	216.57	0.00
Period	1	50.95	12.54	0.00
Error	259	4.06		
Total	262			
R^2 Squared = 0.46				

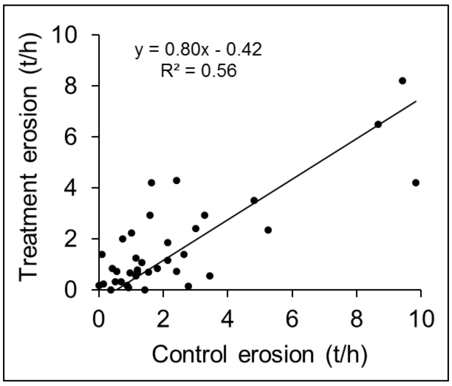

Fig. 4. Regression for control and treated catchments during the calibration period.

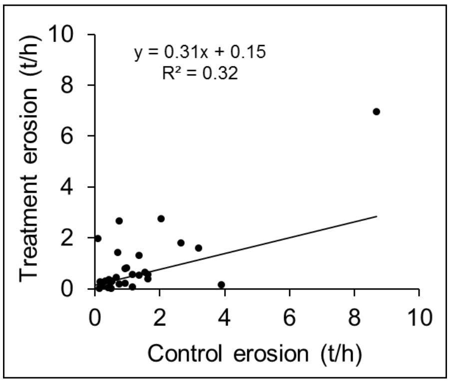

Fig. 5. Regression for control and treated catchments during the treatment period.

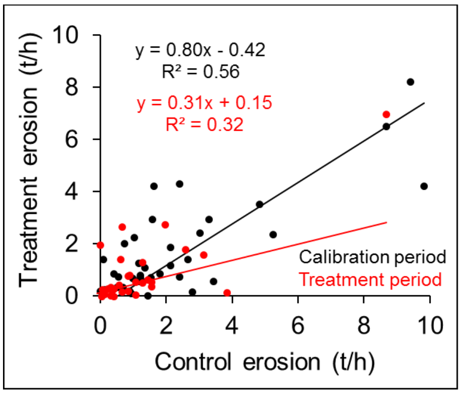

Fig. 6. Regression for the combined calibration and treatment periods.

The results also showed that the soil erosion mean values between the calibration and treatment periods for the treated catchment had decreased by a factor of 6.5 (Table 5). Based on the predicted value derived from the regression equation of the calibration period, a 21% difference was computed between the calibration and treatment period.

Table 5. Mean values of erosion (t/h) by period and catchment.

Period	Catchment		
	Control	Treated	Difference (%)
Calibration	0.37	0.72	
Treatment	0.82	0.11	
Predicted		0.14	21

Conclusion

The reduction of soil erosion has evidently occurred in the second phase of observation during the treatment period where the management was altered with the introduction of bamboo. Overall, the results revealed that the introduction of bamboo is effective as one of the best catchment management options as far as soil conservation is concerned. The choice of bamboo in the list of species for the national greening program of the country is proven appropriate. Decreases in erosion following modified treatment application are remarkable though relatively shorter observation period was considered. The contribution of the plant in reducing erosion should increase with half of the complete life cycle of bamboo which is longer than the duration of the study period. As recommended by Lauren (2008), the uncertainty of the calibration dataset should be included in the paired catchment studies in order to avoid biased estimates of the effect especially when the model fails to meet the assumption of regression homogeneity. A longer period of this kind of study is suggested in order to improve the quality of the paired catchment datasets.

Despite limited observation period, the study has successfully established the relationship of the variable considered between calibration and treatment periods and that the prevailing differences were statistically quantified and established using a paired catchment approach. The study has validated the method used suggesting that change in erosion rates was attributed to bamboo as effective management intervention to control erosion. Planting bamboo in degraded sloping areas is expected to resolve issues on soil and water sustainability. Information generated from this study can be used as baseline inputs to landowner's decisions and policymakers in crafting a more informed and a science-based policy recommendation of using bamboo as a best management practice for soil and water resources conservation and protection.

Acknowledgement

This paper is part of the project "Soil Erosion Management in Taganibong Catchment" supported by the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development-Department of Science and Technology (PCAARRD-DOST), Philippines. The authors are likewise grateful to the full support from the Administration of Central Mindanao University, Musuan, Bukidnon, Philippines.

References

Abam TKS. 1993. Bank erosion and protection in the Niger delta. Hydrological Sciences Journal **38(3)**, 231-241.

Arguelles-Sanchez D. 2012. PCAARRD advocates planting of more bamboos. Available from: www.philstar.com/agriculture/2012/07/29/832559/pcaarrd-advocates-planting-more-bamboos [Accessed 25 September 2017].

Ben-zhi Z, Mao-yi F, Jin-zhong X, Xiao-sheng Y, Zheng-cai L. 2005. Ecological functions of bamboo forest: Research and application. Journal of Forestry Research **16(2),** 143-147.

Fisher M, Deboodt T, Buckhouse J, Swanson, J. 2008. Lessons learned in calibrating and monitoring a paired catchment study in Oregon's High Dessert. In: The Third Interagency Conference on Research in the Catchments, 8-11 September 2008 Estes Park: CO, 237-240.

Gomyo M, Kuraji K. 2016. Effect of the litter layer on runoff and evaporation using the paired catchment method. Journal of Forest Research **21(6)**, 306-313.

Higaki D, Karki KK, Guatam CS. 2005. Soil erosion control measures on degraded sloping lands: A case study in Midlands of Nepal. Aquatic Ecosystem Health & Management **8(3)**, 243-249.

Jokela W, Casler MD. 2010. Transport of phosphorus and nitrogen in surface runoff in a corn silage system: Paired catchment methodology and calibration period results. Can. J. Soil Sci **91**, 479-491.

King KW, Smiley Jr PC, Baker BJ, Fausey NR. 2008. Validation of paired catchments for assessing conservation practices in the Upper Big Walnut Creek catchment, Ohio. Journal of Soil and Water Conservation **63(6)**, 380-395.

Lauren A, Heinonen J, Koivusalo H. 2009. Implications of uncertainty in a pre-treatment datasets when estimating treatment effects in paired catchment studies: phosphorus loads from forest clear-cuts. Water Air Soil Pollution **196**, 251-261.

Loftis JC, MacDonald LH, Streett S, Iyer HK, Bunte K. 2001. Detecting cumulative catchment affects: the statistical power of pairing. Journal of Hydrology **251**, 49-64.

Lyon AS. 2006. Paired catchment analysis to evaluate phosphorus in Spavinaw and Beaty Creeks, Oklahoma. Unpublished MS Thesis. Graduate College of the Oklahoma State University, Oklahoma City, USA.

Marin RA, Jamis CV. 2016. Soil erosion status of the three sub-catchments in Bukidnon Province, Philippines. AES Biofkux **8(2)**, 194-204.

Marin RA, Casas JV. 2017. Soil erosion assessment of the various vegetation cover in Mt. Musuan, Philippines. Journal of Biodiversity and Environmental Science **11(1)**, 105-113.

Prokopy LS, Asligul Gocmen Z, Gao L, Allred SB, Bonnell JE, Genskow K, Molloy A, Power R. 2011. Incorporating social context variable into paired catchment designs to test non-point source program effectiveness. Journal of the American Water Resources Association **47(1)**, 196-202.

Ricker MC, Odhiambo BK, Church JM. 2008. Spatial analysis of soil erosion and sediment fluxes: A paired catchment study of two Rappahannock River Tributaries, Stafford County, Virginia. Environmental Management **41(5)**, 92-105. http://link.springer.com/article/10.1007/s00267-008-9094-6.

Som N, Zegre NP, Ganio LM, Skaugset AE. 2012. Corrected prediction intervals for change detection in paired catchment studies. Hydrological Sciences Journal **57(1),** 134-143.

Ssegane H, Amatya DM, Chescheir GM, Skaggs WR, Tollner EW, Nettles JE. 2013. Consistency of hydrologic relationship of a paired catchment approach. American Journal of Climate Change **2**, 147-164. www.scirp.org/journal/ajcc

Suzaki T, Nakatsubo T. 2001. Impact of the bamboo *Phyllostachys bambusoides* on the light environment and plant communities on river banks. J. For. Res **6**, 81-86.

Udawatta RP, Krstansky JJ, Henderson GS, Garrett HE. 2002. Agroforestry practices, runoff, and nutrient losses: A paired catchment approach comparison. J. Environ, Qual **31**, 1214-1225.

United States Environmental Protection Agency. 1993. Paired catchment study design. Washington, D.C. 20460: Office of Water.

United States Environmental Protection Agency. 1997. Techniques for tracking, evaluating, and reporting the implementation of nonpoint source control measures: Agriculture. Washington DC: Office of Water.

Veum KS, Goyne KW, Motavalli PP, Udawatta RP. 2009. Runoff and dissolved organic carbon loss from a paired catchment study of three adjacent agricultural catchments. Agriculture, Ecosystems & Environment **130(3-4)**, 115-122.