Philippine e-Journal for Applied Research and Development 12(2022), 32-42 ISSN 2449-3694 (Online)
https://pejard.slu.edu.ph/vol.12/2022.05.31.pdf

Assessing Geomorphological Responses to the Fluvial Dynamics of Pasig-Potrero River as Altered by Quarrying

Stephanie Ivy T. Jadormio[1,*]

[1] *Mines and Geosciences Bureau Region III - City of San Fernando, Pampanga*
* *Contact Information (stjadormio@yahoo.com)*

Received, 01 February 2022; Accepted, 27 May 2022; Published, 31 May 2022

Abstract

River degradation may result as an environmental impact of riverine mining (quarrying). In the case of the lahar-inundated Pasig-Potrero River, the alleged degradation due to lahar quarrying has not yet been established, resulting in contrasting claims and weak policy formulation. This study investigates the presence of environmental degradation in the Pasig-Potrero River by obtaining the induced extraction rate of river sediments against its natural replenishment rate through the use of modified erosion poles. Subsequently, a description of the river's geomorphological behavior in response to its sediment mobility performance was made. The twelve-week observation recorded a deficit sediment supply of around 337,023.04 cubic meters from upstream mountain ridges as against the quarrying production rate. The extraction rate is 246 times faster than the ability of the river to replenish new sediment material. Quarrying controls the river's physical environmental health at 56.94% level. Thus, the river is experiencing intensive erosion due to sediment over-extraction.

Keywords: river degradation, riverine mining, river bed erosion, river sediment mobility, lahar inundation, Pampanga, Philippines

Introduction

The Pasig-Potrero River in Pampanga, Philippines was inundated by lahar after the Mt. Pinatubo eruption in 1991. A number of municipalities in Pampanga were buried in lahar, resulting in fatalities and loss of assets (Philippine Institute of Volcanology and Seismology, 2004). After the inundation, however, lahar – which comprises gravel and sand – was found to be commerciable as concrete constituent. As a result, lahar has since been quarried at the river, with the previously caused geological hazard becoming a source of livelihood in Porac and Bacolor, Pampanga (Mercado et al., 1999).

While quarrying has improved the hydraulic capacity of the Pasig-Potrero River basin, this has since raised concerns on the possibility of overquarrying and its impact on the environmental health of the river. The replenishing capability of a radial perennial river like the Pasig-Potrero depends on complex technical factors, one of which is the volume of available pyroclastic material upstream and its capacity to erode and be mobilized. Historically, the magnitude (in km^2) of traceable lahar is variably different every year but shown to be generally decreasing (Gran, Montgomery, & Sutherland, 2006). However, quarry operators are generally unaware of this condition, as they geared towards increasing their production volume not only to increase sales but to support the ever-increasing construction demand.

Environmentalists like Rinaldi et al. (2005) assert that to maintain the ecological health of a river system, the rate of material extraction therein should be below or equal to the capacity of the river to replenish its sediment material as shown in Equation 1. Either too much or too low sediment can pose serious threat to a river's environmental health (Fondriest Environmental Learning Center, 2014). The key is to continuously balance the fluvial budget in the whole river so that flora and fauna can continue its ecological river system. Unfortunately, in the case of Pasig-Potrero river, government regulators and other concerned groups have no direct mechanism to quantify if the current production performance of quarrying is already causing environmental degradation. While the environmental health of the river can be correlated to its current geomorphological behavior in response to the fluvial performance, past researches have little to no account of this direct quantification because of the natural "dynamic equilibrium" of a river that cannot be overpowered, as explained by hydrologists like Estep and Beschta (1985).

The overall goal of this study is to investigate if quarrying is causing environmental degration in the Pasig-Potrero river by quantifying the actual eroded and replenished sediment volumes of the river. Its specific objectives are as follows: (1) to determine the severity of induced sediment extraction rate of quarrying as against the river natural replenishment rate, (2) to determine the effect of the current fluvial mobility performance to its river geomorphological responses, and (3) to observe the prevailing sediment mobility performance and geomorphological responses in the river.

Methodology

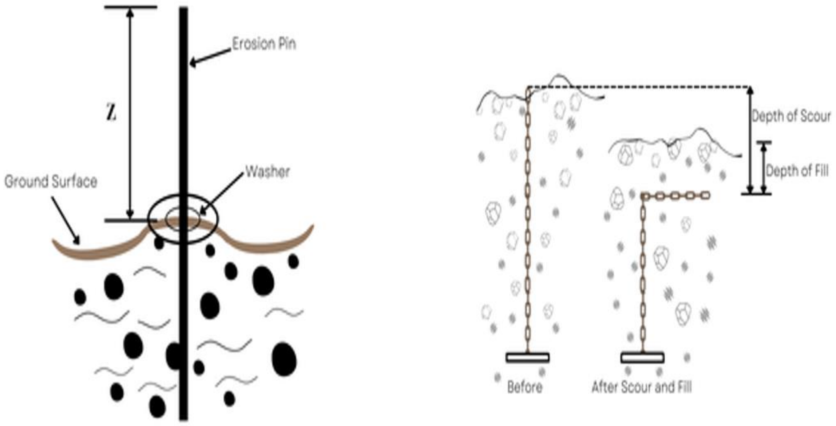
Research Design and Data-gathering Tools

The research used a time-bound quantitative-descriptive design complemented by qualitative analysis. To capture the behavior of river cyclical erosion and deposition, erosion pins and scour chains were used. As erosion pins and scour chains have the same applicability in the study, both were singularly termed as "poles." The study method and the design of the equipment used by Hancock et al. (2008) for erosion pins and Rex et al. (2002) for scour chains were adopted. An elementary surveying method also reported in both works was utilized to record the changes in river morphology.

Conventional pole reading without a sliding plate measures the net change in height as seemingly net replenishment or erosion. However, this procedure does not account for the underlying sediment fluvial processes in terms of the bed layer erosion and new material deposition between observation periods. The strength of the presence of a sliding plate in a pole is capturing the eroded level beneath the plate simultaneously with the newly deposited level above the plate (Kearney, Fonte, Garcia, & Smukler, 2017). This attribute can identify the presence of local and basin-wide erosion and replenishment rate at the same time. Though there are many other accurate ways of determining bedload transport behavior like the Universal Soil Loss Equation (USLE), the employment of erosion pins and chains is still the easiest and cheapest, without compromising any of the two movements. The sliding plate inserted in the barrel of the erosion pin is heavy enough to slide down the ground of the lowering bed from pedestal erosion. It allows itself to be buried by the new deposit carried from upstream (Hancock, Loughran, Evans, & Balog, 2007), illustrated in Figure 1a. This mechanism also applies to scour chain, where it is installed vertically and anchored beneath the ground with the help of a dowel bar. Mindful of the exposed number of chainrings, an additional exposed ring after some time would mean an erosion level of ring size equivalent (Rex et al., 2002) and vice versa, as seen in Figure 1b. The exposed rings are heavy enough to remain toppled to the ground so that newly deposited material will overlay this.

If applied properly, the poles will yield accurate sediment mobility characteristics in the river using the net sediment equation shown in Equation 4. However, this is applicable only in rivers that are underlain by sand-type materials, as the replenishment and erosion equation is expected to yield an efficient result. Otherwise, a river bed blanketed by gravel material may defeat the operationality of this method. The locale under investigation is predominantly overlain by

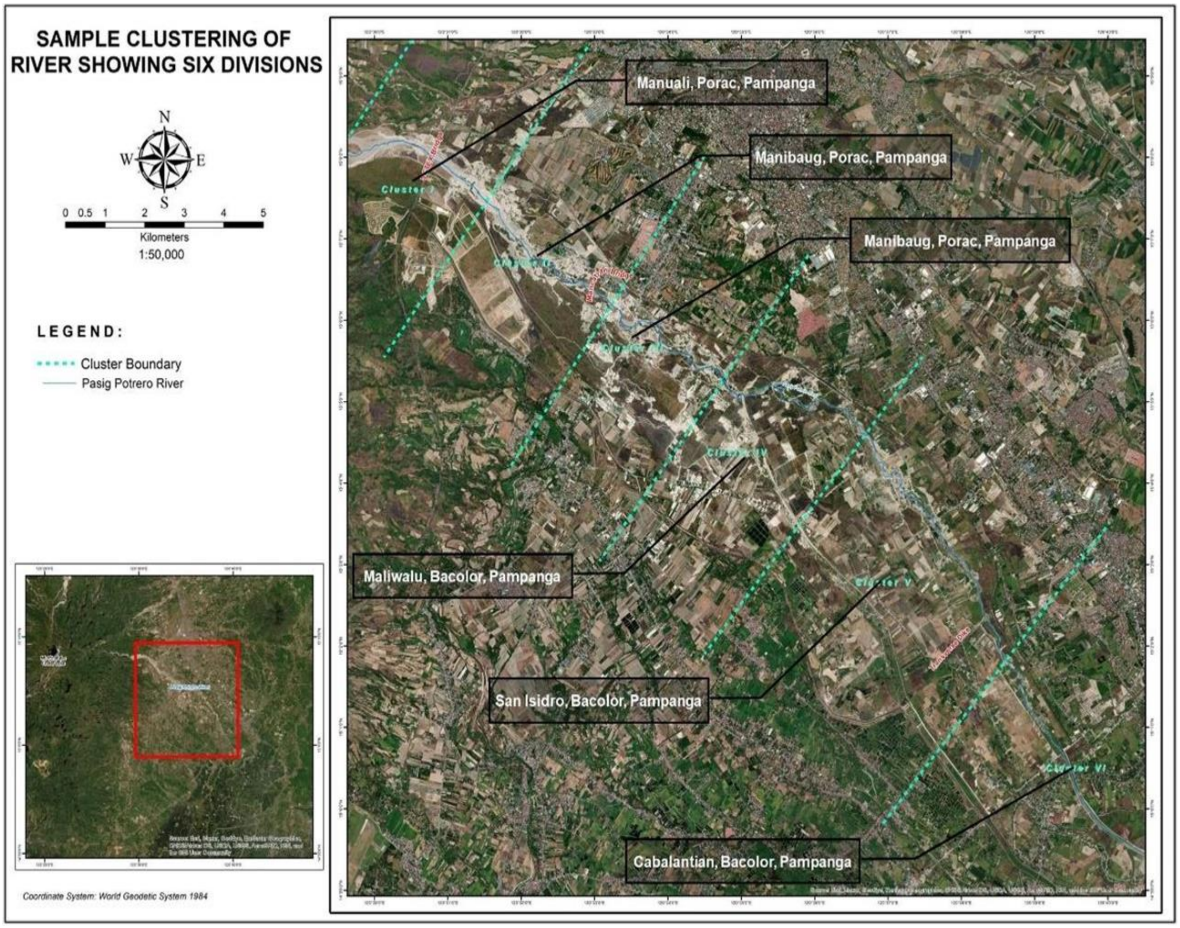
Figure 1. *Mechanism of Modified Erosion Poles (a. Erosion Pin, b. Scour Chain)*



a. b.

Note. Diagram *a* is from Cafferata et al. (2005) while diagram *b* is from Harrelson et al. (1994)

Figure 2. *Clustering of River Showing Six Sampling Divisions*



lahar-mobilized sand material and would thus be ideal for the employment of modified erosion poles.

Procedure and Data-gathering Activities

A census of the Pasig-Potrero River was done by grouping it into almost equally divided six sampling areas. These sampling areas are functionally termed as "clusters" arranged from clusters one to six, starting from the uppermost upstream portion of the river unto its downstream portion (see Figure 2).

GPS and Range Finder were used to establish current river profile. Then erosion pins and scour chains with graduations were inserted and anchored at sampling points in the river. They were observed of the changes in bed level in a regular visiting period that lasted for 12 weeks from January to March 2021. Also, changes in river dimensions were observed alongside bed level measurement to correlate sediment mobility response to physical environmental changes. All the data after site visit were transmitted to computer-aided applications like GIS and AutoCad.

Other surveying measurements used in the study were treated as supplemental to qualitatively describe the geomorphological behavior with respect to actual sediment movement in the Pasig-Potrero River system.

Data Treatment and Analysis

The study tested if the prevailing erosion and deposition phenomena can be attributed to quarrying in the river, and the erosion rate as the extracted volume from quarry operations. This goal was attempted through Pearson statistical correlation technique.

Integrated into the pole and chain method are four equations (see below) that were mainly used in the treatment and analysis of data gathered during field observation.

Equation 1. Fluvial Resiliency Equation

(-) overexploitation / (+) sustainable exploitation = Replenishment Rate – Extraction Rate

Equation 2. Replenishment Equation
|Current Week Bed Level| – |Current Week Plate Level| = (+) New Wash load Replenishment Level

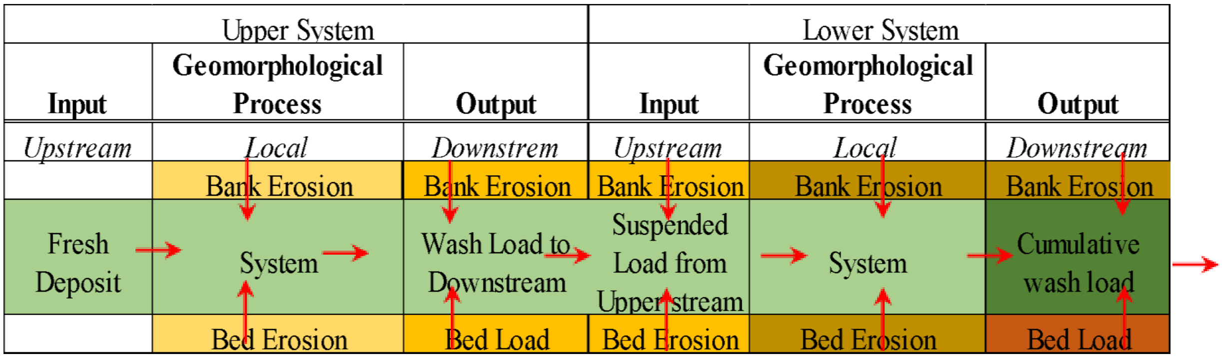
Equation 3. Erosion Equation
|Previous Week Bed Level| – |Current Week Plate Level| = (-) New Bed Material Erosion Level

Equation 4. Net (Sediment) Movement Equation
|Replenishment Level| – |Erosion Level| = +Net Gain/-Net Loss

The above equations followed the theoretical concept of mass balance and mass conservation as illustrated in the hydrogeological flow of river sediments in Figure 3.

The input and output volume of sediment in the river was computed following the theoretical concept of material flow (Figure 3). The missing volume that has not been accounted for in the last segment of the river was treated as the extracted

Figure 3. *Mass Balance Concept of a Fluvial Environment*



Upper System			Lower System		
Input	**Geomorphological Process**	**Output**	**Input**	**Geomorphological Process**	**Output**
Upstream	*Local*	*Downstrem*	*Upstream*	*Local*	*Downstream*
	Bank Erosion	Bank Erosion	Bank Erosion	Bank Erosion	Bank Erosion
Fresh Deposit	System	Wash Load to Downstream	Suspended Load from Upperstream	System	Cumulative wash load
	Bed Erosion	Bed Load	Bed Erosion	Bed Erosion	Bed Load

material (in cubic meter) that has been taken out of the system, which is only through excavation equipment used by quarry operators.

Recognizing sediment mobility as a natural response to an ever-changing river morphology (dynamic equilibrium) even without induced alteration (anthropogenic activity), it is difficult to prove that quarrying is causing overextraction, resulting in the morphological changes in the river. One way is to obtain the actual volume of sediment extracted from the records of quarry operators, to be used for deduction from the constant value of replenished sediment coming from the mountain source (Rachelly et al., 2021) as recorded through experiment. However, this is not possible as there is limited data from quarry operators. In this regard, to still test the allegation (hypothesis) on mining as the cause of environmental degradation, a triangulation technique (Matthews, 2014) was applied to determine the magnitude of participation of quarrying in the overall physical environmental health of the river system. Particularly called theoretical triangulation as defined by Carter et al. (2014), the theoretical relationship of fluvial dynamics to contributing factors and geomorphological responses were inspected simultaneously. Fluvial dynamics were treated here as the connecting point between quarrying effects and the physical environmental changes of the river. A null hypothesis can be accepted if the total number of related variables resulted and goes with the universally recognized relationship between variables. If the negative outcome outweighs the natural relationship between variables, then an alternative hypothesis will be accepted with a systematically determined confidence level to be generalized for the river. Consequently, a theoretical cross-checking model in six steps was adopted for the study (see below).

Step 1. Setting References. A theoretical relationship of sediment mobility behavior to its contributing factor and the ideal response of geomorphological characteristics to this sediment behavior were determined one after the other and concisely put into one matrix. The actual observation reading of these variables in Pasig-Potrero River was put in a single description box.

Step 2. Sign Assignment Matrix. A sign, based on the direction of movement, replaced the qualitative description of each variable outcome in the description box, which then made up the sign assignment matrix. Consequently, the sign agreement of correlated variables in the theoretical matrix was paired, which created the Sign Correlation Guide.

Step 3. Setting Decision Guide Box. A decision guide box was generated, taking the natural relationship of the correlated variable to be the accepted one and the opposite outcome to be the rejected one.

Step 4. Running Transpired Relationship. A preliminary run was done first for the outcome of the effect of physical contributing factors (as the independent variable) to sediment movement, and the description box was replaced from sign values into the final assessment box.

Step 5. Summarizing Implication. The number of rejects across and within-cluster was counted. A logical agreement was made that if more than half of the observation per cluster location and working variables across clusters showed a “reject” relationship, then a conclusion that anthropogenic activities dominate the morphological response in that cluster (alternative hypothesis) or the particular morphological characteristics was mainly affected by quarrying. If the “accept” is higher than the “reject,” then the geomorphological response was a natural phenomenon (null hypothesis) to river dynamic equilibrium.

Step 6. Generalizing Results. To generalize this outcome to the whole river system, the number of observed rejects to the total number of observations was proportioned and assessed if the results would go more than half of the percentage that will dictate the dominant activity in the river.

Results and Discussion

The use of modified erosion poles successfully yielded raw data of simultaneous material deposition and erosion cycle, which enabled the computation and analysis of the effect of quarrying on the river’s environmental health.

The Severity of Induced Sediment Extraction Rate of Quarrying as Against the River Natural Replenishment Rate

An attempt to estimate the monthly quarry production rate and the fresh sediment replenishment rate that will determine the presence or absence of over-extraction is discussed below. Results show that there is around 337,023.04 cu.m. overly extracted sediment material in the river, with the rate of extraction being 246 times higher than the fresh deposit replenishment rate.

Assuming a sediment mass is conserved in the system as to how these sediments should behave as erosion or deposition cluster by cluster, Table 1 shows an ideal mass balanced cumulative flow of these sediments (in cm.) in the system. The procedure was adopted from Hekal's (2018) method in computing transferred hydrologic strength cluster by cluster. In this study it is in terms of sediments being moved cluster by cluster.

Based on the pole readings (see Table 2), the computed erosion volume is the bed eroded volume, while the total replenished volume is the new material deposit from upstream. The net sediment behavior that prevailed in the system is an excess volume of 3,024.83 cu.m., a combination of bank erosion and new deposits from mountain ridges (input). Subtracting the input in the net replenished volume will tell that a bank material erosion of 204,799.52 cu.m. had happened together with a total bed layer erosion of 138,580.16. In short, there is a local erosion of 343,379.68 cubic meters that are added up in the system. Deducting the new deposit from upstream to the local replenishment, there is an excess of 342,004.30, which is the locally eroded material that piled up in Cluster 6 to maintain mass balance. However, there is no recorded replenishment in Cluster 6 but a bed erosion of 3,605.88 cu.m. only. This result would mean that only 3,605.88 cu.m. has been released out of the system as the actual sediment released acted as the suspended wash load that went further downstream. In other words, after deducting this bed erosion from the net excess erosion, an amount of 338,398.42 cubic meters has been removed from the system through other activities

Table 1. Cumulative Calculation of Material Flow from Upstream to Downstream

	Suspended Material	Bed Material	Cumulative	Cumulative Intermediate Outcome (Mass balance Conservation)	Description	Sediment Behavior
	New Deposit	Eroded Bed	Washload from Upstream			
Cluster 1	0.143010687	-0.396262024	0	0.143010687	New deposit	As replenished load
Cluster 2	10.79645365	-3.11402784	-0.396262024	10.40019163	Local erosion	As replenished load
Cluster 3	0.911945762	-0.954965247	-3.11402784	-2.202082078	Washload to downstream	As suspended load
Cluster 4	10.07034028	-20.48778653	-3.157047325	6.913292954	Local erosion	As replenished load
Cluster 5	9.865361884	-1.949579664	-20.48778653	-10.62242464	Washload to downstream	As suspended load
Cluster 6	0	-2.422807636	-12.57200431	-12.57200431	Washload to downstream	As suspended load

Table 2. Summary of Fluvial Performance in the Pasig-Potrero River for 12-Week Observation

Computed Volume, cubic meter	Description
138,580.16	Net bed erosion
206,174.90	Total upstream replenishment load
3,024.83	Net replenished
1,375.38	New deposit from mountain
204,799.52	Bank erosion
138,580.16	Bed erosion
343,379.68	Total local erosion
342,004.630	Excess local erosion
3,605.88	Bed erosion in Cluster 6 lowermost downstream
338,398.42	Taken out of the system through quarrying activity
337,023.04	Over extracted volume of quarrying activity

of sediment retrieval. This result is possible only through quarrying. An over-extraction of around 337,023.04 cubic meters was recorded, after subtracting the volume removed by quarrying from the newly deposited volume coming from upstream ridges.

The overall volume of bank and bed erosion is 56.94% caused by quarrying therein, and the rest is a natural response to changing environment of the river system. The percent representation of quarrying was determined from a theoretical cross-checking model discussed in the next sections.

The determined volume for the 12-week observation was averagely divided into three months (see Table 3), with the results showing that the extraction rate per month is 246 times faster than the river can be able to replenish fresh deposits from upstream mountain ridges. The speed was determined by counting how many recorded replenishments per month should pile up to equalize the speed of monthly sediment recovery.

Table 3. Rated Capacity of Sediment Performance in Cubic Meter Per Month

458.46	Average new material deposition rate
112,799.47	Average extraction rate

Profiling the Fluvial Mobility and Geomorphological Behavior of Pasig-Potrero River

A description of the actual measurement readings in determining fluvial mobility performance and the geomorphological behavior in the Pasig-Potrero River was successfully done through the use of modified erosion poles and surveying instruments. This was explicitly elucidated in Table 4 and Figure 4. Generally, during the 12-week observation, the Pasig-Potrero River experienced immense local erosion mainly due to induced bed layer incision that caused unstable bank walls, which in turn resulted in rapid riverbank accretion and retreat, channel shifting, and narrowing.

The Effects of Quarrying on the Fluvial Mobility Performance and Geomorphological Behavior of the River

Quarrying was correlated to the prevailing fluvial dynamics and subsequent geomorphological responses in the river. A rigorous assessment through theoretical crosschecking (triangulation) technique would indicate that quarrying in the river now controls, in around 56.94% level, the physical environmental changes in the river seen through

Table 4. Summary of Geomorphological Responses to Prevailing Sediment Mobility Performance

Cluster No.	Net Sediment Behavior	Bank Stability Performance	Net Channel Widening/ Narrowing	Prevailing channel evolution	Environmental Phenomena
1	Eroded	Accretion	Expansion	Shifting towards the right bank	Bed layer incision
2	Replenished	Accretion	Contraction	Narrowing	Normal Phenomena – Wash load sediment from upstream
3	Eroded	Accretion	Expansion	Shifting towards the right bank	One bank and bed layer incision
4	Eroded	Erosion	Expansion	Widening	Bed layer incision – total river degradation
5	Replenished	Erosion	Contraction	Shifting towards the left bank	Normal Phenomena – Replenished Sediment from bank erosion, bank collapse, or subaerial erosion
6	Eroded	Accretion	Expansion	Shifting towards the left bank	Bed layer incision

Figure 4. *Channel Evolution per Cluster Area*

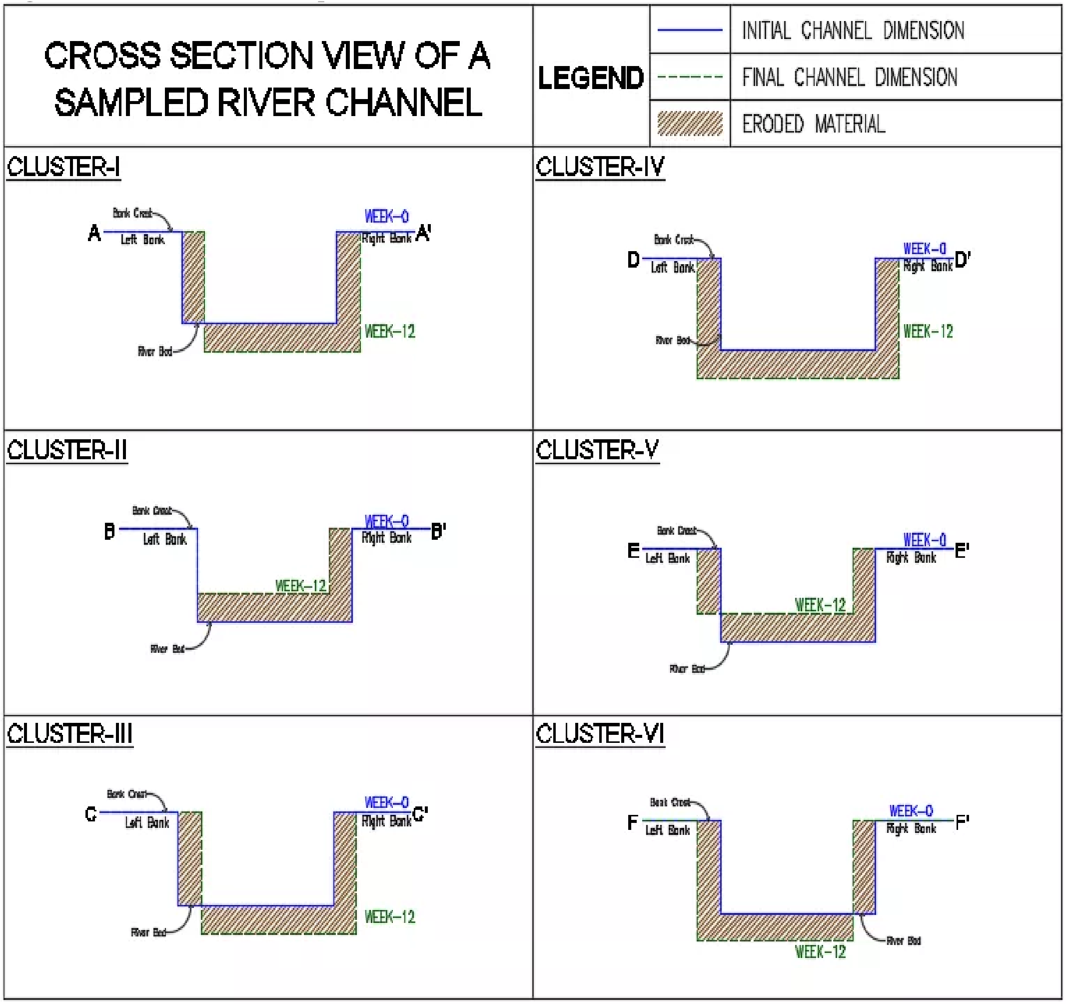


Table 5. Tally Table

Cluster No.	Net Sediment Behavior	Slope Location of Highest to Lowest Value	Dynamic Water Level Location of Lowest to Highest Value	Net Bed Elevation Change	Bank Stability Performance	Net Channel Widening/ Narrowing	Presence of Channel Shifting	Number of Rejects out of six Affecting Factor	Dominantly Affected by Anthropogenic Activity	Conclusion (Nature of undergoing physical changes)
1	-	Reject	Reject	Accept	Reject	Accept	Reject	4	Yes	Induced
2	+	Reject	Accept	Reject	Accept	Accept	Accept	2	No	natural
3	-	Accept	Accept	Reject	Reject	Accept	Reject	3	Cannot generalize	Induced & natural
4	-	Reject	Reject	Reject	Accept	Accept	Reject	4	Yes	Induced
5	+	Reject	Reject	Reject	Reject	Accept	Accept	4	Yes	Induced
6	-	Reject	Reject	Accept	Reject	Accept	Reject	3	Cannot generalize	Induced & natural
Total No. of Rejects		5	4	4	4	0	4			
Dominantly caused by anthropogenic activity		Yes	Yes	Yes	Yes	No	Yes			
Conclusion		Mining	Mining	Mining	Mining	Natural Process	Mining			

Table 6. Proportion Table

	No. of Rejects	Total Observations	Percent Proportion
Per Clustered Area	20	36	55.56
Per Geomorphologic Characteristics	21	36	58.33
River Total	41	72	56.94

its actual geomorphological behavior. The derivation of the result is summarized in Table 5 and Table 6.

Results show that the environmental status for Clusters 1, 4, and 5 has been dominantly affected by quarrying activities. The physical environmental characteristics disturbed by mining are bed topography, bank stability, and induced shifting. Cluster 2 shows a natural process of erosion and deposition happening in the river. In contrast, Clusters 3 and 6 showed a combination of a natural environmental process of channel evolution and induced environmental reaction due to quarrying. Also, the degree of channel widening and narrowing appear to be the secondary outcome of bank and bed stability, which is a natural response mechanism to changing environment in the river.

Outcomes implied that 56.94% of sediment performance was caused by quarrying. The remaining percent is the natural coping mechanism of geomorphological characteristics to the fluvial dynamics in the river.

The above results, however, should be considered with a couple of limitations in mind. First, observations only lasted for three months and were executed sometime in a moderately experienced weather surge. A longer observation time is desirable, as this will decrease the effect of dynamic equilibrium. Second, while the use of modified erosion poles in quantifying sediment movement in a river is proven as practical, easy, cheap and not subject to human bias, future studies can improve on the poles' frequency and strategic placement in order to produce more reliable results.

Conclusion

The 12-week observation has shown that the quarrying extraction rate is way higher than the recorded fresh deposit replenishment rate. Thus, there is over-extraction of river sediments despite fresh replenishments being recorded. In turn, this situation is affecting the general topography of the Pasig-Potrero River. The channel evolution interplay, like the presence of channel shifting, widening, and bank collapse of the river system, is theoretically tested as caused by anthropogenic activities around the river. The results suggest that man-induced alteration is dominantly affecting the environmental health of the river. In general, local replenishment rather than fresh deposit replenishment is noted in the river system. This is mainly due to bed incisions resulting from material extraction and causing bank collapse. Three of the river's significant geomorphologic characteristics (bed topography, bank stability, and channel shifting) are dominantly affected by this induced local replenishment, which is most visible in the uppermost upstream and lower midstream part of the river.

References

Cafferata, P. H., Coe, D., & Munn, J. R. (2005). *Flood Prone Area Considerations in the Coast Redwood Zone.* California Department of Forestry and Fire Protection. California: Research Gate. https://www.researchgate.net/publication/272170568_Flood_Prone_Area_Considerations_in_the_Coast_Redwood_Zone

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J., & Neville, A. J. (2014). The Use of Triangulation in Qualitative Research. *Oncology Nursing Forum, 41*(5), 545–547. https://doi.org/10.1188/14.ONF.545-547

Estep, M. A., & Beschta, R. L. (1985). *Transport of Bedload Sediment and Channel Morphology of a Southeast Alaska Stream.* US Department of Agriculture. Oregon: The Forest Service of the US Department of Agriculture.

Fondriest Environmental, Inc. (2014, December 5). *Sediment Transport and Deposition. Fundamentals of Environmental Measurements.* https://www.fondriest.com/environmentalmeasurements/parameters/hydrology/sediment-transport-deposition/

Gran, K. B., Montgomery, D. R., & Sutherland, D. G. (2006). Channel bed evolution and sediment transport under declining sand inputs. *Water Resources Research*, 42(10). https://doi.org/10.1029/2005WR004306

Hancock, G. R., Loughran, R. J., Evans, K. G., & Balog, R. M. (2007, November 14). Estimation of Soil Erosion Using Field and Modelling Approaches in an Undisturbed

Arnhem Land Catchment, Northern Territory, Australia. *Geographical Research, 46*(3), 333-349. https://doi.org/10.1111/j.1745-5871.2008.00527.x

Harrelson, C. C., Rawlins, C. L.; Potyondy, John P. (1994). *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*. Gen. Tech. Rep. RM-GTR-245. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hekal, N. (2018). Evaluation of the Equilibrium of the River Nile Morphological Changes throughout "Assuit-Delta Barrages" Reach. *Water Science*, *32*(2), 230- 240. https://doi.org/10.1016/j.wsj.2018.09.001

Kearney, S. P., Fonte, S. J., Garcia, E., & Smukler, S. M. (2017). *Improving the Utility of Erosion Pins: Absolute Value of Pin Height*. Science Direct. https://www.sciencedirect.com/science/article/pii/S0341816217304046

Matthews, J. (2014). Triangulation system. In *Encyclopedia of Environmental Change* (Vol. 1, p. 112). SAGE Publications, Ltd. https://dx.doi.org/10.4135/9781446247501.n3972

Mercado, R. A., Lacsamana, J. T., & Pineda, G. L. (1999). *Socioeconomic Impacts of the Mount Pinatubo Eruption*. Philippine Institute of Volcanology and Seismology, Department of Science and Technology. San Fernando: US Geological Survey. https://pubs.usgs.gov/pinatubo/mercado/

Philippine Institute of Volcanology and Seismology. (2004). *FIRE and MUD: Eruptions and Lahars of Mount Pinatubo, Philippines*. Quezon City: US Geological Survey. https://pubs.usgs.gov/pinatubo/prelim.html

Rachelly, C., Friedl, F., Boes, R. M., & Weitbrecht, V. (2021, May 14). Morphological Response of Channelized, Sinuous Gravel-Bed Rivers to Sediment Replenishment. *Water Resources Research, 57*(6). https://doi.org/10.1029/2020WR029178

Rex, J. F., British Columbia. Ministry of Water; Land and Air Protection, Carmichael, N. B., & British Columbia. Resources Information Standards Committee. (2002). *Guidelines for Monitoring Fine Sediment Deposition in Streams*. Resources Information Standards Committee.

Rinaldi, M., Wyzga, B., & Surian, N. (2005). Sediment Mining In Alluvial Channels: Physical Effects. *River Research and Applications* (21), 805–828. https://doi.org/10.1002/rra.884