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Morphological Relationship between Floodplain Area, Wavelength and Amplitude of Quarried and Unquarried River

Raymundo V. Romero[1], Marijane A. Iglesia[2], Alicia S. Pempena,[3], Alejandro Pitallano Jr.[4], Geosan dela Cruz[5], Robert Nueles[6]
[1, 2, 3, 4, 5, 6] College of Engineering and Technology, Partido State University, Gia, Camarines Sur, Philippines

ABSTRAC: This study investigated the relationship between floodplain area, wavelength and amplitude in quarry and unquarried portion of Lagonoy River. Mathematical modelling was applied to gather the data with ground check to see the real situation. Geospatial data were assessed using computer application that represent satellite image of the earth. Mathematical expressions were used to describe the parts of the rivers related to the impact of river morphology and alteration in quarry area done by expressing the relationship between the product of wavelengths (ƛ) and amplitudes (A) of river meanders to floodplain area (Fa). The impact of river alteration and morphology was found that the mean value of ƛA is of great extent compared to the floodplain area on unquarried sections while it is opposite on quarried section. For parts that are not appropriate for quarrying the ratio between the flood plain areas and the product of the wavelength and amplitude are ranging from 0.028 to 0.13 with the mean value of Fa = 0.028ƛA. However, for parts that are typical for quarrying are ranging from 0.71 to 2.83 with the mean value of Fa = 2.13ƛA. Quantitative analysis of the data strenthened the results taken from physical investigation.

KEYWORDS: River, Quarry, Floodplain, Amplitude, Wavelength

I. INTRODUCTION

Human activities along watersheds bring about changes that greatly accelerate the natural erosional process [1]. These directly and indirectly alter the natural hydrology of a catchment that have cascading effects on landforms. Water abstraction and diversions create dewatered river stretches which impede water mediated longitudinal connectivity [2]. Since river connectivity is water-mediated, the force and direction of flow exerts a strong influence on transport of sediment, nutrients, and organisms with limited or no mobility [3]. River as a system always tries to maintain an equilibrium condition by balancing between the input and output. Any kind of interruption within this system may alter hydraulic variables such as slope, velocity profile, depth, width, stream power of the river and result in changes in its morphology [4]. If a part or reach within a river is close to the threshold value, it will be highly sensitive and a small external alteration of input can introduce a significant change in the morphology of that reach [5]. The sensitivity of environmental flows to siltation varies among different river segments, especially in those with low barrier heights [6]. Erosion is caused primarily by the high flow of velocity. Naturally, the strong increase in cross-sectional area induces horizontal flow recirculation, which helps maintain a high velocity in the center of the channel and in the recirculation zones [7] but other situation is elicited from too much extraction of materials such as gravel and sand from the riverbed which contribute to the loosening of soil from the river banks. The extraction of sand and gravel has adverse effect on the environment [8] that destroys riverine vegetation and causes erosion. Sand and gravel are crucial resources to economic development activities in developed and developing nations [10] while the increasing demand for construction projects and other infrastructure development, placed immense pressure on sand and gravel resources [11]. Often the conditions imposed on the approval of quarry activities and ecosystem alterations are expressed without technical consideration of their potential impact on the environment. Lagonoy river is a main river which is formed through tributary rivers coming from Mt. Isarog and adjoining mountains from the municipality of Lagonoy, province of Camarines Sur, Philippines. It has abundant quantities of sand and gravel that were quarried conveniently and economically for a variety of uses. Aside from plentiful capacity are the good quality of sand and gravel. It is also the nearest source of aggregates in Partido district making the riverine area of the aforesaid location alters its original flow and develop effects on the environment.

II. OBJECTIVES

A. General Objective

This study investigated the relationship between floodplain area, wavelength and amplitude in quarry and unquarried area of Lagonoy River

B. Specific Objectives

1. This described the morphological structure considering the floodplain area, wavelength and amplitude of the quarried and unquarried river parts,
2. This derived the mathematical models based from the morphological structures of the river.
3. This determined the mathematical relationship between the floodplain area, wavelength and amplitude of the quarried and unquarried parts.

III. METHODOLOGY

Remote sensing was used in gathering the data. However, field observations were conducted in active sites for ground checking. Satellite imagery was used in determining the changes that have been taken place particularly to those areas devoid with vegetation and the excavations created over time as a result of sand and gravel quarry activities. Graphical measurement was used to determine the value of wavelength, amplitude and floodplain area. Figure 4-1 illustrates how the value of amplitude, wavelength and flood plain area were measured. The result of graphical measurement was used as the data for deriving mathematical models based from the investigated structure of meandering river. Mathematical analysis was also performed to interpret the dreived models based from the physical outlook of the river. Quantitative ananlysis was used to compare the result from mathematical analysis using the t-test result.

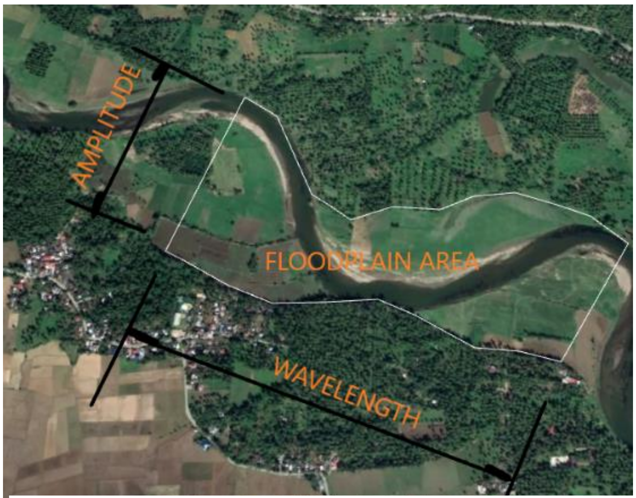

Fig. 4-1. Measurement of amplitude, wavelength and floodplain area of river meander

IV. RESULTS AND DISCUSSION

A. Wavelength (λ), amplitude (A) and flood plain area (F_A)

The wavelengths, amplitudes and flood plain areas from coordinates 13.742972, 123.476773 up to 13.715312, 123.461414 were measured considering five series of river meanders. Table IV-1 shows the data based from the graphical measurement from river meanders. The mean (Ẍ) value of λA is of great extent compared to the mean value of the the floodplain area on unquarried sections while it is opposite on quarried section. The percentage of discrepancy between the values of λA and Fa was seen by computing λA/Fa to derive equations. The computed value of the wavelengts and amplitudes of the series of river meanders for quarried and unquarried sections satisfy the conditions given. The t-test results reveal that there are significant difference on the following: the data of the computed products of wavelength and amplitude compared to the floodplain area of the unquarried sections; the computed data on floodplain areas of the quarried and the unquarried sections; and the computed data on the product of wavelength and amplitude of quarried compared to unquarried sections. However the data reveals that there is no significant difference on the computed product of to unquarried sections. The data reveals also that there is no significant difference on the computed

Table IV-1. Wavelength, amplitude and flood plain area of river meanders on quarried and unquarried sections

No	Unquarried section				
	λ (m)	A (m)	λA (m^2)	F_A (m^2)	$F_A/\lambda A$
1	430	62.39	26,827.70	3,548.50	.1323
2	390	91.60	35,724.00	2,433.60	.07
3	130	170	22,100.00	1,810.20	.082
4	340	100	34,000.00	1247.40	.037
5	310	78.91	24,462.00	676.00	.028
$\bar{x}$	320	100.58	28,622.74	1943.14	.068
Quarried section					
1	1,010	210	212,100	150,000.00	0.71
2	750	81.04	60,780	470,000.00	7.73
3	480	180	86,400	250,000.00	2.89
4	640	220	140,800	140,000.00	0.99
5	580	140	81,200.00	230,000.00	2.83
$\bar{x}$	692	166.2	116,256.00	248,000.00	2.13

Note:
λA VS. F_A; unquarried; Computed t = 10.05 > tcrit = 2.13 or P = 0.003 < 0.05; with significant difference
λA VS. F_A; quarried; computed t = 1.613 < tcrit = 2.132 or P = 0.09 > 0.05; no significant difference
Fa quarried VS Fa unquarried; computed t = 4.136 > tcrit = 2.132 or P = 0.0072 < 0.05; with significant difference
λA quarried VS λA unquarried; computed t = 3.167 > tcrit = 2.13 or P = 0.017 < 0.05; with significant difference

product of wavelength and amplitude compared to flood plain area of the quarried sections The investigation found that the value of amplitudes is less than the wavelength in the series of adjoining river meanders, but individually the relationship may vary. The relationship between the product of wavelength and amplitude (λA) and the floodplain (F_A) area are parameters that could be used to determine if the river section is attractive for quarry activity. The derived equations shows that if the floodplain area is so small it is not appropriate for quarrying which is in contrast if the floodplain area is so big compare to λA. To make a river protected it is thus necessary that the floodplain area be diminished that only the width of the river will accommodate even during the excessive floodings, but it needs enginerring intervention citing [20] that the most visually striking river restoration projects are those involve in the creation of new channel in a new alignment and generally with a form and dimensions that are different from those of the preproject channel. Stopping of quarry activities may affect economic development wherein the workers consider the activities as their source of income and economic dependency while sand and gravel were extracted because it is a resource that has many uses in building infrastructures, plastering and making foundations [21]. Sand and gravel plays important role as aggregate in construction industry but quarrying of the materials plays immense pressure on the environment that may result to destruction of landscape, reduction of farm grazing and lowering of water table [22]. However many rivers and streams can accommodate the removal of some portions of their bedload without serious effects provided that instream mining is conducted without environmental impacts and are kept within the hydraulic limits set by the natural system [23] while close monitoring of concerned government agencies and police department to insure proper mining, prohibit sand quarrying downstream and restriction of tipper trucks transporting through villages [24]. It was suggested for government and public authorities responsible for mining sector and environment to set up and enforce environmental laws, regulations and standards related to mining process; permit sand mining operations based on license; monitor and inspect operation places to ensure obligations arising from standards, regulations, law; and support mining companies that have access to clean technologies [25]. Planned measures must be consider for the whole life cycle of mine, from prospect and exploration to closure and reclamation [26].

B. The derived mathematical models

Mathematical relations were derived to describe the river sections that are typical and not typical for quarrying.

B-1 Sections not typical for quarrying: Based from the presented data in Table IV-1, it was seen that in areas that are not typical for quarrying, the product of the wavelength and amplitude (λA) is greater than the flood plain area (F_A). It also satisfy the condition that $F_a/\lambda A$ ranges from 0.028 to 0.13. The relationship is expressed by the equation:

$$0.028\lambda A < F_a < 0.13\lambda A$$

with a mean value of:

$$F_a = 0.068\lambda A$$

The equation may be expressed as follow if the series of adjoining river meanders be considered:

$$0.028\frac{\lambda_1 A_1 + \lambda_2 A_2 + \lambda_3 A_3 \ldots + \lambda_n A_n}{n} < \frac{F_{a_1} + F_{a_2} + F_{a_3} \ldots + F_{a_n}}{n} < 0.13\frac{\lambda_1 A_1 + \lambda_2 A_2 + \lambda_3 A_3 \ldots + \lambda_n A_n}{n}$$

the equation may be simplified as:

$$0.028\sum \lambda_n A_n/n < \sum F_a/n < 0.13\sum \lambda_n A_n/n$$

where λ is the wavelength; A is the amplitude; F_A, floodplain area; λ_n, wavelength corresponding to the number of river meanders; A_n, amplitude corresponding to the number of river meanders; and n, the number of river meanders. The equation emplies that if the product of wavelength and amplitude is of greatest value compared to flood plain area, it is not a typical site for quarrying. This is the place were aggregates is hard to be quarried for the following reasons: poor accessibilty, far distance from urbanization, steep slope, protected aggregates and abundant vegetation.

***B-2 Sections typical for quarrying*:** The wavelength, amplitude and flood plain area of quarried sections from coordinates 13.745940, 123.508263 down to 13.740881, 123.536504 were measured considering series of five adjoining river meanders and found that the products of amplitudes and wavelengths are less than the floodplain areas. It was seen that the flood plain area (FA) is ranging from 0.71 λA to 7.73 λA. The equation is written as:

$$0.71\lambda A < F_a < 7.73\lambda A$$

with a mean value equal to:

$$F_a = 2.13\lambda A$$

for series of adjoinng river meanders the equation is:

$$0.71\frac{\lambda_1 A_1 + \lambda_1 A_2 + \ldots \lambda_n A_n}{n} < \frac{F_{a_1} + F_{a_2} + \ldots F_{a_n}}{n} < 7.73\frac{\lambda_1 A_1 + \lambda_2 A_2 + \ldots \lambda_n A_n}{n}$$

which is simplified to:

$$\frac{0.71\sum \lambda_n A_n}{n} < \frac{\sum F_{a_n}}{n} < \frac{7.73\sum \lambda_n A_n}{n}$$

The mathematical expression emplies that if the floodplain area is of greatest value compared to the product of the wavelength and amplitude, the area is a typical site for quarrying. This is the place were aggregates are abundant. Sand and gravel deposits are the result of the erosion of bedrock and the subsequent transport, abrasion, and deposition of the particles either by ice, water, gravity, and wind while gravity has a minor influence on the formation of sand and gravel through deposits downslope movement of materials [27]. During the period of flooding in the river valleys, sand, gravel and fines may be spread extensively over the floodplains, resulting in wide spreads of potentially useful aggregates beneath a cover of silty alluvium [28]. On this analyzis of morphology caused by the alteration of the river had seen that there was a significant difference on the content of quarry materials on different parts of the river specifically between ƛA and F_a. It was established that the product of the amplitude and wavelength of the river meanders, has the relationship with the floodplain area that can be used to approximate if the section is typical for quarrying. Such relationship can be used to detect on what parts can a series of serious environmental-geological problems may occur due to the socio-economic development and urban modernization process [29], [30]. The established mathematical model may be used to approximate where the main environmental modifications could happen such as the creation of regular-shaped depressions, minor isolated artificial relief, creation of artificial ponds, partial or total destruction of fluvial terraces, erosion and instability of quarry scarps, depression of piezometric surface, alteration of groundwater flow direction, formation of periodically flooded areas, permanent removal of areas from farming use, alteration of farming practices, and changes to the pedological characteristics of soil [31]. Therefore, it may be used also to locate on the river parts that the protection against hazards and disastrous events be applied which is greatly required for the sustainable use, development and protection.

CONCLUSIONS

Variations were observed on the descriptions of parts of the river particularly between the quarried and unquarried sites. The unquarried sites are located at the upstream parts away from the villages with higher soil slope and poor accessibility. Most of the river widths are narrow with very small percentage of untouched floodplain area. The riverbanks are naturally protected with hard trees and vegetation. Oppositely, parts of the river with active quarrying activities are located in the downstream area with larger widths and floodplain formed through river meanders and gentle slope. It was observed that the mean value of the product of wavelength (ƛ) and amplitude (A) is of great extent compared to the mean value of the floodplain area on unquarried sections while the result is opposite for the quarried sections and was strengthened by the t-test results which reveal that there are significant difference on the following: the data of the computed products of wavelength and amplitude compared to the floodplain area of the unquarried sections; the computed data on floodplain areas of the quarried and the unquarried sections; and the computed data on the product of wavelength and amplitude of quarried compared to unquarried sections. However the data reveals that there is no significant difference on the computed product of wavelength and amplitude compared to flood plain area of the quarried sections. All the above findings were supported by mathematical equations that were derived through physical modelling.

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