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The socio-economic and environmental impacts on gravel mining in rivers: a case study in the Ecuadorian Amazon Region

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Abstract: This article examines the socio-economic and environmental impacts of gravel mining in the community of San Pedro, Ecuador. Data collection from primary sources was carried out through a case study of the community by means of household-level surveys in 2015. These surveys and the community's perceptions about mining activities were considered. It explores community solutions according to the establishment of environmental measures in order to avoid the risks of flooding and direct damage to the environment. Most of the gravel mining is carried out in the river with environmental impacts such as disruption of river courses, landscape involvement and the depletion of biodiversity resources. Population show approval if appropriate measures of mining practices are taken with following environmental restoration.

Community involvement of proper exploitation planning of gravel minerals, the creation of other income-generating activities and environmental restoration criteria are presented and discussed.

Keywords: socio-environmental impact; River Tena; gravel extraction; rural community.

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1 Introduction

Mining is a major economic activity in many developing countries (Hoskin et al., 2000; Tauli-Corpuz, 1998). It has become one of the main means of livelihood for isolated or low-income communities. Exploitation has been carried out in a range from industrially to artisanal or small-scale mining. However, it is highly detrimental to the environment (Makweba and Ndonde, 1996) producing enormous amounts of waste that can have harmful impacts for years (Hoskin et al., 2000). Many studies (Torres et al., 2017) have referred to the potentially-adverse impacts that mining could provoke on: the natural environment, society and cultural heritage, health and safety of workers and inhabitants of nearby communities.

In Ecuador, mining is one of the main sources of income. Over the years, both illegal and legitimate mining have been employed to extract mineral resources mainly in the south of the country (López-Blanco et al., 2015). Several studies in different regions of the country have focused on analysing the main causes of the exploitation of mineral deposits, the environmental effects and social impacts of this activity (Guimaraes et al., 2011; Peña-Carpio, and Menéndez-Aguado, 2016; Tarras-Wahlberg et al., 2001; Walter et al., 2016).

Several studies focus on the basin of the river Puyango. Tarras-Wahlberg et al. (2001) report how small-scale gold mining has affected the quality of water and aquatic ecosystems in the mining district of Portovelo-Zaruma. Moreover, there are geographically great and extensive impacts, due to the use of mercury and cyanide as a result of the poor management of tailings. Betancourt et al. (2005) demonstrate the mining impacts on the environment and human health by detecting high lead and mercury levels in waters, fundamental for various purposes by communities. Many mining impacts may have an impact on children health, according to Betancourt et al. (2015) who studied cognitive dysfunctions, neurobehavioral disorders caused by the manganese presence from gold mining. This study is mainly based on the participatory process of the social actors in Puyango River basin, southern Ecuador to find criteria to establish regulations in order to control environmental pollution by mining activities.

The issue of mining has been strongly addressed in Ecuador, mainly regulations, environmental impacts and socio-environmental conflicts. Regulatory criteria for mining are of great importance. Adler Miserendino et al. (2013) highlight the importance of their adequate interpretation as a potential instrument to manage socio-environmental conflicts, through better training of miners and a revision of the legal framework for artisanal and small-scale gold mining in the area of Portovelo-Zaruma, Ecuador. In this regard, they analyse efforts to address transboundary water pollution, mining waste management and conflicts related to priorities, ambiguities and enforcement of existing regulations and policies. In addition, they refer to the promotion of information-based strategies, including educational outreach programmes, and mitigation methods between scales and levels can also be beneficial. Problems with worker safety due to unsafe handling of explosives, cyanide and mercury, and the impact on the environment, as well as hazardous labour practices are reflected here.

All cited studies are mainly focused on the gold and copper exploitation for international markets, which generates large environmental impacts either by extending the extraction or by the use of chemical substances for the separation of these metals. However, there are few approaches to the gravel extraction, which is one of the country's main economic activities due to growing demands for road, housing and retaining wall construction.

Stone mining is carried out in open quarries, riverbanks, and riverbeds, where severe environmental impacts can occur such as: water pollution, habitat alteration, land conversion and degradation. Sand and gravel are the largest portion of primary material inputs (79% or 28.6 gigatons per year in 2010) and are the most extracted group of materials worldwide, surpassing fossil fuels and biomass (Torres et al., 2017). One of the main problems associated with the extraction of these materials worldwide is the difficulty in regulating their consumption (Torres et al., 2017). In many cases the extraction and illegal trade take place rampant (Rege, 2016), which can generate future socio-political, economic and environmental effects (Torres et al., 2017).

Several environmental problems can be brought about by the extraction of sand or gravel from rivers; for example, it affects the integrity of the ecosystem and can lead to erosion, the physical alteration of benthic habitats and suspended sediments (Peduzzi, 2014). Small rivers are most affected by indiscriminate sand mining due to limited riverbed resources (Padmalal, and Maya, 2014). In addition, it can increase water pollution levels, affecting aquatic life shown at the Jaflong River in Bangladesh by stone mining (Al Mamun et al., 2019), or human life, as reported in Asia at the Mekong Delta, Vietnam, and Sri Lanka (Anthony et al., 2015; Pereira, and Ratnayake, 2013). Furthermore, economic activities that depend on water resources such as fisheries, mariculture and agricultural land, can be affected by erosion processes and degradation induced by the extraction of coastal and riverine systems (Torres et al., 2017).

The impact of mining on local communities has been analysed in the southern region of Jordan through socio-economic indicators (e.g., unemployment, poverty, education, health, and the environment) (Al Rawashdeh et al., 2016). This study shows that mining does not seem to help local communities very much, and that policies and rules need to be made to redistribute some of the wealth from Jordanian mining companies to local communities and pay for the costs of mining in the area (Al Rawashdeh et al., 2016).

Kitula (2006) reported on the socio-economic and environmental impacts of mining in the Geita district (Tanzania). These impacts include land degradation, damage to water quality, pollution, and damage to livestock and wildlife biodiversity. The impact of sediment transport on the river ecosystem has been exposed by Krishnaswamy et al. (2006). They comparing historical data with recent data and finding the effect of mining and associated activities in Kudremukh National Park as major sources of sediment entering the Bhadra River in south India.

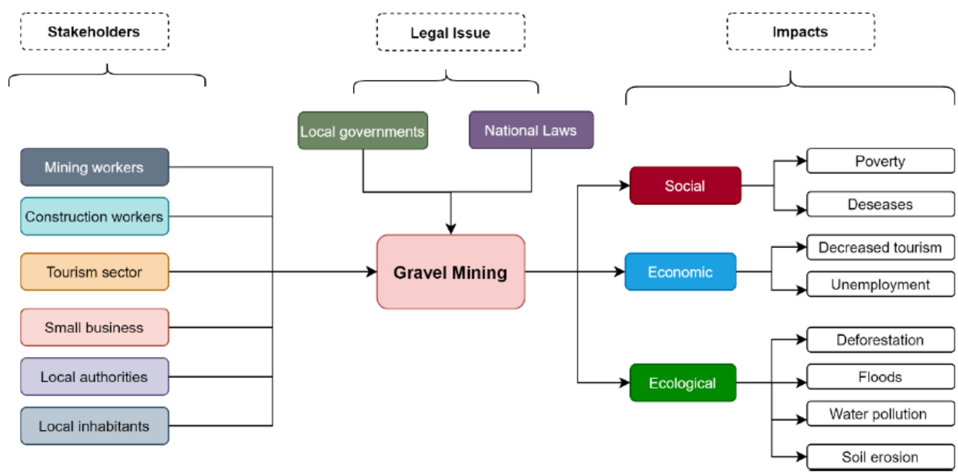
Meanwhile, research by Ofosu et al. (2020) highlights the importance of reformulating resource allocation policies to ensure adequate accommodation of rural communities where small-scale agricultural and mining activities converge. Similarly, on Singkep Island, Indonesia, Syahrir et al. (2020) studied the socio-economic impacts of tin mining. Substantial profits from mining turned into long-term losses after sudden closures and mismanagement of resources. Job opportunities turned into unemployment; economic contributions turned into economic collapse; and infrastructure assets turned into liabilities. Environmental degradation was a negative impact during and after mining. This reflects that governance at the regional level is crucial in mining (Syahrir et al., 2020).

Other studies reveal community members' (residents of resolute and Arctic Bay) perceptions of current and future mining in Nunavut, Canada, where villagers argue that the mines had some short-term positive impacts, but few lasting benefits (Bowes-Lyon et al., 2010). They argue that to increase socio-economic benefits and help communities meet their sustainable development goals, sectors and companies that derive direct benefits from mining activity should emphasise education and training for local people and foster local business development and partnerships through strong relationships and close communication with stakeholders (Bowes-Lyon et al., 2010).

In this sense, the health and well-being of the inhabitants, the protection of cultural resources, employment opportunities, income, and sustainable lifestyles of the community are essential aspects to be considered by the productive activities to be established in the region. The Amazon region has limited employment, and gravel extraction is a source of income for local people, but this activity undermines the physical availability of other resources in the Amazon ecosystems and does not improve the quality of life. Gravel extraction takes place inside the river and on the banks (including slopes and rocky areas). The volumes are variable, ranging from one to several dump trucks per day of 10 m^3 each. This gravel is used in local building projects, and it is also sold to other nearby areas for building roads and homes.

Figure 1 shows the conceptual model of the research. It includes the Stakeholders, the legal issue the links between gravel extraction and development and (local) socio-economic and ecological impacts.

Figure 1 Conceptual model of gravel mining in the River Tena, San Pedro community, Ecuador (see online version for colours)



This study is based on the determination of main socio-environmental impacts of gravel extraction in the Tena River which affects the inhabitants of the San Pedro community, considering a participatory approach. In addition, the research aims to answer the following question: could gravel extraction really improve the quality of life of local people?

2 Materials and methods

2.1 The study area

2.1.1 Physics and environmental factors of the area

The Ecuadorian Amazon Region (EAR) comprises 2% of the Amazon basin and has a total area of 116,441 km^2. Regarding surface area, it is the largest natural region in Ecuador, making up approximately 45% of the nation's territory. It is an ecosystem of great local and global interest due to natural forests and extraordinary biodiversity (Bravo et al., 2015). The Ecuadorian Amazon basin has important water resources. The three major hydrographic basins are the Napo, Pastaza, and Santiago River, tributaries of the Amazon River. The Tena River is a tributary of the Misahualli River, which flows into the Napo River, one of the main rivers in the Ecuadorian Amazon basin.

The Tena River is fed by several tributaries: the rivers Colonso, Lupi, and Shitig. These are born mainly in the native forests and Paramo (Andean moor) of the Eastern Cordillera of the Andes, where its height oscillates between 900 to 2,440 metres above sea level (masl). The relief of the territory is irregular. The human settlement (San Pedro, Muyuna, etc.) are in plateaus and terraces which oscillate at a height of 540 to 800 masl. The climate is warm, tropical, and humid with an annual precipitation of 4,000 mm (rainy season from January to June), and has temperatures ranging from 18°C to 35°C. The relative humidity is greater than 90%, and the wind speed ranges from 8.2 to 10.8 m/s (GADPRM, 2015).

The soils of the basin are mainly clayey-silty, plus some gravel and sand. According to the vegetation cover and land use, the majority of the area is covered by undisturbed tropical forests, mainly in protected areas of conservation, where Amazonian species are mixed with some Andean elements, and a great variety of vegetal species with diverse uses: medicinal, fruit trees, among others. It also hosts more than 100 species of birds, about 25 species of amphibians and reptiles, and 30 different types of mammals. The lower part of the Tena River is characterised by intervention and human settlements and defined by shrub, secondary forests, and agriculture and cattle land.

2.1.2 Demographic characteristics and economic activities of the area

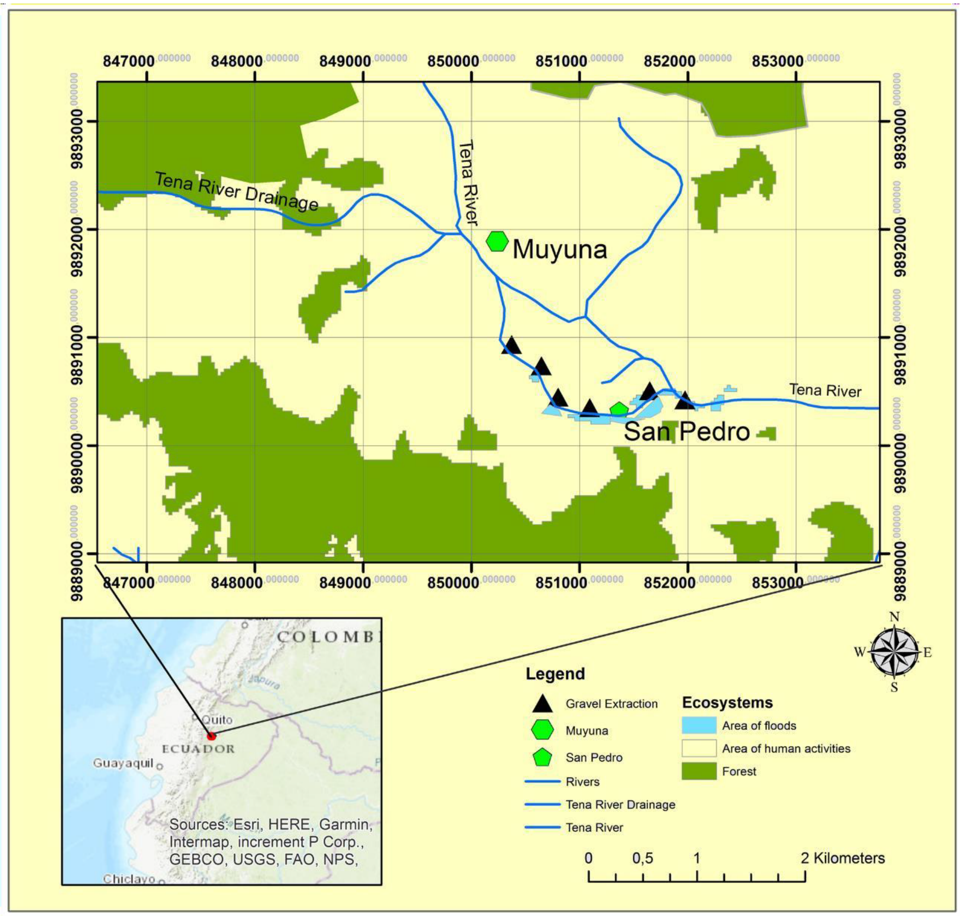
The Tena River has a diversity of natural attractions and cultural events that have special features allowing visitors to learn about the history and traditions of the Kichwa and Huaorani (also known as Waorani or Waodani), people. There are some communities located on the riverbanks very close to the Tena River like San Pedro, Muyuna, Lupi, Atacapi as well as different swimming spots, for example Peña Colorada, Cedros, Río Sol and Piedra Dorada. San Pedro is one of 29 human settlements in the San Juan de Muyuna parish, located 5 km northwest (0° 59′ 8.894′′S, 77° 51′15.684′′ W) of the city of Tena, the capital of the Napo province. 67.25% of the territory is a protected area (GADPRM, 2015). The study involved two communities, made up of several dwellings of 170 families, with 445 and 547 individuals respectively in each of them. These settlements are inhabited mainly by Amazonian Kichwa people who make up about 90% of its population. The remaining 10% is comprised of mestizo, white and montubio families.

The community's economy relies on the output from the service sector, from forestry products, and agricultural and livestock practices: cocoa, banana, and cassava are the major crops consumed domestically.

The communities have natural, cultural, tangible, and intangible resources, amongst them tourist attractions, waterfalls, rivers, caves, vantage points, gastronomy, traditional festivals and others.

Gravel extraction is performed in several sections of the river. This operation is carried out by digging trenches or wells in the riverbed with heavy machinery. Material is selected in order to sell to other locations in the province and region.

Figure 2 Map of gravel mining in the River Tena, San Pedro community, the Ecuadorian Amazon basin (see online version for colours)



2.2 Data collection

The data for this case study was obtained from both primary and secondary sources. Primary data was acquired using a combination of methods, including participatory rural appraisal (PRA) tools and participant observations, informal and formal surveys a direct approach was used towards the affected people, so that the collected information was as accurate as possible. The surveys were implemented using a structured questionnaire administered among 170 households.

2.2.1 Method used for data collection

Participatory rural evaluation activities included 12 community inhabitants (six females and six males). Students, researchers, and community participants were divided into three groups according to different economic income activities: the tourist recreational spots, fishing areas, and the most frequent entry points for gravel extraction machinery into the river. The information was complemented by direct observation in situ, reviewing the specific characteristics of each place and spatial data information was obtained. Therefore, a GPS receiver, Garmin GPSMAP 62s, was used, set at UTM coordinate system, WGS 1984 datum, Zone: 18S, and units in metres.

Walk-along method were carried out in order to interact with the local indigenous people and get more details about mining activities, the natural resources of the area and to establish the main aspects of interest in the area. Walk-along method is conducted for exploring phenomena such as environmental perception, social realms, spatial practices, among others (Kusenbach, 2003). Each group, formed/constituted by community actors who served as guides, took pictures and wrote down notes every 100 steps. Finally, all participants recorded the information and data collected. A diagram was designed with the different resources of the areas of interest (vegetation, soil, drainage systems). The different elements like availability of key resources in the region, limitations or problems in the areas observed and changes in the last ten years were discussed.

Informal interviews were conducted on the main livelihood activities, natural resources, employment, and purposes. Later, semi-structured interviews and structured questionnaires on mining extraction and its impact on local economic activities were elaborated. These interviews aimed to collect preliminary information on each activity, and to evaluate the potential options of the villagers. Ninety families, representatives or heads of households participated. The obtained and tabulated data were analysed, and problems and solution options were identified. A problem analysis workshop was held in order to set up an inventory of the main problems and constraints. Then, the information from the questionnaires was analysed to propose some solutions, which could mitigate the problems and limitations of the locations. Throughout the data collection process, several meetings were held with the community members with an interactive participation.

The open-ended and closed-ended questionnaire has been previously prepared by means of informal and semi-structured dialogues. This questionnaire was filled by the interviewers. The simple random method was used in the sampling. The sample size was composed by 170 people (number of people in this zone: 304, with $z1\text{-}\alpha/2$, 95% confidence (1.96), considering a 5% error, and the success rate of 0.5). The community surveys were carried out by environmental engineering students at the Universidad Estatal Amazónica. As the students belong to these communities, they were familiar to the local conditions and language (Kichwa). This facilitated the completion of the questionnaire for the inhabitants who were not fluent in Spanish and felt more comfortable using Kichwa.

Secondary data was also obtained from the sustainable development office, located in San Juan de Muyuna parish. Socio-economic activities were analysed considering their contribution to household livelihood.

2.3 Data analysis

A quantitative approach was used to compare the results of this study. Frequencies, percentages, and means are used in the discussion. For the case of income percentages, the proportional comparison analysis was used through the χ^2 test, and the processing was performed using IBM-SPSS version 22 statistical software (SPSS, 2013).

The collected points with GPS and the digital continental ecosystems of the National Geodesic Institute and the Environment Ministry (IGM, 2016; MAE, 2013) were employed for the location map of San Pedro. The shapefiles were elaborated by considering the location points where the gravel extraction was carried out in the proximity to populated areas and fragile ecosystems. Figure 1 presents the location of San Pedro and areas of gravel mining.

3 Results and discussion

3.1 Socio-economic mining impacts. Income generation through mining

3.1.1 Socio-economic characteristics of the respondents

Table 1 details the percentages of men and women interviewed during the survey and revealed slightly more surveyed men (51%) than women (49%). The average household size was 4.6 people in the community.

The average household size (4.6 people) is slightly more than the average household size in Ecuador which is 4.1 according to the 'National Statistics and Census Institute' (INEC, for its acronym in Spanish) Household Survey of 2010 (INEC, 2010). The surveyed areas showed comparatively higher household sizes because fertility in rural areas tends to be higher than in urban areas that may be associated with agriculture where it is easier to combine child-raising with farm work (Keats and Wiggins, 2016).

The majority of the surveyed persons were under 30 years old and some had no formal education.

3.1.2 Mining as a source of income

The socio-economic impact assessment of the gravel exploitation in the community was carried out by analysing survey data. The following economic activities were reported: service sector, agriculture, mining, livestock, and subsistence activities. Although, some of them were unemployed (see Table 1).

Only 8% of respondents indicated mining activities as their primary income, but several residents reported indirect profits from the extraction of gravel and allied activities such as construction workers. The main economic activities in the studies area are situated in the service sector (including tourism, commerce, public employment, and construction work) and in the agriculture-livestock industry with 42% and 36% respectively.

As a result, mining was not the main economic activity of the local population in San Pedro, but rather a complementary source of income. Although, 36% considered income from mining activities increased economic wellbeing of the community, but the majority (64%) believed the gravel extraction does not generate any profit. At the same time, it can gradually degrade natural ecosystems, which may affect other activities with higher income (such as: ecotourism, etc). The economic impact such as loss of opportunities in activities such as agriculture, fishing, land productivity have been described in studies about mining areas in Ecuador (Adler Miserendino et al., 2013).

A large segment of the population (approximately 15%) is unemployed, demonstrating a higher value than the national unemployment rate (5.3%) (INEC, 2016), which shows the instability of the local economic situation.

Table 1 Socio-economic characteristic and activities of survey respondents (z = 170)

	Number, n	*Percent, %*
Gender		
Male	87	51.2
Female	83	48.8
Household size		
1–3	43	25.3
4–6	108	63.5
7–9	18	10.6
> 9	1	0.6
Education level		
No formal education	67	39.4
Primary	78	45.9
Secondary or tertiary	25	14.7
Age category (years)		
0–18	17	10.0
18–30	105	61.8
30–45	41	24.1
46–55	6	3.5
> 55	1	0.6
Main occupation		
Agriculture and livestock	32	18.82
Mining	14	8.24
Tourism	16	9.41
Small business	21	12.35
Agriculture, livestock or mining	27	15.88
Government employment	17	10.0
Construction work	18	10.59
Unemployed	25	14.71
Total	170	100

Source: Field survey (2015)

3.1.3 Impact of mining on livelihoods of the local population

Approximately 36% of the 170 respondents in the community benefits from the positive impacts identified from different mining activities: 18% employment; 9% road construction, public water supply and the school building; and 9% from the growing local trade (due to the small subsistence businesses).

A subsequent mean comparison analysis (MCA) of the contribution to local income from agriculture, mining and other activities (see Table A1) indicated that the average household income by these activities was US$269.6, US$242.17 and US$297.66 respectively. The results of the comparison analysis showed significant differences

($P < 0.001$) for the percentages in the community. The main income sources are associated with other productive sectors such as public employment, small businesses, and tourism (60%) and agriculture and livestock (29%). Mining activity income only represents 12%. This generally shows that subsistence activities do not guarantee economic stability.

The average income obtained in the San Pedro community (US$281.74) shows a lower income than the national minimum wage. In Ecuador, a family needs US$642.52 per month to live on (INEC, 2014), which means that at least two people must earn US$372.78 each for their financial support. US$281.74 is a deficiency of 57% and this has led to dissatisfaction amongst the families.

These results differ from other studies in the mining sector where this activity is better paid than other employment options in the region, thus some extent the wages earned by mining employees are spent on goods and services produced by the local population (McMahon, and Remy, 2001). Precious minerals have a higher market value and are more demand, but they also provoke greater environmental impacts.

The results indicate that mining activities do not significantly contribute to the incomes of local community. Consequently, a minority of the population receive directly and indirectly an income from the extractive sector. Indeed, the inhabitants of San Pedro look for other opportunities for economic development.

3.2 Environmental impacts of mining

Regarding the socio-cultural impacts, mining activities do not have generated great harm to the community because the extent of mining has failed to reach high levels and remains concentrated in one area of the river. Therefore, there are no negative social impacts in the communities.

Table 2 shows the effects of gravel mining by altering the physical and biological environment according to community perception. Landscape image and river conditions after gravel extraction can also be observed in Figure 2.

Figure 3 Landscape and the conditions of the river, after the gravel extraction (see online version for colours)

Population growth, economic development and environmental degradation are related. The high population growth speeds up economic activities, which could deteriorate the environment due to increased development of construction projects and massive exploitation of natural resources. Likewise, mining activities have significant impacts on the environment (Carrere, 2004).

Mining offers a variety of socio-economic benefits, but if the environmental costs are not well managed it could have huge impacts in terms of soil degradation, forest depletion, habitat alteration (Khater, 2004), as well as water and air pollution (Adekoya, 2003). These factors have negative consequences for a sustainable development, so they require urgent attention.

All physical changes have a direct impact on the biotic environment. Physical degradation damages natural habitats and disrupts natural succession, since, thin film laminate soil erosion changes the natural conditions and alters biodiversity (Khater, 2004). The San Pedro community is known by its rich biodiversity resources. Much of the area is covered by tropical rainforest and the Tena River is surrounded by areas of primary rainforest. The creation of access roads through the forest for dumper trucks and mining machinery would cause a decline in biodiversity. In this sense, one of the main concerns expressed during the transect walk was the great reliance on the natural resources, and the impacts extractive activities have on fishing and natural swimming spots. Leifsen et al. (2017) employed transect walk in order to obtain information on the mining operation in the Tundayme parish, Ecuador, where local farmers and members of the anti-mining association CASCOMI, provided criteria on the socio-environmental impacts of the Mirador project.

According to Ramírez et al. (2009), extraction alters the equilibrium profile of the channel, affects the dynamics of the river, breaks the pre-existing balance between sediment supply and transport capacity. Kondolf (1997) proposes that gravel mining within the stream may induce channel incision, bed thickening, and lateral river instability. The river slopes may cause landslides in the riverbed, loss of vegetation cover and increase erosion. Moreover, the gravel is separated o select the required granulometry in the extraction of the Tena River, the extracted rejection residues are deposited in the lower areas of river. This process has been identified in many countries, and in most of them, the indiscriminate extraction of sand and gravel from rivers imposes irreparable damage on river ecosystems, including their inland water and floodplain areas (Padmalal, and Maya, 2014), bringing with it severe environmental complications including the cutting of canals, widening of valleys, loss of riparian vegetation, head cutting, and undermining of bridges.

The extractive industry causes serious destruction to the soil, damaging soil structure through excavations leading to the loss of the top layer with fertile soil. In this case, the operation is performed on the river slopes causing landslides into the riverbed, loss of plant cover and increased erosion. The extraction remains occupy areas of waste storage on the ground. Soil erosion was the main problem highlighted by inhabitants with 21 inhabitants (12%) (see Table 2).

Mining operations may disrupt hydrological systems as suggested by Darwish et al. (2011) and additionally modify substrates and water constituents (Stehouwer et al., (2006). Sediments in the Tena River were observed in the water by the community. The informal interviews and the transect walks with local population showed that several animal species could previously be seen but they are no longer frequent. According to the criteria of the inhabitants of three tourist swimming spots, located downstream of the extraction activities, have a great affectation on the natural conditions. This problem is mainly due to the presence of sediments removed from the dredging and the passage of trucks inside the river. Twenty-eight respondents (16%) believe that decreased tourism is the main effect of mining, which may be associated with the loss of natural waterfalls and swimming spots and other landscape changes.

Table 2 Main effects on the community from gravel mining according to respondents

Variable *Effect on the community*	*Number, n*	*Percent, %*
Water pollution and destruction of the river structure	33	19.41
Floods	48	28.24
Decreased tourism	28	16.47
Death of aquatic species	18	10.59
Soil erosion	21	12.35
Deforestation	16	9.41
Diseases	6	3.53
Total	*170*	*100*

Source: Field survey (2015)

Thirty-three respondents (19%) from San Pedro believe that water pollution and the destruction of the river structure are the most important impacts of gravel extraction in the Tena River (see Table 2). However, flooding is the greatest concern of the people (48 respondents or 28%). This is caused by the gravel waste accumulation within and along the riverbanks, preventing the natural course river and causing water logging or flooding in higher precipitation rate months. Occasionally sieving activities are performed with the separation of the fractions; subsequently the rejected fractions are deposited in other areas of the river (downstream) and prevent the normal flow stream. Oil or lubricant spills during operation modifies the physical and chemical characteristics of the water (due to the presence of hydrocarbons, grease and oils). Water pollution limits its domestic or recreational use and threatens human health in the region. Only six people (4%) selected a 'disease cause' as the main impact of extraction.

There are no significant damages from air pollution. However, some dust generation and transport vehicle emissions are due to mining activities. This is dissimilar to the study done by Ming'ate and Mohamed (2016), which refers to the large mine extraction which emit significant amounts of air pollutants. Furthermore, noise levels do not directly affect the local population due to the distance of the mining activities from the community, but noise could interfere with the population dynamics of the surrounding ecosystem, although there were no measurements with a sound level metre in this study.

Another severe impact is produced by the new access route to the gravel extraction area, an activity that generates environmental impacts as mentioned by Madadi et al. (2017). The construction of new roads alter landscape spatial patter which leads to habitat fragmentation with an impact on wildlife, can cause vehicle-related mortality, and provokes animal migration to areas far away from forest systems (Gu et al., 2015), noise and smoke from dump trucks and other machinery also affect these populations. These impacts have been quantified in the studies of D'Odorico et al. (2008). Many plant species have also been affected in forest areas where wide openings for the entry and exit of dump trucks were constructed.

3.2.1 Alteration to biota

Despite not being considered by the population of the parish as one of the main impacts of mining (see Table 2), deforestation is the main concern of 16 people or 9% of respondents. Similarly, 18 people (11%) consider loss or death of aquatic species in the study area to be the main impact.

Regarding flora, there are records of endemic species in both the eastern part of the Andes and the Amazon. There are plants with high medicinal and pharmaceutical potential (Cecropia obtusifolia, Croton lechleri, Uncaria tomentosa), timber trees species (Swietenia macrophylla and Cedrela odorata), fruit plants (Inga Sp. and Gasipaes Bactris) and plants with religious-cultural values (Banisteriopsis caapi). These species are widely used by local communities. Thus, the importance of conservation and care should be greater in the Amazonian region of Ecuador.

Regarding wildlife, there are several species of mammals, amphibians, and birds which are endemic or in the protected categories of IUCN Version 3.1. (IUCN, 2007), while the aquatic species, Cetopsis Candiru, is considered an endemic species (Barriga, 2012) and it may be affected by changes in the river characteristics by extraction.

The vegetation elimination and the soil profile disturbs above and below soil habitat (Rinaldi et al., 2005). According to Kondolf (1994) and Padmalal et al. (2008) it may generate drastic changes in the fauna and aquatic flora biodiversity by endangering the several fish and insect species habitats as an important part of other food chains. In addition, Brown et al. (1998) evaluated the direct impacts to fish populations affected by the sediment presence in the extraction operations. Ashraf et al. (2011) describe the impacts on habitat destruction on birds for foraging and nesting. Moreover the noise and traffic of a heavy industrial equipment may discourage wildlife along the riparian zone (Rinaldi et al., 2005).

3.3 Measures, management options and solutions

Mining operations are connected to the local economies consequently creating jobs and personal income. Moreover, it indirectly provides resources to other industries or sectors; in this case, materials for the construction sector. Table 3 summarises measures for the gravel resources management.

Table 3 Measures for the proper management of mineral resources

Measures or actions	*Frequency, n*	*Percent, %*
Plan the operation properly	39	22.9
Limit exploitation sites	25	14.7
Meet established environmental measures	63	37.1
Prohibit any extraction of stone	43	25.3

Source: Field survey (2015)

Protection/conservation/preservation, management, and the rational use of natural resources belong to the most important issues in our world today. The total support of government bodies, economic sectors and academic research institutions is needed for local communities' participation; they undoubtedly play a vital role in solving these issues. Hinton et al. (2003) mention that community performance is important in protecting the environment. The local communities can contribute to the environmental preservation and conservation.

The community's perspective on the gravel resources management was analysed in the region. According to the majority of the San Pedro population, the solution is not to stop the operation but to achieve more sustainable exploitation goals. Table 3 shows that out of 170 surveyed people, 39 (23%) suggest that the activity should be properly planned, 25 inhabitants (15%) seek to limit exploitation sites and move them to less vulnerable areas. Moreover, 63 inhabitants (37%) suggest that the solution to the problem is to respect the established environmental measures. It is a complex issue to stop the activity due to the difficulty in obtaining replacement materials for the gravel, since Padmalal, and Maya (2014) indicate that the extraction of sand and gravel from river sources is done mainly due to the lack of adequate and low-cost alternatives.

Mining activities in Ecuador are declared in the Oficial (2008), in recent years Ecuadorian legislation has focused on regularising and creating a Mining Law or 'Ley de Minería' (Asamblea-Nacional, 2009) and subsequently a Mining Activities Environmental Regulation or 'Reglamento Ambiental De Actividades Mineras' (MAE, 2014) in order to prevent extractive activities without proper conditions. The state has legal title over all mineral substances and deposits with the preference to exploit such natural resources (Borja Calisto, 2019). The current Constitution mentions that each Municipal Government will assume the responsibility to regulate, authorise and control the exploitation of arid and stone materials found in riverbeds, lakes, lagoons, sea beaches and quarries (within the framework of Article 264). Furthermore, chapter III of the Mining Law deals with construction materials, and consider governments the activity of Temporary Free Use of Construction Materials for Public Works in order to exploit these resources directly through state-owned companies or through its contractors/private parties (Art 144, Mining Law).

Mining activities are mainly regulated by the Ministry of Energy and Non-Renewable Natural Resources, the Mining Regulation and Control Agency (ARCOM), the Ministry of Environment and the Water Secretariat (SENAGUA) (Borja Calisto, 2019).

Environmental impact studies in the exploration phase, environmental management plans in advanced stages, and subsequent exploration become obligations to prevent, mitigate, monitor, and repair the environmental and social impacts of extractive activities. Therefore, these regulations should be fulfilled as a vital task in the areas of exploitation (Asamblea-Nacional, 2009; MAE, 2014). Nevertheless, the Environmental Management Plan often does not really focus on the conditions of the site. In addition, the regulation process should contemplate other articles mentioned in the constitution: communities must be consulted before the establishment of extraction projects (Art. 57, numeral 7, and Art. 400) and have the right to oppose (Art. 98), although this approach is taken towards mineral extraction. Furthermore, the Art. 3 (numeral 1.), 12, 13, 32, and 66 (numeral 2.) (constitution), grants the right to access to health, food and nutrition, drinking water, environmental sanitation, among other, which can be altered by extraction activities.

4 Conclusions

The utilisation of natural resources has caused different environmental damages. This study has analysed the socio-economic and associated environmental impacts of gravel mining in the Tena River in San Pedro, Napo, Ecuador. Although it is not the primary economic occupation for most of the local people in the region, mining provides essential supplementary income. The economy of the region presents great difficulties with employment generation and family income which leads to the natural resource's overexploitation. In terms of environmental impacts, the perception shared by local communities shows that mining has caused the alteration of river courses, landscape alteration and flora and fauna damage of the local Amazonian ecosystems. It is recommended to compile together a flora and fauna inventory to allow the evaluation of ecological importance and diversity indexes.

Despite the environmental pressures on ecosystem resources, the community is in favour of the proposal to implement a gravel mining plan. The villagers argue that it should be done with proper treatment, including waste disposal and compliance with established environmental measures to avoid the risks of flooding and direct damage to the environment. In addition, income-generating activities such as ecotourism, agriculture and small-scale agricultural industries should be promoted in order to reduce pressure on mining, and improve the social, economic and environmental management of natural resources. Furthermore, it is suggested that these things can be looked into in future studies in the area.

The regulatory framework for mining in construction materials is quite permissive, and governments can extract gravel from rivers, depending on their needs, which affects the quality of ecosystems, so regulatory frameworks should be much more severe or value the areas of exploitation, affected communities and socio-economic impacts.

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Appendix

Table A1 Analysis of the contribution of economic activities to total household monthly incomes

Source of income	*Media*	*N*	*$*	*%*	*Standard error and significance*	*Minimum*	*Maximum*	*Range*
Agriculture	270	51	13,750.11	28.71	±0.21	160	700	540
Mining	242	23	5,569.91	11.63	$P < 0.001$	180	300	120
Other activities	298	96	28,575.36	59.66		50	650	600
Total	*282*	*170*	*47,895.38*	*100.00*		*50*	*700*	*650*