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Local Knowledge of Sediment Exploitation in the Usumacinta River Basin: A Theoretical–Methodological Framework Proposal

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Abstract: According to the United Nations Environmental Program, sand is the second most exploited resource on the planet after water, and local knowledge about the effects of sand mining has been little addressed in international studies. In the case of rivers, the sand and gravel used in the construction industry are part of the fluvial sediments, and the effects are different at each exploitation site. In this article, we propose a theoretical–methodological framework of the sandy field of forces for the study of the socioenvironmental aspects related to the extraction of sand and gravel at the site known as La Isla, located in the Usumacinta River Basin in Mexico. This site has specific environmental and social characteristics. Based on the results of our participation in a research project and, subsequently, on the theoretical, conceptual, and methodological thinking for the social analysis of this site, our model demonstrates how the environmental and anthropic systems converge upon the use of sediments. We conclude that social interactions articulate the conditions of the specific context. The sandy field of forces is the reference context in which the local practices of the actors regarding the use of sand and gravel make sense.

Keywords: sandy field of forces; sand mining; sediments; aggregates; local actors; Tenosique; Usumacinta River Basin

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1. Introduction

The worldwide demand for sand has increased over the last decades [1]. In 2022, the United Nations Environmental Program (UNEP) estimated that 40 to 50 billion tons of sand are extracted every year at a global level. This amount is equivalent to approximately 18 kg per person per day [2]. Although sand is the second most exploited resource on the planet, following water, the impact of the extraction of sand remains unknown [1].

In the second half of the 20th century, the rise in urban growth brought about an increase in the prices of construction aggregates because of the expansion of cities onto suburban lands, which have been the sources of these aggregates [3]. The growing distance from these sources of available sand added to the increase in demand derived from urban growth. The search for solutions to this problem gave rise to a body of literature with an economic focus that utilized the idea of aggregates in the United States, especially those of crushed stone [4,5]. As a result, the increase in the extraction of sand, gravel, and crushed stone brought about environmental impacts at the myriad of extraction sites. The production of aggregates is a widely dispersed industry. In addition to quarries, these sites

include stream deposits, alluvial fans, glacial and fluvial–glacial deposits, coasts, rivers, and volcanic deposits [6].

The idea of sand mining arose in the 1990s and has gained popularity since the beginning of the 21st century because of its focus on environmental impacts, giving rise to social conflicts and the consequences of overexploitation of sand for national industries and economies [1,7–9].

Although there are no exhaustive reviews of the historical development of the uses of aggregates or sand mining in general, both represent academic positions for addressing problems of the supply and extraction of sand, gravel, and crushed stone. Aggregates are commodities necessary for the construction industry from an economic point of view [1] while, to a larger extent, sand mining addresses the extraction of sand from any source for various uses in the industry, with a particular environmental perspective [10].

Other ideas that have arisen over the last decades of the present century consider sand extraction in terms of the extraction of mineral aggregates used in the industry and their effects on the socioenvironmental economic flow as part of capitalist expansion [11]. In addition to having economic and environmental impacts, the extraction of sand is a lucrative business linked to corruption and local processes that have given rise to scenes of violence and organized crime in areas of high demand [12,13].

Nowadays, the international literature upholds the idea that the sand crisis is a result of growing demand, especially from the construction industry [1,2,11,13]. We must consider the fact that "the extent of the impact depends, in part, on the kind and intensity of extraction, the fragility of the various elements of the ecosystem and biodiversity, and the specific matters of each country" [14]. Nevertheless, at the core of this discussion lies the paradox derived from the utilization of sand for human needs and the negative impacts of our great demand.

Existing approaches to studying the problems associated with the extraction of sand represent frameworks for studies of the relationship between the global industry that demands sand and the analysis of specific cases in areas of high [1]. In this scenario, the local configurations, in terms of social content due to the extraction of sand, are still unknown [1]. Exploitation of local spaces and their specific interactions contribute to the construction of knowledge, especially in sand extraction areas with low demand and limited industrial activities.

Approaching the problems of sand extraction from the perspective of local spaces implies searching for perspectives that explain the particularities of the processes involved as well as understanding extraction as a socioenvironmental relationship. This relationship goes beyond the dynamics between global demand and local effects in terms of the intensive exploitation in areas of extraction with specific characteristics.

To that effect, it is worth mentioning that in 2018, a group of researchers used the socioecological and interdisciplinary concept of sediment to create proposals for an integral evaluation of the components located in the Mexican section of the Usumacinta River Basin [15]. A specific concern for this research group consisted of the local relationships based on one supply source: the river. Immersed in the fluvial system, sand, to a considerable extent, makes up the sediments of rivers with special importance to the connectivity of ecosystems [16]. River sediments are the result of soil erosion due to physical or chemical processes occurring in the river's currents. Sand and gravel are the kinds of sediments that are attractive to the construction industry [10].

In southeastern Mexico, the Usumacinta River Basin possesses specific characteristics owing to the kind of settlements present, the volume of extraction, and the demand for sediments as well as its specific geospatial particularities, which we will discuss later. Overall, these characteristics allowed us to address the exploitation of resources from a point of view that is different from that of the "sand crisis" seen in the international literature [17,18]. From the perspectives of the basin, the existence of local and state regulations, the mobility of the actors, the methods of extraction, as well as the varied environmental impacts and

the emergence of certain conflicts, we characterized the extraction of sediments from the Usumacinta River as a heterogenic activity [19].

1.1. Elements of the Local Exploitation of Sediment

La Isla is a specific case located in the municipality of Tenosique, in the state of Tabasco. In La Isla, the extraction of sand and gravel sediment is semi-artisanal. The areneros are the persons who extract sand from the river, and they are members of a cooperative. The cooperative business is a legal entity and a form of social organization based on common interests and the principles of solidarity, individual efforts, and mutual help. The aim of these organizations is to satisfy individual and collective needs through the economic production, distribution, and consumption of goods and services. The cooperative of the areneros of Tenosique is based on this organizational framework for conducting activities of exploitation [20]. For the extraction and marketing of sand, the members of this organization interact with other groups such as ejidos (a form of collective social landholding handed down from the Mexican Revolution, based on rural lands organized collectively with an assembly of holders with rights, known as ejidatarios. In 1994, the ejido was converted into private property because of a constitutional change, although the social organization of the structure remained [21]), government offices, a transport union, and construction businesses at the local level that look after local and regional demand.

In this interaction between the organizations that exploit the sediments, there are occasional conflicts despite the existence of a series of contradictions among the actors (members of the cooperative) or among the organizations. The workings of the system of rules and agreements governing the use of the Usumacinta River sediments, as well as the cumulative experience developing this activity, allowed us to observe a specific area of local construction in which environmental and anthropogenic factors converged without the presence of large industries.

Based on the characteristics of the site, to understand the local reality in terms of social interactions, we needed to build a perspective of the specific context. This perspective allowed us to reconcile the knowledge of the functioning of sediments as components of the ecosystem and the social processes that are more complex than the practical knowledge derived from disciplines such as geomorphology, hydraulics, and geography.

1.2. Laying the First Stone

The theoretical and methodological approach to assessing the exploitation that we discuss in this paper sprang from our question of how the sandy field of forces that was derived from the exploitation of river sediments at the local level was built.

With this in mind, and in order to learn the forms of local social interaction surrounding the exploitation of sediments, we constructed a theoretical–methodological model to contextualize the local problems brought on by the exploitation of sand and gravel. Our idea is that the model will help us understand the exploitation of sand and gravel within the context of the specific conditions under which certain forms of social interaction are possible.

The approach was designed based on qualitative fieldwork on the described semi-artisanal exploitation between 2018 and 2022, in addition to information from institutions and interviews with civil servants concerning the extraction of these resources. The theoretical considerations came from our participation in a research project [15] and later discussions among the authors between 2020 and 2022.

In the context of the exploitation of sediments, we conceived a space in terms of context and content that we call the sandy field of forces. The sandy field of forces is an objective and subjective contextual space inspired by the interaction between the natural and the anthropogenic systems, but is based on natural elements. With this, we aimed to understand the multiple relations within which the local space is constituted and operates

based on the utilization of fluvial sediments. This is a perspective that we hope will create new lines of research and methodological aspects.

The word *arena* in Spanish has two meanings. The first concerns the resource or construction material, equivalent to the term in English. However, the second relates to a symbolic dimension understood as a metaphor of field or as the spatial–material and symbolic framework for the study of social relations. In this paper, we adopted the word sediment to refer to the sand in its material meaning. The notion of the sandy field of forces refers then to the framework consisting of the confluence of environmental and anthropic interactions by which the actions of local social actors are articulated for the exploitation of natural resources, in this case, the exploitation of sediments.

Following this introduction, Section 2 describes the materials and methods as well as the case study presented in this paper. Section 3 contains the results and a discussion of the conceptual and relational structure of the contextual model of the sandy field of forces for the local study of the exploitation of sediments. Section 4 concludes that the sandy field of forces as a context is constructed based on the values assigned to the quality of the sediments produced according to their function within the ecosystem. This made it possible to consider the problem of exploitation from its constitution as a scenario of social interaction within a local space.

2. Materials and Methods

2.1. Case Study

The Usumacinta River Basin (Figure 1) is shared by Guatemala, Mexico, and a small portion of Belize [22]. The basin has a complex fluvial network that includes 22 tributaries in addition to the Lacantun, La Pasion, and Chixoy Rivers. Its total area is 77,435.9 km^2 divided into upstream (27%), midstream (40%), and downstream (33%) sections. This distribution was created because of the geographic, environmental, social, and political diversity that comprise a complex reflection of the global system [22,23]. In Mexico, this shared basin is found in two states, Chiapas and Tabasco, mainly in its middle and lower sections [24].

About 83% of the basin is in danger of medium to high levels of erosion. This is in part due to productive activities of extensive cattle grazing (64%) and agricultural activities (36%), which are carried out on five types of soil with high rates of erosion. These are made up of gleisoil and vertisol (29%), fluvisol (21%), luvisol (14%), and regosol (7%) [22]. The rainy season occurs between July and February and the dry season lasts from March to June. During the rainy season there are extensive floods, erosion, and silting [25]. Because of these characteristics, in mountainous areas the rainfall reaches 550 mm. The environmental conditions and the balance of components such as the soil, vegetation, and topography contribute to the rate and volume of runoff, as well as to the rate of loosening and silting of sediments [22,25].

In the lower basin, the silting of sediments in suspension is controlled by the flow of the basin, which contributes to the characteristic silting of this component [26]. In general, in terms of pollutants, the water of the lower basin is not fit for human consumption and does not protect aquatic life. However, these findings corresponded to the time of the study, while throughout the basin the quality of the water depends on the time of year, its geographic location, and the kinds of anthropogenic activities carried out in that section [26,27].

According to the Constitution of the United States of Mexico (CPEUM), the Usumacinta River is a national resource and is administered by the federal water authority, La Comisión Nacional del Agua (Conagua) (National Water Commission) as established in the Ley de Aguas Nacionales (LAN, Law of National Waters). Since 1992, but especially since the constitutional reforms of 2004 to the said law, deposits have been administered through concessions for extraction and are called petrous materials, according to Articles 113 and 113 Bis, which assign rights and obligations to physical and moral persons [28]. Among the 13 sites for the exploitation of sand and gravel identified in the basin during the Val-

Uses project between 2018 and 2020 [29], one of the main points of interest was near the municipal seat of Tenosique in a place called La Isla. This is located in the lower basin, which begins in Boca del Cerro, at the end of the Usumacinta Canyon, a Protected Natural Area the river passes through.

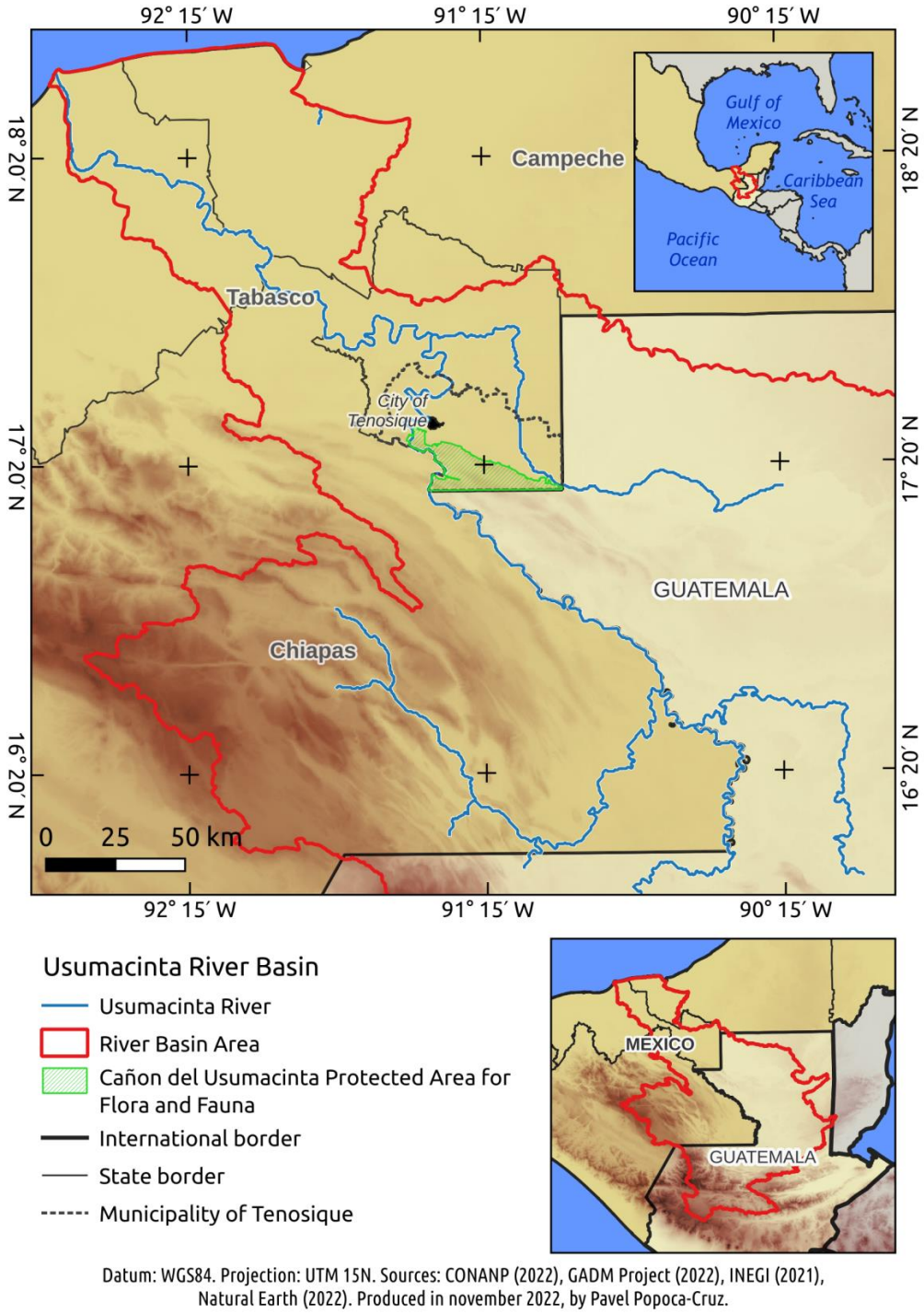

Figure 1. The Usumacinta River Basin and the municipality of Tenosique in the state of Tabasco, Mexico.

La Isla is a local and regional site of sand extraction by means of semi-artisanal exploitation. In this process, there is participation by areneros, members of a cooperative who are dedicated to the extraction and sale of sand and gravel, or barqueros, who are often subcontracted in this process to carry out the extraction with buckets and steer the boats

carrying these materials to the shore. The areneros have extracted and sold sand and gravel from the river for more than five decades. They are organized in a cooperative society that includes residents from three towns on the banks of the Usumacinta River, Pomona, El Faisan, and La Isla. The latter derives its name from an island in the middle of the river and comprises the area of exploitation in the municipality of Tenosique. The extraction takes place in the riverbed using instruments such as fiberglass boats or cayucos (dugout canoes made from boards or the trunks of large trees), sticks, and buckets that are submerged to reach the sediments on the river bottom. Other instruments are also used, such as washing machine tubs, adapted with a mechanism of pullies for raising the material from the river to the banks. The system is complemented by an adapted motorcycle engine. Before the use of these motors, horses or the areneros themselves carried the containers. To raise the material, sometimes family members, such as wives, sons, daughters, and even children, participate in activating the system of pullies on each trip the boats make.

The activity of taking sediment from the river and keeping it on the banks is identified as the extraction of stone material according to the law. However, there are other activities and other actors involved in this activity. Thus, we call the entire operation a process of exploitation. The material is stored on the banks of the river and in situ. The areneros negotiate with the buyers or search for possible buyers in the municipal seat of Tenosique. These buyers may be volqueteros (truck drivers belonging to the transport union), the people responsible for construction sites and businesses, or individuals who use the sediments for small jobs.

The rules governing the activities of extraction have two origins: the legal framework and the local rules. The cooperative and the union govern via constitutive acts and agreements made in the assemblies; the businesses via hierarchies; the public servants who are involved via the laws and rules of the three levels of government, such as the LAN, Ley General de Equilibrio Ecológico y Protección al Ambiente (LGEEPA, General Law of Ecological Equilibrium and Protection of the Environment), and municipal rules in the case of municipal employees. Other rules that may only be followed in keeping with the activities and the participation of the actors involve local agreements on salaries and prices; agreements on buying, fines, and the distribution of space; and the rights of activity among areneros.

Thus, here we find the specific conditions of the technological transformation of the extraction techniques, the forms of organization for conducting a commercial activity as set down in the law as well as by several decades of continuous extraction. La Isla in Tenosique was key to our study since the commercial activity that takes place here differs from the intense activity driven by large global industries, as seen in the international literature [1,2,8,11,17]. The local agreements are the center of the full process since they are made in situ based on the general schemes of regulation and with respect to immediate problems. This is a characteristic of the extraction sites in the Usumacinta River Basin [30]. Nevertheless, the geographic location of the sites in Tenosique provide it with certain characteristics of quality, accessibility, and nearness to the consumption centers in the municipal seat of Tenosique (see Figure 2).

Extraction takes place along approximately seven kilometers of the Usumacinta River, located between Playon de San Antonio and El Recreo. However, today, the areneros also extract sand from a site located between the town of Pomona (point 1 in Figure 2) and El Faisan (point 3 in Figure 2). The rights held by the areneros for carrying out extraction in this area were obtained in two concessions granted in 2010 by Conagua to the cooperative to which the areneros belong. The authorization is for the sites of Playon de San Antonio and La Isla.

As seen in Figure 2, the only route of access from Tenosique to Pomona and La Isla is via the Boca del Cerro bridge and the piers in Tenosique, which is the municipal seat and the largest center of population, development, and urban infrastructure in the region. In the middle of the river, we find an island that is one kilometer long and 100 m wide and has important techno-environmental implications since, according to the geomorphology

of the site, it contributes to the deposition of certain kinds of sediments that are washed in by the natural hydrologic work of the current and riverbed.

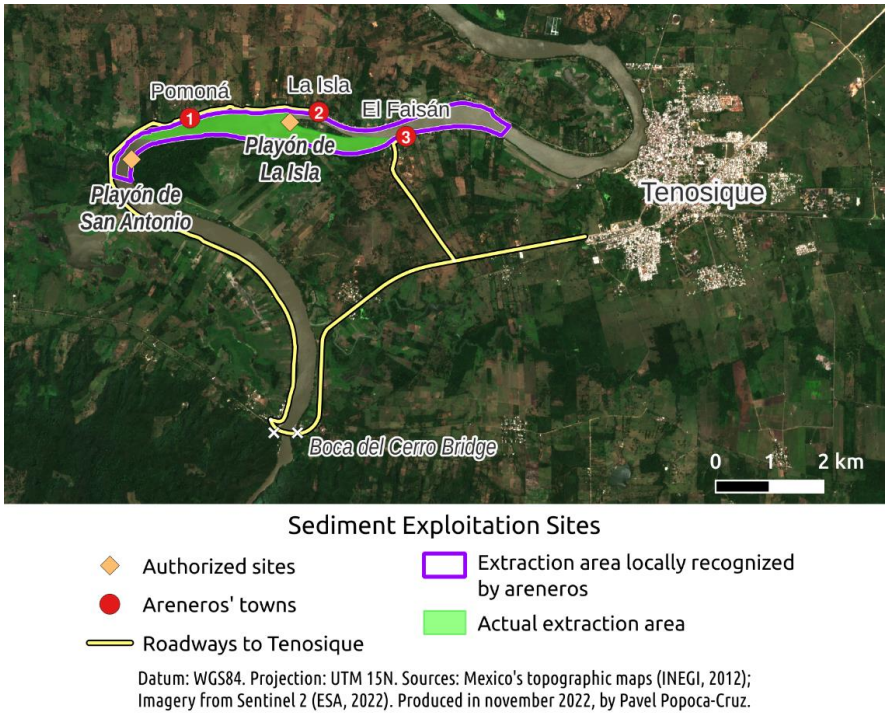

Figure 2. Sediment exploitation sites in the municipality of Tenosique.

In Tenosique, the Usumacinta River has a liquid flow with balanced sediment in suspension, with a drag-out volume that is greater during the rainy season [26]. The production of sediments and their quality depend on various conditions of the workings of the ecosystem components, as well as their relation to anthropic activities [25]. We should point out that this river has no dams in the Mexican section, and thus the natural runoff produces sediments in keeping with its dynamic flow. Similarly, the social conditions of the sediment extraction activities are influenced by environmental aspects linked to the production and kinds of sediments, their quality, demand, and other aspects associated with the exploitation process and the various actors involved.

Along these lines, the theorical–methodological approach allowed us to suggest the environmental and anthropic aspects as a framework of the local characteristics and of the specific activities of local actors. Disciplines such as anthropology, ethnology, history, and environmental knowledge were organized and integrated based on Systems Theory. This way of thinking allowed us to categorize local activities as an interpretation of reality and as an abstraction of the same system. In this sense, our proposal captures abstraction from reality because of the iterative fieldwork. We assume that this approach will help us to conduct a deeper analysis of the utilization of the fluvial sediments in La Isla based on its own features. If possible, the aforementioned model could be adapted for other cases in the basin or for other sites with similar conditions.

2.2. Data Collection and Analysis

This qualitative proposal was based on the iterative process of the empirical activities and the investigative process (Figure 3). With qualitative methods, "it may be fundamentally argued that, in order to understand human conduct, it is necessary to understand the framework in which the subjects interpret their thoughts, feelings and actions" [31]. Thus, our proposal was constructed as a rapprochement with the actors in their local scenarios based on the context constituted by both the environmental and anthropical aspects.

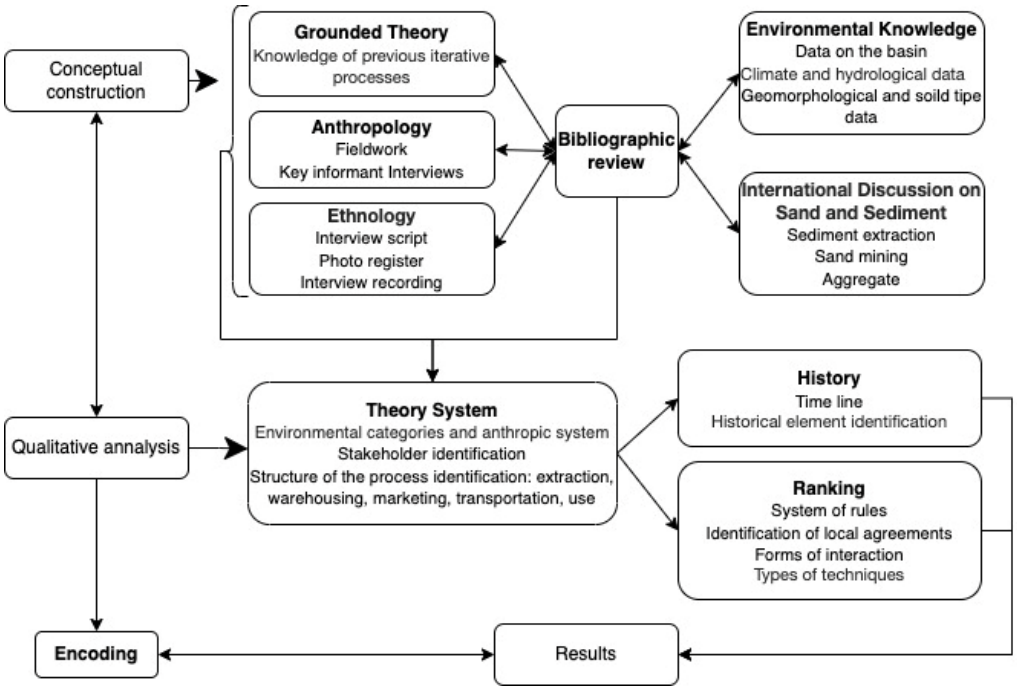

Figure 3. Methodological interpretation of the problem of the sandy field of forces. Source: Our own elaboration, 2022.

We understand that the construction of problems in social relations is a product of the organization and interaction among actors, who order the world in keeping with the schemes of reasoning provided by their contexts, interests, or intentionality [22]. Thus, we must analyze the problems within their spatial context [32].

From this perspective, we decided to identify the exploitation process and its categories as the sandy field of forces from the point of view of the use of sediments within a multiple reality. The local actors conduct various practices to achieve their individual and collective objectives based on a contextual dimension that is historical, reflexive, and discursive.

The methodological model was the result of the use of various instruments. These were structured based on a review of the global context of the exploitation of sand and the local context we found in the activities in Tenosique. As shown in Figure 3, there were three important moments of construction of the proposal at the local level: the process of the conceptual construct, the analysis, and the codification.

The fieldwork and information gathering were carried out within the framework of work 5 of the research project "From Traditional Uses to an Integrated Valorization of Sediments in Usumacinta River Basin (Val-Uses), between June 2018 and March 2022, in which the first three authors of the present article participated. Thus, this proposal made use of Grounded Theory (GT) [26].

GT allowed us to iteratively incorporate previous local knowledge in the theoretical and methodological construction by means of a constant comparison of data [31,32]. Some of the techniques used in social science and instruments from anthropology were also used during this process. These included field work and the identification of the key informants for attaining information. As part of the structure of social relations surrounding the exploitation process, we sought to identify the actors, the ties, the hierarchies, and the roles they played.

The field data were obtained during seven visits to the Mexican section of the Usumacinta River Basin between the states of Chiapas and Tabasco (Table 1).

Table 1. Field work conducted in the Mexican section of the Usumacinta River Basin. Source: Our own elaboration, 2022.

Area Visited	Date
Downstream, Tabasco	June 2018 April 2019
Midstream, Chiapas	June 2019
Midstream and Downstream, Chiapas and Tabasco	February 2020
Downstream, Tabasco	December 2021
Midstream, Chiapas	February 2022
Downstream, Tabasco	March 2022

The main objective of the Val-Uses project was to conduct inventories and descriptions of the past and present uses of the sediments in the basin. Aside from this, we hoped to determine whether these uses contributed to the local and regional economy. We also identified the existence of community organizations for the extraction and use of the sediments. We were seeking to determine the underlying social relations [15]. To this end, we used semi-structured interviews to identify the following actors: civilians (citizens and businesses) and institutions (local, municipal, state, and federal) involved in the management of river sediments. We also hoped to learn about the regulations on the use, handling, and protection of sediments.

With these objectives in mind, between 2018 and 2022 we interviewed more than 50 key actors: areneros, truck drivers, municipal authorities, directors of the cooperatives and unions, ejido authorities, and others in the community associated with the exploitation of sediments. The interviews were recorded on our cell phones with the verbal consent of the informants. The field work included a photographic registry to document the various steps of the process as well as some features of the geographic space where the activities of sand extraction were conducted.

We asked the Plataforma Nacional de Transparencia (PNT, National Platform for Transparency) for information about the extraction of sand and gravel in the basin in 2017, 2018, 2019, and 2021. The information came from the institutions in charge of the environmental evaluation, concessions, and monitoring of these activities. We solicited Conagua, governed by LAN, for information on the titles of the concessions it had granted or those found to be active in the basin of the Usumacinta River between 2000 and 2017, 2018, 2019 and 2021. We also sought information on the authorization of environmental impact granted by the Secretaría de Medio Ambiente y Recursos Naturales (Semarnat, Ministry of the Environment and Natural Resources) along with information on any fines, conflicts, or closures from the Procuraduría Federal de Protección Ambiental (Profepa, Federal Bureau of Environmental Protection), with both of these latter institutions governed by the LGEEPA.

In addition, we reviewed the Internet portals in relation to the concessions granted by Conagua, the Registro Público de Derechos de Agua (REPDA, Public Registry of Water Rights), and the Sistema Nacional de Trámites de la Semarnat (National System of Procedures of Semarnat). The information from these two sources was permanently contrasted to locate contradictions or missing data.

In a parallel process and in constant reciprocity with the field work and the information from government institutions, a national and international bibliographic review was conducted to learn the status of problems associated with sand extraction. In approaching the state of the art of sediment extraction, we searched for information on bodies of water on platforms such as the Web of Science (WOS), JSTOR, Redalyc, EBSCO, and Google Scholar. To this end, we used the following terms: sediment, sediment extraction, sand, and aggregates in English as well as in Spanish. We found few references to social matters

related to the extraction of these components in rivers. For example, on the WOS platform, the word "sediment" brought up 357,177 results, of which the main disciplines with publications were Environmental Science (94,961) and, in second place, Multidisciplinary Geoscience (86,979). The scope of this research was pollution, erosion, and the production and transportation of sediments based on the technical aspects of these activities. From the point of view of the social sciences, these references provided little information regarding the activity of sediment exploitation in rivers.

Based on the identification by the UNEP [27] report, we ran a search on "sand extraction" and added "sand mining." In WOS we found 6611 publications in which, once again, Environmental Science was dominant with 1580 results and Multidisciplinary Geoscience had 1206 results. The search was again narrowed to find publications relating to activities in rivers. The information was concentrated in the Mendeley platform for analysis.

As an independent line of investigation related to the social interactions surrounding sediment exploitation, we continued with the case of La Isla. From 2020 to 2022, the four authors participated in a specific analysis integrating the theoretical–methodological proposal of this article. Thus, previous information obtained from the Val-Uses project was derived from an investigative work on the specific site of La Isla.

Since then, we incorporated aspects of Systems Theory (ST) to create categories of the environment, such as climate hydrology, rainy and dry seasons, runoff, kind of soil, and erosion, along with anthropic categories: population, towns, communication, and kinds of activities related to the extraction, its stages, and the kinds of actors involved, all in relation to the case of La Isla, Tenosique. These also included the identification of key actors and the structure of the exploitation process that was taken from the Val-Uses project [15], divided into five stages: extraction, warehousing, marketing, transportation, and uses.

With the inclusion of historical dimensions in our analysis [33,34], social information about those referents was found. We found these important when dealing with sediment exploitation in Tenosique. For example, the construction of federal works in the 1950s [35] was less related to the present activity than would be expected based on evidence found in the international literature on an intensification in the demand for aggregates. With this technique, it can be seen how, when talking about the past, individuals categorize events in relation to present-day conditions in such a way that they not only contextualize the space for the analysis of documents and field work, but also for the categorization of the aspects that are considered important and not important. The historical perspective helped us realize that within the proposal of the sandy field of forces, not all the objects formed part of that activity, despite their proximity.

Codifying the information took place as a process parallel to the analysis but with an emphasis on the results. In the first place, the information on each site in the basin had to include social–political and social–environmental details. In the second place, we assumed that the results should consider aspects associated with the confidentiality of the actors because of security and ethical issues. The proposal of this document, which is specific to Tenosique, did not require codifying the site since it was already local and regional knowledge, besides being registered with the corresponding institutions. Thus, the codification was only for the specific actors.

In this article, the space of sediment exploitation makes up the context in which the process of sediment exploitation takes place. In this sense, the exploitation is not conducted in an abstract scenario, but rather within the framework of the interaction between the environmental and anthropic scenes. Thus, based on this, the proposal was defined as a perspective on the sediment and the ways it was utilized in terms of social science, which involves an interactive confluence of systems that make up the context with characteristics specific to each place and its conditions. Based on these elements, the constitution of the space was interpreted as a basis for the existence of the social, political, economic, and cultural processes that are built around the local exploitation of sediments.

The proposal we present in this article is part of a first level of the abstraction of the empiric reality of sediment exploitation. Thus, we proposed the formulation of a model

that reflects the reconstruction of a local context of sand and gravel exploitation in the site of La Isla, Tenosique. For methodological precision, we used the draw.io program to create the figures in this paper. In the following section, we will describe the theoretical and conceptual contributions that structure the model for the analysis of sediment extraction, which involves adopting a different methodological approach adapted to the local reality of the case in study.

3. Results and Discussion

Local sediment exploitation takes place within the context of environmental and anthropic interactions. These are the conditions that characterize the kind of exploitation in technical terms as well as the strategies utilized by local actors. While there are no measurements of the volume of the sediment in the river at the site of La Isla, it provides an important concentration of sand, gravel, and pebbles. The geotechnical classification of the sediments at this site indicates that their concentration is in proportions of less than 15%. Of this 15%, 65% is fine sand, and silt comprises between 40% and 84%. Organic material is less than 6% and pollution is below the limits of detection. Thus, the sediment is not considered to be contaminated [36]. Nevertheless, La Isla has important concentrations of sand and gravel that the local inhabitants say is of good quality for use in construction. Tenosique is in the lower stream, near the limits of the middle of the stream. It is above the delta where the river empties into the Gulf of Mexico and where the quality of the sediment changes, having a higher concentration of clay [36].

The uses of the sediments in Tenosique are related to their physical properties. Sand and gravel are in demand for developing local and federal construction jobs in the municipality. As previously stated, the demand for sediments from this site is local and regional, it being near the municipal seat, which is the main population center with a growing urban infrastructure. Sediment extraction began for local, private use as landfill in houses on the banks of the river and in the municipal seat. Municipal urban development and the kind of sediment deposited in this site have satisfied the local and regional demand since the last decades of the 20th century. With increased demand, local inhabitants have organized into a cooperative for sediment extraction. This was possible because La Isla meets all the criteria of accessibility, quantity, and quality required for a small local industry. Nevertheless, extraction activity was not new, and we can only assume that the factors relating to extraction intensified based on the volume required and the search for ways of organization to provide sediments within the technical capabilities of the local areneros to meet local and regional demand. However, despite the economic activity, the local areneros have not accepted the introduction of machinery, which they say would have negative effects on their organization and the environment.

In this respect, aspects within the environmental and anthropic context constitute a scenario of sediment exploitation in La Isla on the Usumacinta River. The natural production of sand and gravel sediment deposited at this site by fluvial dynamics makes it possible to meet the demand. On the other hand, the social–political relationships among various social actors exist where these conditions converge: the natural production of sediment and the need for material for the construction industry. As a result, prior to our analysis of the sociopolitical aspects of sediment exploitation on La Isla, characterized by schemes of personal use and low demand (different from the intensive demand or the existence of large construction industries documented at the international level), we decided to build a conceptual and methodological base. The purpose was to analyze and understand the social forms of sediment exploitation as explained through the context of local conditions.

The starting point for this base was locating the interaction between the environmental and anthropic aspects as seen in Figure 4. Over the past decades, a broad view of the concept of sediment considering the environmental and anthropic processes in terms of a system has formed, which must be understood within the environmental framework. This is significant because, while the concept of sediments is a reference [37,38] to certain

kinds of material, it also recognizes the function of the environmental system. It is not considered one more element that is a result of fluvial dynamics, but is a component of the environment that allows us to understand and document other processes in relation to broader special and ecological levels.

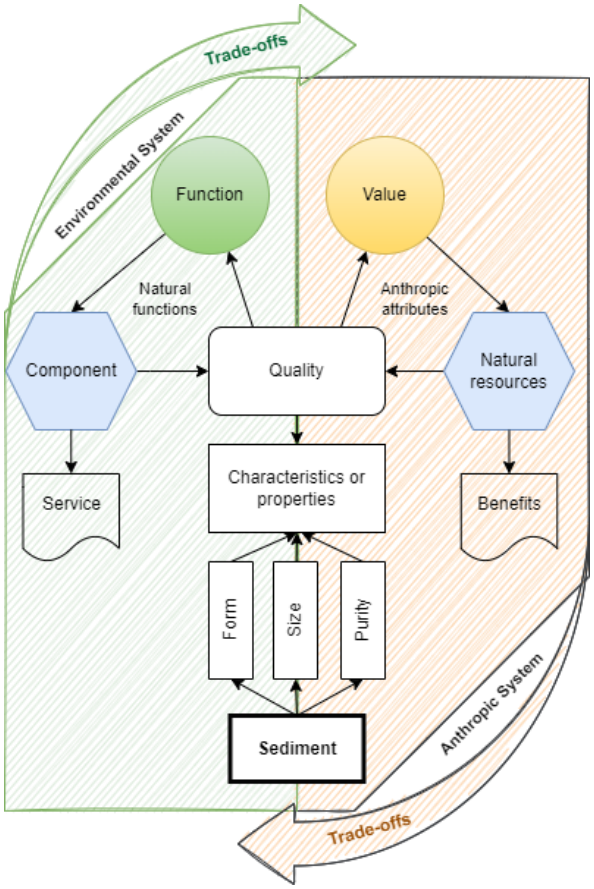

Figure 4. Natural and anthropic system interactions based on the quality of fluvial sediments. Source: Our own elaboration, 2022.

The references to sediment are varied in academic literature. In geomorphology studies, these are known as products of fragmented rocks, despite their physical–chemical qualities, transport processes, and deposition in water [39]. However, this strictly hydrological vision is insufficient since, in general, water transports dissolved substances, organic particles, and mineral material that is actually sediment in suspension [16].

Disciplines such as hydraulics and geomorphology specify certain qualities of sediments depending on their shape, size, and purity. These are the characteristics used to classify certain sediments such as sand, gravel, pebbles, stones, mud, and silt. The properties of shape, size, and purity are acquired in relation to the ecosystems that produce them. Several factors intervene in the process, such as the fluvial and geomorphological characteristics of the river, as well as aspects of the composition and size of the basin [40–42]. Of course, human activity also influences this, as can be observed in the different sediments transported by a dammed-up river and a free-flowing one. The variability of production and the transport of sediments depend on the presence of hydraulic works such as dams, which impact the habitat and alter the geomorphology of rivers. Reforestation, deforestation, and the growth of urban areas promote the processes of erosion and thus contribute to intensifying the blockage of rivers and the increase in delta sizes, which are of vital importance for biodiversity and costal societies [43].

In fluvial geomorphology, the connectivity and interaction of ecosystems associated with sediments are categorized depending on their capacity for production and sedimen-

tation. However, we must not lose sight of the fact that sediments are components of the ecosystem, while at the same time being historical references or documents of nature that illustrate a complex environmental system of great dynamics and change [16,39,40].

In a river such as the Usumacinta, the presence of sediments depends on the functioning of the ecosystem. Large sediment forms the physical structure of the aquatic habitat of various species and constitutes the substrate for the development of vegetation and the habitat for benthic fauna. The finer sediment is food for some organisms and nesting grounds for certain animals, among other functions [44]. As a component with certain functions that maintain the balance of the ecosystem, it forms part of the environmental services [40]. However, environmental services are seen in terms of anthropic benefits and not produced intentionally by nature to favor humans. Thus, in the functioning of the ecosystem, the quality of the sediments plays a key role. Quality refers to the characteristics of shape, size, and purity related to the aspects of production, flow, and sedimentation. As products of a process of the ecosystem of fluvial dynamics, the function and diversity of sediments are associated with their quality.

Natural resources are traditionally classified as renewable or non-renewable. However, these dichotomous categories are associated with a quantity. A natural resource is considered renewable if it can be exploited to the point of being scarce, while a non-renewable resource subject to moderate exploitation maintains availability depending on its demand [45]. This reasoning allows us to observe that even when natural resources have an economic sense, the value assigned to them corresponds more to the conditions of the extraction site than to their importance for industry or the economy in general.

In keeping with our theoretical–methodological model, it is the functioning of the anthropic system that assigns a value for the use or change and for the function as a component of the environmental system with benefits for humans. As long as the function influences the kind of resource component, the quality is used by humans to assign a value. Over the past decades, the assignment of values has been interpreted as representing environmental goods and services [46]. Natural resources may have certain uses for humans. Here we are referring to the utilization of resources in their natural state. The propagation of these uses in a society has an impact on the volume available, a situation that leads to alternatives of technological transformation to guarantee the supply of what, in this process, acquires the sense of a good.

Transformation is a secondary, not a primary, process since it is an alteration of the quality of the natural resources, adapted to the requirements of anthropic activities. The economic model holds the premise that humans transform the natural resources necessary for their material development. In terms of development, this premise is true if we understand it to be a system of the production and accumulation of goods. However, if we assume that humans first adapt to their surroundings, based on the quality of materials that are available, then the premise seems questionable from the local point of view. In fact, the "economic system" is an artifice that is a product of the culture that only exists in an exchange between environmental and anthropic systems. In this space of exchange, however, is where the so-called sub-systems were made possible. From our perspective, there are no such sub-systems, but rather aspects of culture that interact based on the diversity of actors exploiting the resources around them.

This affirmation allows us to establish the artificiality of "needs" and their character in economic systems as initiator axes of nearly inescapable and unchangeable environmental reflection. The problems of the exploitation of natural resources are, then, social constructs based on their properties of function and value. Thus, "the generation of knowledge on specific matters with respect to each sphere of development requires conceptual mechanisms and frameworks which allow for integrating transdisciplinary scientific information" [47].

Nevertheless, functioning in these spaces of systemic interaction permits us to recognize a context based on exchange and transformation. Variability in the value of the obstacles for the development of the function—natural or induced—promotes specific contexts or geographies in which we find a diversity of social relations between utilization,

conservation, and environmental degradation. This vision seeks to incorporate the social aspects of the environmental and anthropic surroundings based on fluvial sediments. In the first place, they are components of the ecological system—the river and basin. In the second place, they are the natural resources that may be exploited, around which, depending on their value, there is a diversity of social interactions. Local conditions in relation to sediments are established between the value and the function, contextualizing the problems of the actors related to their exploitation.

The utilization of sand and gravel sediments by the construction industry at the local and regional level has been constructed as a broad and diverse process in sociopolitical terms. In this sense, it is not only the extraction of sediments in itself that the areneros carry out in the river, but also its links with other actors for maintaining a value chain between the extraction, storage, marketing, transport, and consumer destination sites. This system of relations shares common aspects with other sites as a form of organization, a system of explicit and implicit rules, strategies, and agreements made in everyday practice. However, additionally and principally, it has unique aspects because of the way in which the local space has been constituted around the utilization of sediments.

The actors organize their activities and actions for sustaining exploitation, along with interactions between this anthropic dimension and the environmental aspects. One clear aspect of this interaction is the adopting of techniques. The areneros extract the sediment directly from the basin, using only the sediments that are underwater for matters of quality. According to informants, exposed sediment contains a greater concentration of mud and organic material, which diminishes its potential for making concrete. To extract the sediment, the areneros wade into the water at depths between knee- and shoulder-height, which allows them to stand while scooping the sediment out with buckets. They dump the sediment into the waiting boats or cayucos, and it is then carried to the shore where it is lifted out and up using a pulley system. These activities and technologies are in response to the orographic conditions of the river: a main channel with almost vertical walls of up to five meters that conform the banks. In the middle of the river there is an island that divides the current, creating areas with the best deposits, as we observed in our fieldwork. During the dry season, the water level in the river decreases, allowing for extraction at a lesser depth, while during the rainy season this activity is impossible. Some techniques are not casual. For example, in this section of the river there are areas with large trees that are used to install the pulleys and which help to avoid erosion, while at other points where the river borders on agricultural activities, erosion is intense.

While sediment extraction may be interpreted as an alteration of the fluvial dynamics, it is also true that the techniques used have positive effects for controlling erosion, which is not seen in other kinds of activities such as the shoreline agriculture of the river at this site. Thus, the interaction due to exploitation promotes the adaptation of certain techniques that do not only have a negative effect on the banks and the river. The conditions of the banks make it difficult to introduce machinery for extracting sediments. The areneros are also opposed to this technology since it would alter the river as well as the social organization of extraction.

Understanding the coexistence between the system of relationships, the objects of the space, and the techniques utilized allows us to see how the convergence of the context of exploitation within the environmental conditions and the day-to-day interactions of the actors in their various activities of exploitation is constituted. As we have said, sediment exploitation in the Usumacinta River in La Isla began as a local home production. However, the continuous availability of sediment for local demand is also related to the preference for the semi-artisanal techniques we have described above.

In the anthropic scenario of values assigned to fluvial sediments, we find aspects associated with their quantity and accessibility, as well as the possibility of its transformation for adapting to requirements for certain uses. These arrangements encourage us to rethink the classical interpretation of economy, especially in relation to use and exchange values [44]. Understanding that they are not stages or continuities helps us propose a dynamic relation

belonging to a local and global exchange for the exploitation of natural resources. Figure 5 is an enlargement of the process of sediment exploitation of natural resources based on the previous scheme.

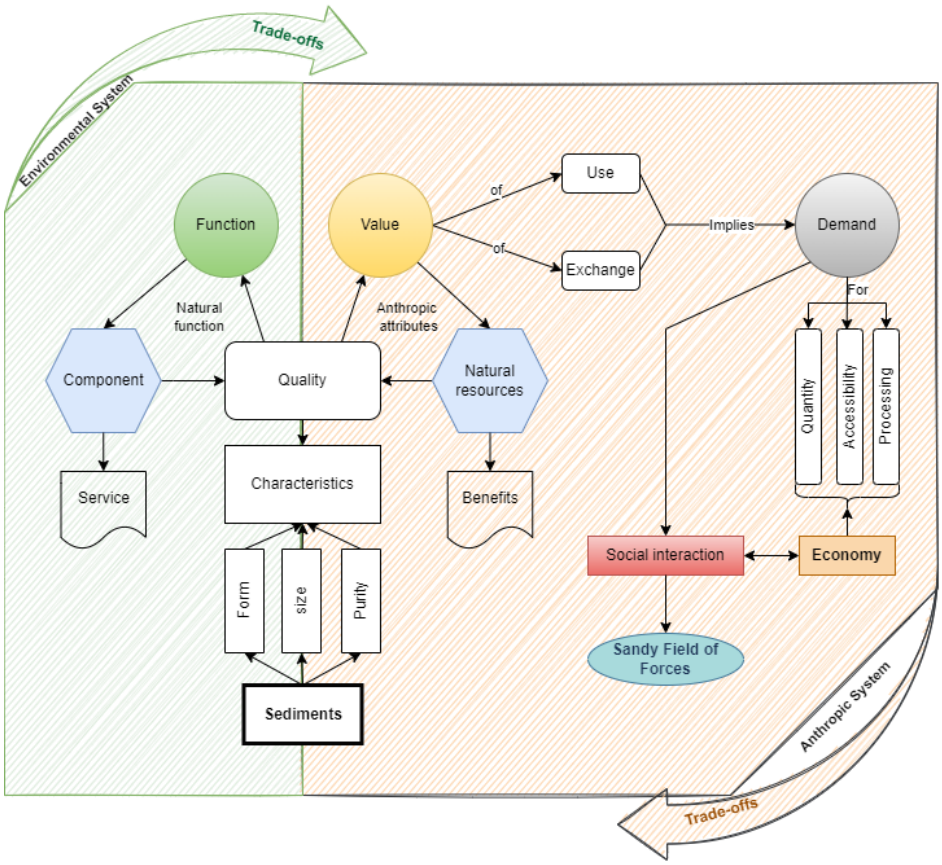

Figure 5. Demand for natural resources and its relationship to systemic interaction. Source: Our own elaboration, 2022.

The requirements of the demands for quantity, availability, or transformation necessary to prepare the sediments for certain specific uses in the industry are not simply demands in the economic sphere, but are rather regulated by the value type. Local inhabitants who use the sediments have fewer demands that the sediments be processed for their use. Sediments with a use value adopted by local inhabitants are in less demand in relation to quantity and are therefore guaranteed to be available. There is less demand that they be transformed for their use while a value of exchange will privilege the supply, and thus, there will be a greater demand in terms of quality, availability, and at times additional treatment for continuing consumption, including measures such as recycling. Consequently, the social interactions related to sediment exploitation are seen in relation to the context in which they take place. Various actors participate in the organizations—associations and individuals—as we have pointed out. In regulating this activity, the state as well as local actors participate by establishing rules and agreements that vary depending on the effects of local and regional demand. However, they interact in relation to the quality of the material supplying construction companies [34,48].

The perspective on fluvial sediments adopts a systemic focus, unlike the concept of aggregates, which focuses on the economic effects, on a lack of product due to increased demand in sand mining and sand extraction and includes the effects of governance and overexploitation. This proposal seeks to understand the local spaces of social interaction rather than to establish global strategies that promote the idea of shared responsibility for the conservation of resources.

We hope that this proposal will allow us to observe how the effects of exploitation combined with the characteristics of the in situ context are perceived as a systemic relation between the environmental and the anthropic, as a relationship of local extraction and the supply to a specific kind of industry. That being said, we hope to surpass the contextual anthropic–economic centrism of the research associated with natural resources. Based on the fact that human beings live in continuous conflict with the environment in order to satisfy their needs, where nature responds in violent ways, the environment has its own subjective reality within systematized scientific thinking. However, this suggests that economic factors are a priori facts and not a human consequence. This leaves a series of conflicts to be reconciled in social–ecosystemic models that depict the problem in a certain way when A (anthropic) happens and then B (natural) happens in an iterative development. We must not forget that this Newtonian relationship of cause and effect is not linear, but rather complex and discontinuous.

The exploitation of resources such as fluvial sediments is a reality in almost all the rivers on the planet. However, its characteristics are conditioned by the interactions between A and B, in which an exchange or reciprocity transforms them in a certain way that makes the reality, C, adjust in certain ways and not in others.

Our proposal seeks to establish ways of approaching a complex reality that is explained in situ. While it may move to schemes of scarcity and conflict depending on the dynamics between the local and the global, the case of La Isla in Tenosique has given us a space for reflection outside of the overwhelming evidence of the crisis based on the global economic model, but still related to it. Thus, the crisis and the violent conflicts over the ownership of resources are seen as a possibility rather than a generalized reality in all sediment extraction sites.

4. Conclusions

The theoretical–methodological model of interpretation advances the context in which the social interactions take place in sediment exploitation. In this respect, our proposal creates an alternative for the local study of sand and gravel exploitation in Tenosique, Tabasco, by identifying resources such as sediments as forming part of the ecosystemic functions and having anthropic values. The proposal allows for identifying the context of local systemic interaction around the exploitation of sand and gravel in rivers. It is based on the context that local actors construct a series of ties through interaction, the forms of organization, the system of rules, and the use and adaptation of techniques that we understand as the sands of tension or social analysis of sediment exploitation.

We agree with the academic approaches based on the problems evident in the utilization of natural resources in terms of overexploitation and intensive local use [49–51]. However, the local interactions allowed us to understand the impossibility of global solutions for sustainable use. For our purpose, the utilization of natural resources is positioned differently than in social–national systems and ecosystemic services [46]. This is because we considered the services, goods, and valorizations as part of the anthropic system. In this sense, the discussion focused on social interaction as the content of what we called the sandy field of forces for the exploitation of fluvial sediments. As conditions of encounters between the environmental and anthropic, the process of mutual influence forms part of the context of the social dimension.

The present proposal, which is based on conservation and degradation, seeks a sustainable equilibrium for development. However, this equilibrium, especially from the economic point of view, is not a general state, but rather a special situation. Thus, based on the demand and the interaction between the environmental and anthropic, associated with a unified system of exploitation, it is not sustainable. Scarcity and degradation, as indicators of well-being, are subject to forms of economic regulation from which the proposals for a solution were derived.

Overtaking the traditional vision allowed us to identify the scenario of the sandy field of forces for social interaction. Contextualizing based on our proposal avoided naturalizing

the economic model, giving it its own local characteristic as well as other political, social, or cultural forms activated in the exploitation of resources. This allowed us to see the inside the sandy field of forces, the social interaction in terms of local actors, interpretations, speech, strategies, and actions that have an immediate impact on the natural resources in their space. In the case of sediments, it was also possible to observe the way the local utilization and other extra-local demands are managed.

Some preliminary results obtained with this model refer to establishing natural categories associated with exploitation. In the social analysis of exploitation, geomorphological and hydraulic aspects, the climate, and the kind of soil were considered along with production, distribution activities and kind of settlement, lines of communication, and material development of the towns. However, categories were presented based on continuous analysis, which helped us to rank them and to identify their roles in the processing of sediment exploitation and mutual influence among systems.

Within the scope of the present proposal is the possibility of understanding a socio-environmental context in which the actors conduct their sociopolitical and economic interactions. Thus, the theoretical–methodological model allowed us a rapprochement in terms of the context for conducting a future study of the content, research that will continue the analysis of the social, political, and economic aspects. Within the internal dimension of the sandy field of forces, we seek to observe the ways in which the actors interact based on the constitution of the contextual space of the social content.

Our framework-proposal is innovative because of its adaptability to the dynamics related to the local reality of sediment exploitation. In fact, it is an abstraction of the changing socio-ecosystemic reality that is in the process of implementation. Nevertheless, we are not aware of its reproduction in other cases that will allow us to verify its adaptability. Despite this, we consider our model to be a novel analysis of the type of problems associated with the exploitation of sand and gravel in rivers based on the local experience.

Finally, we must make clear that this proposal in no way invalidates the progress made in other strategies for the sustainability of sand resources. On the contrary, they offer the possibility for diversifying the discussions while creating alternatives. However, our criticism, which has led to our present proposal, is that traditional ideas prevent attacking the problem of overexploitation despite acknowledging it, since they build alternatives for the continuity of artificial sustainability of the naturalized economy.

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