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Recovery of Mud Materials from the Lalla Takerkoust Dam an Approach for Territorial and Social Development

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Abstract

In Morocco, artificial reservoirs often constitute the principal source of water supply. Yet, they faced natural risks such as the siltation, this phenomenon is increasing in all dams around the world. As a result, governments are constantly looking for innovative solutions and encourages studies in this field. In this perspective, we are trying to valorize the mud from the reservoir of one of the oldest and most important dams in Morocco; the Lalla Takerkoust dam, which is suffering from high sedimentation rates. This study is subdivided into two parts, a social part where we conducted questionnaire surveys, and a technical part, where we carried out a series of physicochemical and mechanical analyses on sediment samples collected from the Lalla Takerkoust reservoir. The results obtained show that the sediments of the studied reservoir can be used in several domains, which the local population can use to improve their living standards by setting up social enterprises.

Key Words: dam, sedimentation, silt, valorization, territorial and social development, governance.

INTRODUCTION

Despite substantial progress in reducing poverty rates, about 800 million people in the world still live in extreme poverty (United Nations 2015), and more than 820 million people in the world still suffer from hunger (FAO 2019). Among the most captivating causes of these increases is the lack of water resources, particularly with climate change representing a major obstacle to its eradication and a threat to decades of development efforts (Lipton 2007; Gabriele and Schettino 2008; OECD 2013).

Morocco is a country with limited water resources. It has an estimated quantity of surface water of 22.5 billion m^3, of which 700 m^3 /inhabitant/year are renewable (Boufala et al. 2019). Most of these resources are located in the northern and north-western regions, leaving a large deficit in the south.

With the periods of drought that have become increasingly frequent in recent years (El Hafid et al. 2017), this deficit is becoming very serious and affects almost the entire kingdom.

To cope with this situation and meet the water demand estimated at 20 billion m^3, Morocco's policy in terms of water resource mobilization was initiated in the 1960s with the launch of the late King Hassan II's dam construction program, providing the country with 140 large dams to ensure a healthy storage capacity for the nation. This mobilization effort has been accompanied by a sustained silting up of the dams which have led to a cumulative loss of storage capacity of about 1650 Mm^3. Today the annual sedimentation rate in Moroccan reservoirs has reached 50 million m^3 (Gourfi et al. 2018). This has a serious environmental and socio-economic impact, as it reduces the lifespan of the reservoirs and could affect the morphological balance of the coastline.

Unfortunately, to face these problems, Morocco's experience at the technical level is very limited. Among the factors of this delay; dredging is a very expensive operation, the lack of necessary data and technical feasibility studies adapted to the reservoirs, the practical management of these reservoirs in Morocco still very poorly defined and the sharing of responsibilities for this management between the State, private companies and local communities are not well determined.

The study concerns the Lala Takerkoust reservoir (commonly called Cavagnac), one of the oldest and most important dams in Morocco. The main objective of this work is to exploit the muds of the reservoir to valorize it so it can be applied to the right field. Through the exploitation of the large quantities of mud, we participate in the increasing of the life-span of the dam sustainably, and also improving living standards of the local population by; creating a new natural source of income, providing employment and encouraging agricultural activity; integrating the women and men of the Lala Takerkoust Dam region into the life of the entrepreneurship, thus enabling them to be financially independent.

MATERIALS AND METHODS

Our methodology is based on two components, firstly, a survey of the local population and technical analysis of the silt from the Lalla Takerkoust dam, secondly the interpretation of the technical and social results, in order, to propose the adequate valorization domain to the needs of the local population.

Survey component

We used the questionnaire survey of the local population to measure the population's knowledge of the siltation phenomenon and its influence on their lives and main activities, and then chose the most appropriate ways of valorization.

Since it was not possible to cover the entire population, we adopted the proportion sampling technique (Gumuchian et al. 2000) using the following equation:

$$n = \left(\frac{z\sqrt{pq}}{c}\right)^2 \quad \text{(eq. 1)}$$

Where *n* is minimum sample size ; *z* is the confidence level (*z* equal to 1.96 to 95% confidence level and *z* equal to 2.58 to 99% confidence level) in our case the confidence level is 95% so *z* equal to 1.96 ; *p* is proportion varying between 0 and 1, in our case *p* equal 0.50 and *q* equal 0.50 then *pq* equal 0.50 ; *c* is the confidence interval (at 95% confidence level *c* equal 0.05).

After the numerical application we found that n is equal to 384.

Then to adjust our sample (Gumuchian et al. 2000) we used the following equation:

$$n^* = \frac{n}{1+(n/N)} \quad \text{(eq. 2)}$$

*n** is the adjusted sample size; *n* is the sample size (based on EQ1 n equal384); *N* is the population, we have a population of 350, focusing on the most representative and accessible Douars (this term means the rural administrative divisions in North Africa countries). After the numerical application, we found that *n** is equal to 165.

Technical and laboratory component

Sampling approach

Several field visits were made to take a sample of the necessary silt, to make the necessary analyses, to know its physical and chemical properties in order to choose the appropriate ways of valorization. The choice to take two samples from the mud (sand and clay) is based on the fact that the sedimentary deposits at the dam are typical of sand then clay sequence, a sand-clay sequence is characteristic of a single flood. The sand deposits are characteristic of sedimentary deposits during the flood period, the clay deposits are characteristic of sedimentary deposits after the flood period (quiet environments).

Analysis techniques

The performed analyses to the selected samples can be summarized as follow (Table. 1):

Table 1. The analyses carried out and their objectives

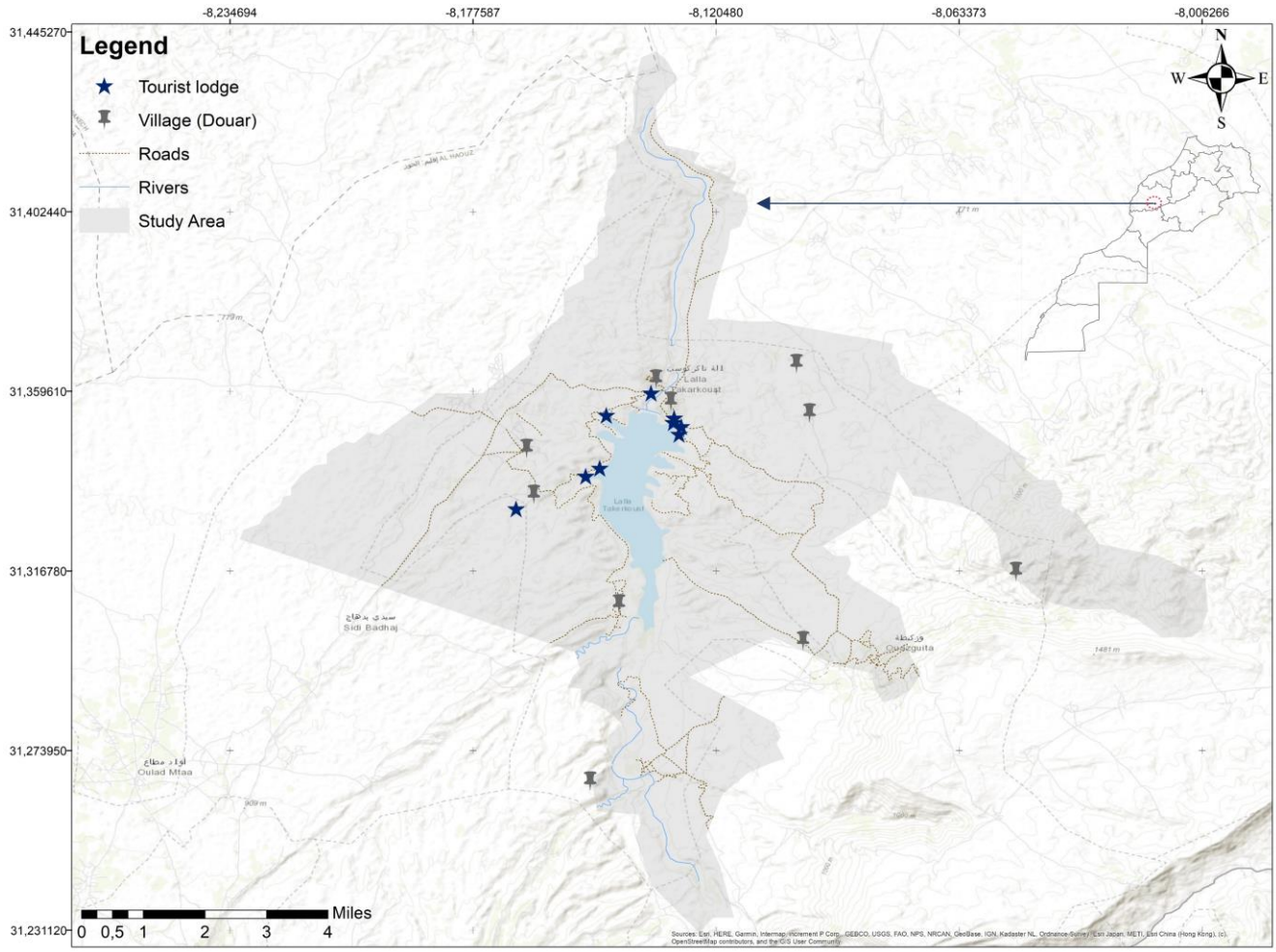
Analysis	Objectif of the analysis
The sand equivalent test	Proportions of fine, dust or clay-like materials and the cleanliness of sand.
Methylene Blue Test (VBS)	
granulometric analysis	Grain size distribution (whole aggregate)
The laser granulometry	Grain sizes (fraction 0.05-600 µm)
Plastic Limit Test	The liquidity and the plasticity limits
X-ray powder diffraction (XRD)	Identification of the crystallized compound(s)
X-ray fluorescence spectrometry (XRF)	Chemical components
loss on ignition analysis	Organic matter

Study area

Spreading over an area of 100 km², the territorial commune of Lalla Takerkoust (Fig. 1) is located in the plain of Al Haouz, foothills of the mountains of the Great Atlas of Morocco, with a semi-arid climate and low rainfall characterized by great spatial and temporal variability, its average annual rainfall is about 239 mm. Examination of the average distribution of monthly rainfall also shows the existence of two differentiated seasons; from October to April, a wet season where almost all the rainy episodes occur, i.e. nearly 80% to 93% of the annual rainfall; from May to September, a dry season with only 7 to 17% of the annual rainfall, thus with average monthly temperatures varying between 17°C and 20°C.

This municipality has a dynamic agricultural and tourist activity and contains important cultural and historical riches, as well as a temporary tourist activity (bivouac, jet skiing, hiking, fishing) favoured by the diversity and the rich landscape of the site, indeed, the presence of the dam Lalla Takerkoust gives it a special position within this provincial and regional ensemble.

Fig. 1. The geographical position of the study area



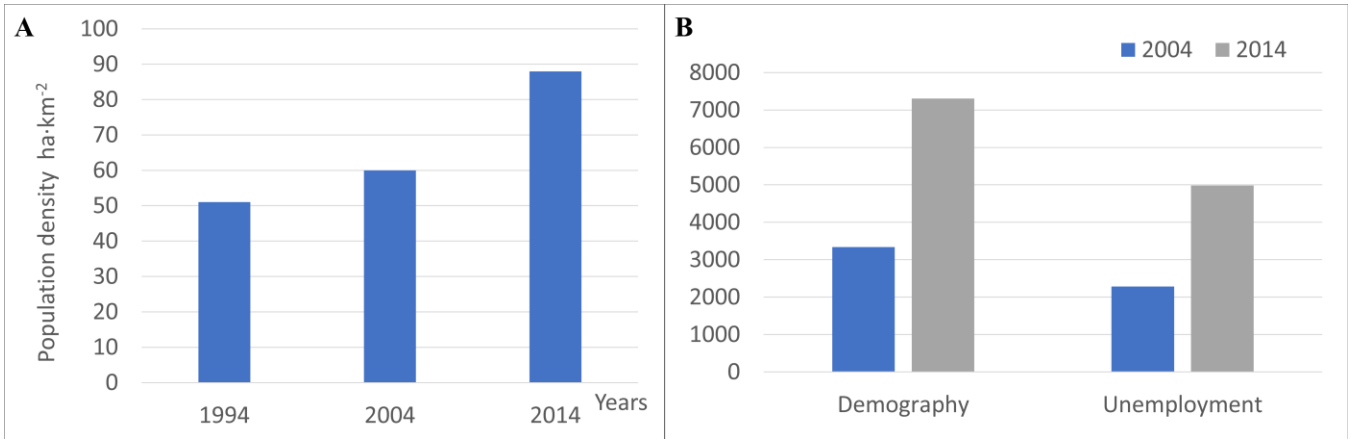
RESULTS

Social analysis results

Demographic evolution, unemployment and educational attainment

The Commune of Lala Takerkoust has undergone profound demographic changes, so that the population has grown from a density of 51.08 ha·km^{-2} in 1994 to 88.02 ha·km^{-2} in 2014 (According to the last census of Morocco 2014), with an evolution of 72.55 % (Fig. 2 A). However, this strong demographic pressure is accompanied by an increase in the unemployment rates (Fig. 2 B), especially for those with limited access to the employment opportunities, such as illiterate people (88% of the local population).

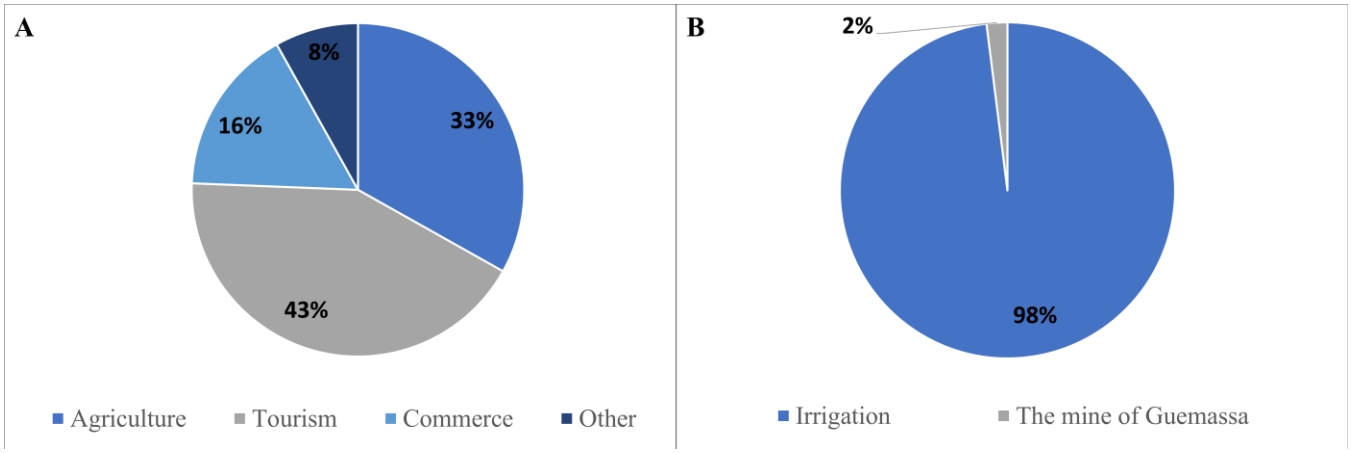
Fig. 2. Population density (A), demographic evolution and unemployment (B)



The principal activities and reservoir area and water uses

After questioning 165 individuals determined by (eq. 1) and (eq. 2), tourism activities were found to be the principal economic activity in the study area representing with a rate of 43%, followed by agriculture with a rate of 33% (Fig. 3 A) which rely in 98% on the reservoir to forecast the sufficient quantities of water necessary for irrigation (Fig. 3 B).

Fig. 3. The principal activity (A) and use of the water (B) of the reservoir

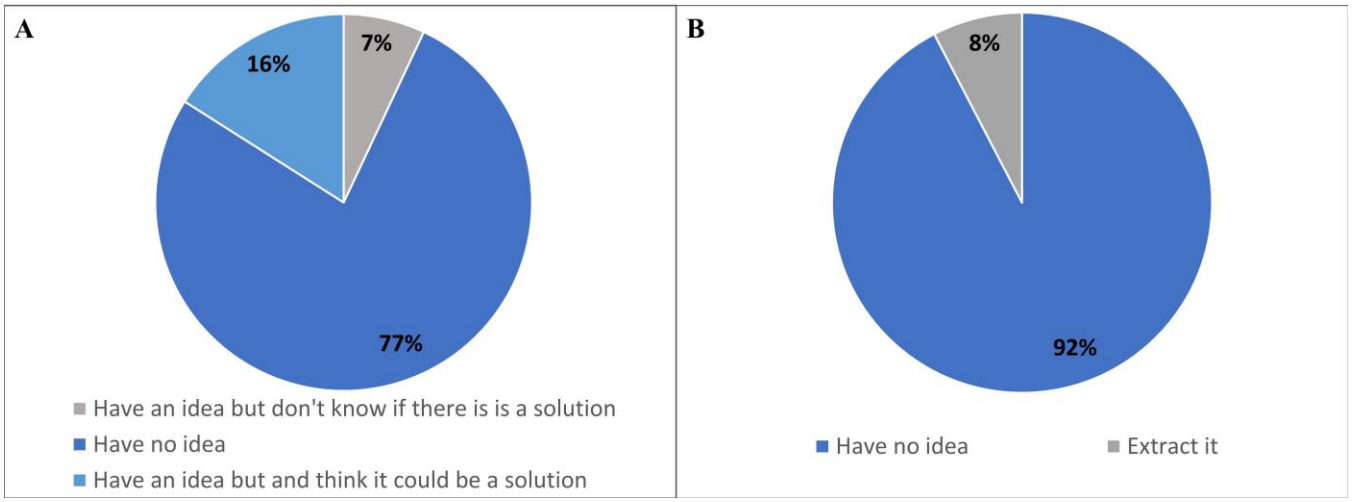


However, the siltation of the Lalla Takerkoust dam is causing serious problems. On the one hand, the siphons of the dam are silted up after each irrigation operation, forcing farmers to carry out periodic manual dredging. On the other hand, it menaces certain tourist activities (jet-skiing), it is noted that the surface area devoted to this leisure activity is decreasing from one year, presenting enormous risks for jet skiers.

Public awareness

Given the problems of unemployment, illiteracy and demographic evolution, the local population remains ignorant of problems posed by the sedimentation of the Lalla Takerkoust dam, i.e. 77% of the surveys have no idea, 16% are conscious of this phenomenon and think that there is a solution, faced with 7% who think that there is no solution to the problem (Fig. 4 A). Nevertheless, we tried to give a little clarification to the respondents on the phenomenon and its effects, and then ask the question (how to get rid of this silt?) But, the majority of the answers remain unsatisfactory as 92% have no idea and 8% think that it can be extracted (Fig. 4 B).

Fig. 4. The population's awareness of the phenomenon of siltation (A) and the possibility of valorizing it (B).



On the other hand, we noted the frequent presence of some people who come to extract the sandy part of the depositions, it was later that these quantities of sands were intended for use in the field of civil engineering construction (Fig. 5).

Fig. 5. Traces left by the sand miners

Technical analyses results

Based on the results of the granulometric analysis, according to WRB classification, our sand sample consists of 30 % of coarse sand (0.63 and 2 mm), 37% of medium sand (0.20-0.63 mm), 14% of fine sand (0.125-0.20 mm) and 19% of clay (less than 0.002 mm).

The sand equivalent is equal to 35. According to the Moroccan standards, the sample can be then classified among clayey sands.

The value of methylene blue equal to 1.24 g per 100 g of dry soil, so according to the Moroccan standards, our sample is classified among a threshold between sandy loamy and sandy clay soils.

According to the Moroccan standard our sample is classified among the medium plastic soil.

X-Ray diffraction analysis of the clay sample allowed us to detect the main minerals composing our sample which are quartz, total clay, augit, dolomite and calcite, with percentages reaching 29%, 27%, 9%, 5% and 5% respectively.

X-Ray Diffraction analysis of the sand sample allowed us to detect the minerals listed below: Apatite, Calcite, Dolomite, Augite, Hematite, K-Feldsp, Plagioclase, Quarters, Sidertite, Halite, Total Clay. With a dominance of Quartz 47% and a low existence of Total Clay 11% which confirms the nature of the sample already quoted in the previous analyses (Methylene Blue of a Soil and Sand Equivalent) which is sandy-silty and sandy-clayey.

Concerning the determination of the organic matter by the calcination method, it was found that the clay sample contains 5.2% of the organic matter and the sand sample contains 2% of the organic matter.

According to the results of X-ray fluorescence spectrometry analysis, the abundant elements in the sand sample are Fe, Ca, Si and K with respectively 5%, 17%, 8% and 6%, the abundant elements in clay sample are Fe, Ca, Si and K with respectively 49%, 24%, 8% and 6%.

DISCUSSION

Several studies have worked on the valorization of natural resources (Franquin and Gérard 1962; Hajatiana 2018; E.Salas-Leiton 2020;), clay materials in the field of ceramics (El Ouahabi 2013; Achiou et al. 2016), but very few researchers have tried to valorize the silt of the dam (Remini 2006; Bourabah et al. 2011; Aoual et al. 2015; Laoufi et al. 2016; Safer et al. 2018), however, there are no studies that have proposed the valorization of the mud of the dam as a solution to generate income for the local population.

In his study, (Remini 2006) analyses silt taken from the discharge conduit of 11 dams of Algeria, the results obtained were very encouraging for the use of mud as a primary raw material for the manufacture of bricks. Moreover, in our study we used as many analyses as possible (Granulometric Analysis By Sifting, Granulometric Analysis By Laser Diffraction, Sand Equivalent, Methylene Blue Of a Soil, Atterberg Limit, analysis by X-Ray Diffraction, determination of organic matter, X-RF X-ray Fluorescence Spectrometry), in order to obtain more information on the physico-chemical characteristics of samples, promoting a more reliable and solid vision on the possible valorization field.

In that respect, sediments of the Lalla Takerkoust reservoir can be used in many fields; Construction domain, The degreasing agent's domain, Amendments domain Use in the field of roads and various networks.

Fields of application

Construction domain

- *Common b*ri*cks*

The particle size distribution of the sandy sample is reported in Winkler's diagram (Winkler, 1954) (Fig. 6 A). According to this diagram on the proportion of 2-20 μm, >20 μm and <2 μm, the sandy materials of the dam correspond to the area favourable for common bricks.

- *Ceramic agent*

The relative abundance of clay minerals can significantly influence the final properties of ceramic products. The ternary diagram (kaolinite/illite/chlorite) (Fig. 6 B) shows that the sample is rich in Illite. These three clay minerals have a ceramic application. Kaolinite is the most widely used clay mineral due to its high melting point and whitish colour (El Ouahabi et al. 2014). Illite is widely used as a flux in traditional ceramics (Ferrari and Gualtieri 2006). Chlorite gives a reddish colour when bricks are fired (El Ouahabi et al. 2014).

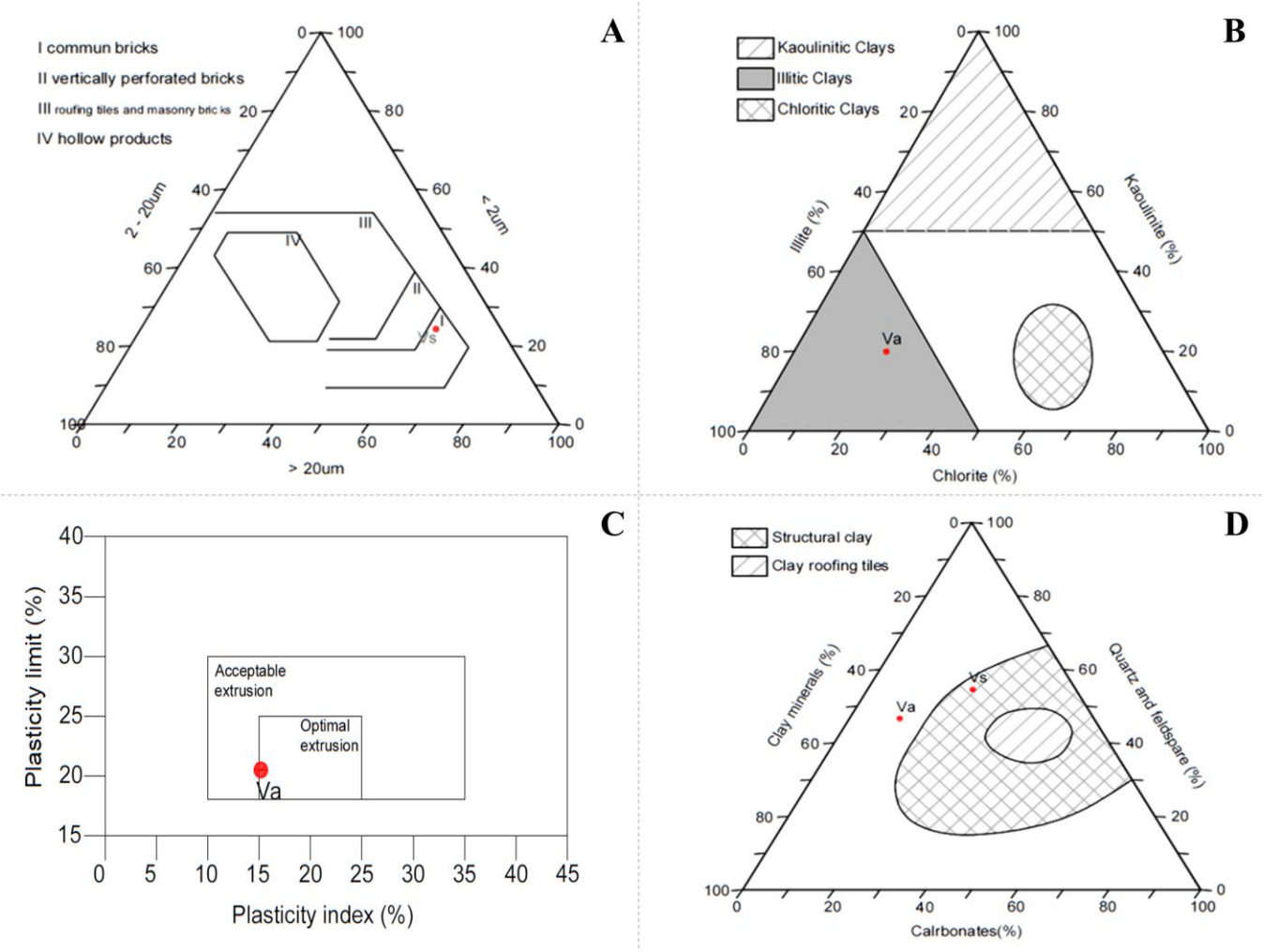
- *Admixture for the manufacture of other products*

Taking plasticity into account, a large proportion of the clay sample studied drags in the region of optimal extrusion (Marsigli and Dondi 1997), (Fig. 6 C). The clay sample is located within the acceptable extrusion region and can, therefore, be used as an adjuvant to change certain physical characteristics without causing problems.

The degreasing agents domain

The ternary diagram of (Strazzera et al. 1997), which uses the abundance of clay minerals, quartz, feldspar and carbonates, relates mineralogical composition to ceramic applications (Fig. 6 D). The sand and clay fraction studied falls within and outside the realm of structural products, and its use in structural ceramics would require the addition of highly fine clay. However, they are suitable only as a degreasing agent.

Fig. 6. The diagrams obtained from the combination of the technical results (Va is clay sample and Vs is Sand sample)



Amendments domain

Depending on the chemical composition and the organic matter (5.2%), clayey silt can be used as an amendment to increase the balance of the soil water balance, clay-based amendment, sand-based amendments or as a calco-magnesian amendment.

- *Amendment to increase the balance of the soil water balance*

Thanks to its composition rich in organic matter, the clay fraction can be used as a fertilizer for poor soils, the organic matter decreases the rapid infiltration of irrigation water down to the root zone, also decreases the capillary upward movement of water and evaporation during periods of water shortage and keeps moisture by its water storage characteristic (Pan et al. 2018).

- *Clay-based amendments*

The grain size nature of the reservoir clays allows them to be used on sandy soils to improve texture, increase particle cohesion and water retention capacity.

- *Sand-based amendments*

The addition of dam silt to soil with its clayey and very fine characteristics will correct the granulometry and porosity.

- *Calco-magnesian amendments*

The silt can be used as an amendment of mineral origin intended to promote the growth of cultivated plants, especially in cases of soil calcium and magnesium poverty, the latter allows the soil particles to be structured and thus retain the nutrients necessary for the development of vegetation, neutralize the H_3O+ ions responsible for soil acidification and finally improve the PH and biological activity making the decomposition of organic matter into nutrients more effective.

Use in the field of roads and various networks

A road rests on an embankment, which is either the original soil or material brought in. Sand can be used as fill, but the technical characteristics are precise. Indeed, the value of the IPI (Immediate Load-bearing Capacity Index) is an indispensable factor to consider for this use. An IPI of at least 10 is required for the backfill, an IPI of 15 for the upper part of the backfill, known as the upper part of the earthworks (TEP), which must have sufficient qualities to allow the placement of the form layer above the backfill. On the one hand, sands have a VBS of 1.24 g, which allows their classification in the class of the very silty sands and gravels with $12 < IPI \leq 30$. These results agree the use of these sands as road embankment, form layer or in various networks (sewerage pipes, drinking water supply pipes...).

Appropriate domain for the Lalla Takerkoust commune

The study area suffers from several socio-economic and environmental problems. The socio-economic problems can be resumed at a high level of illiteracy, a great demographic evolution unsuited to the job offer, a high poverty level and social exclusion. The environmental problems can be resumed in silting up of the dam reservoir, increasing drought and soil erosion risk due to climate change. Dealing with these challenges facing the Lalla Takerkoust commune, the valorization of sediments from the Lalla Takerkoust dam reservoir can be an innovative solution generating a source of income.

After several analysis, materials sedimented in the reservoir could be used in many fields, mainly in the construction domain, the amendments domain roads and various networks or can be used in the field of the degreasing agents domain. Except for the last domain (degreasing agents domain), all the other fields do not require a large investment. In fact, considering the high poverty illiteracy rates of the commune, the selected field does not require a high-level specialized training. Citizens can then, use the accumulated sediments for their own good, for example; as a fertilizer and soil improver by farmers, for the large agricultural land that represents 58% of the total study areas, or it can be used in public works especially in construction and infrastructure given the great demographic development in the region.

However, in order to move the economy of the region, we are proposing the creation of two social enterprises, one for the production of fertilizers and soil improvers, the other for the production of common bricks. These social enterprises (cooperatives) will allow the creation of jobs, the integration of the marginalized population and the territorial development of the region.

However, the absence of a clear regulatory legal framework (other than the law n° 30-15 relating to the safety of dams) on the valorization of the mud of dams or dredging, has prompted our reflection on the environmental governance of dams, as well as the policy measures "responsible stakeholders" to be considered in the perspective of the development of these two cooperatives, this would require an in-depth and detailed study in this field.

Concerning the merchants who transport the sand for its use in the construction field, the results obtained from the analyses carried out (Methylene Blue Test, Sand equivalent, Plastic Limit Test) reveal that the sediments from the dam are not appropriate as construction materials (in concrete, cement or grey bricks), this finding confirms the regulatory vacuum that exists in this sector marked by a great deficiency, not only in terms of regulations but also in terms of monitoring and control.

CONCLUSIONS

Faced with the lack of an adequate solution to the phenomenon of siltation and its influence on the local population downstream of the dam, we have presented through this work an innovative solution; The recovery and reuse of silt as a raw material for several sectors.

Within this framework, we have devoted two main parts to it; the first social part: allowing us to present the influence of the silting phenomenon on the local population of the municipality and the means to face this problem, and the second technical part to characterize the physical, chemical and mechanical property of the silt of the Lalla

Takerkoust dam.

The field investigation shows the existence of several problems in the commune of Lalla Takerkoust namely; social exclusion, poverty and unemployment, in the face of these problems the silting up of the Lalla Takerkoust dam will further deepen the crisis situation of the commune especially as most of the activities are carried out around this structure. Nevertheless, reading the results of the technical analyses shows that the silt from the dam can be used in several income-generating ways.

Finally, a practical response has been proposed. It is the creation of two cooperatives, the first for the production of fertilizers and soil improvers, and the second for the manufacture of common bricks. These social enterprises will play a fundamental role in the development of the commune, through the provision of employment and the inclusion of the marginalized population in the life of social entrepreneurship. Moreover, a vast work of feasibility assembly of these proposed cooperatives would deserve to be carried out in the future. Thus, it would also seem relevant for social science researchers to question the governance, place and influence of silted dams on the local population downstream.

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