

# Guide for valuing mud extracted from dam reservoirs in Morocco

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**Abstract.** All over the world, dam managers are constantly confronted with the siltation of dam reservoirs. This natural phenomenon represents a menace to the safety of the dam; because sediments deposited amplifies the load applied to the dam and shut off the dam's bottom outlet. It also reduces the usable capacity of the reservoir and degrades the quality of the water stored (pollution, eutrophication, turbidity, etc.). In arid and semi-arid countries like Morocco, de-silting stays the best solution for silted dams. However, when we de-silt dam reservoirs, we produce enormous volumes of mud, which represent potential pollution for the environment and occupy immense terrains. Our research was carried out on the possible uses of these sediments. It has enabled us to develop a valuation guide in Civil Engineering, Agriculture, crafts, and the environment sectors. This guide provides a framework for performing tests and analyses to do on the sediments to compare them with the limit values required by regulations and standards in several economic sectors. The results of these evaluations help us to find the most appropriate uses of the sediments in the sectors mentioned above.

**Keywords:** Dam, reservoir silting, de-siltation, valorization, civil engineering, environment, agriculture, Morocco.

## 1 Introduction

Desilting is a mechanical or hydraulic operation to remove mud deposited in a water reservoir and moved it far enough from this reservoir to increase volume for storing water.

Faced with the loss caused by the siltation, desilting operations generate enormous volumes of evacuated mud, which will pollute the environment and will occupy spacious grounds.

The problem of siltation and desilting in Morocco led us to research the various possibilities for using sediments. This work resulted in developing a guide for valuing the mud extracted from the dam reservoirs covered by this article.

This degradation causes silting up of dam reservoirs and the loss of capacity of nearly 73 Mm<sup>3</sup> / year according to the same PNE (SEEE, 2008[1]).

To avoid this phenomenon, engineers design dam reservoirs with "dead sections" below the bottom outlets, intended to store the mud for the lifecycle of the structures, generally 50 years. In addition to reserving dead sections, managers also carry out flushes during flooding to remove some of the mud through the bottom outlets. However, despite these measures, the problem arises more acutely due in particular to the accentuation of erosion by the increased stress on soils and plant cover. The graph below shows, by watershed, the annual losses of dam capacity due to mud siltation.

## 2 Problematic of desilting dam reservoirs in Morocco

Soil erosion affects, with varying intensities, all regions of Moroccan territory. Out of 23 million hectares in mountainous areas, 75% are affected by soil erosion, a third of which is very critical according to the 2008 National Water Plan (PNE) (SEEE, 2008 [1]).

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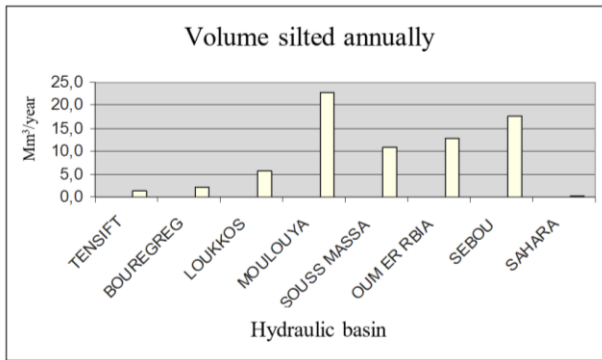


Fig. 1. Loss of storage capacity due to siltation (SEEE, 2008)

Apart from the Sidi Driss dam, which was desilted after a complete emptying of its reservoir, significant works were lead out for just one dam, the Mechra Homadi, in the Province of Berkane. The desilting works were executed from 1997 to 2009 and allowed the extraction of about 8.8Mm<sup>3</sup> of mud.

The dredge unloaded the extracted mud towards a landfill area located 1.5 km from the axis of the dam.

The total cost of the dredging works was about 29 million dollars, without counting the costs of studies, monitoring works, expropriation lands, and the discount rate of currencies. The unit cost was about \$ 3.76 per cubic meter of mud removed (SEEE, 1999, 2005, 2006, 2008, and 2009) [2].

### 3 Possible uses of the sediments retained by dams

The research work that we have completed on the standards and laws adopted in Morocco and on previous experiences of valuing sediments have enabled us to identify possible uses in Civil Engineering, Agriculture, craftsmanship, and the environment.

Due to the lack of clear regulations dedicated to reusing sediments, we used several references (standards, legal decrees, guides, mean values of mud analyzes from compilation scientific publications).

This research work classified the possible uses of this vase as follows:

#### 3.1 Civil engineering uses

To value sediments in Civil Engineering, it must follow the standards given for their fields of use. The sectors targeted by our research are:

##### a. Road works

Considering their physical aspects, the mud extracted from dam reservoirs can be valued as a top layer in the construction of roadways (Seklaoui O., 2016)[3].

The standard to be considered in this case is NF P11-300 which deals with the geotechnical classification of materials used in sub-layers and road embankments (AFNOR, 1992)[4]. This classification relies at first on

the parameters of the nature of the materials: granularity, plasticity index, and clayey.

According to this same standard and taking into account their Organic Matter (OM) content, dredged sediments can be classified into class F: “organic materials or soils and industrial by-products”, and more particularly in subclass F11, whose content in OM is between 3 and 10% by dry mass (Piou S. et al. 2009)[5].

For materials of class F, The standard above recommends considering a classification similar to non-organic materials.

The granularity of dredged sediments allows us to classify them in class A: “fine soils” (P. Bataillard et al. 2017)[6]. This class includes, in particular, bottom ash for incineration of non-hazardous waste (F6), demolition materials (F7), and steel slags (F8).

##### b. Aggregates for concrete

According to the classification of standard NFP18-545 (definition, conformity, and codification of aggregates) and of standard NF-EN12620 relating to aggregates for concrete (AFNOR, 2011 and 2008) [7, 8], dredged sediments are considered as fillers because of their grain size (fillers: granulate of which most of the grains pass through a 0.063 mm sieve and which can be added to building materials to improve their properties).

The function of the fillers is to complete the grain-size curve of the mixture of aggregates used to manufacture concrete. They make it possible to improve certain properties of concrete, in particular:

- By avoiding segregation,
- By increasing the compressive strength,
- By reducing porosity,
- By giving a better appearance to its surface.

French standard NF EN 12620 [8] defines precisely the particle size characteristics of a filler:

- Passing to 2 mm: 100%;
- Increasing to 0.125 mm: 85 to 100%;
- Passing to 0.063 mm: 70 to 100%.

We can determine the chemical characterization of mud by X-ray diffraction, which we can couple with X-ray fluorescence spectrometry to determine the sulfur content and the chloride ion content to compare them with the requirements of the standards mentioned above.

##### c. Brick Manufacturing

Due to its nature clayey, we can use sediments as a raw material in red brick manufacturing. Depending on its mineralogical and chemical composition, we can use the sediments can be used alone or mixed with another clay. For use as a raw material for brick manufacturing, Gippini in 1969 defined an abacus to obtain a mixture with the best moulding and drying properties [9].

Kornmann M. in 2009[10], defined the current limit values for the composition for the components SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, CaO, MgO, Na<sub>2</sub>O, K<sub>2</sub>O, Sulfur, and Iron to be observed in clay mixtures for brick manufacturing.

#### d. Cement manufacturing

Prax A. of the Bureau of Geological and Mining Research of France estimated that we need 1.55 to 1.60 tons of raw material per ton of clinker to produce Portland cement. Thus, the required CaO contents of clinkers imply that the CaCO<sub>3</sub> contents of raw materials are about 73 to 78% (PRAX A., 1979) [11].

The other criteria determining the usability of the mud to produce cement were also defined by Prax A. Principally the magnesia content, the alkali content, the sulfate and sulfide content, and the iron content under a form of pyrite.

### 3.2 Agricultural uses

We can consider spreading the sediments on arable land to provide more material to:

- Fertilization by providing nutrients for cultivated plants;
- Amendment by improving the physical (cohesion, porosity, etc.) and/or chemical (pH, cation exchange capacity, etc.) and/or biological (microbial biomass, mineralizable nitrogen, etc.) properties of soils;
- Ecological rehabilitation of disturbed areas (old industrial wastelands and recent deconstruction, slag heaps, or newly developed areas).

The possibilities for valuing sediments depend on their pollutant content. In the absence of a Moroccan regulation in this subject, we based our research on the Decree of January 8, 1998, of the French law [12]. It specifies for an agricultural valuation of sediments the limit contents of trace elements for cadmium, Chromium, Copper, Mercury, Nickel, Lead, and Zinc as well as the limit levels of organic trace compounds in sediments spreading over organic soils. It is crucial and urgent that Moroccan regulations also look into this aspect.

### 3.3 Environmental protection Uses

#### a. Waterproof layer for lagoon basins or landfills

To avoid the pollution of groundwater by the wastewater infiltration, the settling wastewater basins treatment plant must be perfectly sealed. We can use sediments containing a large clay fraction to improve the waterproofing of these basins.

The same goes for technical landfills where we backfill waste in basins that must be waterproof to protect groundwater from leachate infiltration (Benasla M., 2015)[13].

Marcoen J.M. et al. (2000), defined the main criteria of nature (granularity and OM content) and workability (liquidity limits, plasticity index, and permeability coefficient) of the clay layer that we can use in this objective [14].

#### b. Soil amendment:

Soil amendment is the display of large amounts of material to cover eroded or barren soils. The soil will thus evolve by itself to obtain in a few years a permanent meadow.

We can use sediments as a material for making landforms in the context of landscaping or reshaping certain land and for recharging old quarries and ballast pits as part of the restoration of the site. It can help create spaces for industrialists, for leisure parks, for railway or road developments, or even for the creation of artificial islands (Levacher D., 2006)[15].

The limit values of the various elements present in the sediments according to the social use of the receiving land (children's play areas, residential areas, industrial and commercial areas, etc.) were established by Delcour and Lefebvre (2013) for metals (Arsenic, Lead, Cadmium, etc.) and polluting chemical elements (Benzo [a] pyrene, DDT, Hexachlorobenzole...)[16].

### 3.4 Crafts uses

#### a. Ceramic products and tiles

We can use sediments stored by dams to manufacture ceramics if they respect certain conditions.

According to Guerraoui F. & al. (2008)[17], the ideal particle size composition of the soil and the recommended limits for adequate stabilization and obtaining finished products of acceptable quality is 40% clay or 70% sand (0.2-0.5mm) for tiles and Diameter (d) <50µm for Fine Ceramics.

Jourdain A. (1966) [18] gave acceptable limits for elements entering this industry, in particular silica, alumina, manganese oxide, etc.

#### b. Glass manufacturing

Glass is an amorphous material most often made up of silicon oxide (silica SiO<sub>2</sub>) and fluxes. We can use clay to manufacturing glass if its components vary between the acceptable limits for the elements SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, MgO, CaO, Fe<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, Na<sub>2</sub>O, and K<sub>2</sub>O (Olivier E., 1971)[19].

## 4 Guide for valuing mud extracted from dam reservoirs in Morocco

### 4.1 Presentation of the guide

Our research that led to this issue has enabled us to establish a guide for valuing sediments extracted from dam reservoirs in Morocco.

This guide incorporates an approach based on three main components:

1. A grid of tests to do and limit values to observe;
2. A Matrix of the characteristics to be studied;
3. A diagram of the procedure to follow.

### 4.2 Grid of tests and limit values

The grid defines tests and analyzes to do on the mud and the limits imposed by the regulations, laws, and standards used in Morocco for each sector of activity according to the characteristics sought to facilitate the decision for using sediments extracted from dam reservoirs.

### 4.3 Matrix of the characteristics

To optimize the tests to do according to the grid cited above, we present the activities of the different possible uses of the sediments in various sectors associated with characteristics targeted in a matrix to facilitate the choice of laboratory tests to be carried out by type of activity. The matrix of characteristics to be examined is presented as follows (Table 1):

**Table 1.** Matrix of characteristics by Sector and Activity.

Sector and Activity		Clays	Granularity	Mineralogical characteristics	OM content	Water content	Mechanical characteristics	Chemical characteristics	Traces of metals	Organic compounds - traces
Civil Engineering	A1.1 Road works	X	X		X	X				
	A1.2 Concrete and mortar						X	X		
	A1.3 Bricks	X		X					X	
	A1.4 Cements		X	X						
Craft Works	A2.1 Tiles		X							
	A2.2 Fine ceramic		X							
	A2.3 Ceramic and glass			X						
Environment	A3.1 Lagoon basins and landfills	X	X		X					
	A3.2 Children's play areas								X	
	A3.3 Living areas								X	
	A3.4 Leisure parks								X	
	A3.5 Industrial zones								X	
Agriculture	A4.1 Soil spreading				X				X	X

We can optimize the tests from this matrix by defining a succession of two test phases and by choosing tests to accomplish in each phase according to the targeted activities: The selection of the phasing of the tests amounts to defining the tests common to the targeted activities and start with the cheapest tests.

### 4.4 Diagram of the procedure to follow

We define the procedure to adopt for using this guide in the following sequence:

1. Choice of a dam;

Parameters influencing the choice of the dam are:

- a. The quantity of extractable mud available in the reservoir,
- b. Mud deposition and storage areas,
- c. Proximity to the reuse area;

2. Choice sectors of activity;

We choose the targeted activities based on the following studies:

- a. Market research and supply and demand,
- b. The technical and economic study, the feasibility study, and the profitability study,
- c. The analysis of the project environment according to the following 6 dimensions: political, economic, social, technological, ecological, and legal;

3. Consultation of databases on the sediments of the chosen dam;

The databases to consult are:

- a. Local database (on paper or files),
- b. Geographic Information System (GIS) database;

4. Carrying out laboratory tests according to a phasing that depends on the targeted activity;

The steps of laboratory tests are:

- a. Definition of the tests for each phase,
- b. Sample collection,
- c. First phase trials,
- d. Analysis of the results of the first phase trials,
- e. Second phase trials if the first phase trials are conclusive,
- f. Analysis of the results of the second phase trials;

5. Decision making;

Based on the above, decision-makers make one of the following decisions:

- a. Retain the dam for the valorization of its mud,
- b. Reject the idea of valuing the mud stored by the selected dam;

6. Database filling.

The last step in the process is filling the data into the databases.

- a. Entering the results into the local database,
- b. Entering the results into the GIS database.

We can abridge the process diagram in the following flowchart (fig. 1):

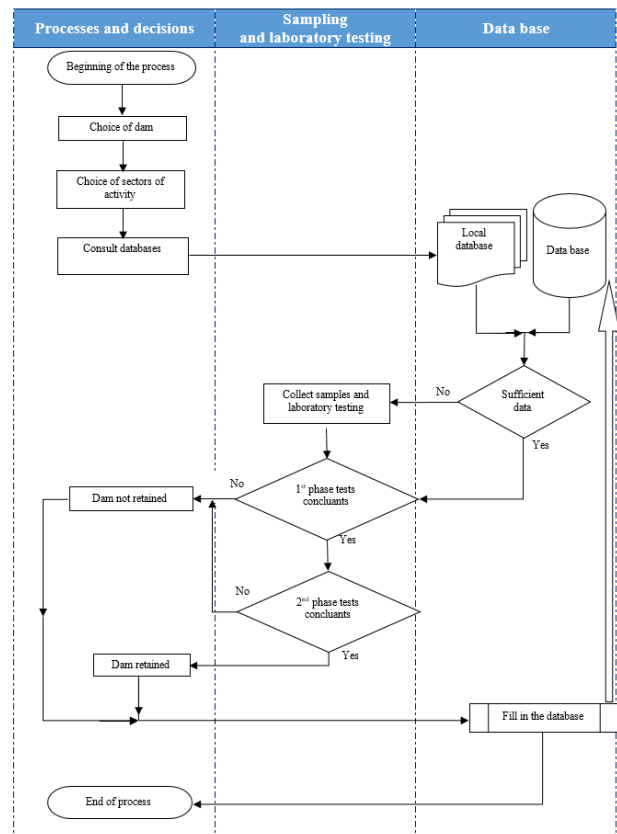


Fig. 2. Flowchart of valuing sediments process.



## 4.5 Case study

In what follows, we will carry out an indicative case study, using the valuation guide mentioned above. This case study is only a not detailed example of how to use this guide.

### ➤ Choice of dam:

For our case study, we chose the Mohamed Ben Abdelkrim El Khattabi dam on the Neckor river, of which the reservoir is about 72,6% silted. This reservoir, which had a storage capacity of 43 million cubic meters of water during its first filling in 1981, is approximately 11,8Mm<sup>3</sup> according to the last bathymetry campaign.



Fig. 3. Mohamed Ben Abdelkrim El Khattabi dam on the Neckor river (SEEE, 2015) [20]

### ➤ Choice of activity sectors

We can consider two scenarios:

- Availability of an investor who operates in a well-defined sector of activity (Take for example the brick-manufacturing sector (Activity A1.3)).
- No investor available or no defined business sector: In this case, detailed market studies are required.

### ➤ Consulting the database

For this dam, no data was found concerning the analyzes of the mud from this reservoir.

### ➤ Laboratory tests according to the following steps

For activity A1.3, the matrix of characteristics to be studied (Table 13) allows us to identify the tests requested by this sector of activity. It is:

- Clayey,
- Mineralogical characteristics,
- Levels relating to trace elements of metals.

We will choose the tests of the first phase according to their production costs. Therefore, we will start with the clayey mud, the tests of which (Atterberg Limits and Methylene Blue Test) are less expensive than the tests for identifying mineralogical characteristics and tests for determining levels relating to trace elements of metals. For the case of an undefined activity, and if we want to study what use we can define for this mud, we must take into account all the tests of the valuation grid. The choice of the tests of the first phase will be in this case the tests necessary to study the clayey, the granularity, and the OM

content, which are less expensive than the tests of plasma or X-ray spectrometry.

If tests of the first phase are conclusive, we carry out the remaining tests in the second phase

### ➤ Decision making

We retain the dam in question if all the tests are successful.

In the case that one of the tests is inconclusive, we reject the dam in question from the valorization process for the selected activity.

### ➤ Filling Database

We must record the results of the tests carried out in the GIS database to use for other valorization studies.

## 5 Conclusion

The guide, which we have developed, is the result of research work on valuing sediments in Civil Engineering, Agriculture, crafts, and the environment. It is a framework to follow for carrying out tests and analyzes on the sediments extracted from dam reservoirs to compare them with the limit values required by the regulations and standards used in Morocco in the fields mentioned above. This guide will help the managers and dams operators in Morocco to compensate part of the cost of desilting by targeting the different users according to the quality of the sediment extracted.

We plan in the second stage of this research work, to use this guide at the level of some silted-up dams in Morocco to define the potential uses of their mud in the areas mentioned above.

The guide can be adapted to other countries by substituting the limit values of the standards used in Morocco by those of the country in question.

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