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Research Article

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# Comprehensively Management of Water Resources in Tunisia with the Innovation Connecting Facility Rehabilitation and Material Development

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**Abstract**

With the advance of global warming and desertification, securing stable water resources is an important issue in Tunisia. However, surface water resources have been gradually reducing due to sedimentation. However, dredging, the simplest countermeasure against sedimentation has not been performed due to high cost.

Southern Tunisia has a low population density but no water supply network. Local water wells are precious water resources but many suffer from fluoride contamination. Worldwide, the population experiencing fluoride contamination in drinking water is at least 100 million.

We offer a solution to both of these issues related to water supply. We are developing a fluoride remover made from the sediment. The required amount of the media in fluoride removers was calculated by considering the volume of drinking water per capita. Processing costs of each component were estimated based on those for ceramics bricks in Tunisia. The selling price of the fluoride remover was assumed using former examples of water purification projects.

The profit from selling the fluoride remover to 100 million, which represents the numbers of people experiencing fluoride contamination in groundwater worldwide, can cover 75 % of the dredging cost of reservoirs in Tunisia.

**Keywords**

Reservoir; Sedimentation; Ceramics; Groundwater; Fluoride

## Introduction

The extension of desertification in arid regions caused by global climate change has gradually reduced the available amount of surface water resources [1] and securing stable water resources has become the most important issue. Little vegetation cover in catchment areas causes severe soil erosion during rainfall events and suspended solid transported by stream flow settles in reservoirs. This sediment accumulation in reservoirs reduces available surface water resources [2]. The loss of surface water resources by sedimentation annually in North African countries has reached 0.5% of total storage capacity in Morocco, 0.5% in Algeria, and 1.0% in Tunisia [3].

Currently 97% of suitable sites for dam construction in our study area, Tunisia, have already been developed or planned [4], so that alternative water resources to compensate for losses by sedimentation cannot be expected – the only way is managing existing reservoirs. Dredging is the simplest countermeasure against sedimentation but has not been performed due to the high cost.

In addition, water resources are a major limiting factor for development of rural area in the south of Tunisia. Drinking water in the area is groundwater that is contaminated with fluoride. Adequate fluoride concentration reduces tooth decay, but a concentration higher than 2 ppm causes dental and skeletal fluorosis. A number of towns and villages experience this problem, including the vicinities of Kairouan, Beja, and Gabes. Fluoride occurs at elevated concentrations in many areas of the world including Africa, the Eastern Mediterranean and southern Asia [5]. Long back it was estimated that more than 260 million people world-wide consume drinking water with a fluoride content of >1.0 mg/L [6].

This study concerns the management of sedimentation in reservoirs and processing clayey sediment to form functional ceramics for water treatment and includes economic considerations. We are using sediment to construct a fluoride remover. This remover consists of three parts; outer case, filter, and media. The capacity of the media to capture fluoride was evaluated by experiment. The required amount of media was calculated by considering the volume of drinking water per capita. Processing costs of the three parts made of ceramics were estimated based on those for ceramics bricks in Tunisia. Selling price of the fluoride remover was based on another example of technical cooperation concerning water purification additives for removing turbidity, but that cannot remove dissolved fluoride.

## Study site, Material and Method

### Sedimentation of reservoirs in Tunisia

High dams (water reservoirs of dam height more than 15 m) are the largest hydraulic facilities for the securing of water resources. The amount of water resource in a high dam is visible as its storage capacity, whereas volumes of groundwater resources are difficult to estimate. Dams represent the most reliable water resource and their sustainability can be guaranteed with strict management if rainfall and river flow rates are stable.

The dams in Tunisia are located in the north of the country (Figure l) and these are the water supply for the north. Many of the dams are constructed on the Medjerda River. A certain amount of seasonal precipitation and river flow discharge can be expected as a water resource for irrigation and potable water in the dry summer. The main water resource in the south is groundwater because only low and occasional precipitation produces run-off in streams.

The construction of new dams is expected to meet water demand for the population and industrial growth. However, almost all candidate sites for dams have been developed. Any further new dam construction is geographically impossible.

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Although the problem of capacity loss due to sedimentation has long been reported, according to the Direction Générale des Barrages et des Grands Travaux Hydrauliques in the Ministry of Agriculture of Tunisia, dredging or other countermeasures have never been performed for economic reasons. Ben Mammou & Louati [4] estimate the storage capacity of reservoirs in the country will decrease gradually after 2010 because no further dam construction is feasible (Figure 2).

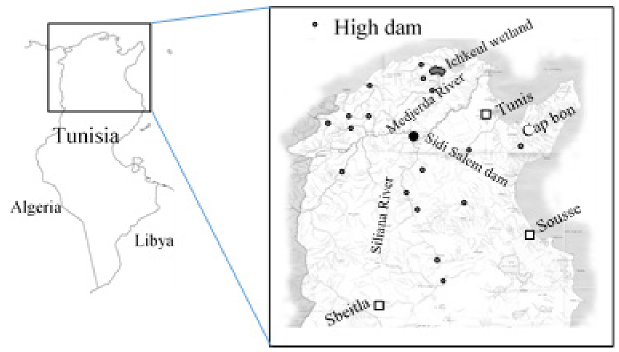


**Figure 1:** Location of the reservoirs in Tunisia.

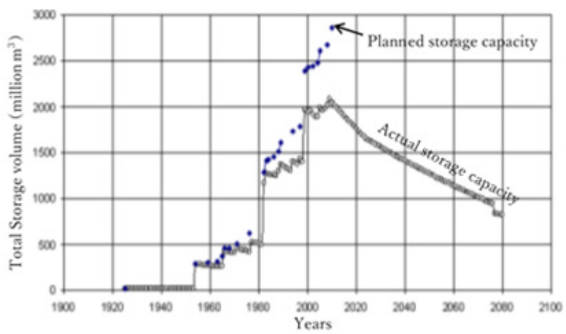


**Figure 2:** Change of available surface water resources (storage capacity of the reservoirs) in Tunisia (Ben Mammou & Louati 2007).

The author sampled the bed materials in some reservoirs in Tunisia and discussed the potential for its exploitation in previous studies. Samples from anywhere in a reservoir showed uniform particle size (Figure 3), categorized as clay or silt [7]. When the transported sediment contains different classes of particle sizes, the more coarse particles settle closer to the inlet. Such spatial distribution of particle size in reservoirs can cause difficulty in quality control for sediment exploitation; however, the observed distribution of fine particles over reservoirs promises easy management for exploitation. Mtibaa & Irie et al. [8] used sediment from a reservoir for soil amendment of a farm field irrigated by treated wastewater. The fine sediment could capture heavy metals contained in the treated wastewater and regulate their uptake by crops. Irie et al. [9] and Fuji et al. [10] tried to produce sintered ceramics from sediment. Test pieces for bending tests were prepared using the same process as used for brick construction in local factories. The ceramic products made from the sediment had the same or higher strength as bricks made from quarried clay but the cost of excavation was lower from reservoirs than from quarries. These studies showed the potential of clayey sediment for the ceramics industry. However, given the volume of the market for brick construction and the total sediment volume in reservoirs in Tunisia, the sediment could not be consumed only in brick manufacture even though almost all buildings in the country are built with bricks.

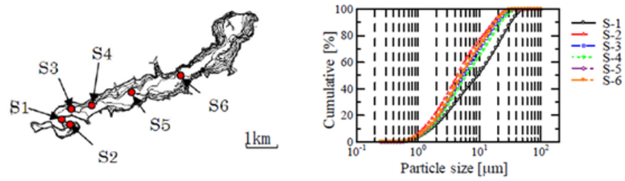


**Figure 3:** Sediment sampling points in Joumine Reservoir and particle distributions of the points (Irie et al. 2011).

## Fluoride contamination in groundwater and countermeasure

Fluoride concentrations in well-water in Tunisia were measured to elucidate the adverse effect of excess intake of fluoride on human health [11]. According to a survey, dental fluorosis was prevalent in Tunisia; a similar drinking water problem occurs all over the world. There are nearly 100 million people suffering from fluorosis across 25 countries [12].

Conventional countermeasures against fluoride contamination include the Nalgonda method, reverse osmosis, and electrolysis. However, these methods do not perform well in reducing fluoride from raw water with low fluoride concentrations to the standard concentration of 1.5 mg/L defined by the World Health Organization. Their material and running costs are also high.

Tafu et al. [13] estimated the removal fluoride using functional materials made from bone generated as waste from food industries. We selected two types of bone materials: chicken bone char (CBC) obtained by calcination of chicken bone, and dicalcium phosphate dihydrate (DCPD) produced from wastewater treatment of gelatin production from bone. The removal of fluoride by CBC was affected not only by hydroxyapatite as an inorganic phase of bone, but also the carbon derived from bone collagen. In case of DCPD, removal of fluoride was effective by reacting with fluoride ion to form stable fluorapatite (FAp) by addition of calcium carbonate with the DCPD. We found that DCPD could remove fluoride ions in the water environments using 10% of the amount and 5% of the cost compared with CBC. Another good point of this chemical reaction system is that the captured fluoride is converted to stable FAp, as also shown by Tafu et al. [14] They examined the concentration of leachate from media after treating water. Fluoride captured in DCPD was more stable than that captured by conventional aluminum method (Table 1). The concentration of the leachate from DCPD was lower than the Japanese soil pollution standard; and so, following its use, the media can be dumped in the environment without specific consideration.

| Water treatment method | Fluoride in leachate (mg/L) |
|---|---|
| Conventional aluminum | 0.95 |
| DCPD | 0.6 |

**Table 1:** Eluted fluoride concentration from sludge obtained by the DCPD and conventional aluminum methods. Japanese soil pollution standard is 0.8 mg/L

## Exploitation of sediment for the water treatment system

The author proposes the use of reservoir sediment to produce a water treatment system that can remove fluoride from drinking water (Figure 4). The system consists of an outer case, filter, and media, with the media functioning in removing fluoride. The media and the filter that separates the media and treated water are not normal ceramics

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as they are both porous. The porous ceramics can be manufactured by the gel-casting method [15]. Pore sizes of the filter and media are 10–100 µm (Figure 5). By using the sediment to manufacture the fluoride purification unit, the two big issues of water stored volume loss by sedimentation and groundwater pollution can be addressed simultaneously.

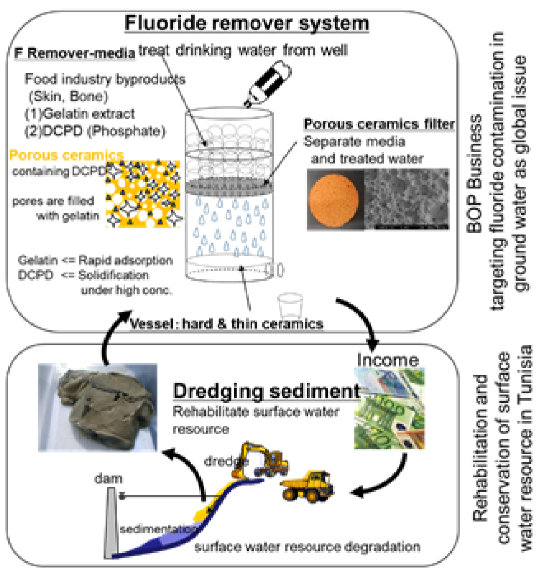


**Figure 4:** Overview of the proposed exploitation for the two issues on water resource.

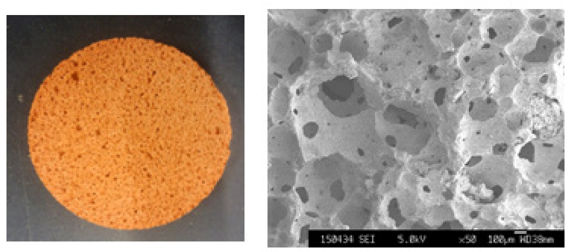

**Figure 5:** Porous ceramics from reservoir sediment, produced by gel-casting method.

## Results and Discussion

The economic balance between dredging cost and profit for the fluoride remover system is evaluated for feasibility of the proposed exploitation cycle, in parallel with the volume balance between demand and supply of the sediment (Figure 6). We assume that the raw well-water contains fluoride of 5 ppm concentration, and this is reduced to 1.5 ppm by the proposed system. The required amount of drinking water is 2 L/capita/day. The amount of fluoride removed from drinking water is 7 mg/capita/day (i.e. -3.5 ppm × 2 L). The results of previous study Tafu et al. [13] were used to determine the DCPD and sediment required for reaction with fluoride. One gram of media composed of 50% sediment and 50% DCPD can capture 1 mg of fluoride. The required amount of sediment for producing media is 1.3 kg/capita/year. Processing cost of the media, including the price of DCPD and sediment is 0.5 USD per 1 kg of sediment. The vessel and filter may have a longer life than the media and so can be shared within a family. Here we assumed the required amount of sediment and life of these two parts as follows. Of sediment, 10 and 1 kg are required for a vessel and filter production, respectively. One system is shared by five family members. The life of vessel and filter are 5 and 1 year, respectively. Converting these numbers to kilogram/capita/year for media, vessel, and filter, results in 1.3, 0.4, and 0.2 kg, respectively.

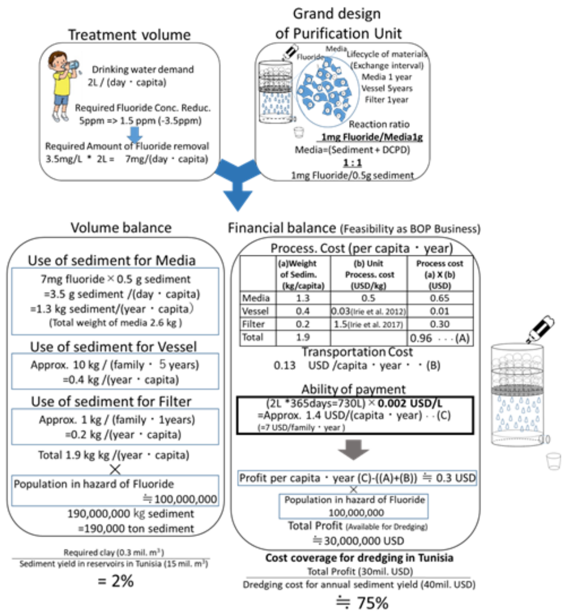


**Figure 6:** The economic balance between dredging cost and profit for the fluoride remover system and the volume balance between demand and supply of the sediment.

The processing cost of vessel and filter can be estimated using the results of previous studies [9,15]. Total processing cost of the system is 0.96 USD/capita/year. One of the difficult point of this estimation is transportation cost of the products. Transportation cost of the fertilizer imported mainly from MENA countries to Japan can be the reference to estimate that of the proposed products. The physical properties (bulk density, package etc.) of the media of the proposed system are similar to the fertilizer, so that their transportation costs might be similar. In addition, the distance from MENA region to Japan is longer than that from Tunisia to Eastern Africa and India that have the problem of Fluoride contamination in groundwater. In this study, we made a calculation with the transportation cost per unit weight of the fertilizer from MENA to Japan. That never gives underestimation.

According to the report of Ministry of Agriculture, Forestry and Fisheries of Japan (2019), the average price of phosphate fertilizer is 1581 JPY/ 20 kg, equivalent to 0.74 USD/kg. On the other hand, the rate of transportation cost against total price of the fertilizer is 5.4 %, reported by Ministry of Economy, Trade and Environment of Japan [16]. Transportation cost of the media, estimated from these numbers, is 0.04 USD/kg. Total weight of the products consumed in the installed area would be 3.2 kg/capita (2.6 kg of media including 1.3 kg of DCPD, 0.4 kg of filter and 0.2 kg of Filter). Then, transportation cost is estimated as 0.13 USD/capita.

The acceptable price of the system for low-income level villagers was based on information from another project treating potable water with coagulant, POLY-GLU [17]. People will pay 0.002 USD to treat 1 L of drinking water. Expected treatment volume for a family

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is 3650 L. This gives an acceptable payment for treating potable water of approximately 7 USD/family/year (1.4 USD/capita/year). To determine this payment burden according to commodity prices, we tentatively chose nominal prices for media, vessel, and filter as 0.5 USD/kg, 10 USD, and 2 USD, respectively, with corresponding averages of 3, 2, and 2 USD/family/year (Table 2). These seem acceptable prices for a low-income level.

| | Unit Price | Annual requirement (kg) | Life (year) | Annual average burden (USD/ family-year) |
|---|---|---|---|---|
| Media | 0.5 USD/kg | 0.65 | - | 3.25 |
| Vessel | 10 USD/ peace | - | 5 | 2 |
| Filter | 2 USD/ peace | - | 1 | 2 |
| Total | | | | ≃7 |

**Table 2:** Nominal price and Annual average burden for each parts

The difference between the payment by the people and the costs of the system is profit that can be appropriated to dredging reservoirs. Assuming that the population requiring installation of the system for removing fluoride is 100 million across the world, total profit with the world market is 30 million USD/year. This is equivalent to 75 % of the cost of dredging 20 high dams in Tunisia annually. This comparison is not for the judgement on whether the proposed exploitation can cover all of the dredging cost of the high dams in Tunisia. The dredging cost in Tunisia is shown here just as a reference to economic potential of the exploitation of the sediment for the proposed purification system. The assumption that the proposed system is provided to 100 million requiring the treatment of fluoride cannot be realized readily with a short term. However, the orders of dredging cost and the profit from the proposed purifying system do not have big difference. The management of water resource has to be carried out as public work but this exploitation idea can reduce it considerably.

The amount of sediment to produce the fluoride remover system is 0.2 kg/capita/year. In a similar calculation to that for the economic balance, assuming the system is supplied to all relevant people in the world, the consumption of sediment is only 2% of the amount yielded in all reservoirs in Tunisia. The potential of resource supply ensures sustainability of the exploitation, but in the case of excess supply, other ways of consuming the dredged sediment have to be considered although its cost has already been met in use for the proposed fluoride remover system. One way is as raw material for constructing bricks as previously mentioned; another way is providing the sediment to local farmers. As mentioned in the previous chapter, fine sediment is suitable for use in fields irrigated with treated wastewater. Local farmers know from experience that sediment from riverbeds is rich in nutrients. Even if purchasing the sediment as a soil amendment was difficult for farmers, the sediment excavated with the profit from selling the fluoride remover system could cover the cost and so sediment could be provided free to farmers. Finally, production of the fluoride remover would never face a shortage of raw material resource, and the excess yield of dredged sediment would never become waste.

For the extension and implementation of the fluoride remover system, the lifetime of the remover media is an important issue and this requires continued monitoring. Users of the fluoride remover system can measure fluoride concentration using a simple colorimetric method. However, conventional colorimetric methods determine the concentration by comparing with colorimetric plates and result in errors due to individual sensing of colors. Furuyama et al. [18] proposed a color reading system using a smart phone fitted with a digital camera and GPS. The fluoride concentration is calculated from an image of the water sample colored with a reagent; and the concentration and location data are transferred to a database. The provider of the media can observe functioning of the system using the database. Such strict management will improve the reliability of the water treatment system and enhance its extension. Finally, supply of safe drinking water to remote villages and recovery of storage capacity of reservoirs will be realized [19].

## Conclusion

The situation of surface water resources in Tunisia is very severe due to sedimentation. Dredging is most simple and effective countermeasure but has not been performed for financial reasons. The author proposes the exploitation of sediment for constructing a water treatment system to remove fluoride, which contaminates groundwater in Tunisia and other countries widely spread over the world.

Trial calculations show the feasibility of using sediment in a water treatment system to remove fluoride. The international market is 100 million people who use well-water contaminated with fluoride. Raw material supply for this new industry is enough for sustainability but consumption of the excavated sediment in the ceramics industry and as soil amendments should be encouraged by a low or zero price. Implementation of the treatment system depends on it reliably functioning. Using an observation system, networked by smart phones, for assessing function is expected be a key tool in its extension.

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### Conflict of interest statement

The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

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