

Effectiveness of Gabions Dams on Sediment Retention: A Case Study

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Abstract: Illegal deforestation changes in land use and climate change have resulted in increased runoff and surface erosion from the upper areas of watersheds, affecting directly the lower lands where human settlements are common. Such is the case of Angangueo in the state of Michoacán, México, where in 2010 an unusual weather event caused substantial damage to infrastructure, and unfortunately human deaths. Against disasters, the government has carried out actions such as implementing infrastructure to alleviate flooding and mudslides. Gabions dams were used to control erosion and runoff, as they are considered environmentally friendly as compared to most of the constructed impermeable weirs. This study was carried out to evaluate the effectiveness of gabions dams in sediment retention in a small watershed East of Michoacán. Eight gabions dams and five masonry dams two years after of construction were studied. The results indicated that the gabions dams retained less gravel than masonry dams, more sand, but no significant differences were found for fine sediments. Regarding the efficiency of gabions dams, there were not identified relationships since the building volume and contribution area is different in each one of them.

Key words: Weir, sediment trap, watersheds management.

1. Introduction

Mismanagement of watersheds in Mexico has brought environmental concerns, and its consequences were severe. Such is the case of the watershed “El Ventilador” in the locality of Angangueo, state of Michoacán, México, where in 2010 an atypical rain event caused substantial damage to the infrastructure, and unfortunately human deaths. Implementing soil and water conservation practices, such as gabions dams, has proven to be a suitable option in mitigating these effects.

Gabions weirs are porous hydraulic structures, which have been successfully used in watershed management to control erosion and flow. They are structures with minimal adverse impact on the water environment and are considered to be more environmentally friendly than most impermeable weirs

[1, 2]. These structures are semi-permanent rock barriers, which are built across the section of the channel, reducing upstream flow velocity, retaining sediments and promoting water infiltration [3]. They are considered elastic structures, which can easily be adapted to the geometric conditions in a natural channel [4]. However, their efficiency and effectiveness on sediments retention regarding their location has not been determined accurately.

Few studies have focused on determining efficiency and effectiveness of gabion dams in sediments retention, and most have focused on investigating the flow over gabions and their influence on the energy loss and flow velocity [4, 5]. The main objective of this work is to determine the efficiency and effectiveness of gabions weirs on sediment retention with respect to masonry dams, so useful information for the government and private institutions about the benefits of implementing such structures can be generated. The data can be used in planning and making decisions in the management and monitoring of watersheds.

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2. Methods and Data

2.1 Study Area and Site Selection

The watershed “El Ventilador” has an area of 362 ha and is located northeast of the town of Angangueo, in the State of Michoacán, México, between the extreme coordinates: 2,171,553 North, 2,174,046 South, 366,083 West and 368,636 East (Fig. 1). The topography elevations varied from 2,740 to 3,400 masl. Hydrologically it is located in the Balsas River Hydrological Region (RH18) and particularly in Cutzamala River Basin and sub-basin of Rio Chiquito. The soils are of volcanic origin with medium texture, predominantly Ochric Andosol (To) (290.26 has, 80.2%), followed by Litosol (I) (42.8 ha, 11.8%), and humic Andosol (Th) (28.93 ha, 8%). As regards to the vegetation of the watershed, most of it is *oyamel* Fir forest, (*Abies religiosa*) with 47.93% of the total surface, followed by oak forest (*Quercus sp.*) with 11.36%. The area occupied by agriculture is 17%. The other types of vegetation occupy areas less than 8% of the total surface.

Eight gabions dams and five masonry dams were built with angular rocks in 2011 as part of the cooperation project number SGIH-GDIT-UAQ-11/03/RF/CC between the Universidad Autónoma de Querétaro (UAQ) and Comisión Nacional del Agua (CONAGUA). Their characteristics are shown in Table 1 and their locations in Fig. 2.

2.2 Sampling

In order to determine the type of sediments retained in each dam, three samples were obtained and taken to the laboratory to be dried at 105 °C for 24 hours and then sieved with a set of meshes (3/4, 3/8, 4, 10, 35, 60, 120). Sediment classification was performed, according to the granulometry and the American Geophysical Union [6].



Fig. 1 Geographic location of the watershed El Ventilador.

Table 1 General characteristics of gabion dams examined.

Dam name	Stream	L (m)	H _e (m)	Original retention capacity (m ³)	Building volume (m ³)	Coordinates	
						X (m)	Y (m)
PG01-02	1	1.6	2.0	4.4	42.0	367,337	2,172,945
PG01-03	1	2.5	3.0	61.4	62.5	366,971	2,172,641
PG01-04	1	2.7	3.0	37.5	69.5	366,960	2,172,645
PG01-05	1	3.0	3.5	99.5	127.0	366,898	2,172,653
PG1A-01	1A	4.5	2.5	39.4	58.5	367,228	2,172,710
PG1A-02	1A	3.9	2.5	25.2	48.0	367,213	2,172,720
PG03-02	3	3.0	2.0	52.5	49.5	366,808	2,172,749
PG05-02	5	6.5	2.5	21.2	39.5	367,765	2,172,876
PM01-01	1	17.6	3.0	422.76	69.9	367,389	2,173,075
PM01-02	1	12.3	2.0	167.53	59.5	367,350	2,172,984
PM01-03	1	12.6	2.1	151.31	27.8	366,924	2,172,651
PM01-04	1	7.1	1.7	101.32	35.7	366,875	2,172,653
PM05-02	5	15.3	2.4	439.17	66.3	367,361	2,172,852

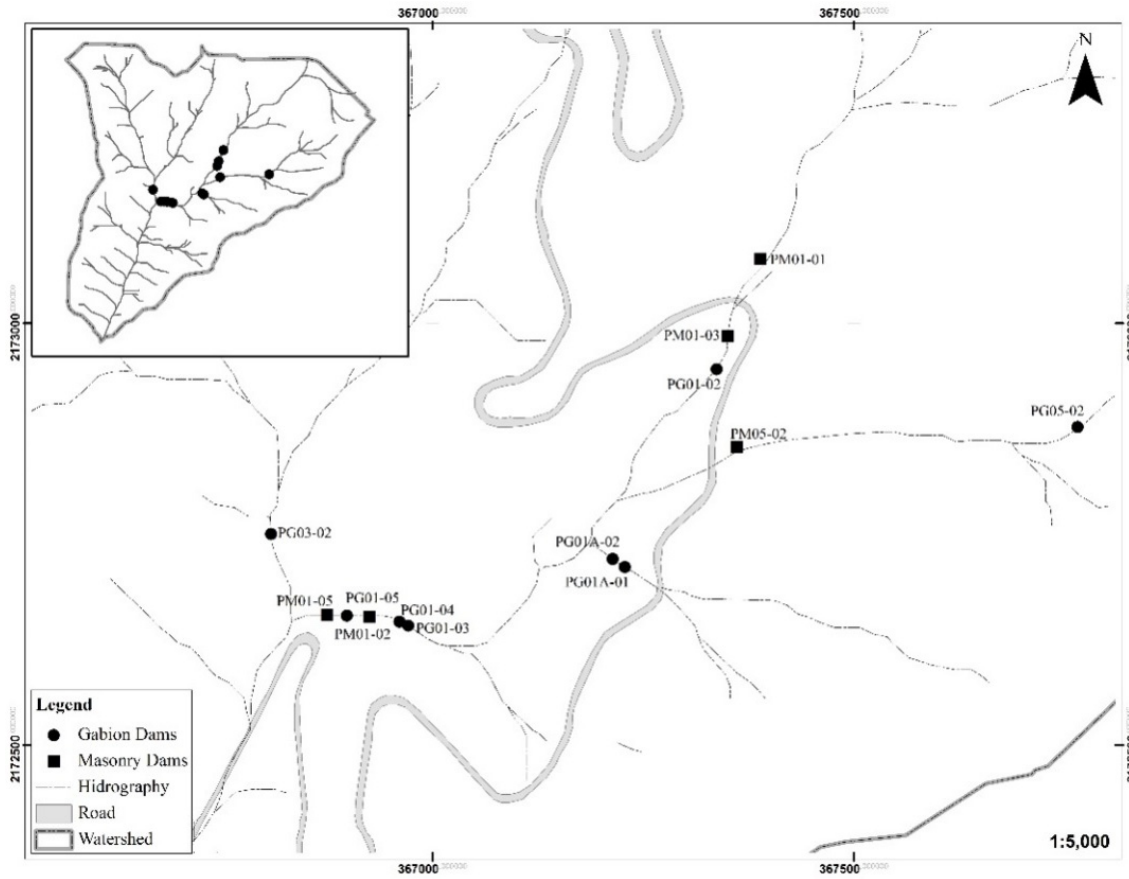


Fig. 2 Geographic location of gabions dams in “El Ventilador” watershed.

2.3 Retention Capacity and Retained Sediments

The capacity of sediment retention was estimated based on the effective height, the length of the reservoir, the width, and slope of the upstream section of the river bed. The values were measured in the field (Fig. 3).

where:

L = Length of reservoir (m);

H_e = Effective height of the wall (m);

S = Upstream slope (%).

Profile area was obtained by the Eq. (1):

$$A_p = \frac{L \times H_e}{2} \quad (1)$$

where:

A_p = Profile area (m^2);

L = Length of the reservoir (m);

H_e = Effective height of the wall (m).

The average width of the storage area (T) was

calculated by at least three transverse measurements (Fig. 4) and the Eq. (2) was used to obtain the volume or sediment retention capacity.

$$V_s = T \times A_p \times 1.5 \quad (2)$$

where:

T = Average width (m);

A_p = Profile area (m^2);

V_s = Sediment volume (m^3).

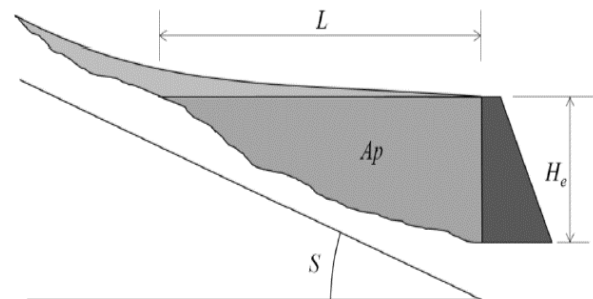


Fig. 3 Longitudinal profile of the accumulation of sediments in control structures.

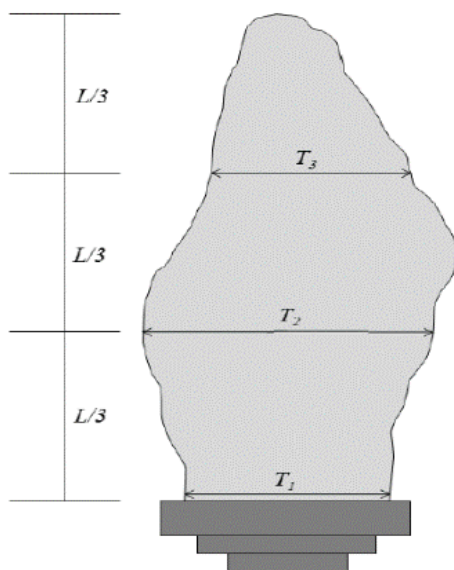


Fig. 4 Upper view of reservoir.

3. Results and Discussion

The grain size distribution of the sediments retained by the dams depends on the type of the sediments transported and the performance of the dams in trapping the sediments [3]. In a masonry dam, water cannot pass through the dam, so most sediments are trapped except suspended sediments in overflow. In gabions dams, the amount of sediments passing through depends on several factors including size and shape of rocks. Nevertheless, the results show the opposite that the percent of gravel retained in gabion dams was lower than that in masonry dams.

For gabions dams, half of these did not retain more than 40% of the gravel, and the other half between 40-45%. In case of the masonry dams, half of them held up to 60% of the gravel and the other half retained in a range not exceeding 70% (Fig. 5).

These differences are attributed to the masonry dams which retain every gabions but still let some pass through.

The percentage of sand retained behind the gabions dams is greater than that for the masonry dams (Fig. 6), and this confirms the good performance of gabion dams, regarding the retention of sand, especially dams downstream (Fig. 7).

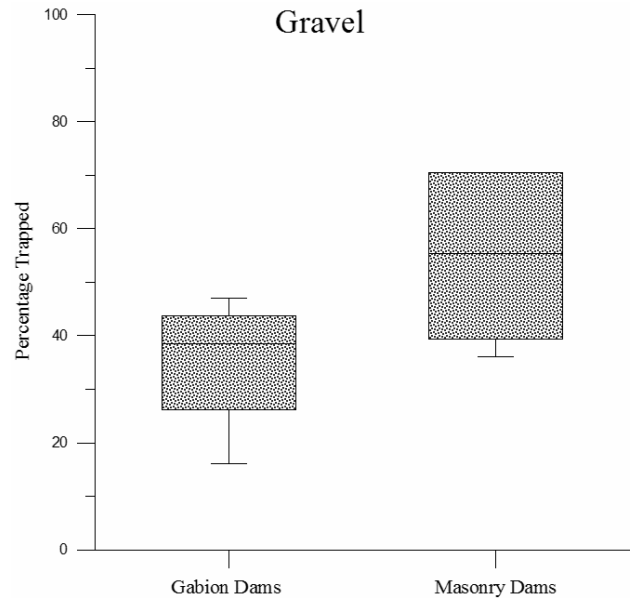


Fig. 5 Percentage of gravel trapped by studied dams in "El Ventilador" watershed.

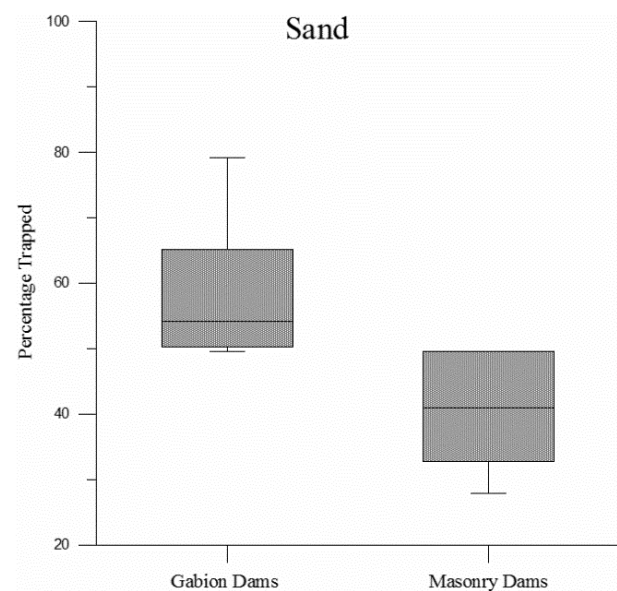


Fig. 6 Percentage of sand trapped by studied dams in "El Ventilador" watershed.

Regarding the trapped fine sediments, clay and silt, no significant differences were found between gabions and masonry dams. In both cases, the percentages were low, even though the masonry dams presented greater variation among them (Fig. 8).

In addition to the particle size of distribution trapped by structures, the volume retained 2 years after the implementation was also analyzed and compared. The results are shown in Table 2. Their efficiency was

calculated comparing actual volume of retained sediments with respect to the total capacity.

Gabion dams presented an average efficiency of 11.7% compared to masonry dams with 58.3%, because masonry dams have a smaller built volume and greater storage capacity. Nevertheless, these can be up to twice as expensive.

It was not possible to find a trend because each has a different tributary area of dams and conditions of topography. However, it is clear that solid dams retain higher sediments volumes compared to porous dams.

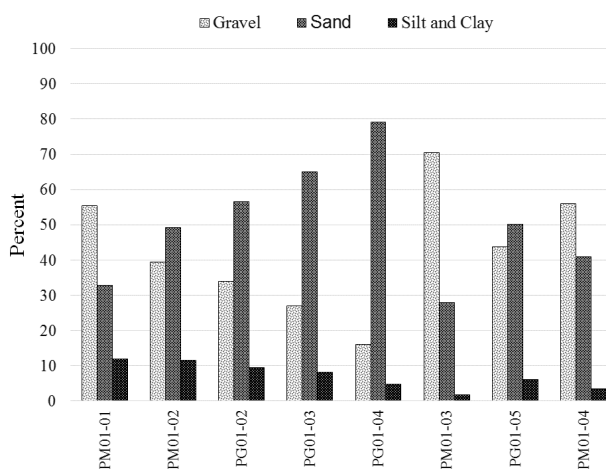


Fig. 7 Percentage of particles trapped by dams located in stream 1.

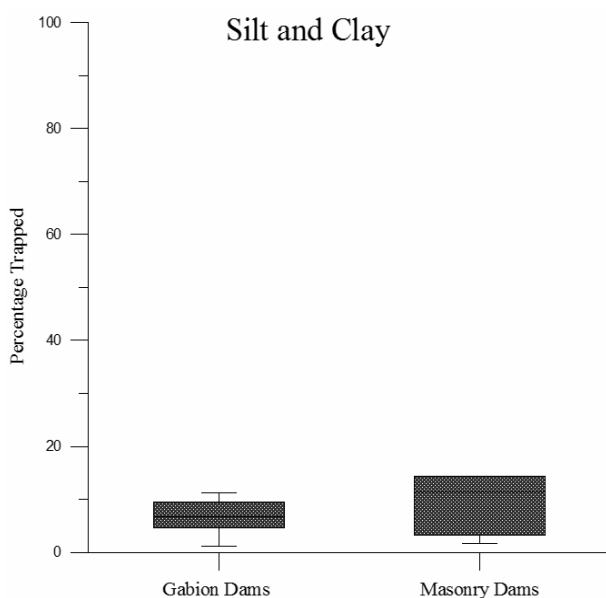


Fig. 8 Percentage of fine sediments trapped by studied dams in "El Ventilador" watershed.

Table 2 Efficiency respect to building volume.

Dam name	Volume of retained sediment (m ³)	Efficiency (%)	Current capacity (%)
PG01-02	2.0	45.5	54.5
PG01-03	3.0	4.9	95.1
PG01-04	3.0	8.0	92.0
PG01-05	3.5	3.5	96.5
PG1A-01	2.5	6.3	93.7
PG1A-02	2.5	9.9	90.1
PG03-02	2.0	3.8	96.2
PG05-02	2.5	11.8	88.2
PM01-01	260.0	61.5	39.0
PM01-02	90.2	53.8	46.0
PM01-03	106.6	70.5	30.0
PM01-04	59.3	58.5	41.0
PM05-02	207.6	47.3	53.0

5. Conclusions

Gabion dams detain less gravel than masonry dams, opposite to the case with sand, and concerning fine sediments, there were no significant differences between them.

The gabion dams represent a viable solution to retain sediment particles resulting from water erosion and then reduce the impact of disasters and accumulation in the lower parts of watersheds. The effect may increase if it is placed in the downstream sections.

Solid dams can retain practically all sediment sizes except a percentage of fine sediments. However, their cost is still high.

Gabion dams can be used to measure the effect of land use changes on sediment yield in catchments.

Data obtained can be used to calibrate hydrological models for assessment and planning in the watershed restoration.

It is necessary to sample soil on the hillslope of the watershed to verify the original source and the particle size of the sediments.

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