Working Paper

Sand Storage Dams: a Tool to Cope with Water Scarcity in Arid and Semi-Arid Regions

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'Water harvesting offers under-exploited opportunities for the predominantly rainfed farming systems of the drylands in the developing world. It works best in precisely those areas where rural poverty is worst. When practiced well, its impact is to simultaneously reduce hunger and alleviate poverty, as well as to improve the resilience of the environment.'

Kevin Cleaver in Mekdaschi Studer & Liniger (2013, p. VII)

Abstract

In arid and semi-arid regions of the world, periodic droughts are common. In these regions, the evaporation rate is higher than the precipitation rate during most of the year. Groundwater dams are a reasonable solution to store water for later use with easy accessibility for local residents. One particular type of groundwater dam is a sand storage dam. This must be built at the right place and in the correct way. It should be built across temporarily dry and sandy riverbeds with a large enough catchment area. The dam spillway should be raised stepwise to accumulate only the coarsest sands of a runoff. This will create a highly permeable sand reservoir, which can be filled up during each rainy season. If constructed correctly, a sand storage dam can be a reliable water supply option, which has many further advantages besides the storage of water, especially in comparison to surface dams. These include: low evaporation rate, low risk of water contamination and malaria transmission, good water quality, low maintenance requirements and the possibility to recharge aquifers. Particular methods of construction and siting may lead to the accumulation of fine sediments, which in turn results in low water yields. Silted-up sand storage dams require adequate reparation works to be able to function. These include flushing or excavating the sand reservoir, or in contrary, leaving them silted-up and using them as a basis for holistic riverbed and riverbank reclamation activities.

Keywords: *sand dam, step-by-step construction, construction site, siltation, coarse sediments, sandy riverbeds, maintenance, reclamation activities, water harvesting, water supply*

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Introduction

Sand storage dams are impermeable structures built across sandy riverbeds in seasonal streams with a crest raised above the riverbed (Lasage et al. 2008). The constructed retention barrier traps coarse sediments transported by runoff and stores water in the voids of the accumulated material (Hanson & Nilsson 1986). The design of a sand storage dam aims to maximise the water storage capacity of the reservoir, in order to fulfil the water needs of riparian communities during dry periods (de Trincheria et al. 2016; de Trincheria, Leal & Otterpohl 2018).

Sand storage dams are considered a type of groundwater dam, a macro-catchment water harvesting method that intercepts runoff, stores it below ground level and helps overcome water shortage during dry seasons (Biazin et al. 2012; Datta 2019; Hanson & Nilsson 1986). Sand storage dams are also considered an in-channel modification technique, a type of managed aquifer recharge method (Dillon 2005; Gale & Dillon 2005; Tuinhof et al. 2003).

As reviewed by Biazin et al. (2012), rainwater harvesting and management (RWHM) techniques comprise practices of water collection, storage and reuse, as well as land-use measures. In arid and semi-arid regions, precipitation is highly variable in space and time and is frequently insufficient to allow crops to complete their growth cycle (Jaeger et al. 2017; Teel 2019). Therefore, RWHM practices are used for domestic or agricultural use or to reduce surface runoff and evaporation and also enhance infiltration (Biazin et al. 2012). In this regard, Lasage & Verburg (2015) suggest that large communal water harvesting structures, such as groundwater dams, have a lower cost per unit of captured water than small household storage structures. However, the former may require a larger initial investment and specialised technical knowledge (Lasage & Verburg 2015).

The main aim of this literature review is to provide an overview on sand storage dams. First, background information related to sand abstraction systems is presented. Later, the functioning principles of groundwater dams are reviewed. Then, the functioning principle of sand storage dams is explained, and the main advantages and disadvantages of its implementation are discussed. Furthermore, important aspects which need to be taken into account in order to build a functioning, efficient and long-lasting sand storage dam according to the state of the art technical literature are mentioned. Additionally, more in-depth sources on each topic and aspects of sand dams are pointed out, to allow the interested reader to get more into detail once she/he has gained an overview from the recent state of the art of the sand storage dam technology. Also, in this review there is a brief mention and discussion on how water can be extracted and how to sustainably maintain a sand storage dam – not only from a technical perspective, but also from a social point of view. Finally, the causes of siltation are reviewed and it is explained how silted-up sand dams can be utilised (e.g. for riverbank reclamation activities or as an erosion prevention approach).

Seasonal Sandy Rivers and Groundwater Dams

Numerous literature sources point out the importance of seasonal sandy rivers as a source of water in arid and semi-arid regions (Biazin et al. 2012; Datta 2019; Hussey 2007;

Wipplinger 1958). When referring to the location of groundwater dams, the terms 'seasonal' and 'ephemeral' are used to describe the flow pattern and are sometimes used interchangeably between different authors (Lasage et al. 2008; Lasage & Verburg 2015; Nissen-Petersen 2000; Nissen-Petersen 2006). On the other hand, de Trincheria et al. (2015) distinguish between the terms ephemeral and intermittent as two types of seasonal rivers. A similar situation can be identified between the terms 'river' and 'stream' (Lasage et al. 2008; Nissen-Petersen 2000; Nissen-Petersen 2006). In this case, a distinction is in regard to the size of the water channel, where rivers are considered to be deeper and larger than streams (Datry, Bonada & Boulton 2017). Furthermore, eds Datry, Bonada & Boulton (2017) give an extensive description about intermittent rivers and ephemeral streams.

Ephemeral streams are considered to flow directly in response to precipitation and to have flow patterns of short duration and low predictability (Datry, Bonada & Boulton 2017; Goodrich et al. 2018; Hadley 1968). An intermittent river has a larger flow duration than an ephemeral stream. In this case, the flow fluctuates in response to temporal cycles, maintaining a continuous flow during wet periods (Datry, Bonada & Boulton 2017; de Trincheria et al. 2015).

Ephemeral streams are widely spread in drylands (Goodrich et al. 2018; Thornes 2009). These regions are characterised by brief, high intensity rainfall, a low average annual precipitation and a strong spatial, seasonal and inter-annual variability (Pereira, Cordery & Iacovides 2009; Thornes 2009). Also, the runoff is variable and the flow patterns in watercourses are of short duration and low predictability (Datry, Bonada & Boulton 2017; Jaeger et al. 2017). Further, groundwater contributions are limited (Jaeger et al. 2017). Drylands cover around 40 % of the world's land (eds Cherlet et al. 2018, p. 72). In these regions, the precipitation to potential evapotranspiration ratio (aridity index, AI) is less than 0.65 (eds Cherlet et al. 2018, p. 72; Maliva & Missimer 2012, p. 24).

In a watershed, large quantities of eroded material are washed while rainwater drains into a particular stream; this material is also known as washload (Hicks & Gomez 2016). The washload constitutes a large part of the sediments transported by watercourses (Hussey 2007; Julien 2002) and is typically composed of clay, silt and fine sand grades (Hicks & Gomez 2016). Another source of sediments is the bed-material-load derived from the riverbed, typically composed of gravel and sand. The total transported material, called sediment load, consists of silt, sand, gravel and boulders, among others (Chanson 2004).

The most common forms of sediment transport in watercourses are bed- and suspended-load (Imran & Parker 2008). The bedload moves along the riverbed sliding, rolling or saltating, and it is only found near the riverbed (Chanson 2004; Imran & Parker 2008). Particles in the suspended load are lifted and dispersed through the flow by turbulence (Armanini 2018; Hicks 2004). The unconsolidated sediments that are deposited and accumulated along the watercourses are called alluvium (Bridge 2004; Nanoso & Gibling 2004).

Sand rivers are defined by Walker et al. (2018) as unconsolidated alluvial deposits along watercourses. Where geology of low permeability is found underlying a sand river, an alluvial river aquifer is formed (Walker et al. 2018). Alluvial river aquifers are recharged mainly from surface runoff, as the flood travels down a seasonal river (Seely et al. 2003; Walker et al. 2018).

The amount of water that is infiltrated and stored in the interconnected voids of the unconsolidated sediments is typically described as the effective porosity of the alluvial material (Brassington 2017; Julien 2002). However, not all water can later be extracted, an indicator of the amount of water that can be drained from an aquifer is the specific yield (Brassington 2017). Unconsolidated sediments generally tend to be more permeable; this means that they have a high specific yield (Brassington 2017).

Seasonal sandy streams are a relatively effective and cheap source of water, which have the potential to fulfil the water needs of local communities (Lasage et al. 2015). A potential for water storage and abstraction exists in places where alluvial river aquifers have sufficient accumulation of coarse sand or gravel and where an underlying impervious or low-permeability layer is found to prevent seepage losses (Hanson & Nilsson 1986; Hussey 2007).

To increase the storage capacity of seasonal sandy rivers, the application of groundwater dams is recommended. There are two types of groundwater dams: subsurface dams and sand dams. Both structures intercept runoff water and store it below ground level, and they are frequently used in combination (Hanson & Nilsson 1986).

General Characteristics of Sand Dams

During rain events, sediments are transported along seasonal rivers by the runoff from an upstream catchment area. The watercourse gradient will determine the size of the sediments deposited along the riverbed (Hussey 2007). Rivers transport sediments from the upstream catchment area towards the dam built across the riverbed. The sediments slow down and settle in front of the dam. Thus, over time, the sand reservoir fills completely with sand, forming an artificial alluvial river aquifer, which stores water from the rainy season in the voids between the sand particles (Lasage et al. 2008; Lasage et al. 2015). Figure 1 illustrates the concepts of bed- and suspended-load described by Imran & Parker (2008) and Hicks & Gomez (2016) and also the concept of accumulation of sediments behind the wall of the sand storage dam illustrated by Onder & Yilmaz (2005).

During the rainy season or any rain event, the sand storage dam is recharged. If it exceeds the storage capacity, excess water simply flows over the dam spillway (Onder & Yilmaz 2005). Then, water can be extracted from the reservoirs by the use of structures such as a waterhole, a hand-dug well, an infiltration pipe, a well shaft in the riverbank, an intake chamber with elevated water tank (Nissen-Petersen 2006) or with the use of pumps (hand, mechanised, solar, etc.).

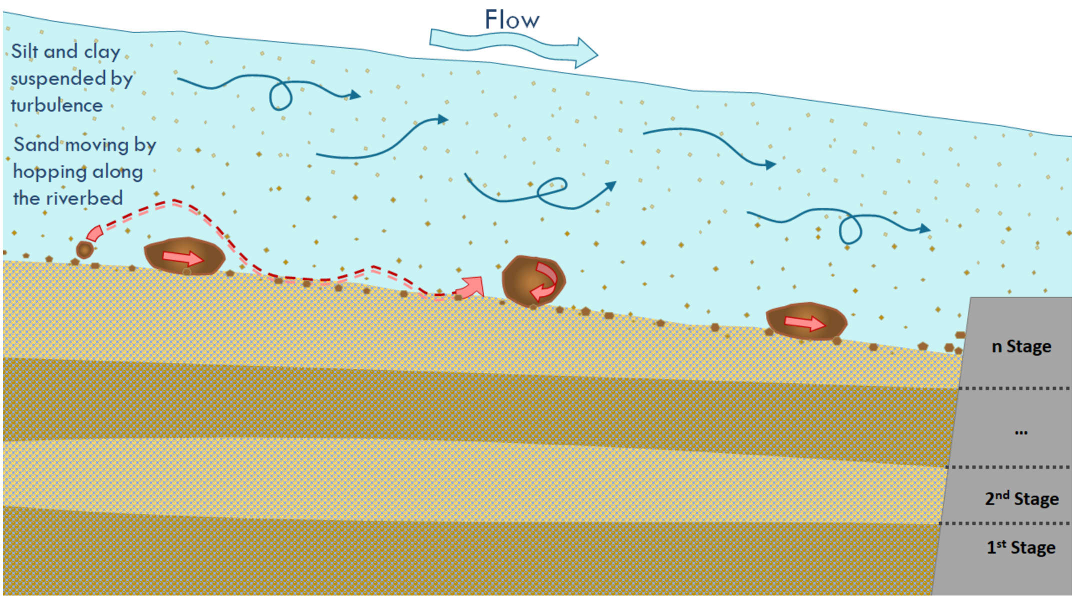

Figure 1: Bedload Transport & Concept of a Sand Dam

Benefits and Constrains of Sand Dams

When sand dams are part of a water supply project, special considerations must be made. Sand dams are a more expensive and more difficult way of extracting water from sandy riverbeds than subsurface dams or other small scale storage structures (Lasage & Verburg 2015). It is strongly recommended that, as a first step, a subsurface dam is built. As a further step, the pre-existing underground dam can be extended to a sand dam, in order to improve the water yield (de Trincheria et al. 2016; de Trincheria, Leal & Otterpohl 2018; de Trincheria & Nissen-Petersen 2015; Nissen-Petersen 2006).

A sand storage dam can be a good method for supplying water. It has several advantages over surface dams, including:

- <u>Less evaporation</u>: The water is stored only a few decimetres beneath the ground surface, shielded from sun rays and wind (Klopfer 2010; Nissen-Petersen 2000). The evaporation rate is only a few millimetres per day (Liu et al. 2015).
- <u>Less contamination and better water quality</u>: Because the water is stored underground, it is also shielded from contamination. Like with groundwater, the infiltration of pollutants is delayed or even totally prevented, as the sand reservoir acts as a natural filter (Avis 2016; Klopfer 2010; Onder & Yilmaz 2005; Quinn et al. 2018).
- <u>Less spread of diseases like malaria</u>: As there are no open water surfaces, the reproduction of malaria mosquitos is inhibited (Klopfer 2010; Yohannes et al. 2005).
- <u>Low cost of maintenance</u>: A properly built sand dam is a robust construction, which can easily be maintained over a lifespan of up to 50 years (Klopfer 2010; Lasage & Verburg 2015).
- <u>Adaptability</u>: A sand dam is always a unique construction, which needs to be adapted to the given local circumstances (e.g. by choosing the right stage height), so a high

storage capacity can be ensured. Each individual sand dam is a unique structure that can be adapted to the specific site (Klopfer 2010; Nissen-Petersen 2000).

- Possibility to combine a sand dam with a subsurface dam: In a water stream, where a natural deposit of sand takes place, the construction of a subsurface dam helps to stop the underground water flow and increases the natural water storage below ground. When the foundations of a sand dam are constructed, a trench is excavated in the riverbed in order to reach the bedrock. A subsurface dam can be used as a first stage. And later, the reservoir storage capacity can be increased by expanding the dam above ground. Therefore, in this case, the subsurface dam works as the foundation of a sand dam (Gur & Spuhler 2018; Klopfer 2010; Nissen-Petersen 2000).
- Low impact on downstream area: As between 2 – 4 % of the runoff water is retained, which would otherwise not be used or evaporate, there are a few negative influences on the downstream area (Aerts et al. 2007; Borst 2006, 6, 83; Klopfer 2010; Pauw et al. 2008, v, 48).
- Further socio-economic advantages: In the affected regions, oftentimes women and children have to spend several hours a day and walk many kilometres in order to get water, which imposes a heavy physical burden on them. A nearby sand dam can significantly reduce the distance and time to get water. Residents have shown to use this saved time for more productive activities, like taking care of the household or generating income. Furthermore, with more water and time at hand, people are able to adapt and implement improved agricultural techniques. Thus, a sand dam can lead to improved nutrition and food security, as well as increased productivity and income (Hussey 2007; Klopfer 2010; Nissen-Petersen 2006; Pauw et al. 2008).

There are also some limitations in the application of sand storage dams. One of these is their rather high technical complexity, at least in comparison to a subsurface dam (Butterworth, Adank & Boelee 2014; Klopfer 2010). A sand dam has specific technical requirements that need to be fulfilled. For a functioning and efficient sand dam, two things are essential: a fitting construction site (Ali et al. 2014; Nissen-Petersen 2006) and a correct construction process (de Trincheria et al. 2016; Nissen-Petersen 2006). In other words, they are often not built at the right place and in the correct way.

Although the stepwise construction of sand dams was already introduced by Wipplinger (1958), many sand dams have still been built in one step or in unsuitable areas. There are no clear, unified criteria on the technical design. Further data collection and research is required. Also, sometimes sand dams are built where a subsurface dam would be a better solution, as it is easier to build and less expensive. A subsurface dam is the preferable solution if there is a big enough underground water reservoir, which contains sufficient water reserves for all the residents (de Trincheria et al. 2016; Nissen-Petersen 2006). Therefore, a sand dam should only be built when a subsurface dam is not feasible (de Trincheria et al. 2016).

Construction of Sand Dams

As already mentioned above, a sand dam is an efficient alternative if the construction of a subsurface dam is not sufficient or possible in a specific location. This section describes the site characteristics necessary for the construction of a sand dam and the construction procedure that should be followed.

Ideal Construction Site Characteristics

In order to determine the best location for the construction of a sand dam, several factors need to be taken into account. The following are the characteristics of an ideal construction site:

- The site is a seasonal sandy riverbed in a valley floor which contains as many crystalline rocks and coarse sands (diameters of 1.5 – 5 mm) and as few volcanic rocks and cohesive soil as possible (de Trincheria et al. 2016; Klopfer 2010; Mekdaschi Studer & Liniger 2013; Nissen-Petersen 2000, p. 15; Nissen-Petersen 2006, p. 2). The same is necessary for the higher, upstream catchment area, which should be large enough to provide plenty of coarse sands.
- The area should not contain calcite, calcrete, halite or other salty rocks, as these can dissolve in water and make it salty (Nissen-Petersen 2006, p. 5; RAIN 2008, p. 11).
- The slope at the construction site should be flat to gentle (around 1 – 5 %). At this slope, two contrary effects are at equilibrium. High slopes lead to a high flow velocity; and therefore, only the coarsest sediments can settle. The infiltration rate is low. In contrary, low slopes lead to a low flow velocity; and therefore, fine sediments can also settle. Infiltration rates are high. Coarse particles and high infiltration are desired (Gur & Spuhler 2018; Hanson & Nilsson 1986, p. 499; Klopfer 2010; RAIN 2008, p. 8).
- The riverbanks are high, and the width of the riverbed is less than 25 m. The wing walls can be fixed to the sides, and no expensive reinforcement of the wall is needed (Nissen-Petersen 2006, p. 49; RAIN 2008, p. 8, 12).
- There is an impermeable ground layer of clay or non-fractured rock beneath in order to avoid seepage (Nissen-Petersen 2006; RAIN 2008).
- Sand dams can also be built on top of an already existing alluvial aquifer and, therefore, can be combined with a subsurface dam. The advantage is that natural reservoirs usually already contain sands of a high permeability and yield, which can interact with the artificial sand reservoir by infiltration and capillary forces (de Trincheria & Nissen-Petersen 2015).

There are highly specific requirements for a sand dam construction site. Some of the specifications, like the availability of enough coarse sediments, have to be met precisely in order to build a functioning sand dam, while others, like the constructing materials, can be varied according to the resources available in the construction site. Nevertheless, geophysical and hydrogeological surveys are always required in order to find a fitting construction site and to determine the construction parameters of the dam. The most important are the capacity and the stage height.

Construction Site Selection

Finding a suitable site for the construction of a sand dam is a complex undertaking. Runoff transports eroded materials, which are deposited when the energy of the flow cannot continue to carry them. But even at ideal sites, the desired coarse sediments (e.g. those found in the bedload) account for only between 5 – 8 % of the total transported sediments in semi-arid areas (Alexandrov et al. 2009, p. 11; de Trincheria et al. 2016; Powell et al. 1996, p. 394). In addition, the bedload transport is highly variable, depending on individual rain events. The rainfall intensity has to reach a minimum threshold in order for bedload transport to even take place. Powell et al. (1996) and Alexandrov, Laronne & Reid (2003) showed that in one out of three runoff events, only fine sediments are entrained (de Trincheria et al. 2016).

The amount of usable sediments which will be transported during the construction period is difficult to predict; and therefore, it is also difficult to plan the construction itself. For this reason, extensive knowledge about potential sites and their runoffs is required. Once an optimal location has been found, the construction process has to be adapted to the given conditions. The studies presented below give some recommendations for site selection.

Nissen-Petersen (2006) and Hussey (2007) give a detailed explanation of site studies and soil probing methods that can be used during this process. These methods include the investigation of:

- height and shape of river banks,
- porosity of sand,
- gradient of the hillside,
- expected volume of dam reservoir,
- depth estimation of water level by vegetation indicators.

Further, the most important concepts related to runoff are presented in the following studies (adapted from Klopfer 2010):

- flow velocity (Armanini 2018, p. 6),
- runoff coefficient (State Water Resources Control Board 2011),
- evaporation losses from soil bodies (Duggal & Soni 1996, p. 144),
- water economics (water supply and requirement),
- soil classification, coefficient of permeability, porosity (Fitts 2013, p. 49),
- general soil erosion (Schnitzer et al. 2013, p. 1285).

de Trincheria et al. (2016) give a simplified decision flowchart to select between a sand dam and a subsurface dam and to determine if there is high siltation potential. Once a site has been chosen, the construction of the dam, especially the stage height, has to be adjusted to the given, non-ideal conditions. The determination of the stage height is thereby a case-by-case decision, which is described in detail by de Trincheria et al. (2016). The determination of the stage height may be conducted on the basis of either a long-term analysis of historical bedload transport (using all the formulas and methods above to obtain the minimum and average historical flux of bedload transport, coupled with empirical information on the magnitude and incidence of rainfalls and runoffs) or the use of a precautionary fixed stage height from 20 – 60 cm on a case-by-case study.

As explained by de Trincheria et al. (2016), long-term studies are oftentimes not affordable; therefore, they introduce a decision guide which contains stage height recommendations based on long-term scientific and empirical studies, summing up the most relevant literature. This decision guide describes the stage height as a function of the key hydrogeological variables with the strongest influence on bedload transport, which take into account:

- the predominant particle grain-size of the original riverbed (coarse, medium, fine),
- the type of seasonal riverbed (intermittent or ephemeral),
- the number of rainy seasons per year.

The guide then suggests a stage height for good or poor years, depending on the desired predominant particle size of the final reservoir. In general, a minimum stage height of 20 cm is suggested, as a typical final spillway height of 1.5 – 5 m can be reached within a typical project time of 1 – 3 years (de Trincheria et al. 2016).

Construction Procedure

Once a survey is conducted and a step-height is chosen, the construction can be planned. The most cost-efficient method is to build the base (underground section) and the wing walls according to the final height from the start. The spillway in the centre can be raised step-by-step (de Trincheria et al. 2016). The construction process usually follows these steps:

1. A deep trench is dug across the riverbed where there is a natural underground dyke in order to increase the storage volume (de Trincheria & Nissen-Petersen 2015). In order to avoid seepage, the trench is dug until either the bedrock layer is reached or there is at least 1 m of another stable, impermeable soil layer (Nissen-Petersen 2006). If built on top of an aquifer, it also needs to be sealed by reaching down to the rock layer (Klopfer 2010). Then, the first stage above ground can be built.
2. The wall is raised step by step. The next step can be built once the previous stage is filled with runoff (Gur & Spuhler 2018).

The materials used to construct the dam depend on local availability. Sand dams are defined by the materials used to construct them (Nissen-Petersen 2000). These types are defined as the following:

- stone-masonry dams made of concrete blocks or stones,
- steel reinforced concrete dams,
- earth dams with impermeable clayey soil or black soil,
- dams made of other local materials, e.g. from a termite hill, which is also used for sealing houses (Klopfer 2010).

Concrete dams are more stable, but the most reasonable option always depends on what is available and the expertise of local craft labour. For concrete dams, waterproof Portland cement is necessary, which may be difficult to obtain. Also, the large water demand for all these types of dams might be problematic and needs to be taken into consideration. Nissen-Petersen (2006) gives some rules of thumb for the dimensions of the dam wall and wing walls:

- width of dam base: ¾ of the dam height,
- wall thickness: 55 % of the dam height,
- crest thickness: 1/5 of the dam height,
- wall leaning downstream gradient of 1/8 of the dam height,
- the apron must be reinforced; placing large stones onto which the spill-over will fall will reduce the spill-over force, preventing apron concrete undercutting,
- the wing walls on the sides should be built with an angle to the main dam in order to prevent overflowing, especially if the riverbank is low.

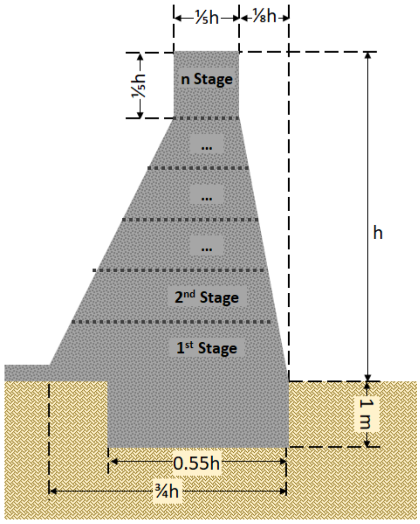

Figure 2: Dam Wall Dimensions, Based on Nissen-Petersen (2006, pp. 51–2)

Water Abstraction from Sand Dams

There are different methods to extract water stored in a sand dam. This section describes some of the traditional methods of drawing water and the key operational issues related to each.

The simpler, but less recommended, is the scoop hole (also called sand well, shallow well or scoop well). A hole is dug by hand in the sand, and water is drawn as it seeps into the hole. A scoop hole can easily be damaged by the river flow and filled by runoff sediments. When scoop holes are not effectively managed, these could compromise the water safety of the whole reservoir, introducing pollutants. Water is filtered through the riverbed over a long distance. So, holes used by the local population should be close to the dam. Also, animals should be kept away to prevent manure contamination. Additionally, water should be always boiled before drinking (Hussey 2007; Quinn et al. 2018; RAIN 2008).

Another abstraction method is to construct a well. This is a better alternative since water is kept underground all the time and protected from evaporation and contamination. For better sustainability, the well needs to be covered and properly maintained. The water lifting can be done with a rope and a bucket or with a hand-, centrifugal- or submersible- pump. Hand pumps are often the easiest to maintain for small communities. The location of the well is very important. Both technical and social aspects need to be considered. The location where the water yield is the highest is often where the riverbed is the deepest. This will require an adequate protection to prevent damages to the well caused by floods. An alternative is to position the well in the riverbanks. Even though this will increase the initial cost, the potential damage from floods is reduced, and the maintenance will be less demanding. Furthermore, wells are recommended to be built close to the previous location of scoop holes used by the community. This prevents the local population from continuing to drink water which may be contaminated (Hussey 2007; Nissen-Petersen 2006; RAIN 2008).

A third water extraction method consists of an outlet tap connected to an infiltration pipe. This is a net of perforated pipes placed at the bottom of the riverbed through which water is collected and directed towards the tap. The pipe should be shielded so as to prevent sand and silt from entering. It should be located just above the impermeable layer and covered with a layer of coarse gravel and a layer of coarse sand. The tap can be located in the dam wall or on a borehole in the riverbank. However, it has some disadvantages. The outlet could weaken the structure of the dam wall, and the maintenance of the system is complicated and expensive (Hussey 2007; Nissen-Petersen 2006; RAIN 2008).

Water Quality and Maintenance

A sand dam has many advantages regarding water quality. Compared to open water storage, a sand dam protects water from many contamination sources. Moreover, water flows through the sand of the riverbed, which filters and cleans it, making it suitable for drinking.

To preserve the water quality of the sand dam, maintenance, though quite basic, is extremely important. During the rainy season, the flow of the river can be very strong; so, the dam has to be robust enough to resist floods. It is very important to repair all cracks and weak points in the dam (RAIN 2008).

To maintain a good drinking water quality, the extraction well should be closed at all times. Moreover, it is highly recommended to have an expert regularly inspect the water quality. If there is any doubt about the quality, the well should be cleaned. In order to prevent silt from blocking tap outlets, the upstream riverbed should be cleaned after a flood. Additionally, the outlet should be easily accessible for cleaning. As already mentioned, silt is a major maintenance issue. However, there are many other pollutants that can affect the performance of a sand dam. The area has to be clear of rocks, branches, leaves, sediments and dead animals or animal defecations, which have a high potential of contamination.

To ensure good operation over the years, local communities must be involved in the project, construction and maintenance. Community empowerment is crucial for two main reasons. First, it is important for the planning and design phase. Local people should define the daily requirements in order to fulfil their needs. They should be involved in the surveys used to select the location and design. Secondly, the participation during the construction stage is a practical way to be trained for the operation and maintenance, as it will be their responsibility (Stephens 2010).

The proper maintenance of a sand dam is important to keep good water quality in the reservoir and to not lose storage capacity. The maintenance is a task for the local community and the skills to do it must be acquired during the construction.

Silted-Up Sand Dams & Erosion Prevention

Certain generally accepted design recommendations – including the evaluation of the catchment area, construction stages of the spillway, the height of the wing walls and the spillway – are well established and were discussed in previous sections. When those recommendations are not met, there is a high risk that the water supply project will fail.

Siltation is one drawback of sand storage dams. As explained by Nissen-Petersen (2006), the coarse sand must be trapped, while the fine sand and lighter silt have to flow over the spillway. Otherwise, the compacted hard layers of soil/silt/clay result in a significant reduction of the water yield (Nissen-Petersen 2006).

In regard to the selected construction site, low gradient catchments and catchments that contain farmland should be avoided, as they originate silt and fine sand and slow down the velocity of flash floods. This allows fine particles to settle in the riverbed, generating siltation (Nissen-Petersen 2006). A sand dam should be located where riverbeds have no bends 50 m upstream and 25 m downstream, in order to prevent the damage to wing-walls and the erosion of the riverbanks (Nissen-Petersen 2000).

Silt will be deposited if the spillway was not built in stages and will keep coarse particles from being trapped (Nissen-Petersen 2006). It has to be noted that several available and well spread handbooks and technical sand dam construction guides do not point out the importance of the multistage construction procedure to prevent siltation of sand dams. As mentioned by de Trincheria et al. (2015, p. 11) it 'is required to reconceptualise and change current technical guidelines and construction procedures'.

The existence of several silted-up sand dams points out the need to offer suitable alternatives to these structures. Some alternatives proposed by de Trincheria et al. (2016) are:

- reconstruction of the spillway,
- dredging,
- holistic agricultural and land reclamation activities,
- application of a smart-agroforestry system, as well as water and soil conservation practices to enhance the water retention capacity,
- holistic riverbed and riverbank reclamation activities.

Sand dams are one of many available techniques for water harvesting. By increasing the water level in the sand deposit, they create a groundwater reservoir (van Steenbergen, Tuinhof & van Beusekom 2009). Sand dams increase the moisture within the soil profile and recharge groundwater. This provides soil and water conservation benefits along the adjacent river banks, increasing vegetation and reducing soil erosion (Knoop, Sambalino & van Steenbergen 2012). Raising the groundwater table has an effect on soil moisture and soil chemistry, which in turn has a positive impact on agricultural productivity.

A sand dam is not an infallible tool. But whether it works properly or not, it has a positive impact on the local environment by providing a reliable water supply and/or improving soil quality. To get the most out of it, other means need to be considered. For example: check dams would decrease the flow speed and reduce the risk of dam breakage during floods. They also prevent soil erosion and diminish silt in the dam.

Conclusion

A sand dam operating at its full capacity may be able to supply enough water for agricultural activities and crop production. The use of sand storage dams may also help to improve the quality of water for human consumption. This method of storing water has several advantages over typical surface storage dams, including reduced evaporation rates and contamination.

Sand dams are a sustainable groundwater management tool which, in combination with other techniques, may help achieve a balance between demand and available water in a basin. As part of a water harvesting system, the construction of sand storage dams is recommended after an underground dam has already been constructed and operated correctly.

When constructing sand dams, special care must be taken in the multistage construction of the spillway, in order to avoid siltation and assure a constant water supply. Otherwise, the rectification could be expensive and reclamation activities would be a better alternative for the existing structure.

The main disadvantage of selecting a sand dam as a water reservoir is that it must be planned, designed and constructed according to specific technical requirements. Else, high costs, low yields and siltation could be faced. In contrast, well-designed sand dams are an effective tool for water harvesting and enhance water yield of pre-existing systems such as subsurface dams.

Picture Credits

Figure 1 (p. 6) Bedload Transport & Concept of a Sand Dam by Berenice Lopez Mendez is licensed under CC BY-SA 4.0 <https://creativecommons.org/ licenses/by-sa/4.0/>.

Figure 2 (p. 11) Dam Wall Dimensions
Based on Nissen-Petersen (2006, pp. 51-2).

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