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Silting of recharge dams in Oman: Problems and management strategies

Hydrolink

SILTING OF RECHARGE DAMS IN OMAN: PROBLEMS AND MANAGEMENT STRATEGIES

BY ALI AL-MAKTOUMI

In the Sultanate of Oman, 155 dams have been constructed as of 2018 for different purposes: flood protection (3 dams), recharge (46) and surface storage (106). Recharge reservoir dams are an effective measure to manage and augment water resources, especially groundwater aquifers, through making use of floodwater which is often lost to the sea and desert. These reservoir dams proved their efficiency, however (like elsewhere in the world) facing challenges that threaten their amenities. One of the most important issues to be countered is the silting of dams (i.e. reservoir sedimentation). The concerned water authorities along with academia are devoting many efforts to solve this problem.

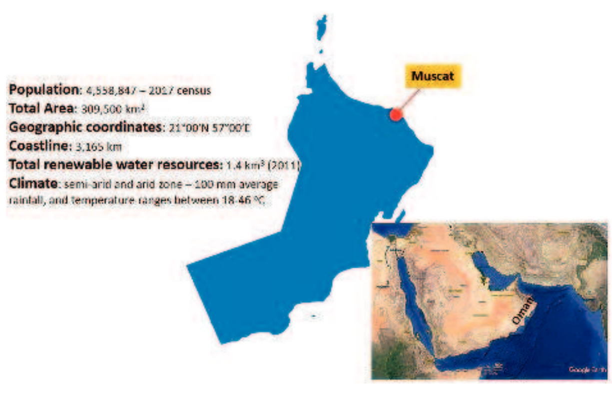

Figure 1. Map of Oman. Muscat is the capital of Oman

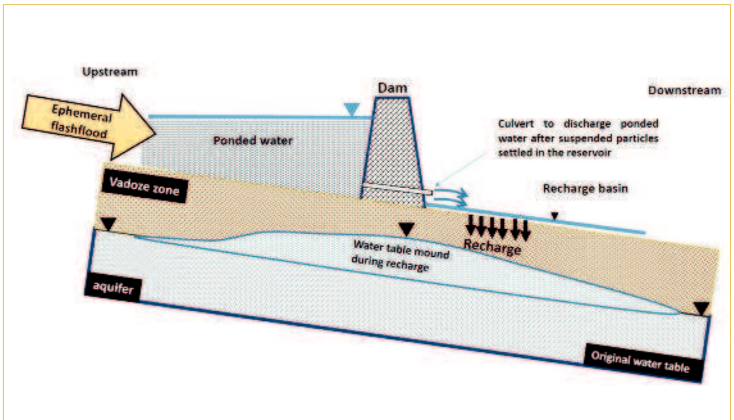

Figure 2. The concept of recharge dam reservoirs

Reharge reservoir dams in of oman: concept and role

The Sultanate of Oman is an arid country where drought conditions prevail and water is precious (Figure 1). Oman experiences a severe water shortage that threatens the national plans for development in all sectors (*e.g.* agriculture, tourism, industry). Government agencies and research institutions have been actively addressing different ways of augmenting water resources, mainly groundwater. Indeed, the water demand in Oman is mostly covered by groundwater withdrawal, supplying 87% of the demand, particularly for domestic and agriculture purposes. However, the intensive use of groundwater has led to the lowering of water tables and saltwater intrusion. One of the prudent measures to mitigate these problems is enhancing groundwater recharge (artificial recharge) by intercepting floodwaters (which are often wasted in the sea or in the desert) after rainfall events, storing them temporarily in reservoirs and down gradient infiltrating this water into the soil and aquifers (Figure 2).The water in the reservoirs is detained for about two weeks to avoid evaporation and health risks. Then the stored water is released slowly through culverts to the recharge basin which is located downstream of the dam. The recharge dam embankments are often made of soil, which is highly permeable, with a low-permeability clay core as the main seepage-checking component.

Forty-six (46) recharge dams have been constructed on alluvial valley wadis between 1970 and 2018 in Oman, with a total storage capacity of 101 Mm^3. While desalination provides a seemingly unlimited but costly water supply, recharge dams provide a limited water supply but relatively cheaply. Additional benefits of recharge dams are flood protection and deceleration or even reversing of seawater intrusion into coastal aquifers by creating groundwater mounds and, correspondingly, excess seaward oriented hydraulic slopes in these aquifers. Therefore, maintaining dam efficiency is necessary to achieve the optimum use of catchment-scale water resources.

Silting of reharge dams: problems and management starategies

Recharge dams in Oman are experiencing the problem of siltation, *i.e.* deposition of sediments

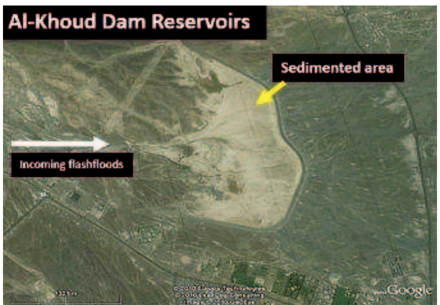

Figure 3. Areal satellite image for the Al-Khoud recharge reservoir (the whitish area indicates the deposited silt) (Google earth). Al-Khoud dam is the oldest and largest recharge dam in Oman (5,100 m long, 11 m high), commissioned in 1985 with initial storage capacity of 11.6 Mm^3.

brought by runoff water (Figures 3 and 4). This adversely affects the storage capacity of the reservoirs along with other problems (*e.g.* dam safety, water quality). Over time, layers of sediments from intercepted and detained water currents cover the entire reservoir area. Consequently, the water infiltration rate decreases, water loss via evaporation increases, and the reservoir volume is reduced. For example, about 3.4 Mm^3 of sediments have been deposited in the Al-Khoud reservoir since 1985[1]. Unfortunately, there is no detailed data on the silting rates of Omani dams, but a number of them have been recently equipped with gauging sticks to assess the volume of sedimentation. The use of low-cost multispectral satellite data for mapping the silting of dams has also been promoted[2].

As a common practice, the deposited material layer is removed to increase water infiltration and storage space of the reservoir, but this is not always possible or feasible. Another solution is building small check dams, or siltation ponds along the flashflood pathways to intercept most of the sediments within the catchment before they reach the reservoir. It is more practical and less costly to clean up the reservoirs of small dams. The trapped sediments are removed and used in the oasis clusters or scattered on the banks of the waterway.

Mechanical intervention (bulldozzing, drilling) greatly improves the ability of the reservoir area to act as a surface-to-subsurface hydrological sink. The responsible water authority in Oman excavates and scraps out the deposited sediments from the dam-beds and utilizes them in agricultural practices, with a plan to use these sediments also in the pottery and stoneware industry. However, mechanical removal of sediments remains costly (*e.g.* around US$ 250,000 for the Al-Khoud dam for basic cleaning of debris), it is tedious and requires recurring actions after each flood-deposition event. More importantly, part of the deposited fine particles is carried by water infiltrating vertically into the porous medium (Figure 5). Hence, the surface scraping cannot remove the clogging particles, which have already migrated deep into the parent bed material (commonly a coarse alluvium). Fine particles gradually change the physiochemical properties of the original subsurface porous medium. Understanding the behavior and patterns of the percolating soil particles and their effect on infiltration and aquifer recharge is of critical importance for better management strategies. This understanding will provide the foundation for future decision making by the Ministry of Regional Municipalities and Water Resources and other governmental agencies as related to future dam design and maintenance. Research has been done to gain more insight into the kinetics of filtration, surface-subsurface water dynamics, evolution of infiltration fronts, in essentially heterogeneous porous media of reservoir beds[1,3,4,5,6]. Analysis of the results revealed that the soil in reservoir areas is rapidly evolving because of intensive anthropogenic hydrologic impacts caused by periodic ponding, infiltration and desiccation. This results in complicated and dynamic heterogeneities as the more fine sediments are translocated vertically into the subsurface, altering therefore the hydrological properties of the substrate material[1,5].

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Along with the problem of the reduction in the reservoir storage capacity, the alteration of the soil properties are found to significantly affect the ponding time , and the infiltration patterns within the reservoir area. This increases the

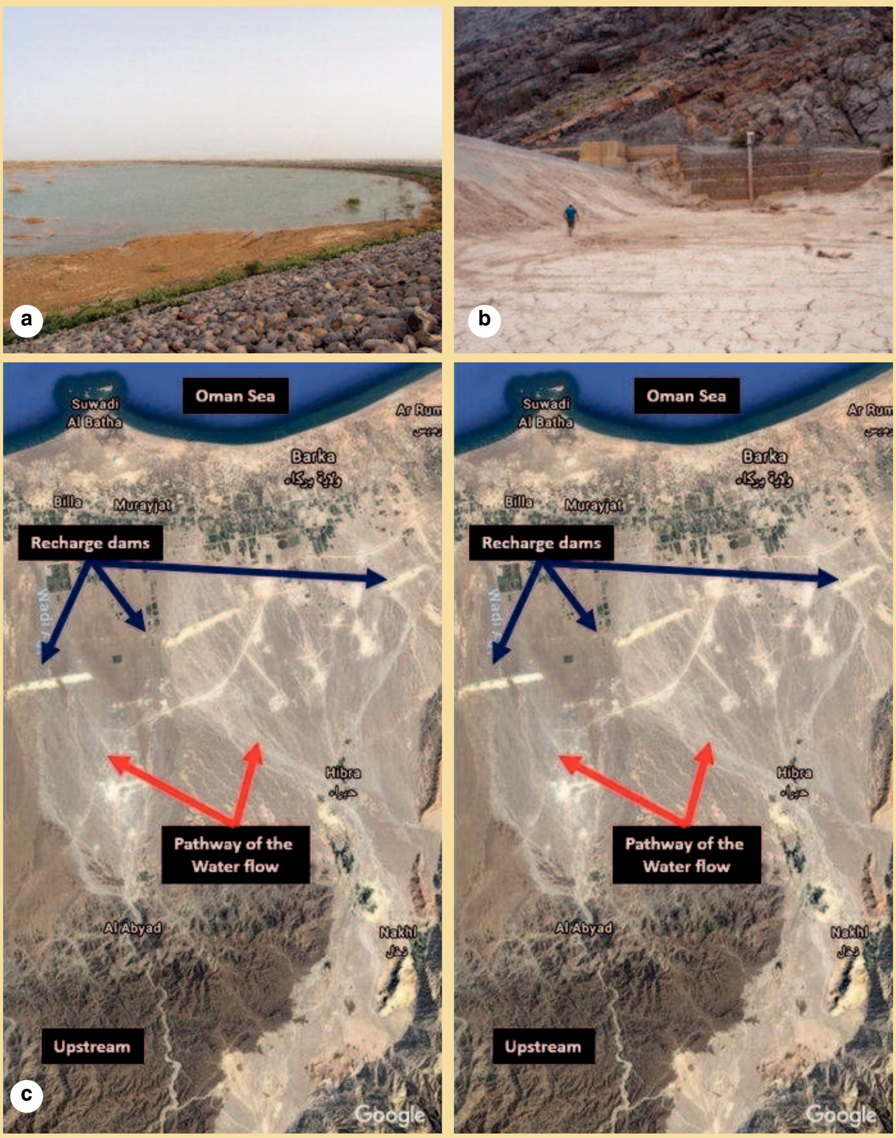

Figure 4. (a) Recharge dam in Oman after a flash flood, (b) Empty dam reservoir in Oman after long dry spell, (c) Satellite images of a number of recharge dams in North coastal line of Oman (left image), and Al-Khoud dam (right Image). Note: the whitish color in these images indicates the siltation patches. Excavations showed that the thickness of the deposited sediments exceeds 2-3 m.

potential hazards of flooding in the areas adjacent and downstream of the dam through over-spilling of ponded water. Zones located downstream of the dam, which are supposed to serve as recharge areas, receive pluses of reservoir water both from the dam's culverts and the spillways. This water is still rich in fine suspended particles which, similarly to what happens in the reservoir itself, in part translocate vertically into the subsurface, hydraulically impair it, *i.e.* adversely affect the recharge process. In addition, reduced infiltration through the recharge area downstream of the dam intensifies surface runoff and hence increases the loss of valuable fresh water resources to the sea or desert, jeopardizing any urbanized areas in its flow path by flooding.

Reservoir sedimentation threatens the stability and safety of the dam due to hydro-ecological interplay[7]. The slopes of the embankment are supported with gabions (Figure 3a) that have large mesh openings, acting as corridors and hosting settled suspended soil particles after each reservoir filling. The gabion serves as a mulch which reduces evaporation from the very wet shoulder and clay core of the dam. Fine textured materials are characterized by high water-holding capacity that intercepts the ex-filtrating water[7], and hence serves as a supply

Figure 5. (a) Soil Pedons of the Al-Khoud dam bed, about thirty (30) years after the dam commission, (b) a typical soil profile illustrating the sedimentation in Al-Khoud reservoir and the deep percolation of fine particles into the original gravelly alluvium

water source that supports the growth of lush vegetation, which thrives in the embankment. A vegetation strip has been observed on the slopes of the embankment of a recharge dam in Oman that emerged after torrential rains and temporary filling of the dam reservoir (Figure 4a). The vegetation is interpreted as the footprint of temporary storage of water, which is a small-sized groundwater mound within the permeable shoulder of the embankment[7]. The responsible governmental entity set a monitoring program to uproot this vegetation from the dam wall and reinforce the core with a concrete wall to avoid possible damage to the dam structure. ■

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management vis-à-vis several competing objectives for the use of these reservoirs. Technical and economic barriers also exist, driven primarily by the engineering challenges and costs of retrofitting existing dams with new infrastructure to flush or bypass sediment. For new and existing dams, sediment management strategies should be evaluated on the basis of cost and efficiency rather than the continuing need for dredging. Finally, several site conditions, such as road access or valley geometry, may impact the suitability of any given sediment management practice at a site. A systematic approach for evaluating the social, economic, ecological, and engineering tradeoffs of sediment management could facilitate this critical aspect of sustainable water resources. Ultimately, for many areas of the world characterized by high sediment yields, a suite of sediment management practices may be necessary.

Acknowledgements

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