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Cost-Effective Solution to Water Scarcity in Dryland Environments using Sand Dam

Charles Ezugwu[a*], Okechukwu Omunakwe[b] Kelechi Onyekweredike[a], Anthony Moluno[c], Chisom Ezugwu[a], Innocent Wokoma[c], Paul Akpan[d], Solomon Anyaeche[c] & Amodu Oloyede[c]

[a]Department of Civil Engineering, Alex Ekwueme Federal University, Ndufu Alike, Nigeria*
[b]Rivers State Ministry of Works, Port Harcourt, Nigeria
[c]Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria
[d]Kenule Beeson Saro Wiwa Polytechnic, Bori, Rivers State, Nigeria

**Corresponding author: charlesezugwu052@gmail.com; ezugwu.charles@funai.edu.ng*

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ABSTRACT

Drylands are homes to many peoples of the world where frequent severe droughts are experienced, and dwellers suffering severe water shortages. Water scarcity in these environments is at alarming rate but can be alleviated by building rainwater collecting structures using sand dams. These mitigation measures are built across ephemeral sand rivers and used to store and provide clean water in these environments. The procedure for this work involves presentation of the principles and functionality of sand dams, sand dam technology, the sedimentation process, financing and future plans. The application of sand dam technology provides water solution in these communities without interruption even during periods of droughts. The challenge is that most communities with potentials for sand dams lack the resources to implement it. It is recommended that self-help group (SHG) committees be formed in these areas to relieve these people of acute water stress. Structure for monitoring and maintenance of the facility should be packaged for optimal performance and sustainability. Before use, the water should be examined, and treated where pollutants are above tolerable levels. The main finding is that some places with sand dam potentials do not have them, either due to lack of awareness or resources. A comprehensive source of funding sand dam projects, a major contribution of this work is novel, being not found in related literatures. Future plan is to work on improving the technology and incorporating waste management in the system for a sustainable environment.

Keywords: Aquifer, Cost-effectiveness; Drylands; Sand dams; Sustainability; Water stress; Financing

INTRODUCTION

There is prevalent water stress in most drylands or arid areas of Africa and many other areas of the world. Water is prevalent in the 2015 United Nations Sustainable Development Goals (SDGs) which suggests that water is critical globally (United Nations General Assembly, 2015). About two million people in the world live on drylamds with the issue of severe droughts. Arid and semi arid regions (ASARs) of the world are known to be experiencing lack of enough water bodies and rainfall; water being the most valued resource in these regions (Olufayo, Otieno, & Ochieng 2009; Xu, Seward, Gaye, Lin & Olago 2019; Faramarzi, Abbaspour, Ashraf, Farzaneh, Zehnder, Srinivasan & Yang 2013; Şen, Al Alsheikh, Al-Turbak, Al-Bassam & Al-Dakheel 2013). It is a fact that Africa has the smallest part of the total water resources on earth, and is the second most populated continent in the universe (Xu, Seward, Gaye, Lin & Olago 2019; Faramarzi, Abbaspour, Ashraf, Farzaneh, Zehnder, Srinivasan & Yang 2013). Attempts to resolve this problem in their rural and urban communities does not give a positive outcome (Oyebande 2001 and Biazin et al. 2012). Persistent droughts increase water shortage and food shortage (Faramarzi, Abbaspour, Ashraf, Farzaneh, Zehnder, Srinivasan & Yang 2013; De Trincheria, Nissen-Patterson, Filho, & Otterpohl 2015; Calow, MacDonald, Nicol, & Robins, 2010). Also, both groundwater and surface water within this environment give rise to global warming and other effects of climate change (Faramarzi, Abbaspour, Ashraf, Farzaneh, Zehnder, Srinivasan & Yang 2013; Conuay & Schipper 2011; Kusangaya, Warburton, Archer & Jewitt 2014; MacDonald, Bonsor, Dochartaigh, & Taylor 2012). Groundwater and sand beds of ephemeral rivers are sources of water for ASARs for domestic purposes, irrigated agriculture and livestock farming (Xu et al. 2019; Gaye and Tindimugaya 2019; MacDonald, Davies & Calow 2008; Duker, Cambaza, Saveca, Ponguane, Mawoyo, Hulshof, Nkomo, Hussey, Van den Pol, & Vuik 2020). Sand rivers should be sources of water in these areas. Sand dams are small dams built on ephemeral streams as rain water collecting method (Ritchie et al. 2021). The water stored in sand pore spaces upstream is free from pollution by mosquitoes and other disease carrying mechanisms are worsened in the future by climate change. Drought periods can be tackled by constructing sand dams which are simple and cost-effective (Ryan and Elsner 2016). As a result of less rainfall, East African drylands are hotter thereby causing drying effect which is projected to be more due to climate change (Funk 2010). The impacts of climate change on the water system are significant (Resnick and Nelson 2011). Climate change is increasing water stress worldwide. Climate change is an important environmental issue because the progressive melting of glaciers and snow cover is sensitive to climate changes (Safieh J, Rebwar D, and Forough J 2020). It has been observed that local dryland communities that are striving to get enough water for various uses are to experience water shortage globally (Huang, Li, Fu, Chen, Fu, & Dai 2017). The political requirement is that water scarcity should be stopped or at least significantly reduced (COM 2011, COM 2012). Ecosystems especially agro ecosystems where human beings depend on their resources for existence are endangered by climate change (Boko, Niang, Nyong, Vogel, Githeko, Medany, OsmanElasha, Tabo, & Yanda 2007; Speranza 2012; Kilroy, 2015). About 41% of the earth's surface are drylands (Safriel and Adeel, 2005). According to UNDP 2014, about 30% of global population or about 2.3 billion people worldwide live on drylands and depend on these dryland natural resources for survival. As a matter of urgency, suitable and sustainable technologies should be developed to make such communities and ecosystems resilient during these devastating periods (Tucker et al. 2015). About 80% of the world's poorest people live in these drylands. Climate models forecasting for most dryland zones show decreased rainfall, higher temperature, including extreme events of increased intensity and frequency (Sörensen et al. 2008). In addition, rainfall configurations, more droughts, greater frequency of increased rainfall, shorter and increased floods are being changed as a result of fluctuations in climatic conditions. The option of employing sand dams for water solution is feasible as a result of its sustainability of water in affected areas.

This work calls on international, national and local communities to promote programmes that will encourage adaptation to climate change using sand dam technology, through public enlightenment of affected communities and through public-private partnerships (PPP). In any case, sand dams are still little understood and practiced. The Road Map is to make construction of sand dams one of the feasible alternatives in providing solution to water scarcity in dryland areas of the world aimed at relieving them from water stress.

They are built in many drylands (arid and semi-arid areas) of the world including Kenya, Ethiopia, some places in Brazil and India (Figure 1). Strong sand dams that are sustainable are constructed without expert engineering knowledge and skills. This research work aims at bringing into public domain the sand dam technology to educate people on its functionality and cost-effectiveness. Required information are (i) a full understanding of flow pattern of seasonal rivers (ii) a complete understanding of sand dam silting principles, design and construction and issues that result to collapse of dams, and (iii) having link with craftsmen with experience, and understanding of building of concrete walls. Borst and Haas, 2006; Hoogmoed, 2007 assert that the water available for abstraction is greater than the volume of water in sands in the river bed due to additional water stored in the banks of the river. The sand dam reservoir is continuously recharged by the water in river banks during drought periods. Hence, the period the water in the sand dam reservoir is available for abstraction is increased. The political, economic, biological, physical, and social factors that are responsible for the well-being of Africa have been altered on international level as a result of variation of climate and effects (Zierrogel et al. 2009).

Previous works did not discuss compressively the financing of sand dam projects. This work attempts to present its financing to ensure provision of these facilities in different communities in the most reliable, cost-effective and sustainable manner. With sufficient funding it will be possible to build many sand dams for various communities in the area for easy getting water without stress. Moreover, it will be possible to provide water treatment facilities where necessary.

BACKGROUND OF STUDY

Most rural communities of the universe do not have good quality water. About 900 million humans do not have potable water. Also, 84% of these people live in rural areas. This is most prevalent in developing countries. This lack of good quality and quantity of water affects negatively the health, nutrition, food security, education and living conditions of humans. Many people especially children die yearly due to health related illnesses. Drylands communities depict highly variable and unpredictable patterns of rainfall and this worsens these problems. Dryland communities show exceedingly changing and irregular rainfall patterns, thereby escalating these water issues. Approximately, 40% of the earth is dryland where 80% of the most impoverished people mostly in Africa and Asia dwell. Nigeria has potential for sand dams in Northern Nigeria where there is availability of drylands resulting in acute water scarcity especially during dry seasons (Figure 1). Recent practice is for the global community to focus on adaptation solution to climate variations (Boko, Niang, Nyong, Vogel, Githeko, Medany, OsmanElasha, Tabo, & Yanda 2007; Schipper & Burton 2009). It is also a known fact that aquifers are recharged after some days of rainfall (Borst & de Haas 2006; Hut, Ertsen, Joeman, Vergeer, Winsemius, van de Giesen 2008). River banks are essential recharge areas for the reservoir since they house water after rains resulting in increased storage capacity in river beds moving horizontally to the banks of the river (Quilis et al. 2009), with resultant improved vegetation in the area.

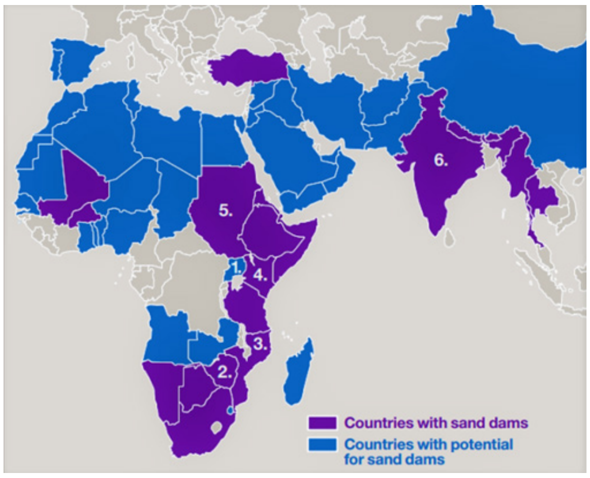

FIGURE 1. Map showing countries with sand dams (purple) and countries with potential for sand dams (blue).

PRINCIPLES AND FUNCTIONALITY OF SAND DAMS

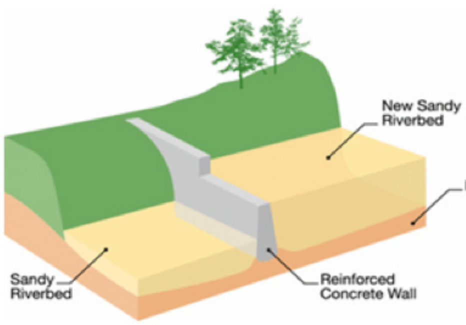

FIGURE 2. Sand dam in a river bed.
Source: Excellent Development (2011)

Sand dams are concrete walls built as barrier across a seasonal riverbed (Figure 2). Sand dams are very suitable for drylands of the world and is one of the cheapest rainwater collecting solutions, known for its simplicity, low cost and highly reduced maintenance cost. It provides all year round water for domestic and livestock farming for this area. The objective is to provide water for diverse uses including drinking, life stock watering, irrigation (Foster & Tuinhof 2004; Hut, Ertsen, Joeman, Vergeer, Winsemius, & van de Giesen 2008). Materials of smaller grain size like silt will be suspended and will flow over the top of the dam and will continue moving with the flow downstream (Fig. 3). This process continues until the reservoir is completely filled with sand thereby attaining full maturity. For effective performance of sand dams, the sand must be composed of materials of high grain size to enable storage of more water in its void spaces (Ritchie al, 2021). These dams should be built in stages to avoid the reservoir from capturing silt and clay sediments during the early rains.

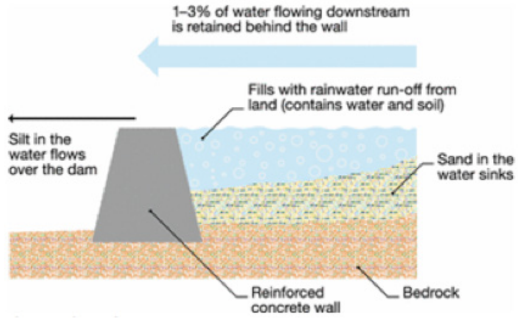

FIGURE 3. Conceptual illustration of how a sand dam works.
Source: Excellent Development (2011)

It is required that the sediment be of uniform size by selecting a river carrying sediments of fairly uniform size; to increase the porosity and yield of the aquifer; since if of varying sizes, the smaller size will fill the space between the greater grains, thereby occupying space the water would have occupied for enhanced yield. The dam reservoir is filled up with soil and water quickly from overland flows from seasonal rains. The soil contains clay, silt and sand. The extent of the sand reservoir increases with every rainfall period thereby allowing more water to accumulate in the sand reservoir; resulting to about 25-40 % of water stored in the reservoir. (Maddrell and Neal 2012). The reservoir may get filled with sand within about two years depending on the sand carrying capacity of the river. Apart from increase in the ability of sand dams to store water, the sand carrying the water can protect the stored water from being evaporated (Borst & de Haas 2006; Quinn, Parker, and Rushton 2018b; Eisma & Merwade 2020), enhancement of the quality of water (Quinn, Avis, Decker, Parker, & Cairncross 2018a; Graber Neufeld, Muendo, Muli, & Kanyari 2020; Manzi & Kuria, 2012; Ryan & Elsner 2016; Eisma and Merwade 2020), moreover rise in the living standard of communities in rural areas (de Bruijn & Rhebergen 2006; Lasage, Aerts, Mutiso & de Vries 2008; Pauw, Mutiso, Mutiso, Manzi, Lasage, & Aerts et al. 2008; Maddrell 2010). Some researchers asset that some sand dams do not withhold and preserve water efficiently (Van Loon & Droogers 2006; Nissen-Petersen 2010; De Trincheria, Nissen-Patterson, Filho, & Otterpohl 2015; de Trincheria, Leal, & Otterpohl 2018;. Eisma & Merwade 2020; Ngugi, Gichaba, Kathumo & Ertsen 2020). It is noteworthy that sand must be used as material in the reservoir for effective performance of the dam facility, not silt and/or clay (de Trincheria, Nissen-Patterson, Filho, & Otterpohl 2015; Eisma & Merwade 2020).

STORAGE CAPACITY

The storage capacity of the dam is determined by the volume of sediment (sand) in cubic metre (m^3) that collects at the upstream of the dam when the dam has been filled with sand.

$$\text{Storage capacity} = \text{Volume of sand} \times \eta \tag{1}$$

where η = porosity of the sand.

The annual yield of a sand dam reservoir may be more than its storage capacity as a result of base flow which recharges the aquifer.

SAND DAM TECHNOLOGY

Overflow collecting methods to enhance availability of freshwater have been used in drylands for hundreds of years ago in different places in Roman Era (Olulayo, Otieno, & Ochieng 2009; Lasage & Verburg 2015). Other names of sand dam are trap dam, sponge dam, sand storage dam, or desert water tank (Van 2004), being known as one of the prevalent overflow collecting methods. The use of sand dams have not been documented appropriately, it has been in use in over a millennium in ASARs of Afrrica, Asia, Middle East, North and South America (Ertsen & Hut 2009; Villani, Castelli, Hagos, & Bresci 2018; Kamel & Almawula 2016); it has also been applied to Europe (Ishida et al. 2011). In recent times, sand dam technology has been applied in great numbers in Africa, mostly in Kenya and Ethiopia; majority of these dams built after the 1990s. More than 1500 dams have been constructed in Kenya since 1960 (De Trincheria et al. 2015). Kenya leads in sand dam application with more than half of sand dams in the world located in Kenya. Great number of sand dams have been constructed in Kenya and Ethiopia in no distant time. Since 1960, above 1500 sand dams have been built in Kenya (de Trincheria, Nissen-Patterson, Filho, & Otterpohl 2015). It is worthy of note that more than half the number of sand dams in the world are housed in Kenya (Ngugi et al. 2020). Water resources development was carried out in arid areas of United States in 1973 by building of sand dams (Yifru, Kim, Lee, Kim, Chang & Chung 2021). This technology has the advantage of protection of water from contamination and evaporation and it does not create enabling environment for disease carrying mosquitoes. Sand dam technology is cost-efficient, improves quality of water and availability, enhances biodiversity, and its construction is simple (Yifru, Kim, Woo Chang, Lee, & Chung 2018); Hut, Ertsen, Joeman, Vergeer, Winsemius, & van de Giesen 2008). Sand dams also serve as road crossings where they are found (Neal, 2012). Boreholes cost more than sand dams in some cases (Teel, 2019). Sand dams sustain their effectiveness for many decades say up to a hundered years as a result of little maintenance and long life. The efficiency is dependent on method of construction, topographic and geological characteristics of the environment, management and change in climatic conditions (De Trincheria, Nissen-Patterson, Filho & Otterpohl, R 2015; Eisma & Merwade, 2020).

ABSTRACTION METHODS

When the reservoir attains maturity (has been filled with sand), the next stage is to collect the water that is stored in the pore spaces of sand in the sand reservoir. The water can be collected by any of the following methods:

1. Scoop holes
2. Infiltrations galleries
3. Shallow wells

SCOOP HOLES

Simple holes are made in the sands in the reservoir to collect water after its maturity. To improve the quality of water collected, existing water in the hole is usually removed and discarded, and then fresh water that seeps into the hole is collected for use. Separate cattle watering opening is usually made beneath the dam to avoid livestock traffic in the dam area in order to eliminate contamination and erosion to the barest minimum. Water extraction methods include wells, pumps, scoop holes within the riverbed or river banks within upstream of dams (Quilis, Hoogmoed, Ertsen, Foppen, Hut & de Vries 2009).

INFILTRATION GALLERY

An infiltration gallery is a horizontal pipe or network of pipes, usually plastic, with slots or holes drilled into the top two-thirds of the pipe placed in the riverbed. Water enters the pipe from the sand aquifer and flows along a gentle slope using chosen abstraction method: pipes through the dam, a tank in the dam wall or an off-take well or land pump located on the adjacent river bank. This has advantage over a scoop hole since the water is filtered as it passes through the sand.

SHALLOW WELLS

These are wells dug at sand dam area to enable collection of water. They are not deep, and do not get to the aquifer.

SITING OF SAND DAM

There is lack of extensive knowledge on the working of sand dams and most of these information are seen in old literature (Van der Steen 2015). The flow chart presented in Figure 4 is used to study the feasibility of a sand dam.

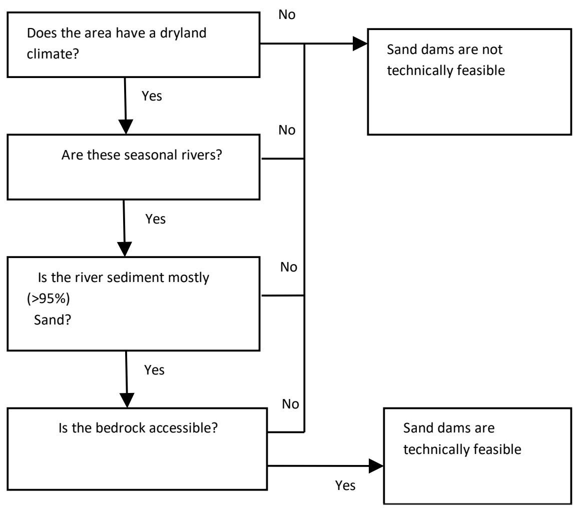

FIGURE 4. Flow Chart on feasibility of sand dams

THE SEDIMENTATION PROCESS

During heavy rainfall events, surface runoff as it flows carries water and sediments (mostly sand) to the sand dam area. The presence of the sand dam results in a lowered velocity of the flowing water resulting in deposition of the sand upstream as bed load, while the less dense silt exists as suspected load and is carried downstream of the dam through the spillway. The type of sediments that will be found in the sand dam reservoir is determined by the materials available in the river bed before construction of the dam. These sediments give rise to Deltas leading to sand accumulating c lose to the dam (Figure 5). The velocity of flow reduces due to the presence of the dam. This gives rise to more sand accumulating in the dam area until the whole area is filled with sand. At this period the dam is mature with sand filling the dam area upstream.

This work recommends that these dams be built in stages to avoid trapping silt and clay materials that will not be capable of trapping much water due to small pore spaces between the soil grains. In this manner, silt and clay materials are not trapped but flows to downstream area of the dam structure. Sedimentation in sand dams is complex and not easily understood in their environments (Nissen-Petersen 2006; de Trincheria et al. 2018; Eisma and Merwade 2020; Ngugi et al. 2020).

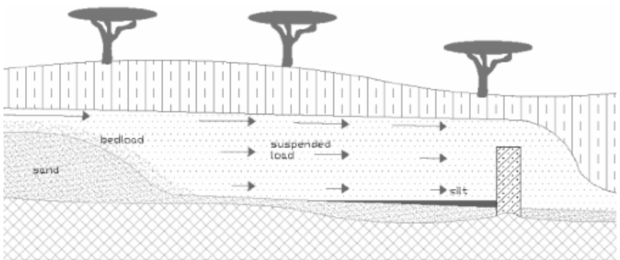

FIGURE 5. Schematic representation of the sedimentation process
Source: Gijsbertsen (2007)

FINANCING

Adequate financing is key to the success of any project. All activities from conception, site selection, clearing, construction, operation and maintenance require proper financing to achieve a comprehensive and sustainable sand dam project. Funds for all these and more, cannot be provided by a single individual. It is important that funds are sourced through various means to achieve the aim of the project. This is novel in this area and is considered to be of utmost importance since most people in communities these projects are located are poor. The different sources of funding are broadly articulated and outlined here.

SOURCES OF FINANCING

Funds could be sourced through any of the following ways:

1. Communal Funding: This is the type of funding for sand dam projects emphasized in past works. Benefiting communities finance this through self-help efforts voluntarily, or through levies to actualize their dream in handling this environmental project (Ezugwu, 2006).
2. Local Money Market: These institutions have products and services that can be used to provide funding for environmental projects, which include medium and long-term loans, Advances, Equipment leasing, bonds and guarantees, Specialized credits, Syndicated loans and financial advisory services.
3. Capital Market: Investment bankers, Insurance companies with capital market operators create special investment vehicles like bonds on the floor of the stock exchange; and the proceeds used for the sand dam project or any other environmental project.
4. Corporation and Associate Funding: Industrial sectors and corporations whose activities have potential adverse impacts on the environment, eg. Polythene producers, pure water producers, etc could set environmental management systems individually or collectively to deal with such environmental impacts and public health.
5. Non-Governmental Agencies (NGOs): These agencies can come up individually to raise funds for these sand dam projects.
6. Private Public Partnership (PPP): The private and public sector could partner to help raise funds for this laudable project.
7. Super Fund Tax: Fund can be got from levies by local government on all sources; ie, on levies on such products and services.
8. Statutory Allocations: The local government could budget money from the monthly statutory allocations to execute some aspects of the project.
9. External Support Agencies (International Bodies Funding): These external supports could come from the following bodies: World Bank (WB), World Trade Organization (WTO), International Finance Corporation (IFC), World Life Fund (WWF), European Union (EU), United Nations Agencies (like UNIDO, UNDP, UNESCO, UNICEF, etc), Global Environmental Facility (GEF).

CONCLUSION

In any case, sand dams are still little understood and practiced. Our vision is for sand dam technology to be one of the best solutions for conserving water globally that is most widely understood, used, cost-effective, and sustainable. Application of sand dam technology raises the groundwater table making water available for these communities in a fluctuating climate (Aerts, Lasage, Beets, de Moel, Mutiso, & Mutiso et al 2007; Hut, Ertsen, Joeman, Vergeer, Winsemius, & van de Giesen 2008; Quilis, Hoogmoed, Ertsen, Foppen, Hut, & de Vries 2009; Lasage, & Verburg ,2015). This can be achieved through proper coordination and financing. Sources of financing discussed in this work is novel in this area. As a result of the critical position of funding in project execution, all possible sources of funding outlined in this work should be explored to access funding to provide water in the most comprehensive, cost-effective and sustainable manner. The water should be monitored and water quality examination carried out to check contamination before, during and post construction.

FUTURE PLANS

Government participation in financing, managing and monitoring sand dam projects should be promoted on a larger scale to ensure sustainability and cost-effectiveness. International aid should be sought for financing these projects since most of these communities are poor. Waste management practices should be integrated into the system to enhance environmental sustainability.

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DECLARATION OF COMPETING INTEREST

None

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