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Run-off Storage in Sand Reservoirs as an Alternative Source of Water Supply for Rural and Semi-arid areas of South Africa

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***Abstract*—**Abstraction of water from the dry river sand-beds is well-known as an alternative source of water during dry seasons. Internally, because of the form of sand particles, voids are created which can store water in the riverbeds. Large rivers are rare in South Africa. Many rivers are sand river types and without water during the prolonged dry periods. South Africa has not taken full advantage of water storage in sand as a solution to the growing water scarcity both in urban and rural areas. The paper reviews the benefits of run-off storage in sand reservoirs gained from other arid areas and need for adoption in rural areas of South Africa as an alternative water supply where it is probable.

***Keywords*—**Groundwater, Perennial river, Run-off storage, Sand reservoir.

I. INTRODUCTION

SCARCITY of surface water is a characteristic of arid and semi- arid regions of the world. This is coupled with the limited amount of rainfall varying, both spatially and temporally. However, the problem of water shortage is not only because of uneven distribution and a low rainfall throughout the season but also because of the untapped potential of excess run-off and the storage of runoff for use when needed. Especially in periods of droughts or when no perennial rivers are available.

It is well-known the main source of water, including groundwater, is meteoric water, that is, precipitation (rain, sleet, snow and hail) [3]. However, the simplest way to meet the ever-increasing demand for water, both in urban and rural areas, is to harvest and store the rain as well as good demand management. By this, the excess overland flow which otherwise would have been lost either as run-off on the surface or as transpiration and evaporation into the atmosphere is saved.

Perennial rivers are scarce in most of the rural areas of South Africa. Many of these rivers are “sand river” types and they form an important groundwater source [18]. The water resources in the North-West (NW) Province alone is characterised by an overall scarcity of water as many surface water are non-perennial. This is the same in the Northern Province and some of the other provinces as well because of aridity. Most of the rivers serving the rural communities are sand rivers and many communities depend on the water from the dry river sand-beds. Naturally, because of consumption and the natural groundwater flow, the aquifer is drained during the dry season and thus the source runs dry [7]. To prevent this, the river needs a dam across the valley for the water to be stored in impounded sediments.

Run-off harvesting techniques for freshwater augmentation have been practiced in dry areas since 400BC [2]. However, many of the techniques for freshwater augmentation have evolved because of the long evolutionary run-off harvesting. Despite this, the technique of run-off storage in sand has not yet been fully and directly exploited in South Africa as a way of dealing with the effects of water shortage where its potential exists. Besides this, the high evaporative demand in most areas makes open surface water storage challenging and thus water storage in sand attractive as a means of recharging the already depleted aquifers. However, the basic purpose of the sand reservoir storage of run-off is to arrest the natural flow of water during the short wet periods and to make water available for abstraction when needed and restore the supplies from drained aquifers. [17] Suggests an idea of subsurface water storage for South Africa as water conservation and storage for municipalities in response to the growing water scarcity.

Reports of many studies have shown that groundwater is a scarce commodity in South Africa [11]. This is coupled with the unfavourable geology of most areas which is underlain with hard rock which causes developing groundwater in operation and maintenance to be unaffordable for rural communities. However, over 290 towns and villages depend, on groundwater in South Africa. Surface water is inadequate to meet the demand as all the readily available surface water is developed [12] with a limited potential for any further development.

Although, in developing and selection of a sand- reservoir run-off storage harvesting technique. There is need to consider all available water sources and choices. Sand-reservoir run-off storage in sand should not necessarily be considered as the universal solution, but as an alternative in where other

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conventional methods are inadequate. However, keeping run-off water in shallow aquifers, especially in the critical and over-exploited areas of North-West and Northern Provinces, as well as other provinces may be a necessary alternative.

This paper presents general overview of the water resources in South Africa. It reviews the benefits of runoff storage in a sand-reservoir gained from other area from which experience can be applied as an alternative water supply for rural arid and semi-arid areas within the context of the growing water scarcity.

II. Overview of South African Water Resources and Rural Water Coverage

South Africa is semi-arid and classified as a water-stressed country. The climate varies from semi-desert in the western part to subhumid along the eastern coast [5]. The average annual rainfall is slightly more than half the world average, which represents about 500mm. The annual potential evapotranspiration is greater than the annual rainfall in large areas of the country. A combination of high variable rainfall and run-off within the rain season and higher evaporation reduces river flow to low levels for most of the time and some are even without water during prolonged dry period. Sometimes unpredictable high flow is experienced resulting in soil erosion and consequential flash floods carrying large amounts of sediment loads [10]. Compared with other neighbouring countries, South Africa's water resources are small. The total average annual surface run-off of all rivers is about 49 000 million m^3 which is less than half of the Zambezi's annual flow [5]. However, about 75% of run-off flows into the sea along the eastern and southern seaboards, while groundwater often represents the most important and alternative source of water for towns and villages in South Africa [12]. Fig. 1 shows the average groundwater exploitation potential for South Africa.

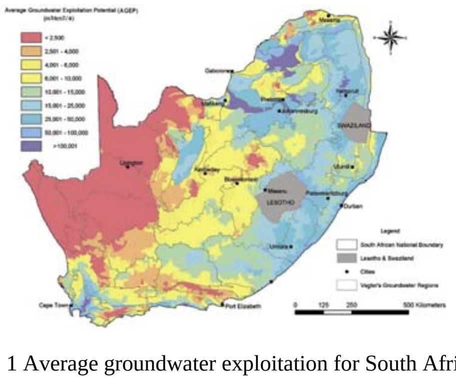

Fig. 1 Average groundwater exploitation for South Africa

Accessibility to water is a major concern to water managers and rural areas which represent 45% of the total population are the most vulnerable [4]. Reference [16] depicts rural water coverage in South Africa as shown in Table I, with figures suggesting that 35% of all rural dwellers have access to an "adequate" water supply and 65% does not have access.

In the NW Province, rural users currently need about 70 million m^3 a year, of which 25 million m^3 a year is used for domestic consumption and the rest used for stock-water and subsistence agriculture [19]. Therefore, for development of water resources, storage of run-off in sand offers a practical alternative method for sustainable water resources in rural areas.

TABLE I
Rural Water Coverage in South Africa

Level of service	Description	% coverage
Minimal	No infrastructure	40
Upgradable	Upgrading required in order to be classified as basic	25
Basic	25l/c/d to within 200m of every resident	20
Intermediate	Households have access to yard taps	10
High	Households have access to in-house connection	5

Source: [16]

III. A Review of Run-Off Storage in Sand Reservoir

Sand reservoir run-off storage is a dam built across ephemeral streams on an impermeable layer. It is built in such a way to block the subsurface flow of water, by creating a reservoir upstream of the dam within the riverbed material. The barrier dam traps the sediment in flow. The dam wall is raised as it is silted up from the following successive floods. The sediments create an artificial "aquifer" which its water can be tapped by boreholes in the dry seasons. And simple plumbing can be used to deliver water to rural communities. Fig. 2 shows the schematic diagram of sand reservoir run-off storage.

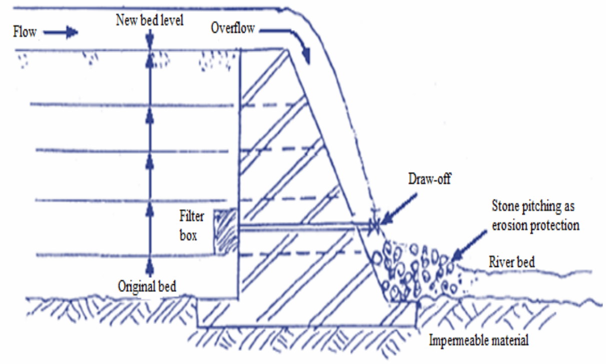

Fig. 2 Schematic diagram of sand reservoir storage

The use of a sand reservoir for water harvesting techniques is well-known and has been used for domestic and agricultural supplies but only a few studies on description, development and benefits are reported in the literature. Reference [6] evaluates the technical strategy, social benefit and economic effectiveness of subsurface storage based on experience gained by the Sahelian Solution Foundation (SASOL) in Kitui, Kenya and by the Universidad Federal de Pernambuco in north-eastern Brazil. The study recognises the technology is not new but its efficiency in conserving groundwater, use for an engaging location and its relative simplicity has recently revived interest in the technique. In a related study, the results of the effects of a water harvesting project in Kenya by building small-scale sand reservoirs in the communities were presented [9]. A method using socio-economic vulnerability indicators was linked to the state water resources system and this enabled assessing the impacts of changes in water management. It was noted that sand dams had an effect on the local community with average income of farmers living near dams increasing by 60%. Recent work done by [14] includes a hydrological survey for the success of a single sand-storage dam and the regional effects of a network of sand dams. Their results from the hydrological processes in the surroundings of sand storage dams in the Kitui District in Kenya, showed that groundwater levels increased quickly after rain. Based on these results, a groundwater model for a single sand-storage dam was developed. The model explained how a sand-storage dam will successfully change hydrological systems in semi-arid Kenya. Parallel to the single sand dam model, a model for series of sand dams was also developed. This second model showed the interdam distance was an important limiting factor. It was reported that overlapping influencing areas between sand dams decreased the stored water volume by dam; otherwise dams behave like individual structures.

The capacity to harvest rainwater run-off has been studied to empower women and men in many countries of the world to secure the livelihood of their families [2]. This is shown in a study conducted in the Chivi District, Zimbabwe. Reference [13] studied contributions of rainwater harvesting technologies to rural livelihoods in the Chivi district, Zimbabwe. The study focused on the successful adoption of such technologies and the potential to reduce the problems faced by resource-poor 'subsistence' farmers. It was noted the benefits of run-off harvesting increased agricultural productivity, thus improving household food security and raising incomes. Also noted was the improving environmental management through water conservation, reduction of soil erosion and revival of wet lands.

IV. Need for Storage of Run-Off in Sand Reservoir Techniques in Rural Areas of South Africa

In South Africa, all 19 Water Management Areas (WMAs), except Mzimvubu and Keiskamma management areas are linked to another management area through intercatchment transfers [5]. To respond to the water-stressed and unequal distribution of water resources in the WMAs, small-scale and decentralised water harvesting techniques may provide a direct solution, especially in rural and drought-prone areas by increasing water availability in the WMAs. For urban areas, dam construction, long-distance conveyance of water or desalinization may provide choices for ensuring water availability. However, such solutions are too costly and complicated for rural water supply. For rural application small-scale, low technology are often more suitable than sophisticated systems. Rural populations need inexpensive systems that can be constructed with readily available material, which can be used and maintained with a minimum skills requirement. The sand reservoir water harvesting technique reduces the need for deep well drilling or other expensive investments in piped water supplies. Sand reservoir water harvesting can also have a positive impact on soil conservation, groundwater replenishment and restoring eco-systems and does not contribute to stream reduction. Downstream water users get their own fair share of water as the dam silts up.

V. Water from Alluvial Deposits

Groundwater bearing alluvium sediments of the sand river, is familiar to communities and has been supplying alternative freshwater to rural dwellers where aridity make it impossible to assess the potable water in rural areas. South Africa has not taken full advantage of this technique as an alternative to rural water supply to augment her existing freshwater volumes.

In most areas, ephemeral rivers experience flash floods during high rainfall. During such flows, sands silt and gravel are transported downstream. The transported sediments are usually deposited downstream of the river. The sand and gravel deposits that form the sand-bed of the river become saturated with the flood flow and the deposited layers enlarge the aquifer overtime and store water underground. Water is abstracted from these created aquifers through sinking wells or tube-wells in the riverbed for drinking purposes as well as for irrigation during dry periods. The water abstracted in this way is an addition in the water cycle of the river basin and not usually taken from the existing groundwater regime. [1] Studied the hydrological process around sand storage dams. The study revealed the added storage of water achieved through water infiltrating the riverbanks and hill slopes which later then contributes to the base flow of the riverbed as water abstracted.

Apart from added water storage to groundwater level. [1], [7] highlighted the advantages of subsurface water storage over surface reservoirs. Such advantages are decrease in pollution risks because water is stored underground and away from surface contaminations, decline in evaporation losses and health hazards.

About 380m^3/s has been estimated to evaporate from small dams in Namibia, having geographical and climatic similarities with South Africa. [15] Reported of the Sterkfontein Dam, which is an efficient storage unit in South Africa. An average annual evaporation of 1300mm, which is about 35million m^3/annum and represents more than 60% of the average annual rainfall for the country are recorded. Even a small 1% decrease in evaporation in the Sterkfontein Dam could save up to 350000m^3/annum of valuable water. The need to store water in the sand sediments can be further stressed by the recurring outbreaks of cholera reported in certain rural areas. Sand reservoir storage has much potential in improving the economic well-being of rural communities where water infrastructure does not exist and water delivery is difficult.

VI. Characteristics of Storage Material in Ephemeral-Fluvial Deposits

Ephemeral-fluvial sand forms the main and ideal material for storage of run-off in a sand reservoir in arid regions' ephemeral streams. The quality of the transported sediments and grain sizes deposited are important factors in determining quantity of water collected as well as the resultant yield of the reservoir. The sand-wash found within the catchment will also significantly influence the aquifer storage characteristics. The grain size is essential because it decides the pore space of the sediment. The coarser the grain size of the sediment, the more the storage capacity of the riverbed aquifer. Flood flow infiltrate faster in coarse sand on one hand and groundwater flows faster through the aquifer with a larger grain size on the other hand. Also, when the grain size of the river bed deposition is larger, water can be abstracted more easily from wells in the riverbed aquifer.

Most of the land is bare at the beginning of the rainy season, and soil poorly protected against soil erosion, resulting in a high silt and sand load in floodwater. Silts form most flow in transported sediments, however their deposits are prevented. Silt quickly fills up the void space between sand and gravel particles, thereby reducing the potential storage capacities of the formed aquifers. This is prevented by stepping construction done in such a way to allow silt over the reservoir and coarse sand deposited behind the reservoir. So far, there is no documented scientific evidence available on a worked-out criteria or a model that can be used as a guide for successive incremental construction of the sand reservoir walls. Thus, optimising on the quality of sand collected behind the sand reservoir walls for the various field conditions of the river reach such as varied slopes, channel form, flow regimes et cetera.

Fine sediments are susceptible to transport even during low rainfall events and will also impact on water quality [8]. Few studies focus on the impact of such on sand reservoir performance. Existing published studies are either on qualitative and speculative or they discuss ephemeral-fluvial deposits where it is difficult to relate coarse sand deposits with silt.

VII. Conclusion

One of the basic conditions justifying construction of a sand reservoir runoff harvesting technique in rural areas is depleting groundwater storage through groundwater flow and over abstraction. Run-off storage in sand reservoirs is essential to solve the important growing problem of reduced groundwater levels which causes water scarcity in rural areas. Many a time, deep groundwater exploration, development and abstraction is expensive and beyond the reach of rural dwellers and thus preventing assess to safe water. It is recommendable to establish and decentralise sand reservoir runoff harvesting in rural areas where the potential exists and serves as model for other similar areas.

The increasing water scarcity and decreasing available river flows because of drought periods, thus makes the storage of runoff in sand to increase groundwater. This will be a probable option for a large part of the new water demand and makes it a strategically important alternative.

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