Water from sand rivers: Guidelines for abstraction

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Sand rivers

IN THIS CHAPTER:
- What sand rivers are and where they can be found
- The cause and effect of erosion and sedimentation in sand rivers
- The conditions that give rise to sand rivers
- How sand rivers build up and then remain in sediment equilibrium
- The water quality of sand rivers

What are sand rivers?

In arid-land conditions erosion processes are often immature[2] and soils are comprised of coarse-grained particles generally classified as sand. Soil erosion increases where there is bare land or where the surface slope is steep. Where excessive erosion occurs, particles of soil will reach and eventually fill the river channel, possibly to a depth of several metres. Sand rivers, therefore, are literally rivers that are full of sand. In very dry areas sand rivers often have no headwater or outlet. Isolated heavy precipitation causes runoff that rapidly runs into a river channel causing it to flow until the water is absorbed by the sediment. Such rivers are known as 'wadis'.

The formation of a sand river

In arid and semi-arid areas the precipitation is less than the potential evapo-transpiration[3]. The rainfall that does occur is usually erratic and varies from one year to another. An area that might have an annual average precipitation of 350mm may receive less than 300mm a year for several years and then receive over 1000mm. Although temperatures in dryland

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2. In this context 'immature' means 'not completely broken down' i.e. — the erosion process has reached a stage where the soils are predominantly sandy. Further breakdown is required in order for the soil to consist of smaller particles that are not as easily eroded.

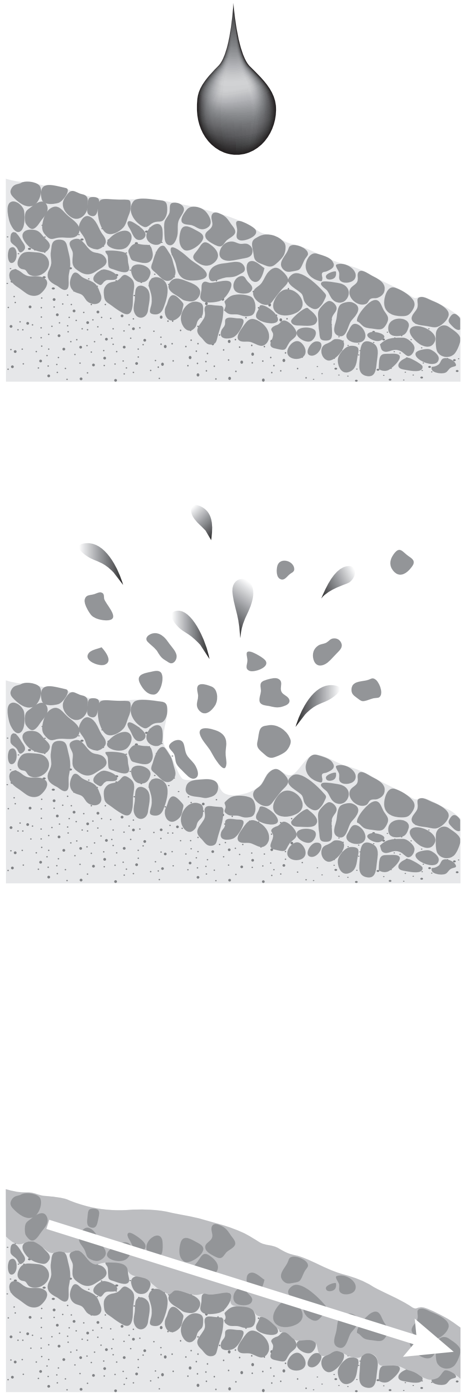
3. Evapo-transpiration: the total loss of moisture from the soil and open water through evaporation and by transpiration from growing plants in the form of water vapour.

Photograph 2.1. An aerial view of the Manzamnyama River, a sand river in a dryland area of western Zimbabwe

areas are typically hot they may also range to cold, particularly at night. These extremes, the combination of erratic, but generally low rainfall and typically hot conditions results in little organic matter residing in the soil.

Low rainfall also means that the process of soil formation remains incomplete resulting in sandy soils that do not hold together and are easily washed away. Figure 2.1 (a) and (b) represent the effect of a drop of rain on sandy soil with little organic matter, whilst (c) represents the loosened particles in suspension which are easily moved. In particular, where there is little vegetative cover, soils without organic matter can become compacted and rainfall cannot easily penetrate. In very dry soils the surface tension of water can prevent percolation. The soil is then exposed to the full impact of heavy rain and eventually becomes loosened and carried away by water run-off.

As water moves across the land surface it carries suspended sediment into the waterways; first into runnels, then streams and finally into



(a) Dry compacted surface. The action of the sun has removed almost all moisture and destroyed the organic matter that would have helped to absorb precipiation.

Soil particles are in contact with each other. There is no organic matter to bind soil particles together.

(b) A falling raindrop impacts on the soil surface, it does not penetrate the soil but rebounds and consequently dislodges soil particles.

(c) The soil surface with its loose particles becomes saturated. As precipitation increases so water movement occurs and there is a flow of water and soil particles that will eventually reach a river.

Figure 2.1. The action of a raindrop on soil with a low organic content

rivers. Depending on the slope of the river, sediment of differing grades is deposited along the length of the river channel. In fast flowing sections of a river with a steep incline only gravel and cobbles are retained and the depth of sediment does not appreciably accrue, frequently remaining at half a metre or less. Rocks and boulders remain in the riverbed as the finer material is swept further downstream. Table 2.1 provides a classification of eroded material by individual grain size, description and discontinuity.

As the slope of the river channel decreases, first gravel then sand and fine sand is deposited along the riverbed, until where the river course levels and the velocity of flow is reduced silt and clay are deposited. It is the slow moving sections of rivers where the slope of the riverbed has levelled that the finer sediment is retained.

Deposits of alluvium[4] are usually not of a uniform particle size throughout their depth. As sediment is transported through the river channel so it becomes 'sorted' with larger, heavier material moving toward the base of the riverbed. Depending on the depth of water that flows through the river channel each season, and the subsequent volume or depth of sediment that is transported and deposited, separate layers of sediment are formed and reformed. Each layer is itself graded and thus bands of alluvium occur from fine to coarse and back to fine again, as shown in Photographs 2.2

Table 2.1. Classification of eroded material by size, description and discontinuity based on BS 5930 (1981)

Grain size	BS 5930 standard	Description	Void space
Rock < 256mm	>2000mm	Boulders	Extremely large
Rock fragment between 256mm and 64mm	2000 - 600mm	Boulders	Very large
	600 - 200mm	Boulders	Very large
	200 - 60mm	Cobbles	Large
Cobble	60 - 20mm	Coarse gravel	Large
Rock fragment between 64mm and 2mm	20 - 6mm	Medium gravel	Moderate
	6 - 2mm	Fine gravel	Moderate
Mineral or rock grains - 2mm – 0.0625mm (often composed of quartz)	2 - 0.6mm	Coarse sand	Small
	0.6 - 0.2mm	Medium sand	Small
	0.2 - 0.06mm	Fine sand	Very small
Sediment with particles	0.06 - 0.02mm	Silt	Very small
Sediment with particles	<0,002mm	Clay	Extremely small

4. Alluvium: soil or sediments deposited by a river or other running water comprising gravel, sand, silt and mud.

Photographs 2.2 and 2.3. Sorting and layering of sediment in river alluvium

and 2.3, with an overall general increase in particle size with depth. The grade of sediment deposited also depends on the material that is washed into the river channel. In steep hill regions the source material will be large and heavy but in flat areas that are comprised of wind-blown sand the river alluvium will be comprised of smaller and more uniform size 'clasts'[5].

Depending on the conditions and depth of the river channel as the gradient reduces so sediment is retained to a greater depth. At a stage where the slope is reduced to about 1:250, sediment begins to build up in the depressions and undulations of the riverbed and behind natural impediments such as rock outcrops. As more sediment is deposited so a point is reached where there is no further increase in depth. At this stage the amount of sediment deposited equals the amount transported through the river channel. The river is then in equilibrium, with the same depth of sediment being retained from one year to the next. In this condition (provided there is a sufficient depth of sediment) the river channel will have a potential for useful water storage in the river alluvium.

5. Clasts: Clastic sedimentary rocks. Sedimentary rocks are those composed predominantly of broken pieces or 'clasts' of older weathered and eroded rocks.

The incline of the riverbed and the subsequent velocity of flow of the river determines the grade of sediment that is deposited, which then builds up in depressions and behind rock bars and outcrops of the riverbed as shown in Figure 2.2. Sediment is held by underground dykes that prevent the water from progressing downstream. Where water is held in existing natural formations people living downstream are not artificially deprived of water.

Every river and stream that retains sediment will at some time and to some degree hold water within that alluvium. Even small streams that keep water for just a few weeks or only days in a year can be used for the transient reserve of water that occurs following periods of runoff. The more extensive the sediment bed and the greater the recharge, the greater the likelihood of a perennial supply of water.

The amount of water which can be retained in a given volume of sediment can be established through calculating the porosity, which is the ratio of the fraction of pore space or voids to the volume of material of the sediment. The period of water retention within the river channel is dependent on the recharge from rainfall to the river aquifer, the corresponding water-table level and losses from the alluvium. Figure 2.3 indicates the relative position of the groundwater table in a dryland area to the river aquifer in seasons associated with differing rainfall.

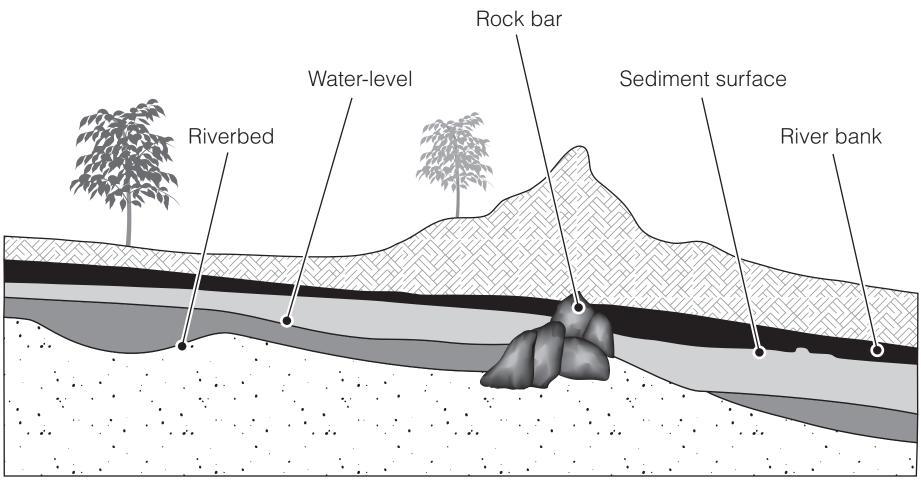


Figure 2.2. A section of sand river channel showing sediment retention and water-levels in relation to the riverbed and sediment surface level

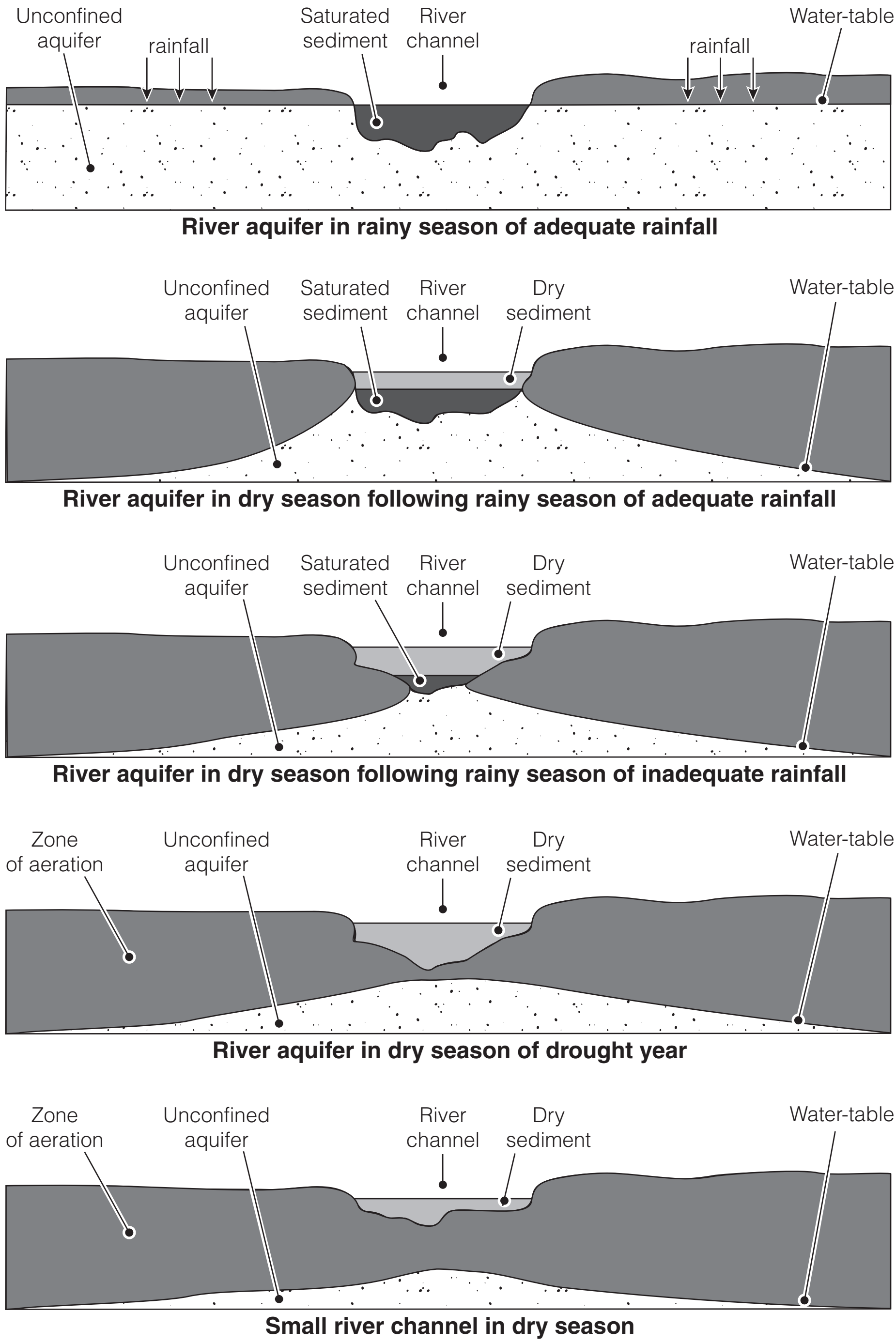


Figure 2.3. Unconfined aquifers in wet and dry seasons

Conditions that create a sand river where sand-abstraction can be put into practice

- Prolonged dry seasons with hot ambient temperatures and a potential for evaporation that greatly exceeds precipitation during most of the year.
- Poorly developed unstable soils prone to erosion.
- A low organic matter content of surface soil and low microbial populations within the soil that preclude the percolation of moisture through the soil.
- A limited vegetation canopy with little litter due to a sparse distribution of trees and shrubs. This contributes to soil compaction and the subsequent formation of a seal on the soil surface from the impact of rain drops which reduces permeability and creates overland flow and subsequent erosion of the soil surface over large areas of land.
- A river channel with gentle bends and low banks. A channel with steep sides indicates high rates of flow and high rates of sediment transport with possible damage to abstraction equipment and possibly little sediment retention. A meandering channel indicates slow river flow with possible deposits of fine deep sediment and silt.
- Sections of riverbed with depressions or natural barriers that hold bodies of water and prevent downstream movement.
- A sediment grade of medium sand. Gravel and coarse sand indicate a fast draining aquifer, fine sand and silt indicate low transmissivity and a higher rate of evaporation.

A temporary sand aquifer requires:

sufficient depth of sediment;
coarse deposits; and
extensive bed of sediment.

Ancient river channels

In certain parts of the world the principles of sand-abstraction may be applied in paleo river channels. These are ancient river courses that have been filled with sediment in the same way as present day sand rivers are, but from which the watercourse has subsequently been diverted or where climatic changes have occurred causing the river to stop flowing. The waterway has thus been lost and subsequently may well have been vegetated. The result is an aquifer of unconsolidated alluvium, generally with good water storage characteristics. These sandbeds are particularly prevalent in the Sahel region in areas such as northern Nigeria and western Sudan.

The occurrence of sand rivers

Sand rivers occur in all dryland regions of the world where erosion occurs. They are found, therefore, in the drier regions of many countries in Africa and Asia, as well as Australia and parts of both North and South America. Figure 2.4 shows the major arid areas of the world.

People have always drawn water from these sand rivers but with improved technology it is possible to abstract greater quantities of cleaner water.

Water storage potential of sand rivers

Within a sand river, water is stored in the pore space between the particles of sediment. When the river flows the sediment becomes saturated and if there is sufficient precipitation, flow will occur above the sediment surface. Because of the nature of short, sharp tropical storms the surface water quickly drains through the river channel leaving the riverbed sediment fully saturated. This is now a sand river aquifer at full storage capacity. The potential for water storage differs, however, depending on the river basin and the source material that has been eroded and reached the river channel. Where the deposited material is coarse sand from granite or gneiss, there is good potential for water storage but where it is fine, aeolian sand[6] the potential is considerably reduced.

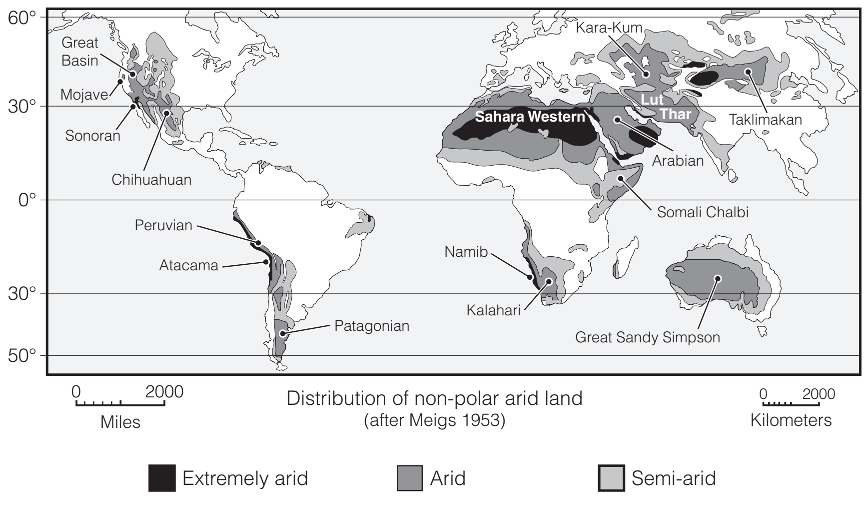


Figure 2.4. United States Geological Survey World Arid Zone Map

[6] Aeolian sand: material which has been transported by the wind and as a consequence is worn and deposited as small, rounded particles.

As with all aquifers water retained in the river sediment is subject to losses:

Channel drainage
Even though there is no flow of water in the river above the surface of the sediment, water still continues to drain along the river channel through the sediment, although more slowly.

Evaporation
Evaporation continues from the surface although the deeper the water drops in the sediment the slower the rate of loss. Depending on the grain size and grading of sediment there is very little effect of evaporation below around 900mm.

Percolation/ bed seepage
Seepage occurs into the riverbed and riverbank. The amount depends on the height of the surrounding water-table and on the nature of the riverbed (i.e. whether it is formed of rock or sand.)

Abstraction
This is influenced by the human activity carried out near the river for domestic needs, livestock watering, gardens, brick moulding and other livelihood-based requirements.

Water quality of sand rivers

The quality of water drawn from the deep sediment of sand rivers is often of a remarkably high quality. Typically it may be considered safe for use as a household water supply and almost certainly for use as livestock water and for irrigation and other project purposes. In effect, the percolation of water through river sediment is a huge slow-sand filter system, and as the water does not come into contact with sunlight there is little or no growth of algae.

Although it cannot be guaranteed that all water drawn from sand river sediment is immediately potable, the cleaning process that occurs usually results in a 'safe' water supply. However, where there is excessive contamination of the sediment — for instance where there is a very heavy concentration of livestock fouling the surface beside a drinking point within the river — the process cannot be expected to remove all harmful bacterial.

Table 2.2 shows the low count in a chemical analysis of a sample of water drawn from sediment in the Pohwe River, Gokwe South District, Midlands Province, Zimbabwe.

The water purification process

Water purification through sand river alluvium is a process of mechanical and physical actions that remove unwanted impurities and organic matter and leave them harmlessly within the sediment bed.

Very fine particles and pathogenic organisms that are present in the raw water are removed through a combination of sedimentation, filtration, adsorption and chemical and biological actions.

As contaminated water passes through the sediment bed the larger impurities are deposited and smaller particles are removed by straining. The process continues to the smallest impurities which become attached to individual grains of sediment. Each sediment particle becomes covered with a thin layer of silt, organic material and micro-organisms which in turn adsorb further impurities.

Harmful bacteria are removed by the action of protozoa that also become attached to the sediment grains. Organic matter that is removed by filtration is broken down to carbon dioxide and other oxides by micro-organisms that exist within the sediment bed.

Table 2.2. Chemical analysis of water from a sand-abstraction source

		Standards Association of Zimbabwe. Standard 560:1997		Sample from Pohwe River
		Maximum recommended limit	Maximum allowable limit	
Conductivity	m^3/m	70	300	53
pH		6.5 - 8.5	6-9	8.0
Turbidity	NTU	1	5	4.2
Total Hardness	As $CaCO_3$	20 - 300	500	128
Calcium	As $CaCO_3$	150	200	60
Magnesium	Mg	70	100	17
Alkalinity		NS	NS	376
Chlorine	Cl	200	300	2

NS – Standard not specified

Chapter summary

Conditions that give rise to sand rivers occur in almost all hot dry areas where there are long periods without rainfall. Invariably, in these arid areas there are incomplete weathering processes and little organic matter in the soil so it erodes easily. River channels in these areas fill with coarse sediment that retains water in the pore spaces. The conditions that give rise to sand rivers and the formation and extent of sediment beds in the river channel influences the water reserve and the potential to abstract water. Geological conditions, the local environment and nature of the river channel as well as atmospheric conditions, each have a significant impact on the water retention and loss characteristics of water in a sand river.

Frequently, there are useable quantities of safe water retained in the river alluvium. To maximize the potential of this water resource, the identification of a suitable river is required along with water abstraction sites within a river channel.