Climate Variability and Change—Hydrological Impacts (Proceedings of the Fifth FRIEND World Conference
held at Havana, Cuba, November 2006), IAHS Publ. 308, 2006.

413

Climate change impacts on water resources in Guyana

KAILAS NARAYAN

Caribbean Institute for Meteorology & Hydrology, Husbands, St. James, Barbados, West Indies
knarayan@cimh.edu.bb

Abstract With climate change and an expected consequent rise in sea level, salt water intrusion into rivers and possible adverse effects on aquifers is a major concern. Guyana is situated on the northeastern coast of South America, has an area of 215 000 square km^2, and a population of about three quarters of a million people more than 90% of whom reside on a narrow coastal strip, less than 10 km from the ocean. The coastal strip is below high tide level of the Atlantic Ocean, is extremely flat, and is protected by a system of dykes that are constructed mainly of concrete and clay. A large number of large rivers flow south to north into the Atlantic Ocean. Water supply for domestic, agricultural and industrial uses is obtained from a combination of ground and surface water sources. In this paper, an attempt is made to analyse situations that could arise as a result of sea level rise. A specific sea level rise of one metre by the end of the century and the impacts of this rise on water resources is investigated. The results indicate that the consequences for the surface water resources could be severe, but not as severe as for the groundwater resources.

Key words contamination; advection; dispersion; stratification; intrusion; aquifer

GENERAL

Guyana lies on the northeastern coast of South America and covers an area of about 215 000 km^2. The vast majority of the 772 755 (1999) people of Guyana live on the narrow coastal strip (approximately 5–15 km wide) between the Pomeroon and Corentyne rivers, where most of the agricultural and industrial activities are concentrated. The climate of Guyana is characterized by high rainfall and humidity, and the narrow range of temperature that is typical of the equatorial region. The annual average rainfall over the country varies between about 3600 mm. and 1600 mm. The seasonal distribution of rainfall is characterized by two rainfall seasons, i.e. May to mid-August and December–January on the coast.

The principal streams (flowing from east to west) which discharge into the Atlantic are the Berbice, Abary, Mahaicony, Mahaica, Demerara, Essequibo, Pomeroon, Waini and Barima rivers.

The coastal artesian basin occupies a total surface area of 20 000 km^2, and is known to contain three main aquifers, the Upper Sands, the "A" Sands and the "B" Sands aquifers, which were described by Gibson (1971).

The Upper Sands is the shallowest of the aquifers. It is found along the coast at a depth varying from 30 to 60 m in an easterly direction, and its thickness correspondingly ranges from about 20 to 150 m. The "A" Sands aquifer underlies the Upper Sands and it is from this aquifer that almost all of the country's domestic water supply is obtained. It varies in thickness from 20 to 60 m and is found at depths ranging from 100 to 300 m. It has a rather high transmissivity of about 2500 m^2 per day. The "B" Sands is the deepest aquifer and extends eastwards from the Demerara River, varying in depth from 400 to 800 m, and in thickness from 20 to 60 m. Its transmissivity is much less than that of the "A" Sands.

Guyana can be divided into the following geomorphologic zones: The Pakaraima Plateau, the Pre-Cambrian Crystallines, the White Sand Series and the Coastal Plain. The sediments of the Coastal Plain together with those of the White Sand Series are referred to as the Coastal sediments. It is their composition and configuration which give rise to the artesian conditions on the coast; such sediments are exploited for the coastal water supply.

SEA WATER INTRUSION INTO RIVERS

The problem

When the freshwater from a river empties into a saline water body (the ocean), the saline water tends to propagate into the river mouth, resulting in contamination of the river in its lower reaches. The density of saline water is higher than that of freshwater; this results in the saline water sliding over the bottom of the river in an upstream direction against the flow of the river. This sea water
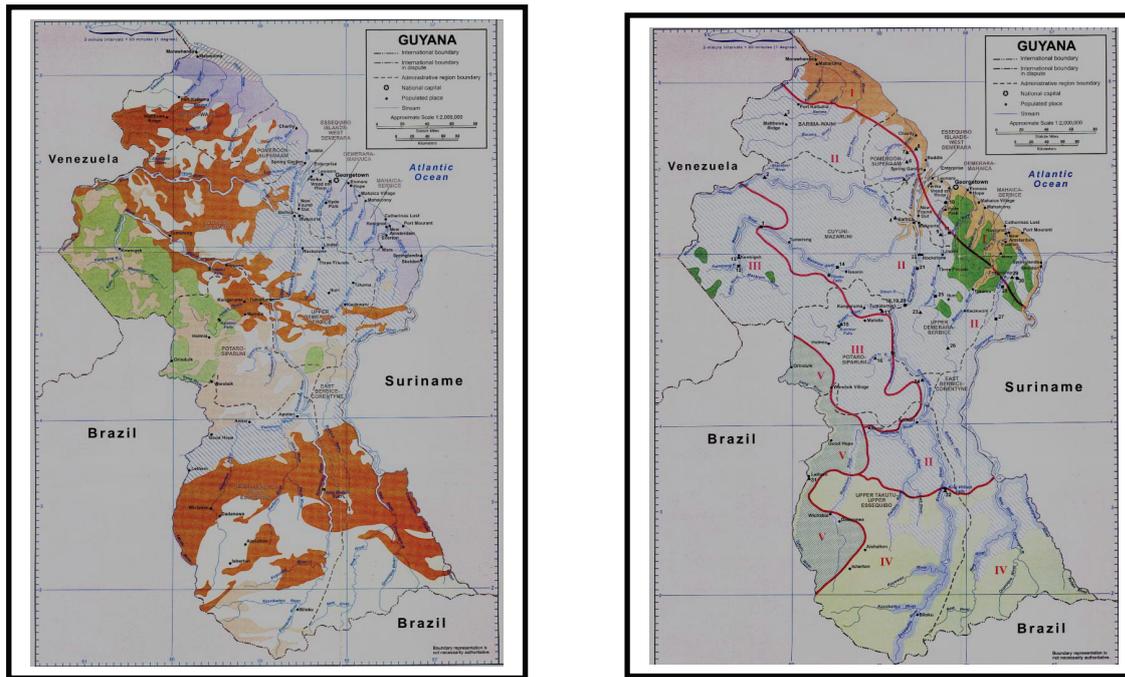
Fig. 1 Left, groundwater resources map of Guyana. Right, surface water resources of Guyana.

LEGEND FOR GROUNDWATER RESOURCES MAP

FRESH WATER GENERALLY PLENTIFUL
Large quantities of fresh groundwater are available from marine sand and clay at depths ranging from 150 to 215 m.

Moderate to large quantities of fresh water are available from unconsolidated sand and sandstone at depths ranging from 3 to 75 m..

FRESH WATER LOCALLY PLENTIFUL
Small to large quantities of fresh groundwater are available from volcanic ash, tuff, sand and conglomerate at depths from 10 to 300 m.
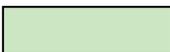
Small to moderate quantities of fresh groundwater are available from fractured granites, cherty mudstones, gravels and sands at depths ranging from 3 to 150 m.

FRESH WATER SCARCE OR LACKING
Meagre to moderate quantities of fresh groundwater are available from igneous and metamorphic rocks at depths from 10 to 300 m.

Meagre to very small quantities of fresh water are available from igneous dikes and andesitic flows at depths ranging from 3 to 150 m.

Large quantities of brackish to saline water are available from unconsolidated sand and clay at depths from 3 to 30 m. Locally fresh water lenses may be present above the brackish to saline groundwater.

Waterfall.

LEGEND FOR SURFACE WATER RESOURCES MAP

FRESHWATER PERENNIALLY PLENTIFUL.
Enormous quantities year-round from perennial rivers and streams, extending throughout the country.

Enormous quantities from April through August and November through January from perennial rivers and streams draining the interior plains, coastal lowlands and western highlands. Large to very large quantities available the rest of the year.

FRESHWATER SEASONALLY PLENTIFUL
Large quantities from April through August and November through January available from perennial and intermittent streams, tributaries, canals and ditches in the coastal lowlands, interior plains and western highlands. Small to moderate quantities available the rest of the year in perennial streams.

Large quantities from April through August generally available from perennial and intermittent streams and tributaries in the southern uplands. Meager to moderate quantities available the rest of the year.

Moderate to large quantities from April through August generally available from perennial and intermittent streams and tributaries in the southwest savannahand tributaries of the Amazon. Meager to small quantities available the rest of the year in perennial streams, while intermittent streams generally have no discharge.

FRESHWATER SCARCE OR LACKING.
Large to enormous quantities of brackish to saline water available throughout the year from tidal influenced rivers and streams, coastal marshes, mangrove swamps and tidal lowlands.

intrusion can be discerned up to several tens of kilometres upstream, and under extreme conditions, the reach of the river affected can extend for more than 200 km.

Mechanisms of sea water intrusion

The salt content of sea water is higher than that of freshwater. Consequently sea water is heavier than freshwater, the density of sea water being higher than that of freshwater. This difference in density has a significant effect on the flow in an estuary, where the sea water is measurably diluted by the freshwater from land drainage (Cameron & Pritchard, 1963).

The differences in density have the major effect of causing stratification in estuaries and also have an effect on pressure.

To overcome this stratification, mixing within the water body is required; this in turn requires energy. This energy is supplied by tidal flow which induces turbulence and effects the mixing. Stratification is therefore most pronounced in estuaries through which a river issues into a non-tidal sea, while it is weaker when tidal action is strong.

On this basis Pritchard (1955) and Cameron & Pritchard (1963) have classified estuaries according to their stratification and salinity distribution. They defined the following types of estuaries: highly stratified salt-wedge type estuaries; partly mixed estuaries; well mixed estuaries. Based on these three types of mixing of sea water and river water, sea water intrusion into rivers can be distinguished as: a well mixed situation; a partly mixed situation; a salt water wedge situation.

The hydrodynamic formulation of well and partially mixed situations are similar and can be carried out on the basis of two concepts : advection and dispersion, and tidal prism. The one dimensional equation of advection and dispersion of salt in the river part of the mouth can be written as:

$$\frac{\delta S}{\delta t} + v\frac{\delta S}{\delta t} = \frac{\delta}{\delta x}\left\{D_x\frac{\delta S}{\delta x}\right\} \tag{1}$$

where: S is water salinity; v is flow velocity; D_x is longitudinal dispersion coefficient. The solution to this equation gives the distance to which brackish water will intrude into the river.

The tidal prism concept allows for the estimation of the length of seawater intrusion into a river at high water slack (HWS). Computations were done based on a deduction by Mikhailov (1971), with the following assumptions:

(i)   Water density and salinity are homogeneous over the cross section.
(ii) Freshwater is present at the end of the ebb tide over the whole river part of the mouth.
(iii) The intrusion of salt or brackish water begins through the coastal edge of the river channel just after the reversal of the ebb current into the flood current or at low water slack (LWS).

Applications

The foregoing analyses have been applied to the Mahaica, Demerara and Essequibo rivers of Guyana. Because of the extremely flat nature of the terrain, these rivers are tidal for great distances inland, ranging from in excess of 50 km for the larger creeks to more than 150 km for the bigger rivers. These rivers are therefore very susceptible to salt water intrusion.

The base line conditions used for analysing the extent of salt and brackish water in the rivers are as given in Table 1 (Geer, 1980). The data used in these analyses have been taken from the records of the Hydrometeorological Service of the Ministry of Agriculture (1977). The computations have also been made using long-term mean flows of the rivers. Table 2 summarizes the results obtained.

Table 1 Base line conditions

River	Salt water extent (km)	Brackish water extent (km)
Demerara	4	50
Mahaica	2	20
Essequibo	6	60

Table 2 Extent of salt/brackish water into the Mahaica, Demerara and Essequibo rivers.

	Sea level rise (m)	Salt water intrusion	Brackish water extent (km)
Mahaica River	1.0	2.8	28
Demerara River	1.0	5.6	64
Essequibo River	1.0	8.5	80

DISCUSSION

The results have been obtained using mean flows of the rivers. Rising temperatures will also disrupt the hydrological cycle with the result that rainy seasons may be shorter and more intense, while dry seasons may be longer. This will mean lower flows during the dry season, resulting in greater salt water intrusion into the rivers. Some sensitivity analyses done for a range of low flows indicate that intrusion can be up to four times as great as for the mean conditions analysed above.

Effects of sea level rise

A rise in sea level will inundate wetlands and lowlands, accelerate coastal erosion, exacerbate coastal flooding, threaten or destroy coastal structures, raise water tables and increase the salinity of rivers and aquifers (Barth & Titus, 1984).

Projected impacts on Guyana's coast

Most of the settlements on coastal rivers are located within a few tens of kilometres from the coast and within a few hundreds of metres from the edges of the rivers. Also the vast agricultural areas of the country are adjacent to coastal rivers. From the previous results obtained, these areas are well within the domain expected to be affected by salt/brackish water intrusion. Water for domestic and agricultural requirements are extracted from the rivers. With salt/brackish water penetration getting further inland, the adverse effects expected can be summarized as follows:

(i)   The concentration of salt content will be increased. This will be detrimental to agriculture, as there will be further penetration of salt water into the land.
(ii) Water tables will rise and, because of the higher salt content, prime agricultural lands now under cultivation will become useless.
(iii) Population will be displaced because of a reduction of sustainable agriculture and the presence of salt/brackish water in the rivers for extended periods.

Aquifers

Contamination of the aquifer systems in Guyana due to sea level rise can occur from two possible directions.

Assuming hydraulic connection with the ocean, rising sea level will induce saline water penetration from the outlets of the aquifers to the ocean by the amounts in Table 3. The "A" Sands aquifer is the most exploited one of the three aquifers, and even though decline in piezometric levels have not been too significant in general, averaging about 0.03 to 0.06 m per year, (Worts, 1958), in some locations, notably the Georgetown area, the decline has been substantial, about 20 m since extraction started in 1926. However, there has been no problem with saline intrusion into any wells so far.

The other two aquifers, the Upper Sands and the "B" Sands, have not been much used. It is known that private individuals have been extracting freshwater for household uses from the Upper Sands from depths down to about 100 m, on a continuous basis without any detection of increase in salt content.

Table 3 Saline water penetration distance (m) from outlets .

Aquifer	1.0 m. S.L.R.
Upper Sands	150
"A" Sands	180
"B" Sands	380
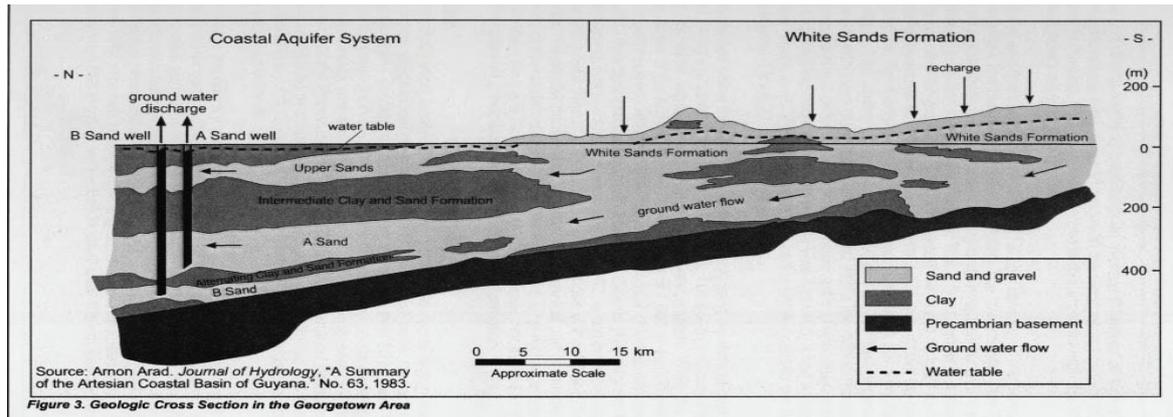
Fig. 2 Geological cross–section in the Georgetown area.

Intrusion from rivers

What will be of greater concern is the possibility of salt water contamination of the aquifers from the rivers and from above land surface. Figure 2 shows a geological cross-section of the coast from the ocean inland. The extremely flat nature of the coastal plains for more than 40 km inland is very evident. This is already in the White Sands formation area, the presumed recharge area for the coastal aquifer systems.

With the estimation of salt/brackish water intrusion into the rivers encroaching on this area, contamination of the aquifers from the rivers will be unavoidable. It is estimated that over the next century salt water will intrude into the recharge zones for a distance of 1–2.5 km. Extraction of water from the aquifers will enhance intrusion.

REFERENCES.

Barth, M. C. & Titus, J. G. (eds) (1984) *Greenhouse Effects and Sea Level Rise: A Challenge for this Generation.* Van Nostrand Reinhold Company, New York, USA.

Cameron, W. M. & Pritchard, D. W. (1963) Estuaries. In: *The Sea* (ed. by M. N. Hill), vol. 2. John Wiley, New York, USA.

Geer, B. (1980) Ground Water Recovery in Guyana – Some Aspects. HYM-No.TP24. Hydrometeorological Service, Guyana.

Gibson, U. (1971) Water Resources Management in Guyana.

Hydrometeorological Service, 1977. Compilation of Surface Water Data to December 31, 1965.

Mikhailov, V. N. (1971) *Dynamics of the Flow and the Channel in Non-Tidal River Mouths*. Hydrometeorological Press, Moscow (in Russian).

Mercado, A. (1997) Management of the Guyana Artesian Coastal Aquifers: Preliminary Assessment of Alternative Approaches. Guyana Water Authority.

Pritchard, D. W. (1955) Estuarine circulation patterns. *Proc. Amer. Soc. Civil Engng* **81**, 717.

Worts, G. F. (1958) A brief appraisal of groundwater conditions and proposed program for water resources investigations in the coastal artesian basin of British Guiana. US Geological Survey.