ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Estimates of the outflux of groundwater along the perimeter of coastal aquifers

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Abstract
Mauritius is a volcanic basaltic island, located off the east coast of the Republic of Malagasy. The island harnesses both surface water sources and groundwater sources to cater for its water demand. Since the water storage capacity of the water network is poor, the island is often faced with major water stress problems during drought conditions. Increasing the water storage capacity is financially too demanding for the island. However, an alternative option is to optimise the exploitation of the existing water resource. Presently groundwater sources contribute up to 50% domestic water supply, and in some parts of the island, groundwater is the only source of domestic water supply. From past hydrogeological studies carried out over the island, it is known that the aquifers of the island are all unconfined and coastal in nature. Hence overexploitation of the groundwater sources may have serious adverse impacts, such as inducing salt water into the groundwater bodies, and hence polluting this valuable water resource. It is also known that the basement of these coastal aquifers slope downwards towards the sea, and since along the coastal regions there is not geological barriers which can act as retaining walls to the groundwater, significant losses of groundwater takes place along the coast. Past hydrogeological studies, Huntings' (1973) and SIGMA & SOGREAH (1980) do give a rough indicate of an average rate characteristing the potential groundwater losses to the sea for the whole island. An average value for the whole island is too approximate to be used in studies involving estimates of the potential of aquifers. So far there has not been any study carried out to illustrate the variation of these groundwater loss rates along the coasts of the island. The present study has been undertaken with the objective of highlighting the magnitude and direction of the outflux of groundwater into the sea.

INTRODUCTION

Mauritius is situated in the Indian Ocean between latitudes 19°50' and 20° 32' south and longitudes 57°17' and 57°48' east. It is volcanic in origin and has a surface area of about 2000km^2. The physiography of the island can be characterised by a central plateau with mean elevation of 300-400m, rising up to 600m in the southwest of the island, surrounded by a ring of mountain ranges and coastal plains, of mean elevation of 100m. The climate is tropical in nature, with a wet summer season from November to April, and a dry winter season from May to October. Rainfall varies from around 4000mm per year over the higher lands of the Central Plateau to around 900mm per year along the coastal areas. The annual potential evapotranspiration for the island range from 1100mm to 1600mm per year, from the Central plateau moving towards the coast.

The island has a dense and heterogeneous network, which has resulted from both its drainage pattern and its geology with the majority of the rivers taking their source from the Central Plateau, and draining towards the sea. Most of the rivers are perennial in nature, being fed by groundwater during the dry winter periods. Presently there are about 340 abstractions from the rivers, for both agricultural and domestic purposes. The aquifers of the island have been divided into four main aquifers with respect to the degree and extent of connectivity. All the aquifers are presently being exploited and these groundwater bodies constitute a major source of good quality water and contributing about 13% total water demand of the island (Table 1).

Table 1. Present water utilisation.

Purpose	Surface (Mm^3)	Groundwater (Mm^3)	Total (Mm^3)	%
Municipal water requirement	81	82	163	19
Industrial (private boreholes)	-	7	7	1
Irrigation water requirement	444	13	457	53
Hydropower generation	235	-	235	27
Total	760	102	862	100

The present water requirement of the island has been estimated to be around 467 Mm^3 (CWA, 1990) and is forecasted to rise to 761 Mm^3 in the year 2040 (CWA, 1990). Thus the need is already being felt to both increase the water supply to satisfy present demand and to plan for the coming years. Increasing storage capacity along productive rivers will alleviate the problem of inadequate water supply but at the same time this solution is financially demanding. Hence, the alternative of increasing groundwater supply has to be looked into, either the exploitation of new boreholes at safe yield capacity or the minimisation of groundwater losses to the sea.

GROUNDWATER RESERVES OF THE ISLAND

Past hydrogeological studies undertaken by Sentenac (1963) through resistivity surveys have reported that all the aquifers of the island are not interconnected, and following these results, the aquifers have been divided into a number of smaller units. Most recent hydrogeological studies (SIGMA & SOGREAH (1980) and WRU (1999)) have regrouped all the smaller geological units, into four main aquifers for the whole island (Figure 1).

These hydrogeological studies have contributed significantly to better understanding of the complex basaltic aquifers of the island. The groundwater reserves of the island have specific characteristics, they are dynamic in nature responding quickly to recharge from rainfall events. They operate as buffer during drought seasons but their storage capacity is low, and hence they cannot be relied upon to alleviate water problems during drought periods. Owing to the nature of formation the geology of these aquifers is highly complex, being characterised by zones of low and high transmissivities, and location of preferrential pathways. The hydraulic gradient within the aquifers are high, this being dictated by the relatively small distance from the major recharge zone, the Central Plateau, and the sea. The productive capacity of each aquifer is characterised by the geological formations of the area and its recharge capacity. The sections below illustrate the properties associated with each of the main aquifer of the island.

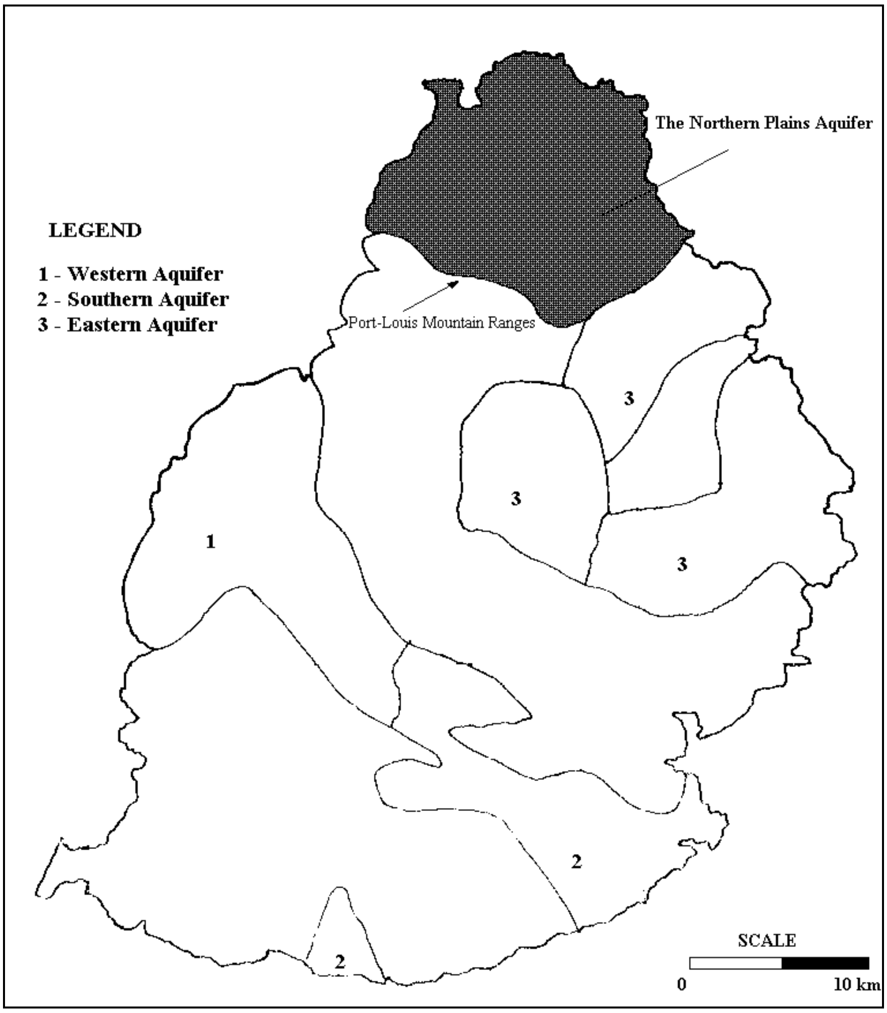

Figure 1. Aquifers of the island.

Curepipe Aquifer

The Curepipe Aquifer (Figure 1) is the one which is presently most heavily exploited, and its exploitation dates back to some 25 years ago, covering an area of about 204km^2. This aquifer has many major lava tunnels (WRU, 1999) and being connected directly to the main recharge zone of the Central Plateau, it has a steep hydraulic gradient of the order of 3.2% in some isolated areas. The aquifer is unconfined in nature, being recharged directly from rainfall. The aquifer presently provides an order of 80,000 m^3/day during the dry winter periods, and 100,000 m^3/day during the wet period, with water being abstracted mostly for domestic and industrial purposes. According to Proag (1995), location of fresh water springs along the coast, indicate some groundwater losses to the sea, and SIGMA & SOGREAH (1980) have estimated an average the outflux of groundwater to the sea as being 0.69m^3/s.

Eastern Aquifer

The eastern aquifer covers an area of 350km^2. It is not well exploited at present, but future plans of the local water authorities include intensification of the exploitation to cater for water demand in both the eastern regions and the northern parts of the island. This aquifer also gets its major recharge from the Central Plateau, and has a steep hydraulic gradient of 3% in localised zones. Evidence of seepage zones under the storm beach and seawater of low electrical conductivity along the eastern coasts (Proag, 1995) and fresh water springs in the open sea identified by (WRU, 1999), do indicate that major groundwater losses take place from this aquifer, though the rate may vary from one point to the other along the coast

Southern Aquifer

This aquifer similar to the Eastern Aquifer, benefits from the same high rainfall patterns of the Central Plateau. This aquifer is presently not meeting the demand of water for the southern region, part of the water supply comes from imported water. However, the future plans aim at exploiting this aquifer to cater for all water demands of the area. The aquifer.

Northern Aquifer

The Northern Aquifer is the one which has relatively low water resource potential, the main reason being because it is not connected to the high recharge zone of the Central Plateau and it receives only about 1500mm average rainfall per year. Consequently, there are very few rivers located in this part of the island, and the Northern Aquifer has been tapped to cater for almost 90% total domestic water demand for the Northern part of the island. This basin is highly vulnerable to salt water intrusion, since it has a weak hydraulic gradient (Nowbuth, 1999), and unless much care is taken to safely exploit the groundwater, salt water intrusion can present a major threat to the quality of this water resource. Here also, owing to the sloping downwards gradient of the aquifer, much groundwater is being lost to the sea. Since this aquifer is presently catering for domestic water supply, there is a need to optimise this water resource in the near future.

METHODOLOGY BEHIND THE ESTIMATES OF OUTGOING GROUNDWATER FLUXES TO THE SEA

Groundwater motion is essentially governed by the hydraulic gradient and the resistance (hydraulic conductivity) of the water bearing strata within an aquifer. The flow of groundwater through porous geological media has been defined by Darcy's law based upon the assumption that flow of groundwater being very slow, and this motion can be assumed to be laminar. In the case of basaltic formations, flow most of the time takes place within either lava tunnels, fractures, in between lava layers and via preferrential flowpaths, and hence, the assumption of laminar flow may not always hold true. However, since the groundwater flow analysis in this present study is being carried out over a regional basis, assumption of Darcy's law is acceptable.

The methodology behind this study, is the use of potentiometric maps and the transmissivities characteristics of geological units along the coastal zone, to quantify both the rate and spatial distribution of the groundwater losses to the sea. The final objective of this study was to map these information for the whole island, as such type of information is not available at present. Groundwater levels have been monitored over the island since long, dating back to some 30 years ago. Monthly groundwater levels are taken at monitoring wells and these information are available for use at the Water Resources Unit, Ministry of Public Utilities. Furthermore, minimum and maximum levels are reported in hydrological year book, published every five years, by the local water authorities. For estimation purposes, the approach has been to make use of the minimum and the maximum groundwater levels at each corehole over the island, and from there the elevation of the water levels were estimated. These values were then interpolated over the whole island, for the two different scenarios, the dry winter periods, and the wet summer period, being reflected by the minimum and the maximum water elevation at each corehole.

RESULTS & ANALYSIS

The results of the present study indicate that the rate at which groundwater flows into the sea, varies from 0.5 to 8 m^3/s. When converted to a yearly basis, the range lies between 16Mm^3 to 252 Mm^3. Presently the groundwater consumption over the whole island is of the order of 102 Mm^3 per year. When these figures are compared, it can be deduced that since a major component of groundwater is presently being lost to the sea, there is thus much scope for optimising groundwater uses,

These results have also be compared with those obtained from past hydrogeological studies (Table 2). Table 2, clearly illustrates that the values obtained by these two different studies significantly differ from each other in most cases, except for the Northern Aquifer, which is almost similar. Before reaching any conclusion the main assumptions involved in each each study needs to be compared.

Table 2. Comparison of results (Present and Past studies).

	Outgoing Flux Rate (m3/s)	
Aquifer	Present Study	Sigma & Sogreah (1980)
Curepipe	8-2.52	0.69
Northern	2.85 - 0.5	2.5-1.5
Southern (Rose Belle)	4.41-2.85	3.25-1.56
Eastern	2.85-1.22	0.6-0.25

SIGMA & SOGREAH (1980) carried out their estimates, by assuming that the effective depth of the aquifer along the coast varied from 25 m during the wet periods, to 5 m during the dry periods, the aquifers being unconfined in nature. In the present study, the aquifer depth along the coast was computed based upon hydrogeological information obtained from coastal coreholes, both with regards to depth of water and type of geological units. As far as the variations in hydraulic gradient along the coast is concerned, both the present study and SIGMA & SOGREAH (1980) used the same variations as these are obtained from the potentiometric maps.

It can therefore be deduced that the results obtained from the present study are more reflective of the actual field conditions, but to confirm the extent to which the values indicated in Table 2 are reliable, we need to perform field studies of seepage rates along selected sites.

CONCLUSIONS

The results obtained have indicated that in case it is possible to either capture or retain the groundwater presently being lost to the sea, there is much scope in improving the contribution of groundwater to cater for the increasing water demand. Another interesting feature illustrated by the study, is the degree to which use of an average outflux rate is not representative of what happens in reality. Location of high loss rates, is indicative of locations of preferrential pathways, characteristics of basaltic aquifers. Hence, with this understanding, the approach would be to either increase the yields of boreholes located within these areas, and monitor the impact of such an increase on groundwater levels of coastal coreholes. Similarly, where loss rates are relatively small, these would indicate zones which are sensitive to salt water intrusion, hence, it would not be advisable to exploit groundwater further in these areas.

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