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Water Quality Indexing Applied to Groundwater Quality Parameters

M.D. Nowbuth[1] and A. Chan Chim Yuk[2]
Department of Civil Engineering
University of Mauritius, MAURITIUS
E-mail: [1]mnowbuth@uom.ac.mu; [2]achan@uom.ac.mu

ABSTRACT: Landuse activities have both direct and indirect impacts on the quality of water resources, be it surface water or groundwater sources. In addition, once polluted groundwater bodies may not recover from that pollution. The unsaturated soil zone overlying groundwater sources is known to act as a natural protective cover to groundwater bodies, but in volcanic basaltic medium, most of the time, the depth of unsaturated zone is either very small or almost inexistent. In addition, presence of fractures, lava tunnels, and caverns, render groundwater bodies very vulnerable to pollution. Thus groundwater resources in volcanic media cannot rely on the protection cover of their unsaturated zone. In Mauritius, all the aquifers of the island are volcanic in nature and are characterised by high permeability, and are hence quite vulnerable to landuse activities. The present study investigates the impact of landuse activities on groundwater quality in volcanic basins, and the applicability of the water quality indexing technique as a reliable groundwater quality indicator in such type of geological environment. An integral part of any water quality monitoring program is the reporting of results to people who are not conversant with the technical aspects of data collection, analysis and interpretation. This poses a particular problem in the case of water quality monitoring because of the complexity associated with analysing a large number of measured variables. Water quality indexing method is a simpler and concise way of reporting such information.

Keywords: Water Quality Index, Volcanic Media, Aquifers.

INTRODUCTION

The easiest and most convenient way to meet the public demand for water is to utilise surface water resources. Unfortunately, fresh water such as rivers and lakes are less plentiful as may first be imagined, accounting in fact for less than 0.01 percent of the world's total water, and less than 2% of the world's fresh water. To complicate matter further, what little fresh water there is tends to be distributed, spatially and temporally, in an irregular manner, while the sources that are available have often been over-developed or polluted. Groundwater sources account for 98% of the world's fresh water and are fairly well distributed throughout the world. They provide for a reasonably constant supply and have a strong buffering capacity, and are of relatively quite high quality. Furthermore, the surface area of land required for exploitation of groundwater is negligible compared to the land surface that goes into the exploitation of surface water. Until recently, the quality of groundwater was generally taken for granted, because it was believed that this source was effectively shielded from pollutants by the unsaturated zone. Nowadays, water scientists have realised that even groundwater bodies need some sort of protection, and in basaltic medium the need for groundwater protection is even stronger.

In Mauritius (Figure 1), water resources is exploited and managed by two main bodies, the Water Resources Unit (WRU) and the Central Water Authority (CWA). WRU is responsible for long term development and management of surface and groundwater resources of the island, while the CWA is mainly concerned with distribution and supply of the water to consumers. Potable water comes from rivers intake, impounding reservoirs, and boreholes. The island of Mauritius has 5 main aquifers, and all of them are being tapped to cater for water demand, but at rates which vary with the potential of the aquifer. Some two hundred and fifty (250) boreholes have been developed and equipped for the use and tapping from aquifers. About 100 of the boreholes are large capacity boreholes and are exploited by the CWA through 70 pumping stations. The remaining 150 boreholes are relatively of smaller capacity and are privately owned, with 80 being used for industrial purposes and the remaining for irrigation purposes. The exploitation of groundwater has been increasing drastically over the years, with groundwater contributing up to 50% of the total potable water demand. With respect to total water demand, groundwater however contributes to 10% of the total demand, which amounts to about 90 million m^3 per year.

The main objectives of the water resources management in Mauritius are to increase the storage capacity of the water resource network in a sustainable way. Optimising the use of existing water supply network, promoting use of treated wastewater in the irrigation sector and creating awareness to minimise wastage of water are among some of the issues which need to be addressed by the island. One of the indicators that will be of help in addressing these issues is water quality, and the water quality indexing method may be used to obtain a consolidated parameter.

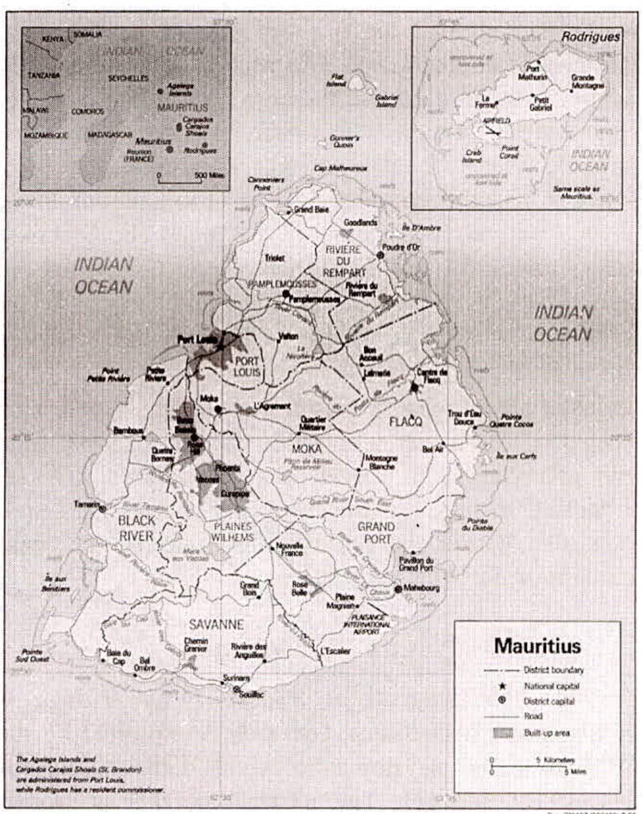

Fig. 1: Map of Mauritius

THE STUDY AREA

The present study was carried out in the north of the island. The Northern plains (Figure 2) covers a surface area of about 220 km^2, and about 50% of the total land surface is under agricultural cover. The area is also relatively poor in drainage network, and is served by only 2 main rivers. Rainfall pattern varies from about 1000 mm along the coastal areas to about 2500 mm at the highest elevation regions of the study area. The geology of the area was shaped by the recent lava flows which formed the island. It is characterised by five gently sloping volcanic cones surrounded by plains, with the surface elevation varying from about 270 m for the highest peak and 100 m for the plains.

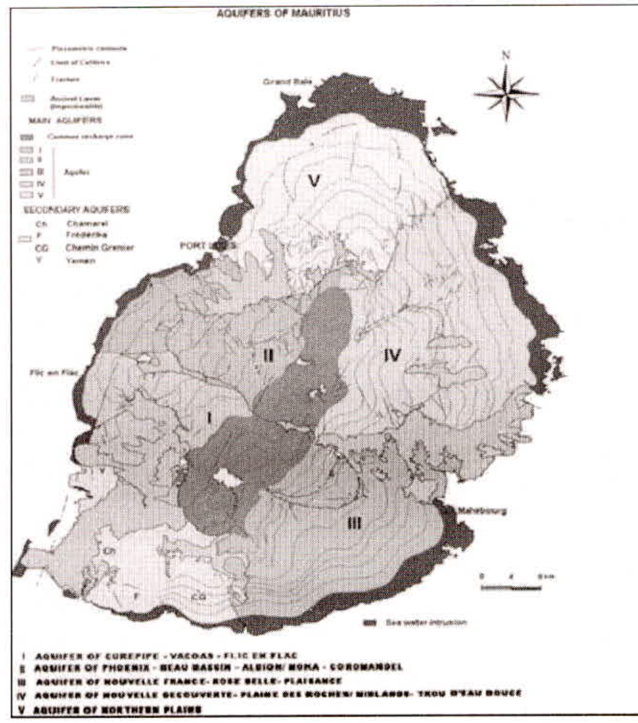

Fig. 2: Location map (Aquifer V—The Northern Plains Aquifer)

The Northern Plains is served by a large number of boreholes to cater for domestic, agricultural and industrial water demand. Groundwater levels are monitored monthly through a network of about 70 piezometric points. The soils of the Northern Plains are high in organic matter, 30–120 g per kg of soil and are highly aggregated. Mauritian soils contain between 5000 to 10000 kg of nitrogen per hectare. The nitrogen exists under organic form and gets gradually converted into mineral form when it gets either absorbed by the plant or leached (Proag, 1995). The response of the Northern Plains aquifer to rainfall events has been found to be quite quick, and the aquifer gets fully recharged within six (6) months during the rainy season. A rough estimate of recharge potential of the Northern Plains Aquifer is of the order of 15 to 30 percent of the total annual rainfall (Nowbuth, 1999).

The high yield of modern agriculture in Mauritius is only possible with considerable inputs of fertilisers and pesticides. On average 57500 tonnes of fertilisers is used per year for Mauritius, and a study carried out by Ng Kee Kwong *et al.* (1997) noted that average annual fertiliser application rate was of the order of 600 kg per hectare which was 3 times that of Western Europe and 60 times that in Africa.

Thus, it can be said that the Northern Plains Aquifers, given its geological setting, the landuse activities prevailing, and the groundwater exploitation practices, is very much vulnerable to pollution, and unless proper assessment and monitoring is carried out the quality of the groundwater of the Northern Plains Aquifer may deteriorate beyond repair.

METHODOLOGY

Currently the CWA monitors groundwater quality at 70 locations over the Northern Plains on a monthly basis. For a better understanding of the variation of the water quality in the Northern Plains Aquifer it was decided to carry out monitoring activities on a weekly basis. Hence, weekly tests were carried out at 4 locations, (BH123I, BH123IV, BH209 and BH1), these locations having been selected on the basis of prevailing landuse activities. Another set of weekly data were collected at seven (7) other locations (BH750, BH720, BH692, BH552, BH391, BH595 and BH309), these having been selected on the basis of the geological setting and prevailing pathways for groundwater flows.

A set of physico-chemical tests were carried out, namely; temperature, pH, conductivity, nitrate level, phosphate, colour, turbidity, total dissolved solids, salinity, and hardness. Temperature measurements were made using a good grade mercury-filled Celsius thermometer, reading to the nearest 0.1°C. Temperature readings were need in the calculation for alkalinity and salinity. Conductivity was measured using a conductivity meter, of the platinum-electrode type. The pH was measured using a pH meter of the glass electrode type, since it is less subject to interference from colour, turbidity, colloidal matter, oxidants, or reductants as compared to the hydrogen electrode. A reference electrode, the calomel, silver-silver chloride or other constant-potential electrode was also used in conjunction with the glass electrode. Nitrate, phosphate and colour were measured using the HACH DR/2000 spectrophotometer. The Cadmium reduction method was also used to determine the concentration of nitrate in the samples when samples tended to record low level nitrate. Turbidity level was measured using the turbidimeter, which consists of a nephlometer with a light source and photoelectric detectors for recording the light scattered at 90° to the path of the incident light. This apparatus measures turbidity over the rang of 0 to 40 nephlometric turbidity units (NTU). Total dissolved solids was tested both by correlation with conductivity values and by the oven dry method, hardness was tested by titration method, and salinity was measured using the Salinity meter.

The weekly tests spanned over the period January 1999 to September 2001, and the results were compared to the Drinking water standards prescribed by the Ministry of Environment for Mauritius and also to the World Health Organisation (WHO) guidelines.

RESULTS AND ANALYSIS

(a) BH123I—Poudre D'Or Hamlet

The borehole situated at Poudre D'Or Hamlet is governed by two particular landuse activities, agricultural and residential. The abstraction rate of the borehole is about 1400 m^3/day, and the depth of the borehole is about 62 m. The region of Poudre D'Or Hamlet is unsewered and the agricultural land is under sugar cane plantation. The nitrate level recorded at this borehole over the test period, noted that the level varied from a minimum of 15.8 mg/l to a maximum of 33 mg/l with a mean value of 22.3 mg/l. The Drinking water standards for Mauritius have prescribed an acceptable nitrate level of 50 mg/l as NO_3 and WHO guideline for NO_3 is 45 mg/l. Though the observed nitrate levels were always below the acceptable limits, however an increasing trend was noted. It was also noted that Nitrate concentration fluctuated over time without any apparent reasons linked to surface activities or rainfall events. All the other parameters measured were also within the permissible limits of the local standard or the WHO guidelines.

(b) BH123IV—Poudre D'Or Village

The borehole situated at Poudre D'Or Village is mainly under agricultural cover. It is exploited by the CWA to cater for domestic water demand and for agricultural demand. The abstraction rate is around 2600 m^3/day, with the depth of the borehole being around 41 m. Poudre D'Or Village is also unsewered and is under the threat of fertilisers since almost the whole area is under agricultural cover. According to the statistical analysis performed on the date, nitrate level varied from a minimum of 12.5 mg/l as nitrate to a maximum of 46.5 mg/l, with a mean value of 22.2 mg/l. For this particular site, the data recorded over the test period, showed a decreasing trend in nitrate level over time. All the other parameters tested were below their corresponding acceptable limits set by either in the local water standards or the WHO guidelines.

(c) BH209- Goodlands

The borehole at Goodlands is privately owned, and is exploited for industrial purposes. The abstraction rate is around 30 m^3/day, and the depth of the borehole is 63 metres. The raw water extracted is used mainly for dyeing and washing in the textile industry. This borehole is situated in the Goodlands Village, which is characterised by both residential and agricultural landuse activities. There are quite a few industries nearby, around 14 in total, and these include textile and electronics industries. In addition, Goodlands village is not sewered.

Tests results showed that the concentration of nitrate varied from a minimum value of about 44 mg/l to a maximum value of 70 mg/l, with an overall mean value of 52 mg/l. Apart from the minimum value, the maximum and mean values are above the acceptable standards or WHO guidelines. The nitrate concentration shows an increasing trend over time. The other parameters tested were however within the permissible limits set in the local drinking water standards and WHO guidelines.

(d) BH1—Fond Du Sac

Borehole Fond Du Sac is a large borehole exploited by the CWA for domestic purposes. It has an abstraction rate of about 700 m^3/day, and the depth of the borehole is 49 m. The borehole is located in Fond Du Sac Village which is mainly an agricultural zone. There is also a large crushing stone plant located just close to BH1. Fond Du Sac also is not sewered.

Results shows that the nitrate level varied from a minimum of 26 mg/l to a maximum of 53 mg/l with an overall mean value of 41 mg/l. The nitrate concentration also shows an increasing trend over time.

ANALYSIS

Analysis of the data will concentrate on the nitrate concentration at the different test points, the remaining parameters will be considered in the water quality indexing method.

The Northern Plains aquifer, just like the remaining aquifers of the island, is unconfined in nature. The movement of nitrate to the groundwater is mainly governed by rainfall and irrigation practices. To observe the impact of rainfall on the movement of nitrate, 5 days antecedent rainfall data together with rainfall data were plotted against time. It was noted that nitrate levels did rise significantly after heavy down pour, but tend to fall after low or moderate rainfall. However nitrate concentration in Goodlands always seem to increase with increase in rainfall.

In 1976, the Mauritius Sugar Industry Research Institute (MSIRI) which is a centre that carries out research with regards to sugar cane plantation in Mauritius, carried out a study to monitor the level of nitrate in the Mauritian soils. The results of this study showed that less than 5% of the nitrogen from fertilisers was washed away from the soil, nitrogen seems to be retained in the top 15 cm layer of the soil zone and very rapidly fertiliser nitrogen in the form of nitrates or ammonia was converted into organic forms. This form was being fixed in the soil, and could not be washed away easily. From the results obtained by this study, it can be concluded that the organic content in the Mauritian soils tend to trap the nitrogen in the top soil layers, and hence reduce the risk of the nitrogen finding its way into the groundwater bodies. Several studies have since been carried out by MSIRI (Ng Kee Kwong *et al.*, 1984, 1987, 1996) over the island and these studies tend to confirm that leaching of nitrates from fertilisers into groundwater bodies was almost negligible, and also that nitrate level did not seem to rise over time. The groundwater quality parameters monitored on a monthly basis by the CWA also reported that nitrate levels at all points monitored were below acceptable limits.

However, the results of the present study seem to be recording a different pattern, both in terms of magnitude at some points but specially as far as the temporal trend in nitrate level in the Northern Plains Aquifer was concerned. It could well be that the geology of the Northern Plains is responsible for the rising trend of nitrate over time.

GROUNDWATER QUALITY INDEXING ANALYSIS

Apart from nitrate concentration, several other parameters were noted. The discussions about the results concentrated on nitrate levels since this was the only parameter which showed a level at times higher than permissible levels. With a view of incorporating all the tested groundwater quality parameters in the analysis, the water quality indexing method was chosen.

The indexing systems for water quality are an attempt to communicate the information content of a number of measurements of water quality variable in a form, which can be readily comprehended by managers and laypersons. The venture is to produce just one number, or at times a few numbers, into which a larger set of data is being integrated in a way that will indicate the suitability of the water for a given intended use. All indexing systems start with measurements of a group of water characteristics, or variables, considered as being indicative of its quality or suitability for its intended use. From these measurements, a sub-index rating is determined based on whether the given value of the variable is considered to indicate high or low quality. The water quality indices are able to facilitate quantification, simplification of complex environmental data, and they also generate actions to solve the problems they summarise, because they serve as a tool to monitor the state of the environment. Water quality indexing has been widely used but has not been accepted generally as an adequate means of communicating proper information about the state of the quality of a water body (Smith, 1990), so care must be taken when interpreting the information obtain by this method.

Physico-Chemical Indexing

Physico-chemical indexing method combines information on the larger number of physico-chemical and microbiological determinants into a single figure, in a simple, rapid, objective and reproducible manner (House, 1989b). The National Sanitation Foundation Quality Index (NSF WQI) devised in 1990 by the United States National Sanitation Foundation (Canter, 1996) was used in this study. The system considers nine parameters; Dissolved Oxygen (DO), Feacal Coliforms, pH, 5 day Biochemical Oxygen Demand (BOD_5), Nitrates (NO_3), Phosphate (PO_4), temperature deviation, turbidity (JTU) and Total Solids (TS). The weightage given to each parameter and their sub-index rating curves were devised using the Delphi method and a panel of water quality experts throughout the United States. The weightages given to each parameter are as shown in Table 1:

Table 1: Weightage Parameters in NSF WQI

Variable	*Weightage*
DO	0.17
Feacal Coliforms	0.15
PH	0.12
BOD_5	0.10
NO_3	0.10
PO_4	0.10
Temperature Deviation	0.10
Turbidity	0.08
Total Solids (TS)	0.08

Sub index rating curves are then used for each parameter to work out the Water Quality Index for each one; NSFWQI = $\sum W_i I_i$, where W_i is the weightage of the parameter and I_i is the sub-index rating of the parameter.

The results are then to be compared with the table of descriptor words (Table 2).

Table 2: Descriptor Words for NSFWQI

Descriptor Words	*Numerical Range*
Very Bad	0–25
Bad	26–50
Medium	51–70
Good	71–90
Excellent	91–100

In this study, the following physico-chemical parameters were measured; nitrate, pH, conductivity, total dissolved solids, salinity, hardness, turbidity, phosphate, colour and chloride. For some of the parameters the sub-index rating curve and the weightage were not available from the NSF WQI method, these were thus not taken into account in the water quality indexing method.

DATA ANALYSIS

The first step was to revise the weightage associated with the list of parameters to be included in the analysis and these were as shown in Table 3.

The next step was to use the sub-index rating curves for the parameters highlighted in Table 3, to work out their sub-index value (Table 4 to 7).

The summary of the NSFWQI value reflecting the overall quality of water from each borehole is as shown in Table 8.

Table 3: New Weightage of Parameters in NSF WQI

Variable	*New Weightage*
pH	0.250
NO_3	0.208
PO_4	0.208
Turbidity	0.167
Total Dissolved Solids	0.167

Table 4: Sub-Index Values for Fond Du Sac Borehole BH1

Parameters	*Average Value*	*Sub-index Value*
pH	7.1	93
NO_3	42.5(mg/l)	15
PO_4	0.38(mg/l)	99
Turbidity	0.26 NTU	98
Total Dissolved Solids	287 (mg/l)	61

Table 5: Sub-Index Values for Goodlands Borehole BH209

Parameters	*Average Value*	*Sub-index value*
pH	7.3	93
NO_3	55.1 (mg/l)	8
PO_4	0.16 (mg/l)	97
Turbidity	1.22 (mg/l)	97
Total Dissolved Solids	292 (mg/l)	62

Table 6: Sub-Index Values for Poudre D'Or Hamlet Borehole BH12I

Parameters	*Average Value*	*Sub-index value*
pH	7.2	93
NO_3	21.6(mg/l)	30
PO_4	0.16(mg/l)	97
Turbidity	0.36 NTU	99
Total Dissolved Solids	162 (mg/l)	79

Table 7: Sub-Index Values for Poudre D'Or Village Borehole BH123IV

Parameters	*Average Value*	*Sub-index value*
pH	7.1	93
NO_3	25.4 (mg/l)	27
PO_4	0.16 (mg/l)	97
Turbidity	0.59 NTU	99
Total Dissolved Solids	177(mg/l)	75

Table 8: Summary of the NSFWQI Values for Each Borehole

Borehole	*NSF WQI*	*Description*
BH1	74	Good
BH209	72	Good
BH123I	79	Good
BH123IV	78	Good

Results from Table 8 indicate that the overall quality of groundwater in the 4 boreholes tested are good, as per the NSF WQI guidelines for water quality indexing method.

DISCUSSIONS AND CONCLUSIONS

The NSF WQI method for overall water quality assessment indicates that the quality of groundwater in the aquifer tested is good. To be able to use this method as an absolute indicator of the quality of the groundwater, it is worth noting the restrictions associated with it. The sub-index rating curves have been derived using data collected in the United States from rivers that are subjected to general purposes and not to specific uses. Besides the weightage for different parameter is also a function of the importance of that particular parameter in the local context.

This method however provides a good start for integrating several water quality parameters into a single value. It is important to note that WQI provides a snapshot of water quality. In a way it can be said that WQI provides the non-expert with a way of understanding the overall water quality.

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