Groundwater recharge in Molepolole area, SE Botswana

Nata T. Tafesse[1]*, K. Laletsang[1], R.B.M. Mapeo[1] and Ronald Yaw Appia[1]

[1]: University of Botswana, Geology Department, Private Bag UB 00704, Gaborone, Botswana

*: **Corresponding author:** Tafessen@ub.ac.bw; ORICD ID: 0000-0002-4687-7540

Abstract. Groundwater recharge estimation using chloride mass balance (CMB) method was conducted in Molepolole area, SE of Botswana. The study area is semi-arid area with uneven distribution of rainfall throughout the year. The mean annual rainfall of the area is 423.64 mm. Climatically the area is characterized by two rainy seasons during the year separated into two by dry months. The first rainy season occurs during January, February, March and April and contributes 55.08 % of the mean annual rainfall of the area. The five months in the dry season are May, June, July, August and September and contribute 5.98 % of the mean annual rainfall of the area. October, November and December constitute the second rainy season and contribute 38.94 % of the mean annual rainfall of the area. The main source of groundwater recharge is rainfall. The computed groundwater recharge in the area is 0.82%, 3.14% and 0.09% of the mean annual rainfall of the area during the first rainy season, second rainy season and dry season, respectively.

Keywords: Aquifer, Groundwater recharge, Molepolole, Rainfall, Wellfield.

1. Introduction

The study area, Molepolole Village and its surroundings, is located in the Kweneng district in the south east of Botswana bound by the latitudes 24.83°S and 23.20°S and the longitudes 24.31°E and 25.81°E (Figure 1), covering an area of approximately 8,300 km².

Water supply to Molepolole and surrounding villages is mainly from 3 wellfields, namely Gaotlhobogwe, Malwelwe and Suping wellfields. These wellfields comprise of 17, 6 and 8 boreholes, respectively. The total average monthly abstraction volumes from these wellfields is 53360m³/month with Gaotlhobogwe producing a monthly average of 20890m³/month, Malwelwe producing 19900m³/month and Suping producing 12570m³/month. This translates to an average annual abstraction of 640320m³/yr.

The climate is semi-arid with a hot wet summer and cold, dry winters. The mean annual minimum temperature is 13.2˚C, the mean annual maximum temperature is 28.5˚C, and the mean annual air temperature of the area is 20.5˚C. The minimum air temperature is 13.6˚C in July, and the maximum air temperature is 25.5˚C in January. The annual range of temperature is 11.9˚C. The maximum mean monthly summer temperature range from 27.8˚C to 32.1˚C, while the minimum mean monthly winter temperatures range from 4.1˚C to 12.0˚C. The rainfall is mainly in months from January – April and October to December, and the annual precipitation averages ranges from 68.50 mm to 866.50 mm.

The study area is located on the southern edge of the Karoo West Central Kalahari Sub-Basin and is underlain by strata of the Karoo Supergroup. The Karoo strata, which include the Ecca and Dwyka groups were deposited unconformably over Proterozoic metasediments of the Waterberg Supergroup and pre Karoo doleritic units. Sedimentary succession within the Karoo Supergroup shows changes in depositional environment from the lowermost Dwyka glacial deposits to the fluvio-deltaic conditions of the lower/middle Ecca to the argillaceous, lacustrine depositional environment of the upper Ecca. Palaeotopography was an initial major control on sedimentation patterns and with subsequent late-post Karoo faulting resulted in variation in both lateral and vertical deposition of sediments.

The aquifer units are Lebung group (Ntane sandstone) and the Upper Ecca (Boritse Formation) and Middle Ecca (Kweneng Formation) sandstones.
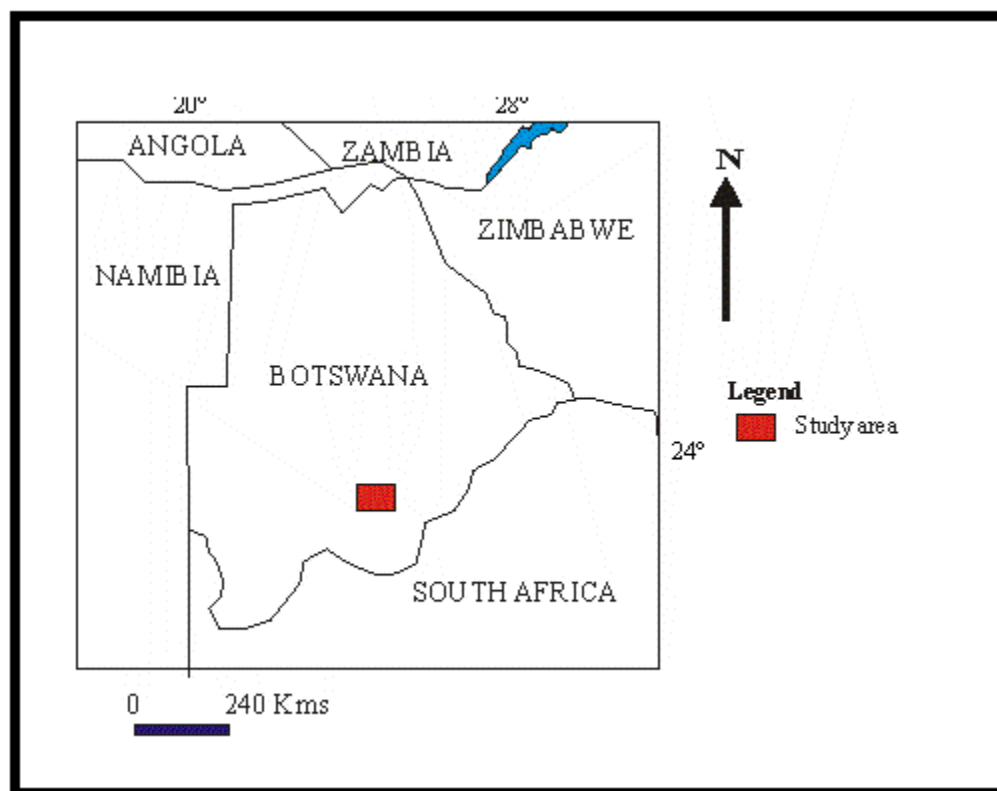
1

Figure 1. Location of the study area,

2. Methods

Rainfall data (1986 to 2017) of Molepolole was recorded at Molepolole meteorological station within the study area. Rainfall amount and its seasonal distribution were analyzed and determined using these data. These data were collected from the Department of Meteorological Services of Botswana. Rainfall coefficient was computed for each month using Eq. 1 (Daniel, 1974) to determine the seasonality of rainfall in the study area.

$$RC = \frac{MMR}{\frac{1}{12} \, X \, AM} \qquad (1)$$

Where RC is the rainfall coefficient; MMR is mean monthly rainfall for each month (mm); and, AM is the annual mean (mm).

Sixteen groundwater samples were collected from 16 boreholes from the three wellfields during the rainy and dry seasons between the years 2018 and 2019, and the samples were analysed for chloride and bromide concentrations using ion chromatography at

the Department of Water Affairs Chemistry Laboratory. The laboratory is accredited with the Botswana Bureau of Standards (BOBS).

Rainfall chloride concentrations documented in groundwater recharge evaluation study (GRES) main report (Gieske, 1990) were used in this study as supplementary data (Table 1).

Table 1. Weighted average concentrations (mg/l) of Chloride in rainwater for different seasons (GRES data) - Molepolole.

Months	1st Rainy Season	Dry Season	2nd Rainy Season
	Chloride Concentration		
January	1.36		
February	-		
March	0.79		
April	0.71		
Mean	**0.953**		
May		0.99	
June		0.73	

July		-
August		-
September		-
Mean	**0.860**	
October		13.76
November		0.94
December		0.73
Mean		**5.143**

To investigate the groundwater source and its evolution in the study area, Cl/Br ratio was computed for all the analysed groundwater samples using Eq. 2 (Naily and Sudaryanto, 2018).

$$R = \frac{rCl}{rBr} = 2.25\frac{pCl}{pBr} \tag{2}$$

Chloride mass balance (CMB) was employed to estimate the groundwater recharge using Eq. 3 as expressed by Marei et al. (2010):

$$Rg = \frac{P.Cl_p}{Cl_{gw}} \tag{3}$$

Where: Rg is the recharge rate (mm/yr.); P is the mean annual precipitation (mm/yr.); Clp is the mean precipitation-weighted chloride concentrations (mg/l); and Clgw is mean chloride concentration in groundwater (mg/l).

3. Results and Discussions

The thirty-two years rainfall data of was and analysed and a mean annual rainfall of 423.64 mm (Table 2) is determined for the area.

Table 2. Mean monthly and seasonal distribution of rainfall (in mm) at the Molepolole station

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MAR
MMR	84.55	69.15	54.63	25.01	7.96	5.91	0.42	1.85	9.20	33.32	63.46	68.18	423.64
RC	2.40	1.96	1.55	0.71	0.23	0.17	0.01	0.05	0.26	0.94	1.80	1.93	
DES	R	R	R	R	D	D	D	D	D	R	R	R	

Where MMR is Mean monthly rainfall; MAR is Mean annual rainfall; RC is Rainfall coefficient; DES is Designation; R: is Rainy month; and, D is Dry month.

Two rainy seasons that have seven months together (January, February, March, April, October, November and December) and a dry season that has five months (May, June, July, August and September) were determined using Rainfall coefficient (Daniel (1974). 94.02% % of the average annual rainfall in the area is occurred during these two seasons.

In the analyzed groundwater samples the chloride concentration ranges from 10.61 mg/l to 91.60 mg/l with a mean value of 62.20 mg/l and the bromide concentration ranges from 0.09 mg/l to 0.44 mg/l with a mean value of 0.30 mg/l. The Cl/Br ratio of the analyzed groundwater ranges from 265.25 to 549.33, match with the typical continental rainwater values (Davis et al., 1998). In the months of the rainy seasons, the concentrations of chloride in the analyzed groundwater samples ranges from 10.87 mg/l to 91.52 mg/l with a mean of 63.88 mg/l whereas in the months of the dry season it ranges from 10.34 mg/l to 91.68 mg/l with a mean of 60.14 mg/l.

Rainfall is the main source of recharge in the Molepolole area. The estimated groundwater recharge using Eq. 3 in Molepolole area ranges from 3.481 mm/yr to 13.282 mm/yr in the 1st rainy season and 2nd rainy season which is 1.49% and 8.05% of the weighted average rainfall of each season, respectively. In the dry season, recharge was estimated to be 0.362 mm/yr which is 1.42% of the weighted average rainfall of the season.

4. Conclusion

The computed Cl/Br ratio values match with the typical continental rainwater values revealing that the source of recharge is rainfall. Molepolole area is characterized by two rainy seasons and one dry season during the year. The amount of rainfall in the first and second rainy seasons is 233.34 mm and 164.97 mm, respectively. In the dry season the amount of rainfall is 25.33 mm. The computed groundwater recharge in Molepolole area is 0.82%, 3.14% and 0.09% of the mean annual rainfall of the area during the first rainy season, second rainy season and dry season, respectively.

5. References

Daniel, G. (1974), Aspects of climate and water budget in Ethiopia, Addis Ababa University Press, Addis Ababa.

Davis, S.N., Whittemore, D.O. and Fabryka-Martin, J. (1998), Uses of chloride/bromide ratios in studies of potable water, Ground Water, 36, 338 - 350.

Gieske, A. (1990), Dynamics of groundwater recharge: A case study in semi-arid eastern Botswana. Groundwater recharges evaluation study (GRES) main report, Geological Survey of Botswana,

University of Botswana, Free University of Amsterdam, Gaborone, Botswana, App. III, 30.

Marei, A., Khayat, S., Weise, S., Ghannam, S., Sbaih, M. & Geyer, S. (2010), Estimating groundwater recharge using the chloride mass-balance method in the West Bank, Palestine, Hydrol. Sci. J.55(5), 780–791.

Naily, W. and Sudaryanto, (2018) Cl/Br ratio to determine groundwater quality. IOP Conf. Series: Earth and Environmental Science 118 012020. IOP Publishing, .4.