

## Physico-Chemical Properties of Spring (Mineral) Waters Commonly Consumed by Grazing Animals Cattle in Wakwa (Cameroon)

<sup>1</sup>W.M.L. Fezeu <sup>1</sup>M.B. Ngassoum, <sup>2</sup>G. Echevarria, <sup>3</sup>M. Crétin and <sup>1</sup>C.M.F. Mbofung

<sup>1</sup>ENSAI-University of Ngaoundere, P.O. Box 455 Ngaoundere, Cameroon

<sup>2</sup>Laboratoire Sol et Environnement, E.N.S.A.I.A.-INPL, 2,

Avenue de la Forêt de Haye-BP 172, 54501 Vandoeuvre-lès-Nancy, France

<sup>3</sup>Institut Européen des Membranes, U.M.R 5635 C.N.R.S 1919,

Route de Mende 34293, Montpellier Cedex 5, France

**Abstract:** Wakwa is an intensive cattle-grazing area in Northern Cameroon. The present study was carried out to determine the physico-chemical characteristics of different samples of spring waters commonly consumed by cattles in this area. Water samples were collected in dry season (February and April) of 2002 from four (Wakwa Palestine, Massagali, Djomtari and Lahoré Vina) springs and analysed for their mineral ( $\text{NO}_3$ ,  $\text{Cl}$ ,  $\text{PO}_4^{3-}$ ,  $\text{HCO}_3^-$ , Ca, Mg, Mn, Al, Zn, Cu, Fe, ammoniacal nitrogen) and organic matter content using appropriate and current analytical methods (Absorption spectrophotometer, Inductive Coupled Plasma Atomic Emission spectrometry (ICP-AES) and Colorimetry). Mineral content of the waters was found to vary very significantly ( $p < 0.05$ ) with sources. Of all the springs, that of Lahoré Vina was found to contain the highest levels of such elements as  $\text{HCO}_3^-$ , Na, Ca, the Mg, Na and K. In general, the levels of Mn and organic matter (0.05 mg, 1.4 mg of  $\text{O}_2/\text{l}$ , respectively) found in the Lahoré Vina springs were higher than the E.P.A recommended levels. Equally high in these waters were the levels of such trace elements as Al and Mn. Zinc concentrations were highest in waters obtained from Wakwa Palestine Springs. Iron levels in the different waters did not vary with source. Based on an average daily consumption of 21 litres a day water from the Lahoré Vina springs grazing animals could meet their requirements of Na and Ca. On the same basis, the other sources can supply only about 14% and 5% of daily requirements for Na and Calcium.

**Key words:** Spring waters, cattle, mineral requirement

### INTRODUCTION

Water is an important requirement for animals. It accounts for 50-80% of an animal weight and is involved in every physiological process: transport of nutrients and other compounds to and from cells; digestion and metabolism of nutrients, takes part in the metabolic reactions, elimination of waste materials by urine, feces and respiration<sup>[1]</sup>. While the water found in plants is absorbed directly from the ground, that in man and animals, is obtained through daily intake with food. Several factors such as physiological state, Milk Yield (MY), Dry Matter Intake (DMI), body size, rate and extent of activity, diet composition including types of feedstuffs quantity of milk produced<sup>[2]</sup> influence the quantity of dry matter intake<sup>[3]</sup> a high consumption of fodder increases the water requirements because of the loss of water by feces and urines<sup>[2]</sup>.

In most tropical countries, grazing cattle generally use surface water like rivers or lakes as well as the springs to satisfy their requirement of water. Because of the universal solvent action of water, many chemical elements and compounds are found in solution as ions, molecules and radicals<sup>[4]</sup>. The quality of ground water consumed by grazing animals is of much importance especially with respect to their growth and reproduction. In this connection such waters need to be characterised with respect to such factors as organoleptic properties (odor and taste), physiochemical properties (pH, total dissolved solids, total dissolved oxygen and hardness) presence of toxic compounds (heavy metals, toxic minerals, organophosphates and hydrocarbons), presence of excess minerals or compounds (nitrates, sodium, sulfates and iron) and presence of bacteria<sup>[1]</sup>. Although water is not a major source of minerals, all essential mineral elements occur to some extent in water<sup>[5]</sup>. To some extent

**Corresponding Author:** W.M.L. Fezeu, ENSAI-University of Ngaoundere, P.O. Box 455 Ngaoundere, Cameroon

and depending on the source the salt (NaCl) and to a lesser degree, Ca, S and Mg, may be present in significant quantities in water for some species<sup>[6]</sup> and as such contribute to the satisfaction of the daily requirements of the animals drinking such waters.

In Adamawa Province which is a major cattle rearing area of Cameroon, there are several mineral springs which have long been known and used by shepherds for mineral cures of animals<sup>[7]</sup>. A number of these have been characterised as producing waters of high concentrations of such minerals as Na, K, Ca and Mg<sup>[8,9]</sup> and as such may be making significant contributions to the mineral requirements of the grazing cattle that drink from them. Generally, such grown waters have been reported to be easily contaminated<sup>[10-12]</sup>. According to Nunez-Delgado<sup>[10]</sup>, the faecal droppings of cattle represents an important source of mineral and organic matter contamination of such waters. Other forms of contamination of such waters have been reported to decrease their overall performance<sup>[11,14]</sup>. As of now, no specific studies have been carried out to determine the contribution of spring waters to the mineral intake of grazing animals in the Adamawa region. A knowledge of the exact composition of these waters will be necessary to attain this goal.

The present study was therefore carried out to determine the physicochemical quality of some spring waters of the cattle rearing region of Wakwa in Cameroon so as to ascertain their potential as source of mineral for animal nutrition.

## MATERIALS AND METHODS

For the present study, four mineral water sources (Masagali, Djomtari, Lahoré Palestine and Lahoré Vina) in the Wakwa (located at about 10km from Ngaoundere), commonly visited by grazing animals were selected for water sampling. These sources were springs that had over the years been converted into wells to satisfy the increasing water needs of grazing animals in the region<sup>[7,15,9]</sup>. The geographical co-ordinates of these different sources are as represented in Table 1. Wakwa is located in a soudano-Guinean climate with one dry season which generally goes from November to March and one rainy season which goes from April to October<sup>[16]</sup>. The sampling were carried out in dry season (February and April) which is the period during which the highest numbers of cattle visit the sources for water. Samples were collected in cleaned polypropylene bottles and quickly transported to the laboratory for mineral chemical analysis.

Water pH was determined using a portable pH-meter (PICCOLO-ATC brand) while conductivity (x)

Table 1: Geographical situation of the points of sampling

Sampling points	Longitude	Latitude
Wakwa palestine	7°25'783N	13°54'194E
Djomtari	7°22'132N	13°60'731E
Massagali	7°21'713N	13°59'775E
Lahoré Vina	7°21'983N	13°60'102E

was determined using a TACUSSEL CD-60 resistivimeter. While the bicarbonates, carbonates and chlorides content were determined by titrimetric methods<sup>[17]</sup> the sulphates and nitrates levels in samples assayed according to the colorimetric methods described by Rodier<sup>[18]</sup>. Also a method described Rodier<sup>[18]</sup> which makes use of the oxidative properties of permanganate was employed in the determination of the organic matter content of samples.

Samples passed through a 0.2 µm filter were digested with concentrated nitric acid and analysed for calcium, magnesium, sodium, iron, aluminium, manganese and zinc using Inductive Coupled Plasma Atomic Emission spectrometry (ICP-AES) while copper content was assayed using atomic absorption spectrophotometry (Varian SpectraAA-600).

All analysis were carried out in duplicate and all data obtained were subjected to statistical analysis by ANOVA. In the case of significant variation, Duncan Multiple Range Test (DMRT) was use to copper individual means. All statistical analyses were carried out using the software S-Plus 2000.

Based on the assumption that tropical cattle about 20.9L of water in dry season<sup>[19]</sup>, the results of the chemical analysis of the waters were used to estimate the daily mineral intake of the animals from the different sources. Estimation assumed an average body weight of 250 kg live weight per animal (tropical livestock unit) and a daily food intake of 6.25 kg dry matter<sup>[20,21]</sup>. These figures were used in the calculation of the daily requirement of cattle for the different minerals analysed. In this respect, the following recommendation of the expected mineral composition per kg dry weight of forage was taken in to consideration<sup>[22,5]</sup>: 0.3% (Ca), 0.2% (Mg), 0.06% (Na), 0.8% (K), 40 mg kg<sup>-1</sup> (Mn), 50 mg kg<sup>-1</sup> (Fe), 30 mg kg<sup>-1</sup> (Zn) and 10 mg kg<sup>-1</sup> (Fe).

## RESULTS AND DISCUSSION

**pH, organic matter and ammoniacal nitrogen:** Analysis of results of the pH measurements for the different water samples exhibited a variation between 6.07 and 7.12 (Table 2). The recorded pH values fall within the acceptable range (6 and 8.5) for cattle<sup>[23]</sup>.

On a comparative basis, water from the Lahoré Vina source contained the highest amount of organic matter (OM) (10.5-22.4 mg of O<sub>2</sub>/l). OM values for the other sources ranged between 0.7 and 4.7 mg of O<sub>2</sub>/l. The high

**Table 2: Physical characteristics and major minerals concentration**

Point d'eau	Mois	pH	x (µs)	HCO <sub>3</sub> (mg l <sup>-1</sup> )	Cl (mg l <sup>-1</sup> )	SO <sub>4</sub> (mg l <sup>-1</sup> )	Ca (mg l <sup>-1</sup> )	Mg (mg l <sup>-1</sup> )	Na (mg l <sup>-1</sup> )	K (mg l <sup>-1</sup> )
Wakwa	February	7.12	321.35	331.78±0.75	6.66±0.13	4.15±0.352	1.53±0.01	14.11±0.03	2.58±1.98	3.46±0.18
palestine I	April	6.84	356.07	332.31±3.00	19.97±0.13	5.04±0.22	17.47±0.21	14.11±0.13	5.06±2.27	13.33±0.35
	Means	6.98±0.16 <sup>b</sup>	338.71±20.05 <sup>b</sup>	332.05±1.81 <sup>b</sup>	13.31±7.69 <sup>b</sup>	4.60±1.00 <sup>b</sup>	19.50±2.35 <sup>a</sup>	14.11±0.08 <sup>b</sup>	2.32±1.61 <sup>a</sup>	8.40±5.70 <sup>a</sup>
Djomtari	February	7.04	219.19	202.25±0.75	2.57±0.13	2.65±0.11	11.80±0.02	11.58±0.27	11.73±0.36	4.71±0.18
	April	6.66	165.90	180.04±3.88	5.44±0.09	3.52±0.05	11.44±0.12	10.02±0.01	3.21±0.44	12.83±0.71
	Means	6.85±0.22 <sup>b</sup>	192.55±30.77 <sup>a</sup>	191.15±13.02 <sup>a</sup>	4.01±1.66 <sup>a</sup>	3.10±0.59 <sup>a</sup>	11.62±0.22 <sup>a</sup>	10.80±0.91 <sup>a</sup>	12.47±0.91 <sup>a</sup>	8.77±4.71 <sup>a</sup>
Massagali	February	6.45	202.34	201.72±1.50	11.27±0.13	1.76±0.35	15.41±0.02	19.42±0.74	4.71±0.76	1.71±0.18
	April	6.36	226.87	207.56±0.75	3.11±0.13	3.34±0.22	15.67±0.07	8.67±0.35	1.79±1.22	5.21±0.18
	Means	6.41±0.05 <sup>a</sup>	214.61±14.17 <sup>a</sup>	204.64±3.51 <sup>a</sup>	7.19±4.72 <sup>b</sup>	2.55±1.10 <sup>a</sup>	15.54±0.15 <sup>a</sup>	14.04±6.23 <sup>a</sup>	4.02±1.30 <sup>a</sup>	3.46±2.02 <sup>a</sup>
Lahoré Vina	February	6.96	4711.94	2749.80±135.13	89.73±6.40	13.75±0.34	404.53±10.77	130.84±8.92	291.40±2.76	58.46±4.42
	April	6.92	4897.25	2590.54±30.03	87.33±1.00	13.44±0.13	380.90±9.88	139.21±5.75	269.51±1.00	65.95±3.01
	Means	6.94±0.02 <sup>b</sup>	4804.59±106.99 <sup>c</sup>	2672.96±121.47 <sup>c</sup>	88.53±3.99 <sup>c</sup>	13.60±0.27 <sup>c</sup>	392.72±16.04 <sup>b</sup>	135.02±7.81 <sup>b</sup>	280.45±17.58 <sup>b</sup>	62.21±5.31 <sup>b</sup>

**Table 3: Estimated major mineral intake of an average 250 kg cattle**

	Ca (g)	Mg (g)	Na (g)	K (g)
Daily requirement*	18.8	12.5	3.8	50
Lahoré vina	7.28-8.45	2.66-2.73	5.15-6.09	1.22-1.26
Others springs	0.22-0.45	0.17-0.27	0.23-0.48	0.04-0.25

\*Calculated from a daily food intake of 6.2 kg dry matter

concentration of OM recorded for water samples from the Lahoré Vina may be due to the fact that the water contained in this source is practically stagnant and as such, the activity of biological organisms could have contributed to raise the OM content. In addition, this particular water source showed less signs of pollution as evidenced by levels of such pollutants as N-NH<sub>4</sub>, NO<sub>3</sub> and PO<sub>4</sub><sup>2-</sup>. Except of Wakwa Palestine source with a nitrate level of 0.05 mg l<sup>-1</sup> of NO<sub>3</sub>, all other sources contained on the average less than 0.01 mg l<sup>-1</sup> of N-NH<sub>4</sub>, NO<sub>3</sub> and the PO<sub>4</sub><sup>2-</sup>.

**Conductivity and mineral content:** Conductivity of the different samples varied significantly (p<0.05) with sources with individual values ranging between 180 and 2750 µs. The kind of spring significantly influences this variation. Water of the Lahoré Vina had highest conductivity compared to that of the other sources. Conductivity values for water samples taken from the Lahoré Vina varied from 4712 to 4897 µs as against 166 to 356 µs for the other sources. As such the conductivity of waters from the Lahoré Vina source highly the limiting level of 2500 µs, recommended for water for grazing animals. The high levels of conductivity observed in the samples of water from Lahore Vina directly translate its relatively high content major mineral as opposed to the other sources.

The Table 2 shows the anions content of the different water sources. The levels of the different anions measured are lower than the critical recommendation for cattle water. The exception to this observation was in the case of the Lahoré Vina water source with which contained HCO<sub>3</sub><sup>-</sup> (2750 and 2590 mg l<sup>-1</sup>) in amounts much higher than the recommended limit (1000 mg l<sup>-1</sup>) for water

for cattle. The levels of Ca, Mg, Na and K were equally quite high in samples taken from the Lahoré Vina source. With particular reference to Ca, Mg and K values recorded in the samples from the Lahoré Vina were higher than those recommended for water for cattle. The level of Na in samples from this source was relatively high (269 and 291 mg l<sup>-1</sup>). On the whole the water from the Lahoré Vina is saline in nature. It has been shown that the consumption of water of high salt content tend to increase water intake and decrease the quantity of milk secretion in cattle<sup>[1]</sup>. With particular reference to the effect of mineral consumption on milk production, there are other studies that tend to support a contrary view<sup>[24]</sup>. According to these authors it is the consumption of high levels of chloride and sulfate and not sodium that is detrimental to milk production. Based on this later view point, it can be said that the waters from the different sources in Wakwa do not pose any danger to milk production as their levels of Cl and weak SO<sub>4</sub><sup>2-</sup> are quite low.

On a general basis, the different sources studied are likely to make significant contributions to the daily mineral intake of grazing animals which drink from them. Table 3 shows the estimated major mineral intake of an average 250 kg cattle from the different sources. A cow of that size drinking fully from the Lahoré of Vina source would be consuming about 1.2 to 1.3 g/day, of potassium which represents about 2.6 to 2.9% of it recommended daily intake. Similar estimates made using concentration values of the other waters show that the average intake of potassium would be much lower and within the range of 0.03 to 0.59% of daily potassium requirement. Other the apparent estimated daily potassium intake from the other are low, there is no course for alarm as it has been shown that tropical animals obtain sufficient potassium through grazing<sup>[25,26]</sup>.

With respect to magnesium nutrition, it has been reported that tropical pastures are generally low in their content of this mineral and as such tend not to satisfy the daily requirements of animals which graze on them<sup>[27]</sup>. The magnesium profile of the different water sources do not

Table 4: Trace minerals concentration

Point d'eau	Date	Al (mg l <sup>-1</sup> )	Fe Total (mg l <sup>-1</sup> )	soluble Fe (mg l <sup>-1</sup> )	Mn (mg l <sup>-1</sup> )	Zn (mg l <sup>-1</sup> )	MO (mg d'O <sub>2</sub> /l)	NO <sub>3</sub> (mg l <sup>-1</sup> )
Wakwa palestine	February	0.39±0.07	0.15±0.01	< 0.01	< 0.01	0.11±0.00	1.30±0.14	< 0.01
	April	0.07±0.02	0.19±0.03	0.20±0.02	< 0.01	0.06±0.00	3.70±0.14	0.05±0.05
	Means	0.23±0.19 <sup>a</sup>	0.17±0.03 <sup>a</sup>	0.10±0.12 <sup>a</sup>	< 0.01 <sup>a</sup>	0.09±0.03 <sup>b</sup>	2.50±1.39 <sup>a</sup>	0.03±0.04 <sup>a</sup>
Djontari	February	0.30±0.02	0.28±0.04	0.06±0.01	< 0.01	0.02±0.00	4.30±0.14	< 0.01
	April	0.24±0.01	0.07±0.02	< 0.01	< 0.01	0.04±0.00	0.65±0.07	< 0.01
	Means	0.27±0.04 <sup>ab</sup>	0.18±0.12 <sup>a</sup>	0.03±0.04 <sup>a</sup>	< 0.01 <sup>a</sup>	0.03±0.01 <sup>a</sup>	2.48±2.11 <sup>a</sup>	< 0.01 <sup>a</sup>
Massagali	February	0.17±0.04	0.05±0.02	< 0.01	0.02±0.02	0.02±0.00	1.50±0.28	< 0.01
	April	0.05±0.02	0.04±0.01	0.06±0.00	0.02±0.01	0.02±0.00	4.70±0.14	< 0.01
	Means	0.11±0.07 <sup>a</sup>	0.05±0.01 <sup>a</sup>	0.03±0.03 <sup>a</sup>	0.02±0.01 <sup>ab</sup>	0.02±0.00 <sup>a</sup>	3.10±1.86 <sup>a</sup>	< 0.01 <sup>a</sup>
Lahoré vina	February	0.33±0.03	2.53±0.48	0.11±0.02	0.10±0.03	0.02±0.00	22.40±1.84	< 0.01
	April	0.51±0.04	0.27±0.01	< 0.01	0.00±0.00	0.03±0.00	10.45±0.35	< 0.01
	Means	0.42±0.10 <sup>b</sup>	1.40±1.33 <sup>b</sup>	0.05±0.06 <sup>a</sup>	0.05±0.06 <sup>b</sup>	0.02±0.01 <sup>a</sup>	16.43±6.98 <sup>b</sup>	< 0.01 <sup>a</sup>

Table 5: Estimated trace mineral intake of an average 250 kg cattle

	Al (mg)	Fe (mg)	Mn (mg)	Zn (mg)
Daily requirement*		312.5	250	187.5
Lahoré Vina	6.90-9.74	5.16-52.88	0.42-0.57	
Others springs	0.96-8.15	0.79-5.85	0.38-2.30	0.42-2.35

\*Calculated from a daily food intake of 6.2 kg dry matter

provide any hope for helping the situation. Estimated magnesium intake from the sources is very low. From the Lahoré Vina source, estimate contributions to recommended daily intake will stand at 0.003% and less than 0.001% for the other sources.

Using the same approach for estimating daily intakes, the Lahoré of Vina source was observed to be a good source for calcium intake for animals which drink mainly from it. Estimates show that this source will potentially contribute between 45 to 46% of the daily requirement of calcium of a 250 Kg animal. With respect to sodium, estimates indicate that contributes to daily intake from the same source will much higher (147 to 167%) than the recommended daily requirement. Estimates for the other sources show that calcium intake will vary between 1.3 to 5% of daily requirement while those of sodium will vary between 6.3 to 14%. In view of the fact that the daily calcium requirements of grazing cattle in this zone is hardly met by forage consumed<sup>[28]</sup>, the potential contributions of these water sources to daily intakes cannot be underestimated. Equally worthy of note is the fact that sodium is one of the most deficient mineral elements in pasture<sup>[2,29,30,23]</sup>. The different springs studied thus constitute good sources of this element for grazing animals. Infact it is for this reason that shepherds are said to have been using these springs as far back as the 19th century<sup>[7,31]</sup>.

**Trace minerals:** Table 4 present the trace minerals in the different water samples analysed. Total Fe content varied from 0.04mg l<sup>-1</sup> (Massagali) to 2.53 mg l<sup>-1</sup> (Lahoré Vina) ; Al concentrations from 0.05 (Massagali) to 0.50 mg l<sup>-1</sup> (Wakwa Palestine) and Zn content from 0.02 (Djontari, Massagali and Vina Lahoré) to 0.26 mg l<sup>-1</sup> (Wakwa Palestine). The high values of soluble Fe and Mn were

estimated at 0.2 mg l<sup>-1</sup> (Wakwa Palestine) and 0.1 mg l<sup>-1</sup> (Vina Lahoré), respectively. With respect to copper, it was observed that all the water sources contain very low levels (less than 0.01 mg l<sup>-1</sup>) of this element.

With the exception of the Lahoré Vina whose Mn concentration was found to be higher than recommendation for animal grazing water, that must be lower to 0.05 mg l<sup>-1</sup><sup>[32]</sup>, all other trace elements were low in samples collected from the different sources. Thus values of 0.2 mg l<sup>-1</sup>, 0.5 mg l<sup>-1</sup>, 1 mg l<sup>-1</sup> and 5 mg l<sup>-1</sup> were obtained for Fe, Al, Cu and Zn<sup>[32,33]</sup>. However, these waters bring some non negligible trace elements to grazing animal.

Based on the average concentrations of manganese in samples, estimated calculations indicate that the consumption of water from the Lahoré Vina source can cover up to 1% of their daily requirements of these elements (Table 5). The relatively low levels of manganese in the other water sources go to add to earlier reports of low concentrations of manganese in fodder within the region<sup>[28]</sup>. Grazing animals in this zone thus run the health risks associated with manganese deficiency. The reality of this will have to be investigated in future studies.

Zinc levels in the different waters are such that the sole consumption of the waters by animals could be estimated to contribute between 0.2 to 2.7% of their daily requirements. Earlier reports of studies in this region had revealed that fodder for animals was generally low in their content of zinc<sup>[28]</sup>. The present observation of low levels of zinc in the spring waters is thus a matter of concern for sound animal nutrition. The situation becomes even more worrisome when it is observed that Fe levels are relatively quite high in the water and in a situation of nutrient interaction, could further impair the absorption and bioavailability of zinc as well as of copper. In deed such interaction would normally go to aggravate problems related to Cu bioavailability<sup>[34]</sup>, as well as that of deficiency that has been observed in tropical pasture<sup>[35,28,36]</sup>.

## CONCLUSION

The spring waters of the grazing zone of Wakwa contain varying concentrations of  $\text{HCO}_3^-$ , Ca, Mg, Na and K. Of the different springs, the Lahoré Vina contains the highest concentrations of these elements and as such can make important contributions to the daily requirement of grazing animals for these elements. The other springs contain relatively low levels of the different elements studied. The Wakwa Palestine, Djomtari and Massagali springs are poor sources of zinc, copper and manganese but could contribute about 0.59, 5 and 14%, respectively of the daily requirements of grazing animals for K, Ca and Na. Of particular note is the fact that these springs are relatively good sources of sodium which has been reported to be very low in animal fodder in this zone. Studies to evaluate the exact bioavailability and status of mineral nutrition in grazing animals in the zone under study need to be carried out for a better understanding of the mineral nutrition status of the animals.

## ACKNOWLEDGEMENT

This study was funded by the Agence Universitaire de la Francophonie (financing travel and subsistence to LSE-France) and the Laboratoire Sol et Environnement (LSE) of Nancy-Lorraine, France.

## REFERENCES

1. NRC (National Research Council), 2001. Nutrient Requirements of Dairy Cattle, Seventh Revised Edn. 2001. Nationl Academy Press, Washington DC., pp: 381.
2. Dahlborn, K.M., M. Alkerling and G. Gustafson, 1998. Water intake by dairy cows selected for high or low milk-fast percentage when fed two forage to concentrate rations with hay or silage. *Swedish J. Agric. Res.*, 28: 167-176.
3. Holter, J.B. and W.E. Urban, 1992. Water partitioning and intake in dry and lactating -Holstein cows. *J. Dairy Sci.*, 75: 1472-1479.
4. Shirley, R.L., 1985. Water requirements for grazing ruminants and water as a source of minerals, pp:37-57. In McDowell (editeur), *Nutrition of grazing ruminants in warm climates*, Academic Press, pp: 443.
5. McDowell, L.R. and J.D. Arthington, 2005. Minerals for Grazing Ruminants in Tropical Regions. Institute of Food and Agricultural Sciences. Bulletin. 4th Edn., pp: 85.
6. NRC (National Research Council), 1974. Nutrient and Toxic Substance in Water for Livestock and Poultry. National Academy of Sciences, Washington, DC.
7. Boutrais J., 1974. Les conditions naturelles de l'élevage sur le Plateau de l'Adamaoua (Cameroun). XI N°2. Cahiers ORSTOM, Série Sciences Humaines, pp: 160-163.
8. Fezeu, W.M.L., 2000. Caractérisation physico-chimique des sources de l'Adamaoua (cas de quelques Lahorés de Ngaoundéré et de Tignère. Mémoire de DEA de Sciences Alimentaires et Nutrition, ENSAI Univ. de Ngaoundéré, pp: 90.
9. Le Marechal Alain, 1976. Géologie et Géochimie des sources thermominérales du Cameroun. Travaux et Documents de l'ORSTOM N°59, Paris, pp: 176.
10. Nunez-Delgado, A., E. Lopez-Periago, F.V. Diaz, 2002. Pollution attenuation by soils receiving cattle slurry after passage of slurry-likefeed solution. *Colun Experiments. Rev. Bioresource Tech.*, 84: 229-236.
11. Smith, D.C., J. Sacks and E. Senior, 1999. Irrigation of soil with syntetic landfill leachate-Speciation and distribution of selected pollutants, *Environmental Pollution*, 106: 429-441.
12. Xue, H., P.H. Nhat, R. Gächter and P.S. Hooda, 2003. The transport of Cu and Zn from agricultural soils to surface water in a small cathment. *Advances Enviro. Res.*, 8: 69-76.
13. Mignolet, C., V. Thénard, M. Benoît, M.N. Anfrie, D. Foissy, M. Grospe and Trommenschlager, 1999. Livestock farming systems and sustainable drinking water production : proposition of risk indicators at different organisational levels. *Livestock Production Sci.*, 61: 307-313.
14. Sangodogin, A.Y., 1991. Ground and Surface Water Pollution by Open Refuse Dump in Ibadan, Nigeria. *Dircovery and Innovation*, 3: 37-43.
15. Le Marechal Alain, 1970. Les sources thermominérales de l'Adamaoua: Analyses chimiques et utilisation. Fiche de la recherche scientifique et technique Outre-Mer. Centre ORSTOM de Yaoundé, pp: 48.
16. Pamo, E.T. and S. et Yonkeu, 1983. Etude de l'évolution de quelques paramètres climatiques de l'environnement pastoral de Wakwa, Adamaoua-Cameroun. *Revue Science et Tech. Série Sci. Zootechnique*, 2: 19-34.
17. AFNOR, 1986. Eaux Méthodes d'essai. Recueil de la Norme Française. Paris, pp: 624.
18. Rodier, J., 1978. L'analyse de l'eau : Chimie, Physico-chimie, Bactériologie, Biologie. 6ème Edn. Dumod-Technique. Paris, pp: 1136.
19. MCD (Ministère de la Coopération et du Développement), 1991. Memento de l'agronome. 4ème Edn., pp: 1635.

20. Bellefontaine R., A. Gaston and Y. Petrucci, 1997. Cahier FAO Conservation 32 [http://www.fao.org/documents/show\\_cdr.asp?url\\_file=/docrep/w4442f/w4442f01.htm](http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/w4442f/w4442f01.htm)
21. Messine, O., 1994. Evolution de l'élevage dans l'Adamaoua, protection sanitaire des animaux domestiques sur les ressources naturelles. Concertation régionale sur l'environnement pour la province de l'Adamaoua, Thème 3. Ministère de l'Environnement et des Forêts du Cameroun (Cellule de coordination du PNGE), pp: 17.
22. Conrad J.H., L.R. McDowell, G.L. Ellis et J.K. Loosli, 1985. Minéraux pour les ruminants de pâturage des régions tropicales. Bulletin du Département de Zootechnie de l'Université de Floride, Gainesville et de l'Agence des Etats-Unis pour le Développement Intl., pp: 96.
23. WQM (Water Quality Management), 1996. South African Water Quality Guidelines: Agricultural Water Use: Livestock Watering. 2nd Edn. Depart. Water Affairs and Forestry. Pretoria South Africa, 5: 179.
24. Sanchez, W.K., M.A. McGuire and D.K. Beede, 1994. Macromineral nutrition by heat stress interactions in dairy cattle: Review and original research. *J. Dairy Sci.*, 77: 2051-2079.
25. Moffor, F.M., S. Yonkeu, C.L. Tawah, D.A. Mbah and E.T. Pamo, 1994. Mineral and Crude Protein Content on Natural Pastures on Adamawa Highlands, Cameroon. *Discovery and Innovation*, 6: 184-188.
26. Ogebe, P.O., J.A. Ayoade, L.R. McDowell, N.S. Wilkinson and F.G. Martin, 1995. Mineral concentration of forages and soils in Benue state, Nigeria. I. Macrominerals and forage *in vitro* organic matter digestibility and crude protein concentration. *Commun. Soil Sci. Plant Anal.*, 26: 1989-2007.
27. Ogebe, P.O. and L.R. McDowell, 1998. Forage Nutrient Composition in the Wet Season in Benue State, Nigeria. I. Macrominerals and *In vitro* Organic Matter Digestibility. *Commun. Soil Sci. Plant Anal.*, 29: 1199-1210.
28. Njwe, R.M. and L. Lou Issa, 1990. Mineral status of natural pastures in the Adamaoua region of Cameroon. *Revue Elev. Méd. Vét. Pays Trop.*, 43: 375-380.
29. McDowell, L.R., 1997. Minerals for Grazing Ruminants in Tropical Regions. Cooperative Extension Service. Institute of Food and Agric. Sci. Bulletin. 3rd Edn., pp: 81.
30. Hassana, A., 1989. Preliminary survey of mineral status of pastures and cattle in the North-West province of Cameroon. Final study memoire. National Institute of Rural Development. Dschang University Centre. ix, pp: 45.
31. Doufissa, A., 1993. L'élevage bovin dans le Mbéré (Adamaoua camerounais). Collection Études et Thèses Institut Français De Recherche Scientifique pour le Développement en Coopération Editions de l'ORSTOM Paris, pp: 274.
32. EPA (Environmental Protection Agency), 1997. Current drinking water standards (Human): Office of Ground Water and Drinking Water. U.S. Environ. Protection Agency Wash, DC. EPA, 815-k-97-002.
33. NRC (National Research Council), 1980. Mineral Tolerance of Domestic Animals. National Academy Press, Washington, DC.
34. Thornton, I., 2002. Geochemistry and mineral nutrition of agricultural livestock and wildlife. *Applied Geochemistry*, 17: 1017-1028.
35. Espinoza, J.E., L.R. McDowell, N.S. Wilkinson, J.H. Conrad and F.G. Martin, 1991. Monthly variation of forage and soil minerals in central Florida II. Trace minerals. *Commun. In Soil Sci. Plant Anal.*, 22: 1137-1149.
36. Velasquez-Pereira, J., L. McDowell, J. Conrad, N. Wilkinson and F. Martin, 1997. Mineral status of soils, forages and cattle in Nicaragua. I. Microminerals. *Rev. Fac. Agron. (LUZ)*, 14: 73-89.