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Assessment of the Impact of the Saltwater Wedge on the Physical-Chemical Quality of Groundwater in the Grand-Popo District (Southern Benin)

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Abstract

In coastal areas, freshwater aquifers are exposed to saltwater intrusion, threatening their quality. This study, carried out in the Grand-Popo district of Benin, assesses the impact of salt water intrusion on the physico-chemical quality of groundwater. Twenty wells in ten villages were sampled. Analyses revealed high levels of electrical conductivity and concentrations of chloride and sodium ions, often exceeding the standards set by the WHO (World Health Organization). A significant correlation was observed between chloride and sodium ions ($R^2 = 0.84$), confirming the influence of the salt wedge. The results highlight an increased health risk for local populations, justifying reinforced management of water resources.

Keywords

Salt Wedge, Groundwater, Salinity, Saline Intrusion, Grand-Popo

1. Introduction

"Water is the lifeblood of the earth, the source of life, essential to the survival of all living beings", as [1], rightly exclaimed. The earth is called the blue planet because that's how it appears from space, with 70% of its surface covered by water. Although water is abundant, freshwater (surface water and groundwater) represents only 2.53% of the planet's total water, and only this freshwater sustains terrestrial life, especially human life. Freshwater is therefore a rare and precious resource which, if contaminated, may no longer be able to fulfill its various ecological roles. Its availa-

bility in quantity and quality is essential to prevent disease and improve quality of life [2]. Freshwater is a rare and vital resource. In coastal areas, this resource is subject to multiple pressures, notably saline intrusion caused by intensive groundwater exploitation and rising sea levels. These phenomena disrupt the natural balance between fresh and salt water, compromising water quality and the health of local populations. The Grand-Popo district in southern Benin is particularly hard hit by this problem, due to its proximity to the Atlantic Ocean and the increasing use of groundwater for domestic and agricultural purposes. The aim of this study is to assess the impact of the salt wedge on the physico-chemical quality of groundwater in this region.

2. Material and Methodology

2.1. Study Area

Grand-Popo is a coastal town in southwest Benin, located between 6˚15'N and 6˚20'N latitude and 1˚46'E and 1˚55'E longitude. Covering an area of 289 km^2, Grand-Popo is bordered to the north by the municipalities of Athiémé, Comè and Houéyogbé, to the south by the Atlantic Ocean, to the south-east by the municipalities of Ouidah and Kpomassè, and to the west by the Republic of Togo (**Figure 1**). It has an average population density of around 199 inhabitants/km^2 [3]. It has seven (07) districts, including Grand-Popo, which in turn has eleven (11) villages: Agonnèkanmey, Akodessewa, Apoutagbo, Ewé-Condji, Hêvê, Houndjohoundji, Hounssoukoè, Onkuihoué, Saligato, Toklanhon and Yodo-Condji. The climate is sub-equatorial, of the Guinean type, characterized by four (04) seasons of varying intensity. Over the 90s, average annual rainfall in Grand Popo was around 900 mm, with minimum of 730 mm and maximum of 1145 mm. The soils of the Littoral and the sandy dunes are made up of fine sands, poor in organic matter and very permeable, dominated by well-drained sandy alluvium. These soils support *Cocos nucifera* (coconut) vegetation. The hydrographic network of the municipality of Grand-Popo, like that of the district, is locally extensive, comprising the Mono river and series of tributaries and effluents, including the Sazué, the Grand-Popo lagoon, the Aho channel, as well as marshes and swamps.

2.2. Water Sampling and Analysis

A total of twenty (20) well water samples were taken, with a maximum of two (02) samples per village in the Grand-Popo district, as shown in **Figure 2**, in accordance with the method for taking groundwater from a well. Each sample was collected in sterile 1.5 L bottle using a well sampler. Each bottle was labelled with its number, sampling time, date, location and geographical coordinates. Each sample was then carefully stored in a cooler filled with ice, and transported as soon as possible to the laboratory for analysis at the end of the campaign. Various parameters such as pH, temperature, electrical conductivity and salinity were measured using a multi-parameter in the field. The data collected was analyzed using Excel for descriptive statistics and QGIS for mapping the affected areas. Correlations between the various parameters were calculated to identify key relationships be-

tween salinity and chemical compounds.

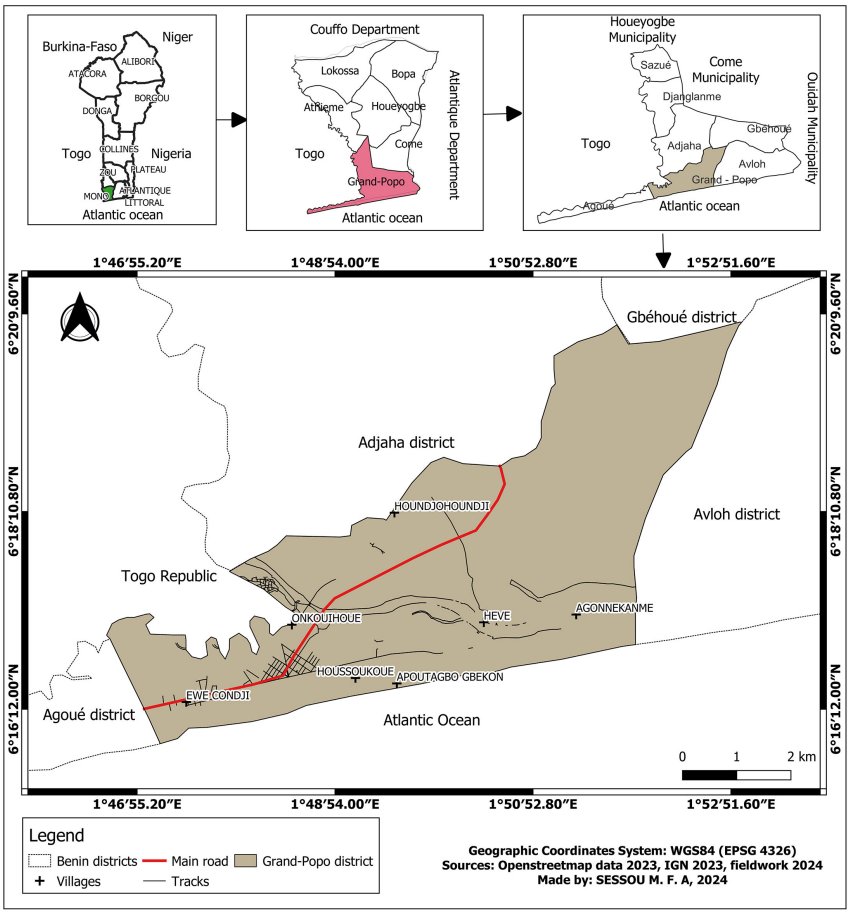

Figure 1. Location map of the study area.

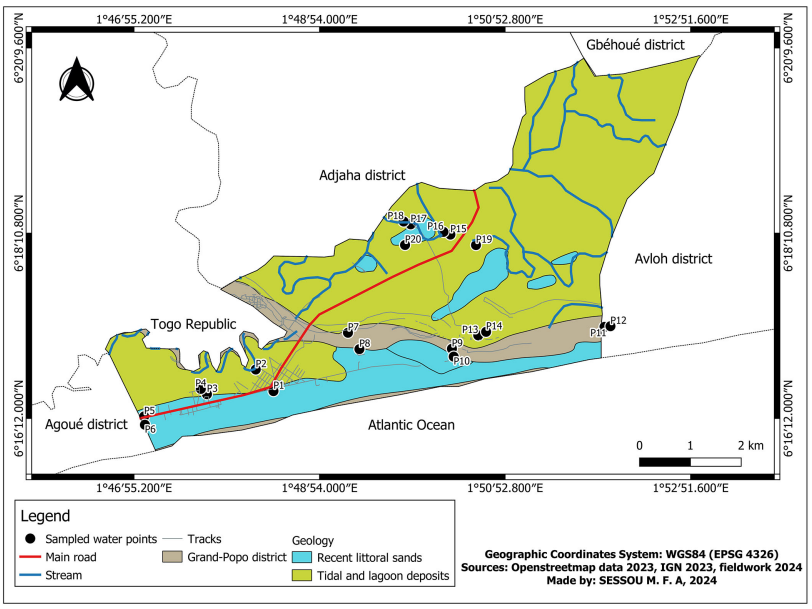

Figure 2. Sampling map of Grand-Popo district.

3. Results

3.1. Physico-Chemical Characteristics of Water

Table 1. Physico-chemical characteristics of sampled sites in Grand-Popo district.

Parameters Sites	Temperature (˚C)	pH	Electrical conductivity (µS/cm)	Salinity (ppm)	Chloride (mg/L)	Sodium (mg/)	Potassium (mg/L)
P1	28.9	7.68	806	403	107.1	95.76	1.23
P2	29.1	7.23	440	220	43.31	30.81	0.42
P3	29.6	7.84	1004	502	156.91	170.17	2.67
P4	29.7	7.61	558	279	68.87	10.41	0.73
P5	29.4	7.34	1140	569	210.16	100.66	1.02
P6	29.8	7.71	1550	773	371.33	180.03	2.11
P7	28.6	7.69	1942	973	446.59	300.89	1.51
P8	29.7	7.62	900	450	145.55	130.93	2.56
P9	29.6	7.66	2190	1100	680.87	300.64	0.83
P10	29.3	7.85	1395	698	360.68	100.64	1.49
P11	29.9	8.48	320	159	46.15	30.32	1.88
P12	30.2	7.91	354	177	38.34	30.54	0.65
P13	29.6	7.46	1854	930	355	200.44	1.02
P14	28.9	7.52	2370	1180	510.12	300.89	0.68
P15	29.2	7.04	1259	628	210.16	160.78	2.32
P16	28.6	7.26	3970	2000	1160.44	1000.32	17.88
P17	29.6	7.29	1940	972	450.44	259.54	4.15
P18	29.4	7.18	3210	1630	850.91	900.36	11.67
P19	29.2	7.46	330	374	53.96	60.15	8.40
P20	29.4	7.47	560	740	63.19	60.3	9.11

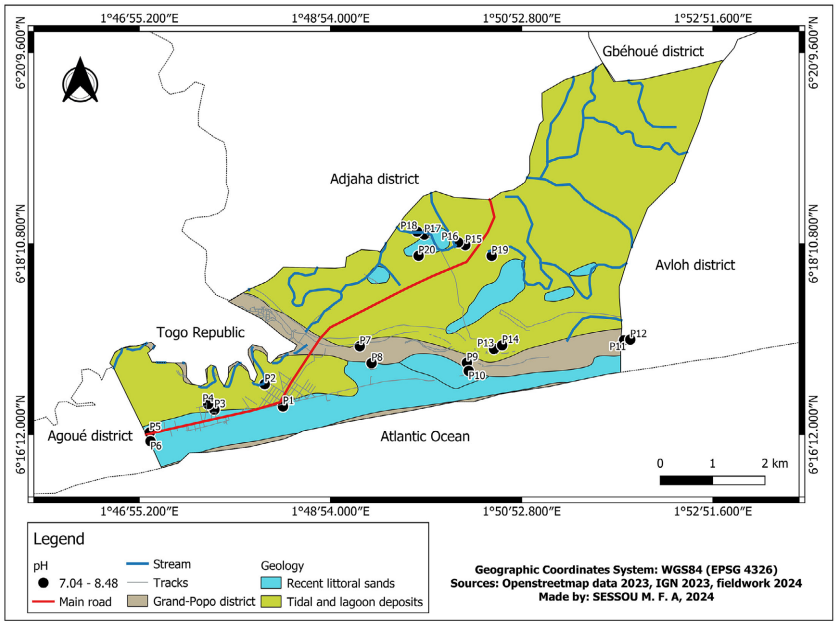

Figure 3. pH content of groundwater in Grand-Popo district.

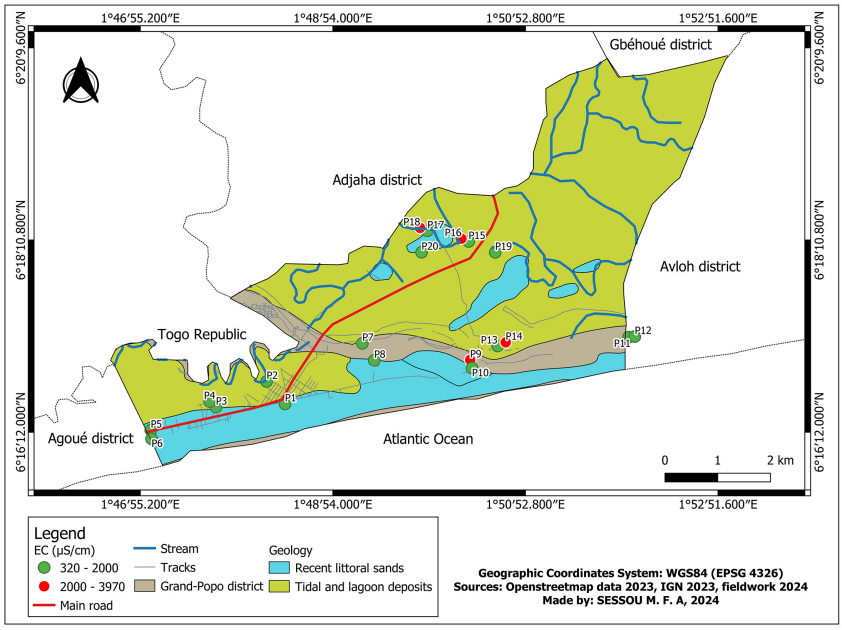

Figure 4. Electrical conductivity content of groundwater in Grand-Popo district.

The results of the physico-chemical analyses of water sampled from studied wells are shown in Table 1. Water temperature in wells in Grand-Popo district averaged 29.4˚C, exceeding the WHO standard (<25˚C). It ranged from 28.6˚C to 30.2˚C. The pH ranged from 7.04 to 8.48, with an average value of 7.57 (Figure 3). Electrical conductivity values ranged from 320 µS/cm to 3970 µS/cm, with an average of 1404 µS/cm for all boreholes studied (Figure 4). Recorded salinity values ranged from 159 ppm to 1630 ppm, with an average value of 737.85 ppm. Electrical conductivity values ranged from 320 µS/cm to 3970 µS/cm, with an average value of 1404 µS/cm. The results show that, although 80% of the wells sampled had electrical conductivities below WHO standards, high conductivity values were recorded at some wells. Chloride concentrations ranged from 38.34 mg/L to 1160.44 mg/L, with an average value of 316.53 mg/L. Sodium concentrations ranged from 10.41 mg/L to 1000.32 mg/L, with an average value of 244.888 mg/L.

3.2. Correlation

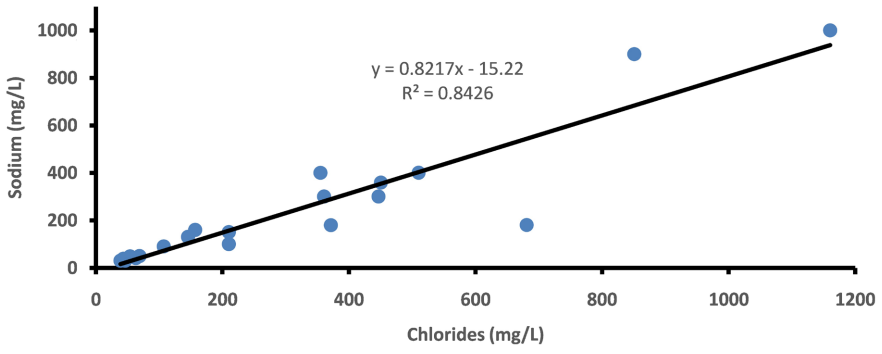

Figure 5. Correlation between chloride and sodium ion concentrations in sampled well water.

A significant correlation ($R^2 = 0.84$) was observed between chloride and sodium ions, suggesting a marine origin of salinity. These results confirm the impact of the salt wedge (**Figure 5**).

3.3. Health Impacts

Contaminated water increases the risk of water-borne diseases (diarrhoea, infections) and health problems such as high blood pressure, endangering the health of local populations.

4. Discussion

Generally speaking, the parameters measured do not comply with Beninese standards or WHO guidelines. Indeed, the temperature values measured vary from 28.6˚C to 30.2˚C. compared with those measured by [4] between 26.5˚C and 32˚C and between 28.4˚C and 33˚C during the fieldwork of [5]. On the other hand, they are similar to those reported by [6] and [7] in groundwater from Chad and Burkina Faso. Based on the results, all water temperatures at the various sampling points exceed the quality reference set at 25˚C [8]. Although these values are high, they do not present any danger to human health, but they do pose a problem of acceptability, as cool water is generally more pleasant to the taste than lukewarm water. The pH values recorded range from 7.04 to 8.48. These pH values oscillate within the range of values ($6.5 < pH < 8.5$) tolerable by Beninese standards [9], as stipulated in article 17 of Decree N˚2001-094 of February 20, 2001 setting drinking water quality standards in Republic of Benin. These pH values are, for the most part, below those (6.1 and 8) obtained by [5] in the municipality of Grand-Popo. As far as salinity is concerned, the recorded values are not so great compared with those of the seas and oceans on average (34 and 35 PSU) [10]. Electrical conductivity values range from 320 to 3970 µS/cm. This indicates an average mineralization of 1404.6 µS/cm. The maximum value recommended for electrical conductivity by the WHO is 2000 µS/cm. The results show that the conductivities recorded are quite high, although 80% of the sampled wells had electrical conductivities below WHO guidelines. Given that the sampled wells at Yodo-Condji (P7 et P6), Hounssoukoè (P7), Apoutagbo (P9 et P10), Hêvê (P13 et P14) and Toklanhon (P15) have conductivity values in excess of 1000 µS/cm to 3000 µS/cm, they could be classified as "saline water". If conductivity exceeds 3000 µS/cm, the water is characterized as "seawater" according to water classification based on conductivity [11]. In addition, those sampled at Toklanhon (P16) and Houndjohoundji (P18) show values in excess of 3000 µS/cm. This undoubtedly attests to seawater intrusion. However, it should be noted that the two water points sampled (Toklan-hon and Houndjohoundji) are close to the Grand-Popo lagoon. This configuration could explain the high electrical conductivity values obtained in these two locations, which are also close to the sea. With regard to chloride concentrations, the levels of the water samples analyzed ranged from 38.34 mg/L to 1160.44 mg/L. Water points with high chloride ion values suggest salt water intrusion, as the val-

ues obtained at these water points are higher than those recommended by Beninese standards, *i.e.* 250 mg/L. As for sodium, average sodium levels in the water at the points studied ranged from 10.41 mg/L to 1000.32 mg/L. According to [12] recommendations, the amount of sodium required in water intended for consumption should be less than 200 mg/L. However, the levels obtained for the water points sampled in certain localities are above this value. These waters therefore fail to meet potability standards. As for potassium levels, most of them comply with WHO standards (<12 mg/L). They are similar to those obtained by several authors [13] [14]. Based on the piezometric map [5], we can say that the piezometric levels in the Grand-Popo district are equivalent to −1 m in the piezometric depressions, testifying to the sensitivity of these sectors to invasion by salt water from the sea and brackish water from the Grand-Popo lagoon. These depressions are found at Hêvê, Apoutagbo, Houndjohoundji and Toklanhon. This further justifies the high conductivity, chloride and sodium concentrations in the water sampled in these localities. The saltwater wedge is therefore located along the Grand-Popo coastal lagoon and the villages of Houndjohoundji and Toklanhon. In addition, the survey results revealed that water-borne diseases such as diarrhoea and infections are largely observed in the villages, although the main use of well water is not for drinking but for cooking. On the other hand, high blood pressure is not so much recorded as a disease. Sustainable water resource management measures, including awareness-raising and control of groundwater use, are needed to limit the effects of saline intrusion.

5. Conclusion

This study highlights the significant impact of the salt wedge on groundwater quality in the Grand-Popo district. High concentrations of electrical conductivity, chlorides and sodium compromise water potability, with serious implications for public health. Sustainable water resource management measures, including raising public awareness and controlling groundwater exploitation, are needed to limit the effects of saline intrusion.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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