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The quest for safe drinking water: An example from Guinea-Bissau (West Africa)

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A B S T R A C T

While humans require water for life, one-sixth of our species lives without access to safe water. In Africa, the situation is particularly acute because of global warming, the progression of the Sahara desert, civil unrest and poor governance, population growth, migration and poverty. In rural areas, the lack of adequate safe water and sanitary infrastructures leaves millions with doubtful water quality, increasing the harshness of daily life. In this paper, a pilot study was conducted during the wet season on Bolama Island (Guinea-Bissau, West Africa), a UNESCO Man and the Biosphere Reserve. Twenty-eight shallow wells, supplying water to most of the population, were sampled for microbiological, physical and chemical water quality characteristics. A ten-parameter water quality index (WQI) adapted to tropical conditions was applied to compare the different wells. About 79% of the wells showed moderate to heavy fecal contamination. From the surveyed parameters, it was found that chemical contamination was less important, although all samples were acidic, with the pH averaging 5.12 ± 0.08. The WQI was $43 \pm 4\%$ (0%—worst; 100%—best quality), showing that the water from the majority of wells was polluted but should be suitable for domestic use after appropriate treatment. At the onset of the wet season, diarrhea represented 11.5% of all medical cases, 92.5% of which were children aged <15. This paper suggests inexpensive steps to reduce the fecal contamination and control the pH in order to increase the potability of the well water and, concomitantly, to raise the living standards of the population in one of the poorest countries of the world.

1. Introduction

The access to safe and sufficient water and sanitation are basic human needs and are essential to health and well-being of the human population (UN, 2006). Sub-Saharan Africa has the highest proportion of poor people in the world, 44% of the population in 2002 (World Bank, 2006), but shows the fastest population growth (approximately 2.2% a year), with a subsequent increased pressure on water resources. Although water is abundant in the region, particularly in coastal West Africa, most of the population lacks adequate and safe drinking water and improved sanitation. As a consequence of poor hygiene, diarrhea is the most common condition, its effect being greatest among children under 5-years old (Helmer, 1999). Owing to problems in planning and absence of sound monitoring programs, the water quality is, in most

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cases, unknown, thus making difficult the design and implementation of measures to improve characteristics of the water in order to make its consumption safe and not a source of disease. Moreover, as many as 22 African countries fail to provide safe water for at least half their population (deVilliers, 2002), 14 of them in the sub-Saharan region located north of the Equator.

The Republic of Guinea-Bissau, a former Portuguese colony, is located in sub-Saharan West Africa (Fig. 1). A coastal country with the only estuarine delta in the region, it contains an enormous biodiversity. Most of its 28,000 km^2 land area are covered with tropical rain forest (85%). Two seasons exist: wet with SW winds from June to November and dry, with NE winds from December to May.

The estimated present population of 1,586,000 (WHO, 2006a) has nearly doubled in the last 25 years. Life expectancy at birth is low (46.9 years), and the official HIV/AIDS prevalence rate reaches 10% (WHO, 2001). Communicable diseases such as endemic malaria, diarrhea (including cholera) and respiratory infections dominate. Health infrastructure is minimal and was greatly affected during the civil unrest in the late 1990s. With a per capita GDP of $240 (UN, 1997), Guinea-Bissau is one of the 10 poorest countries of the world, with over 50% of the population living below the poverty line.

The most recent estimate of total per capita water withdrawal for Guinea-Bissau is 49 l per day with 63% of the water used for agriculture and 31% allocated for domestic needs (WHO, 2000), i.e., each person has only 21 l of water available for daily personal needs. This value is well under the 50 l minimum water requirement for human domestic use (Gleick, 1998). On average, adequate water supply and sanitation cover less than half of the population (INEC, 2004). The water distribution networks that exist date from the colonial period and are mostly restricted to the capital, Bissau (ISDS, 2006). Thus, only 13.6% of the population has access to potable water, and no treatment of public wastewater is available. Outbreaks of cholera (from contaminated water through food and drinking water) are common. In 2005, during the wet season, 14,303 cases of cholera were diagnosed and 252 people eventually died (WHO, 2006a).

The Bolama-Bijagós Archipelago (Fig. 1) was designated a UNESCO Man and the Biosphere Reserve (MAB) in 1996. Bolama Island, a former colonial capital, is the most populated island that does not have any working water network. The 6000+ inhabitants retrieve water for domestic needs from shallow wells. No data on water quality are available, and the eventual link between water quality and human health has never been assessed, making it impossible to estimate the risk for the entire population. Moreover, one of the authors was assigned a 3-month rotation resident medical officer for the NGO AMI (International Medical Assistance) program in Bolama and the preponderance of water borne diseases paved the basis for the research presented here. Thus, the impetus for this paper was to: evaluate the water quality of well water during the wet season; assess the impact on human health of the water quality; and tentatively design comprehensive measures to improve water quality in the short-term.

2. Material and methods

2.1. The environment

The Bolama-Bijagós archipelago consists of 88 islands and islets within the ancient delta of the River Geba and River Grande. Bolama Island is located at 11°N and 15°W (Fig. 1). The area is influenced by the Canary current, from the north, and the Gulf of Guinea current from the south, creating

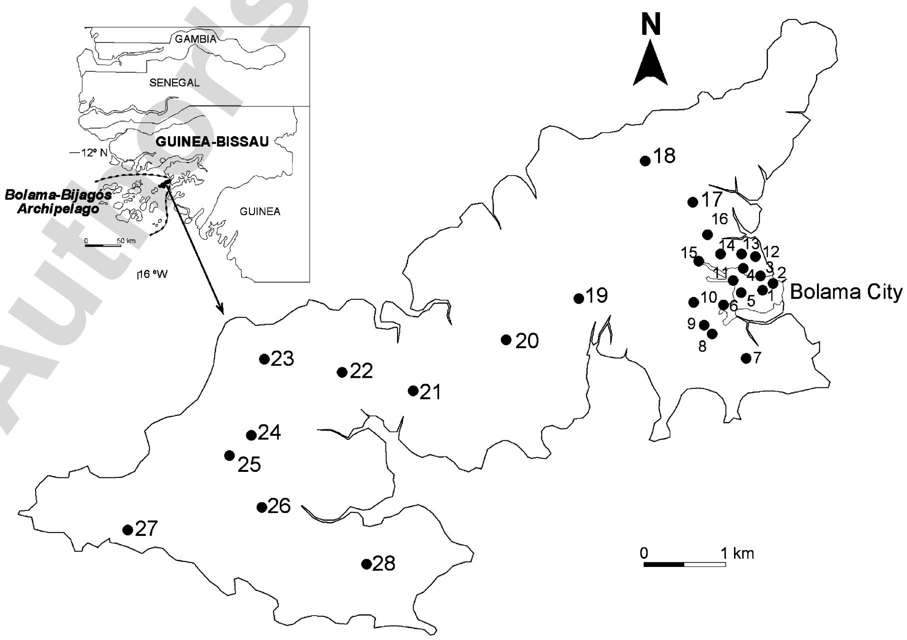

Fig. 1 – Location of sampling stations in Bolama Island, Guinea-Bissau.

regional climate conditions with much higher precipitation (>2500 mm) than on the continent. Although not the largest island of the archipelago Bolama (102 km^2) is the most densely populated, with 32% of the archipelago population. The hydromorphic sandy-clay soils are acidic, with low organic matter contents. The sediments are mainly Cenozoic to Recent (Teixeira, 1968). The vegetation consists of dry, deciduous forest and semi-deciduous rain forest, palm and chew-nut forests, coastal and wet savannas and extensive mangrove forests lining the coastal one-third of the island. Due to its location, Bolama receives upwelled, nutrient-rich water from the north as well as from multiple river watersheds (Amorim et al., 2004). The area has a high natural diversity and environmental richness: large mammals such as brackish water hippopotamus, manatees and dolphins are common (van Waerebeek et al., 2000), as well as reptiles such as Nile crocodiles and turtles. About one million migratory birds use the wetlands during the dry season (Dodman et al., 2004).

The Bolama employment is in agriculture (90%). No continuous electricity is supplied. No working water or sanitation networks are available, and water for different uses is obtained exclusively from wells. Sanitary wastewater is disposed of in public and private latrines often close to the wells. Malaria, diarrhea, sexually transmitted diseases, trachoma and scabies are the main ailments affecting the island population. The regional hospital in Bolama City has no permanent electricity supply and a single resident medical doctor is available; a second one, from the Portuguese NGO AMI (International Medical Assistance), is on 3-month rotations since 2002.

2.2. *Location of sampling sites and sample collection*

The regional health authority provided a list of 30 major wells covering the entire island, which supply most of the population with water for domestic use. Twenty-eight of them were visited on July 24, 2006 (Fig. 1). The exact position of each well was obtained by means of GPS (Magellan 600). At each site digital photographs were taken in order to document the environment surrounding the well. Whenever possible, the well depth was measured. About 54% of the wells were fitted with manual pumps, 39% were open pits serviced by plastic buckets and 7% had electric pumps. Water was retrieved by pumping or by bucket and the initial 10 l (one bucket) were discarded. A 500 ml plastic sterile flask was filled as well as one 1.5 l clean plastic bottle. In the latter case, bottles were washed and rinsed with 500 ml of the sample before filling. For sampling, the island was divided into four sectors: (i) Bolama city; (ii) SE Bolama; (iii) central Bolama; and (iv) W Bolama. After collection, the samples were refrigerated with locally produced shredded ice in 48 l chests and transported to the field laboratory for analysis no later than 3.5 h after collection.

2.3. *Analytical procedures*

All equipment and supplies were shipped from Portugal as personal effects yielding a total of 52 kg. The field laboratory was assembled in a house provided by AMI, in a room fitted with ceramic flooring and plaster-coated walls with natural light. No continuous electricity supply was available from the grid. During nighttime candles supplied the light.

2.4. *Bacterial analysis*

Each water sample was filtered through a sterile disposable filtering devise (Pall Co) onto a gridded 0.45 μm membrane filter provided with the individual kit. Vacuum was obtained by means of a hand pump (Mityvac) or an adapted 12-V vacuum cleaner connected to a car-battery. Asepsis was achieved with an alcohol burner, and the working bench was covered with a thick plastic sheet periodically disinfected with absolute alcohol. Duplicate filters were placed in 60 mm Petri dishes containing mFC agar (Difco) for fecal coliforms (FC), Slanetz-Bartley agar (Oxoid) for fecal enterococci (FE) and MacConkey agar (Oxoid) for total coliforms (TC). Incubations were performed in mini-incubators (Merck) at 44.5 °C (FC and FE) and 37 °C (TC) for 24 h. Typical colonies were counted and results expressed as colony forming units (CFU) 100/ml.

In selected samples, clostridia, an alternative indicator for fecal contamination in tropical waters (Hazen and Toranzos, 1990) as well as a suitable indicator of soil and domestic livestock manure contamination (Huysman et al., 1993), were enumerated in double-strength meat-liver agar (Sanofi Diagnostics Pasteur). The sample (20 ml) was heated for 10 min at 80 °C in 50 ml screw-cap sterile plastic tubes. Twenty ml of melted agar was added and air-sealed by means of 1 cm layer of glycerin. Following 24 h incubation, all black colonies were counted; results were expressed as CFU 20/ml.

2.5. *Physical and chemical analysis*

In situ measurements of temperature, conductivity, dissolved oxygen, oxygen saturation, pH and turbidity were made with a YSI meter (6000 series) calibrated according to the specifications from the manufacturer. Because this study was designed to reflect the quality of water consumed by the local population, water samples were not filtered (Reimann et al., 2003). Nitrate, nitrite, ammonium, copper, iron, chromium and cyanide were assayed in a 9-V multiparameter Hanna 200 photometer (www.hannacom.pt) according to standard methods supplied by the manufacturer. Individual blanks were prepared for each sample. Arsenic concentrations were measured with a high sensitivity Merckoquant As kit (ref 17927). All methods were previously checked in the main laboratory (Portugal) for accuracy against standards (Table 1).

Biological oxygen demand was measured as the difference in oxygen concentrations before and after 5 days incubation at 20–22 °C. Incubation was performed in an ice chest in the dark and temperature regulated by periodically adding shredded ice. Chemical oxygen demand was assayed photometrically after acid-digestion in a dry bath for 2 h at 150 °C (Merck Spectroquant COD cell test).

Total suspended solids were assayed by filtering 500 ml of water through a precombusted GF/F glass filter, drying until constant weight and re-weighting the filter. The microbiology disposable filtration unit was re-used since the filters had the same diameter.

Table 1 – Resolution, accuracy and precision of analytical methods used throughout the study

Parameter	Unit	Method	Resolution	Accuracy	Precision (%)
Temperature	°C	Electrode	0.01	±0.15	—
Conductivity	μS/cm	Electrode	1	±1	0.5
Dissolved oxygen	mg/l	Electrode	0.01	±0.1	1
pH	—	Electrode	0.01	±0.2	—
Turbidity	NTU	Electrode	0.1	±0.3	2
Color	PtCo	Colorimetric	1	±1	5
Nitrate	mg NO_3/l	Cadmium reduction	0.1	±0.5	10
Ammonium	mg NH_4/l	Nessler	0.01	±0.04	4
Nitrite	mg NO_2/l	Diazotization	0.01	±0.02	4
Copper	μg/l	Bicinchoninate	1	±10	5
Iron	mg/l	TPTZ	1	±10	8
Chromium	μg/l	Diphenylcarbohydrazide	1	±1	4
Cyanide	μg/l	Pyridine-pyrazolone	1	±5	3
Arsenic	μg/l	Mercury bromide	5	±5	10

2.6. *Water quality index*

The water quality index (WQI) used is a tropical modification of the original Scottish Water Quality Index (Bordalo et al., 2001). The 10-parameter index consists of the aggregation of three groups of parameters: physical (temperature, conductivity, suspended solids), chemical (pH, ammonia, nitrate, dissolved oxygen), and organic/microbiological (fecal coliforms, biological oxygen demand, chemical oxygen demand). The chosen method for subindices aggregation (weighted arithmetic average) is particularly suitable for indexation of the general water quality, as stated by House (1989). The final, modified, arithmetic, weighted index is the result of squaring the sum of the products of water quality ratings (q_i) and weighting each individual parameter (w_i) divided by 100, according to the following equation:

$$\mathrm{WQI} = 1/100\left(\sum_{i=1}^{9} q_i w_i\right)^2.$$

In the SDD WQI, 0% represents the poorest and 100% the highest water quality. In this study, the House and Ellis (1987) class rating was adopted: 10–25%, badly polluted; 26–50%, polluted; 51–70%, reasonable; 71–90%, good; 91–100%, very good.

2.7. *Health data*

The health data presented in this paper cover the first month after the onset of the wet season (June 2006). They were obtained from the Bolama City Hospital logbook and from the ambulatory medical records of one of the authors (JSB), as a rotating AMI mission medical doctor.

2.8. *Data analysis*

Bacterial data were log(n+1) transformed prior to analysis. Furthermore, data were tested for normality, using the Kolmogorov–Smirnov test, and for homoscedasticity using Leven's test (Zar, 1998). Least-square regression was used to compare relationships between two variables. Mapping was performed with Surfer using krigging as the interpolating method. In the absence of Guinea-Bissau water quality standards, the European (EU, 1998) and WHO recommendations (WHO, 2006b) were adopted in this study.

3. Results

In Table 2, the averaged results are summarized. The wells were shallow with an average depth of 5 m. Although water temperatures ranged from 29.55 to 30.13 °C, the average oxygen concentration was 6.58±0.24 mg/l, thus wells were well oxygenated, with the percentage of oxygen saturation averaging 86.9±3.2%. However, in five wells, including the four located in the western part of the island, the percentage of oxygen saturation dropped to values <75% (Fig. 2A).

The underground water feeding the wells was acid, with pH ranging from 4.36 to 6.02 (Fig. 2B), with low salt content as shown by the modest conductivity values (Table 2). The central zone of the island presented the highest pH values. In general, heavy metal (Cu, Fe, Cr, As) and cyanide concentrations were below the parametric value for drinking water (EU and WHO standards). Cyanide was an exception in the vicinity of an abandoned colonial-time military airfield (site 18). Another well, located close to a mangrove area and subject to forest clearing for subsistence agriculture, had both Fe and Cr above the parametric value (site 28).

Fecal contamination was found in all but six wells; these were located in the central zone of the island and in pockets within the city of Bolama. The ratio FC:FE averaged 6.6±1.5 and in five out of the 22 contaminated wells fecal enterococci were undetected. TC and FC were significantly correlated as expected ($R^2 = 0.778$, $P < 0.001$). In some wells, essentially those located in the western section as well as in Bolama City suburbs, fecal coliforms exceeded 1000 CFU 100/ml. According to EU and WHO standards, potable water should have neither coliforms nor fecal enterococci per 100 ml of sample.

A significant relationship between turbidity and clostridia was found ($R^2 = 0.467$, $P < 0.05$), suggesting the contribution of

Table 2 – Arithmetic mean, median, minimum, maximum and standard error (SE) for major parameters assayed during the wet season survey at Bolama Island, Guinea-Bissau

Parameter	Unit	Average	Median	Minimum	Maximum	SE	EU	WHO
Temperature	°C	29.05	29.23	26.55	30.13	0.15	—	—
Conductivity	μS/cm	136	107	27	326	18	2500	—
DO saturation	%	86.9	90.9	37.6	107.9	3.2	—	—
Dissolved oxygen	mg/l	6.58	6.95	2.97	8.14	0.24	—	—
pH	—	5.12	5.2	4.36	6.02	0.08	$\geqslant$6.5 and $\leqslant$9.5	—
Turbidity	NTU	6.5	3.0	1.0	26.0	1.5	[a]	—
Color	PtCo	31	6.5	1	169	9	[a]	—
Nitrate	mg NO_3/l	16.6	14.8	0.9	55.3	2.4	50	50
Ammonium	mg NH_4/l	0.11	0.07	0.01	1.37	0.05	0.5	—
Nitrite	mg NO_2/l	0.04	0.03	0.03	0.13	0.00	0.5	0.2
Copper	μg/l	96	49	1	395	19	2000	2000
Iron	mg/l	66.5	21.5	3.0	440.0	18.7	200	—
Chromium	μg/l	26	25	3	76	3	50	50
Cyanide	μg/l	12	10	1	55	2	50	70
Arsenic	μg/l	1.0	1.0	n.d.	5.0	0.2	10	10
Fecal coliforms	CFU 100/ml	410	35	0	5000	201	0[b]	0
Fecal enterococci	CFU 100/ml	74	3	0	850	35	0	0
Total coliforms	CFU 100/ml	2306	160	0	23,000	1040	0	0

EU—European Union parametric values for drinking water (EU, 1998), WHO—World Health Organization guideline values (WHO, 2006b).
n.d.—non-detectable.
[a] Acceptable to consumer.
[b] As *E. coli*.

soil for the increase of particles in well water. This was particularly evident at two sites in the western part of the island (sites 27 and 28). Although fecal contamination was moderate (FC < 100 CFU 100/ml), clostridia were astonishingly high in the range 1100–1300 CFU 20/ml.

The spatial distribution of water quality is plotted in Fig. 3. The average value was $43 \pm 4\%$, denoting polluted water. High fecal coliforms numbers and low pH values were the major parameters responsible for the low scores. The highest quality was found in the central zone of the island as well as in parts of Bolama City. The six non-fecal contaminated wells had an individual score >51% even with acidic water, which falls in the reasonable water quality category.

During the first month after the onset of the wet season, 347 patients visited the doctor (5.8% of the total island population). Among them, 32.7% were children aged <15 (Table 3). Diarrheic patients represented 11.5% of the total, and most of them were children (92.5%).

4. Discussion

On Bolama Island, most wells are shallow (5–11 m), thus particularly vulnerable to infiltration of soil from rainfall. They are dug by hand, without any wall isolation and have unprotected wellheads, which are permeable to surface runoff. Due to their shallow depth, all wells draw water from sediments and not from the bedrock. During the wet season, this may favor the renewal of groundwater and the recharge of the well, avoiding water stagnation, as shown by the rather high percentage of oxygen saturation values ($86.9 \pm 3\%$). Typically, well waters contain lower concentrations of dissolved oxygen than surface water. However, rainfall also mobilizes soil-contained bacteria and viruses (both natural and pathogens), and greatly promotes their transport to groundwater (Gerba and Bitton, 1984), the greatest degree of drinking water well contamination occurs after periods of heavy rainfall, as in the case of the 2005 cholera outbreak in Guinea-Bissau (WHO, 2006a). In this study, the influence of a heavy rainfall episode on the turbidity of a closed urban well, fitted with a manual pump (site 1), was evident: turbidity jumped from 4 to 68 NTU, showing the almost immediate effect of water contamination by soil particles. Additionally, clostridial abundance correlated well with turbidity, illustrating the vulnerability of at least some wells to surface contamination.

Most diarrhea episodes that occurred in Bolama during the first two months after the onset of the wet season in 2006 lasted 5–6 days (Savva-Bordalo J. unpublished data), suggesting a non-viral origin, since viral infections usually are of shorter duration (Payment et al., 1997). The most likely source of bacterial contamination to groundwater in Bolama Island was from human wastewater disposal and, to lesser degree, domestic animals although they are not confined to stables but rather range and wade everywhere. In Muslim areas goats dominate, whereas in animistic and Christian areas pigs are more commonly found, in this latter case close to the pumps and wells in order to enjoy the muddy environment. In addition, free-ranging cattle and chickens are abundant.

Former colonial houses have western-type toilets, but due to poor maintenance the pipe systems eventually broke down and open-pit drains were dug, often close to private backyard wells. In upscale, traditional mud-brick houses, outside private latrine and separate bathing areas connected to the

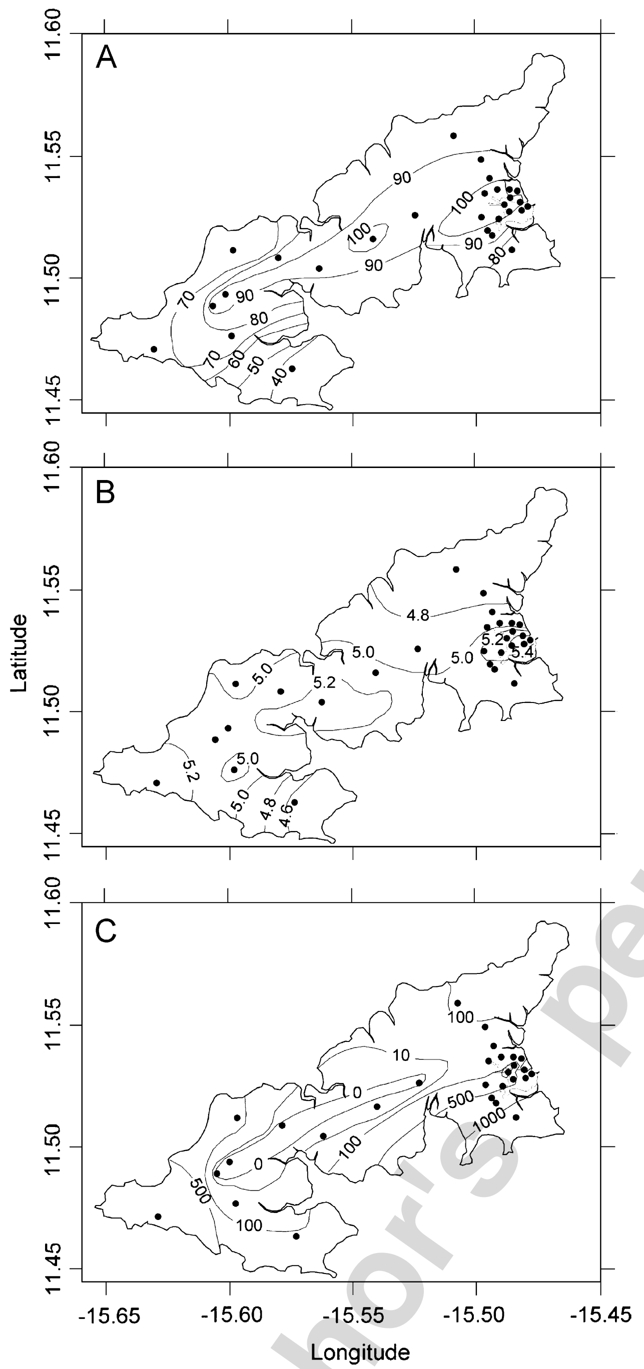

Fig. 2 – Spatial distribution of: (A) oxygen saturation (%); (B) pH; (C) fecal coliforms (CFU 100/ml) in Bolama Island, Guinea-Bissau.

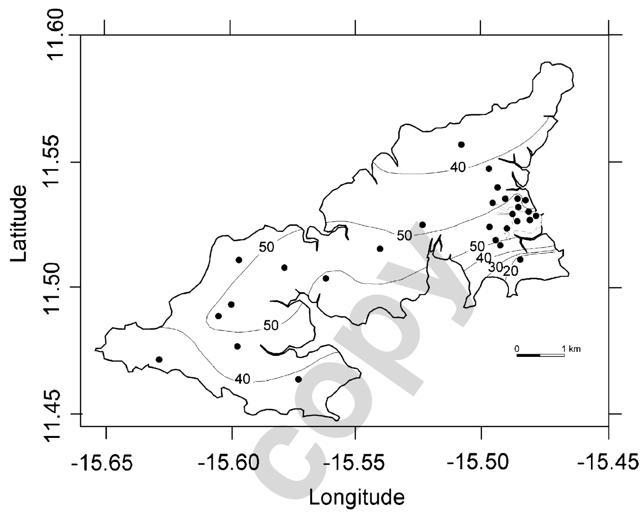

Fig. 3 – Spatial distribution of the well water quality index (WQI %) in Bolama Island, Guinea-Bissau.

Table 3 – Total and children patients in Bolama Island during June 2006 and the number of diarrheic cases registered

Location of care	No patients		Diarrhea	
	Total	Children	Total	Children
Hospital	240	94 (39.2%)	34 (14.2%)	32 (94.1%)
Ambulatory	107	30 (28.0%)	6 (5.6%)	5 (83.3%)
Sum	347	124 (35.7%)	40 (11.5%)	37 (92.5%)

house may be available. However, most houses have no such facilities and communal latrines are used instead. In some rural areas in the Western part of the island, latrines may not be available at all, and human feces are spread onto the surrounding fields. Since the disposal of fecal solids and wastewater is a source of contamination for groundwater, and most inhabitants use latrines, this aspect should be addressed attentively. One realistic way to deal with the problem is to use quicklime to disinfect fecal solids (Meckes and Rhodes, 2004). Quicklime, an easily available building material on the island, is an alkaline agent that works by saponifying lipids within the envelopes of microorganisms (Maris, 1995). A few hundred grams, depending on the liquid waste volume, may be enough to achieve a high degree of disinfection (Hoffman and Hoffman, 1972), and can reduce bacterial and viral pathogens by 99% or more, including helminthic parasites by one-order of magnitude (EPA, 1995).

In general, water with a low pH (<6.5), as in the case of Bolama Island, is soft, and corrosive when in contact with metallic surfaces. On the one hand, since no working water network is available, the risk of metal contamination from pipes is presently avoided, but such low pH values can impair the rehabilitation of the water network if suitable materials (e.g. PVC plumbing) are not used, accelerating corrosion of traditional iron pipes. Since the primary way to treat the problem of low pH water is with the use of a neutralizer, a readily available solution for the islanders exists: calcium carbonate-rich oyster shells, intact, crushed or reduced to ash by fire added to the bottom of the 50–80 l drinking water wide-mouthed barrels commonly used by the population. Moreover, the shells contain biomineralized calcium capable of rapid sequestration of metal ions, thus effectively removing such pollutants from drinking water (Tudor et al., 2006). Due to the generally low conductivity of well water (136 μS/cm), the risk of increasing the salt content of the water is probably negligible.

In this study, it was found that the concentrations of metals (Cu, Fe, Cn, As) were lower than the EU and WHO parametric values for drinking water, except in the cases where soil particles were present. Thus, the risk of contamination exists, especially after heavy tropical storms due to the shallow depth of the wells and the almost immediate increase of turbidity. However, the problem could be reduced by not collecting water from wells during the afternoon/evening, the periods more prone to heavy rainfall during the wet season. This would allow the particles to settle to the bottom.

According to the cultural values and practices of the people of Bolama, care for personal hygiene plays a central role in everyday life. From discussions with the locals, it was estimated that an adult requires 30–40 l of water to meet all daily domestic needs, including drinking, preparing meals and washing, as well as bathing. This is within the typical values (10–40 l) estimated for regions with insufficient water resources (Shiklomanov, 1998), but lower than the 50 l suggested for basic human requirements (Gleick, 1998). Nevertheless, the amount of water used per capita is well above the national average of just 21 l (WHO, 2000), the equivalent of water contained in two commonly used plastic buckets. This reflects not inadequate water availability but lack of infrastructures to make it possible for the water to reach the households. Each well serves 20–500 people and is located from a few meters up to 900 m from the houses, as in the case of site 28. Thus, access to water in quantity is presently a major obstacle for human development, although the island is rich in underground resources and signs of saltwater intrusion as well as contamination from agricultural or industrial activities (with exception of well 18 near an abandoned airfield) were not noticed.

Water quality indices are intended to provide a simple and understandable tool for managers and decision makers on the quality and possible uses of a given water body (Bordalo et al., 2001). Basically, this indices attempt to provide a method for presenting a cumulatively derived, numerical expression that can define the level of water quality (Miller et al., 1986), and is easily understandable by managers. In this case study, fecal contamination and low pH were the main factors responsible for the rather low WQI values. Moreover, 79% of the wells did not meet the water quality required by EU and WHO standards for drinking water and pose a serious health risk. In other parts of Africa, similar ratios have been obtained (e.g. Reimann et al., 2003). Using the rating scale proposed by House and Ellis (1987), we found that even in the few cases where the WQI was $>50\%$, i.e., falling within the reasonable category, water treatment to increase potability was required, Thus, a particular effort should be applied to solve the problem of adequate water quality as well as quantity.

In Guinea-Bissau the under-five mortality rate is estimated to be 203 children per 1000 births (UNICEF, 2005), higher than in neighboring countries such as Guinea (155/10000), Senegal (137/10000), Gambia (122/10000) or Cape Verde (36/10000). More than one-third of the deaths are attributed to persistent and acute diarrhea (Molbak et al., 1992), an astonishing high number when compared to the already high 15% average for Africa (UN, 2006). In the course of this study, children represented about one-third of the patients visiting a doctor during the first month of the 2006 wet season but $>90\%$ of all diarrheic patients. This highlights the vulnerability of this segment of the population to poor sanitary conditions. While we recognize that data reported here cannot be directly related to the diseases treated including diarrhea, water quality does impair general health and, when it is poor, contributes not only to specific water borne diseases (e.g. diarrhea, intestinal parasites), and also produces chronic infections which lower natural resistances to other diseases such as TB, STD and HIV (Brooks et al., 2006; Franz and FitzRoy, 2006; Lule et al., 2005). In sub-Saharan Africa, 10.7% of all mortality is due to poor water supply, sanitation, and hygiene (Mara and Feachem,1999). In the face of the described situation, further studies are planned on Bolama Island in order to relate the sanitary status of the population to the well-water quality.

In the short run, improving the access to safe drinking water could have a dramatic effect on reducing health problems and, concomitantly, poverty in Bolama Island and in strengthening the family fabric. For example, chlorinating drinking water with commercial bleach could successfully decrease the number of pathogenic bacteria and the incidence of diarrhea (Gadgil, 1998; Mintz et al., 1995; Quick et al., 2002). However, a more durable solution should be found, besides controlling bacterial pathogens and pH in drinking water. Particular attention should be given to the rehabilitation of the existing water and sewage network in Bolama City. The infrastructure was abandoned in the late 1990s during civil unrest, and requires electrical power for pumping as well as continuous maintenance. Also, new networks in largest villages, and the improvement of latrines in rural communities (design and disinfection) should be considered. If an adequate water plan is implemented: (i) fewer people will fall ill; (ii) fewer working days will be wasted by the ill and the caregiver; (iii) less pressure to the already decrepit health system will be applied; (iv) more time could be allocated for family affairs, promoting the cohesion of the household and lowering the harshness of daily life in one of the poorest countries in the world, but rather rich in water resources.

5. Conclusions

The results of the research presented here fill a gap on the knowledge of water quality in Bolama Island, which is a UNESCO Man and the Biosphere Reserve. The water supply originates mainly from communal, shallow wells, since no pipe network is in operation. While water is abundant in this humid island and most of the population has access to water within the vicinity of their homes in quantity, this abundance of water masks the lack of quality, a real health risk. In four out of five wells, water was seriously contaminated with fecal bacteria. Furthermore, by applying an adapted-to-tropical environment WQI, it was found out that even in the few fecal uncontaminated wells, water still would require treatment to attain potability, a procedure that presently is out of reach due to the lack of infrastructures and the scarcity of economic and human resources. The high incidence of diarrhea among young children serves as a proxy for the poor water quality and hygienic conditions prevailing in the island. Thus, as a result of the research, the authors suggest implementation of a simple plan with several feasible steps that should be taken by the competent authorities to optimize water use in the short-term. On the one hand, the plan could raise public awareness of water quality issues and on the other hand, dramatically improve the sanitary status and therefore the living conditions in rural areas on all coastal Western Africa with similar conditions as in Guinea-Bissau:

1. Remove the latrines from the immediate vicinity of wells and promote its disinfection with quicklime.
2. Prevent wandering domestic animals from the vicinity of the wells, by fencing with locally available materials, particularly in Bolama City.
3. Lower the bacterial pathogenic risk by adding inexpensive bleach to drinking and kitchen water according to internationally accepted practices.
4. Increase the water pH by adding readily available oyster/clam shells to drinking water wide-mouthed barrels.
5. During the wet season, collect water for drinking late in the morning, before the arrival of heavy rainfall, which usually occurs in the afternoon and evening.

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REFERENCES

Amorim, P., Duarte, G., Guerra, M., Morato, T., Stobberup, K.A., 2004. Preliminary Ecopath model of the Guinea-Bissau continental shelf ecosystem (NW Africa). In: Palomares, M.L.D., Pauly, D. (Eds.), West African Marine Ecosystems: Models and Fisheries Impacts. Fisheries Center Research Reports 12(7). Fisheries Center, UBC, Vancouver, pp. 95–112.

Bordalo, A.A., Nilsumranchit, W., Chalermwat, K., 2001. Water quality and uses of the Bangpakong River (Eastern Thailand). Water Res. 15, 3635–3642.

Brooks, J.T., Ochieng, J.B., Kumar, L., Okoth, G., Shapiro, R.L., Wells, J.G., Bird, M., Bopp, C., Chege, W., Beatty, M.E., Chiller, T., Vulule, J.M., Mintz, E., Slutsker, L., 2006. Surveillance for bacterial diarrhea and antimicrobial resistance in rural Western Kenya, 1997–2003. Clin. Infect. Dis. 43, 393–401.

deVilliers, M., 2002. Water and sustainability in sub-Saharan Africa. Can. J. Policy Res. 3, 51–56.

Dodman, T., Barlow, C., Sá, J., Robertson, P., 2004. Important Bird Areas in Guinea-Bissau. Wetlands International, Dakar/Gabinete de Planificação Costeira/ODZH, Bissau, p. 130.

EPA, 1995. White House Document: Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge EPA/625/R-92/013 [revised in 2003]. US Environmental Protection Agency, Washington, DC.

EU, 1998. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. L 330, 05/12/1998, pp. 32–54.

Franz, J.S., FitzRoy, F., 2006. Child mortality and environment in developing countries. Popul. Environ. 27, 263–284.

Gadgil, A., 1998. Drinking water in developing countries. Ann. Rev. Energy Environ. 23, 253–286.

Gerba, C.P., Bitton, G., 1984. Microbial Pollutants: Their Survival and Transport Pattern to Groundwater. Groundwater Pollution Microbiology. Wiley, New York, pp. 65–88.

Gleick, P.H., 1998. The human right to water. Water Policy 1, 487–503.

Hazen, T.C., Toranzos, G.A., 1990. Tropical source water. In: McFeters, G.A. (Ed.), Drinking Water Microbiology. Springer, New York, pp. 32–52.

Helmer, R., 1999. Water quality health. The Environmentalist 19, 11–16.

Hoffman, G.L., Hoffman Jr., G.L., 1972. Studies on the control of whirling disease (Myxosoma cerebralis). I—the effects of chemicals on spores in vitro, and of calcium oxide as a disinfectant in simulated ponds. J. Wildlife Dis. 8, 49–53.

House, M.A., 1989. A water quality index for river management. J. Inst. Water Eng. Sci. 3, 336–344.

House, M.A., Ellis, J.B., 1987. The development of water quality indices for operational management. Water Sci. Technol. 19, 145–154.

Huysman, F., Van Renterghem, B., Verstraete, W., 1993. Antibiotic resistant sulphite-reducing clostridia in soil and groundwater as indicator of manuring practices. Water Air Soil Pollut. 69, 243–255.

INEC, 2004. Instituto Nacional de Estatística e Censos da Guiné Bissau. 〈http://www.stat-guinebissau.com〉.

ISDS, 2006. Integrated safeguards data sheet. Report No. AC/845, World Bank, Washington, p. 7.

Lule, J.R., Mermin, J., Ekwaru, J.P., Malamba, S., Downing, R., Ranson, R., Nakanjako, D., Wafula, W., Hughes, P., Bunnell, R., Kaharuza, F., Coutinho, A., Kigozi, A., Quick, R., 2005. Effect of home-based water chlorination and safe storage on diarrhea among persons with human immunodeficiency virus in Uganda. Am. J. Trop. Med. Hyg. 73, 926–933.

Mara, D.D., Feachem, R.G.A., 1999. Water- and excreta-related diseases: unitary environmental classification. J. Environ. Engineer 125, 334–339.

Maris, P., 1995. Modes of action of disinfectants. Rev. Sci. Tech. Off. Int. Epiz. 14, 47–55.

Meckes, M.C., Rhodes, E.R., 2004. Evaluation of bacteriological indicators of disinfection for alkaline treated biosolids. J. Environ. Eng. Sci. 3, 231–236.

Miller, W.W., Joung, H.M., Mahannah, C.N., Garrett, J.R., 1986. Identification of water quality differences in Nevada through index application. J. Environ. Qual. 15, 265–272.

Mintz, E.D., Reiff, F.M., Tauxe, R.V., 1995. Safe water treatment and storage in the home. J. Am. Med. Assoc. 273, 948–953.

Molbak, K., Aaby, P., Ingholt, L., Hojlyng, N., Gottschau, A., Andersen, H., Brink, L., Gansted, U., Permin, A., Vollmer, A., 1992. Persistent and acute diarrhoea as the leading causes of child mortality in urban Guinea Bissau. Trans. R. Soc. Trop. Med. Hyg. 86, 216–220.

Payment, P., Siemiatycki, J., Richardson, L., Renaud, G., Franco, E., Prévost, M., 1997. A prospective epidemiological study of gastrointestinal health effects due to the consumption of drinking water. Int. J. Environ. Health Res. 7, 5–31.

Quick, R.E., Kimura, A., Thevos, A., Tembo, M., Shamputa, I., Hutwagner, L., Mintz, E., 2002. Diarrhea prevention through household-level water disinfection and safe storage in Zambia. Am. J. Trop. Med. Hyg. 66, 584–589.

Reimann, C., Bjorvatn, K., Frengstad, B., Melaku, Z., Tekle-Haimanot, R., Siewers, U., 2003. Drinking water quality in the

Ethiopian section of the Esat African Rift Valley I—data and health aspects. Sci. Total Environ. 311, 65–80.
Shiklomanov, I.A., 1998. World water resources. A new appraisal and assessment for the 21st Century. World Water Resources, International Hydrological Programme, Unesco, Paris, 37pp.
Teixeira, J.E., 1968. Geologia da Guiné Portuguesa. J. Inv. Ultramar. 1, 53–104.
Tudor, H.E.A., Gryte, C.C., Harris, C.C., 2006. Seashells: detoxifying agents for metal-contaminated waters. Water Air Soil Pollut. 173, 209–242.
UN, 1997. Guinea-Bissau, country profile. United Nations Commission on Sustainable Development, 〈http://www.un.org/esa/earthsummit/gbisau-c.html#chap18〉.
UN, 2006. African water development report—2006. UN-Water/Africa, Addis Ababa, Ethiopia, 370pp.
UNICEF, 2005. The state of the world's children 2006. Excluded and invisible. The United Nations Children's Fund, Editorial and Publications Section, New York, 143pp.
van Waerebeek, K., Edouard, N., Djiba, A., Mamadou, D., Murphy, P., Alpha, J., Câmara, A., Papa, N., Tous, P., 2000. A Survey of the Conservation Status of Cetaceans in Senegal, The Gambia and Guinea-Bissau. UNEP/CMS Secretariat, Bonn, 80pp.
WHO, 2000. Global Supply & Sanitation Sector Assessment 2000 Report. Part II: Water Resources Development. WHO-UNICEF, New York, pp. 137–142.
WHO, 2001. Guinée-Bissau: OMS/AFRO, 〈http://www.afro.who.int/guineebissau/introduction.html〉.
WHO, 2006a. 〈http://www.who.int〉.
WHO, 2006b. Guidelines for Drinking-water Quality. First Addedum to 3rd Edition, vol. 1. WHO Press, Geneva, 515pp.
World Bank, 2006. Regional Fact Sheet from the World Development Indicator 2006-Sub-Saharan Africa. World Bank, Washington, pp. 2.
Zar, J.H., 1998. Biostatistical Analysis, fourth ed. Prentice-Hall Inc., Upper Saddle River, NJ, 931pp.