Forensic Science International 274 (2017) 99–106

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

High concentrations of lead and barium in hair of the rural population caused by water pollution in the Thar Jath oilfields in South Sudan

Fritz Pragst[a,*], Klaus Stieglitz[b], Hella Runge[c], Klaus-Dietrich Runow[d], David Quig[e], Robert Osborne[f], Christian Runge[c], John Ariki[g]

[a] Institute of Legal Medicine, University Hospital Charité, Turmstraße 21, Building N, 10559 Berlin, Germany
[b] Sign of Hope e.V., Schneckenburgstraße 11d, 78467 Konstanz, Germany
[c] African Water Ltd., Mariendorfer Straße 15e, 48155 Münster, Germany
[d] Institute of Functional and Environmental Medicine, Buttlarstraße 4a, 34466 Wolfhagen, Germany
[e] Doctors's Data, Inc., 3755 Illinois Avenue, St. Charles, IL 60174-2420, USA
[f] Sign of Hope e.V., P.O. Box 21335-00505, Nairobi, Kenya
[g] Director Centre for Remote Sensing and GIS, University of Juba, P.O. Box 82, Juba, South Sudan

ARTICLE INFO

Article history:
Available online 23 December 2016

Keywords:
Barium
Drinking water
Environmental pollution
Hair analysis
Lead
Oil exploration

ABSTRACT

In the oil fields of Thar Jath, South Sudan, increasing salinity of drinking water was observed together with human incompatibilities and rise in livestock mortalities. Hair analysis was used to characterize the toxic exposure of the population. Hair samples of volunteers from four communities with different distance from the center of the oil field (Koch 23 km, n = 24; Leer 50 km, n = 26; Nyal 110 km, n = 21; and Rumbek 220 km, n = 25) were analyzed for altogether 39 elements by inductively coupled plasma–mass spectrometry. Very high concentrations and a toxic health endangerment were assessed for lead and barium. The concentration of lead increased steadily with decreasing distance from the oil field from Rumbek (mean 2.8 μg/g) to Koch (mean 18.7 μg/g) and was there in the same range as in highly contaminated mining regions in Kosovo, China or Bolivia. The weighting materials in drilling muds barite ($BaSO_4$) and galena (PbS) were considered to be the sources of drinking water pollution and high hair values. The high concentrations of lead and barium in hair demonstrate clearly the health risk caused by harmful deposition of toxic industrial waste but cannot be used for diagnosis of a chronic intoxication of the individuals.

1. Introduction

Since 1974, exploratory drillings for crude oil were performed in the southern areas of Sudan and large deposits were discovered between 1979 and 1982 in the states Upper Nile and Unity of the later South Sudan [1]. However, caused by civil war and political instability, oil production in larger scale started only in 1999 in the Unity oilfield (Fig. 1). The Thar Jath and Mala oil fields (block 5A, Unity state) were discovered in 2001 and production began there in 2006 and 2007 respectively after the Comprehensive Peace Agreement was signed and the political autonomy of South Sudan was granted. The oil production increased until 2012 when new military conflicts emerged between Sudan and the meanwhile independent South Sudan and the pipeline to Port Sudan at the Red Sea was shut down. Since then, oil is produced only sporadically and to a much lower level. Production facilities are abandoned and dilapidated.

In 2007, complaints of the population of the Thar Jath region became known for the first time about a bitter and salty taste of the drinking water. Diarrhea and gastrointestinal problems had increased reportedly, particularly of children and older persons. Increased mortalities of livestock were also associated with the contaminated water. Drinking water for the rural population of about 180,000 and for livestock in the surrounding villages of the oil fields is mainly supplied by hand pumps from the upper aquifer in 40–80 m depth. Altogether 90 water samples from hand pump operated wells, surface water of wetlands, ponds of oil processing water and drilling mud pits were collected during five field trips in 2008 and 2009 and were tested for pH, electrical conductivity, total

* Corresponding author. Fax: +49 30 450 525904.
E-mail addresses: fritz.pragst@charite.de (F. Pragst), stieglitz@hoffnungszeichen.de (K. Stieglitz), hella@african-water.com (H. Runge), info@ifu-wolfhagen.de (K.-D. Runow), dquig@DoctorsData.com (D. Quig), osborne@sign-of-hope.org (R. Osborne), info@african-water.com (C. Runge), ariki@gmx.net (J. Ariki).

http://dx.doi.org/10.1016/j.forsciint.2016.12.022
0379-0738/

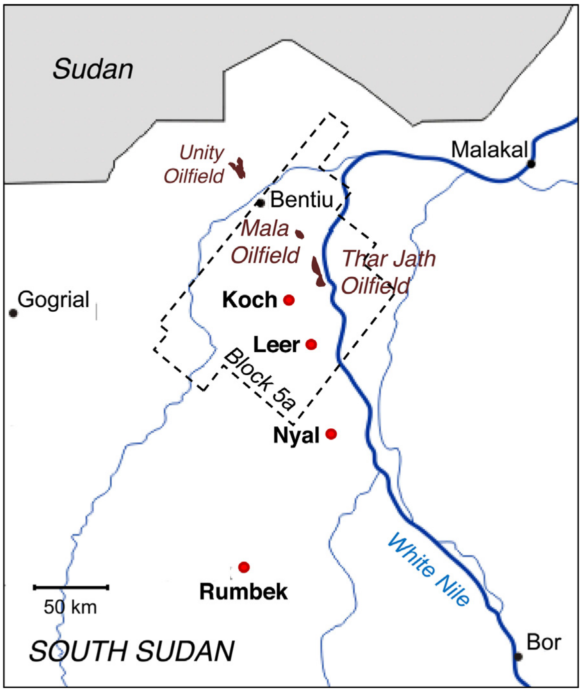

Fig. 1. Map of the oilfields in South Sudan with the locations of hair sampling Koch, Leer, Nyal and Rumbek.

dissolved solids (TDS), usual electrolyte anions and cations as well as heavy metals and polycyclic aromatic hydrocarbons [2,3]. A strongly increased total salt content with TDS up to 6400 mg/L and strongly elevated electrical conductivity up to 8150 μS/cm were found in 24 from 37 drinking water samples (drinking water standards <1000 mg/L and <2500 μS/cm). This increased salinity was mainly caused by high levels of Cl^- (up to 1600 mg/L), SO_4^{2-} (up to 2980 mg/L) and Na^+ (up to 1400 mg/L). Typical was also an increased content of K^+ (up to 189 mg/L with one extreme sample of 5180 mg/L).

Extremely high concentrations of these ions were measured in the samples from drilling pits, e.g. Cl^- 42,400 mg/L, SO_4^{2-} 2786 mg/L, Na^+ 8630 mg/L, K^+ 24,570 mg/L in a pit north of the village Koch. It was concluded from the direction of groundwater flow, the spatial distribution of salt contamination and the hydrogeological boundary conditions found in low water permeable alluvial deposits that the cause of high conductivities in drinking water wells can only be attributed to selective seepage of salt-containing water from the produced water ponds and drilling mud pits of the Unity, Mala and Thar Jath oilfields operating in the studied area [2].

Lead above the limit level of 0.01 mg/L with a maximum value of 0.59 mg/L was measured in 14 from 37 drinking water samples. The water samples from three abandoned drilling pits contained 0.37, 2.06 and 2.15 mg/L lead. Furthermore, chromium (0.01–0.52 mg/L), barium (0.10–0.30 mg/L) and strontium (0.27–8.0 mg/L) were found in many of the drinking water samples whereas arsenic, cadmium, copper and mercury were always below the limits of detection (0.001 mg/L, 0.0002 mg/L, 0.005 mg/L and 0.001 mg/L respectively). The concentration of barium was 140 mg/L in a sample from an abandoned drilling pit and 0.61–1.2 mg/L in samples from oil processing water ponds. Aluminum and iron had concentrations above the Sudanese drinking water standards (0.2 and 0.3 mg/L) only in surface water but not in drinking water. Manganese was below the Sudanese drinking water standard (0.5 mg/L) in all samples with exception of one deep drilling water sample (0.91 mg/L), but 5 drinking water samples from the upper aquifer with 0.25–0.43 mg/L were above the German drinking water standard of 0.05 mg/L. Cobalt, thorium and vanadium which had elevated concentrations in hair (see below) were not measured in water.

In order to evaluate the health hazard of the population caused by this contamination of drinking water, hair samples from inhabitants of the locations Koch, Leer, Nyal and Rumbek (geographic map see Fig. 1) were collected in 2015 and investigated by multi-element analysis using inductively coupled plasma–mass spectrometry (ICP–MS). Whereas the distance from the Thar Jath oilfield to Koch (23 km), Leer (50 km) and Nyal (110 km) is relatively close, Rumbek (220 km) is further away from the oil activities and can be regarded as a relatively unpolluted region for comparison.

2. Material and methods

2.1. Participants of the study and living conditions

The participants of the study were inhabitants of the locations Koch (n = 24), Leer (n = 26), Nyal (n = 21) and Rumbek (n = 25) and lived there steadily and for a long time. They were not employed in oil exploration and production. Under the constraints of the situation, they were chosen as most easily available. They were recruited as customers of barber shops, were approached in the immediate surroundings of a health care center of the organization Sign of Hope or after announcement of the study in a church. Age and gender of the participants are given in Table 1. There is a difference in age distribution between the four locations with elder participants in Rumbek and younger participants in Nyal. However, this does not essentially impair the study since the metal concentrations in hair were found not to be statistically biased by age within the locations. Female participants were generally difficult to persuade for the study and only five women took part in Koch.

Most of the participants lived in traditional homesteads made from clay and wooden poles for the walls and thatched grass for roof. Housing conditions were damp during the rainy season (4–5 months per year). Water was supplied by local hand pumps. The usual diet was a combination of local food (sorghum, dried fish, green vegetables, cow milk) and food from the World Food Program. Hygiene was generally poor. The 10–18 year olds washed their hair once a day when taking a bath either in the river/swamp

Table 1
Age and gender of volunteers. m = male, f = female, y = years.

Location	Number	Age, years		Age distribution, numbers				
		Mean	Median	<10 y	10–20 y	21–30 y	31–40 y	>40 y
Koch	19 m + 5 f	21	22	1	10	11	1	1
Leer	26 m	25,8	16,5	0	15	4	3	4
Nyal	21 m	17,3	15	3	15	3	0	0
Rumbek	25 m	41,3	38	0	0	0	16	9
Total	91 m + 5 f	27,1	23,5	4	40	15	23	14