Natural Pastures and Mobile Animal Husbandry Under Pressure:
The Cases of Lapland and the Tibetan Plateau, 12-14 June 2002,
University of Oulu, Oulu, Finland.

Drinking water quality in the alpine pastures of the eastern Tibetan plateau

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Abstract: The need for water quality research on the Tibetan plateau has arisen after the rangeland was allocated and leased as pasture grounds to individual nomadic families in the 1990s. These policies changed the access to water sources. The imposed fencing of the pasture tenures makes the situation even more delicate. Nomadic families are now obliged to use only water sources existing on their own site. The restrictions have caused the urge to use all available water, which resulted in increasing water quality and quantity problems. In the past, natural water sources were in common use. During the Collective era, machine-dug wells near the collective settlements facilitated the procurement of drinking water. Based on recent investigations in Dzoge county (Sichuan province), the nomadic families of some regions considered the availability of adequate drinking water for humans and animals as their biggest problem. For this study, eight water samples were collected from the Dzoge county area. All samples were from different kinds of sources, but all in continuous use by humans and animals. The samples were analyzed for typical potable water quality factors (hygienic and technique-aesthetic). The results show that the Chinese national guideline values were exceeded for NO_4-N and PO_4-P in most open sampling locations. Those parameters do not spoil the water by themselves, but together with suspended solids and organic materials produce a great environment for bacteria like *E. coli* and fecal streptococci to grow. The result analysis and pictures seen from the location reveal that bacterial growth may be the biggest problem in water quality. Even primitive protection around the water source (i.e. concrete rings, wooden barriers around edges, covers) seem to have a great impact on water quality.

Key words: access to water resources, animal husbandry, China, nomads, rangelands.

Rangifer, Special Issue No. 15: 47-52

Introduction

Atmospheric conditions, as well as rock and soil sources derive the chemical composition of surface waters. In addition, human acticity is an important factor. Human activities have changed the quality of surface waters directly and indirectly by atmospheric pollution, effluent discharges and land use. Therefore it is necessary to monitor the quality of surface water, as well as ground water, used for human consumption.

The purpose of this study was to examine how potable waters from different sources in the rangelands of the Tibetan plateau meet the existing national water quality standards. The samples were collected in 2001 in Dzoge (Chinese: Zoige) county, Sichuan province, from water sources used for human consumption. The main interest was on trace element concentrations and general water quality.

Up-to-date investigations on drinking water quality on the Tibetan plateau were rare. Yaxin *et al.* (1995) made studies in the southern part of the Tibetan Autonomous Region (TAR). In the year 1991, they collected 10 water samples from natural water sources like lakes and streams. The obtained results revealed that chromium and cadmium levels were elevated in two samples. The authors suggested that the increasing anthropogenic influences affect the water quality which urges long-term monitoring, and that further research is warranted from a health point of view.

The research area is located on the eastern Tibetan plateau, in the northwest of the Sichuan province, at the border of the provinces Qinghai and Gansu. The landscape of the county is dominated by the Hongyuan-Dzoge basin which has an average altitude between 3400 and 3800 meters, with the highest elevations reaching 4300 meters. The average annual temperature is 0.8 °C. The annual precipitation of 654 mm results mainly from monsoon precipitation. More than 50% of the annual rainfall comes during the summer months (June-August), and almost 90% between April and September. In winter the average snowfall is 15 mm. The main water systems in Dzoge county are the Yellow River (Tibetan: rMa chu), and its two tributaries, the Bai He (Tib.: dGa' chu) and the Hei He (Tib.: sMe chu). The water level of the rivers fluctuate significantly during the year. In terms of geomorphology, ancient sand dunes, sand fields, sand losses and swamps cover most of the ground in the Dzoge basin. The groundwater quantity in the swampy areas varies a lot within the year, but also between years (Lehmkuhl, 1993; Lehmkuhl, 1997).

The main vegetation type is alpine meadows, which are used as pastures by Tibetan nomads for mobile animal husbandry. Their livestock consists of sheep, yaks and horses (Manderscheid, 1999). Arable field cultivation makes up less then 1% of the total area.

During investigations in Dzoge county in the years 2000 and 2001, the nomadic families of some regions considered the availability of adequate drinking water for humans and animals as their biggest problem. Since the pastures were allocated to the individual families in the 1990s, using rights and access to water sources changed. The imposed fencing of the pasture tenures makes the situation even more delicate. Nomadic families are now obliged to use only water sources existing at their own site. In the past, natural water sources like rivers and depressions, in which water accumulated, and was in common use, even though the pasture tenures were allocated to the individual households due to the conventions of their tribal affiliation. The nomads reported that water problems occurred already in connection with the drainage of the swamp areas during the Collective era (1960s-1980s). Machine-dug wells near the collective settlements facilitated the procurement of drinking water.

The latest situation has caused the urge to use all available water. Nomadic families reported to have access to inadequate quantities of water for human consumption and for livestock, since not all households possess a site with available groundwater sources, or the possibility to build decent wells. Due to a lack of finances, the governments on the district and county levels are not able to help build wells in the seasonal pastures of the individual families. It is questionable whether a well in each pasture tenure denotes the appropriate measure for a sustainable development of rangelands used by mobile animal husbandry.

Materials and methods

In September 2001, 8 water samples were collected in two periods (4 samples per period). Fig. 1 shows the research area. The samples were collected in 250-ml acid-rinsed plastic bottles, and were then transported to Oulu, Finland, where they were analyzed by the Trace Element Laboratory and Water Resources and Environmental Engineering Laboratory of Oulu University approximately after 1 week of sampling. The analyses were done using ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectroscopy) and a graphite oven. All major constituents and trace metals were analyzed.

Biological oxygen demand (BOD), suspended solids and bacterial growth were not analyzed since they require a large sample size. At this point, only small sample volumes were able to be obtained.

Sample 1 from Xiamen district was collected from a 5-m deep well (diameter 1-m), in an alpine meadow at an elevation of about 3500 m, used as a summer pasture. The well is used by four nomadic families to get drinking water for animals and people. The walls of the well and the one adjacent to it (see Fig. 2), were supported by concrete rings near the water surface. When the wells were not in use, they were covered. The edges of the well were fixed with wooden bars. A well-user stated that the pasture tenure is not very favorable for digging a well because it is a dry place and the ground water level is very low. In the past, they guided the livestock to the Yellow River or used a depression in the meadow where water gathered after rainfall.

Sample 2 was from the shores of the Yellow River. Water fetched from the river is used for human and animal consumption during the winter stay at the river banks. The water was reported to be clean by the locals. Any problems that could occur take place in the winter when the river freezes, and a hole must be made into the ice.

Fig. 1. Research area (Manderscheid, 1999).

Fig. 2. The water source of sample 1. The well is protected by wooden barrens around the edges and a cover. The nomads use this well for drinking water for humans and animals. (Photo: A.Manderscheid, 9/2001).

The third sample was collected from a small river, Den Chu, in a swamp meadow at the altitude of 3475 m. The water was in animal and human consumption, and no water problems were reported.

Sample 4 at 3597 m was from a small current used for human consumption by a nomadic family. The stream has its source in a spring at a slope, and was considered by the family as clean. The stream runs near bedrock.

Sample 5 was from a spring in the steep Bobtso valley, where a water pipe delivered the water out of the slope near the street. The water was used for human consumption.

Sample 6 was collected from Torma valley near Dzoge Xian. The water source was a small stream running through alpine meadow, and it was used as drinking water by people and animals. No water problems were reported.

The seventh sample was from a well located near the road connecting Dzoge and Tankhor. The well (diameter 0.3 m) was dug by nomads in a swamp meadow (Fig. 3). The well was 2 m deep with a sand base, and had no covers, which caused problems with the water quality (the surface water runs into the well during rainy days). Surface water from swamps was reported to cause stomach problems for livestock.

Sample 8 was tap water from a hotel in the town of Dzoge.

Fig. 3. The water source of sample 7. The well was dug in swamp meadow. When it rains the surface water runs into the well. (Photo: A.Manderscheid, 9/2001).

Results and discussion

Table 1. Results of water chemistry characterization. The electric conductivity (EC) is in units mS m^{-1} and chemical oxygen demand (COD_{Mn}) is in units mg l^{-1} O_2. All other parameters are in units µg l^{-1}.

Sa	pH	EC	NH_4-N	total N	PO_4-P	total P	Cl	SO_4	COD_{Mn}	Na	K	Mg	Ca
1	7,4	66	<10	<500	<10	36	4502	9530	2,3	6357	1879	11040	100400
2	7,8	25	130	1192	183	270	3151	7785	10,8	4652	2331	6913	29670
3	7,5	30	100	1105	163	310	4237	<1000	15,6	5793	3394	6008	41500
4	7,5	21	10	1194	<10	33	1760	1083	3,7	5253	3504	3717	24600
5	7,9	42,0	21	854	<10	<10	2851	14074	0,5	8007	2174	19660	33400
6	7,6	14,0	38	622	63	144	1495	988	12,0	2647	1301	2219	16250
7	6,1	12,4	98	1345	51	93	1364	8147	27,4	8564	354	1831	9802
8	7,4	17,4	11	<500	<10	<10	13695	2233	1,7	3035	1586	2522	19770

Table 2. Heavy metal concentrations (mg l^{-1}).

Sam.	Mn	Fe	Cu	Cd	Pb	Zn	Ni	Cr	Co	As	Hg
1	<0.1	0.31	<0.1	<0.1 µg l^{-1}	0.001	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
2	0.13	1.8	<0.1	<0.1 µg l^{-1}	0.0025	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
3	<0.1	0.27	<0.1	<0.1 µg l^{-1}	0.0024	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
4	0.18	4.0	<0.1	<0.1 µg l^{-1}	0.0008	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
5	<0.1	0.14	<0.1	<0.1 µg l^{-1}	0.001	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
6	<0.1	0.60	<0.1	<0.1 µg l^{-1}	0.0012	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
7	<0.1	0.98	<0.1	<0.1 µg l^{-1}	0.0007	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
8	<0.1	0.15	<0.1	<0.1 µg l^{-1}	0.0005	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002

In China, water quality standards exist on a national level as well as on provincial and county levels. In this article, the cited standards are sourced from the national level and are presented in Table 3. The values for surface waters are the lowest maximum and the highest maximum level. The differences in maximum levels are due to different water use. The strictest values are for water used from springs and nature protection areas. The higher values are for water used to agricultural purposes.

The guideline values for drinking water are met for all parameters except for NH_4-N and PO_4-P. Those parameters are exceeded in samples 2,3,5,6, and 7 for NH_4-N, and 2 and 3 for PO_4-P. The nitrate and nitrite levels in all samples were below the detection limit of 500 µg l^{-1}, except for NO_3-N in sample 5 (690 µg l^{-1}). The results reveal that the samples are from Ca-dominant waters, since the electric conductivity is quite low in all samples. The average conductivity is 28,5 mS m^{-1}.

Samples 2 and 4 exceed the criteria for Mn, and samples 1, 2, 4, 6 and 7 for Fe when compared to Chinese guideline values. All other trace element concentrations meet the existing standards.

When compared to Finnish guideline values (7) for potable water quality in small house units (953/1994) and potable water quality (74/1994), the analyzed water samples meet the guideline values. The analyzed concentrations exceed the guideline values slightly for total N in samples 2,3,4 and 7, for PO_4-P in samples 2 and 3, for COD_{Mn} in samples 2,3,4,6 and 7, and for Mg in sample 5. However, all the parameters exceeded are technique-aesthetic, and have no significant relevance in health related water quality. Mg causes a peculiar taste to the water, but is not dangerous for human health at existing concentrations.

Reasons for the over-limit concentrations might be that samples 2, 3, 4 and 6 are from open waters (stream or a river), and sample 7 is from an open well. The surface waters have straight access to the water. For those samples, the guideline values are too strict for water without treatment. By purification one can remove the possible bacteria growth, but not the actual cause. The best way to achieve the existing guidelines is to prevent the surface water access to the water source, and to reduce use of fertilizers near the water sources. However, the latter is of no relevance for the area in discussion because only less than 1% of the total area is in agricultural use. This means that the most likely sources of nitrogen and phosphate contaminants come from the soil itself (fertile soil type), or as fall-out with rain. The high natural nutrient content in the soil is most likely the reason for high concentrations in the water samples. During heavy rain seasons the momentary flows can be quite significant. When the rain season is over, the water volumes get smaller. During dry season when water volumes are small, the nitrogen and phosphate concentrations are relatively large. Heavy rain brings fall-outs to wells, but also dissolves nitrogen and phosphate from soil. These kind of problems are easily solved by covering the well when it is not used.

The best way to prevent the soil from collapsing into the well (bringing more nitrogen and phosphate into water) is to block the walls and edges by barriers.

Table 3. National Chinese water quality standards (Dimianshui Huanjing Xhiliang Biaozhun GH2B1, 1999 and Sternfeld, E., 1997).

Parameter	Drinking water	surface water*)
pH	6.5-8.5	6.5-9
NO_2-N	-	<10-25 mg l^{-1}
NO_3-N	-	0.06-1.0 mg l^{-1}
NH_4-N	-	0.02-0.2 mg l^{-1}
total N	-	0.5-2 mg l^{-1}
PO_4-P	-	0.02-0.2 mg l^{-1}
total P	-	
Cl	-	<250-250 mg l^{-1}
SO_4	-	<250-250 mg l^{-1}
COD_{Mn}	-	<15-25 mg l^{-1}
Na	-	-
K	-	-
Mg	-	-
Ca	-	-
Mn	0.1 mg l^{-1}	<0.1-1.0 mg l^{-1}
Fe	0.3 mg	<0.3-1.0 mg l^{-1}
Cu	1.0 mg l^{-1}	0.01-1.0 mg l^{-1}
Cd	0.01 mg	0.001-0.01 mg l^{-1}
Pb	0.05 mg l^{-1}	0.01-0.1 mg l^{-1}
Zn	1.0 mg l^{-1}	0.05-2.0 mg l^{-1}
Ni	-	-
Cr	0.05 mg l^{-1}	0.01-0.1 mg l^{-1}
o	-	-
As	0.05 mg l^{-1}	0.05-0.1 mg l^{-1}
Hg	0.001 mg l^{-1}	<0.00005-0.001 mg l^{-1}

*) Five different categories depending on the water usage

Conclusion

Total N and PO_4-P together with suspended solids and organic matter produce a good environment for bacteria. Since nitrogen and phosphate come partly from agricultural activities and use of fertilizers, they may cause some increase in bacterial growth if the suitable media is available. In this case, the impact is not expected to be significant. In this kind of environment, the most common bacteria is *E. coli*, but also fecal streptococci can occur (due to animal and human manure). The bacteria can be destroyed by boiling the water, using disinfection chemicals or partly by filtration.

In further studies, bacterial cell counts should also be analyzed. The cell counts should be analyzed immediately on-site, or the samples should be preserved. If the samples are preserved for example by thiosulphate, *E. coli* and fecal streptococci can also be analyzed after a few days of sampling. The preserved samples must be stored in a steady temperature before analysis. In the latter case, the results will not be accurate, but they will give a rough estimate of the type and quantity of bacteria existing within the samples.

When results from sample 1 are compared to results from any of the open water sampling places, one can conclude that even primitive technical solutions can prove the water quality. The well where the first sample was taken had only one concrete ring, and some wooden barriers around the edges, but it was enough to achieve better water quality. The main benefit of this well compared to open sources was the cover. It not only preventsthe nitrogen and phosphate from running into the well, but it also prevents small animals (rodents, birds) from getting into the well. If a rodent drowns in the well, it can cause a significant increase in bacterial growth hence polluting the water.

Water problems occurring in Dzoge county were mainly caused by a lack of water. The insufficient access to drinking water occurred in some areas only, but there the impact was significant and alarming. The collected water samples showed that significant differences in water quality exist as well. The differences were affected by the state and protection of the water sources.

The nomadic families as well as the local authorities are beginning to cope with such water problems. The local administrative bodies stated that they have no financial resources to support the individual families.

Firstly, most of the existing wells were dug by themselves or they paid workers to do this (total costs for one well are about 1500 Yuan or 200

Euro). Furthermore, they had collected information about measures for improvement of the wells, and visited far away market places to buy, for instance, concrete rings to support the walls. Others supported the walls of the wells by stones, which they transported from mountainous regions within the county. Even wooden barrens, which were used around the fringes of the wells, are not easily available in those woodless areas. However, not every family in need is able or can afford this. An individual well in each seasonal pasture for all families is not necessarily the only and best solution. As well, the practised fencing and the changed water using rights must be scrutinized.

Acknowledgement

The data was collected during the second field excursion in the frame of the research project "Ecological Carrying Capacity of Natural Pastures: A Case Study on the Tibetan Plateau", which is financed by the Academy of Finland (project number: 1684779). Thanks to Yan Zhaoli for translating the interviews in the field, to Timo Kumpula for carrying the first set of samples to Finland and to Dr. Eva Sternfeld, who translated and provided us with the Chinese water standards. Katie Chan (University of Waterloo, Canada) is thanked for the language revision.

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