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Temporal changes in peri-urban drinking water practices and quality

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ABSTRACT

This paper simultaneously explores temporal changes in drinking water quality and practices in peri-urban Peru. A mixed methodology approach was used, which included a household survey ($n = 96$) and analysis of water samples taken at source ($n = 33$ 2006, $n = 64$ 2007) and from households ($n = 51$ 2006, $n = 91$ 2007), during both the dry (2006) and rainy season (2007). Variations in practices were found, the most important being the type of water being used, but these changes were found to be contextual and linked to the termination of municipal piped water to the community, rather than seasonal. Seasonal changes in quality of ground water sources were found, but the change in the quality of the major water sources used for drinking and cooking were again not seasonal. A relationship between drinking water practices and quality was identified, due to household contamination of water, which was linked to perceived quality of source. Although the results from this study do not establish any link between seasonal drinking water quality and practices, evidence supporting the general hypothesis of this work was uncovered.

Key words | Amazon, chemical quality, household survey, microbiological parameters, Peru, seasonal changes

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INTRODUCTION

There has been a renewed interest in drinking water quality as an intervention to reduce diarrhoeal diseases. Historically, improvements in drinking water quality were thought to be a poor intervention for reducing diarrhoea cases compared with improved sanitation. However, it must be noted that even a 15% reduction in the 4 billion worldwide diarrhoea cases should not be undervalued, as 600 million cases of diarrhoea could be prevented worldwide. Studies (Fewtrell *et al.* 2005) have shown that when point of use or household treatment is taken into account, improvements in drinking water quality can be as effective an intervention as sanitation in the prevention of diarrhoea. Household water treatment and safe storage has now been recognised to provide rapid and significant health impacts by the WHO (WHO 2011). So, regardless of whether a source of water is clean or safe it may become contaminated through drinking water practices, i.e. transport, handling and storage (Wright *et al.* 2004). Even piped chlorinated water sources become contaminated if the supply is not continuous, as the water needs to be stored and handled (Oswald *et al.* 2007).

Temporal changes in drinking water practices occur and have been linked to the seasonal availability of sources (Nyong & Kanaroglou 2001; Hoque *et al.* 2006; Herbst *et al.* 2009), and it is known that drinking water quality varies seasonally (Gelinas *et al.* 1996; Hoque *et al.* 2006). These relationships have been acknowledged by the WHO, as seasonality and variance of contamination at source is thought to affect drinking water practices i.e. household drinking water treatment (WHO 2012). Until now these seasonal variations have been studied in isolation. The hypothesis of this paper is that drinking water practices vary, as they are linked to source and actual quality through perception of quality. The aim of this paper is to explore simultaneously seasonal changes in drinking water quality and practices in a community and how they are interrelated.

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Case study area

Bellavista Nanay is an example of a community that is actively choosing its drinking water sources. It was reported that this community had three available drinking water sources: river water, rainwater, and municipally treated water (supplied via a standpipe), and that the community had a preference for drinking river water over the two other water sources (Plumb 2004). It is a peri-urban suburb situated 5 km from the city of Iquitos, which is located in the north east of Peru in the Amazon basin. Bellavista Nanay is located on the banks of the River Nanay, with an estimated population of 2,867 (Furlong 2009). The economy of the area relies on agriculture, fishing, commercial activities, petroleum and gas.

There is no wastewater treatment in the city of Iquitos or in Bellavista Nanay. Wastewater is discharged directly into the rivers that surround the settlement. Iquitos does have a municipal water treatment plant (EPS Sedaloreto S.A.) and treated water is pumped directly across the city (Tickner & Gouveia-Vigeant 2005), but the design of the supply system has caused inequalities in the service delivered. Bellavista Nanay is among the areas furthest from the treatment plant, therefore it has only one to two hours of service per day, as reported by Furukawa (2005) and confirmed by Furlong (2009).

Water-related diseases are prevalent due to the climate, landscape and water practices. Malaria and dengue fever are endemic within the community due to its geographical location and the need for water storage within households. Other water-related diseases that occur locally include cholera, yellow fever and bacteriological and protozoan diarrhoeal diseases.

METHODOLOGY

The data presented in this paper are part of a larger study exploring the link between actual and perceived drinking water quality and practices (Furlong 2009). A combination of qualitative and quantitative approaches (a mixed methodology approach) was used (Bryman 2008). This approach is especially applicable in research where social and physical issues interact, and has been successfully applied to a number of water-related fields such as water politics (Laurie & Crespo 2007), water management (Katsi *et al.* 2007) and water and gender (Faisal & Kabir 2005). The approach adds greater validity to the result gained as data is triangulated and the weakness of one approach can be offset by the other. Qualitative data can also be used to illustrate quantitative findings, create context and deepen understanding.

To capture seasonality this research was undertaken in the dry (June and July 2006) and rainy (September to December 2007) seasons and the focus of this paper is on the household survey and the water quality results.

Household survey

The survey was developed in Spanish and trialled with five Spanish speakers in the UK. It was then trialled in Bellavista Nanay with five people, which led to the incorporation of colloquial terms, after which it was translated into English to verify accuracy. The survey was piloted from the 15th to the 21st June 2006 with 25 respondents from the community, which led to further modifications.

Criterion sampling strategy was used; the person responsible for the water management in the household was targeted. This strategy was used because this person would have first-hand knowledge of their household's practices. It was therefore thought that the data supplied would be more valid. This strategy has been used by other authors when investigating drinking water practices (Quick *et al.* 1999).

Every third household was targeted (non-probability systematic sampling); this enabled a representative sample to be gained within the time spent in the field. If no response was gained, then the next household was targeted. This was repeated until a response was gained, and all non-responses were noted in the field diary. During the second field visit, the household water managers that had previously responded to the surveys were re-interviewed. This strategy was used so that any seasonal changes could be identified. In this paper only the data from the household water managers that completed the surveys in both years are presented ($n = 96$), approximately one-quarter of the households in the community.

The surveys were administered by a local field assistant who was accompanied by the lead researcher in June and July 2006 (dry season) and October and November 2007 (rainy season). The survey covered eight distinct topics: 1. Household demographics, 2. Socio-economic information, 3. Community water supplies, 4. Household drinking water practices, 5. Importance of drinking water quality, 6. Water and health, 7. Water and hygiene and 8. Sanitation. The majority of questions were closed and used tick boxes. A seven-point scale was most appropriate for questions that required ratings for importance, quality and gravity, while a five-point scale was more appropriate for recording frequency of activity (Oppenheim 2003). Open questions were used to probe further on a number of issues where depth of knowledge could not be gained through other questioning methods. Forced ranking questions were used to force the respondents to prioritise either drinking water parameters or characteristics.

Water samples

The respondents were asked to provide a sample of their drinking water in a sterilised sealed bottle. Fifty-one household samples were collected and analysed in 2006 and 91 in 2007. For comparison, water samples were also taken directly from all major water sources in the community, 35 samples in 2006 and 70 in 2007. Source samples were taken directly from the sources identified in the survey: tap or standpipe water, tankered water, well water, rainwater, vended sealed water (in water cooler bottles), vended unsealed water (in barrels), shop vended water (in bottles) and river water. River water samples were collected from two sites where the community had been observed most commonly to collect water. Site 1 was beside a small port where the River Nanay meets the Amazon River, while Site 2 was behind a row of houses backing onto the River Nanay. Site 1 was located on the River Amazon with no large settlements upstream, although it was approximately 200 m from the mouth of the river Nanay. Site 2 was located on the River Nanay, a tributary to the river Amazon, and directly downstream from the city centre of Iquitos. It should be noted that the number of household samples and, to a lesser degree, source samples was limited by availability.

Samples were analysed for faecal coliforms, pH, turbidity and total chlorine using the OXFAM DELAGUA potable water testing kit (Robens Centre for Public and Environmental Health 2004). Apparent colour was measured using a Lovibond® Nessleriser 2250 in combination with colour discs (28411-4) 5–70 and (28412-2) 70–250 Hazen units (Hazen units are directly interchangeable with Pt-Co units). The microbiological results were divided into risk categories for easier interpretation (WHO 2011).

Qualitative methods

Participant observation was undertaken whilst the researcher lived in Bellavista Nanay. The presence of the researcher and the project aims were fully disclosed, due to embedding the project in the community. Field diaries were kept during both field visits. The information recorded included not only the data from the methods above, but also weather conditions, queries, comments, additional information gained from the survey respondents and the researcher's ideas and feelings. Photographs were taken of the community, housing, drinking water sources and practices.

Text documents were collected to achieve a better understanding of the context of the study, such as government-produced maps and Peruvian national and local publications. Analysis of the labels on bottled water was undertaken in 2007, to gain a deeper understanding of the types of water available in the community. Information of special interest was the wording used and how this was related to the type of water in the bottle i.e. treated water, natural water. Monthly water bills were also examined to gain further information to aid the analysis of the cost of municipally treated piped water.

In-depth semi-structured interviews were undertaken with the 'gatekeeper', a local woman, a doctor at the medical centre, a trainee nurse, a water treatment plant operator and local shop keepers. The interviewees were chosen due to their specialist knowledge on specific subjects such as medical issues in Bellavista Nanay and the availability of vended water. Key themes were developed for each interview and notes were taken throughout the interviews.

These qualitative methods were used to support, validate, question and give depth to the results from the survey.

Data analysis

Statistical analysis of survey results was carried out using SPSS 12.0.1. The method chosen to compare the two data sets was determined by data type and the null hypothesis being tested. The Wilcoxon Sign-Rank test (WSR) was used for interval data, Sign Test (ST) for ordinal data and McNemar test for dichotomous data. The null hypothesis tested was that there was no difference between the responses gained in the two sampling periods. Mann Whitney U (MWU) was used to test if the data were drawn from the same population. Associations between two sets of variables were tested using Phi for nominal or above data. The null hypothesis of these tests were accepted if $p > 0.050$.

RESULTS AND DISCUSSION

Household drinking water practices

Five drinking and cooking water sources were identified as being currently used in households in 2006 and 2007 at the time of the survey (Table 1). From the qualitative data collected contextual information on the sources available to the community was discovered. The tankered water and tap or standpipe water was known to be chlorinated and originated from the water treatment plant. The well water originated from hand-dug shallow wells, which were situated in the outside space surrounding the house. River water was collected from various points along the river, including off shore by canoe. Those who collected and used river water spoke of leaving it to settle before using it.

The vended bottled water category consisted of three types of water: vended sealed water (bottled in Iquitos, of unknown source and delivered to the door by a motorised vehicle), vended unsealed water (containing water from an unknown source delivered by handcart) and shop vended bottled water. Three brands of shop vended bottled water were available in the community: Agua de Mesa, Celio and San Luis. Agua de Mesa was bottled in Iquitos by Persa S.A. and was described as a purified drinking water. Very little information could be found on these waters through their labels or the internet. In 2007 no respondents were using shop vended bottled water for their current drinking and cooking water. The most popular water in this category was vended unsealed barrels followed by vended sealed bottles (7 and 10 respondents). Due to the diversity of these sources this category was subdivided in 2007, but merged for the data analysis undertaken.

There was a statistically significant change in respondents' current drinking and cooking water sources between the two seasons (ST $p < 0.001$). Fifty-one respondents changed their current drinking and cooking water source, 41 switching to tankered water, increasing the community's dependency on this drinking water source. The change was found to be supply driven, as the community's piped municipal water supply was terminated and the municipality had increased the delivery frequency.

Two interesting practices were uncovered through the layering of questions combined with qualitative data from household bills etc. One was the gifting of water: those with a municipal water source would give water for free to relatives or friends, which could be from outside the community. Alongside this practice, there was also an informal trade in standpipe and tap water within the community.

The number of households collecting their water rose to 82% in the rainy season (2007) from 69% in the dry season (2006). This change was found to be statistically significant (McNemar $p = 0.037$) and can be attributed to the community's increased reliance on tankered water in 2007, which was collected at the side of the main street at fixed points. Time (which included the time spent travelling) and distance were compared for respondents that collected their drinking water in both sampling periods ($n = 55$). No significant difference between seasons was found in the amount of time spent collecting drinking water (WSR test $p = 0.097$), but a significant difference was found in the distance travelled to collect water (WSR test $p = 0.001$). This increase in distance in the rainy season (2007) can be partly attributed to the increased collection of water from outside of the community as motorised transport was used, so the

Table 1 | Drinking and cooking water sources currently used in the community

Water type	2006 ($n = 96$) (%)	2007 ($n = 96$) (%)
Tankered water	35	77
Vended bottled water	26	18
Standpipe or tap water	34	2
Well water		1
River water	4	2

collection time was relatively consistent. Many others were choosing to collect water from the tanker when they had wells in their compounds or lived close to the river. Other authors have found that in rural communities preference for water was influenced by proximity (Asthana 1997; Nyong & Kanaroglou 2001); in this peri-urban community preference for drinking water sources was seen to be related more to perceived quality than to proximity.

All of the respondents in both seasons stored their water in a container, in buckets or large bins (98% in 2006, 100% in 2007). In the dry season (2006), over half of the respondents (52%) were treating their drinking water in their household, but this fell to 37% in the rainy season (2007). In both years, chlorination was the most popular method of household water treatment (70%, $n = 50$ in 2006; 67%, $n = 36$ in 2007), followed by boiling (28%, $n = 50$ in 2006; 31%, $n = 36$ in 2007). No relationship was found between the current source of drinking and cooking water and whether the respondents used household drinking water treatment, in either season. However, the proportion of the respondents not treating their water in their household but using tankered water as their current source of drinking and cooking water increased from 44% ($n = 34$) in the dry season (2006) to 64% ($n = 74$) in the rainy season (2007). This was due to people being aware that this water source was already treated at source, but being unaware that water can become contaminated during storage. This is an example of perceived drinking water quality affecting drinking water practices, which supports the general hypothesis of this work.

It can be stated that the situation within the community was more complex than originally thought. Variations in practices were found such as type of water being used, increased collection of water, increased collection time and decreased treatment, but these changes were found to be contextual and linked to the termination of municipal piped water to the community rather than seasonal.

Drinking water quality at source

The average water quality of the sources can be seen in Table 2. In the dry season (2006), River Site 1 was less biologically contaminated, turbid and coloured than Site 2, but this situation was reversed in the rainy season (2007). Due to the location of the sites and prevalent river currents this suggests that the predominant contamination of the river in the dry season came from the community itself and during the rainy season from the city of Iquitos. Higher levels of microbiological contamination were found in river water (Site 1 only MWU $p = 0.014$) and well water samples (MWU $p = 0.005$) in the rainy season (2007) compared to the dry season (2006). This would indicate that more faecal contamination was being washed into these water sources by the increased rainfall. Increased microbiological contamination in shallow ground water sources during the rainy season has also been found to occur in Kampala, Uganda (Howard *et al.* 2003) and Conakry, Guinea (Gelinas *et al.* 1996). It can be stated that seasonal changes in river water and well water quality occurred, but these water sources were not generally used for drinking or cooking.

In the dry season (2006) of the samples taken at source, 50% of the tap or standpipe water, tankered water, vended sealed water and vended unsealed water conformed to WHO guidelines (WHO 2011) for microbiological water quality compared to 100% of the shop-vended water. In Table 2 it can be seen that in the dry season (2006) the tankered water samples had more consistent and higher levels of chlorine compared to samples taken directly from the tap or standpipe and all of the samples of vended unsealed bottled water contained low levels of chlorine. This would indicate that the vendors were either selling municipally treated water or treating the water with chlorine prior to vending. Low pressure in the distribution system and infiltration of organics were problems highlighted by Tickner & Gouveia-Vigeant (2005). This accounts for the lower levels of chlorine found in the tap or standpipe water samples compared with tankered water samples in the dry season (2006). Since both were derived from the source, the tap or standpipe water was therefore contaminated during distribution. The community of Bellavista Nanay knew this: one respondent said '…it is the pipes which are dirty'.

The quality of tankered water differed between the sampling periods, although in both periods it originated from the municipal water treatment plant. In 2007, tankered water had lower and less consistent amounts of chlorine (MWU $p = 0.019$) and higher levels of colour (MWU $p = 0.037$) than those samples taken in the dry season (2006).

Table 2 | Water quality of samples taken directly from the sources

Period	Water type	Thermotolerant coliforms (CFU per 100 ml)	Total chlorine (mg l^{-1})	Turbidity (NTU)	pH
Dry season (2006)	Site 1 river ($n = 4$)	7,850 (sd = 4,968)	<0.1 (sd = 0.00)	24.25 (sd = 5.38)	<6.80 (sd = 0.00)
	Site 2 river ($n = 4$)	19,725 (sd = 6,370)	<0.1 (sd = 0.00)	94.75 (sd = 47.51)	<6.80 (sd = 0.00)
	Tap or standpipe water ($n = 4$)	3 (sd = 5)	1.05 (sd = 1.03)	<5 (sd = 0.00)	7.00 (sd = 0.10)
	Tankered water ($n = 4$)	<1 (sd = 1)	2.50 (sd = 0.59)	<5 (sd = 0.00)	7.15 (sd = 0.10)
	Well water ($n = 4$)	1,096 (sd = 1,204)	<0.1 (sd = 0.00)	9.88 (sd = 3.66)	6.80 (sd = 0.00)
	Vended unsealed water ($n = 4$)	22 (sd = 50)	0.23 (sd = 0.12)	<5 (sd = 0.00)	6.85 (sd = 0.00)
	Vended sealed water ($n = 4$)	2 (sd = 2)	<0.1 (sd = 0.00)	<5 (sd = 0.00)	<6.80 (sd = 2.00)
	Shop-vended water ($n = 5$)	<1 (sd = 0)	<0.1 (sd = 0.00)	<5 (sd = 0.00)	7.0 (sd = 0.00)
Rainy season (2007)	Site 1 river ($n = 10$)	81,223 (sd = 101,579)	<0.1 (sd = 0.00)	37.60 (sd = 11.11)	6.66 (sd = 0.25)
	Site 2 river ($n = 10$)	27,262 (sd = 23,178)	<0.1 (sd = 0.00)	29.20 (sd = 13.42)	6.67 (sd = 0.17)
	Tankered water ($n = 4$)	<1 (sd = 0.00)	0.58 (sd = 0.66)	<5 (sd = 0.00)	6.44 (sd = 0.47)
	Well water ($n = 10$)	29,452 (sd = 37,516)	<0.1 (sd = 0.00)	13.80 (sd = 7.83)	6.41 (sd = 0.09)
	Vended unsealed water ($n = 10$)	1,769 (sd = 2,905)	0.03 (sd = 0.09)	0.60 (sd = 1.80)	6.33 (sd = 0.99)
	Vended sealed water ($n = 10$)	<1 (sd = 0)	<0.1 (sd = 0.00)	<5 (sd = 0.00)	6.83 (sd = 0.27)
	Shop-vended water ($n = 10$)	<1 (sd = 0)	<0.1 (sd = 0.00)	<5 (sd = 0.00)	6.97 (sd = 0.11)

sd = standard deviation.

The municipal water company tested the levels of water leaving the treatment plant to assure that it reached the set standard, so the water was most likely being contaminated in the tanker. This was probably due to greater usage and poor maintenance, caused by the increased demand for tankered water in 2007.

Although seasonal changes in quality of ground water sources were found, the change in the quality of the major water sources used for drinking and cooking (tankered and tap or standpipe) were not seasonal, but contextual.

Drinking water quality in the household

Many respondents spoke of the tankered water as being yellow. The maximum level of colour that is generally acceptable is 5 Hazen (WHO 1997); 42% ($n = 51$) in the dry season (2006) and 23% ($n = 91$) in the rainy season (2007) of samples conformed to this level. The colour in household samples significantly increased from the dry (2006) to the rainy season (2007) (WSR test $p < 0.001$). When the means of the source and household water samples were compared in Table 3, the results imply that water was becoming contaminated at the household level.

Only 41% ($n = 51$) of household samples taken in the dry season (2006) and 29% ($n = 91$) in the rainy season (2007) contained chlorine. Only 36% ($n = 42$) of household samples that originated from the municipal water treatment plant contained chlorine in 2006, which dropped to 19% ($n = 72$) in 2007. This drop in chlorine levels was found to be statistically significant (WSR test total chlorine $p = 0.001$). This was not unexpected as the chlorine levels in the samples taken at source had also dropped (Table 2). The drop in chlorine levels from source to household was probably due to additional household contamination.

Table 3 | Comparison of mean apparent colour in source and household samples

Source	Mean apparent colour (Hazen) 2006 Source	2006 Household	2007 Source	2007 Household
Tankered water	<5 (sd = 0.00) ($n = 4$)	17.86 (sd = 13.68) ($n = 15$)	16.67[a] (sd = 11.55) ($n = 3$)	25.86 (sd = 24.75) ($n = 70$)
Standpipe or tap water	10.00 (sd = 9.13) ($n = 4$)	13.06 (sd = 8.43) ($n = 25$)	N/A	22.50 (sd = 24.75) ($n = 2$)
Vended bottled water	6.88 (sd = 5.58) ($n = 13$)	10.00 (sd = 5.00) ($n = 8$)	11.75 (sd = 9.86) ($n = 30$)	21.09 (sd = 25.08) ($n = 16$)

[a]Outlier of 85 Hazen removed from the analysis.
sd = standard deviation.

Chlorination was the most widely used household drinking water treatment in the community: 48% of households who supplied a sample in the dry season (2006) stated that they used this method compared to only 20% in the rainy season (2007). The associations between self-reported chlorination, and the presence and levels of chlorine in household samples were investigated, but no associations were found in either data set (phi 2006 $p = 0.764$, 2007 $p = 0.050$; total chlorine $p = 0.942$, total chlorine $p = 0.211$). Therefore it can be said that the presence of chlorine in household samples was influenced by household contamination of drinking water more than self-reported chlorination or the presence of chlorine in the source water.

In the dry season (2006), 45% of household samples were classified as very high microbiological risk, compared with 31% that conformed to the WHO guidelines (WHO 2011). In the rainy season (2007) this changed, as 68% of households were classified as very high risk and only 20% conformed to the WHO guidelines (WHO 2011). The household drinking water quality decreased significantly from 2006 to 2007 (WSR test $p = 0.002$). This was thought to be due to the predominance of tankered water and the associated increase in storage times leading to higher levels of contamination.

In both years, more samples taken at source conformed to the WHO guidelines (WHO 2011) compared to those taken at household level (2006 Source 44% $n = 33$, 2006 Household 31% $n = 51$; 2007 Source 43% $n = 64$, 2007 Household 20% $n = 91$). In both years there was a statistically significant difference in the thermotolerant coliform levels of samples taken at source compared to those taken at household level for tankered water (MWU 2006 $p = 0.018$, 2007 $p = 0.007$). This indicates that in both years, thermotolerant coliform concentration increased after collection. This complies with the findings of a systematic review of 57 studies, which found that the bacteriological quality of water significantly declines after collection in a number of settings (Wright *et al.* 2004).

Household drinking water quality was found to vary between the two periods, which were linked to changes in the main source. Practices were found to affect quality as there was evidence that water was becoming contaminated within the home. This supports the general hypothesis of the work that drinking water practices are related to perceived and actual drinking water quality.

CONCLUSIONS

Drinking water practices were more diverse and complicated than originally thought due to the large number of water sources available to the community. Any seasonality in drinking water practices were overshadowed by the changes caused by the termination of the tap and standpipe water supply within the community. Although seasonal variation was found in quality at source in river and well water, changes in the quality of water sources used for drinking were found to be contextual. There was evidence that drinking water was becoming contaminated within the household due to poor drinking water practices in this community. Although the results from this study do not establish any link between seasonal drinking water quality and practices, evidence supporting the general hypothesis of this work was discovered. It is therefore felt that this hypothesis warrants further exploration.

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