

## **Chapter 6**

**PhD Thesis Childhood diarrhoea and its prevention in Nicaragua**

**University of Maastricht, The Netherlands**

**1998**

**A randomized trial of the impact of rope pump on water quality**

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**Published in *Journal of Tropical Medicine and Hygiene*, 1995; 98:247-255**

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## **Abstract**

Rope-pumps are now widely promoted as a low cost, easily maintained means to improve water availability in developing countries. However, in some instances their acceptance has been limited by concerns over the microbiological quality of the water. This study looked at the well water quality under a variety of different conditions, comparing unimproved bucket and rope wells, with wells with a windlass and rope-pump wells with and without a concrete cover. Other factors influencing the water quality were also examined.

Results indicate a 62% reduction of the geometric mean of the faecal coliform contamination of the well water as a result of the installation of a rope-pump with or without a concrete cover on wells which were originally equipped with a rope and bucket. Other factors found to influence the level of contamination of water in hand-dug wells were rainfall, number of households using the well, amount of water extracted daily and the distance of the well to the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well.

The installation of a simple rope-pump on family wells improves the water quality and availability at a favorable cost/benefit ratio.

## **Introduction**

The use of inadequate water supplies relates closely to the high incidence of childhood diarrhoea in most developing countries. Both quality and quantity of water used are believed to play a role. There is a reasonable consensus that interventions which increase water availability have a greater impact than those which improve the quality of water, but combined interventions have been associated with the greatest reduction in disease (Esrey *et al.* 1991).

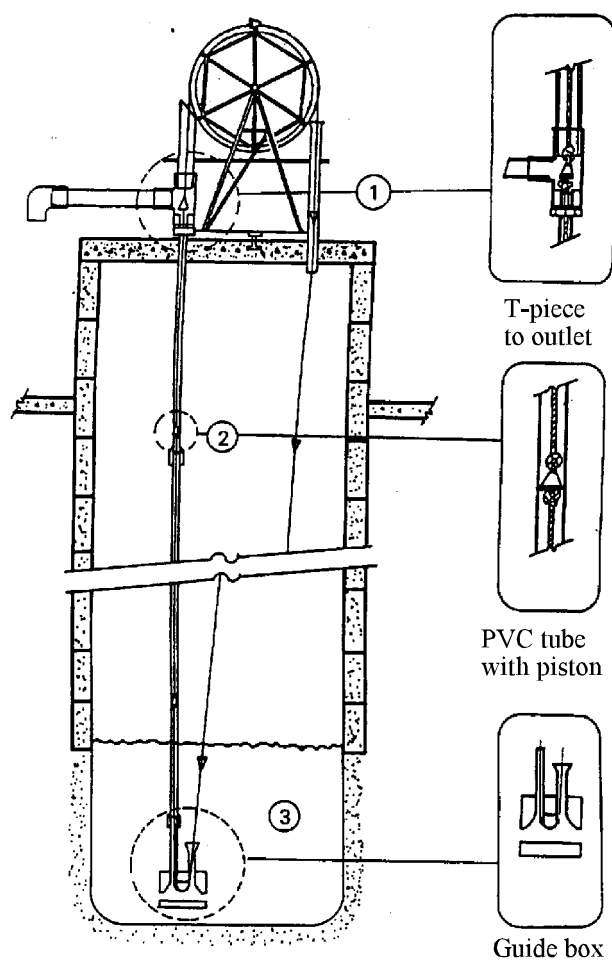
From the small amount of relevant literature available, it would appear that reduction of faecal contamination from very high levels to moderate levels is more likely to have a positive health impact than reductions from moderate to low levels (Moe *et al.* 1991; Sutomo 1987; Trivedi *et al.* 1971). Reductions of faecal contamination from very high levels are likely to be more effective where many families share a water source, than where the water source is used by just one or two households.

In rural Nicaragua the preferred type of water supply is the family hand-dug well (Gorter *et al.* 1991). Sharing of a hand-dug well mostly occurs between families who are relatives or in cases where the economical and/or geological factors have made it impossible to dig more wells. In the rural municipality of Villa Carlos Fonseca, more than half of the population is served by these private wells which are almost entirely equipped with a bucket and rope or a windlass. An earlier study (Sandiford *et al.* 1989) showed that these wells have high levels of contamination which rise after the rains, though not as much as other traditional water sources.

Improvements in water quality and availability for this type of rural populations can only be made at a favorable cost/benefit ratio only by upgrading the private wells and improving the method of water extraction. The few published studies of the effectiveness of the numerous potential interventions to improve microbiological water quality of hand-dug wells suggest that upgrading

of wells through improvements such as a headwall, apron, drainage channel, lining, cover, handpump, windlass, or bucket cage are effective when provided as a combination (Buchrieser *et al.* 1989; Lacey *et al.* 1990; Morgan 1991). It is not known, however, how effective are the individual components of the upgrading in reducing contamination or whether their combined effect is greater or smaller than the sum of the separate effects. In order to design an effective cost/benefit intervention on hand-dug family wells the impact of the individual components of upgrading should be known.

In Nicaragua the rope-pump (Figure 1), based on the simple chain and washer pump (Lambert 1990), was introduced in 1983 (Sandiford *et al.* 1993). Extensive modifications have enabled rope-pumps to be produced which are easy to operate, have a high efficiency, low cost, and are easy to maintain (Alberts *et al.* 1993). More than 3,000 are installed in private and project sectors and recently the first 50 were introduced in Honduras.



**Figure 1.** Cross-section of a rope-pump on a well.

## Material and methods

The study was carried out in Villa Carlos Fonseca, a rural municipality on the Pacific coastal plains of Nicaragua with a population of approximately 30,000. The area can be characterized as a tropical dry zone with small rivers which tend to dry up during the dry season. Thirty wells

in 14 different communities were selected for the study and randomly assigned to three groups of 10 wells each: one group to be fitted with a rope-pump and concrete cover, a second group with only a rope-pump and the third group as a control group, not receiving a rope-pump until the end of the study.

To determine the baseline level of faecal contamination, two or three water samples were taken weekly from each well in the dry season and less than one month before the installation of rope-pumps and covers began. A baseline interview and observation were carried out to identify behavioral, structural and socio-economic factors which might influence faecal contamination. Days of rainfall were registered. Seven water samples were taken from each well every 3 weeks following installation for a total of 5 months.

The Oxfam Delagua portable water quality testing kit was used to measure faecal coliform counts by the membrane filtration method. The water quality laboratory of the water and sewage Ministry prepared the cultures and trained the research assistant to prepare the kit, take the samples and perform the water quality tests. At the study midpoint the kit was taken to the national laboratory after incubating and samples were counted independently by the research assistant and the head of the laboratory. No differences in counts were found. The temperature reading of the incubator was also checked. Samples of 50 ml were taken from the wells using the existing method of water extraction. The samples were incubated within 6 hours of sampling at 44° C for 16-18 hours, on pads impregnated with lauryl sulphate broth.

Data were entered in Epi-info and analyzed using Epi-info and SPSS programs. A water quality model was fitted by analysis of covariance with the natural logarithm of the faecal coliform counts as the dependent variable. The independent variables considered were; method of water extraction, design of the well, protection and distance from a source of contamination, amount of water extracted daily, amount of water in the well, and various socio-economic factors.

## **Results**

### ***Description of wells and users***

Table 1 lists the characteristics of the 30 wells, and those of the well users. The latrine to well distance averaged 28 meters (range 8-67 meters), which means that, for the type of soil existing in the area (ocean sediments of clay and limestone, sometimes covered by volcanic sand), no lateral contamination of the water from latrine to well is likely (Lewis *et al.* 1981). The 61 families had a total of 396 members. Almost a quarter of the heads of families is illiterate. The vast majority are farmers though some work in the nearby capital.

Figure 2 shows that the more water is needed and the greater the well distance, the more people shift from the well to the river. For drinking, cooking and washing dishes, all families used only well water. In 25% of cases well water was also used to irrigate their premises and in 26% to water the cattle.

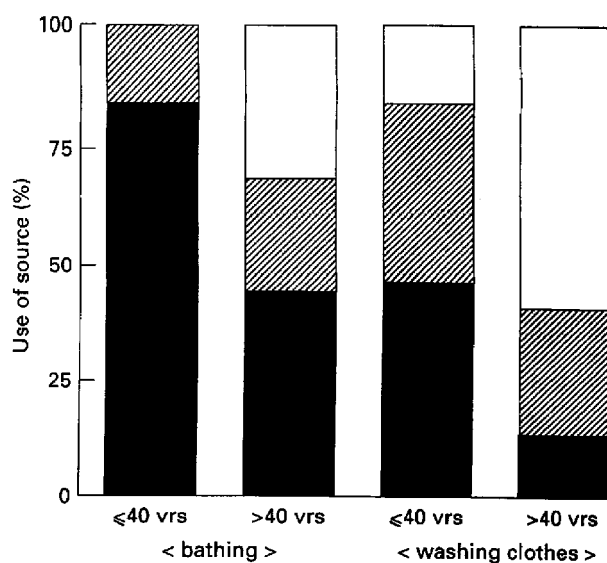
**Table 1.** Characteristics of the study wells and their users

Characteristics of the wells		
Presence of a headwall	100 %	
Upper section lined with masonry	100 %	
Equipped with a windlass	53 %	
Some sort of cover on headwall	43 %	
Cover is complete and in use	20 %	
Apron around headwall	10 %	
Drainage system	0 %	
Protection against animals	0 %	
Presence of a corral in the yard	43 %	
Cattle watered from the well	37 %	
Well has been cleaned	93 %	
Average time since well was cleaned(years)	0.5	
Average age of the wells (years)	17	(1-70)
Average depth of the wells (m)	14	(6-27)
Average water depth in the well (m)	1.1	(0.2-3.3)
Average distance to kitchen (m)	16	(0.85-70)
Average distance to corral (m)	19	(1-80)
Average daily water extraction (gallons)	134	(25-330)
Average number of families/well	2.1	(1-9)
Average number of persons/well	13.7	(3-65)
Characteristics of the users		
Average schooling heads families (years)	3.1	(0-11)
Amount of family-heads illiterate	21 %	
Average number of members/family	6.5	(2-16)
Average age children start drawing (years)	10	(6-15)
Average time to draw water (minutes)	40	(15-120)
Average distance family/well (m)	40	(0.7-170)
Average distance family/river (m)	650	(17-2000)
Average daily water use/family (gallons)	67	(10-330)
Usual drawers of water		
Women	63 %	
Men	19 %	
Children	10 %	
Children together with women or men	5 %	
Men and women together	3 %	

***Water quality***

Table 2 shows the number and type of wells in each group. The Nicaraguan rope-pump company Bombas de Mecate SA installed 30 rope-pumps. Due to an initial misunderstanding between the research group and the company 3 wells in the intervention group with only a rope-pump received their rope-pump in error before the baseline measurements could be made and were therefore

shifted to the control group. Of the rope-pump group with covers, 2 wells did not receive their



**Figure 2.** Choice of water source for bathing or washing clothes in relation to the distance to the well. □, Only river; ▨, well and river; ■, only well. vrs, Varas; 1 vara=0.8539 metres.

**Table 2.** The number and type of well in each group

Baseline Type	Baseline Wells	After modification		
		Control Wells	Only pump Wells	Pump/cover Wells
Bucket	14	4	5	5
Windlass	13	8	2	3
Rope-pump	3	3	-	-
Total	30	15	7	8

rope-pump due the very low water levels in the wells after 3 years of severe drought in the study area and thus were also shifted to the control group. Eventually the control group consisted of 15 wells, as did the intervention group.

During a total of 283 visits 273 water samples were taken. Ten samples could not be taken because 4 wells were dry on 1-4 occasions. Of these 273 samples 15 were discarded because of an error in the culture and 4 because of well construction or cleaning activities in the week before sampling, leaving a total of 254 samples for analysis.

**Table 3.** Effect of rain on the geometric mean of faecal coliform contamination of the 15 control wells

	GM FC/100ml	N
Dry season (February-mid May)	189	48
First rains (mid May-end July)	268	42
After first rains (end July-September)	221	32

Rainfall commenced shortly after intervention and just one sample was taken in the dry period after intervention. Table 3 shows the effect of the rainfall on the level of contamination of the control group.

**Table 4.** Geometric means of faecal coliform contamination for different methods of extraction during the baseline measurements and the entire study

Method	Baseline study		Entire study		
	Crude FC/100ml	<i>n</i>	Crude FC/100ml	Adjusted <sup>1</sup> FC/100ml	<i>n</i>
Bucket	323	34	288	324	56
Windlass	165	32	215	196	79
Only rope-pump	81	7	174	169	72
Rope-pump/cover	-		131	136	47
<b>Total</b>		<b>73</b>			<b>254</b>

<sup>1</sup> Adjusted for the parameters used in the water quality model; rainfall, number of families/well, distance of well/ kitchen and amount of water extracted.

Table 4 shows the geometric mean faecal coliform contamination of the different methods of extraction of the 30 wells during the baseline measurements and the entire study. The third column shows the results when adjusted for all the parameters included in the water quality model. Comparison of these values gave better results for the intervention with a rope-pump and concrete cover than for the rope-pump alone. Also it gives the impression that rope-pump wells are associated with better water quality than wells with a windlass.

However, the results of faecal contamination of the different subgroups before and after intervention as presented in Table 5 show no difference for rope-pumps with or without a concrete cover. A reduction of 62% in contamination was seen in the intervention group which was originally equipped with a rope and bucket; no reduction was seen in the group originally

equipped with a windlass. Overall reduction of the faecal coliform counts of all the wells supplied with a rope-pump was 47%.

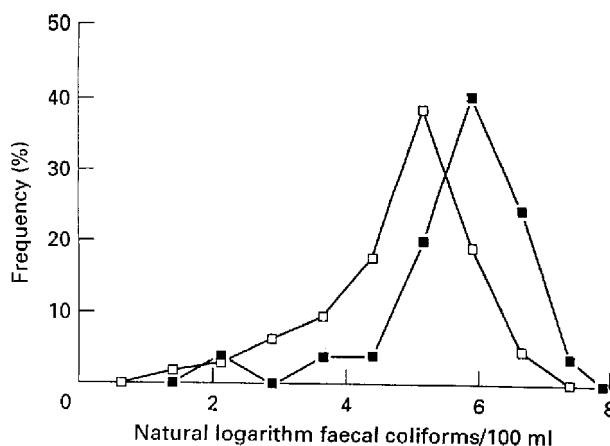
**Table 5.** Geometric mean faecal coliform counts before and after the intervention for the different types of baseline wells intervened and for the control group

Type of baseline well	Before intervention		After intervention		Corrected for rain <sup>1</sup>	Change (%) (95% CI)
	Crude FC/100ml	n	Crude FC/100ml	n		
Control group	189	35	238	189	87	0%(-28/ 40)
Bucket modified with only rope-pump	455	13	211	167	33	-63%(-78/-39)***
Bucket modified with rope-pump/cover	196	12	99	79	30	-60%(-82/-10)*
Windlass modified with only rope-pump	108	5	147	116	14	+ 7%(-66/250)
Windlass modified with rope-pump/cover	171	8	213	169	17	- 1%(-54/114)
All modified bucket wells	304	25	147	117	63	-62%(-77/-37)***
All modified windlasses	143	13	180	143	31	0%(-48/ 91)
All modified wells wells	235	38	158	125	94	-47%(-65/-20)**

\*  $P < 0.05$ ; \*\*  $P < 0.005$ ; \*\*\*  $P < 0.0001$

<sup>1</sup>In order to compare the counts before and after intervention, the effect of rainfall was removed. Differences between the means of the natural logarithm of FC counts in the dry period and the other two weather periods (see Table 3) were calculated and subtracted from the natural logarithm of each FC count of the corresponding weather period.

Figure 3 shows the frequency distributions, before and after intervention, of the natural logarithm of faecal coliform counts of the group originally equipped with a rope and bucket.



**Figure 3.** Frequency distribution of the  $\log_{10}$  counts of the whole bucket group ■, before and □, after intervention. (After intervention corrected for rain.)



When assigning the faecal contamination of the bucket wells to groups of very high, moderate, and low levels of contamination, all counts at the very high level are eliminated after intervention and part of the moderate counts is reduced to the low level (Table 6).

**Table 6.** Proportions of very high, moderate and low readings before and after intervention in the group originally equipped with rope and bucket

	Low level 0-100 FC/100 ml (%)	Moderate level 101-1000 FC/100 ml (%)	Very high level >1000 FC/100 ml (%)
Before	12	80	8
After	31	69	0

***Other factors influencing water quality***

The complete model, fitted on the water quality results of the entire study, is shown in Table 7, together with the significance level for each variable. In fitting the water quality model, each measurement of a single well is considered as an independent sample as there was almost as much water quality variation for repeated samples from the same well as there was for different samples from different wells. No interactions were seen for the main effects. No difference in results of the fitted model was seen when the wells which mistakenly received their rope-pump too early and/or the wells which did not receive the planned intervention because of the drought, were excluded.

**Table 7.** Parameters included in the water quality model

Variable name (and type)	Range of values
Main effects	
Method of extraction*** (categorical)	1 rope-pumps 2 windlass 3 rope/bucket
Rainfall period* (categorical)	1 dry period (February-mid May) 2 first rains (mid May-end July) 3 after first rains (end July-September)
Number of families/well* (dummy)	1=1 2>1
Covariates	
Distance well/kitchen**	continuous
Amount of water extracted*	continuous

\*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$

Contamination of the wells increases when more families are using the well and when more water is extracted daily, although these effects are less significant than the distance of the well from the nearest kitchen (Table 8). Structural factors such as a wooden cover and its use, the age or depth of well, the presence and distance from a latrine or corral, and socioeconomic factors such as schooling, type of waterdrawer and possessions of user families had no effect on water contamination. The effect of an apron, a good drainage system and protection against animals could not be assessed because none or almost none of the study wells possessed one. Neither could the effect of cleaning the well be determined, since the vast majority had cleaned their well within the last half year.

**Table 8.** Impact of the distance of the well to the nearest kitchen on the level of water contamination of the well

Distance well/kitchen (varas)	Crude	Adjusted*	<i>n</i>
	GM FC/100ml	GM FC/100ml	
1 - 9	251	260	77
10 - 19	201	200	87
20 - 29	177	176	26
>30	150	143	64
Total			254

1 Vara = 0.8359 meter

\* Adjusted for the parameters used in the water quality model; method of extraction, rainfall, number of families/well and amount of water extracted.

## Discussion

Results of this study indicate that faecal coliform counts are reduced by an average of 62% when a rope-pump is installed in place of a bucket and rope. A concrete cover appeared to effect no additional improvement, but the concrete covers in this study were of a poor design and did not seal the headwall hermetically. A better design is needed and its impact should be investigated.

The effect of a simple windlass seemed almost as great as that of a rope-pump, although pre and post-installation measurements were not made. The effect of a rope-pump or windlass must be ascribed to the elimination or reduction of contamination of the rope and bucket being dragged on the ground and touched by the hands. Improvement of water quality by installing a windlass and upgrading the well with a cover, drainage apron and lining has been reported in other studies (Morgan 1991; Lacey *et al.* 1990).

Other factors found to have an impact on contamination of the wells included rainfall, number of households using the well, amount of water extracted daily and the distance of the well from the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well. The association with the number of households using the well has been described in Kenya (Nyangeri 1986). The amount of water within the well may have some influence; reflecting dilution of the faecal contamination introduced daily into the well and its subsequent die-off. The fact that contamination of wells peaks during the start of the rainy season and returns to normal levels after the first rains is consistent with studies in other regions (Barrell & Rowland 1979; Blum *et al.* 1987; Feachem 1974; Mertens *et al.* 1990b; Moore *et al.* 1965; Wright 1985).

In developing countries, only around 40% of the rural population have access to good quality of water (Huttly 1990). The other 60% use traditional water sources of generally poor quality, among which the protected hand-dug well is one of the less contaminated; only springs are usually cleaner (Feachem 1980; Lindskog & Lindskog 1988; Sandiford *et al.* 1989; Tensay 1991; Utkilen & Sutton 1989; White *et al.* 1972; Wright 1985). Geological, socioeconomic and ethnographic

factors determine the type of water supply and, in the case of hand-dug wells, the density of these wells. Where water depth makes it possible, people dig their own private or communal wells and this remains the most common method of groundwater exploitation, probably even more important than drilled wells (Clark 1988). To improve water and sanitation for this rural population, hundreds of programmes have been developed to drill, dig or upgrade communal wells and to equip them with a handpump. Many programmes failed due to abandoning of wells because of frequent breakdowns of the pumps and insufficient maintenance and hygiene education. Maintenance and hygiene education have now become a central feature of these programmes (Reynolds 1992; Kerr 1990). Besides, studies of water quality have shown that hand-pumps do not always yield the expected water quality improvement (Lloyd & Suyati 1989; Mertens *et al.* 1989; Wedgwood 1989). Consequently a shift has taken place and programmes to upgrade the old-fashioned family well and equip them with an improved method of extraction have gained in popularity (McIntosh 1989; Morgan & Chimbunde 1991; Utkilen & Sutton 1989).

Such programmes could have an important impact on the incidence of diarrhoeal disease. In the first place, the amount of water used for hygiene purposes will increase as availability increases through a decrease in the distance to the water source, improvement of the method of extraction or a decrease in the number of users per water source (Cairncross & Cliff 1987; Frankel & Shouvanavirakul 1973; Hoque *et al.* 1989; Sandiford *et al.* 1990; White *et al.* 1972). Secondly, the level of contamination of the well will decrease from high to moderate and eliminate very high levels of water contamination. Finally, protected hand-dug wells are used by fewer families than most unimproved sources. Since disease transmits readily by person-to-person contact in such households, water quality is less important. Many studies of in-house contamination of stored drinking water found no relation with diarrhoeal disease (Han *et al.* 1991; Henry & Rahim 1990, Mertens *et al.* 1990, Moore 1965). The same could account for the family well, in contrast to the community well where contaminating pathogens can come from all the families using the water source and where the source could be an important transmission route. Whether a persisting low level of faecal contamination of family well water still poses a serious risk for diarrhoeal diseases remains to be investigated.

Simple cheap rope-pumps can yield a significant improvement in water quality while simultaneously increasing availability. Upgrading the well with a drainage system, a well designed cover or an extra large tube (to shift domestic activities around the wells to a point of some 10-20 meters from the well) and hygiene education programmes may further improve water quality. The low cost and easy maintenance of the rope-pump makes it appropriate for family wells.

## **Conclusions**

Results indicate a 62% reduction in the geometric mean of the faecal coliform contamination of the well water due to the installation of a rope-pump with or without a concrete cover. Other factors found to influence the level of contamination of water in hand-dug wells were rainfall, number of households using the well, amount of water extracted daily and the distance of the well from the nearest kitchen. The last three factors probably reflect domestic activities with poor hygiene around the well.

The installation of a simple rope-pump on family wells improves the water quality and availability at a favorable cost/benefit ratio. They can be considered a viable option for rural water and

sanitation programmes in developing countries and a good adjunct to the traditional family wells. Additional programmes of upgrading the wells and hygiene education may improve the water quality, but their impact remains to be investigated.

## Acknowledgements

This study was funded by the British Embassy in Nicaragua. The authors would like to express their gratitude to Mario Gutierrez and Aura Perez of the Instituto Nicaraguense de Acueductos y Alcantarillados for their assistance during this investigation.

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