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# A randomized trial of the impact of rope-pumps on water quality

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## SUMMARY

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 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. 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 favourable cost/benefit ratio.

**Keywords:** rope-pumps, hand-dug wells, family wells, water quality, water quantity, diarrhoeal diseases

## 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 it 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 economic 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

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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 population can be made at a favourable 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 3000 are installed in the private and project sectors and recently the first 50 were introduced in Honduras.

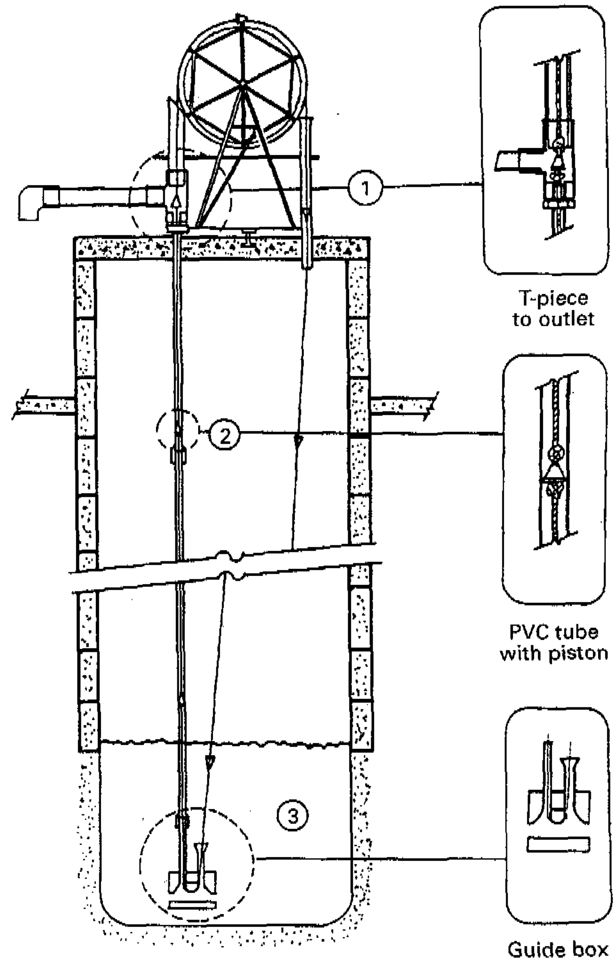


**Figure 1.** Cross-section of a rope-pump on a well.

## MATERIALS 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 behavioural, structural and socioeconomic 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

  

**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) |
| Proportion of family heads illiterate | 21% | |
| Average number of members/family | 6.5 | (2–16) |
| Average age of 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% | |

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 analysed 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 socioeconomic 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 m (range 8–67 m), which means that, for the type of soil existing in the area (ocean sediments of clay and limestones, 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 are 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% of cases to water the cattle.

### 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 rope-pump due the very low water levels in the wells after 3 years of severe drought in the study area

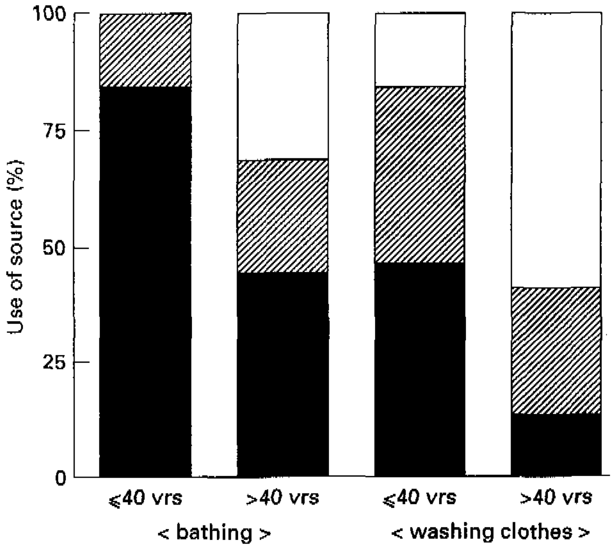


**Figure 2.** Choice of water source for bathing or washing clothes in relation to the distance to the well. □, Only river; ▨, well and river; ■, only well. vrs, Varas; 1 vara=0.8539 metres.

**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 |

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.

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

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

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%.

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.

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).

## 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

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

| Method | Baseline study Crude FC/100 ml | *n* | Entire study Crude FC/100 ml | Entire study Adjusted[1] FC/100 ml | *n* |
|---|---|---|---|---|---|
| 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 |
| Total | | 73 | | | 254 |

[1]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 5.** Geometric mean faecal coliform counts before and after the intervention for the different types of baseline wells modified and for the control group

| Type of baseline well | Before intervention Crude FC/100 ml | *n* | After intervention Crude FC/100 ml | After intervention Corrected for rain[1] FC/100 ml | *n* | Change (%) (95% CI) |
|---|---|---|---|---|---|---|
| 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 well | 304 | 25 | 147 | 117 | 63 | −62% (−77/−37)*** |
| All modified windlasses | 143 | 13 | 180 | 143 | 31 | 0% (−48/91) |
| All modified wells | 235 | 38 | 158 | 125 | 94 | −47% (−65/−20)** |

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

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.

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 those 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.

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 the well, the presence and distance from a latrine or corral, and socioeconomic factors such as schooling, type of water-drawer 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

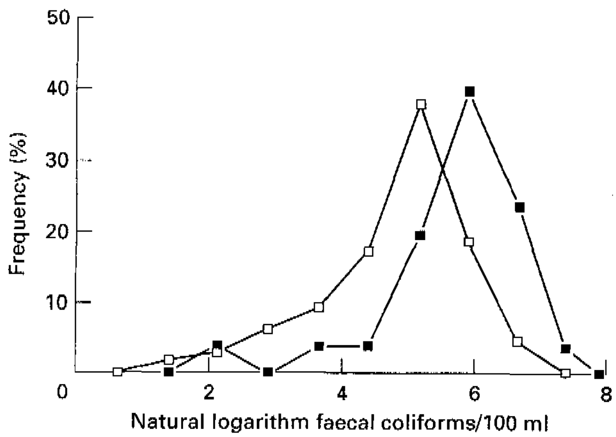


**Figure 3.** Frequency distribution of the $\log_e$ counts of the whole bucket group ■, before and □, after intervention. (After intervention corrected for rain.)

cleaning the well be determined, since the vast majority had cleaned their well within the last half year.

## 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).

**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<br>2 windlass<br>3 rope/bucket |
| Rainfall period* (categorical) | 1 dry period (February-mid May)<br>2 first rains (mid May-end July)<br>3 after first rains (end July-September) |
| Number of families/well* (dummy) | 1 = 1<br>2 >1 |
| Covariates | |
| Distance well/kitchen** | continuous |
| Amount of water extracted* | continuous |

$^*P<0.05$; $^{**}P<0.01$; $^{***}P<0.001$.

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 water

**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 |

**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* | |
|---|---|---|---|
| | GM FC/100 ml | GM FC/100 ml | *n* |
| 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 m.
*Adjusted for the parameters used in the water quality model; method of extraction, rainfall, number of families/well and amount of water extracted.

(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 hand-pump. 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.* 1990b; Wedgwood 1989). Consequently a shift has taken place and programmes to upgrade the old-fashioned family wells 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.* 1990a; Moore *et al.* 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 some 10–20 m 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 favourable 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.

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