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Boiling of drinking-water: can a fuel-scarce community afford it?

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In the prevention of diarrhoea, health professionals often advocate boiling as a method of choice to provide safe household drinking-water to villagers in the less developed countries. We have examined the financial feasibility of this recommendation in a village study in Bangladesh. Family income was categorized and the pattern of household fuel consumption was determined. Families in the lowest income quartile would have to spend approximately 22% of their yearly income on fuel, and those in the highest income bracket approximately 10%. Boiling of drinking-water would result in an 11% increase in the household budget (as a percentage of income) for a typical family in the lowest income quartile, compared with a 3% increase for a family in the highest income quartile. We conclude that recommendations concerning boiling of drinking-water in developing countries should not be made until their economic feasibility has been demonstrated.

Health professionals often advocate boiling as a simple and effective method for making safe drinking-water in homes in the less developed countries. This recommendation, for example, is found in training manuals for community health workers in the sections concerned with diarrhoeal disease prevention and treatment.[a, b]

In theory, the boiling of water for drinking is a rational and easy method, but persuading Third World villagers to boil contaminated drinking-water has met with limited success. In Bangladesh, for example, rural villagers almost never boil their drinking-water. This failure may be attributed to various factors: (1) the inability of poorly educated villagers to comprehend the germ theory of disease; (2) social and cultural factors (e.g., traditional "hot" and "cold" food beliefs) (*1, 2*); (3) the unacceptability of boiling the water because of changes in taste or the time required to boil it; and (4) the limited availability and high cost of fuel.

The continuing efforts by the health authorities to promote the boiling of drinking-water are based on two key assumptions. The first is that, given a more effective health education effort and/or a more highly educated constituency, the first two of the above factors can be overcome. The second is that, with the exception of a few arid and semi-arid countries, boiling of water is not prohibitively expensive. However, growing worldwide fuel shortages point to the need for a more careful examination of the latter assumption. A general decrease in the availability of fuels traditionally collected by villagers and a marked increase in the cost of commercial fuels in the last decade suggest that, in the village context, boiling of drinking-water may not be a financially viable option. Bangladesh, a cholera endemic country where fuel shortages are recognized as a serious and growing problem (*3*),[c] provides a good setting in which to test this hypothesis.

METHODS

Description of the study village

The data for this study were collected as part of a health and nutrition study conducted in 1978-79 in

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[a] *Guidelines for the trainers of community health workers on the treatment and prevention of acute diarrhoea.* Unpublished document, WHO/CDD/SER/80.1, 1980, p.22.

[b] *A manual for the treatment of acute diarrhoea.* Unpublished document, WHO/CDD/SER/80.2, 1980, p.16.

[c] DOUGLAS, J. *Consumption and supply of wood and bamboo in Bangladesh.* UNDP/FAO/Planning Commission (Government of Bangladesh) report on project BGD/78/010 (1981).

the village of Nandipara, one of a growing number of transition villages in Bangladesh.[d] Nandipara, located on the eastern outskirts of Dhaka consists of a series of small islands of tightly clustered huts surrounded by paddy fields (flooded during the monsoon months). It has a population of approximately 1450 (262 families), of which 70% are Muslims and 30% are Hindus. The work force consists of 58% labourers (sharecroppers, land-owning farmers, casual labourers, rickshaw pullers, etc.), 33% self-employed businessmen (artisans, retailers, moneylenders, etc.), and 9% administrators and employees of either the government or of a Dhaka-based private or public corporation.

Hindus and Muslims differ in their opportunity to acquire collectable fuel; 22% of Hindu families earned all or part of their income working as artisans (mainly carpenters) and thus had access to residual by-products of such employment (e.g., wood scraps). Muslims, on the other hand, were primarily rickshaw drivers in the lower income groups and office workers in the higher income groups. In addition, the higher rate of cattle ownership of Nandipara's Hindu families gave them much better access to cow-dung for use as a cooking fuel.

Less than 10% of Nandipara's families were employed exclusively in agricultural activities. This is not typical of most Bengali villages where the majority work full-time as farmers. Nevertheless, Nandipara provides a suitable setting for this study for the following reasons: (1) household income, which is largely cash income, can be accurately estimated; (2) with little collectable fuel available in the village and no access to electricity or gas, it represents today the situation which is expected to prevail in the majority of rural Bengali villages before the end of this decade (*3*); and (3) the number of transition villages is increasing rapidly in Bangladesh because of accelerated rural to urban migration.[e]

Economic and fuel use surveys

Data used in this analysis were collected during the monsoon season of August 1978 and the dry season of March 1979. Interviews were conducted by one of three persons, using separate questionnaires concerned with economics and fuel use. Verbal responses to open-ended questions were recorded on separate questionnaires for each family unit or household. Heads of households (usually male) were interviewed in the economics survey, and female family members in the fuel use survey. Where possible, the responses to both questionnaires were corroborated by observation. Special attention was given to determining household size, and to recording household assets considered to be potential sources of collected fuels (cows, cropland, and village land). These data were used to determine the following variables:

(*a*) *Income* was defined as the sum of total cash income, the assumed net value (at 1978–79 prices) of crop income, the assumed value of ration card subsidies, and the market value (using "wood equivalents", described below) of collected fuels. A ration card was assigned the market price of 300 Taka or US$20 (1978–79 exchange rate, US$1 = 15 Taka) if mortgaged.

(*b*) *Bought calories*, expressed in units of 10^6 kcal (or 4184 MJ)/household/year, were defined as the sum of the assumed energy content of reported purchases of wood, kerosene, sawdust, and rice straw. On the basis of data reported by Tyres and the *Bangladesh energy study*,[f, g] it was assumed that firewood and kerosene used in Nandipara contain 3600 kcal (15.1 MJ) per kg and 12 000 kcal (50.2 MJ) per kg, respectively. Wood and kerosene in 1979 cost 0.6 Taka (US$0.04) per kg and 3.0 Taka (US$0.20) per litre, respectively. Sawdust and rice straw were measured in "wood equivalents" as described below.

(*c*) *Collected calories* were defined as the energy content of the 8 most common collected fuels (wood, straw, cow-dung, water hyacinth, jute sticks, paddy husks, leaves, and *dhuncha* (a leguminous shrub, *Sesbania*)).

(*d*) *Total calories* indicated the sum of bought calories and collected calories. Therefore, collected calories were equal to total calories minus bought calories.

Respondents were asked to indicate by how much their consumption of purchased wood fuel fell when replaced by collected solid fuels. These "wood equivalents" were then assigned a caloric value equal to that of the displaced wood to arrive at a rough approximation of collected calories. While the use of "wood equivalents" is admittedly an imprecise method for measuring collected fuels, it does not greatly distort the figures for total fuel consumption because bought wood and kerosene, both of which allow relatively precise measurement, contribute at least 85% of total fuel consumption for each income quartile.

[d] Transition villages in Bangladesh are defined by the following characteristics: (1) close proximity to a major city; (2) village crop land still used primarily for growing rice; (3) village employment mainly non-agricultural; (4) land ownership by absentee landlords who buy land for real estate speculation; and (5) a pattern of accelerated migration into the village.

[e] *Foreign aid to Bangladesh in theory and practice*. Report to Bangladesh Information Action Group (Britain), 1983.

[f] TYRES, R. *Optimal source allocation in transitional agriculture: case studies in Bangladesh*. Ph. D. thesis, Harvard University, 1978, p. 461.

[g] *Bangladesh energy study*. Main report for the Government of Bangladesh on UNDP (Asian Development Bank) project BGD/73/038/6/01/45, November 1976.

Determination of fuel consumption for boiling the water

All households in Nandipara use one (or both) of two standard stoves (*chulah*): both are earthen and have similar efficiencies (15%), but one is fixed and the other is portable. The investigators conducted field trials using these stoves to establish the energy required for boiling water for 10 minutes in the village situation. Wood was purchased from local vendors and weighed on laboratory scales. Ten village women were then randomly selected, provided with a measured amount of fuel (in excess of possible requirements) and requested to boil exactly two litres of water in a vessel of their choice for precisely 10 minutes. In all instances, the vessel chosen was a *hari*, a locally manufactured aluminium pot with a relatively narrow opening. After the water had boiled for 10 minutes, fuel not already placed in the stove was weighed and the net fuel use recorded. In a separate experiment, the amount of wood consumed to bring the water just to boiling was determined.

Household fuel consumption patterns

Fuel consumption was modelled as a linear function of household income and family size. Fuel consumption = $\alpha_1 + \beta_1$ (household income) + β_2 (family size) + error term.

In the economics literature, fuel consumption is usually considered on a household rather than a per capita basis (*4*). In this study, we also examined the per capita fuel consumption. We were unable, however, despite testing a wide range of linear and non-linear functional forms, to explain variations in the per capita fuel consumption with any acceptable level of precision (R^2 always less than 0.25).

Statistical analysis

The significances of the differences between socio-economic indicators and fuel consumption by income category were assessed by Student's *t*-test. The stepwise multiple regression was employed in a least-squares analysis of the relationship between fuel consumption and economic and demographic parameters. Religion was included as a logic variable. Correlation coefficients (*r*) were calculated with a linear regression model. The income elasticity of fuel use (percentage change in income divided by the percentage change in fuel use) and the family size elasticity of fuel use (percentage change in family size divided by percentage change in fuel use) were calculated for mean income and mean family size, respectively. The data were expressed as means ± the standard deviation.

RESULTS

Both questionnaires were completed by 203/262 (77%) of Nandipara families. Comparison of village census data, which included all the villagers, showed no significant difference between the group that was interviewed and the group that we were unable to interview in all categories (age of the household head, percentage of migrants or refugees, house size, and ratio of Hindus to Muslims) except two (education of the household head, and family size). The non-respondents appeared to have received significantly more education (3.8 ± 4.5 v. 1.8 ± 3.3) and had smaller families (4.7 ± 2.3 v. 5.4 ± 2.4).

The higher the income of a family, the smaller the percentage of total income spent on wood ($r = -0.35$), total fuel ($r = -0.45$), and total fuel plus fuel for boiling ($r = -0.60$) ($P < 0.01$ for all). The latter parameter is the total fuel cost plus the additional cost of boiling drinking-water calculated as 441 Taka (US$29.40) per year per family. Those variables which showed a significant ($P < 0.01$) positive correlation with income were house size ($r = +0.47$), family size ($r = +0.54$), household land ($r = +0.58$), cropland ($r = +0.30$), and cattle ($r = +0.20$), bought calories ($r = +0.53$), total calories ($r = +0.51$), and ration card ownership ($r = +0.38$). In agreement with the findings reported by others,[a] income was associated with an increase in family size; in other words, the rich had larger families than the poor.

Using a stepwise regression which included other economic variables, we found that income and family size (independent variables) were able to explain 44% of the variability in total calories (total calories = 1.80 + 0.51 family size + 0.0021 income. $F = 76$; $R^2 = 0.44$; $P < 0.01$). When we included the variable of religious group (Hindu or Muslim) in the simple linear model, a higher R^2 was achieved (total calories = 3.75 + 0.43 family size + 0.0020 income − 1.97 Muslim: $F = 75$, $R^2 = 0.54$; $P < 0.01$). The importance of religious group as a variable is probably due to the easier access to collectable fuels by Hindu compared with Muslim families.

The income elasticity and family size elasticity of fuel use were calculated to be 0.32 and 0.28, respectively. These values show that fuel use is inelastic with respect to changes in income or family size. However, the combination of income and family size do affect the consumption of fuel in a household. The appearance of constant per capita consumption of fuel across income quartiles (derived from Table 2) is

[a] ALAUDDIN, M. *Socio-economic determinants of fertility in Bangladesh: a review*. Report prepared by USAID and the Institute of Social Welfare and Research, University of Dhaka, September 1980.

Table 1. Comparison of socioeconomic variables[a] by income quartile in Nandipara, Bangladesh, 1978–79

Inter-income quartile (in Takas/family/year)	No. of families	Per capita income (Taka)	House size (m^2)	Number (per family) of				
				Persons	Ration cards	Cows	Katas[b] of houseland	Bighas[c] of cropland
≤ 4599[d]	51	985[d]	9.7	4.5	0.10	0.16	1.8	0.11
4600–5999	50	1358	10.1	4.4	0.28	0.12	1.4	0.18
6000–9599	51	1452	12.5	5.6	1.92	0.35	2.4	0.30
9600–32000	51	2106	20.1	7.2	3.69	0.88	6.0	0.80
Mean	203 (total)	1476	13.1	5.4	1.50	0.39	2.9	0.36

[a] $P < 0.01$ for each variable, tests were performed for each income quartile compared to the lowest income quartile.

[b] 20 katas = 1 acre = 0.4047 hectare.

[c] 3 bighas = 1 acre = 0.4047 hectare.

[d] US$1 = 15 Taka.

an artefact of the parallel increase in household income and family size.

Tables 1 and 2 show that the upper income families were significantly larger and consumed significantly more of both bought and collected fuels. In addition, upper income families owned significantly more of the three village assets (cropland, cattle and house plot size), which are a major source of collected fuels (Table 1). There was a two-fold difference in fuel use between the lowest and highest income quartiles.

Families in the lowest income quartile spent approximately 22% of their yearly income on fuel, while those in the highest income bracket spent approximately 10%. Wood is the major fuel consumed in the village. Approximately 16% of the income of the poorest income quartile was spent on fuel wood. The remaining percentage of income spent on fuel was nearly all spent on kerosene. Similarly, for the highest income quartile, 8% of income was spent on wood and most of the remaining 2% was spent on kerosene. Two litres of water brought just to boiling ($n = 6$) consumed 0.37 ± 0.04 kg of wood. When the boiling was maintained for 10 minutes ($n = 10$), 0.50 ± 0.08 kg of wood was consumed.

The potential effect on household budgets of boiling all drinking-water for 10 minutes is shown in Table 2. Assuming an average daily consumption of 8 litres of drinking-water per family (personal communication, M. M. Rahman & M. U. Khan, International Centre for Diarrhoeal Disease Research, Bangladesh), at the 1979 fuel prices of 0.60 Taka (US$0.04) per kg of wood, a family would be expected to spend 441 Taka (US$29.40) per year for boiling all drinking-water for 10 minutes. This would

Table 2. Fuel consumption and the effect of boiling of drinking-water on the percentage of income spent on fuel in Nandipara, Bangladesh, 1978–79[a]

Inter-income quartile (in Takas/family/year)	No. of families	Bought calories[b] (in 10^6 kcal/year)	Total calories[b] (in 10^6 kcal/year)	Percentage of income spent on household fuel				Percentage of income for boiling of drinking-water
				Wood	Kerosene	All fuels[c]	All fuels + fuel required if drinking-water is boiled	
≤ 4599	51	4.3 (18.0)[d]	4.6 (19.2)[d]	16	6	22	33	11
4600–5999	50	5.0 (20.9)	5.3 (22.2)	13	4	17	26	9
6000–9599	51	5.6 (23.4)	6.5 (27.2)	11	3	14	2C	6
9600–32000	51	7.7 (32.2)	8.4 (35.1)	8	2	10	13	3
Mean	203 (total)	5.6 (23.4)	6.2 (25.9)	12	4	16	23	7

[a] $P < 0.01$ for each variable, tests were performed for each income quartile compared to the lowest income quartile.

[b] Collected fuel can be derived from these figures by subtracting bought calories from total calories.

[c] Assumed additional cost to family of 441 Taka/year (US$1 = 15 Taka).

[d] Figures in parentheses are the S.I. equivalents of kilocalories, expressed here in megajoules (MJ) × 10^3.

result in an 11% increase in the fuel budget (as a percentage of income) of a typical family in the lowest income quartile, and a 3% increase in the fuel budget (as a percentage of income) of an average family in the highest income quartile (Table 2).

DISCUSSION

Can a fuel-scarce community afford to boil its drinking-water? The present study demonstrates that when collectable fuel is limited, the cost of purifying drinking-water by boiling is prohibitive for the poor.

The feasibility of boiling of drinking-water is related both to the availability of collectable fuel in the village and to the relative effect of the increased fuel consumption on household expenditures. Two major determinants of the availability of collectable fuel are (1) the stock of trees growing in and around the village, and (2) the land and livestock resources owned by each household. Because land holdings, crop residues, house plot size, and numbers of livestock are smaller in the periurban transition villages compared with the typical rural village, there is a lower availability of collectable fuels. Nevertheless, previous studies indicate that collectable fuel is becoming a scarce resource in most rural villages as well (*5*, *6*). The total area of arable land remaining fixed, continuing increases in the rural population are leading to a situation of progressively smaller land holdings and a gradual decrease in the proportion of land-holding families.[i]

Village trees are the major source of fuel wood in the country. As all collectable fuels become scarcer, these trees are being harvested of their branches at such a rate that many die each year, leading to a serious depletion of energy capital.[j] The introduction of short-stemmed, high-yielding varieties (HYV) of rice as a substitute for traditional long-stemmed rice (a major source of fuel and fodder) has further reduced the supply of fuel at the village level. The HYV strain has increased grain production, but the straw is not well suited for fodder owing to its high silica content; nor does the HYV strain yield as much fuel as the long-stemmed rice because their stems are shorter. Not only are collectable fuel resources being depleted at an alarming rate, but the costs of bought fuels are expected to continue increasing in the future.

For individual households, we found income, family size, and religious status to be the socio-economic variables mostly responsible for the energy expended in cooking. The inverse relationship between income and the percentage of income spent on fuel implies that the poor must bear a disproportionately high cost for any increase in fuel consumption. This is clearly demonstrated by the potential effect that boiling of drinking-water has on household expenditure patterns. The increased percentage of income spent on fuel is 3% for the richest quartile compared to 11% for the poorest quartile, a difference of 8%. Decreasing the time of boiling the water would not markedly decrease fuel consumption since two-thirds of the fuel consumed is used for bringing the water to boiling-point.

The full implication of boiling of drinking-water is revealed by including minimum (survival level) food expenditures in the family budget of the lowest income quartile. A per capita consumption of 6.69 MJ (1600 kcal)/day, expressed in terms of rice would result in an average yearly requirement of 160 kg/person (*5*), or 720 kg/family for the lowest income quartile. The cost to the family of 720 kg of rice, at 1979 prices of 4.5 Taka (US$0.30) per kg, would be 3240 Taka (US$216). Using the *highest* income in the lowest income quartile, minimum food expenditures would consume 70.5% of the budget. Adding to this the percentage of the budget spent on fuel (for boiling the water), we get an implied expenditure of 104% of total income. Thus, in the poorer households, any increase in fuel expenditure will result in a marked decrease in the money available to buy food.

The question of health impact is of equal importance to that of economic feasibility. In particular, boiling of drinking-water has been recommended as a preventive measure against diarrhoeal diseases. This recommendation is useful when fuel availability, fuel costs, and labour inputs are not constraints. For example, it is appropriate for expatriates in Bangladesh to boil their drinking-water. In villages in developing countries, however, where faecal contamination of most traditional water sources is common, the provision of clean water solely for drinking has seldom reduced diarrhoeal disease rates (*6*), because ingestion of water is seldom restricted to a single source (i.e., the "pure" drinking water located in the home). Thus, villagers in the highest income quartile who financially are able to boil their drinking-water would probably not receive a significant benefit by doing so, since it is likely their rate of diarrhoea would not be greatly affected. For the reduction of diarrhoeal disease rates, increasing the quantity of water available to a community appears to be a more important factor than improving the quality of that water (*7*, *8*).

Hand pumps could provide villagers with easy access to large quantities of high-quality water.

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[i] JANUZZI, F. T. & PEACH, J. T. *Report on the hierarchy of interest in land in Bangladesh*. Dhaka, USAID, 1977.

[j] See footnote *c*, page 157.

Improvements in hand pump design, materials, and construction have greatly increased their reliability and reduced the cost of their manufacture and maintenance. In view of these recent improvements, we recommend that public health programmes encourage the increased deployment of hand pumps rather than boiling of water as a means of providing potable water in rural villages where ground water is easily accessible.

The benefits are even more apparent when one considers that the money saved in a 5-year period by not boiling the water would allow a typical family in the lowest income quartile (assuming a 5-year loan at 10% interest) to purchase its *own* locally manufactured iron hand pump (1700 Taka or US$114 for purchase and installation, at 1979 prices). A properly constructed tube-well located close to the house would provide large quantities of clean water; in practice, these wells are usually used by several families, thus allowing the costs to be shared.

Boiling as a standard method for making drinking-water safe is clearly not an economically feasible option for the majority of families in the study village. With fuel prices rising more quickly than the general rate of inflation, the cost implications of boiling of drinking-water are more serious today than they were at the time the study was conducted (in 1979). These results suggest that health planners particularly in fuel-scarce countries, before recommending that village families should boil their drinking-water (for daily usage), should first demonstrate the economic feasibility of such a practice.

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RÉSUMÉ

UNE COMMUNAUTÉ PAUVRE EN COMBUSTIBLE PEUT-ELLE SE PERMETTRE DE FAIRE BOUILLIR L'EAU DE BOISSON?

Pour la prévention de la diarrhée, les professionnels de la santé préconisent souvent l'ébullition comme méthode de choix pour fournir aux villageois des pays les moins avancés une eau de boisson saine. Nous avons examiné la faisabilité, du point de vue financier, de cette recommandation dans un village du Bangladesh. Nous avons établi des catégories de revenu familial et déterminé le type de consommation de combustible domestique. Les familles dont le revenu se classe dans le quartile le plus bas devraient consacrer environ 22% de leur revenu annuel aux dépenses de combustible et les familles de la catégorie la plus élevée environ 10%. Faire bouillir l'eau de boisson entraînerait une augmentation de 11% du budget familial (en pourcentage du revenu) pour une famille type du quartile le plus bas, et de 3% pour une famille du quartile le plus élevé. Nous en concluons qu'on ne doit pas recommander de faire bouillir l'eau de boisson dans les pays en développement sans avoir préalablement démontré la faisabilité économique de cette pratique.

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