On-Site Water Contamination in an Urban Slum

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ABSTRACT

The provision of piped water has often been considered a major sanitation measure which will improve the general health of a given population. The associated problems of maintaining a functioning sewerage system so as to insure the quality of the piped water have received increasing recognition. From November 1978 to December 1979, and under varying meteorological conditions, water samples were drawn from ten taps of a piped water supply in an urban slum of Madras, Tamil Nadu, South India. Samples were tested for fecal coliform organisms as an indicator of fecal contamination of water at the taps. Regression analyses were performed on the data, using distance from the tap to the slum's boundary as the independent variable (x) and regressing average log concentration of fecal coliforms (y) during periods of dry and wetter weather, on x. It was found that during wet conditions there was a regression coefficient of +0.972 whereas during dry conditions the regression coefficient was +0.816. The linear regression model suggests that during wet conditions, especially, there is on-site contamination of piped water in the high population density conditions of this urban slum.

INTRODUCTION

It is common knowledge that the water supply systems encountered in the developing countries are often prone to contamination. This is due mainly to the combination of low and/or intermittent line pressures and badly fouled environments [1]. In large urban centers this problem is exacerbated by the poor sanitary conditions associated with crowding.

In traditional comprehensive development and health care planning, there has been an assumption that provision of a piped water system will eliminate many of the health hazards implicit in transporting water from an 'unprotected source', such as a river, well or lake. Ironically, the economic feasibility of installing a piped water distribution system is highest in urban areas [2] where the likelihood of on-site fecal contamination is also the greatest.

There appears to be a beneficial relationship between presence of a water tap within the home and diarrheal disease or parasite loads. The literature seems to indicate that such a beneficial relationship does not exist between health indices and a water tap outside the home [3,4].

Several reasons may explain this anomaly. People who can afford a tap within the home are generally characterized by socioeconomic factors which predispose to good health. In-home supplies possibly employ a distribution system which flows through a cleaner environment since population densities would probably be lower than in communities which use public standpipes. The presence of an in-house tap would encourage good hygienic practices affecting health status directly and result in cleaner environments outside the home (e.g. people with in-house water may tend not to defecate indiscriminantly outside the home). Since proper use and maintenance of a latrine requires a dependable supply of easily accessible water, persons with in-house taps usually have access to larger quantities of water. In transporting water from the tap and in storing it in vessels at home there is a greater chance of contamination than in simply drawing the water from the tap and using it immediately.

Due to the paucity of quantified data on the kinds of problems associated with urban public taps, it was decided to study the water supply system of a high population, low-income urban area. The area chosen appeared to have a water

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supply system which could be prone to on-site contamination. That is, water was supplied intermittently, under low pressures and in an environment characterized by the presence of fecal contaminants.

Excreta disposal facilities are often poor or nonexistent in the developing countries and ground surface fecal contamination is characteristic of many congested urban areas. India, though provided with better water supply systems than other developing countries, generally lags behind in terms of excreta disposal systems [5]. Few urban households relying on public water taps have private in-house latrine facilities, and the inhabitants must rely either on a public latrine or use nearby vacant land. Conversely, few households which have a private in-house water tap do not have an in-house latrine.

Even in some of the largest cities in the developing world supply of water is marked by long periods of daily, as well as other periodic, interruptions of service [6]. The city of Madras, South India is no exception to this rule [7].

Seasonal monsoon flooding may be a factor causing back-siphonage of surface contaminants. These heavy rains bring up to 80% of the area's total precipitation in under three months' time. This may influence a periodicity in fluctuating levels of contamination. However, at all times of the year, fecal contamination of many urban ground surfaces in the presence of intermittent water supply and negative line pressures may result in local contamination of individual water taps.

STUDY SITE

A slum in Madras, Tamil Nadu, consisting of mixed tenement and traditional housing was chosen as a suitable experimental site for monitoring an urban water supply system. The slum consisted of approximately 1000 households on 3.5 hectares of land. Its eastern boundary was a 125 foot wide beach sloping to the Bay of Bengal. Its substrate was very porous beach sand. The slum was served by ten taps of the Madras Metropolitan Water Supply and Sewerage Board system and several private and public wells. Well water was generally avoided for drinking and cooking due to its brackish taste.

The area has been settled by fishermen for approximately 100 years. About 80% of the population lived in the newer tenement buildings, and the remaining portion lived in the huts. Water was equally available to the residents of both areas. The amount of water varied greatly with season. During the monsoon, approximately three times as much water was supplied to the communities as during the dry season.

The area surrounding the slum consists of the Bay of Bengal to the east, Marina Beach to the north, a small tenement habitation of thirteen buildings adjoined by a large open area of several hundred meters in length to the south and a mixed business and residential area of low population density to the west. Water service is by one four inch main and two smaller service pipes. The main runs parallel to the beach at the western boundary of the settlement. The two other pipes run roughly perpendicular to the main and extend approximately 250 feet through the populated area.

A slum consisting of mixed tenement and traditional housing was chosen as a suitable experimental site

Defecation habits of the adults centered around using the nearby beaches. The children used the open areas outside of their houses, as well as the beach. Each tenement apartment had one water tap which supplied brackish well water, and a latrine. In addition, there was a communal latrine located between the tenement area and the hut area. The latrines, even when available, were not operational for two reasons. The first was that a general water scarcity and independable pumping facilities made them difficult to keep clean, and the second was that even with sufficient water, there was an upward slope from the latrines to the sewer main. In order to function properly, a pump would have been needed. The major effect of a lack of latrines was on young children, who would defecate indiscriminantly. Their parents and older children would walk to the beach, where the tidal action worked to maintain a level of cleanliness.

Low pipe pressure in the Madras water system has caused engineers to provide water outlets in subterranean access pits. These pits enable the taps to run under less line pressure than they otherwise would, given a conventional standpipe access. The taps farthest from the western, or uphill, boundary of the slum are located in the deepest access pits (see Fig. 1).

The supply points were valveless and ran uncontrolled for the few hours of the day that they did function. Because of the high demand for water, someone was in constant attendance while the water was flowing. Since none of the taps

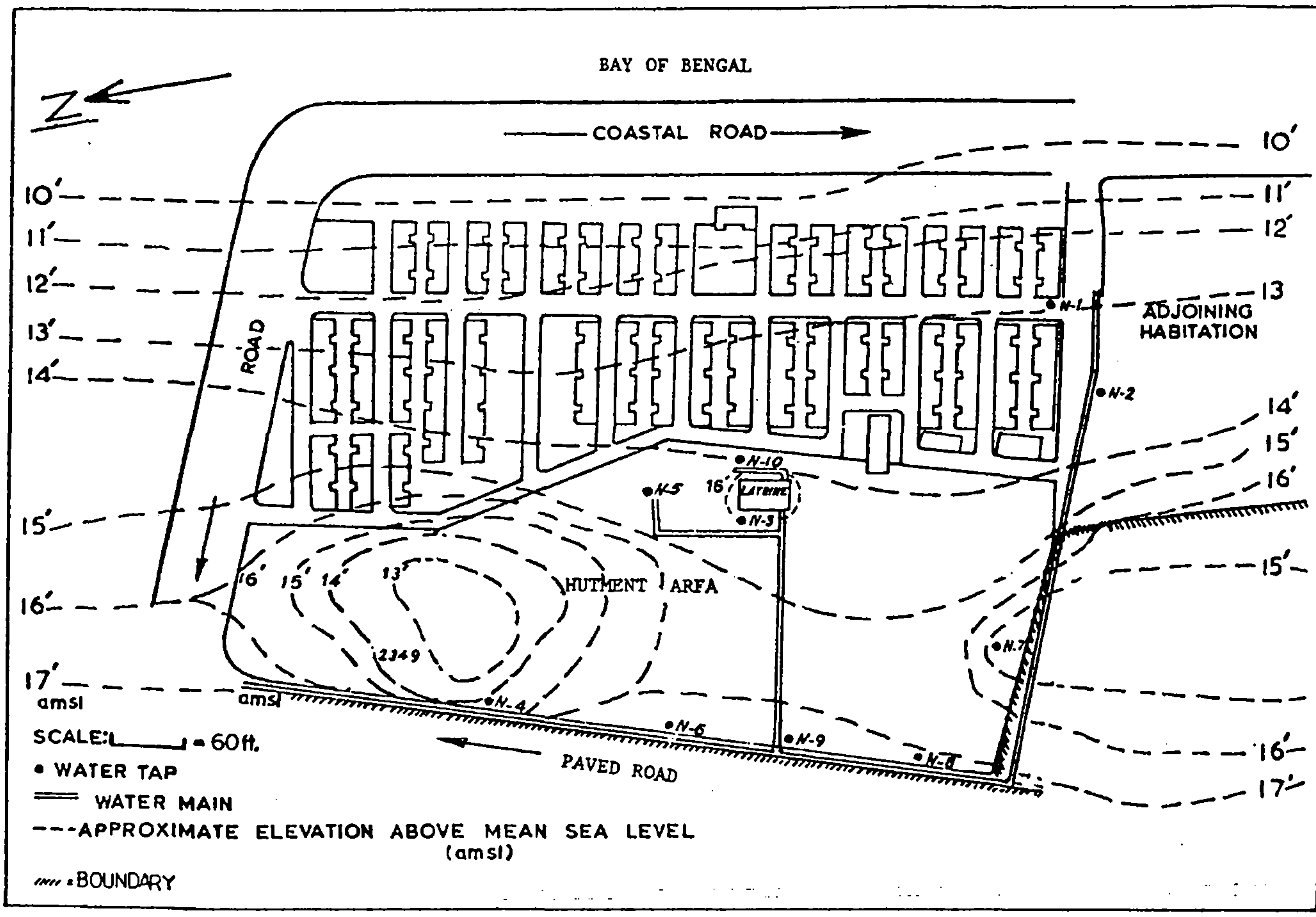

Fig. 1. Map of the area.

were equipped with functional valves, sampling was done by inserting sterile 120 ml sample bottles directly into the stream of water, then removing and capping before the bottles were completely filled (i.e. with about 10 ml of air/ sample). From November 28, 1978 until December 19, 1979 water was collected from the ten water taps serving the community. Average frequency of sampling was once every 15.4 days. A total of 177 samples were analyzed.

Sampling was done according to the specifications set forth by the American Public Health Association and the American Water Works Association, in *Standard Methods for the Examination of Water and Waste Water* [8]. Water was tested for total coliforms using the multiple tube fermentation technique and the fecal coliform procedure was done as the confirmatory test, as specified in section 908c "Fecal Coliform MPN Procedure", of *Standard Methods.* While these organisms may or may not be pathogenic, their presence indicates fecal contamination of the water supply by animals or humans. The test is the most widely practiced method for estimating such contamination.

STATISTICAL METHODS

It was the aim of the study to describe fecal coliform concentration (contamination) in terms of linear distance. Both the independent variable (linear distance from the tap to the compound edge) and the dependent variable are measured on a continuous scale. The data are appropriate to submit for linear regression analysis. Validity requires that the assumptions of the general linear model are met. The five assumptions of the general linear model are: (1) that for any fixed value of x (the independent variable), y (the dependent variable) is a random variable, (2) the y values are independent of one another, (3) the mean value of y, given x, is a straight line function of x, (4) the variance of y is the same over the values of the parameters (homoscedasticity) and (5) for any fixed value of x, y has a normal distribution [9].

The distributions from which the MPN are derived show clearly that the variance of y increases with the value of y. The log transformation is used to stabilize the variance when the variance of y increases markedly with values of y. Although the 95% confidence interval for MPN =

12 is 25 microorganisms (m.o)/100 ml, for MPN = 110 is 219 m.o./100 ml and for MPN = 1600 m.o/100 ml is 5,160 m.o./100 ml., the $\log_e$ 95% confidence intervals of all three values are roughly equal: i.e. 2.23, 2.08 and 2.20 respectively. In effect the conversion to $\log_e$ values functions as a variance stabilizing transformation. The log transformation satisfies the general relationship

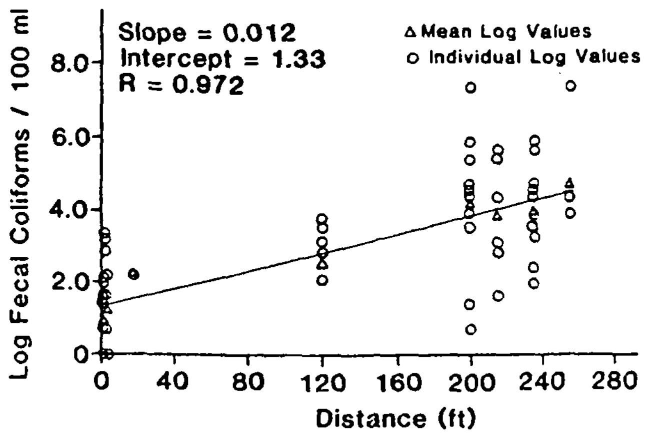

Fig. 2. Coliform concentration in relation to distance from taps during rainy weather.

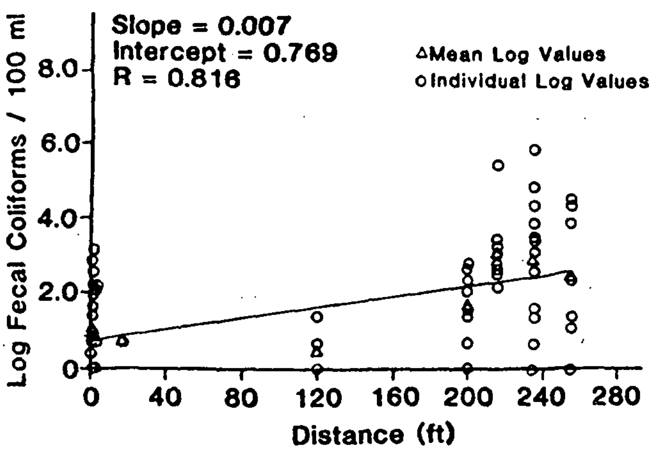

Fig. 3. Coliform concentration in relation to distance from taps during dry weather.

$$\mathrm{var}(y_e) = (dy_e/dx)^2_{x=E(x)}\mathrm{var}(x)$$

The log transformation was originally devised in the context of bacterial counts which have log-normal rather than normal growth characteristics. The transformation, in addition to stabilizing the variance, therefore normalized the distribution

Transformed coliform concentrations appeared normally distributed

[10]. The transformed coliform concentrations appeared normally distributed in preliminary analyses as one would expect. The untransformed data satisfied only the first three assumptions of the model, the transformed data satisfied the last two assumptions, as well.

RESULTS

Data collected across the thirteen months of the study were subjected to two linear regression analyses using the distances from the taps to compound edge as the independent (x) variable and the average $\log_e$ coliform concentration for each of the ten taps as the dependent (y) variable. Individual and mean $\log_e$ values for the MPN are plotted in Figs. 2 and 3, for rainy and dry weather, and the least squares line of best fit was drawn for those two sets of mean $\log_e$ fecal coliform concentrations. Slopes and intercepts of the lines are shown along with regression coefficients.

Table 1 shows a summary of the tests as well as geometric means and distances for each of the taps. Distances shown in the Figures and stated in

TABLE 1

Mean $\log_e$ and geometric mean coliform concentrations compared by distance and weather conditions

Distance from water main (feet)	Tap ID number	Rainy conditions		Dry conditions	
		Mean $\log_e$ concentration	Geometric mean	Mean $\log_e$ concentration	Geometric mean
1	N4	1.48	4.39	0.98	2.66
1	N6	1.33	3.78	1.02	2.77
1	N9	0.92	2.51	1.01	2.75
3	N8	1.20	3.32	0.86	2.36
17.5	N7	2.20	9.03	0.69	1.99
120	N2	2.57	13.07	0.46	1.58
200	N1	4.17	64.72	1.65	5.21
215	N3	3.81	45.15	3.12	22.64
235	N5	3.96	52.46	2.94	19.92
255	N10	4.68	107.80	2.39	10.91

the Table were determined by measuring from the tap to the nearest border from which the water flows. That is, to the western or closest edge under which the water must flow (see cross-hatching in Fig. 1).

Using mean $\log_e$ rainy weather MPN as the dependent variable and taps' distances from the contamination-free area (i.e. away from the Bay of Bengal) as the independent variable, it was found that there was a coefficient of regression of +0.972. For dry weather the regression coefficient was +0.816. This means that for rainy condition 94.5% of the variability in y ($\log_e$ fecal coliform density) was explained by the regression of y on x (distance); for dry conditions, the figure is 66.6%. Analyses were performed to test the significance of r, the regression coefficient (i.e. on the null hypothesis that $H_0 : B = 0$) where Z, the test statistic, is estimated by $t = r/((1 - r^2)/(n - 2))^{1/2}$. It was found that for rainy conditions, the t value was 11.67 ($p < 0.001$) and for dry conditions, the t value was 3.99 ($p < 0.001$). This result shows that the slope is significantly different than zero and therefore x provides significant information for the prediction of y (i.e. the model $y = 1.34 + 0.0123x$ is much more useful than $\hat{y} = \bar{y}$). A better model may have a non-linear term although there would be a dominant linear component given the large r^2.

It should also be noted that the distance of the taps was negatively correlated with elevation above mean sea level. This factor seems to have become extremely important during the rainy season. Elevation of the tap relative to the surrounding ground surface in its immediate vicinity was found to be negatively correlated with the distance to contamination-free area; $r = -0.42$. For lack of proper surveying tools, an exact analysis of the taps' distance/elevation/depth relationship was not possible. Existing data suggests that the observed distance/contamination relationship was based partly on elevation and tap depth factors.

Figure 3 presents data on the relationship between water quality and distance for dry conditions. It should be noted that taps N3 and N5, at 215 and 235 feet respectively, had mean fecal coliform concentrations in excess of what one would expect solely on the basis of the regression of y on x. $\log_e$ value for tap N10, at 255 feet, lies nearly on the regression line. These taps were all in the vicinity of the public latrine facility and a small area of severe contamination. Tap N3 was located in a subterranean pit at the north west corner of the latrine and Tap N10 was about thirty feet to the east of tap N3 and just three feet north of a large concentration of waste. Tap N5 was about 55 feet north of these two, and also within 45 feet of the tenement/traditional housing borderline (see Fig. 1). This area, being in neither the hutment area nor the tenement area, and not having sufficient water to keep it clean, was the most severely neglected area within the settlement. The latrine facility, rather than encouraging good hygiene, had become a focal point for severe degradation in terms of environmental health.

DISCUSSION AND CONCLUSIONS

The Madras Metropolitan Development Authority, along with other concerned agencies, are well aware of the problems in water supply that Madras faces.Because of acute and chronic shortages of water and concomitant low pipe pressure, the Madras system is characterized by many subterranean service points which function irregularly and intermittently. Of the ten water taps in this slum, only two are at elevations above the level of the surrounding ground surfaces. The eight others are prone to flooding during even moderate rains. Due to the downward slope of the land toward the Bay of Bengal, the presence of fecal material on ground surfaces, the subterranean nature of access facilities and the absence of valves on the taps, contamination of the piped water seems to have occurred, especially during the monsoon rains.

The results of this study suggest that on-site contamination of piped water was taking place. Contamination appears to have been especially pronounced during the rainy season when environmental factors combined to make that event likely. Fouling of the protected water supply was shown to be associated with the distance the water must travel through the community. Noting that the intercepts for both rainy and dry conditions were small ($y = 1.33, 0.77$), the data suggest that water entered the slum somewhat free of contamination. Therefore, although it was possible that coliform organisms were growing in the mains, the major predictor of water contamination appeared to be related to the distance the water traveled through the

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smaller delivery pipes and to fecal contamination found on the ground above the pipes.

As possible factors in the transmission of disease, two attributes of water, namely its quantity and its quality, are important. The former impacts directly on factors of personal and environmental hygiene. It may indirectly affect water quality by affecting public hygiene around the water pipes [11]. The findings in this study suggest that water was being contaminated within the piped distribution system of an urban community. Inadequate maintenance of latrine facilities, due to the overall scarcity of water, and lack of appropriate pumps to make the latrines functional, were likely indirect causative factors. By providing piped water, it is not necessarily the case that the water will be protected from fecal or other sorts of contaminants. It must be kept in mind that water supply and sanitation are inextricably linked [12].

Water supply and sanitation are inextricably linked

The effects of season on water quality are not always obvious. In this case, the monsoon rains washed the fecal material into and around the water access pipes, but the effect of the dry season water shortage and increased concentration of fecal material was also an important variable.

Although other factors may be operative in this or other communities, water from the public access points serving the community was of poor enough bacteriological quality (up to four orders of magnitude higher than either the Indian or the American coliform upper limits) and raises serious questions concerning its direct effect upon the health of its inhabitants.

In conclusion, evaluating the effectiveness of piped water interventions involves not only the bacteriological quality of the delivered water, but also the other existing sanitation facilities and the hygienic behaviors of the inhabitants of the area. In addition, seasonality of water supplies and integrity of the water pipes themselves play an integral part in the overall provision of good water.

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