Health Risks Associated with Wastewater Irrigation: An Epidemiological Study

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Abstract: An analysis of morbidity was made in 11 kibbutzim (cooperative agricultural settlements), with a total population of 3,040, that had switched from nonwastewater to wastewater sprinkler irrigation or vice versa. Generally, partially treated stabilization pond effluent of poor microbial quality was used for irrigation. Vegetables or salad crops were not irrigated with effluent. The results showed that a seasonal, twofold, excess risk of "enteric" disease was found in the 0 to 4 year-old age group during the summer irrigation months in those years in which wastewater was used for irrigation, compared with the parallel summer months of nonwastewater irrigation years in the same kibbutz. On the year-round rates basis, little or no excess enteric disease was found in wastewater irrigating communities. (*Am J Public Health* 1986; 76:977–979.)

Introduction

The application of wastewater to the land has been practiced in Europe and the United States for over 100 years as a method of treatment and water pollution control and/or as a source of water and nutrients for agricultural purposes. There is strong evidence that health risks are involved in irrigating vegetables and salad crops with raw wastewater.[1] However, there have been few studies on the health risks to nearby population groups exposed to aerosolized pathogens disseminated by wastewater sprinkler irrigation. The present study deals with the possible health risks associated with this mode of transmission.

The findings in this report are based on moribidity and environmental data collected in 11 kibbutzim, geographically distributed throughout Israel. The kibbutz (plural kibbutzim) has been defined as a "voluntary collective community, mainly agricultural, in which there is no private wealth, and which is responsible for all the needs of its members and their families." The population usually varies from a few hundred to over a thousand. Residential areas are situated at a distance of 250–1,000 meters from irrigated fields. Six of the 11 kibbutzim in this study switched from sprinkler irrigation with noneffluent water sources to wastewater effluent irrigation (Group A), and five switched from effluent to noneffluent irrigation sources (Group B). Each kibbutz practiced effluent irrigation and irrigation with clean water for two years each.

Methods

Morbidity data on 17 symptoms and diseases were recorded for a four-year period for each of the 11 kibbutzim (total population 3,040). There were nine potentially wastewater borne "enteric" diseases and eight "control" diseases, nonwastewater borne (Table 1). The data were culled from kibbutz clinic medical files. Each kibbutz has one clinic located on its grounds, staffed by a physician and several nurses. The clinics provide medical services to the kibbutz residents. The data collected in 1978 from the kibbutz files covered a period of 14 years (1963–76). In each individual kibbutz, a four-year period was studied: two years directly prior to and two years directly after switching from one type of irrigation to the other. The numbers of kibbutzim in the two groups were distributed as follows: 1963–67, Groups A-1 and B-1; 1968–71, Groups A-0 and B-1; 1972–76, Groups A-5 and B-3.

Environmental data were collected from questionnaires filled out during direct interviews with the kibbutz managers and irrigation supervisors. The data included effluent use, irrigation periods, source and volume of irrigation water, size and location of irrigated tracts, wind speed and direction, and types of crops irrigated. The effluent, applied by high pressure sprinkler irrigation, was of poor quality, and had been treated in stabilization ponds with a 5 to 10-day detention period. Following such treatment the total coliform concentration in the effluent was generally 10^{6-8}/100 ml and the enteric virus concentration $10–10^3$/100 ml. The wastewater effluent was mostly used for irrigating such crops as cotton and fodder, but not vegetable or salad crops.

Based on field observation in other studies, it was determined that the level of recording of diseases in clinic files varied within the same kibbutz from period to period due to personnel changes in the medical staff, absences due to military service, and variations in seasonal work load. Thus, enteric disease rates between one period and another may not be completely comparable, unless adjusted for the variations in "quality of reporting." Therefore, control diseases (nonwastewater associated and having a high incidence rate) were selected to be used in this study as an index of the quality of reporting.

To control the inter-kibbutz differences in quality of reporting of clinical visits and differences in the type of switch (from noneffluent to effluent and vice versa) and age distribution, and to further examine their possible modifying effects a log linear model[2] was employed. Such a model assumes that the logarithms of the enteric disease rate within an age group (0–4, 5–18, 19+) in a kibbutz is linearly related to the following explanatory variables: logarithms of the corresponding control diseases rate and dummy variables for the kibbutz factor, effluent versus noneffluent irrigation, type of switch, age group, sequence of irrigation years (i.e., first or second year of irrigation), and interaction between types of irrigation, form of switch, age group, and sequence of irrigation year. Enteric disease rates may have, according to this model, a larger variance than the one expected under the Poisson Model.[2]

The model's parameters were estimated by the weighted least squares method[2–4] with the use of the BMDP-1R linear

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TABLE 1—List of Diseases Recorded from Patient Clinic Files in the Kibbutzim Studied

Potential Wastewater-borne Diseases (Enteric)	Nonwastewater-borne Diseases (Control)
Typhoid Fever	Upper Respirator Infections
Paratyphoid	Urinary Tract Infections
Salmonellosis	Throat Infections
Shigellosis	Measles
Gastroenteritis (including diarrhea)	Chickenpox
Aseptic Meningitis	Accidents
Infectious Hepatitis	Rubella
Fever of Unknown Origin	Mumps
Coxsackie Virus Infections	

regression program. The number of enteric disease cases during the study period (summer or annual) within an age group in the kibbutz served as the regression weight.[2] Confidence intervals for each risk ratio of interest were derived from the asymptotic normal distribution of the estimated model parameters.

Results

Disease rates were calculated separately for the summer irrigation period (most kibbutzim irrigating between April–September) as well as on an annual basis for the full 12-month period. The population at risk during effluent and noneffluent years in each age-group (0–4, 5–18, 19+) together with the corresponding rates of enteric and control diseases during the summer irrigation period are shown in Table 2.

The summer enteric disease rates were higher during effluent irrigating years than in noneffluent years. This increase was seen particularly in the kibbutzim that switched from noneffluent to effluent irrigation. There seemed to be, however, a similar but lower excess of control diseases in these kibbutzim. We assume that these variations in control diseases are mainly due to variations in the quality of reporting.

The log linear model, adjusting the difference in enteric disease rates for the level of reporting as indexed by the rate of control diseases, showed a good fit to the data ($R^2 = .91$). The model estimates for the relative risk of enteric disease for effluent versus noneffluent years by form of switch and age group showed a doubling in the rate of enteric diseases in the summer during effluent irrigation years in the 0 to 4 year-old age group regardless of the form of switch (Table 3). No excess was found in other age groups. The ratios of enteric to control disease rates were not related to the size of the effluent irrigated fields or their distances from residential areas.

TABLE 3—The Log Linear Model Estimates and 95% Confidence Intervals for Rates Ratio of Enteric Disease for Effluent versus Noneffluent Irrigation during the Irrigation Period among the Three Age Groups, by the Form of Switch

Form of Switch	Age Group (Yrs)	Rate Ratio Estimate	95% Confidence Interval
Noneffluent	0–4	1.91	1.30, 2.80
to	5–18	1.23	0.46, 3.25
Effluent	19+	2.06	0.69, 6.16
Effluent	0–4	2.03	1.15, 3.61
to	5–18	1.33	0.60, 2.95
Nonefluent	19+	.59	0.30, 1.15

Note: The ratio of enteric to control disease rates during effluent irrigation years was higher than the corresponding ration during noneffluent years in nine out of 11 kibbutzim (four in noneffluent to effluent group and five in effluent to noneffluent group).

The enteric disease rates for the entire year, rather than just the summer period, were also compared. The crude rates for enteric diseases during effluent and noneffluent irrigating years were essentially the same. The log linear model showed a 27 per cent excess of enteric disease in the 0 to 4 age group and in the total group during effluent irrigation years. Clinical gastroenteritis, including diarrhea, was the dominant disease of the enteric disease group studied (54 per cent in all ages).

Discussion

The findings of this study provide evidence that enteric diseases can be transmitted during the summer irrigation months to population groups, particularly young children, residing in the vicinity of sprinkler irrigation sites in which poor quality wastewater effluent is used. The "before and after" study of the same communities, similar to the classical block design type study, enables circumvention of numerous inter-community confounding factors. Also, the fact that the data for the four consecutive years in the 11 kibbutzim covered various intervals during the period 1963–76, reduced, to some extent, the possible effects of national or regional epidemic cycles.

To ascertain whether the results obtained by the methods used are not entirely dependent on the particular form of the log linear model used, we also analyzed the data by two other procedures. One was a stratified analysis of the odds ratio of enteric to control disease rates during effluent and noneffluent years in each kibbutz, separately by age and by type of switch. The other was by applying the logistic regression model[2] with the log of the ratio of enteric to control disease rate as the target variable and the same qualitative factors as entered into the log linear model as explanatory

TABLE 2—Crude Rates (per 1000 person-years) of Enteric and Control Diseases during "Summer" Irrigation Period of Effluent and Noneffluent Years in the Three Age Groups, by the Form of Switch

			Enteric Disease Rate		Control Disease Rate	
Form of Switch	Age (yrs)	Pop #	Noneffluent Years	Effluent Years	Noneffluent Years	Effluent Years
Noneffluent	0–4	222	274	518	672	936
to	5–18	431	66	112	298	440
Effluent	19+	1018	18	47	57	121
Effluent	0–4	186	436	451	797	817
to	5–18	424	53	101	398	432
Noneffluent	19+	759	46	56	116	147

variables. Both methods confirmed the findings of excess enteric disease rates in the summer irrigation period during effluent irrigation years in the 0 to 4 age group as in the log linear model. However, the finding of an excess in the 0 to 4 age group and all ages on a year-round basis was not supported by the other methods. These conflicting findings make it difficult to draw conclusions as to the existence of a year-round excess of enteric disease in those years that effluent irrigation was practiced.

It might be hypothesized that during the summer months of effluent irrigation there is indeed increased transmission of enteric pathogens, possibly enteric viruses, resulting in increased infection and disease only among the highly susceptible youngest age-group. By the end of the intensive exposure during the effluent irrigation months, the remaining number of susceptible individuals in that age group would have been reduced. While some enteric disease transmission would continue by the normal contact infection routes, the monthly rate of infection would be very much lower. Similarly, it might be hypothesized that in noneffluent exposed communities, there would be constant tranmission of enteric disease by the normal contact infection routes in the highly susceptible age groups without such a stronger summer peak. However, the year-round rate of infection in both groups reaches a certain level that is apparently the same in both exposed and nonexposed communities. This finding would suggest that, with highly infectious enteric disease agents such as viruses, transmitted by multiple concurrent routes to a given pool of susceptible children, an annual "saturation" level is reached regardless of whether there is additional exposure to pathogens from an external source such as wastewater effluent use.

In the kibbutz situation, with intimate communal living, including communal care of babies and infants, there are many opportunities for continuous multiple exposure to the endemic enteric pathogens in the community that may lead to a saturation level of infection regardless of wastewater use practices.

A somewhat parallel phenomenon has been reported by Bernstein[5] for respiratory disease among highly susceptible US Air Force recruits living in high and low density barracks arrangements. While the initial rate of respiratory infection in the crowded (high density) barracks was greater than in the low density group, both groups reached about the same level of the infection by the end of the basic training period.

Regardless of whether this hypothesis fully explains the findings, it is difficult to say that a real public health problem exists in the communities studied as a result of wastewater irrigation if, in the final analysis, there is no important difference in the year-round rate of enteric disease in the exposed versus the nonexposed communities. Whether or not this same situation would hold for other communities with less intense interpersonal contact among the very young susceptible individuals cannot be determined from the results of this study.

It is difficult to compare the findings of this study with those of an earlier kibbutz wastewater irrigation study of Katsenelson, *et al* in 1976.[6] The earlier study[6] compared the incidence of four specific enteric diseases (shigellosis, salmonellosis, infectious hepatitis, and typhoid fever) between wastewater irrigating kibbutzim and nonexposed controls, for a total population of 82,825 persons in 207 kibbutzim. That study detected a two to four-fold excess of the above diseases in the exposed kibbutzim among all ages both during the summer period and on a year-round basis. In the present study with a much smaller population, the number of recorded cases for the above diseases were too few for separate analysis. The analysis was therefore based on pooling all enteric diseases (Table 1). The dramatic earlier findings were not generally confirmed by the current study, in that we found only a seasonal excess of total enteric disease among the youngest age group. There are serious methodological problems associated with the Katzenelson, *et al*, study,[6] as described in detail by Fattal in 1983.[7] Most of these difficulties were overcome in the present study so that more reliable basic data were obtained.

Extrapolation of the findings in this study to other situations must take into consideration the fact that, for the most part, the effluent used for irrigation in the kibbutzim had been only minimally treated in short detention stabilization ponds and was of poor microbial quality. Whether the same limited seasonal risk of enteric disease associated with wastewater utilization would exist if fully treated effluents (typical of those from long detention in stabilization ponds, conventional biological treatment plants or their equivalent) had been used is a moot question. In extrapolating these findings to other communities, differences in endemic diseases and immunity levels should also be considered.

Notwithstanding the above considerations, the results of this study suggest that when using effluent for irrigation or land application, it would be prudent to utilize treated wastewater of good microbial quality in order to minimize health risks and to provide a reasonable factor of safety for exposed irrigation workers and adjacent population groups.

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REFERENCES

1. Shuval HI, Yekutiel P, Fattal B: Epidemiological evidence for helminth and cholera transmission by vegetables irrigated with wastewater: Jerusalem—a case study. Wat Sci Technol 1984; 17:433–442.
2. McCullagh P, Nelder JA: Generalized Linear Models. London: Chapman and Hall, 1983; 72–87, 123–127.
3. Grizzle JE, Starner CF, Koch GG: Analysis of categorical data by linear models. Biometrics 1969; 25:489–504.
4. Bapkar VP: ANOVA and MANOVA: models for categorical data. *In:* Krishnaiah PR (ed): Handbook of Statistics—1. Analysis of Variance. Amsterdam: North Holland, 1981; 343–388.
5. Bernstein SA: Observations on the effects of housing on the incidence and spread of common respiratory diseases among air force recruits. Am J Hyg 1957; 65:165.
6. Katzenelson E, Buium I, Shuval HI: Risk of communicable disease infection associated with wastewater irrigating in agricultural settlements. Science 1976; 194:944–946.
7. Fattal B: The prevalence of viral hepatitis and other enteric diseases in communities utilizing wastewater in agriculture. Wat Sci Technol 1983; 15:43–58.