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INTERRELATION BETWEEN HEALTH AND POPULATION: OBSERVATIONS DERIVED FROM FIELD EXPERIENCES

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Abstract—This paper presents information and concepts concerning the health of populations in less developed countries as background for discussions of more focused and detailed papers on these and related subjects.

It begins with a review of health status and trends in developing countries since 1950, followed by a section identifying the major health problems and their causes.

The third part includes analyses of associations between health resources, water and sanitation facilities, food availability, and economic and social indicators taken as independent variables and measures of health status—life expectancy, crude death rates, and infant mortality—as the dependent variables.

The final section discusses health policies and their implementation and offers an analysis of the resource requirements and health effects of different methods of organizing and combining health programs in a few developing countries. The objective is to illustrate a method of determining preferred activities at any given level of investment and the probable health effects of varying increases in the level of health expenditures.

LIFE EXPECTANCY AND DEATH RATES IN LESS DEVELOPED COUNTRIES: STATUS AND TRENDS

Methodological note

Two sorts of statistics will be relied upon to delineate the shape and trends of health problems in the developing world, their meaning and magnitude. These are life expectancy at birth and mortality. The first tends to describe the overall state of affairs in a given country: how well it is doing in bringing higher levels of health to its citizens. The second pinpoints the major causes of health problems and indicates areas that may be ripe for intervention strategies to be designed.

Life expectancy at birth will be used as the principal proxy measure of health. This is justified, in part, because causes of mortality are similar to the major causes of morbidity. Thus, analysis of life expectancy and the specific causes of low expectation of survival will tend to paint a generally accurate picture of the major health problems in developing areas. Furthermore, population averages for life expectancy may be closely related to the *quality* of life in less developed countries. In developing countries, levels of income, sanitation, literacy, education, and disease are all closely related to life expectancy: all manner of social "goods" seem to go hand in hand.

Using statistics of expectation of life at birth also avoids some of the statistical problems caused by comparing crude death rates in societies with markedly different age distributions of their populations. Mortality data available from less developed countries is exceedingly weak. For example, the data available from WHO cover less than 10% of the population of Africa or of Asia. Even if an attempt is made to estimate the remaining unreported deaths by adding available sample surveys, the result is still far from a complete picture. Annual totals of infant mortality, from registration or surveys, cover half or less of the infants of those continents [1]. Government officials who must choose health policies and allocate resources to combat diseases often know how misleading the official reported statistics can be [2]. Morbidity data is even less available and likely to be of even greater uncertainty and bias.

Health data reporting in developing countries is incomplete, uncertain, and frequently biased towards countries, urban areas, and health facilities that have superior but not representative statistical systems—and likely better than average health conditions. Almost all the life expectancy data used are, therefore, from the United Nations [3]. Some of the 1970–75 estimates may be somewhat high, but they remain the best current source of information for such a large number of countries.

For these reasons, then, we have relied on data reported to and by the World Health Organization for selected countries in illustrative fashion only. For measures of trends and as dependent variables in statistical correlation analyses, we have relied on the estimates published by the Department of Economic and Social Affairs of the United Nations. These estimates have used demographic evaluation and adjustment techniques which, it is hoped, make the best use of such information as is available [4].

Countries of the developing world can be grouped into three broad regions with respect to levels of life expectancy and mortality (Table 1). First is Tropical Africa, poorest on all measures of mortality. Second, in the middle, is a band of countries beginning in North Africa and then going through all of Southern Asia to Melanesia. Third, and best, are East Asia and the Latin American and Caribbean countries. The differences in levels of mortality are substantial among the different regions. East Asia and the Western

Table 1. Measures of health in less-developed regions, 1970–1975

Region	Life expectancy at birth (years)	Infant mortality per 1000 live births	Mortality ages 1–4 per 1000	CDR per 1000
Tropical Africa	41	200	40	22
Northern Africa	52	150	26	15
Western South Asia	54	135	22	14
Middle South Asia	48	145	25	17
Eastern South Asia	51	120	18	15
Melanesia	48	150		17
East Asia	61	70	7	10
Caribbean	63	64	7	9
Tropical South America	61	100	10	9
Middle America	62	70	9	9

Sources: United Nations, Department of Economic and Social Affairs. *World Population Prospects as Assessed in 1973*. Population Studies no. 60, 1977; Vallin J. World trends in infant mortality since 1950. *World Hlth Stat. Rep.* **29**, 11, 1976; Dyson T. Levels, trends, differentials and causes of child mortality —A survey. *World Hlth Stat. Rep.* **30**, 4, 1977.

Hemisphere are close to levels of many developed countries; the countries of Africa and most of Asia have mortality levels far in excess of the rest of the world.

A striking feature of life expectancy and mortality trends in developing countries is that improvement over the last 20 years has been both large and general. Gains in life expectancy at birth averaged over 10 additional years, moving from 42 to 52 years for the total of less developed regions (Tables 2 and 3). In the same time, crude death rates fell by 40% from 23 to 14 per 1000 population (Tables 4 and 5).

The exceptions to this general trend, in that their rates of improvement were substantially less than other countries, are few: the Sahel countries, which experienced severe drought for a period of years and countries exposed to the effects of protracted war (Vietnam, Cambodia, and Laos) and Bangladesh,

Table 2. Changes in life expectancy at birth, 1950–55 to 1970–75

	1950–55	1955–60	1960–65	1965–70	1970–75	Increases 1950–55 to 1970–75 Years	%
More developed regions	65.0	68.2	69.5	70.3	71.1	6.1	
Less developed regions	41.6	45.0	48.0	50.4	52.2	10.6	25
Absolute difference: more developed vs less developed	23.4	23.2	21.5	19.9	18.9		
Ratio: less developed as % life expectancy of more developed	64	66	69	72	73		

Source: United Nations, *op. cit.* (Table 1) Population Studies No. 60, 1977.

Table 3. Life expectancy at birth, 1950–55 to 1970–75

	1950–55	1970–75	Absolute gain (years)	% Gain
Eastern Africa	34.7	43.8	9.1	26.2
Middle Africa	35.2	41.9	6.7	19.0
Western Africa	32.0	40.9	8.9	27.8
Southern Africa	43.2	50.8	7.6	17.6
Northern Africa	42.0	52.0	10.0	23.8
Eastern South Asia	40.4	50.6	10.2	25.2
Middle South Asia	38.6	48.0	9.4	24.4
Western South Asia	43.9	53.8	9.9	22.6
China	45.0	61.6	16.6	36.9
Other East Asia (except Japan)	48.2	61.1	12.9	26.8
Caribbean	52.9	63.1	10.2	19.3
Middle America	49.6	61.5	11.5	23.2
Tropical South America	51.9	60.5	8.6	16.6
Less developed regions	41.6	52.2	10.6	25.5

Source: United Nations, *op. cit.* (Table 1) Population Studies, No. 60, 1977.

Table 4. Changes in crude death rates 1950–55 to 1970–75

	1950–55	1955–60	1960–65	1965–70	1970–75	Decreases 1950–55 to 1970–75 Absolute	%
More developed regions	10.1	9.3	9.0	9.1	9.2	0.9	9
Less developed regions	23.3	19.9	17.4	15.5	14.3	9.0	39
Absolute difference: more developed vs less developed	13.2	10.6	8.4	6.4	5.1		
Ratio: death rate in less developed regions as % of more developed	230	210	190	170	160		

Source: United Nations, *op. cit.* (Table 1) Population Studies No. 60, 1977.

which had both warfare and food distribution problems [5].

There is substantial improvement in both life expectancy at birth and crude death rates from 1950–55 to 1970–75 throughout the regions of the less developed, low-income countries. While the data in the tables concern the period beginning in 1950, the rapid improvement in mortality in developing countries is not just a post-World War II phenomenon. The limited estimates available point to a trend that has been underway since 1930 [6]. It is encouraging that this trend is found independent of economic level. Change for the better seems possible, and if efforts can be focused on those changes—in health care and/or other aspects of social and economic development—that seem most closely related to improved health, even more rapid strides may be taken. The assumption that health interventions may explain recent improvements in life expectancy needs to be examined closely. If there are interventions that seem especially effective, these should be identified so that salutary trends can be accelerated. The latter half of the paper deals with this issue.

Life expectancy trends

Most gain in life expectancy has been in East Asia, where China, Mongolia, and the two Koreas moved from levels below 50 years to over 60 years at birth (Table 3). Middle America had almost as large a gain. In Middle Africa and Tropical South America, increases in life expectancy are substantially less than the LDC average of about half-a-year gain per year. The regional slowness of growth in Middle Africa is probably accounted for by a much lower than average growth in Zaire, which has over half the population of the region. In Tropical South America, slow rates of improvement characterize Bolivia (in which life expectancy increased only 6 years in the 20 under review) and Brazil (where it rose by 7).

The absolute gains in life expectancy, however, have diminished progressively over the twenty-year period, averaging 3.4 years between 1950–55 and 1955–60, but less than 2 years between 1965–70 and 1970–75. There is considerably more variation among and within regions with respect to this deceleration of gain than in the total gains over the period 1950–55 and 1970–75 (Table 6).

Regional deceleration in gains in life expectancy are most noticeable in Eastern Africa, the Caribbean, and Middle South Asia. In Eastern Africa, rises in life expectancy fell sharply to almost no gain between 1965–70 and 1970–75 in Rwanda, Burundi, and Ethiopia, probably directly associated with economic and political events of the period. There were considerably

Table 5. Crude death rate per 1000 population, 1950–55 to 1970–75

	1950–55	1970–75	Absolute decrease 1950–55 to 1970–75	% Decrease
Eastern Africa	28.6	20.7	7.9	27.6
Middle Africa	28.4	21.7	6.7	23.6
Western Africa	28.7	23.0	5.7	19.9
Southern Africa	18.4	16.2	2.2	12.0
Northern Africa	23.6	15.2	8.4	35.6
Eastern South Asia	23.9	15.4	8.5	35.6
Middle South Asia	25.8	17.0	8.8	34.1
Western South Asia	21.2	14.3	6.9	32.5
China	21.1	10.3	10.8	51.2
Other East Asia (except Japan)	18.6*	8.7	9.9	53.2
Middle America	16.9	9.4	7.5	44.4
Caribbean	14.3	9.1	5.2	36.4
Tropical South America	14.5	9.2	5.3	36.6
Less developed countries	23.3	14.3	9.0	38.6

* Democratic Korea and Republic of Korea 1950–55 estimate was adjusted to eliminate Korean War effects. Unadjusted CDR = 30.2.

Sources: United Nations, *op. cit.* (Table 1) Population Studies, No. 60, 1977; Hwan Kwon T. *et al. The Population of Korea*, p. 23. Seoul National University, 1975.

Table 6. Increases in life expectancy by regions (no. of years)

	1950–55 to 1955–60	1955–60 to 1960–65	1960–65 to 1965–70	1965–70 to 1970–75
Eastern Africa	2.5	2.6	2.3	1.7
Middle Africa	1.6	1.7	1.9	1.5
Southern Africa	2.4	2.0	0.7	2.5
Western Africa	2.1	2.4	2.3	2.1
Northern Africa	2.5	2.5	2.5	2.5
Western South Asia	2.5	2.3	2.5	2.6
Caribbean	3.5	3.2	2.2	1.3
Middle America	4.3	3.3	1.9	2.4
Tropical South America	2.6	2.1	2.0	1.9
China	5.5	5.0	3.5	2.6
Other East Asia (except Japan)	5.0	2.7	2.4	2.8
Eastern South Asia	2.8	2.5	2.5	2.4
Middle South Asia	2.9	2.8	2.4	1.3
All less developed regions	3.4	3.0	2.4	1.8

Source: United Nations, *op. cit.* (Table 1) Population Studies. No. 60, 1977.

smaller than usual gains estimated for Zambia, which has suffered from severe price declines in its dominant product—copper. The Middle South Asian decline in rate of increase is related solely to the tragic circumstances in Bangladesh. On a more positive note, the decrease in rate of increase of life expectancy in the Caribbean seems related to the most populous islands reaching life expectancies at birth of close to 70 years, beyond which no large gains could be predicted.

Trends in mortality by age groups

In developed societies, dramatic increases in life expectancy at birth have been, historically, largely the result of falling mortality rates in infants. The data on changes in mortality by age in less developed countries, on the other hand, show substantial declines in *all* age classes. In fact, mortality declines at ages below 5 years have not matched those of young adults up to age 35 [7]. India has reported that "while the general mortality level during the last half century has decline by about 50%, the infant mortality rate has dropped by only 30%" [8]. Table 7 shows age-specific mortality rate changes in several countries. Data from Korea (1935–70) and the city of Peking, China (1949–57) also show significant declines in all age-specific mortality rates [9]. Only a moderate portion of the overall gains in life expectancy in developing countries can be attributed to changes in infant mortality even though, mathematically, changes in mortality risks for infants and young children have proportionately greater effects on these statistics than changes in mortality at later ages. As a result, improvements in life expectancy have also been notable at ages other than birth.

Thus, developing countries, unlike more developed countries, have had declines in mortality rates and increases in life expectancy at adult years, while their declines in infant mortality rates since World War II have lagged behind the historical declines in these rates in the more developed countries [10]. The reasons for this trend and the possibilities for effective interventions to increase infant survival are important areas for further exploration.

CAUSES OF DEATH

Deaths under 5 years

In most developing countries the bulk of the deaths are of children under 5 years of age. In general, the higher the overall mortality in a country, the larger the proportion of deaths are of children of such ages. Since deaths in the 0–4 group are underestimated in less developed countries, this group really accounts for an even greater percentage of deaths than noted in

Table 7. Percentage decline of mortality rates by age group in selected developing countries, both sexes, 1940–1965

Age (in years)	Ceylon 1946–1963	Chile 1940–1960	Taiwan 1940–1965	Jamaica 1943–1960	Mauritius 1944–1962	Puerto Rico 1940–1960	Trinidad and Tobago 1946–1960
Under 1	70	38	84	49	68	78	47
1–4		69	86	47	73		
5–14	69	52	82	72	76	84	68
15–24	72	71	73	70	83	81	73
25–34	72	56	75	67	84	82	64
35–44	66	45	73	59	78	73	56
45–54	58	36	64	45	67	62	45
55–64	48	27	50	30	54	55	36
65 and over	22	24	27	25	39	38	12

Source: Computed from data in various issues of the United Nations *Demographic Yearbook*.

Table 8. Percent of deaths by age, selected developing countries

			CDR 1965–70	0–4	5–14	15–49	50+
Nigeria	1967	F	24.0	55	5	16	22
Bolivia	1966	M	19.0	48	4	20	26
Pakistan	1968	M	18.7	54	5	18	22
India	1966–70	M + F	17.6	45	8	18	29
Algeria	1965	M	17.4	58	6	11	23
Egypt	1972	M	15.9	47	4	13	36
Tunisia	1971	M	15.8	43	5	12	39
Philippines	1972	F	12.2	40	6	21	33
Sri Lanka	1968	M	7.5	28	5	17	50
Cuba	1965	F	6.6	24	2	14	60

Sources: United Nations *Demographic Yearbooks*; Gwatkin D. Health and nutrition in India. 1974; United Nations, *op. cit.* (Table 1) Population Studies No. 60, 1977.

Table 8. Significantly, it is precisely in this age group that reductions in mortality have been relatively slow while the causes of mortality remain largely preventable at fairly low cost.

Deaths in the under 5 age group are generally broken down into childhood (1–4) and infant (0–1) mortality. While reliable records on the specific causes of these deaths are scarce, there is an increasing body of evidence that points to most deaths of children as occurring from a limited number of largely interrelated problems.

The Inter-American study of child mortality noted the importance of:

1. Immaturity (low birth weight) as a cause of neonatal fatalities
2. Malnutrition as an underlying or associated cause of port-neonatal deaths
3. The synergistic effects of diarrheal disease and malnutrition.

> Through the study of mortality by multiple causes, 57.0 percent of the children who died under five years of age were found to have had immaturity or nutritional deficiency as either the underlying or associated cause of death... [11].

When data from the Latin American projects are combined, the significance of the combination of infection and nutritional deficiency becomes evident: nutritional deficiency was associated with 61% of the deaths from infectious diseases.

Recent research, using existing studies and the judgments of public health officials, estimated causes of mortality by age for specific rural regions in Ghana, Pakistan, Nepal, and Indonesia. The estimates for the under 5 (Table 9) show that 80–94% of all deaths are attributable to processes where infection and malnutrition act together to produce morbidity and mortality.

Rohde and Hull at Gadjah Mada University in Indonesia have studied causes of death from statistics available for Mexico and the Philippines, and also survey data from Java [12]. They have described the causal complex underlying infant and child deaths as follows:

I. Preconditioning factor:

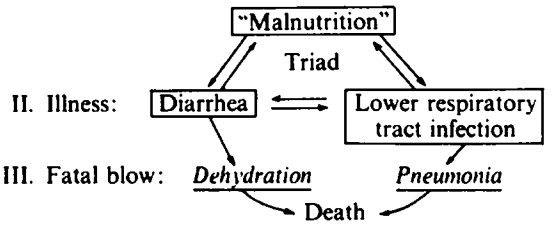


Table 9. Percent of deaths, ages 0–4

Causes of death	Nepal (Terai)	Indonesia (E. Java)	Pakistan (Punjab)	Ghana (Eastern regions)
Diarrhea and malnutrition	37	62	38	35
Measles	11	13	43	37
Lower respiratory infection	26	15	8	8
Tetanus	18	9	5	6
Malaria	0	0	1	11
Total of the above	92	99	95	97

Source: Research Seminar in International Health. School of Public Health. The University of Michigan. Ann Arbor. Michigan, 1978.

Pakistan: Fida H. Quantitative estimates of the costs and effectiveness of different health sector policy alternatives in rural Punjab (Pakistan). May 1978.

Java: Siagian Berlian T. P. and Wijowidagdo S. Quantitative estimate of the cost and effectiveness of different health sector policy alternatives in rural Java. January 1978.

Ghana: Adibo M. Quantitative estimates of different health sector policy alternatives in rural Ghana.

Nepal: Manandhar D. and Anderson M. Quantitative estimates of the costs and effectiveness of different health sector policy alternatives in rural Nepal.

They estimate the percent of deaths from the "synergistic triad" as accounting for 68% of infant deaths in Mexico and 64% in the Philippines; for children in Mexico the estimate is 80% and in the Philippines 73%. Rohde and Hull estimate that two-thirds of the deaths of under-fives in Java were caused by the same triad [3].

One implication of this "synergistic triad" is that a multi-faceted strategy may be required to reduce deaths. Because of the close interactions of many variables, it cannot be assumed that addressing only one contributing factor will produce signal improvements in health status. Rohde and Hull have estimated that about 30% of total deaths and 40% of infant deaths in Java could be averted if the following measures were implemented: immunizations for DPT and measles given to children and tetanus toxoid to pregnant women, early detection and penicillin provided for respiratory infections, mothers taught to mix a rehydration solution for diarrhea using materials found in most homes, prenatal exams, nutritional supplements and education for lactating mothers or those whose children are being weaned [14]. Similarly, in Bangladesh, it has been calculated that a program of measles, diphtheria, pertussis, tetanus, and BCG (antituberculosis) vaccination would avert about 24% of all childhood deaths. A further 14% of all childhood deaths might be avoided by home oral rehydration backed up by local facilities for parenteral fluid replacement [15]. A relatively simple primary care package could thus be expected to prevent almost two-fifths of all childhood deaths.

A prospective field study of the interactions of nutrition and infection was conducted by Johns Hopkins University in the Punjab at Narangwal in 1971. In its summary of fatalities of children between the ages of 4 months and 35 months, the Narangwal study concluded:

> The death rate for malnourished children in this age group was almost nine times that for the corresponding well-nourished group. The rate for well-nourished children is not much higher than that seen in areas where the most sophisticated medical care is available. In 68 percent of the deaths observed, malnutrition was present and probably an important causative factor [16].

Obviously, where total available food supplies are below total requirements, there will exist significant undernutrition. For example, Bolivia and Haiti have per capita caloric availability at about 70–80% of requirements and have the highest mortality rates. A similar situation obtains in the Sahel and Ethiopia in Africa, as well as in Afghanistan and the Yemens [17].

On the other hand, the fact that the total supply of food would be adequate if it were divided equally among all the people of a country has not prevented widespread chronic malnutrition in many developing countries. Low effective demand, stemming from inequitable distribution of income, is common and means that family shortages of food cannot be corrected simply by increasing supply [18] especially if large fractions of the rural populations are not in the cash economy.

Although evidence is scanty, there have been observations that food distribution within families, especially in poor, generally undernourished, populations, may sometimes be a serious problem. A study in villages of rural Zambia showed that while men received between 90 and 116% of requirements as their average calorie intake in the villages, women's and children's average calorie intake ranged only between 48 and 65% [19]. "The patterns of food disposition and consumption acutally observed in many rural, traditionally low-income environments may closely correpsond to the pattern predicted by economic theory," suggest Butz and Habicht, where "an optimal allocation of resources gives much food to persons having the highest value of marginal production, generally the men, and little to persons having the lowest marginal product, children" [20]. In addition, it has been observed in poor populations that protein-calorie malnutrition occurs sometimes even where pre-school age children have access to seemingly ample amounts of family food [21]. This may reflect, in part, withholding of food or appetite reduction during illness.

Food availability, then, may not be the only factor responsible for malnutrition. Other factors that Behar suggests be considered are:

1. Appetite may be reduced by the frequently occurring infections or parasitic infestations, even if they are mild and not recognized as diseases.
2. The diet may be somehow inadequate in terms of bulk (calorie density), other physical or organoleptic characteristics, or in nutrient balance.
3. The amount of stimulation in the home and the mother's behavior toward her child may be suboptimal. (This set of variables has been found to be most significantly associated with malnutrition but the mechanism of how this might produce malnutrition has not yet been elucidated.)
4. Actual requirements may be reduced as a consequence of previous malnutrition during early life; there may be adaptation to a lower level of metabolic needs with slower growth rate and lower activity than normal children of the same age [22].

One significant nutrition variable is infant feeding pattern. The Khanna study in the Punjab noted that mortality rates were many times lower during the first months of life for infants who were breastfed than for those who were not. It was also noted that the death rate increased sharply after 6 months. By that age, few children had received any solid food, and delays in starting solid food were associated with a greatly increased risk of death [23].

Similar conclusions about the effects of breastfeeding and supplementary foods were found in a study of rural Chile by Plank and Milanesi.

> During 1969–70, 1712 rural Chilean mothers were interviewed to see if their feeding practices contributed to infant mortality. There were three times as many deaths among babies given bottles before the age of 3 months as among those who were wholly breast-fed. Nearly half the children had started bottle feeding by that age, and it was thus a major factor in infant mortality [24].

Beverly Winikoff has summarized the significance of breast-feeding:

> The importance of breastfeeding for children's health has been emphasized by laboratory evidence on the biochemical, nutritional, immunological, and anti-allergenic proper-

ties of breast milk, as well as by epidemiological studies showing improved nutrition, health, and survival among breastfed babies. It has become apparent that mother's milk is not only precisely tailored to the nutritional needs of human infants, but is also a living fluid with active and passive factors to protect against infection. The truly remarkable nature of these properties is demonstrated by recent findings that secretory immunoglobulin A-producing cells in milk come originally from lymphocytes in the gastrointestinal tract of the mother. These cells respond precisely to the pathogens present in the immediate environment of the mother (and baby), travel to the breast, are excreted in the milk, are ingested by the baby, and protect the baby's gastrointestinal tract against the organisms most likely to threaten health at that particular instant. More elegant tailoring of host defenses to shifts in environmental threats could hardly be imagined. This precision certainly cannot be replicated by either prepared infant formulas or technical medical interventions such as immunizations or health care services [25].

The Khanna study further reported:

During the early months of life those children who survived the birth process were progressively faced with infections, and if not reasonably well fed, they suffered the direct and indirect effects of malnutrition. At each of the critical three-month periods between 6 and 18 months, close to 40 percent of deaths of children on all four feeding regimens were among those children with symptoms of diarrhea. This observation suggests that no special infection attacked the children taking one or another feeding regimen. Although they all had essentially the same infections, the more children were deprived of adequate food the more frequently they died [26].

The relation of fertility behavior to infant mortality has been studied, and conclusions point out that low age of mother, high birth order, and short spacing between births have significant effects on mortality of infants [27]. In each social class in each culture studied, women of lower economic status had higher rates of mortality among their children.

Early infant mortality

Infant mortality statistics include all deaths from ages 0 to one year. This grouping, if not broken down further, obscures some very significant data. The causes of death are quite distinct in babies under one week, under one month, and over one month, and deaths under one year are not evenly distributed over these periods.

Immaturity, birth injuries, congenital anomalies, asphyxia, and atelectasis of the newborn, and tetanus neonatorum in less developed countries characterize the initial week... fatalities from late effects of causes originating in the early period are features of the remainder of the first months, as are some immediately acquired infections. The deaths of the last eleven months are chiefly from infectious diseases acquired post-neonatally and a progressively increased incidence of malnutrition [28].

Death rates in infants are relatively low during the second to fifth months, and then increase. Later, there is a decline in death rates with age.

Neonatal mortality, that is, deaths occurring during the first 28 days of life, makes up a substantial portion of infant deaths, ranging in developing countries between about 35–60% of total infant mortality [29]. There is a great deal of evidence that deaths in the first few days of life are far less likely to be reported than deaths at any other stage of life, thus the number of neonatal deaths may be even greater than implied by these data.

Low birth weight and tetanus, two important and often preventable causes of very early mortality, serve as examples of the problem:

Low birth weight. There is a strong relationship between birth weight and infant mortality, which has been demonstrated in both developed and developing societies [30]. The cut-off point for normal birth weight derived from studies in developed countries has customarily been set at 2500 grams. The neonatal mortality rate for a U.S. 1960 cohort was 172 deaths per thousand live births at 2500 grams or less, and only 5.5 deaths per thousand for infants with birth weights of 2501 grams or more. Neonatal mortality increased sharply with decreases in birth weight below the 2500 gram level.

Similar relationships were found for China [31] and in the Latin American studies of Puffer and Serrano [32]. In 9 of the 13 Latin American projects low birth weight occurred in more than 60% of the neonatal deaths, and a recent Guatemalan study noted that the birth weight/mortality relationship held not only for the neonatal period but for the entire first year of life [33]. The exact cut-off point at which birth weight predicts greatly increased mortality may differ in different societies, however.

Low birth weight is associated with inadequate nutrition during pregnancy, and with small stature of the mother, a function of early female nutrition [34]. There is evidence that improved maternal nutrition increases birth weight [35]. Studies in India, Indonesia, Pakistan, Iran, Congo, and Ghana, among others, have shown that low birth weight is, logically, associated with mothers of low economic class [36] who tend to be smaller and more poorly nourished both before and during pregnancy.

Neonatal tetanus. Tetanus incidence has considerable variation; annual ranges are from less than one death per 100,000 population to over 32 per 100,000 in developing countries [37]. In fact, in some areas of the world where neonatal deaths are high, deaths from tetanus of the newborn are so frequent that tetanus appears as a major problem of infant mortality. In the Uttar Pradesh area of the Kanpur study, tetanus dominated all other causes of *neonatal* death (53%), accounting for 32% of the total of all *infant* deaths in the area [38]. In 1977, the Bangladesh Ministry of Health and WHO found that in infants "tetanus was the leading cause of death, accounting for 27% of all infant deaths" [39]. In a rural area of Colombia, over 60% of infant deaths were from tetanus [40]. The Berggrens' study of the history of neonatal tetanus in a rural region of Haiti showed it to have caused about half of childhood deaths prior to 1968 [41]. After an intense immunization program, there was a sharp decline in such deaths.

The Pan American Health Organization's study of morbidity and mortality in childhood did not show tetanus as anywhere near as serious a problem in the Americas [42]. We do not know whether this variation is due to differences in immunization, delivery and newborn care practices, environmental conditions or reporting. In Southern Asia, the presence of large animals in rural villages, and the practice of treating

the umbilical stump with cow dung, together with contaminated instruments, may bring about very different results from the Latin American areas studied.

Adult mortality and disability

While childhood mortality accounts for a large proportion of deaths in most developing countries, the disabilities and premature deaths of working age people may have significant impact on the functioning of families and communities. Parental morbidity, even minor and temporary, can disrupt family income and further contribute to the health problems of all family members. Chronic conditions may not only prevent working people from supporting others dependent on them but may even result in such persons becoming additional dependents upon society. Diseases that may have such devastating effects include tuberculosis, leprosy, some parasitic infections, improperly cared for injuries, such as fractures and burns, and losses of limbs. Blindness is also found at much higher levels in many developing than in developed countries. Vitamin A deficiency, onchocerciasis, trachoma, and operable cataracts are all contributory.

Tables 10 and 11 contain estimates of the distribution of days of disability and death by diseases for persons aged 15–44 in some developing countries. These estimates have been computed from data and judgments about attack rates, utilization of health services, and lengths and effects of various illnesses. There are variations in disease patterns from one region to another, as well as possible differences in criteria used for diagnosis.

Changes in causes of death by disease

Breaking down the components of decreases in mortality by disease is difficult [43]. This is partly because of the incompleteness and unreliability of reports and partly because general associated or underlying causes, such as malnutrition, may manifest themselves in a number of different "diseases". The table for Mexico (Table 12) is offered as an illustration of information that is available. Of the reduction in crude death rates from 1498 per 100,000 to 952 per 100,000, reductions in diarrheas accounted for 34%, pneumonias for 16%, and malaria for 16%.

Poverty and death

Throughout investigations of the causes of death is the persistent theme that the sequelae of poverty, in the forms of maternal depletion, low birth weight, undernutrition and understimulation of young children, exposure to infections, limited access to medical care, and lack of knowledge, lie at the base of many different health problems. Studies of who dies early and of the nature of events leading to death both lead to this conclusion.

It should be noted that poverty and low-income per capita are not the same. There are areas, of which the State of Kerala in India and Sri Lanka are outstanding examples, where low per capita incomes and high levels of health coexist. Life expectancy at birth in Sri Lanka is close to 70 years and the crude death rate is 6.3 per thousand [44]. Infant mortality is less than 50 per 1000 live births. Kerala had a crude death rate of 8.4 in 1975 [45] and an infant mortality rate of about 55 per thousand. But Sri Lanka's annual per capita GNP is only $120; Kerala's is even lower at about $96 [46]. Analyzing the causes of the low mortality of these areas, Davidson Gwatkin pointed out the wide and mutually supporting impacts of actions in education, health services, and nutrition, concluding:

the central moral of what's happened in Sri Lanka and Kerala is the importance of general governmental political

Table 10. Percentages of disability days per year, ages 15–44 years

	Pakistan (Punjab)	Indonesia (E. Java)	Ghana (Eastern regions)	Nepal (Terai)
Malaria	15	7	2	1
Complications of childbirth and pregnancy	19	6	28	1
Diarrheas, enteric fever	20	41	26	5
Diseases of the gen-urin system	6	—	.	—
Lower respiratory infections	9	3	1	6
Anemia	8	.	.	11
Accidents	1	5	7	1
Acute upper respiratory infections	7	—	—	49
Tuberculosis	4	9	3	9
Skin diseases	2	—	—	1
Diabetes	1	—	—	—
Intestinal parasites	—	18	1	13
Heart; c.v. disease	1	3	4	—
Typhoid fever	.	4	9	—
Hepatitis	—	2	5	
Yellow fever	—	—	4	—
Cirrhosis of liver	—	—	3	—
Hypertension	—	—	1	—
Other	7	2	6	3
Total	100	100	100	100

Source: Research Seminar in International Health, School of Public Health, The University of Michigan, 1978.
See sources, Table 9.

Table 11. Percentage distribution of deaths, ages 15–44 years

	Pakistan (Punjab)	Indonesia (E. Java)	Ghana (Eastern regions)	Nepal (Terai)
Tuberculosis	15	15	10	36
Lower respiratory disease	3	5	4	14
Stroke, heart, and c.v. disease	1	12	16	
Diarrheas, cholera	10	17	16	11
Complications of childbirth and pregnancy	20	22	15	2
Typhoid fever	—	15	8	—
Malaria	10	7	—	—
Enteric fever	40	—	—	
Anemia	—	—	—	15
Accidents	—	—	—	4
Tetanus	—	3	—	11
Meningitis	—	—	9	—
Cirrhosis of the liver	—	—	8	—
Hepatitis	—	—	4	—
Genito-urinary diseases	1	—	—	—
Diabetes	—	—	—	—
Yellow fever	—	—	3	—
Acute abdominal disease	—	—	—	6
Other	—	4	7	1
Total	100	100	100	100

Source: Research Seminar in International Health, School of Public Health, The University of Michigan, 1978.
See Sources: Table 9.

commitment to the poor majority for the achievement of both nutrition and health objectives [47].

Given the greater concentration of health resources in urban areas and the generally higher levels of income, education, and sanitary systems, one might expect mortality and morbidity to be less devastating in cities than in rural areas. Yet, dependence on money for food, decreased breast-feeding, malfunctioning water and sewage facilities, and crowded living and working conditions are factors of city life that may exacerbate ill health. Nonetheless, most studies indicate that mortality is, indeed, higher in the rural areas of Africa, Latin America, and Asia than in the cities [48]. These aggregate figures, however, may obscure some crucial facets of reality, especially in urban areas: though there may be a larger percentage of poor people in rural areas, the poor who *do* live in cities may face equally or more dismal health prospects. A description of the nutritional and health characteristics of cities in developing countries makes the following observation:

> Though health facilities are more abundant in cities, university training and specialty hospitals do not generally cater to the needs of the masses. More diseases may be contracted and spread in urban centers through contaminated water and close contacts. Decreased breast-feeding in cities... may cause serious nutritional problems for infants and young children [49].

Finally, while the focus of this discussion has been on mortality—largely because data has been better developed for mortality than for other measures of health and their consequences—it is important to note that the difficulties of those who manage to survive malnutrition, diarrheas, and infections are per-

Table 12. Death rates per 100,000, by disease class, Mexico 1952–67

Disease class	Death rates 1952	Death rates 1967	Change in death rate 1952–1967	% change in disease/of total	
Dysentery, gastr. typhoid, cholera	288	104	183	64	34
Pneumonia	206	118	88	43	16
Malaria	85	0	85	100	16
CNS & heart, etc.	94	56	38	40	7
Trauma	95	68	27	28	5
Dip/pertussis	35	12	23	65	4
Tuberculosis, res.	32	19	14	42	3
Other	472	450	22	5	4
Undefined	145	84	61	42	11
Total	1498	952	547	37	100

Source: United Nations, *Demographic Yearbooks*, 1957 and 1974.

haps the greatest health problems of all. Their lives and those of their children will be altered by long-range effects, not only on health and reproduction but on intelligence, productivity, and adaptive behavior [50]. These consequences of poverty in developing countries are only suggested by mortality data.

CORRELATES OF LIFE EXPECTANCY IN LESS DEVELOPED COUNTRIES

The fact that life expectancy at birth has risen about 10 years over the past two decades in most of the less developed countries should not be taken to mean that, over time, more substantial improvements will occur inevitably. Continuing improvement may be slowed if all aspects of socioeconomic development do not move in balance. The contemporaneous rises in economic levels, social well-being, and health service investments that took place in the more developed countries may not automatically repeat themselves in the less developed countries.

In order to understand the processes by which mortality has fallen in less developed countries, it is useful to identify the forces that have determined the course of mortality experience to date, and which may predict the mortality experiences of the future. The next section of this paper attempts to identify factors that determine life expectancy at birth and changes in life expectancy over time.

There has long been argument over whether economic growth or social and health programs account for most of the large gains in life expectancy observed in developing countries. One commonly held hypothesis is that economic conditions, alone, are losing their historically strong power to predict levels of mortality at all levels of development. This hypothesis was explored by examining the relative contributions of different aspects of economic development, social, and health indicators to levels of mortality. Data from 90 countries classified as "less developed" were used in the analysis [51]. Developed-country data and data from any country with a population of less than 1 million were excluded.

Some of the more interesting findings from the data analysis include:

1. There is a strong and significant correlation between per capita income and level of life expectancy.
2. There is *no* correlation between income per capita and years gained in life expectancy ("absolute improvement" in life expectancy).
3. If life expectancy is already at relatively higher levels, its improvement over time is relatively less.
4. At later time periods, each year improvement in life expectancy appeared to require more economic gains. (In 1960–65, 10 years of additional life expectancy at birth implied a gain of $300 per capita, whereas for 1970–75, ten additional years of life expectancy was associated with a rise of $500 per capita; see Fig. 1).

These findings agree with the suggestion of other mortality studies that the level of economic production in a nation is not associated with changes in life expectancy and that the relationship of economic performance to level of life expectancy has become less important with the passing of time.

Variables aside from income are also associated with life expectancy. Five groups of factors were explored to determine their relationship with expectation of life at birth:

1. Sanitation (power and utilities usage and availability)
2. Health expenditures (including various pharmaceutical imports)
3. Health personnel and facilities
4. Economic indicators (revenues, expenditures, employment, GNP/caput, exports and imports, income distribution)
5. Social indicators (literacy, nutrition, transportation, and communication).

Three categories were dominant in accounting for levels of life expectancy. These were sanitation (represented by percent of urban population with water taps), economic (represented by percent of labor force in agriculture), and social (represented by per cent literate). The most important indicator was the social, which explained 78% of the variation in life expectancy by itself. The addition of the sanitation factor increased the variation explained to 88%, while the addition of the economic factor added only an additional 2% to bring the total variation in life expectancy at birth explained to 90%. For infant mortality in 1974, social indicators (literacy) predominate, accounting for about 75% of variation. Here, the importance of literacy was so overwhelming that no additional explanatory power was added by inputs in the other four categories.

This was a considerable change from the 1960–65 regression model results. For that period's data the economic variable alone explained 49% of the variation. The addition of the social variable raised the percentage of the variation explained to 71%. Addition of any of the other variables to the model, once the economic and social variables are included, did not increase, significantly, the total correlation or the amount of variation explained.

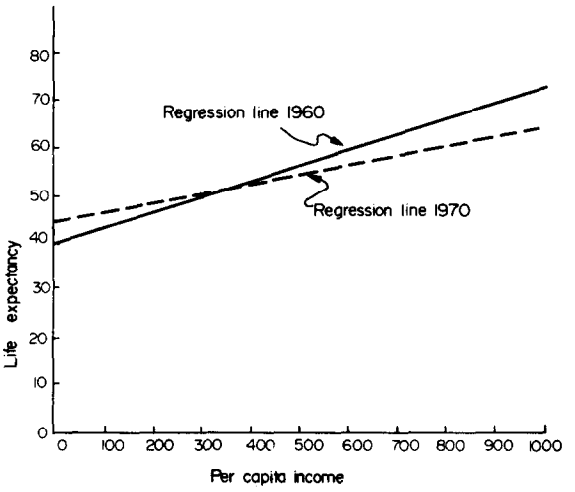


Fig. 1.

In determining what "explains" mortality and changes in mortality, it is necessary to consider many variables, resources, and environmental conditions. At any given level of mortality, all of the factors make contributions. The question of which factors to increase, and by how much, in order to improve the outcome is answered by testing the effect of small changes in different variables on the final level of mortality. It is essential to remember that the marginal productivity of any improvement is related closely to the simultaneous utilization of the other factors. The relative costs of different interventions are significant considerations, which must be viewed in relation to outcomes.

In this work, we have sought the "social production functions" that relate actions in society to the desired outcomes, represented by gains in life expectancy. The great interdependency of factors affecting health is paralleled by interdependencies of other factors affecting development. The weakening power of income per capita to predict levels of health in developing countries has been noted frequently [52]. Our tentative conclusions support the initial idea that income per capita explains only a fraction of life expectancy variations and is lessening in power to do so. Although many assert that disease control programs and medical technology must, therefore, have been responsible for favorable trends in mortality decline, we found that health inputs (expenditures, personnel, facilities) and sanitation facilities were much less able to explain variations in levels of life expectancy than were social factors.

This seems quite consistent with conclusions of the second section of this paper: that infant feeding practices, personal hygiene, fertility behavior, and nutrition (with emphasis on distribution rather than production problems) are critical. Areas with both low income per capita *and* low mortality, such as Sri Lanka and Kerala, did not have large amounts of health resources per capita but rather placed these resources among the rural people [53]. These distributional policies are in contrast to the frequent pattern in developing countries of concentrating the bulk of health resources in large urban areas. Stocks of physical and human resources are necessary, but it is their distribution that brings useful effects.

RESOURCE ALLOCATION IN THE HEALTH SECTOR

The health portions of the development plans of many developing countries in the 1970s appear to have striking similarities in objectives. It seems generally accepted that (1) it is the role of government to redistribute health services to the poor and to the rural areas, both previously underserved; (2) prevention is both better and cheaper than cures; (3) previous medical training has been inappropriate and should undergo reorientation; and (4) the bulk of the health services must be delivered by paramedical and auxiliary personnel [54].

Implementation of these objectives, however, seems slowed by internal and external constraints and planning seems fraught with contradictions. Budgets, site selections, facility authorizations, and training do not usually show as significant a shift in emphasis towards rural poverty areas, prevention, and paramedical activities as might be expected from the stated objectives. Further, actual allocations and expenditures seem heavily skewed towards more complete use of authorized money in cities, for hospitals, and for physicians' training [55].

Explanations for these patterns vary by country. In the case of Guatemala, for example, while the national economic development plan specified the additional population to be covered each year and in each province, the plan did not develop any mechanisms for implementing these objectives, which had been termed the highest priority health need. Activities funded under the new plan were much the same as those previously carried on under other titles. Little attempt was made by the economic planning body, the Finance Ministry, or the Ministry of Health, to analyze methods of achieving objectives, to specify programs, projects, or authorities, or to monitor accomplishment of goals [56]. In most countries, the sophisticated urban organizations, such as hospitals and medical schools, are best able to arrange contracts and assure a flow of resources. In one African country, district hospitals spent 110% of their allocations, while rural health posts used only 14% of what they had been allowed by the development plan [57]. This is no doubt the extreme of an occurrence that is neither unusual nor unexpected.

While there may be general agreement that primary health care is a desirable policy, there remain questions about the costs and health effects of different patterns of such care, including the numbers and types of personnel, their training, locations, and duties. What will be the effects of particular choices of services, delivery modes, and personnel on the utilization of services? On the effects of services? What investments should be made in rural sanitation? In nutrition? Should programs rely on chemical prophylaxis or vector control? Finally, calculations of potential effectiveness of program actions are not sufficient by themselves to determine what course should be adopted. Resource requirements and costs of program alternatives must also be taken into account.

In addressing issues of resource allocation, two interrelated questions need to be answered. First, at any stipulated budgetary level, which combinations of activities minimize mortality and disability? The answer to this question would give guidance in selecting the appropriate programs of intervention at any budget level chosen, but does not answer the question, "What should be the level of the health budget?"

To answer this second question, we must examine changes in health effects associated with changes in budget levels, with a "most effective" combination of activities at each level. The costs need to be compared by parallel analyses of the effects of budgetary changes in other sectors of society, such as education, agriculture, transport, etc. The social values of trading health effects for other social goods need to be determined—in terms of the value of specific gains in one social sector as opposed to another. Analysis of the health sector alone, while it gives us information on health effects, is insufficient to determine the "best" level of health activities from society's overall viewpoint. Yet, such information, even in the absence of complementary analyses, may assist decision-makers

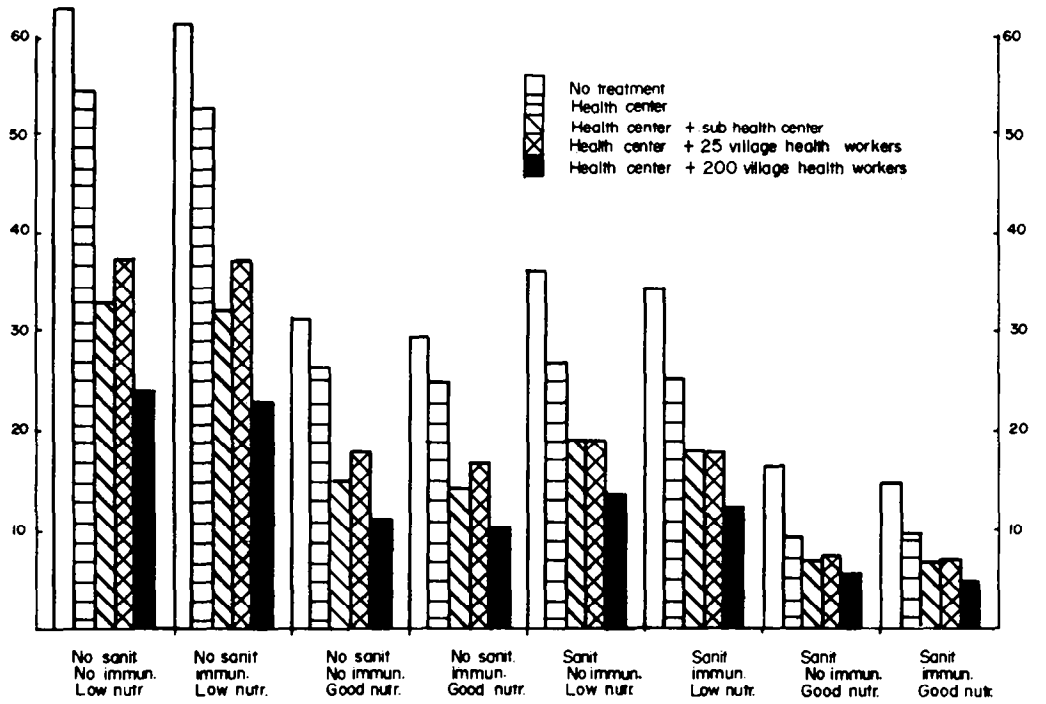


Fig. 2. Mortality per 100 population, 0–4 years (rural Java, 1 health center per 50,000 people in 25 villages).

by giving an idea of what specific health gains might be associated with different levels of spending.

A collaborative research effort of epidemiologists, environmental health scientists, medical care analysts, health officers, and economists from both less- and more-developed countries has been designing a model that can be used as a framework for calculating the health effects and costs of alternative programs [58]. The group has developed "disease profiles" of rural areas of several countries, which include attach rates by age class, utilization of health services, and estimates of the effects of using (or not using) particular medical care services, such as sanitation, nutrition, immunization and vector control, on case fatality rates and days of disability.*

Figure 2 shows postulated effects on child mortality of different combinations of care in rural Java. The estimates, which are tentative and illustrative, are derived from existing surveys, studies, and observer judgment. To give an idea of how the model can be used, some exercises using a fixed budget and several alternative resource allocation strategies are presented for Indonesia, Ghana, and Pakistan. For each alternative, with a fixed total five-year cost, the effectiveness model was used to calculate deaths and days of inca-

* See Appendix for Technical Notes on these calculations.

Table 13. Indonesia: Age-specific mortality and morbidity under alternative medical care delivery system funded equally $61,800,000 for 5 years; East Java—population 30,000,000

	Organization of health delivery system for each 50,000 pop. district	Coverage: Pop. covered at U.S. $61,800,000 for 5-year outlay	Mortality: Death–1000 0–4	Mortality: Pop./year All ages	Morbidity: Days/person/year 15–44	Morbidity: Days/person/year All ages
A	Health Center *only*	100	51.8	12.4	3.1	11.4
B	Health Center, 8 Sub-Health Centers	37	52.3	12.5	3.1	11.3
C	Health Center, 8 Sub-Health Centers, 200 Village Health Workers, immunization	10	59.1	13.9	3.1	11.5
D	Health Center, 8 SHC, 200 VHW, immunization, sanitation, nutrition	5	60.7	14.2	3.1	11.4
E	25 VHW, immunization	65	44.4	10.9	3.0	10.7
F	25 VHW, nutrition, immunization	29	58.9	12.6	3.1	10.9
G	25 VHW, sanitation	13	57.4	13.6	3.0	11.0
H	25 VHW, sanitation, nutrition	10	58.2	13.7	3.0	11.1
I	200 VHW, nutrition, sanitation	6	60.3	14.3	3.1	11.4
J	200 VHW, nutrition, sanitation, immunization	6	60.1	14.2	3.1	11.4

Table 14. Pakistan: Age-specific mortality and morbidity rates under alternative medical care delivery system funded equally $150,000,000 for 5 years: Rural Punjab—population 30,000,000

	Organization of health delivery system for each 50,000 pop. district	Coverage: % Pop. covered at U.S. $150,000,000 for 5-year outlay	Mortality: Death/1000 0–4	Mortality: Pop./year All ages	Morbidity: Days/person/year Male, 15–44	Morbidity: Days/person/year All ages
A	Rural Health Center *only*	92	49.7	17.82	7.3	17.81
B	Rural Health Center immunization	79	32.2	13.44	7.1	15.05
C	Rural Health Center malaria control, immunizations	62	37.4	14.37	6.3	15.18
D	Rural Health Center, 10 Basic Health units, 80 Village Health Workers, nutrition, immunizations	32	44.0	15.91	7.2	16.41
E	Rural Health Center, 3 Basic Health Units, sanitation, immunizations, nutrition	21	47.2	16.25	7.0	16.82
F	Rural Health Center, 8 Basic Health Units, 60 Village Health Workers, 16 Hakims, sanitation, immunization	19	48.4	16.54	7.0	16.97
G	Rural Health Center, 16 Hakims, 120 Village Health Workers, nutrition	59	36.1	13.99	6.9	16.27
H	Rural Health Center *only* 8 Basic Health Units	28	53.6	18.28	7.3	17.96
I	Malaria Control, nutrition, immunization	99	19.2	12.91	5.8	9.3

pacitation for each disease for each age category. The different interventions studied included curative medical care, immunizations, nutrition programs, and sanitation programs of various types. Medical care alternatives were examined for trade-offs between effectiveness and utilization as large numbers of lesser-trained personnel are brought into the system. Logically, with more expensive packages of programs, fewer of the population can be covered by the programs at the same cost.

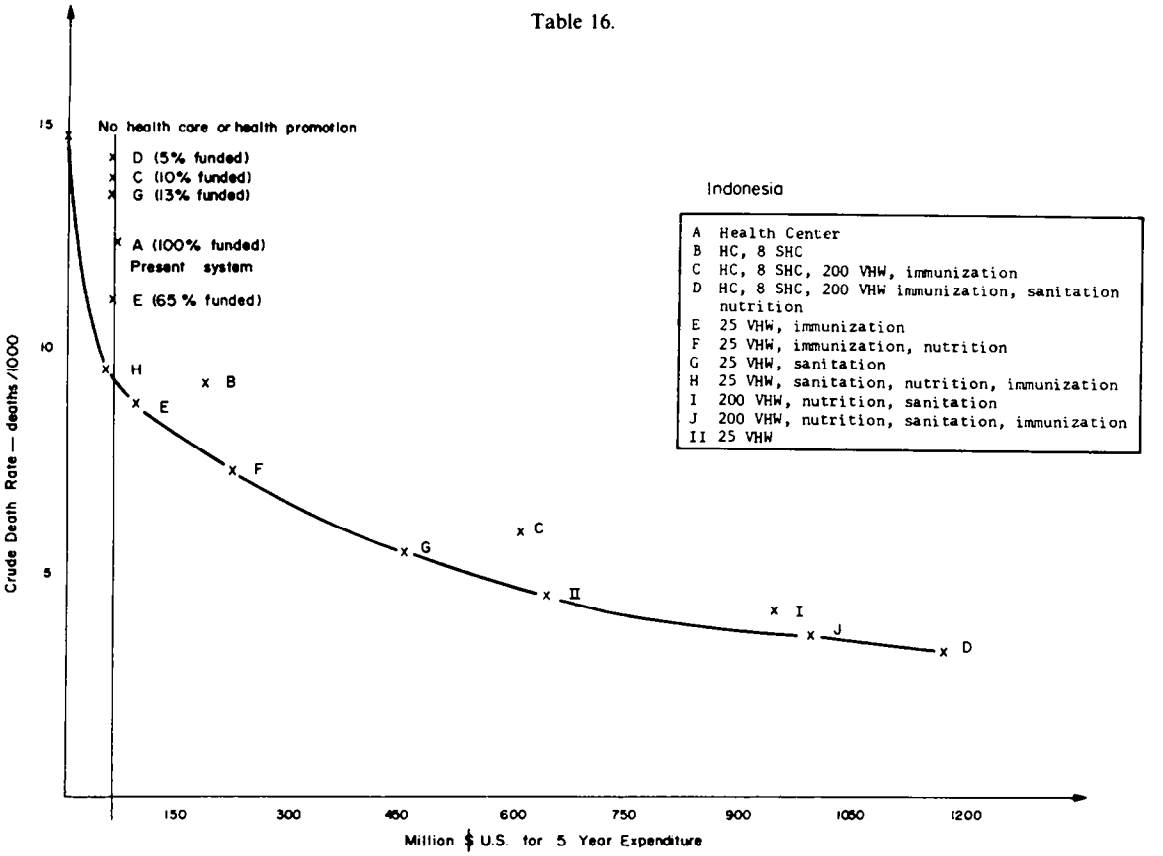
Tables 13–15 demonstrate the different morbidity and mortality outcomes for 10 alternative health schemes, at fixed funding, in Indonesia, Pakistan, and Ghana. Tables 16–18 demonstrate the different effects on mortality of the same 10 interventions with variations in funding levels. Calculations such as these have many uncertainties, but they do attempt to summarize what is known about the health behavior of a population, the epidemiology of a region, the utilization and efficacy of various medical care delivery systems, the possible effects of preventive programs, and what has been learned from previous interventions. This provides an estimate, on the basis of existing knowledge and judgment, of the consequences of alternative health promotion strategies at different levels of budget and manpower constraint.

Conclusions from the calculations are tentative and region-specific, yet there are some generalizations that

Table 15. Ghana: Health benefits of equal resource allocation to alternative health care delivery system in rural eastern Ghana, population 250,000

	Organization of Health Delivery Service for Each District	Coverage: % Covered at fixed 5-year budget of U.S. $4,130,000	Mortality: Deaths/1000 0–4	Mortality: Pop./year All ages	Morbidity: Days/person/year 15–44	Morbidity: Days/person/year All ages
A	1 Hospital, 1 Health Center, 2 Health Posts for each district, no healt promotion activities	100	90.1	24.9	8.9	20.9
B	1 Hospital, 1 Health Center, 2 Health Posts for each district, sanitation, nutrition, immunization	39	83.0	24.0	8.8	19.2
C	1 Hospital, 20 Health Stations, nutrition, sanitation	19	101.6	28.4	9.2	21.2
D	1 Hospital, 20 Health Stations, nutrition, sanitation, immunization	18	98.6	27.7	9.2	20.7
E	1 Hospital, 20 Health Stations, 300 Village Health Workers, sanitation	18	98.9	27.5	9.0	20.8
F	No curative system, sanitation	79	92.3	27.3	8.6	20.0

Table 16.



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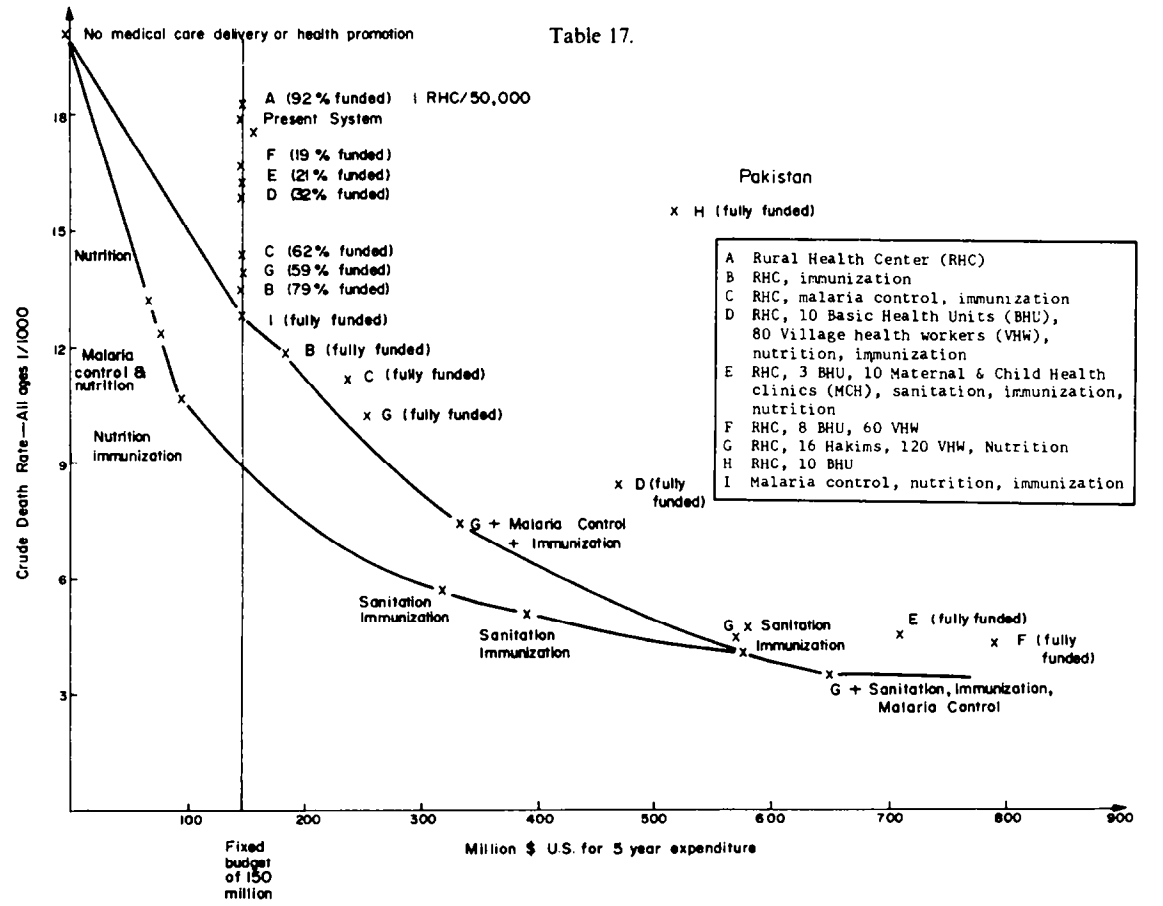

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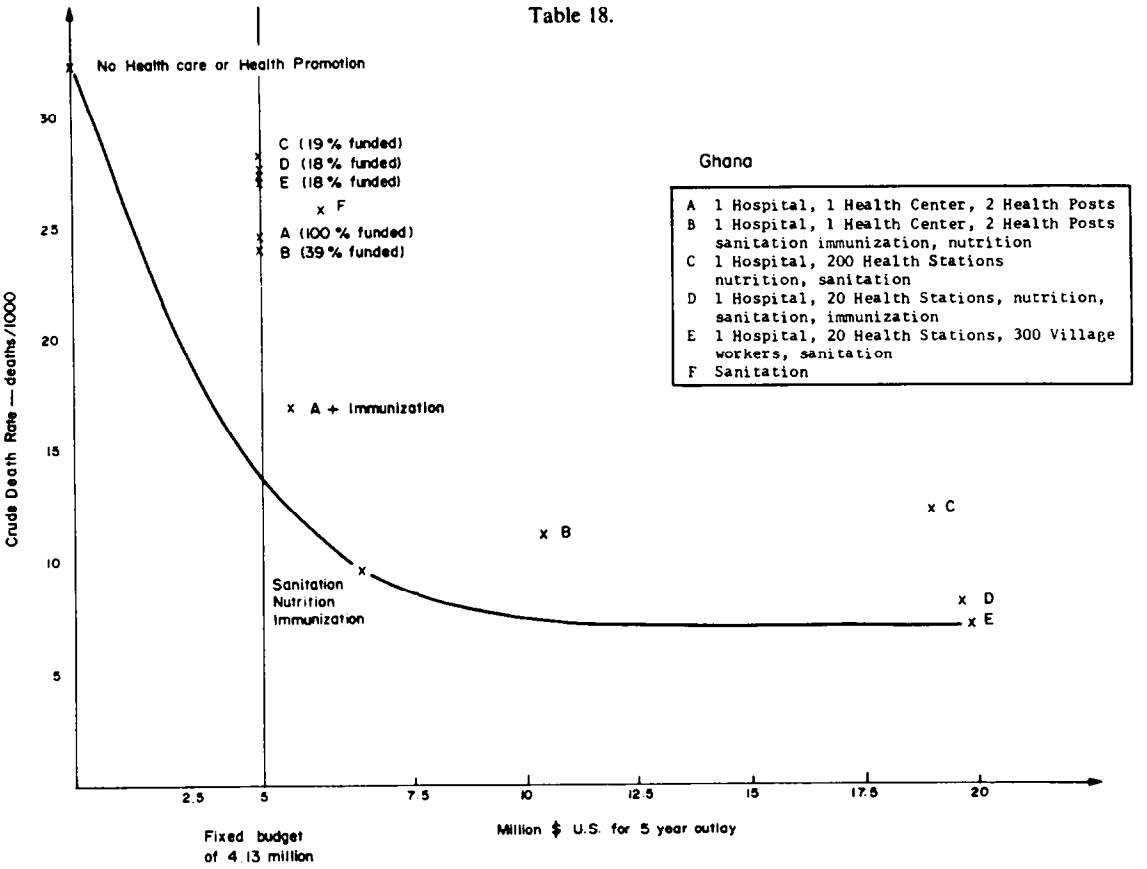

emerge. One is that the effectiveness of village health-worker systems is related to the available resources and the worker-population ratio in an area. Analysis has indicated that in Indonesia it is probably more effective to allocate additional resources to upgrade the training of village health-workers than to provide more of them for the population in each area [59]. While there always appear to be gains in health status associated with adding sanitation programs, an even greater effect on health status can be achieved with the same resources by adding immunization and nutrition programs instead. These analytic conclusions need to be tested by careful evaluation of alternative programs in the field.

CONCLUSION

Significant improvements in the health of people in developing countries has occurred throughout the past several decades, as measured by life expectancy at birth. The levels that have been reached in most developing countries, however, are well below what could be attained. Most distressing are the high mortality levels for infants and children.

The direct causes of this high mortality are linked to the many dimensions of poverty, and assert themselves, in health terms, overwhelmingly in the "malnutrition–diarrhea–respiratory infection" triad. Food availability, feeding practice changes, hygiene and sanitation practices, oral and other rehydration, and immunizations against childhood infections, particularly pertussis, tetanus, and measles, are candidates for health sector action. Statistical analysis indicates that, among the variables for which comparable information is available, social factors (represented by levels of literacy and school enrollment) seem dominant explainers of variations in infant mortality and life expectancy among developing countries. Communication and availability of information may play critical roles in health maintenance. In choosing among the policies for the improvement of health, resource constraints need to be taken into account by relating activities both to their effects and their costs.

In summary, the situation is far from hopeless, The major causes of excess mortality in infants and children are known, and means of reducing such mortality are also known. The costs of applying some of these interventions may be high, relative to resource availability in developing countries. Care must be taken to select the interventions and their mode of delivery that will yield the greatest results for the resources expended.

APPENDIX A

This Appendix describes the process of deriving correlates of life expectancy in less developed countries.

First, the relationships between economic level alone and level of life expectancy, as well as economic level and *change* in life expectancy, were examined. Simple correlations for the data used demonstrate that in developing countries when income alone is examined there is a strong and significant correlation between per caput income and level of life expectancy, but no correlation between *absolute changes* in life expectancy and level of income per caput (Table 19 and Figs 3 and 4).

Table 19. Some variables examined and their correlations

Independent variable	Dependent variable	r	r^2	Significance level
Per capita income 1960	Life expectancy at birth, 1970–75	0.72	0.52	$P < 0.01$
Per capita income 1970	Life expectancy at birth, 1970–75	0.66	0.44	$P < 0.01$
Per capita income 1960	Life expectancy at birth, 1960–65	0.75	0.56	$P < 0.01$
Log of per capita income, 1960	Life expectancy at birth, 1960–65	0.79	0.63	$P < 0.01$
Log of per capita income, 1970	Life expectancy at birth, 1970–75	0.77	0.59	$P < 0.01$
Per capita income 1960	Change in life expectancy, 1950–55 to 1970–75	−0.15	0.02	NS
Per capita income 1970	Change in life expectancy, 1950–55 to 1970–75	0.02	0.004	NS

r = correlation coefficient, r^2 = proportion of variation explained.

Percentage changes in life expectancy and percentage changes in income were also compared. A small but significant negative correlation was found between level of income and percent change in life expectancy. This is consistent with the expectation that if life expectancy is already relatively better in higher income countries, its change over time will be proportionately less.

From these correlations, we can conclude that levels of mortality at any one time are related to average levels of income, but that variations in changes in mortality over time are not. Also, as higher incomes and life expectancies are examined, the ratio of income to life expectancy becomes less (a flattening of the curve on an arithmetic scale). A comparison of the regression lines between life expectancy in 1960 and in 1970 as compared to income per capita (in 1970 U.S. $) is shown in Fig. 1 (see text). The slopes of the lines are different, with that for 1960 being somewhat steeper. This can be taken to mean that, in 1970 as compared to 1960, increases in life expectancy required more economic improvement for each year gained.

Variables aside from income are also associated with life expectancy. The relative importance—and the changes in importance over time—of each of the major variables which determine mortality rates were next explored. Multiple regression analyses using more than 300 potentially explanatory variables were performed in a search for cau-

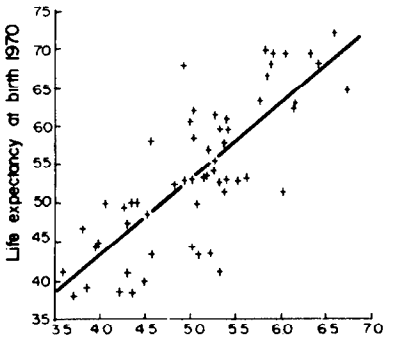

Fig. 3.

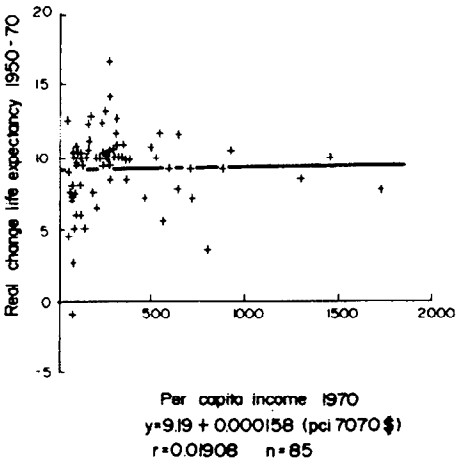

Fig. 4.

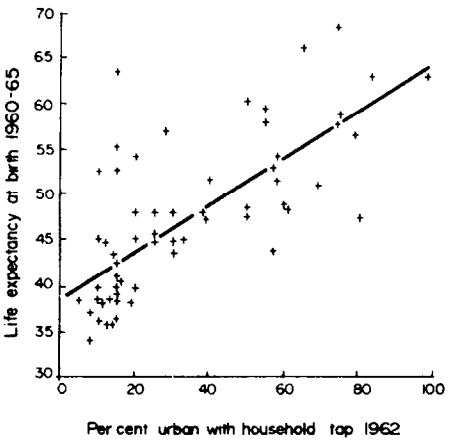

Fig. 5.

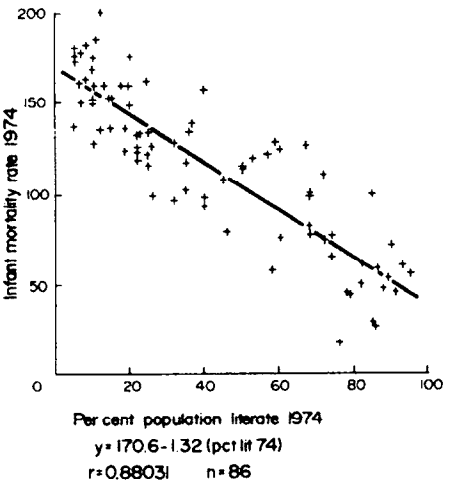

Fig. 6.

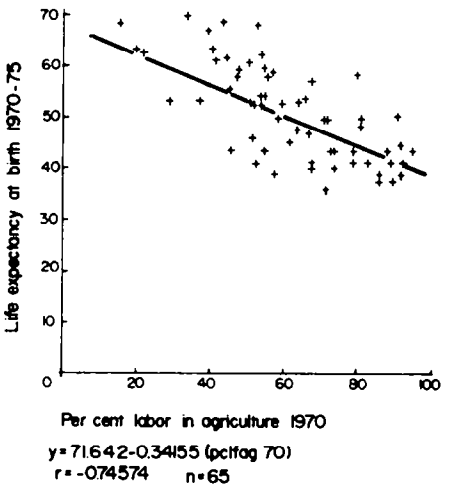

Fig. 7.

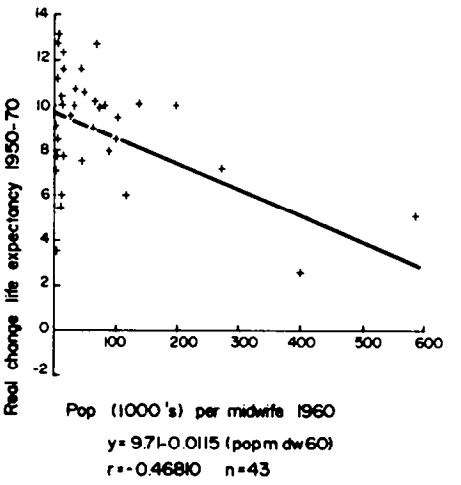

Fig. 8.

sal patterns. The data were grouped into five categories, suggestive of broad program areas: sanitation, health expenditures, health personnel and facilities, economic indicators, and social indicators.

Stepwise multiple regression was used to show the relative impacts of different sets of variables and their combinations on life expectancy—and the changes in these impacts over time. The largest source of error in this calculation was likely to result from the limited numbers of observations for each variable. To address this weakness, the maximum number of countries is included at each step of the analysis.

Table 20. Simple and multiple correlation coefficients for association with level of life expectancy in the 1960–65 period

Independent variable	Simple correlation coefficient		1st level multiple regression (R)		2nd level multiple regression (R)
Utilities (power and sanitation):					
5004 Per capita electrical consumption (kWh)	0.750 (67)	*			
5006 Percent of urban population with household public water taps	0.729 (65)	*□	0.830		
5011 Percent of urban population with access to standpipe	−0.291 (65)		(49)		
5014 Percent change, urban access to standpipes	−0.262 (57)	*			
5016 Urban total water coverage (tap or standpipe)	0.648 (65)				
Health expenditures:					
3079 Total expenditure on health	0.262 (86)	*□	0.355		
3081 Per capita health expenditure	0.361 (85)		(54)		
8001 S.I.T.C. 541 total imports (medicinal and pharmaceutical products)	0.408 (56)				
Health personnel and facilities					
6000 Total number of hospital beds	0.286 (58)		0.564	*	* 0.915
6008 Population per general hospital	−0.346 (50)		(44)		(29)
7001 Population per doctor	−0.551 (64)	*□			
Economic variables:					
3006 Per capita national income	0.750 (59)	*□			□ 0.841
3020 Percent of labor force in agriculture	−0.789 (58)	*	0.793	*□	(38)
3022 Percent of G.D.P. derived from agriculture	−0.461 (47)		(35)		
3045 Total imports and N.F.S.	0.280 (54)				
3049 Merchandise exports	0.307 (54)				
3053 Total exports of good and N.F.S.	0.362 (54)				
Social indicators:					
2006 Primary school enrollment as a percent of children 6–11 years old	0.532 (74)	*□			
2008 Secondary school enrollment as a percent of children 12–17 years old	0.745 (77)	*			
2012 Radios per 1000 population	0.525 (78)		0.915	*□	
2014 Automobiles per 1000 population	0.690 (63)	*	(52)		
2019 Per capita available kilocalories per day	0.564 (76)				
2022 Percent of required calories	0.317 (65)				

* The starred variables are the selections resulting from the 5 intra-group analyses. In some cases, only very small numbers of countries existed for which all these data were available. Where this was the case, subsets of variables were combined (indicated by □) to provide a larger number of observations for the final regression equations.

Zero order or bivariate correlations were performed with four dependent variables: life expectancy 1960–65; life expectancy 1970–75; change in life expectancy from 1950 to 1975; and infant mortality in 1974.

Plot diagrams for some of the more interesting bivariate regressions are shown in Figs 5, 6, 7, and 8. (Life expectancy at birth positively correlated to percent urban with tap; infant mortality rate negatively correlated to percent literate; life expectancy negatively correlated to percent labor in agriculture; change in life expectancy negatively correlated with population per midwife.)

After selecting those variables that had the highest correlations with the health indicators, a 2-step process of regression was performed. First, the most significant correlates within each of the 5 categories of explanatory variables were selected. Second, the strongest correlates of all 5 categories were combined to see the relative importance of each in determining levels of life expectancy—and changes in life expectancy—in the presence of the other explanatory variables. Tables 20–23 illustrate the process and show the results of the stepwise regressions.

As an example of the results of this analysis, one can examine the relationship of utilities (power/sanitation) to life expectancy in the 1970–75 period. For the 38 countries with recorded information on seven indicators in this area, the effects of (1) access to electricity, and (2) percent of urban population with household taps accounted for virtually all of the association between power/sanitation and life expectancy: no *additional* explanatory power came from the other five urban and rural sanitation measures.* This is not to say that remaining variables are insignificant in their impact on life expectancy. It does suggest that their real relationship with life expectancy may well be through *other* variables to which they are also related.

After a similar procedure was followed for each of the 5 major areas, life expectancy in the 1970–75 period was examined as a function of the strongest representatives from each of the five groups. Sanitation, economic, and social variables were dominant explanatory variables.

The variation in life expectancy explained by each of these was:

Sanitation (in presence of economic and social variables) 38%

Economic (in presence of sanitation and social variables) 12%

Social (in presence of economic and sanitation variables) 60%.

* The combination of electricity and urban household taps yielded a multiple correlation coefficient (r) of 0.86, associated with 73% (r^2) of the variation in life expectancy in 1970–75. Because of this, subsequent selection of sanitation proxies came only from this group of two. In fact, a final stepwise regression was performed only with the electric consumption variable consistent with efforts to include as many countries as possible in the final regression.

Table 21. Simple and multiple correlation coefficients for association with level of life expectancy in the 1970–75 period

Independent variable	Simple correlation coefficient		1st level multiple regression (R)		2nd level multiple regression (R)
Utilities (power and sanitation):					
5004 Per capita electrical consumption (kWh)	0.717 (67)	*†			
5007 Percent of urban population with household public water taps	0.612 (74)				
5008 Percent of urban population with household public water taps	0.721 (56)	*□	0.855 (38)	*□†	
5017 Urban total water coverage (tap or standpipe)	0.278 (73)				
5033 Percent rural population with some form of excreta	0.399 (58)				
5024 Percent of total population with water	0.563 (69)				
5027 Percent urban population with in-house public excreta disposal system	0.483 (62)				
Health expenditures:					
3079 Total expenditure on health	0.276 (86)	*□†	0.486 (51)		
3081 Per capita health expenditure	0.362 (85)				
8001 S.T.I.C. 541 total imports (medical and pharmaceutical products)	0.407 (56)				
8009 S.T.I.C. 554 total imports (soap, cleansing & polishing preparations)	0.478 (53)	*			* 0.97 (30)
Health personnel and facilities:					□ 0.948 (47)
6000 Total number of hospital beds	0.275 (58)				
6008 Population per general hospital	−0.361 (50)				† 0.851 (63)
6019 Population per hospital bed	−0.369 (85)		0.719 (21)	†	
7004 Population per physician	−0.676 (85)	*□†			
7035 Population per midwife	−0.281 (51)				
7037 Population per nurse	0.303 (69)				
7040 Population per lab. technician, lab. assistant	−0.266 (63)				
Economic variables:					
3007 Per capita national income	0.661 (85)		0.746 (65)	*□†	
3021 Percent of labor force in agriculture	−0.746 (65)	*□†			
Social indicators:					
2004 Percent of population literate	0.881 (85)	*□			
2005 Percent of children 5–19 in school	0.772 (85)		0.910 (66)	*□	
2013 Radios per 1000 population	0.597 (67)				
2021 Per capita available kilocalories per day	0.642 (85)	*†			

* The starred variables are the selections resulting from the 5 intra-group analyses. In some cases, only very small numbers of countries existed for which all these data were available. Where this was the case, subsets of variables were combined (indicated by □ and †) to provide a larger number of observations for the final regression equations.

Table 22. Simple and multiple correlation coefficients for association with absolute change in life expectancy 1950–55 to 1970–75

Independent variable	Simple correlation coefficient	1st level multiple regression (R)	2nd level multiple regression (R)
Utilities (power and sanitation):			
5000 Percent of dwelling units without piped water	0.532 (33) *	0.569 □	
5018 Urban total water coverage (tap or standpipe)	0.308 (56) †□	(21)	
Health expenditures:			
3079 Total expenditure on health	0.310 (86) †□	0.328	
8008 S.I.T.C. 541.9 total imports (pharmaceutical goods other than medicaments)	0.324 (51) *	(50)	
Health personnel and facilities:			
6019 Population per hospital bed	−0.243 (85)		
7004 Population per physician	−0.330 (85) □	0.681	
7006 Population per nurse	−0.273 (52)	(25)	
7010 Population per midwife	−0.468 (43) *†		†0.527
7035 Population per midwife	−0.304 (51)		(26)
7037 Population per nurse	−0.263 (69)		
Economic variables:		0.283	□0.317
3078 Total expenditure on education	0.283 (86) *†□	(86)	(53)
Social Indicators:			
2002 Percent of population literate	0.247 (64) *		
2003 Percent of population literate	0.220 (82) †□	0.386	
2006 Primary school enrollment as a percent of children 6–11 years old	0.345 (74)	(56)	
2009 Secondary school enrollment as a percent of children 12–17 years old	0.260 (79)		

* The starred variables are the selections resulting from the 5 intragroup analyses. In some cases, only very small numbers of countries existed for which all these data were available. Where this was the case, subsets of variables were combined (indicated by □ and †) to provide a larger number of observations for the final regression equations.

Because of multicollinearity, these percentages are not additive, but do serve to suggest a difference in relative importance of each in the presence of the other two.

In a similar manner, health personnel (population per midwife) or sanitation (urban water coverage) dominated as explanations for variation in *changes* in life expectancy from 1950 to 1970 (Table 22). Using the 26 countries that had complete data for the 5 areas, the health personnel and facilities indicator (population per midwife) had a correlation of 0.53 with change in life expectancy, accounting for 28% of the variation. No further explanation of the change in life expectancy 1950–1970 came from any of the other four areas. Switching the health personnel indicator to population per physician (to increase to 53 the number of countries that could be included in the analysis) again yielded only one significant correlate from the group of 5: the sanitation variable (urban total water coverage) accounted for 10% of the variation, no additional variation explained by any of the other four areas. In general, correlates with the change in life expectancy, as contrasted to level of life expectancy at one point in time, were much more difficult to find. These tentative results suggest that the causes of variations in these changes will not be found directly in any of the measures usually considered.

Because of the interrelatedness of all the variables in the model, it must be emphasized that, in the real world, isolated changes in any one independent variable would not be expected to produce the associated level of change in dependent variables unless other background, independent variables also conform to the specifications of the model.

APPENDIX B

It may be helpful to indicate the way in which effectiveness of different interventions is calculated in the model:

Let:

R_{ij} = attack rate per person in age class j of disease i
P_j = number of population in age cohort j
N_{ijk} = proportion of people in age cohort j with disease i who seek and receive care from source k
F_{ijk} = case fatality rate of disease i in age cohort j when utilizing medical care from source k
$\bar{F}_{ij}$ = case fatality rate of disease i in age cohort j for those who do not use medical care
D_{ijks} = days of disability of level s associated with disease i in age cohort j of those who seek care from delivery source k
$\bar{D}_{ijs}$ = days of disability at disability level s associated with disease i in age cohort j who do not use medical care.

The effectiveness calculations have two major portions. One multiplies population by attack rates ($R \times P$). The other calculation is a composite age and specific disease death or disability rate made up of a weighted average of individual rates based on receipt or lack of receipt of care.

Then:

Number of deaths

$$= \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} R_{ij}P_j[(N_{ijk}F_{ijk}) + (1 - N_{ij})(\bar{F}_{ij})]$$

Number of days of incapacitation at each level of disability

$$= \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} \sum_{s=1}^{q} R_{ij}P_j[(N_{ijk}D_{ijks}) + (1 - N_{ij})(\bar{D}_{ijs})].$$

Table 23. Simple and multiple correlation coefficients for association with level of infant mortality 1974

Independent variable	Simple correlation coefficient		1st level multiple regression (R)		2nd level multiple regression (R)
Utilities (power and sanitation):					
5005 Per capita electrical consumption (kWh)	−0.696 (67)	*□			
5007 Percent of urban population with household public water taps	−0.585 (74)				
5012 Percent urban population with access to standpipe	0.337 (70)		0.715		
5016 Urban total water coverage (tap or standpipe)	−0.613 (65)		(39)		
5017 Urban total water coverage (tap or standpipe)	−0.290 (73)				
5024 Percent of total population with water	−0.583 (69)				
5027 Percent urban population with in-house public excreta disposal system	−0.488 (62)	*			
5033 Percent rural population with some form of excreta disposal system	−0.312 (58)				
Health expenditures:					
3079 Total expenditure on health	−0.242 (86)		0.348		
3081 Per capita health expenditure	−0.282 (86)		(52)		
8009 S.I.T.C. 554 total imports (soap, cleansing and polishing preparations)	−0.348 (52)	*□			
Health personnel and facilities:					* 0.867
6008 Population per general hospital	0.363 (49)				
6019 Population per hospital bed	0.290 (86)		0.556		(31)
7031 Population per doctor	0.351 (75)	*□	(21)		
7035 Populatipn per midwife	0.283 (51)				□ 0.866
7010 Population per midwife	0.397 (40)				(42)
Economic valuables:					
3007 Per capita national income	−0.543 (82)				
3021 Percent of labor force in agriculture	0.664 (65)	*□			
3023 Percent of G.D.P. derived from agriculture	0.461 (65)		0.679		
3043 Merchandise imports	−0.292 (58)		(45)		
3046 Total imports and N.F.S.	−0.430 (71)				
3054 Total imports of goods and N.F.S.	−0.358 (71)				
Social indicators:					
2003 Percent of population literate, 1970	−0.793 (81)				
2004 Percent of population literate, 1974	−0.880 (86)	*□			
2005 Percent of children 5–19 in school	−0.752 (86)	*	0.903	*□	
2013 Radios per 1000 population	−0.616 (67)	*	(65)		
2015 Automobiles per 1000 population	−0.561 (67)				
2021 Per capita available kilocalories per day	−0.576 (86)				
2025 Percent of requires calories	−0.613 (86)				

* The starred variables are the selections resulting from the 5 intra-group analyses. In some cases, only very small numbers of countries existed for which all these data were available. Where this was the case, subsets of variables were combined (indicated by □) to provide a larger number of observations for the final regression equations.

Attack rates (R_{ij}) vary with nutritional status, immunization coverage, and sanitation practices. The proportions seeking care are related to the distance, time, and cost of visiting the medical care facility, as well as anticipated benefits and alternatives to such care. Disability days and case fatality rates vary with nutritional status, and where care is received, with the effectiveness of that care.

Following quantitative description of the current system, alternative approaches to the health protection of rural populations were designed and specified in such fashion that investment and operating costs as well as the health effects (in terms of days of incapacitation and deaths) could be calculated. If it appeared that alternative reasonable assumptions might lead to different preferred policies, the next step was to design research to resolve the uncertainties. This last stage has begun in Indonesia, where the National Center for Health Services Research in Surabaya is conducting surveys and field observations for this purpose.

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