STATISTICAL ESTIMATION OF USEFUL LIFE OF TUBEWELLS

by

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INTRODUCTION

The use of deep public tubewells on a large scale in areas where the twin menace of waterlogging and salinity emerged as a serious threat to the fertile irrigated lands in the Punjab was the first major effort which the Government undertook in the shape of SCARPS (Salinity Control and Reclamation Projects) in order to effectively combat waterlogging and salinity. SCARP-I, the Pilot Project under this programme was launched in the central Rachna Doab area of the Punjab—the area found to be worst affected by the menace. This project involved installation of more than 2000 tubewells of medium to large size, with pumping capacity varying from two to five cusecs, at a substantial capital and maintenance cost. As the expenditure involved was large it was essential to keep a continuous watch on the performance of tubewells and project their future behaviour in terms of their discharge. The question most relevant to the cost-benefit study of such a project is obviously the estimates of expected length of time for which the tubewells could go on functioning efficiently with routine maintenance.

While it may be possible to arrive at an estimate of tubewell life by carrying out engineering-cum-hydrological studies of one or more tubewells by actual observation in the field or by simulation techniques, a statistical estimate based on observation from a whole group of tubewells would be of equally significant importance, for arriving at expected average life based on the simultaneous experience of a large group of tubewells. It is within this context that the author of this paper has made an effort to use the technique of Life table on the observed discharges of each tubewell in SCARP-I, for which a systematic record is available. This paper, therefore, essentially provides a statistical model based on the demographic technique of Life table, providing projected future trends in discharge deterioration of tubewells in SCARP-I.

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HISTORY OF THE MENACE AND SCARP TUBEWELLS

Provision of irrigation facilities is of primary importance for agricultural development in West Pakistan. The River Indus and its five tributaries form one of the best natural water resources in the world. To utilize this resource, a unique system of canals was developed and millions of acres of land were brought under intensive cultivation. However, the irrigation system upset the dynamic equilibrium between groundwater recharge and discharge as a result of seepage from canals so that the subsoil water began to rise. Consequently the water table rose over much of the irrigated area by the early 1940's to a level which was between 10 to 15 feet below the ground surface [2, p. 358]. The canal seepage continued thereby bringing the water level to dangerously high levels causing waterlogging and salinity on a large scale. It was estimated that nearly 100,000 acres of irrigated land were being severely affected or were going out of cultivation every year. The areas in the central portion of Rechna Doab were extensively affected [9, p. 6].

Years of research and investigations led to the conclusion that the problem of waterlogging could be overcome by the introduction of a vertical drainage system by means of tubewells which would pump out groundwater from the aquifire and thus lower the subsoil water table to a safe level. In the process of lowering water table, the tubewells would also provide large quantities of water for irrigation purposes. On the basis of detailed investigations by the Punjab Irrigation Department, and the Water and Power Development Authority, a pilot Salinity Control and Reclamation Project (SCARP-I) in Rechna Doab was prepared to fulfil the dual purpose of elimination of waterlogging and salinity, and supply of additional underground water for irrigation purposes [10]. Later on the Revelle Report, also recommended an extensive use of tubewells for this purpose [8].

With the above mentioned background 2043 tubewells were installed and commissioned in different areas of SCARP-I. The individual capacity of tubewells ranged from 2 to 5 cusecs. Most of these tubewells were commissioned between the years 1961 and 1963. It was observed that the tubewells after continuous operation for some years were deteriorating at a faster pace than was envisaged at the time of initiation of the project. By the end of 1969 different tubewells had deteriorated to different discharge levels, the average decline being of the order of 35 percent. This obviously implied that many of the tubewells had already crossed their useful life and many were on the verge of such crossing.

ASSUMED USEFUL TUBEWELL LIFE

Assumption of average useful life of a tubewell is necessary for working out the extent of benefit which could possibly be drawn from a tubewell project in return for the cost incurred. The concept of useful life has not been clearly stated in any reference available to the author except for one where it was assumed on the basis of field experience that a tubewell exhausts its useful life when its discharge deteriorates to fifty percent of designed discharge [5].

Some of the estimates of life of tubewells, either assumed or guessed, which have been made so far are given below.

Tipton and Kambatch in 1959, estimated that average useful life of tubewells would at least be 40 years [7, p. 18]. According to Revelle Report the estimate of tubewell life was 30 years [8, p. 325]. Harza Engineering Company's estimate of average life of a tubewell was 20 years [3, p. 49]. According to another estimate the economic life of many tubewells was 10 to 15 years [6, p. 25].

It seems from the above that the estimates made so far have been based on individual guesses and are not statistical estimates. They vary from 10 to 40 years and it is very difficult to place any degree of confidence in any one of them.

METHODOLOGY OF LIFE ESTIMATION

The purpose of this paper is to provide estimates of expected life of tubewells from the level of full discharge to subsequent lower discharge levels. The estimates of average expected life of tubewells have been worked out in this paper on the basis of Life table technique. This technique was primarily developed for estimating average expected Life of human population at birth and at subsequent ages. Life table is defined as a life history of a hypothetical cohort of population as it is diminished gradually by deaths [1, p. 93]. It is a scheme for expressing the facts of mortality in terms of probability [4, p. 1]. The method of construction of Life table involves application to a hypothetical cohort, a set of age specific mortality rates computed from the data actually observed either by following a cohort of babies born at a particular point of time throughout their life until each one of them is dead (longitudinal observation of deaths), or from deaths in different age groups of population in a given year (cross-sectional observations of deaths). The former method is not easily practicable since this requires a complete record of deaths year by year of a cohort throughout its life. The latter method is thus the one which is mostly applied for Life table construction. In this method the basic assumption is that the age specific mortality rates of a particular year represent the mortality rates at various stages of life. In other words it is assumed that the population in a particular age group, when passing through subsequent age groups, would experience age specific mortality rates of an actual population for a given year.

The other steps involved in constructing Life table are computation of (i) person—years of life completed by a group of persons between one age level to the next (L_x) (ii) person—years of life to be lived by one cohort at all ages from a particular age level onward until all have died (T_x) and (iii) average expected life or average years of life to be lived after a particular age ($e^o{}_x$).

In order to estimate the expected life of tubewells we have utilized the data on designed discharge of each tubewell and the actual discharge as observed at the end of 1969. The tubewells were then grouped into 10 categories of discharge level to represent on the average 100%, 90%, 80%......10%, discharge. It may be mentioned here that different tubewells started functioning at different points of time. Within each category also, all the tubewells were not necessarily commissioned at the same time.

Adding the number of years completed by all the tubewells in a category the tubewell-years completed by each category-group were obtained. On the basis of average time taken by tubewells to reach stages in which they were classified at the end of 1969, the average numbers of years to be taken by tubewells from one stage to reach each of the subsequent stages was estimated. Multiplying these averages by number of tubewells, tubewell-years expected to be completed in the subsequent stages were estimated.

For each group of tubewells classified by discharge levels, the tubewell-years completed, upto each stage of deterioration already crossed, were estimated assuming that they followed a straight line upto 1969. The tubewell-years completed by them so far were thus divided equally into each past stage. A minor adjustment was however made in the case 100% stage and 90% stage, since tubewells in 100% group in fact were more close to 95% discharge level and therefore half the weight was given to interval between these two stages.

The expected future trend of each group after 1969 was constructed by estimating stage to stage declines. For example for the tubewells falling in 100% stage in 1969, the estimate of tubewell-years was made upto 90% stage assuming that it will follow the trend of tubewells which were already at 90% level in 1969. Similarly the estimate of tubewell-years to be completed by 100% group from 90% to 80% stage was estimated on the basis of trend followed so far by tubewells which had already reached 80% level in 1969. Estimates for tubewell-years to be completed between subsequent stages were estimated similarly, The same procedure was adopted for constructing future estimates for tubewells falling in other stages of discharge levels in 1969. Adding up the tubewell-years completed by each group from one discharge level to the next, the estimates of tubewell-years completed from stage to stage by all the tubewells together were obtained.

These estimates represent (L_x) of tubewell Life tables corresponding to each stage of deterioration comparable to age groups of human life. From these L_x values corresponding values of T_x or the number of years to be taken by tubewells from one stage of deterioration till they reach 10% level or below, were obtained by adding up cummulatively values of L_x from bottom to top. For example $T_{10\%} = L_{10\%}$ but $T_{20\%} = L_{10\%} + L_{20\%}$. Similarly $T_{30\%} = L_{10\%} + L_{20\%} + L_{30\%}$ and so on for other values of T_x.

Values of e^o_x were obtained by dividing T_x value for each stage of deterioration by the total number of tubewells $\Sigma\, t_i$. It should be pointed out that the number of tubewells remains the same for all stages of deterioration, since we are following up same group of tubewells from one stage of deterioration to the next. In other words, by dividing total tubewell-years to be lived by the group of tubewells, from one stage of deterioration till the last stage, with the number of tubewells, we get average expected years to be lived by tubewells from that stage till the last stage, or the average expected life e^o_x from that stage. The computed trend of life expectancy from stage to stage represents in fact a weighted average of the ten groups of tubewells. The procedure explained above is described in Table I.

LIFE ESTIMATES AND LIMITATIONS

The analysis described above was carried out for each of SCARP-I reclamation scheme separately and for SCARP-I as a whole. The life table for SCARP-I as a whole is given in Table II. Table III gives only expectation of life column for the life tables relating to individual reclamation schemes.

TABLE I
EXPECTED LIFE OF TUBEWELLS—ESTIMATION PROCEDURE

Stage of deterioration or discharge levels as per cent of designed discharge	Number of Tubewells at each discharge level in 1969 (t_i)	Number of years completed upto 1969 (y_i)	Estimates of tubewell-years of life completed upto different discharge levels by all tubewells before the years of observation (1969) and afterwards (L_x)									
			Stage of deterioration or discharge levels as percent of designed discharge									
			100% (95%+)	90%	80%	70%	60%	50%	40%	30%	20%	10% or less
100% (95%+)	t_0	y_0	y_0t_0	$\frac{1}{2}y_1t_0$	$\frac{1}{2}y_2t_0$	$\frac{1}{3}y_3t_0$	$\frac{1}{4}y_4t_0$	$\frac{1}{5}y_5t_0$	$\frac{1}{6}y_6t_0$	$\frac{1}{7}y_7t_0$	$\frac{1}{8}y_8t_0$	$\frac{1}{9}y_9t_0$
90%	t_1	y_1	$\frac{1}{2}y_1t_1$	$\frac{1}{2}y_1t_1$	$\frac{1}{2}y_2t_1$	$\frac{1}{3}y_3t_1$	$\frac{1}{4}y_4t_1$	$\frac{1}{5}y_5t_1$	$\frac{1}{6}y_6t_1$	$\frac{1}{7}y_7t_1$	$\frac{1}{8}y_8t_1$	$\frac{1}{9}y_9t_1$
80%	t_2	y_2	$\frac{1}{4}y_2t_2$	$\frac{1}{4}y_2t_2$	$\frac{1}{2}y_2t_2$	$\frac{1}{3}y_3t_2$	$\frac{1}{4}y_4t_2$	$\frac{1}{5}y_5t_2$	$\frac{1}{6}y_6t_2$	$\frac{1}{7}y_7t_2$	$\frac{1}{8}y_8t_2$	$\frac{1}{9}y_9t_2$
70%	t_3	y_3	$\frac{1}{6}y_3t_3$	$\frac{1}{6}y_3t_3$	$\frac{1}{3}y_3t_3$	$\frac{1}{3}y_3t_3$	$\frac{1}{4}y_4t_3$	$\frac{1}{5}y_5t_3$	$\frac{1}{6}y_6t_3$	$\frac{1}{7}y_7t_3$	$\frac{1}{8}y_8t_3$	$\frac{1}{9}y_9t_3$
60%	t_4	y_4	$\frac{1}{8}y_4t_4$	$\frac{1}{8}y_4t_4$	$\frac{1}{4}y_4t_4$	$\frac{1}{4}y_4t_4$	$\frac{1}{4}y_4t_4$	$\frac{1}{5}y_5t_4$	$\frac{1}{6}y_6t_4$	$\frac{1}{7}y_7t_4$	$\frac{1}{8}y_8t_4$	$\frac{1}{9}y_9t_4$
50%	t_5	y_5	$\frac{1}{10}y_5t_5$	$\frac{1}{10}y_5t_5$	$\frac{1}{5}y_5t_5$	$\frac{1}{5}y_5t_5$	$\frac{1}{5}y_5t_5$	$\frac{1}{5}y_5t_5$	$\frac{1}{6}y_6t_5$	$\frac{1}{7}y_7t_5$	$\frac{1}{8}y_8t_5$	$\frac{1}{9}y_9t_5$
40%	t_6	y_6	$\frac{1}{12}y_6t_6$	$\frac{1}{12}y_6t_6$	$\frac{1}{6}y_6t_6$	$\frac{1}{6}y_6t_6$	$\frac{1}{6}y_6t_6$	$\frac{1}{6}y_6t_6$	$\frac{1}{6}y_6t_6$	$\frac{1}{7}y_7t_6$	$\frac{1}{8}y_8t_6$	$\frac{1}{9}y_9t_6$
30%	t_7	y_7	$\frac{1}{1}y_7t_7$	$\frac{1}{14}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{7}y_7t_7$	$\frac{1}{8}y_8t_7$	$\frac{1}{9}y_9t_7$
20%	t_8	y_8	$\frac{1}{16}y_8t_8$	$\frac{1}{16}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{8}y_8t_8$	$\frac{1}{3}y_8t_8$	$\frac{1}{9}y_9t_8$
10%	t_9	y_9	$\frac{1}{18}y_9t_9$	$\frac{1}{18}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$	$\frac{1}{9}y_9t_9$
All tubewells $=\Sigma t_i$		L_x	L_{100}	L_{90}	L_{80}	L_{70}	L_{60}	L_{50}	L_{40}	L_{30}	L_{20}	L_{10}
		T_x	T_{100}	T_{90}	T_{80}	T_{70}	T_{60}	T_{50}	T_{40}	T_{30}	T_{20}	L_{10}
		e^o_x	$\frac{T_{100}}{\Sigma t_i}$	$\frac{T_{90}}{\Sigma t_i}$	$\frac{T_{80}}{\Sigma t_i}$	$\frac{T_{70}}{\Sigma t_i}$	$\frac{T_{60}}{\Sigma t_i}$	$\frac{T_{50}}{\Sigma t_i}$	$\frac{T_{40}}{\Sigma t_i}$	$\frac{T_{30}}{\Sigma t_i}$	$\frac{T_{20}}{\Sigma t_i}$	$\frac{T_{10}}{\Sigma t}$

e^o_x columns in both the Tables II and III give the life expectancy from a particular discharge level till discharge of tubewells declines to almost nil. For example for 100 percent level it gives 18.57 years to be taken on the average from full discharge level to nil discharge level. Similarly years expected to be taken from 90 percent and subsequent discharge levels are estimated as 15.8, 13.58,........; respectively. Taking 50% discharge as the level where a tubewell consumes its useful life, the estimated average useful life of SCARP-I tubewell is given by $e^o_{100\%} - e^o_{50\%} = 18.57 - 6.23 = 12.4$ years. The expected life to subsequent discharge levels, if desired, can be computed similarly.

Referring to Table III, it is observed that the total life as well as useful life of tubewells vary from scheme to scheme. Scheme-wise total life and the life to 50 percent discharge level (useful life) are summarized below:

Schemes	Total expected years of life from full discharge till nil discharge level	Expected life till 50% discharge (useful life)
1. Pindi Bhattian	11.8	6.3
2. Chichoki Malian	11.9	7.4
3. Chuhar Kana	19.6	15.1
4. Jaranwala	22.1	16.0
5. Shahkot	17.03	13.0
6. Shadman I	17.77	13.8
Shadman II	13.9	7.6
7. Zafarwal	16.28	11.5
8. Hafizabad	15.55	9.0
9. Khanqah Dogran	15.46	14.0
10. Sangla Hill	17.50	14.5
11. Beranwala	16.95	13.0
12. Harse Sheikh	15.91	12.3
SCARP-I (All schemes)	18.57	12.4

Although the estimates of tubewell life provided in this paper are the first of their kind in this country, they are based on certain assumptions which may or may not exactly hold good from time to time and from area to area. These estimates have been prepared out of discharge levels observed at the time when the tubewells in SCARP-I had completed about 8 years or more of their performance, hence different tubewells were at diffierent discharge levels in the year for which data were collected. Some tubewells were still giving full discharge while the others were at subsequent discharge levels. Some of them had already gone to very low discharge levels or had ceased working. Before this model is applied to another group of tubewells it must be ascertained that a similar situation regarding discharge levels exists in the group of tubewells for which a study is to be conducted.

TABLE II

LIFE TABLE OF TUBEWELLS IN SCARP-I

Discharge Level as Percent of Designed Discharge	SCARP-I (All Schemes)		
	L_x	T_x	Life Expectancy e^o_x
100%	4661.31	31798.90	18.57
90%	3883.39	27137.59	15.85
80%	5324.07	23254.20	13.58
70%	4065.79	17930.13	10.47
60%	3198.85	13864.34	8.10
50%	2611.89	10665.49	6.23
40%	2278.18	8053.60	4.70
30%	1897.96	5775.42	3.37
20%	1554.93	3877.46	2.26
10%	2322.53	2322.53	1.36

Expected Useful Life of Tubewells in SCARP-I (All Schemes) upto 50% discharge

$$e^o_{100\%} - e^o_{50\%} = (18.6-6.2) = 12.4 \text{ years.}$$

TABLE III

SCHEME-WISE LIFE EXPECTANCY IN YEARS FOR TUBEWELLS IN SCARP—I

Discharge Level as Percent of Designed Discharge	Pindi Bhattian	Chicho-ki-mallian	Chuhar kana	Jaranwala	Shahkot	Shadman-I	Shadman-II	Zafarwal	Hafizabad	Khanqah dogran	Sangla Hill	Beranwala	Harse Sheikh
	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x	e^o_x
100%	11.8	11.9	19.6	22.1	17.03	17.77	13.9	16.28	15.55	15.46	17.50	16.95	15.91
90%	11.0	10.9	17.1	17.5	13.67	14.46	12.6	13.54	14.02	12.77	14.39	14.16	13.21
80%	10.2	9.9	14.5	15.7	111.07	12.00	11.6	11.39	12.66	10.23	11.59	11.79	11.08
70%	8.4	8.1	10.3	11.2	8.06	8.56	9.7	8.57	10.34	6.47	7.87	8.43	8.05
60%	7.0	6.1	6.9	8.4	5.71	5.97	7.9	6.46	8.32	3.72	5.16	5.90	5.60
50%	5.5	4.5	4.5	6.1	3.87	3.95	6.3	4.76	6.55	1.60	3.08	3.87	3.64
40%	4.1	3.0	2.1	4.2	2.42	2.27	4.9	3.38	5.03	—	1.39	2.47	2.02
30%	2.7	1.8	1.8	2.6	1.26	0.86	3.6	2.20	3.71	—	—	1.14	1.97
20%	1.5	0.7	1.6	1.2	1.25	—	2.5	1.19	2.56	—	—	—	0.84
10% or less	1.2	0.6	1.4	0.9	0.50	—	1.5	0.38	1.61	—	—	—	0.82
Life expectacy upto 50% discharge ($e^o_{100\%} - e^o_{50\%}$)	11.8 − 5.9 = 6.3	11.9 − 4.5 = 7.4	19.6 − 4.5 = 15.1	22.1 − 6.1 = 16.0	17.0 − 3.9 = 13.0	17.8 − 4.0 = 13.8	13.9 − 6.3 = 7.6	16.3 − 4.8 = 11.5	15.6 − 6.6 = 9.0	15.5 − 1.6 = 14.0	17.5 − 3.0 = 14.5	17.0 − 4.0 = 13.0	15.9 − 3.6 = 12.3

Furthermore, the study is based on one year data on discharge of tubewells in a particular month. The study is therefore a cross-section study and not a follow up study based on discharge observations from year to year till the end. This model therefore assumes that the conditions prevailing before the year of observation would continue to be the same in future as well. This may not hold good, for with proper treatment at proper times the discharge of a tubewell may be restored to some extent which would ultimately tend to lengthen its life.

It is also to be kept in view that the results obtained in the study represent averages of groups of tubewells. So it would not be fair to expect them to forecast performance of individual tubewells.

The behaviour of tubewells is also subject to the conditions prevailing in SCARP-I schemes. The estimates of life therefore would only tend to hold good in areas similar to those in SCARP-I.

SUMMARY AND IMPLICATIONS

The paper is an attempt to estimate discharge deterioration trends for tubewells on the basis of life table technique which is generally applied to estimate average human life expectancy. The idea behind the preparation of this statistical model was: (1) to provide estimates of life of tubewells with some scientific basis, using existing statistical data on discharge of a sizeable group of tubewells even when the data represent observations for one year only; and (2) to demonstrate the usefulness of statistical techiques as against generalizations based on assumed guesses from localized experiences.

As is true for human life tables, the life tables prepared in this paper are based on certain assumptions, characterizing prevalant conditions in SCARP-I area which represented interaction of many variables. Some of the variables are water quality, type of strainer, strata of soil, quality of machinery, general maintenance of tubewell machinery, periodicity of ameliorative treatment to strainer, subsoil water level, etc. The discharge level of tubewells can be affected by one or more of the factors mentioned above.

It will be observed from Table III that expectation of life of tubewells in individual reclamation schemes of SCARP-I varies from scheme to scheme. Some of the schemes show better life expectancy than others. The direct applicability of these results depends on comparability of the conditions in the group of tubewells for which these tables are to be used, with those of SCARP-I schemes upto 1969.

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