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A COST ESTIMATE MODEL FOR SEWERAGE SYSTEM

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ABSTRACT
Detailed design and cost estimation of a sewerage system consumes a lot of time due to the involvement of various components and technicalities. Many a times, a rapid assessment of a probable cost of a sewerage system is vividly required for budget projection. As such no preliminary cost model is available for the purpose. The present work attempted to derive a preliminary cost model. Population is the main factor based on which quantity of sewage to be handled is decided. Moreover, it governs the length of sewer, pipe size etc. Keeping the population as an independent factor, an empirical relationship has been derived between the population and installation cost of the sewerage scheme from the actual data. The developed relationship will help the planning engineers to prepare a cost estimate rapidly if the population of a city is known.

Keywords: Installation cost of sewerage system, empirical relationship, population and installation cost. .

INTRODUCTION
Sewerage system includes sewer networks, which conveys wastewater used by individuals, commercial and industrial establishments to wastewater treatment facilities for ultimately to be returned to the natural environment, and sewage treatment facility. The cost of sewerage system incorporates the installation of both sewer networks (collection system) and treatment facility. A sewerage network involves sewer pipes and various types of sewer appurtenances such as manholes, street inlets, inverted siphons, sewage pumping stations etc. The total cost of sewer network is equal to the cost of sewer pipe, cost of earthwork excavation for trenches including laying and jointing and manholes (Nagoshe, Rai and Kadam, 2014). As the sewerage system has various components, the planning and design and cost estimation consume a lot of time. Commonly, a rapid cost estimation of sewerage system is warranted (within a day or two) for budget preparation and planning. The data on this aspect is very scanty and field engineers struggle very much during such situation. A cost model for only sewer component has been proposed (Vijayan *et al*, 1995; Elangovan *et al*, 1997). Components like a sewage treatment plant, lift stations and pumping main were not incorporated in the model proposed. A model with the cost of all components of a sewerage system is the real requirement. Most of the earlier researches address the optimization of sewer network. Optimization of sewer networks using an adaptive genetic algorithm has been done (Ali Haghighi, Amin E Bakhashipour, 2012). Considering the need for a relationship between the installation cost of sewerage scheme and the population, an attempt has been made to develop an empirical relationship between the population and the installation cost of sewerage system from the already available data.

Basic concept and hypothesis
Population is the very basic independent factor based on which the size of the sewer network and capacity of the sewage treatment rest. Street length of a town again depends upon the population. In general, the street length and population of a town will be available readily with the town authority. This exercise has been done based on the 31 numbers of Under Ground Sewerage Scheme (UGSS) projects formulated for various Urban Local Bodies (ULBs) of different size of population in the Tamil Nadu, India during the year 2011-2012 and being implemented. The details of the projects with costs considered are presented in the Table-1.

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Table-1. Population and costs of the projects (data).

S. No.	Name of the Project town	Design quantity (MLD)	Street/Sewer length (KM)	Design population	Total project cost (Rs. In Lakh)
1	Arumbavur	1.64	20.9	16400	2024
2	Kurumbalur	1.97	26.68	19700	2473
3	Pullambadi	1.4	30.33	14000	1926
4	Vasapettai	1.8	25.31	18000	2240
5	Annavasal	1.15	22.34	11500	1689
6	Karambakudi	2.4	35.98	24000	3214
7	Keeranur	2.05	20.31	20500	2743
8	Mettupalayam	0.9	21.67	9000	1328
9	Poovalur	1.07	15.22	10700	1500
10	Pullambadi	1.9	23.1	19000	2236
11	S. Kannanur	1.8	23.43	18000	2436
12	Thanthaiyangarpettai	1.77	26.99	17700	2458
13	Uppiliyapuram	0.9	17.16	9000	1556
14	Velankanni	1.7	23.44	17000	2618
15	Vaitheesvarankoil	1	19.1	10000	2010
16	Manalmedu	1.2	21.51	12000	2105
17	Kivelur	1.3	22.16	13000	2050
18	Thattacheri	1.2	20.24	12000	1792
19	Needamangalam	1.2	14.76	12000	1600
20	Muthupettai	2.9	37	29000	2867
21	Valangaiman	1.55	23	15500	2290
22	Koradacheri	0.9	11.45	9200	1435
23	Kodavasal	2.6	33	26000	3440
24	Madukur south	2.6	29.34	26000	2927
25	Perumagalur	0.9	8.5	9000	1299
26	Thirubuvanam	2.1	19.59	21000	2269
27	Vallam	2.3	38	23000	3185
28	Ammapettai	1.8	27.54	18000	2482
29	Melattur	1.15	20	11500	1749
30	Thiruvaiyaru	2.2	28.9	22000	2458
31	Melathirupanthuruthi	1	14.1	10000	1381

All the above projects are designed as per the Manual on Sewerage and Sewage Treatment, Government of India (CPHEEO, 1993). The projects were formulated for the population of minimum 9000 numbers. The rate of water supply considered was 135 LPCD and the estimate sewage generation was 80% of water supply plus infiltration at the rate of 2% over the sewage generation. The Geographical condition of this Urban Local Bodies (ULBs) is similar with plain terrain and considered with same soil classification in the engineering estimate.

Though there are many factors accounted for the estimate like, Length of pipe, Material of pipe, Size of Pipe, Manhole, Depth of cutting, pumping stations etc., all the above factors basically depends on the population, length and density and ultimately the quantity of sewage that has to be conveyed and treated. The estimate of sewage quantity directly depends on the population and

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the project depends upon the quantity of sewage to be conveyed and treated, so there is a correlation between the population and the project cost. Based on the above correlation and the assumption the evaluation of the equation has exercised to help the planning engineer to prepare the tentative cost quickly.

COST OF SEWERAGE SYSTEM

Installation cost (C_T), hereafter termed as cost of a sewerage scheme is mainly the sum of cost of sewer network (pipe and laying and jointing), manholes, lift stations if any, pumping main and sewage treatment plant. Many researchers have proposed cost model for the sewer network alone. Vijayan *et al*. (1995) proposed a cost model for the sewer network as given below.

$$C_T = \alpha_1 D^p + \alpha_2 D^q H^r + \alpha_3 H^s \quad (1)$$

Where, C_T = total cost, D-pipe diameter, H- depth, α_1, α_2, α_3, p, q, r, s are constants.

The first term represents the pipe cost, second term takes care of laying and jointing and the last accounts for the manhole. Regression analysis was done to obtain the values of constants from the rate analysis. Cost of items of work viz: lift stations, pumping main and sewage treatment plant was not accounted for in the above model.
Swamee (2001) has proposed an equation for the cost of a sewer in terms of length and the diameter of pipe as given below.

$$C_m = k_m L D^m \quad (2)$$

Where km and m are the pipe cost parameters, L - length and D- diameter.
The cost of earth work excavation a link, C_e, is given as

$$Ce = k_e L (d_1 + d_2) \quad (3)$$

Where ke -earthwork coefficient, d_1, d_2 are invert depths at the start and end of the link.
The cost of manhole, Ch,

$$C_h = k_h d_h \quad (4)$$

Where k_h -manhole coefficient and d_h= depth of manhole.
The total cost of sewer network is the sum of the equations (2), (3) and (4), and given as

$$C_T = k_m L D^m + k_e L (d_1 + d_2) + k_h d_h \quad (5)$$

The pipe cost term in equation (1) and equation (5) is almost similar. Other two terms differ from each other.

The cost of pipe per unit length (meter) is given by the expression.

$$C_p = a D^b \quad (6)$$

Where C_p- cost of pipe per meter length in Rupees, D- diameter of pipe in mm, a and b are constants. Depending upon the depth of sewer line, pipe material like stoneware and reinforced cement concrete (RCC) is recommended (CPHEEO, 1993).

Proposed concept

As the sewerage system is commonly designed for a design population for which the system is expected to serve. Length of the sewer network again depends on the population. More is the population; higher will be the length of the streets (sewer network). Quantity of sewage generation is also determined by the population. The size (diameter) of the sewer, pumping main and sewage treatment plant is defined ultimately by population. Hence, an algorithm for the total cost of the sewerage system is proposed with population as given below.

$$C_T \alpha P \quad (7)$$

Where C_T is the cost in Rupees, α is the proportionality constant and P is the design population. Depending upon the form of relationship, the proportionality constant may be represented by more the one constant.

METHODOLOGY

Total cost

The total installation cost of sewerage schemes of 31 towns, for which the detailed engineering (detailed planning and design, cost estimation) has already been made during 2011-12, with population is used to develop empirical equations between the population and installation cost by the method of regression analysis. The following five form equations are derived using the EXCEL application software using MS OFFICE software.

a) Linear equation,
b) Exponential equation,
c) Logarithmic equation,
d) Polynomial equation, and
e) Power equation.

The correlation coefficient for each form is compared and most suitable form is suggested.

RESULTS AND DISCUSSIONS

The results of the correlation analysis between the population and the installation cost of sewerage system are tabulated (Table-2). In all the five forms of equations generated, the correlation coefficient values obtained take the value above 0.91. Almost all the five equations are found to be showing a good correlation. In the case of linear, logarithmic and polynomial equations, the constant term gives some value for the zero population. As the cost must be zero for the nil population, the above three equations do not represent the true sense of relationship. Hence, they are expelled from consideration. Of the

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balance, exponential and power form equations, later enjoys superiority over the other by way of its correlation coefficient value. Considering the suitability and other factors, power form of the equation is suggested as the cost estimate model. Though the relationship with more accurate and correlation coefficient value closer to unity could not be obtained, the power form of the equation may be used for rapid assessment with a certain degree of accuracy. A graph with data and the trend line of the proposed model is depicted in Figure-1. It is seen from the Figure-1 that the data is almost close to the trend line. Though, most of the data points are very close to the trend line and a few samples only fall away from the best fit line. It indicates the complexity of phenomena and the various factors involved in the subject. Topography and soil types and availability of site for sewage treatment plant, etc. decide the installation cost. Plain area and sandy substrata require higher cost due to depth of cutting and shoring and shuttering expenses. Topography with gentle slope mostly involves lesser depth of cutting since the sewer grade follows the natural slope, maintaining almost minimum depth to develop required non-silting velocity of flow. Commonly, installation cost for the towns located in the plains will be more than the one situated in the sloping terrain in lieu of depth of cutting in laying and jointing of sewer.

Table-2. Different forms of relationship between Population and Installation cost of sewerage scheme.

S. No.	Form of equation	Equation	Correlation coefficient
1	Linear	$C_T = 0.0928 * P + 677.99$	0.92
2	Exponential	$C_T = 1051.40\ e^{4E-05*P}$	0.91
3	Logarithmic	$C_T = 1500.8 \ln (P)-12272$	0.92
4	Polynomial	$C_T = -2E-10P^3 + 7E-06P^{2+}0.0026 * P +972.90$	0.924
5	Power	$C_T = 2.3599 * P^{0.7054}$	0.93

C_T- Installation Cost, Rs. lakh, P- population

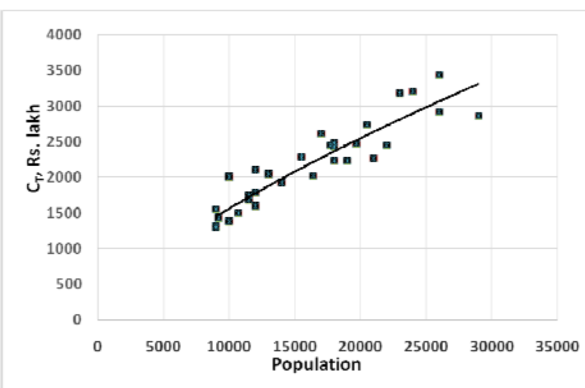

Figure-1. Population versus installation cost of Sewerage system.

Chi-square test and goodness of fit

Chi-square (χ^2) has been performed to test the validity of the developed model. The observed values are taken as 100% and the assessed values are read as a percentage of the observed value to determine the confidence limits by setting:

H_o = Null hypothesis

There is no significant difference between the assessed cost, employing the mathematical model and the original cost (actual cost).

H_1= Alternate hypothesis

There is a significant difference between the assessed cost (E) and actual cost (O). The Chi-square value is determined using the following relationship.

$$\chi^2 = \sum_{i}^{n} \frac{(Oi - Ei)^2}{Ei} \quad (8)$$

With the degrees of freedom of 30, the Chi-square value workout to 31.20 (detailed working sheet is given in Table-3) which is well within the limit of the tabulated value of 43.773 at the 5 % level of significance and hence the null hypothesis can be accepted. Therefore, this cost model (power form equation) may be used to obtain the cost of a sewerage scheme.

CONCLUSIONS

An examination of the different forms of relationships derived from the data of actual costs of various sewerage schemes for the rapid assessment of the installation cost of the same for budgeting and planning indicates the possibility of getting simple, quick and reliable model. The suggested empirical relationship to assess the total project cost of sewerage system with the population as independent parameter is given below (Equation 9).

$$\text{Total Project cost, Rs. in lakh } (C_T) = C_T = 2.3599 * P^{0.7054} \quad (9)$$

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The above equation has been statistically validated using chi-square test. As something is better than the absence of anything, the proposed model can used for all practical purposes by the planners and field engineers for the rapid tentative cost estimation till an improved method is developed. The above equation has been derived based on the market rates of 2011-12. The annual escalation of price may be added accordingly to arrive at the current cost.

Table-3. Determination of Chi-square value.

S. No.	**Name of the Project town**	**Design population**	**Total project cost** (Rs. In Lakh)	**Assessed total project cost** (Rs. In Lakh)	**Total project cost** (%)	**Assessed total project cost** (%)	**O-E**	**$(O-E)^2$**	**$(O-E)^2/E$**
			O	**E**	**O**	**E**			
1	Arumbavur	16400	2024	2218	100	109.6	-9.6	92.3	0.8
2	Kurumbalur	19700	2473	2525	100	102.1	-2.1	4.4	0.0
3	Pullambadi	14000	1926	1984	100	103.0	-3.0	9.1	0.1
4	Vasapettai	18000	2240	2369	100	105.8	-5.8	33.2	0.3
5	Annavasal	11500	1689	1727	100	102.3	-2.3	5.1	0.0
6	Karambakudi	24000	3214	2902	100	90.3	9.7	94.2	1.0
7	Keeranur	20500	2743	2597	100	94.7	5.3	28.5	0.3
8	Mettupalayam	9000	1328	1453	100	109.4	-9.4	88.4	0.8
9	Poovalur	10700	1500	1641	100	109.4	-9.4	88.9	0.8
10	Pullambadi	19000	2236	2461	100	110.1	-10.1	101.3	0.9
11	S. Kannanur	18000	2436	2369	100	97.2	2.8	7.6	0.1
12	Thanthaiyangarpettai	17700	2458	2341	100	95.2	4.8	22.6	0.2
13	Uppiliyapuram	9000	1556	1453	100	93.4	6.6	44.0	0.5
14	Velankanni	17000	2618	2275	100	86.9	13.1	171.3	2.0
15	Vaitheesvarankoil	10000	2010	1565	100	77.9	22.1	490.3	6.3
16	Manalmedu	12000	2105	1780	100	84.5	15.5	238.8	2.8
17	Kivelur	13000	2050	1883	100	91.9	8.1	66.3	0.7
18	Thattacheri	12000	1792	1780	100	99.3	0.7	0.5	0.0
19	Needamangalam	12000	1600	1780	100	111.2	-11.2	126.1	1.1
20	Muthupettai	29000	2867	3316	100	115.7	-15.7	245.7	2.1
21	Valangaiman	15500	2290	2132	100	93.1	6.9	47.7	0.5
22	Koradacheri	9200	1435	1476	100	102.8	-2.8	8.0	0.1
23	Kodavasal	26000	3440	3071	100	89.3	10.7	115.3	1.3
24	Madukur south	26000	2927	3071	100	104.9	-4.9	24.1	0.2
25	Perumagalur	9000	1299	1453	100	111.8	-11.8	140.2	1.3
26	Thirubuvanam	21000	2269	2641	100	116.4	-16.4	269.0	2.3
27	Vallam	23000	3185	2816	100	88.4	11.6	134.1	1.5
28	Ammapettai	18000	2482	2369	100	95.4	4.6	20.7	0.2
29	Melattur	11500	1749	1727	100	98.7	1.3	1.6	0.0
30	Thiruvaiyaru	22000	2458	2729	100	111.0	-11.0	121.8	1.1
31	Melathirupanthuruthi	10000	1381	1565	100	113.3	-13.3	177.4	1.6
	Total		67780	67468	3100	3115.1	-15.1	3018.3	31.2

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