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Determining suitable probability distribution models for agricultural drainage envelope clogging data

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ABSTRACT

Determination of suitable probability distribution function in among frequency distribution models in evaluating occurrences for any phenomena is very important. The gradient ratio is the one of the best important parameter for evaluation of envelope clogging. To conduct this research, data of each replicate was divided into four hourly periodic lengths of 24, 48, 72, and 96. Then, with analysis of data in time series according to HYFA software output and goodness fit of Relative Residual Square Mean, suitable frequency distribution function for each envelope was selected. Based on relative frequency, the best fitted distribution was found to be Three Parameter Log Normal distribution (Moment method) and Two Parameter Log Normal distribution (maximum likelihood method) for synthetic envelope of PP450, Normal distribution (Moment method and maximum likelihood method) for synthetic envelope of PP700, Three Parameter Log Normal distribution (Moment method) and Two Parameter Log Normal distribution (maximum likelihood method) for synthetic envelope of PP900 and Pearson type III distribution (Moment method) and Normal distribution (maximum likelihood method) for envelope of gravel.

Introduction

Investigations in the Netherlands showed that nearly 80% of drainage projects failed as the result of inappropriate performance of drain filters. Mineral materials are still the most common filters used in drainage projects. Continued usage of these filters encounters major problems such as lack of gravel sources, close to the project location, transportation of the materials and executive limitations (digging wide trenches, controlling gravel PSD, etc.). Because of the reasons, the cost of drainage projects has raised. In recent years, geotextile filters have become more common because of lower costs, higher installation speed, less land loss (because of excavation) and some other benefits, especially in countries such as the Netherlands, the USA, Pakistan, and Egypt.

Among popular products are synthetic materials. These materials are mainly manufactured of petrochemicals and oil industry by-products. Geo-synthetics materials are being used with acceptable performance in soil and water projects worldwide. Geotextiles are one of the categories of geo-synthetics being used in drainage systems. First generation of geotextiles used in the late 1950’s as an alternative for gravel envelopes.

Karimi (2009) assessed the performance of three models of geotextiles (PP450, PP700 and PP900) in comparison with common drain envelopes. They recommended PP450 for Khorram Shahr drainage project using required tests (flow variations, hydraulic conductivity, gradient ratio and hydraulic conductivity ratio tests). Hasanoghli (1997) used an especial kind of geotextile filters as drain pipe which was made of wicker-like textile with polyester wraps and polypropylene hollow wefts. In this test, pipes were completely flexible and water could get into the pipe from small openings which were evenly distributed throughout the pipe length. The size and distribution of these openings and of course the pipe water conductivity was controllable by changing the function of the geotextile. In such a situation, provided that the pipes performance were acceptable, there was no need for gravel envelopes and trenchless installation would be possible leading to major reduction in expenses. Palmeira and Gardoni (2002) measured the effects of different pressure on hydraulics and physical properties of geotestiles and found that for drain pipes installed deeper and for increased soil pressure on pipe and envelope, the size and conductivity of filter openings would be smaller and a lower performance of drain pipe and filter would result. Fernando et al. (2006) conducted a study on biological clogging of geotextiles and mineral materials (for filtering agricultural waste waters in a 5-year period). This study revealed that both kinds of filters had some effects on water quality. Also, they found that geotextiles are more frugal in terms of economic and technical issues. Soubaida et al. (2008) studied woven and non-woven geotextile filters using a pressure membrane and assessed the tensions on geotextiles. They concluded that tensions and strains on drain filters have a major effect on outflow rate and filter’s hydraulic conductivity which is depended on the density of threads used in the envelope. Also, the resistance of these filters is related to surrounding soil particle size distribution. Cho-seng et al. (2005) carried out an experiment in laboratory to assess the performance of a geotextile envelope and determine the values of outflow rate, hydraulic conductivity and gradient ratio. They found envelope clogging potential by placing sandy granular material on it. The results of this study showed that usage of particles smaller that the envelope opening spaces because the outflow values to be

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smaller.

Using different size of soil particles around the drain envelopes increases outflow from drains and decreases the variations of gradient ratios.

Available studies that were done for prediction of drainage envelope clogging are numerous and in this study, a statistical approach to estimate envelope performance was developed. Among accomplished studies using statistical method are:

Gholami (2000) concluded that for most stations, Gumbel distribution (L-moment method) and three-parameter log normal (moment method) had the best fit on maximum and minimum annual discharges and Gumbel (L-moment) had the best fit for mean and minimum annual discharges.

Bedeustani (1999) performed a study in the East Azerbaijan, Iran, and showed that although there is no suitable distribution for discharge prediction in short term, three-parameter log normal distribution and log Pearson type III distribution would have better fit on the data series by increasing statistical period length.

In addition, for maximum precipitation in short and long terms, three-parameter log normal and three-parameter log normal along with log Pearson type III distributions were suitable, respectively.

Markovich (1965) described minimum Square method for flow evaluation and concluded that gamma distribution had the best fitness among other distributions.

Keshtkar (2001 and 2006) compared moment and L-moment methods to determine the probability distribution parameters and suitable distribution for annual discharge series. 20 and 17 hydrometric stations were chosen for minimum, mean and maximum annual discharges and maximum peak discharges, respectively.

In the central plateau watershed, the best fitted distribution for different annual discharges was studied.

Results show that the best fitted distributions for minimum discharges was Pearson distribution type III (L moment method); for Medium annual discharges were Pearson type III and Log Pearson type III distributions (L moment method); for Maximum annual discharges were Pearson type III (L moment method), Log Pearson type III and two-parameter Log normal (moment method) distributions; for Maximum annual momentous discharges were Log Pearson type III (moment), Pearson type III, three-parameter Log normal and two-parameter Log normal (L moment method) distributions.

Methods and Materials

Site Description

The laboratory tests were conducted using soil samples of a drainage project under construction in the northern Khorram Shahr, south west of Iran (Figure 1).

This drainage system is constructed as part of major agriculture development project improving water usage, providing more employment in the region and attracting university graduates.

Water is supplied by the Karun River via pumping station and is carried into the region by a 7350m long concrete canal.

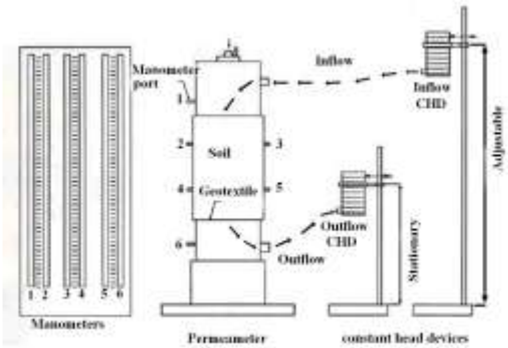
At the end of canal, the required pressure head for irrigation network (low pressure irrigation systems) is provided by a secondary pumping station.

Project area is divided into 38 51-ha and 374 5.2-ha agricultural units.

Figure 1. Location of case study in the north of Khuzestan province

In the study, a permeameter system (according to the ASTMD-5101 standard) was used for determining hydraulic conductivity and clogging potential of the combined soil-geotextile system, as well as mineral filter. The main part of the system was a transparent cylinder made of Plexiglas with inner diameter of 100mm and wall thickness of about 5mm. At different levels, piezometers were installed to assess variability of hydraulic gradient through the soil sample and around the geotextile. This test was carried out for the three types of geotextile (PP-900, PP-700 and PP-450). The main difference between the types is related to their fiber density and weight of unit length. In the next step, the performance of these types of filters was analyzed using standard permeameter test. The suggested type, according to soil particle size distribution curve and soil texture, was PP-700 and the other two types were used as the upper and lower boundaries. A mesh steel plate (with openings of 4.76mm, mesh #4) was placed between the main part and foundation where geotextile sample was placed on. Piezometers were installed in sets of two at the same height with respect to the steel plate, i.e. Piezometer couples were at 25 and 75mm heights above the steel plate. Another piezometer was installed 143mm away from the steel plate and, contrary to other piezometers. It was placed outside the soil sample. The inlet section was 162mm above the geotextile sample. In the topmost section of the system, an air valve was installed to be used for saturating the soil sample (Figure 3). In order to prevent piping, two wall-to-wall rings were placed horizontally in the system casing. After installation, by creating different hydraulic gradient (25, 50, 75 and 100), the values of permeability and hydraulic conductivity of soil-geotextile system, outflow and hydraulic conductivity of the geotextile were measured. Another similar system was built using gravel filter with 4 piezometers for comparison to the previous system. At first, system was saturated by an upward flow (to prevent the air from entering) and increasing total head. After 24hr, the test began. Both tests were conducted simultaneously.

Figure 2. Permeameter device used in this experiment



Hydraulic Gradient Calculation

Hydraulic gradient is calculated as:

[1] $$G = \frac{\Delta h}{l}$$

Δh : Difference between piezometers readings.

l : Length or thickness of soil sample.

[2] $$\Delta h_{es} = \frac{M_2 + M_3 - 2M_6}{2}$$

[3] $$G_{es} = \frac{\Delta h_{es}}{l_{es}}$$

[4] $$\Delta h_s = \frac{M_2 + M_3 - M_4 - M_5}{2}$$

[5] $$G_s = \frac{\Delta h_s}{l_s}$$

[6] $$\Delta h_e = \frac{M_4 + M_5 - 2M_6}{2}$$

[7] $$G_e = \frac{\Delta h_e}{l_e}$$

$\Delta h_{es}, \Delta h_s, \Delta h_e$: Head loss in soil-geotextile column, soil column and geotextile, respectively.

l_{es}, l_s, l_e: The length of soil-geotextile column, soil column and geotextile, respectively.

G_{es}, G_s, G_e: Hydraulic gradient of soil-geotextile column, soil column and geotextile, respectively.

M_x : The values of ***x***th piezometer (cm).

Gradient Ratio

Gradient ratio is calculated as the ratio of hydraulic gradient of the soil-geotextile system to soil hydraulic gradient:

[8] $$GR = \frac{i_{es}}{i_s}$$

Where GR is Gradient Ratio, i_{es} is hydraulic gradient of soil-geotextile system and i_s is soil hydraulic gradient. In this case, the filter will be prone to mineral clogging if gradient ratio is greater than unit.

Gradient ratio data from 4 envelopes was used to investigate fitness of statistical distributions. According HYFA (Hydrological Frequency Analysis) program results, the best-fitted statistical distribution is selected for each envelope in periods of 24, 48, 72 and 96-hour. In HYFA, relative residual mean square and chi-square test has used and the parameters of the distributions were estimated by the methods of moments and maximum likelihood method.

In this study, normal, two-parameter log-normal, three-parameter log-normal, Gumbel, two parameter gamma, Pearson type III and log Pearson type III distributions were explored. After selecting the best-fitted distribution, it is possible to predict envelope clogging for return periods of 1, 2, 4 and 6 month and also for return periods of 1, 2, 5, 10 and 20 year. By analyzing relative residual mean square and chi-square test tables (in HYFA output) for different time series, the distributions ranked. Then scores 1 to 7 was given to any distribution respectively. Finally, the best-fitted probability distribution selected by relative frequency of first classes (by analyzing the best-fitted distribution in any station) and total given scores for each statistical distribution.

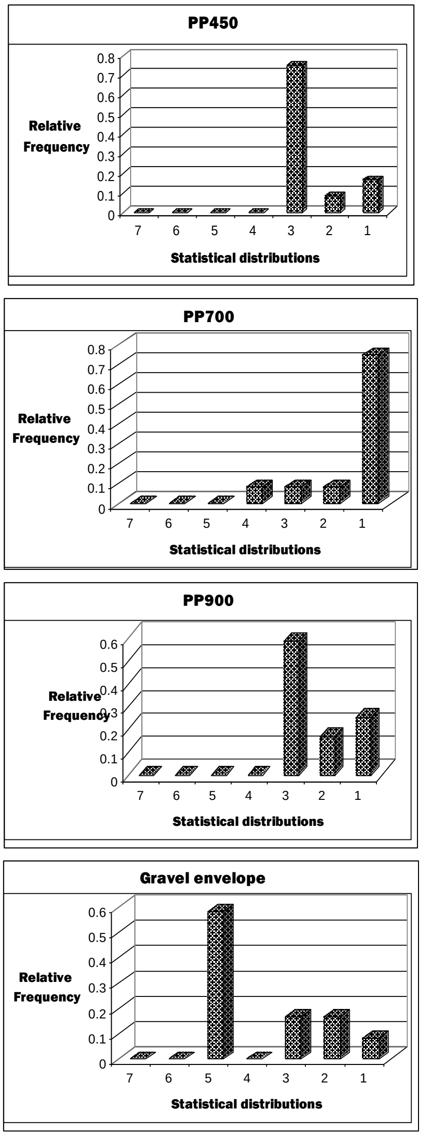
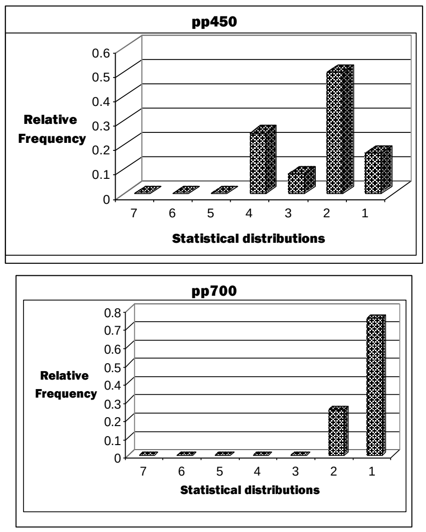
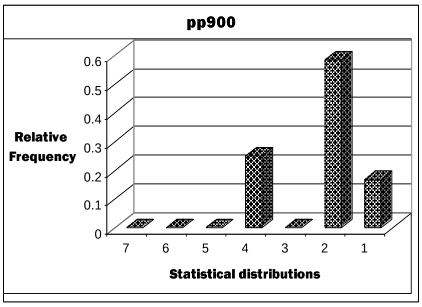
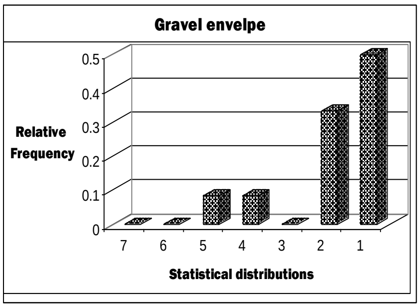


Figure 3. Relative frequency of the first class statistical distribution using moment method (1) normal, (2) two-parameter log-normal, (3) three-parameter log-normal, (4) two parameter gamma, (5) Pearson type III, (6) log Pearson type III, (7) Gumbel)







Results

Considering HYFA results and according to deviation table and values of relative residual mean square, the best statistical distribution that had the least deviation was selected and considered as the best-fitted distribution to the data. Based on sum of the given scores to each distribution using moment method, for PP450 envelope, three-parameter log-normal distribution and two-parameter log-normal distribution were the most suitable distributions with the scores of 75 and 71, respectively and using maximum likelihood method, two-parameter log-normal distribution with the score of 76 was the best distribution. For PP700 envelope, by moment and maximum likelihood methods, normal distribution was the most suitable distribution with the scores of 77 and 81, respectively. The best-fitted distribution for PP900 envelope were, by moment method, two-parameter log-normal distribution and three-parameter log-normal distribution with the scores of 70 and 69, respectively and by maximum likelihood method, two-parameter log-normal distribution was the best. Finally, for conventional envelop, using moment method, Pearson Type III (with the score of 66) and, using maximum likelihood method, normal distribution (with the score of 75) and two-parameter log-normal distribution (with the score of 73) were the best distributions (Tables 1 and 2).

In the next step, available data was divided into four periods with temporal step of 24, 48, 72 and 96 hours and changes in statistical period length were evaluated. Result showed that for PP450 envelope there was no change in the best distribution selected and for moment and maximum likelihood methods, two parameter log-normal distribution and three-parameter log-normal distribution were the most distributions, respectively (Tables 3 and 4). In case of PP700 envelope and by moment method, with changes of statistical period length, only for period of 24 hours, Gamma distribution was selected as the most suitable distribution and for the other periods, normal distribution was the best distribution. Also, using maximum likelihood method, only for the period of 24 hours, two-parameter log-normal distribution was suitable and for the remains, normal was selected (Tables 5 and 6).

For PP900 envelope and using moment method and for the period of 48 hours, two-parameter log-normal distribution (with the score of 19) was selected and for the periods of 24, 72 and 96 hours, three-parameter log-normal distribution (with the scores of 18, 21 and 18, respectively) was selected. By maximum likelihood method and for all of the periods, two-parameter log-normal distribution (with the scores of 20, 19, 19 and 18 for the periods of 24, 48, 72 and 96 hours, respectively) was selected as the best-fitted distribution (Tables 7 and 8).

Statistical distributions were different with any change of statistical period length for mineral envelope. By moment method for the periods of 24, 48, 72 and 96 hours, three-parameter log-normal was selected and by the maximum likelihood method, Pearson Type III and normal distribution were selected, respectively.

Then, for selecting the best distributions, sum of scores in four periods were used and results showed that Pearson Type III was the suitable distribution by moment method (16+13+21+16=66) and, by maximum likelihood method and for the periods of 24 and 48 hours, two-parameter log-normal distribution (with the scores of 19 and 20 respectively) and for the periods of 72 and 96 hours, normal distribution (with scores of 21 and 19 respectively) were the best. Based on sum of the scores in the four considered periods, normal distribution (with the score of 75) (16+19+21+19=75) has the greatest score in comparison with the other distributions (Tables 9 and 10).

According to relative frequency of the distributions, the best fitted distribution is three parameter log normal distribution (moment method) and two parameter log normal distribution (maximum likelihood method) for PP450 synthetic envelope, normal distribution (moment method and maximum likelihood method) for PP700 synthetic envelope, three parameter log normal distribution (moment method) and two parameter log normal distribution (maximum likelihood method) for PP900 synthetic envelope and Pearson type III distribution (moment method) and normal distribution (maximum likelihood method) for gravel envelope were the best distributions (Figures 3 and 4).

Conclusion

Using results of this research, if we selected a drainage envelope based on available criteria, we could use from statistical distributions to estimate envelope treatment and performance of these in future. According to accomplished researches, those were done upon these envelopes by Nejadyani (2007), Azizi (2007) and Karimi (2009) distinguished that PP450 envelope has a high performance. Results showed that there was no change in the best distributions selected and we can better estimate the performance of PP450 in future and accepted results of this study with much confidence.

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Table 1. Total of given scores for each statistical distribution for moment method in all of envelopes

Envelopes	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
PP450	55	71	75	63	24	24	24
PP700	77	63	40	72	29	29	26
PP900	61	70	69	64	24	25	23
Gravel	59	60	43	63	66	23	22

Table 2. Total of given scores for each statistical distribution for maximum likelihood method in all of envelopes

Envelopes	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
PP450	68	76	54	65	26	28	19
PP700	81	70	34	65	30	28	28
PP900	68	76	40	72	23	29	28
Gravel	75	73	38	57	49	21	23

Table 3. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on Moment method in envelope PP450.

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	12	18	21	15	5	7	6
48	13	19	18	16	8	7	3
72	15	17	18	16	5	6	7
96	15	17	18	16	6	4	8

Table 4. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on maximum likelihood method in envelope PP450.

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	16	19	13	18	8	7	3
48	17	20	12	17	5	6	7
72	19	19	14	13	9	7	3
96	16	18	15	17	4	8	6

Table 5. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on Moment method in envelope PP700

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	17	15	12	19	7	9	5
48	21	15	10	18	7	4	9
72	21	16	8	17	10	9	3
96	18	17	10	18	5	7	9

Table 6. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on maximum likelihood method in envelope PP700.

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	19	20	10	15	9	4	7
48	21	16	7	17	6	9	8
72	21	17	9	16	8	8	5
96	20	17	8	17	7	7	8

Table 7. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on Moment method in envelope PP900.

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	15	16	18	17	5	6	7
48	18	19	12	17	8	5	5
72	12	18	21	15	4	8	6
96	16	17	18	15	7	6	5

Table 8. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on maximum likelihood method in envelope PP900.

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	19	20	12	15	8	7	3
48	17	19	11	18	3	6	10
72	15	19	10	20	8	7	5
96	17	18	7	19	4	9	10

Table 9. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on Moment method in gravel envelope

Statistical Period (hours)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	10	15	19	14	16	7	3
48	13	18	12	17	13	5	6
72	18	12	8	15	21	6	4
96	18	15	4	17	16	5	9

Table 10. Total of given scores for each statistical distribution in different time series 24, 48, 72 and 96-hour based on maximum likelihood method in gravel envelope.

Statistical Period (hour)	Normal	Two Parameter Log Normal	Three Parameter Log Normal	Two parameter gamma	Pearson Type III	Log Pearson Type III	Gumble
24	16	19	12	12	16	6	3
48	19	20	9	14	11	5	6
72	21	17	9	14	12	5	6
96	19	17	8	17	10	5	8