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# Design of deep open drains for sugarcane crop in the Ukai Right Bank canal command area using probability distribution

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**ABSTRACT:** The study area, Ukai Right Bank canal command area is spread over Bharuch and Surat districts of Gujarat. Screening of annual rainfall data of Sisodara meteorological station was performed for absence of trend and stability of variance and mean. The time series revealed no major discrepancies and trend, and variance and mean were stable. Later since the probability of occurrence of 24 h maximum rainfall is of importance in drainage system design, this information was obtained by frequency analysis. The probability of exceedence of maximum rainfall events of each year was found by using Weibull's empirical method and three other analytical methods *viz.* Gumbel's extreme value distribution, Log Pearson distribution, and Log normal distribution. For testing the agreement between the observed data and estimated data, the Chi - square test for goodness of fit was carried out to select the best fit distribution. Gumbel's extreme value distribution gave the best fit for annual maximum rainfall data. The curve number method was used to estimate the direct runoff from the rainfall data.

To cater the agronomic criteria for sugarcane crop and on the basis of general size and shape of land holdings in the area, the suggested spacing between drains and depth should be 45 m and 1.0 m, respectively in heavy black soils for sugarcane crop. The bottom width may be 0.30 m with side slope of 1:1 and longitudinal slope should follow the ground slope but in lands having flat topography it may be 0.001 m per m. The suggested design has many times more capacity than the theoretical discharges calculated. The estimated cost of the drainage system was worked out to be Rs. 10,000 $ha^{-1}$. However, on farmers' field it was found reduced to Rs. 5000 $ha^{-1}$, when the farmer used his own farm labour.

**Key words: Drainage design, Rainfall analysis, Rainfall distribution, Sub-surface drainage**

The study area of Ukai Right Bank canal command, spread over Bharuch and Surat districts of Gujarat, is situated in 72°53'30" E Longitude, 21°29'30" N Latitude and at 15 m AMSL. The area receives annual rainfall of about 1000 mm mainly during the monsoon season. After inception of canal irrigation in 1970's, farmers of the area shifted to sugarcane and paddy crop. The farmers not receiving canal water also started cultivating high water requiring cash crops using poor quality well water. Further due to over exploitation of ground water by adopting surface methods of irrigation and because of location of the districts near to the Arabian sea, in most of the areas, sea water has ingressed deep inside the aquifers. Large areas have gone out of cultivation because of water logging and soil salinity. To cope with this problem, a pilot research project on sub - surface drainage was initiated under Indo – Dutch network project at two sites - Segwa and Sisodara by Water Management Research Unit, Gujarat Agricultural University, Navsari. In this article theoretical analysis was done for designing deep open drains considering the rainfall, shape and size of fields, sugarcane crop, economic condition of the farmers and acceptance of the technology.

Rainfall is a stochastic variable and large number of years of rainfall data is needed for its depth-duration-frequency analysis. Higher the rainfall less often it occurs. Higher the recurrence interval, higher the design rainfall, implying more costly project with less risk of failure. Failure in agricultural sense is loss of production. An average failure of 5 to 10 years is generally accepted for land drainage.

## MATERIAL AND METHODS

### Screening of data

Annual rainfall data for a period of 1971 to 1998 and daily rainfall data from 1988 to 2007 was collected from Sisodara Meteorological Station and was used for the present study. Hydrological data for water management studies should be stationary, consistent and homogeneous when they are used in frequency analysis or system simulations. A simple procedure for screening the data is to test annual series for absence of trend with Spearman's rank correlation method and F test was applied for stability of variance and t test for stability of mean.

The probability of occurrence of 24 h maximum rainfall is of importance in drainage system design. This information could be obtained by frequency analysis of the point rainfall data. The probability of exceedence of maximum rainfall events of each year was found by using technique of maximum likelihood through Weibull's empirical method and three other analytical methods *viz.*, Gumbel's extreme value distribution, Log Pearson distribution, and Log normal distribution (Chow 1964).

**Chi - Square test for goodness of fit**

This test is widely applicable to numerous problems of significance of hydro-meteorological nature. This is primarily used for testing the agreement of the observed data with those expected upon a given hypothesis. The Chi - square values 'C' are calculated as follows

$$C = \frac{(O - E)^2}{E} \quad ....................(1)$$

where, O and E are the observed and expected rainfall values, respectively. The distribution having the least sum of the C values for all the return periods were adjudged the best as suggested by Agrawal *et al.* (1988).

**Runoff estimation method (Curve Number method)**

Since for drainage basins where no runoff is measured, the Curve Number method could be used to estimate the direct runoff from the rainfall data measured with non-recording rain gauges. Rainfall – runoff relationship used in Curve Number method is as follows.

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \text{ for } P > 0.2\,S \quad ....................(2)$$

where, Q is accumulated runoff depth (mm), P is accumulated rainfall depth (mm) and S is potential maximum retention (mm). The potential maximum retention S is converted to curve number CN in order to make the operations of interpolation, averaging and weighting linear (Subramanya 1994). This relationship is

$$CN = \frac{25400}{254 + S} \quad ....................(3)$$

**Estimation of drainage coefficient and surface drainage design**

Drainage system is designed generally on the basis of drainage coefficient, which usually depends on consecutive days maximum rainfall corresponding to desired return period varying from 2 to 10 years and crop tolerance period. The value of drainage coefficient was estimated for one, two, three, four and five consecutive days-maximum rainfalls for 2, 5 and 10 years recurrence interval.

To accommodate even the peak discharge of monsoon, deep drains are not required but compromise between theoretical design to handle monsoon discharge, agronomic criteria, investment capacity of the farmers, and adaptability of the design is to be made. The agronomic criteria for sugarcane suggest that for getting optimum production, the water table should be around 1 m deep (Ritzema 1994). Since the water table in the command was generally less than 1 m below ground level during monsoon or for few days during heavy irrigation. The cost of laying sub - surface drains at 0.90 m depth at 45 m drain spacing as per the government rates was approximately Rs 40000 $ha^{-1}$ (Shrivastava *et al.* 2000) and to meet the agronomic criteria for maintaining the water table at 1m, the estimated drain spacing calculated is around 30 m or less (Parikh *et al.* 1999) thus drastically increasing the cost. The spacing of sub surface drains kept for sugarcane crop at Segwa pilot area was 45 m.

In the present approach based on general size and shape of land holdings, to maintain the distance between two borders of fields in the area and to cater the criteria explained previously, deep open drains are suggested. The deeper drain depths are not economically feasible as still more cultivable land would be covered by drains to give stable side slopes. The dimensions of trapezoidal shaped deep open drains should be as under:

| | | | |
|---|---|---|---|
| Bottom width (BW) | - 0.30 m ; | depth (d) | - 1.0 m |
| Side slope | - 1:1 ; | top width (TW) | - 2.30 m |
| Longitudinal slope | - 0.001 m per m (or could also follow ground slope, if available) | | |

Maximum permissible

| | |
|---|---|
| velocity (v) in clay loam soil | - 1.2 $ms^{-1}$ |
| Cross sectional area (A) | - 1.30 $m^2$ |
| Wetted perimeter (P) | - 3.128 m |
| Hydraulic radius (R) | - 0.415 |
| Manning's coefficient | - 0.04 |

By using the Manning formula,

Q (designed) = 0.57 cumec

Considering the standard earthwork rates of Government of Rs. 50 cum$^{-1}$, for manually excavating and finishing the drain in a trapezoidal shape, the cost of deep open drains were estimated. The suggested design was adopted by farmers of the area and it was found that the rates drastically reduced, by about half of the estimated cost when the farmer used his own farm labour.

## RESULTS AND DISCUSSION

Rough screening of Kosamba rainfall data and plotting the data as time series revealed no major discrepancies. Spearman rank correlation was -0.187 and students 't' test was -0.972, the data is symmetrical around t= 0, thus depicting there was no trend. F test value was 1.775 with a test statistic $t_t$ of 1.417, showing variance and mean were stable. Therefore, the time series was stationary and the data could be used even at lower level of aggression, i.e. those covering a day (Table 1) or a month, etc.

Table 1. *Maximum consecutive rainfall (mm) in different years*

| Year | Consecutive days rainfall (mm) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1988 | 145 | 206 | 257 | 287 | 299 |
| 1989 | 87 | 127 | 162 | 175 | 195 |
| 1990 | 123 | 210 | 210 | 212 | 212 |
| 1991 | 52 | 96 | 97 | 128 | 164 |
| 1992 | 200 | 320 | 370 | 390 | 390 |
| 1993 | 158 | 218 | 238 | 251 | 262 |
| 1994 | 171 | 271 | 294 | 319 | 359 |
| 1995 | 123 | 185 | 203 | 236 | 297 |
| 1996 | 86 | 131 | 140 | 140 | 158 |
| 1997 | 83 | 116 | 145 | 145 | 148 |
| 1998 | 112 | 142 | 172 | 189 | 219 |
| 1999 | 110 | 200 | 290 | 310 | 310 |
| 2000 | 116 | 178 | 207 | 224 | 243 |
| 2001 | 127 | 195 | 225 | 243 | 262 |
| 2002 | 117 | 180 | 209 | 225 | 245 |
| 2003 | 159 | 243 | 279 | 298 | 314 |
| 2004 | 181 | 277 | 317 | 338 | 353 |
| 2005 | 144 | 220 | 254 | 272 | 290 |
| 2006 | 156 | 239 | 274 | 294 | 310 |
| 2007 | 121 | 186 | 216 | 233 | 252 |
| Mean | 129 | 197 | 228 | 245 | 264 |
| SD | 36.4 | 57.2 | 66.4 | 69.6 | 67.9 |

The estimates of one, two, three, four and five consecutive days maximum rainfall at 2, 5, 10, 20, 25 and 50 years recurrence intervals using Weibull, Gumbel, Log Pearson Type III distribution and Log Normal distribution were tabulated (Table 2). The sum of Chi-square values for 2, 5 and 10 years recurrence interval for the maximum storm of 1, 2, 3, 4 and 5 consecutive days maximum rainfall was worked out for Gumbel, Log Pearson type III and Log Normal distribution. The Chi square values of one day maximum were 2.55, 18.15 and 14.30 for Gumbel, Log Pearson Type III and Log Normal distribution, respectively. The distribution having the least sum of the C value for all return periods was adjudged the best. Therefore, Gumbel distribution gave the best fit for annual maximum rainfall data. The table value at 2 degree of freedom and 5 % level of significance was 5.99. Thus calculated values are smaller than tabulated value which means there was non - significant difference between estimated data from Gumbel distributions and the observed data.

Table 2. *Estimation of one, two, three, four and five consecutive days maximum Rainfall (mm) at 2, 5, 10, 20, 25 and 50 year recurrence intervals (RI)*

| Days | RI | Observed (mm) | Estimated (mm) | | |
|---|---|---|---|---|---|
| | | Weibull | Gumbel | Log Pearson Type III | *Log Normal* |
| 1 day | 2 | 119 | 124 | 129 | 123 |
| | 5 | 157 | 162 | 145 | 143 |
| | 10 | 186 | 188 | 176 | 184 |
| | 20 | 215 | 213 | 185 | 204 |
| | 25 | 224 | 221 | 191 | 214 |
| | 50 | 254 | 245 | 199 | 236 |
| 2 day | 2 | 181 | 189 | 194 | 189 |
| | 5 | 243 | 250 | 221 | 219 |
| | 10 | 289 | 290 | 274 | 280 |
| | 20 | 335 | 329 | 285 | 309 |
| | 25 | 350 | 341 | 290 | 324 |
| | 50 | 396 | 379 | 303 | 356 |
| 3 day | 2 | 210 | 218 | 227 | 218 |
| | 5 | 280 | 289 | 257 | 254 |
| | 10 | 334 | 336 | 316 | 328 |
| | 20 | 387 | 381 | 336 | 362 |
| | 25 | 404 | 395 | 347 | 381 |
| | 50 | 458 | 439 | 365 | 420 |
| 4 day | 2 | 227 | 235 | 242 | 236 |
| | 5 | 300 | 309 | 275 | 272 |
| | 10 | 356 | 358 | 340 | 347 |
| | 20 | 412 | 405 | 364 | 382 |
| | 25 | 430 | 420 | 378 | 401 |
| | 50 | 486 | 466 | 401 | 440 |
| 5 day | 2 | 246 | 254 | 262 | 255 |
| | 5 | 317 | 326 | 294 | 291 |
| | 10 | 371 | 374 | 356 | 363 |
| | 20 | 425 | 420 | 378 | 396 |
| | 25 | 442 | 435 | 390 | 413 |
| | 50 | 496 | 480 | 412 | 450 |

The curve number is a dimensionless parameter indicating runoff response characteristics of a drainage basin. This parameter is related to land use, land treatment, hydrological condition, hydrological soil group and antecedent soil moisture condition in the drainage basin. In Ukai Right Bank canal command, approximately 65 % and 35 % area is under sugarcane and paddy, respectively and the soil surface is not directly exposed to rainfall. The hydrological condition is poor and the hydrological soil group is 'D' which is for clay soil and high watertable. Soils are practically saturated from antecedent rainfalls or soil moisture content at field capacity (AMC III) and the slope is less than 5 %. Therefore, for the given set of conditions for sugarcane and paddy the final weighted CN value obtained from the tables (Ritzema 1994) was 78.

The rainfall values used in design were obtained through log-normal analytical method for 10 year recurrence interval, since in India, for temporary soil and water conservation structures and for deep open drains, storm of 10 years recurrence interval is considered. Later, the direct runoff depth was estimated using the curve number method. The maximum drainage coefficient value is used for estimating the peak drain discharge (Table 3).

Table 3. *Peak drain discharge for respective maximum consecutive days rainfall*

| Storm days | Rainfall 'P' (mm) | Runoff 'Q' (mm) | Runoff 'Q' (mm day$^{-1}$) |
|---|---|---|---|
| 1 | 186 | 118 | 121 |
| 2 | 289 | 206 | 109 |
| 3 | 334 | 251 | 87 |
| 4 | 356 | 274 | 71 |
| 5 | 371 | 289 | 59 |

The estimated peak discharges for different length and area covered by individual drains is shown in Table 4. It shows that capacity of suggested drain is that single drain can carry the discharge of 9000 m length or 41 ha area. The peak discharge was calculated using drainage coefficient of 118 mm day$^{-1}$. The designed capacity of drain is much higher than the estimated discharges because of the compulsions of agronomic criteria, and necessary shape of drain according to soil type. The drain depth of 1m would not only help in lowering the watertable but also leach out the salts form the root zone during monsoon and at each irrigation. Further the drain spacing could be coincided with the field boundaries that exist at around 45 m spacing in the area.

Table 4. *Estimated carrying capacity of deep open surface drain*

| Length (m) | Area (ha) | Estimated peak discharge (cumec) |
|---|---|---|
| 200 | 1 | 0.01 |
| 500 | 2 | 0.03 |
| 1000 | 5 | 0.06 |
| 5000 | 23 | 0.32 |
| 9000 | 41 | 0.57 |

The estimated cost, based on government standard rates was found to be Rs 10000 ha$^{-1}$, whereas, it has been observed that when the farmer himself employed farm labour he could make the drains with above specifications within Rs. 5000 ha$^{-1}$.

## CONCLUSIONS

To cater the agronomic criteria for sugarcane crop and on the basis of general size and shape of land holdings in the area, the suggested spacing between drains and depth should be 45 m and 1.0 m, respectively in heavy black soils for sugarcane crop. The bottom width may be 0.30 m with side slope of 1:1 and longitudinal slope should follow the ground slope but in lands having flat topography it may be 0.001 m per m. The estimated cost of the drainage system worked out to be Rs 10,000 ha$^{-1}$.

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