## *Example 1:*

The ordinates of a rainfall mass curve of a particular storm are tabulated below.

| *Time* | *Cumulative rainfall in mm* |
|---|---|
| *7 00* | *0* |
| *7 15* | *9.5* |
| *7 30* | *17* |
| *7 45* | *27* |
| *8 00* | *40.5* |
| *8 15* | *49* |
| *8 30* | *63* |
| *8 45* | *84* |
| *9 00* | *95* |
| *9 15* | *102* |
| *9 30* | *110* |
| *9 45* | *112* |
| *10 00* | *112* |

a) Construct the hyetograph of this storm using a uniform time interval of 15 minutes.
b) Compute the maximum intensities of rainfall for durations of 15, 30, 45, 60, 90, 120 and 180 minutes and plot the intensity duration graph.
c) For the intensity – duration graph of part b fit an appropriate regression equation.

## *Solution:*

a) The intensities of rainfall are calculated using uniform time interval of 15 minutes as given in the following table. Also The corresponding hyetograph is shown in fig.1.

| Time | Rainfall in mm | Rainfall in successive 15 mt. intervals | Rainfall intensity in $^{mm}/_{hr}$ |
|---|---|---|---|
| 7 00 | 0 | | |
| 7 15 | 9.5 | 9.5 | 38 |
| 7 30 | 17 | 7.5 | 30 |
| 7 45 | 27 | 10 | 40 |
| 8 00 | 40.5 | 13.5 | 54 |
| 8 15 | 49 | 8.5 | 34 |
| 8 30 | 63 | 14 | 56 |
| 8 45 | 84 | 21 | 82 |
| 9 00 | 95 | 11 | 44 |
| 9 15 | 102 | 7 | 28 |
| 9 30 | 110 | 8 | 32 |
| 9 45 | 112 | 2 | 8 |
| 10 00 | 112 | 0 | 0 |

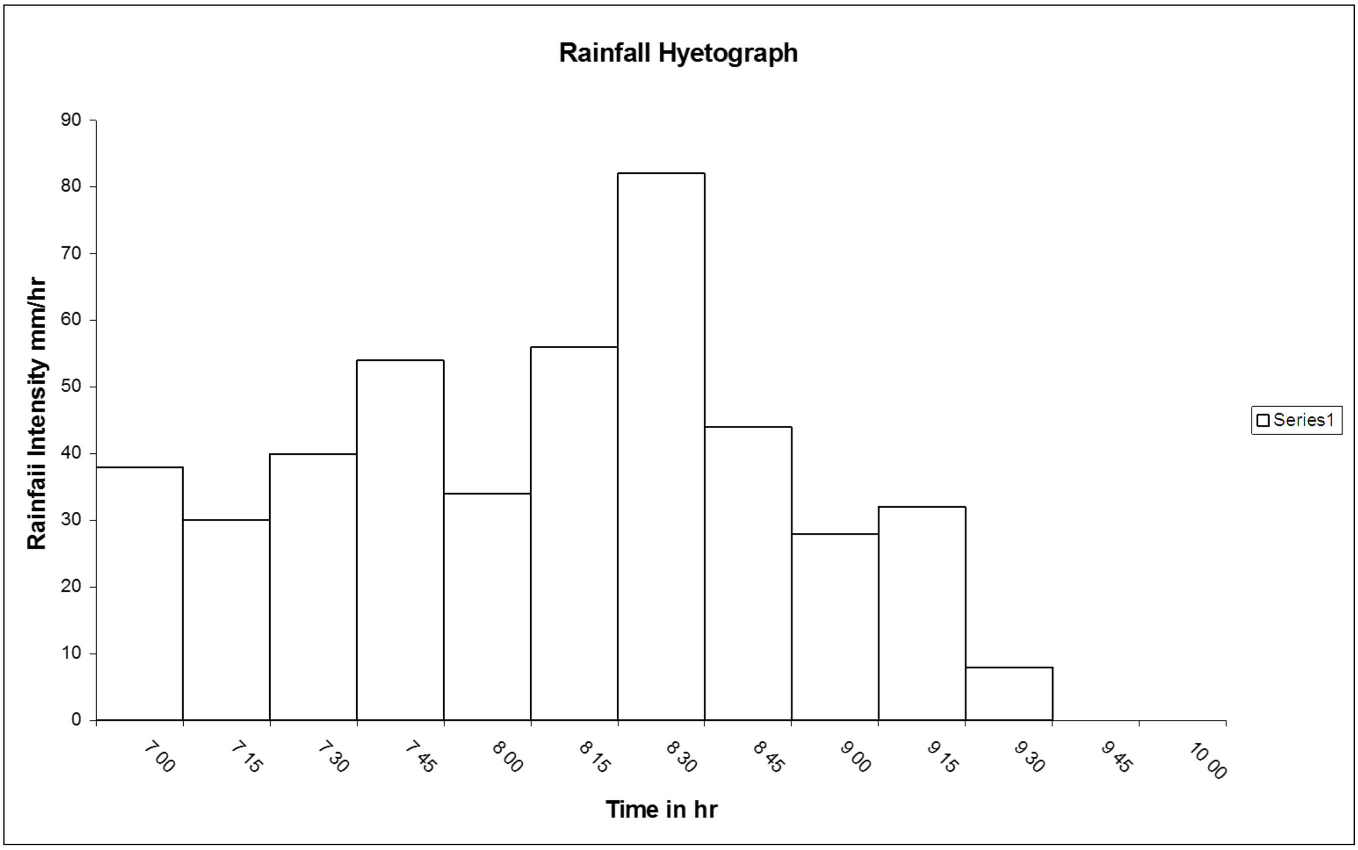


Fig.1. Rainfall Hyetograph

b) The necessary calculations to obtain the maximum intensities are shown in the following table.

| *Time* | *Cumulative Rainfall* | *Rainfall in any possible time interval equal to* | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | *15 mt* | *30 mt* | *45 mt* | *60 mt* | *90 mt* | *120 mt* | *180 mt* |
| *7 00* | *0* | | | | | | | |
| *7 15* | *9.5* | *9.5* | | | | | | |
| *7 30* | *17* | *7.5* | *17* | | | | | |
| *7 45* | *27* | *10* | *17.5* | *27* | | | | |
| *8 00* | *40.5* | *13.5* | *23.5* | *31* | *40.5* | | | |
| *8 15* | *49* | *8.5* | *22* | *32* | *39.5* | | | |
| *8 30* | *63* | *14* | *22.5* | *36* | *46* | *63* | | |
| *8 45* | *84* | *21* | *35* | *43.5* | *57* | *74.5* | | |
| *9 00* | *95* | *11* | *32* | *46* | *54.5* | *78* | *95* | |
| *9 15* | *102* | *7* | *18* | *39* | *53* | *75* | *92.5* | |
| *9 30* | *110* | *8* | *15* | *26* | *47* | *69.5* | *93* | |
| *9 45* | *112* | *2* | *10* | *17* | *28* | *63* | *85* | |
| *10 00* | *112* | *0* | *2* | *10* | *17* | *49* | *71.5* | *112* |

Maximum intensity for 15 minute duration: $\Rightarrow = \frac{21}{0.25} = 84 \, {}^{mm}\!/_{hr}$

Maximum intensity for 30 minute duration: $\Rightarrow = \frac{35}{0.5} = 70 \, {}^{mm}\!/_{hr}$

Maximum intensity for 45 minute duration: $\Rightarrow = \frac{46}{0.75} = 61.33 \, {}^{mm}\!/_{hr}$

Maximum intensity for 60 minute duration: $\Rightarrow = \frac{57}{1} = 57 \, {}^{mm}\!/_{hr}$

Maximum intensity for 90 minute duration: $\Rightarrow = \frac{78}{1.5} = 52 \, {}^{mm}\!/_{hr}$

Maximum intensity for 120 minute duration: $\Rightarrow = \frac{95}{2} = 47.5 \, {}^{mm}\!/_{hr}$

Maximum intensity for 180 minute duration: $\Rightarrow = \frac{112}{3} = 37.33 \, {}^{mm}\!/_{hr}$

The intensity– duration graph for this storm is shown in fig.2.

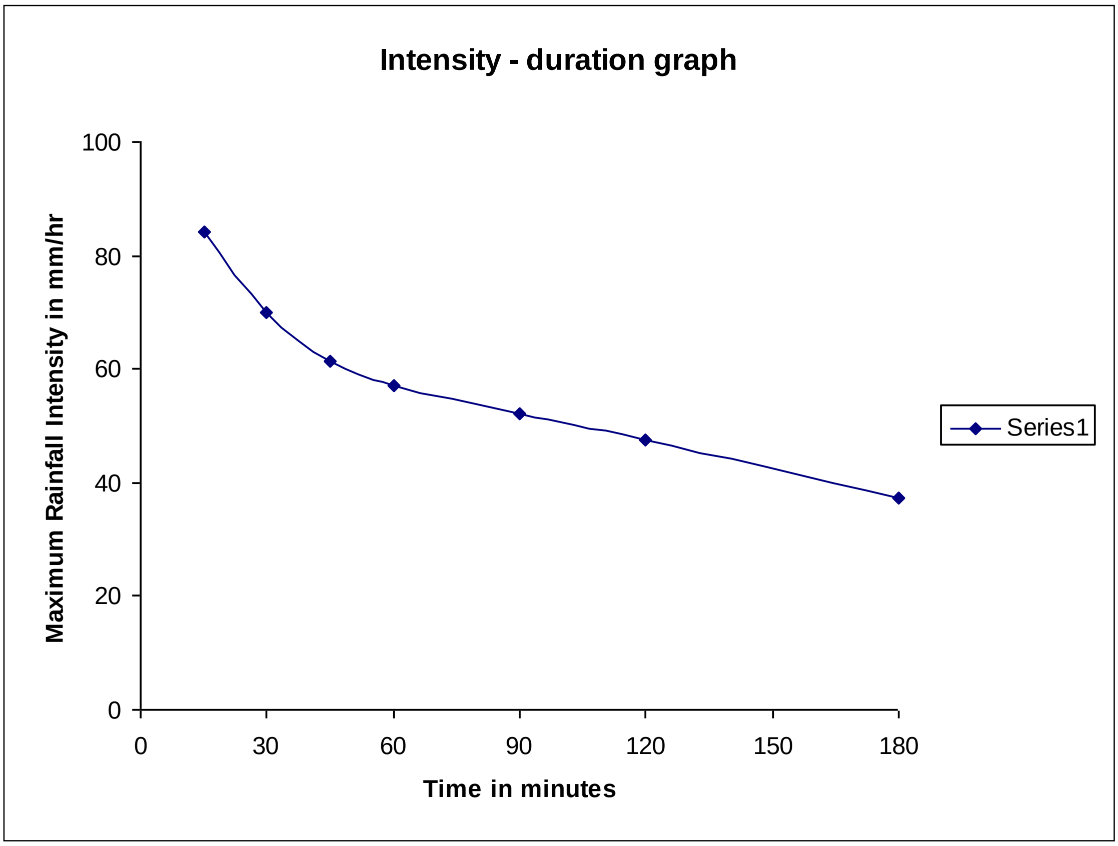


Fig.2. Intensity– Duration Graph

c) The relationship between intensity and duration is assumed to be of the following form. $i = \frac{a}{(t+b)^c}$, the necessary computations to arrive at the best values of a, b and c are shown in next table.

The detailed analysis is given only for one trial value of "b" which is assumed to be 8. Similar analysis is carried out with other values of "b" equal to 10, 12 and 14 respectively. On substitution of the relevant summations in following equations

$$\sum \log i = \sum [\log a - c \log(t+b)]$$

$$\sum [\log i . \log(t+b)] = \log a \sum \log(t+b) - c \sum [\log(t+b)]^2$$

12.2777=7log a -12.8709 c

22.3604=12.8709log a – 24.2585 c

The solution of the above two simultaneous equations is

c=0.362; log a =2.4196⇒a=262.76

Therefore the best equation with b=8 is

$$i = \frac{262.76}{(t+8)^{0.362}}$$

| Duration in minutes $t$ | Max.intensity in mm/hr $i$ | log i | log(t+b) | log i log (t+b) | (log(t+b))^2 | $\hat{i}$ | $\Delta i = i - \hat{i}$ | $\Delta i^2$ |
|---|---|---|---|---|---|---|---|---|
| 15 | 84 | 1.9242 | 1.3617 | 2.6203 | 1.8543 | 84.4527 | -0.4527 | 0.2049 |
| 30 | 70 | 1.8450 | 1.5797 | 2.9148 | 2.4957 | 70.4170 | -0.4170 | 0.1738 |
| 45 | 61.33 | 1.7876 | 1.7242 | 3.0824 | 2.9731 | 62.4268 | -1.0968 | 1.2030 |
| 60 | 57 | 1.7558 | 1.8325 | 3.2176 | 3.3580 | 57.0415 | -0.0415 | 0.0017 |
| 90 | 52 | 1.7160 | 1.9912 | 3.4169 | 3.9649 | 49.973 | 2.0270 | 4.1087 |
| 120 | 47.5 | 1.6766 | 2.1072 | 3.5331 | 4.4403 | 45.3679 | 2.1320 | 4.5455 |
| 180 | 37.33 | 1.5720 | 2.2741 | 3.5751 | 5.1717 | 39.4742 | -2.1442 | 4.5978 |
| | $\sum$ | 12.2776 | 12.8708 | 22.3605 | 24.2583 | | | 14.8359 |

Using the above equation the intensities for various durations are determined and entered in column $\hat{i}$ . The sum of the squared deviation for this case is 14.8356. The procedure is repeated for other value of "b" and results are as given under.

| Trial No | b | a | c | $\sum \Delta i^2$ |
|---|---|---|---|---|
| 1 | 8 | 262.76 | 0.362 | 14.836 |
| 2 | 10 | 281.33 | 0.375 | 14.475 |
| 3 | 12 | 300 | 0.387 | 14.412 |
| 4 | 14 | 320 | 0.399 | 14.636 |

It is thus seen that the sum of the squared deviations is least when b=12. therefore the desired regression equation for the data under consideration is

$$i = \frac{300}{(t+12)^{0.387}}$$

***Example 2:***

The rainfall data obtained from 7 rain gauge stations located in and around the basin area shown in fig.3. The basin has an area of 2790 $km^2$ .

a) Compute the average depth of rainfall for the basin using the three methods discussed in the lesson.
b) Analyse this data and develop the depth – area – duration curves for the storm.

| *Time hrs* | *Cumulative Rainfall in mm* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *A* | *B* | *C* | *D* | *E* | *F* | *G* |
| *4* | *0* | *0* | *0* | *0* | *0* | *0* | *0* |
| *6* | *12* | *0* | *0* | *0* | *0* | *0* | *0* |
| *8* | *18* | *15* | *0* | *0* | *0* | *6* | *0* |
| *10* | *27* | *24* | *0* | *0* | *9* | *15* | *6* |
| *12* | *36* | *36* | *18* | *6* | *24* | *24* | *9* |
| *14* | *42* | *45* | *36* | *18* | *36* | *33* | *15* |
| *16* | *51* | *51* | *51* | *36* | *42* | *36* | *18* |
| *18* | *51* | *63* | *66* | *51* | *60* | *39* | *18* |
| *20* | *51* | *72* | *87* | *66* | *66* | *42* | *18* |
| *22* | *51* | *72* | *96* | *81* | *66* | *42* | *18* |
| *24* | *51* | *72* | *96* | *81* | *66* | *42* | *18* |

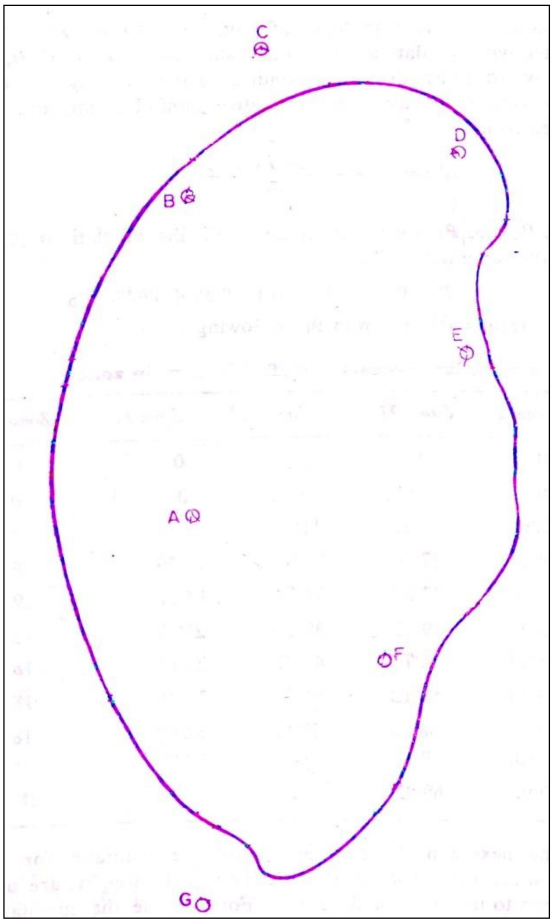

Fig.3. Rain gauge stations in and around the basin area

***Solution:***

a) The total rainfalls of 51,72,96,81,66,42 and 18 mm are indicated at the corresponding rain gauge stations A,B,C,D,E,F and G, respectively on the map. The average depth of precipitation is obtained by the three methods as given below.

1) Arithmetic mean

$$P = \frac{P_1 + P_2 + ... + P_n}{n} = \frac{51 + 72 + 81 + 66 + 42}{5} = 62.4mm$$

2) Theissen method

The construction of Theissen polygons for the given rain gauge network in the basin is shown in fig 4. the required computations to find the average rainfall depth are given in the following table.

| *Rain gauge station* | *Observed rainfall in mm* | *Theissen polygon area in $km^2$* | *Rainfall volume in $km^2\_mm$* |
|---|---|---|---|
| *A* | *51* | *775* | *39525* |
| *B* | *72* | *463* | *33336* |
| *C* | *96* | *58* | *5568* |
| *D* | *81* | *294* | *23814* |
| *E* | *66* | *505* | *33330* |
| *F* | *42* | *455* | *19110* |
| *G* | *18* | *240* | *4320* |
| | $\sum$ | *2790* | *159003* |

$$P = \frac{\sum P_i A_i}{\sum A_i} = \frac{159003}{2790} = 56.9903mm$$

3) Isohyets method

The isohyets of 30, 45, 60 and 75 mm of rainfall are drawn on the basin area map with linear interpolation and are shown in fig 4 too. The areas between successive isohyets are measured and tabulated below for necessary computations.

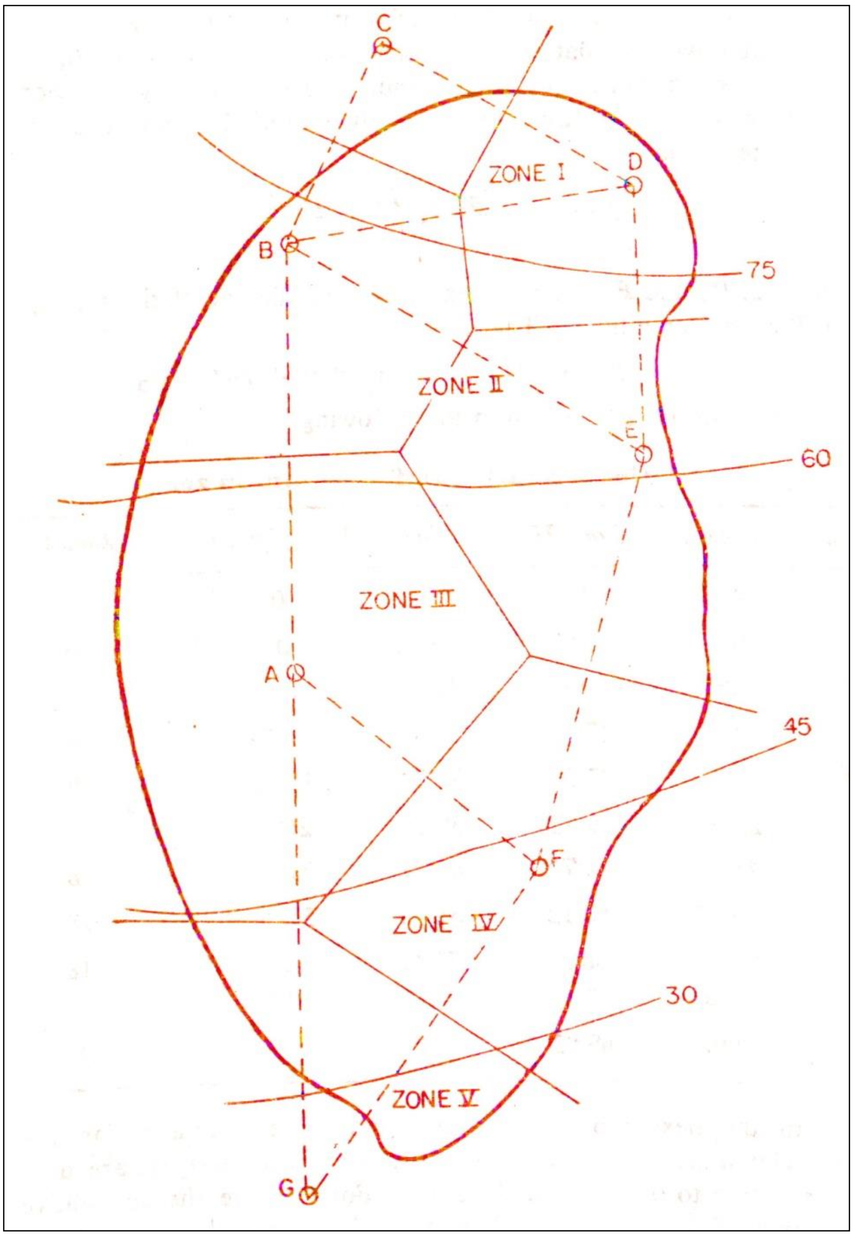


Fig.4. Theissen polygon and isohyetal map

| *Isohyet value in mm* | *Net area between isohyets in* $km^2$ | *Average rainfall in mm* | *Rainfall volume in* $km^2$ _ *mm* |
|---|---|---|---|
| *75* | *330* | *80* | *26400* |
| *60* | *755* | *67.5* | *50962.5* |
| *45* | *1195* | *52.5* | *62737.5* |
| *30* | *435* | *37.5* | *16312.5* |
| *<30* | *75* | *27* | *2025* |
| $\sum$ | *2790* | | *158437.5* |

$$P = \frac{\sum P_i A_i}{\sum A_i} = \frac{158437.5}{2790} = 56.7876 mm$$

b) The isohyets divide the basin area into five zone (see above table and fig 4) From the Theissen polygons and the isohyets the following information is noted;

   Zone I is influenced by 3 stations B, C and D with areas 58, 58, and 214 $km^2$, respectively
   Zone II by stations A, B, D and E with areas 45, 405, 80, and 225 $km^2$
   Zone III by A, E, and F with areas 730, 280, and 185 $km^2$
   Zone IV by G and F with areas 165 and 270 $km^2$
   Zone V by G with 75 $km^2$

The cumulative average depth of rainfall for each zone can be calculated with the data at individual stations at A, B, C, D, E, F, and G by adopting the corresponding Theissen weights. For example in zone I, the average cumulative rainfall at any time, is computed from

$$P_I = \frac{58 \times P_B + 58 \times P_C + 214 \times P_D}{330}$$

where $P_B$, $P_C$, and $P_D$ are the cumulative rainfalls at stations B, C, and D at the same time. That is

$$P_I = 0.1758 P_B + 0.1758 P_C + 0.6484 P_D$$

These results are shown in the following table

Cumulative average rainfall in mm in zones

| *Time* | *Zone I* | *Zone II* | *Zone III* | *Zone IV* | *Zone V* |
|---|---|---|---|---|---|
| 4 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0.72 | 7.33 | 0 | 0 |
| 8 | 2.64 | 9.12 | 11.93 | 3.73 | 0 |
| 10 | 4.22 | 17.16 | 20.94 | 11.59 | 6 |
| 12 | 13.38 | 22.25 | 31.34 | 18.31 | 9 |
| 14 | 25.91 | 39.28 | 39.2 | 26.18 | 15 |
| 16 | 41.27 | 46.74 | 46.57 | 29.18 | 18 |
| 18 | 55.75 | 60.12 | 51.25 | 31.04 | 18 |
| 20 | 70.75 | 68.33 | 53.11 | 32.90 | 18 |
| 22 | 82.06 | 69.92 | 53.11 | 32.90 | 18 |
| 24 | 82.06 | 69.92 | 53.11 | 32.90 | 18 |

In the next step the average cumulative rainfalls for accumulated areas are worked out. Here again the weights are used in proportion to the areas of zone. For example the cumulative average rainfall over the first three zones is given as

$$P_{I+II+III} = \frac{330P_I + 755P_{II} + 1195P_{III}}{(330+755+1195)} = 0.145P_I + 0.331P_{II} + 0.524P_{III}$$

The results are as tabulated below

Cumulative average rainfall in mm for accumulated areas

| *Time* *hrs* | *I* *330* $km^2$ | *I+II* *1085* $km^2$ | *I+II+III* *2280* $km^2$ | *I+II+III+IV* *2715* $km^2$ | *I+II+III+IV+V* *2790* $km^2$ |
|---|---|---|---|---|---|
| 4 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0.5 | 4.08 | 3.53 | 3.34 |
| 8 | 2.64 | 7.15 | 9.65 | 8.7 | 8.47 |
| 10 | 4.22 | 15.28 | 17.26 | 16.35 | 16.08 |
| 12 | 13.38 | 24.43 | 28.04 | 26.49 | 26.02 |
| 14 | 25.91 | 35.22 | 37.3 | 35.52 | 34.97 |
| 16 | 41.27 | 45.08 | 45.85 | 43.18 | 42.51 |
| 18 | 55.75 | 58.79 | 54.84 | 51.03 | 50.14 |
| 20 | 70.75 | 69.07 | 60.71 | 56.26 | 55.22 |
| 22 | 82.06 | 73.61 | 62.87 | 58.08 | 56.98 |
| 24 | 82.06 | 73.61 | 62.87 | 58.08 | 56.98 |

Now for any zone the maximum average depth of rainfall for various durations of 4, 8, 12, 16 and 20 hrs. can be obtained from the above table using the procedure explained in previous example. The results are given in the next table.

| *Duration hrs.* | *Maximum average rainfall in mm* | | | | |
|---|---|---|---|---|---|
| | *330 $km^2$* | *1085 $km^2$* | *2280 $km^2$* | *2715 $km^2$* | *2790 $km^2$* |
| *4* | *29.84* | *23.99* | *20.04* | *19.17* | *18.89* |
| *8* | *57.37* | *44.64* | *37.58* | *34.68* | *34.06* |
| *12* | *77.84* | *61.92* | *51.06* | *47.56* | *46.8* |
| *16* | *82.06* | *73.11* | *60.71* | *56.26* | *55.22* |
| *20* | *82.06* | *73.61* | *62.87* | *58.08* | *56.78* |

For each duration the maximum depths of rainfall are plotted against the area on logarithmic scale as shown in fig.5.

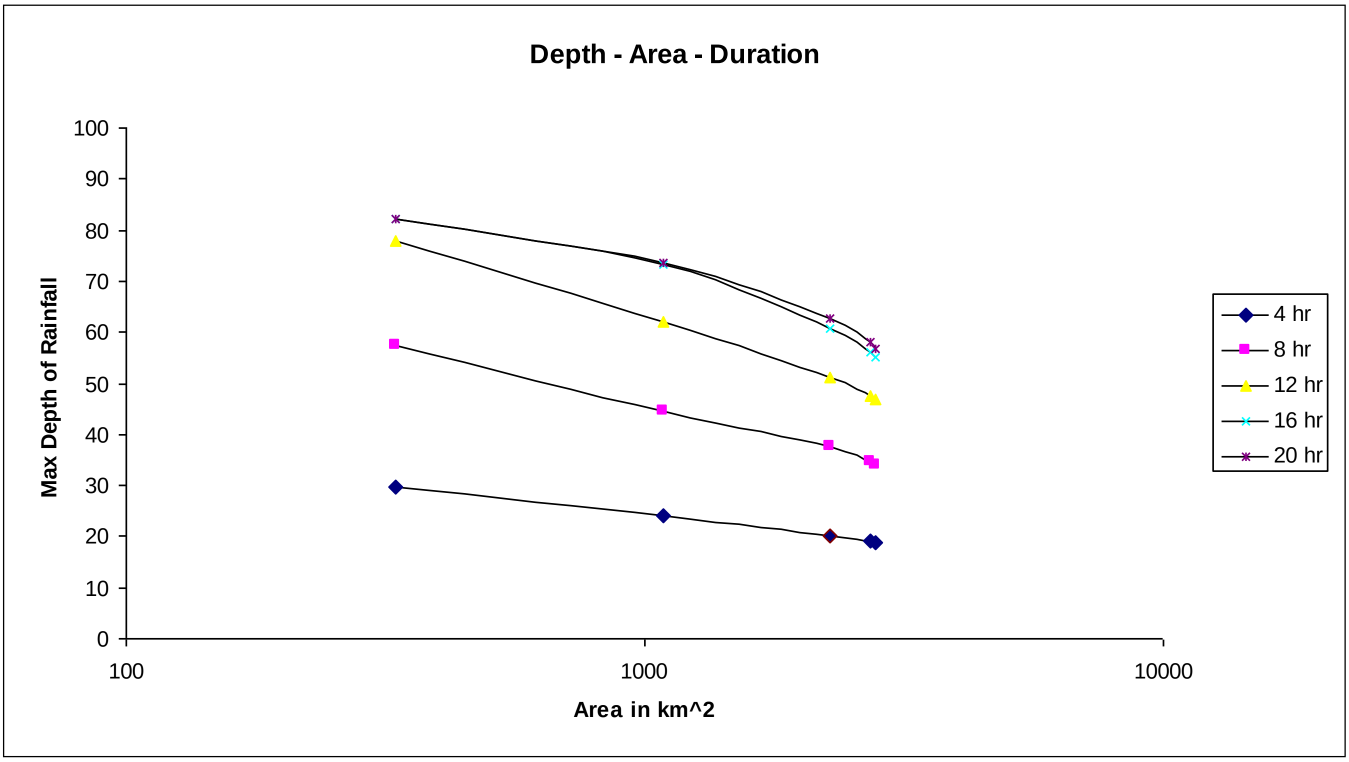


Fig.5. Dept – Area – Duration Curves