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Impact of Urbanization on Rainfall-Runoff Response and an Integrated Approach for Urban Storm Water Drainage Systems of Central Agartala-A Case Study

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***Abstract*— During last 20 years the share of urban populations to the country has increased 14% to 30%. This rapid urbanization brings significant changes in the nature of land surfaces in urban areas which affects the runoff process and overland flows during flood. Efficient computation of potentiality of overland flow on a modified land use is a difficult task and equally essential requirements to achieve optimal performances of storm water drainage systems. Present study is an attempt to highlight the role infiltration capacity of soil for efficient design of storm water drainage. Central Agartala, mainly a low lying area experiences severe water logging at many places during monsoon. Land use maps and soil categorization based on infiltration characteristics were performed by field observations at many places of the study area. Necessary hydro-meteorological parameters including various drainage data were collected to compute the flow volume at the inlet of each sub-drainage zone. SCS Curve number methods were adopted as design philosophy in the present study and the results obtained are compared with field observation. This provides inputs for the validation of calibrated parameters. The accumulated flow volume was used to identify the extension of water-logged areas and a probable solution to remove the stagnation of waters during flood.**

***Keywords*—Rainfall, runoff, drainage, water-logged areas**

I. INTRODUCTION

Population of Agartala Town has increased by 20.32% during last one decade and this rapid urbanization gradually reduces the number of ponds, lakes and other detention storages in the area. Presently many low-lying areas of the Agartala are getting waterlogged and cause urban flooding. Generally, construction of new roads and buildings modify the land use pattern of any city or town and arise many difficulties in passing storm water through existing storm water drainage systems. Also congestion of buildings and other constructions are the major issues to lying of drainage network. During monsoon storm water along with the foully sanitation sewage in many part start rising after completely filling up the sewers to an abnormal height and stands at a static level even after the rain stops. Immediate removal of accumulated storm water from the low lying areas is very essential during monsoon for smooth functioning of normal life. Keeping in view the importance of the issue, the need of rainfall-runoff response has been felt as one of the most effective area of research in urban storm water management. SCS Curve number method provides good correlation between the measured and estimated runoff (Nayak and Jaiswal, 2003 [1]). The method is also widely used to compute runoff. (Rao et al., 1996[2]; Chandramohan and Durbude,2001[3]; Sharma and kumar, 2002[4]).

II. AREA UNDER STUDY

Agartala, a small town and capital of the state Tripura receives heavy rainfall during monsoon and mean annual rainfall recorded is 2200 mm. About 80% of annual precipitation occurs during monsoon months (i.e. June-September). The area chosen for the present study is central Agartala drainage zone. A 6 meter wide Akhawrah drain is the main storm water collection drain which is running along the entire length of the area up to India–Bangladesh border. There are many other lateral feeder drains connected to Akhawrah drain. These are used for carrying both the storm water and the sewage water. Rapid urbanization in this area recently accelerated the response of the rainfall-runoff processes over the entire area and the storm water along with the foully sewage water start rising to an abnormal height in the existing drains resulting stagnation of water in many surrounding areas for 2-4 days even after the rain stops. Objective of the present study is to develop a mathematical model of storm water drainage system for central Agartala with the purpose of improving water logging hazards at many areas, which also includes

- Determining the flow volume through all the feeder drains and at the junctions linked to Akhawrah drain.
- Percentage increase in the accumulated runoff due to urbanization.
- Comparison of estimated and observed velocity of flow in all the drainage links.
- Determination of soil group based on infiltration rate over the area.

Fig.1. Drainage map of the study area

III. Complexities in Rainfall-runoff Process in urban areas

Overland flows or run-off resulting from rainfall is a complex process. Infiltration losses and detention storage are the two important parameters in this complex process. Infiltration losses depend on the soil type, ground coverage, antecedent moisture and other watershed properties which is changing with the massive increase of impervious surface like road, pavement and other concrete structures whereas detention storages are reducing in most of the urban areas due to continuous filling up of water bodies, lakes etc. Subsequently, if the existing drains are not capable of draining the entire runoff or overland flow, the drains get surcharged and the storm water along with the foully sanitary sewage start rising to an abnormal height. However a large number of parameters are needed which are related to drainage data and these parameters are not homogeneous over the entire area. This makes the mathematical modeling a difficult task.

iv. Methodology

Double ring infiltrometer method was used for measurement of infiltration rates at all the locations. Two concentric rings were used with 25 cm high, and diameter of 30 cm for inner ring and 60 cm for outer ring. The rings were driven about at about 15 cm deep in soil by using falling weight type hammer striking on a wooden plank placed on top of rings uniformly and without disturbing the surrounding soil as shown in fig. 2. The observed data are compared with Horton's equation for soil infiltration capacity expressed as

$$f = f_c + (f_0 - f_c)e^{kt} \tag{1}$$

Where f is infiltration capacity at any time.
f_c is steady state infiltration capacity.
f_0 is initial infiltration capacity.
K is Horton's constant representing rate of decrease in infiltration capacity.
t is time in hour

To maintain a constant head within the inner rings and annular space a point gage was used. The volume of liquid was recorded that is added to maintain a constant head in the inner ring and annular space during each timing interval by measuring the change in elevation of liquid level in the appropriate graduated cylinder. Also, the temperature of the liquid within the inner ring was record

Fig.2. Experimental setup for Double ring infiltrometer

SCS curve number method was developed for determining peak rate of runoff [5]. The SCS method with initial abstraction consideration is given by

$$S = \frac{25400}{CN} - 254 \tag{2}$$

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{3}$$

where P_e= runoff depth in mm.
P = Rainfall in mm.
S = detention storage.
Ia = 0.2S = Initial abstraction of rainfall by soil and vegetation.

The CN value referred in the present study is AMC-I and AMC-II and to adjust the CN values for the cases of AMC-I and AMC-II, the following equations were used, where CN(I), CN(II) and CN(III) represents curve number for normal, dry and wet conditions respectively.

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}$$
$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} \tag{4}$$

A runoff curve number (CN) is developed through field studies by measuring run-off from different soils at different locations. The moisture condition and the physical characteristics of the drainage zones are correlated to give hydrologic soil group. In the present study the computed flow by the rational methods in all the link drains were compared with the results obtained by SCS Curve number (CN) method for the validation of calibrated parameters. The development of mathematical model in the present study consists of following elements:

V. COMPUTATION OF DRAINAGE DATA BASE

The total Akhawrah drainage zone is discretized into 9 No. of sub zones, 62 No. of Link drains and 65 No. of joints. All the discretized sub-zones are shown in fig.3. Flow directions and invert levels of all the existing feeder drains linked to main Akhawrah drain are also shown in fig.3. Parameters representing the hydrological characteristics such as sub-zone area, mean slope, length of all link drains, longitudinal slope, R.L at all junctions/nodes are computed. In choosing storm sewer pipe diameters, the minimum required diameter is computed by

$$D = \left(\frac{2.16Qn}{\sqrt{S_0}} \right)^{3/8} \qquad (5)$$

Where Q = discharge entering the sewer pipe, n = Manning's roughness coefficient, and S_0 = bed slope of the sewer pipe lines. The required capacity of the storm sewers of all the 62 numbers of link sewers draining from all the 9 subzones is computed.

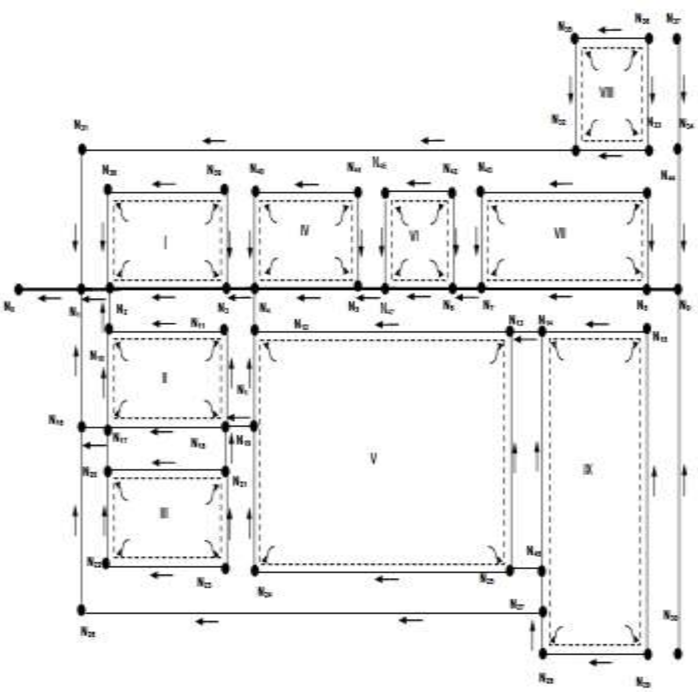

Fig. 3. Schematic for Development of Mathematical Model of Urban Storm water Drainage for Central Agartala

V. RESULTS AND DISCUSSION

The runoff estimation is the most important aspect in the present study and there are a number of empirical methods for its estimation. In the present study Soil Conservation service-Curve Number (SCS-CN, 1972) method were used. This CN is estimated using combination of land use, hydrological soil group and antecedent moisture content (AMC). For land use computations, entire drainage zone is subdivided into nine sub-zones and percentage of nature of land surfaces was computed. Rate of infiltration of soil were recorded at four locations of the study area. Rate of infiltration of soil has been determined by double ring infiltrometer method for soil categorization and these tests were conducted at four places of the drainage zone in the month of October, 2012, and the soil group obtained by infiltration of soil is shown in table 1.

Table 1: Soil group by rate of infiltration at different drainage sub-zone

Location	Soil type
Ramnagar	Loam
Orient Chowmuhini	Clay loam
Motorstand	loam
Rabindra Bhavan	Clay loam

The measured infiltration rates of soil at four different locations were compared and from the result it is found that the study area mainly of clay loam type (group B) and measured data are best fitted with the Horton's equation for soil infiltration and shown in fig. 4.

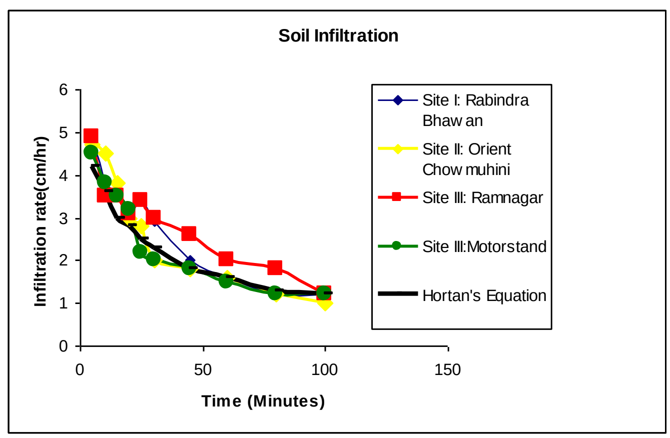

Fig.4: Infiltration Rate in the study area

Isopluvial maps of one hour rainfall for different frequencies (such as 2 years, 5 years and 50 years) prepared by IMD for Agartala were used in the present study. Also previous 10 years data obtained from IMD Agartala centre and showed that an average intensity of 10-12 cm per hour is very common during the monsoon period in Agartala. The rainfall of 1st August 2012, which was the maximum one day rainfall in that year recorded at every 15 minutes intervals by an automatic Rain gauge installed at NIT Agartala near by the study area. An Intensity duration curve is developed to estimate the production of surface runoff over the area and rainfall intensity estimated is about 68 mm/hr which is very close to value provided by IMD.

Table 2: Data recorded during first storm (Name of the recording station: N.I.T. Agartala, Date: 02-08-2012)

Period	Time (minutes)	Rainfall (mm)	Cumulative rainfall(mm)	Intensity (mm/hr)
13:30-13:37	7	8.1	8.1	69.0
13:37-13:45	8	6.52	14.62	58.0
13:45-14:00	15	0	14.62	29.2
14:00-14:05	5	8.375	22.925	39.4
14:05-14:10	5	8.0	30.995	46.4
14:10-14:25	15	6.5	37.495	40.9

The runoff coefficient, *C* is the integrated effect of the catchments losses which depends upon the nature of the surface slope and rainfall intensity. In case of homogeneous catchments area the value of *C* will be not be different, that will be unique for whole catchments area. But in case of non–homogeneous catchments area for finding the run off co-efficient, the whole area is sub divided into number of sub catchments each having a different run off coefficient. Then the equivalent run off coefficient can be calculated as

$$C_e = \sum C_i \times A_i \qquad (6)$$

Where A_i= Aerial extent of the sub area i.
C_i= run off coefficient of individual sub area Ai.
A= total catchments area.

Calculation of runoff coefficient for the drainage sub-zone III: Location: Rabindra Bhavan,

Table: 3 Runoff coefficient for the drainage sub-zone III

Nature of Land Surface	Area (m^2)	Percentage of area	Runoff coefficient
1.Lawn:sandy soil	902	28.28	0.1
2.Residential Area (single family)	37.5	3.6	0.4
3.Residential Area(multi-unit attached)	997	31.28	0.7
4. Shops	510	16.00	0.9
5.Streets	662	20.75	0.9

Equivalent runoff coefficient, C_e= 0.58
Similarly, runoff coefficients for other drainage sub-zones are also calculated.

Calculations of SCS curve Number for the drainage sub-zone III:
Location: Rabindra Bhavan,

Table 4: SCS curve Number for the drainage sub-zone III

Nature of Land Surface	Area (m^2)	Percentage of area	Curve Number (CN)	Product (for soil group B)
1.Open spaces:				
Grass cover >75%	706.35	22.71	61	1351.76
Grass cover 50-75%	195.52	6.28	69	422.28
2.Commercial business area	510.00	16.05	92	1472
3.Residential: Impervious (50-75%)	997.58	31.28	85	2658.8
Impervious (20-50%)	37.5	1.81	70	123.08
4.Street and road	662	20.75	98	2033.5
				8061.42

Therefore, wetted CN = (8061.42/98.12)= 82.15
And maximum retention, S= (1000/CN) – 10 = 5.5 cm
Pe = 8.60 mm

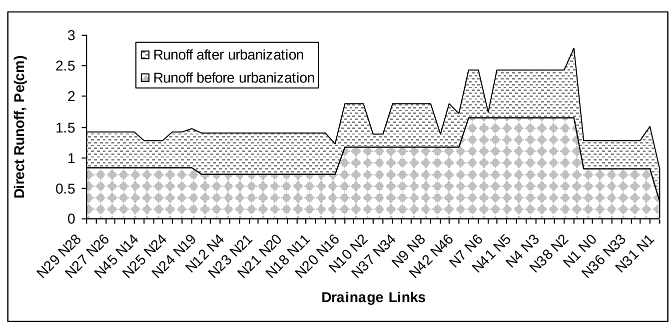

Fig.5: Excess runoff due to urbanization

During the past 15 to 20 years, hydrologists have paid considerable attention to the effect of urbanization. The effects of urbanization on the flood hydrograph include increased total runoff volumes and peak flow rates. In general, the major changes are due to increased impervious cover provided by parking lots, streets, and roofs, which reduce the amount of infiltration. From the available record it is seen that 25 to 30 years ago the land use of the study area was open land with fair grass cover and a Curve No. of 65 may be considerably acceptable before urbanization. Under this conditions the runoff calculated as with *P* = 37.459 mm as wetted CN = 56, and maximum retention, S= (1000/CN) – 10 = 7.85 cm, Pe =

5.9 mm (before urbanization). So the impact fo urbanization is to cause 8.60 – 5.9 = 2.7 mm of additional runoff from this storm, a 28 percent increase. Similarly for other sub-drainage zones the runoff are computed and shown fig. 5.

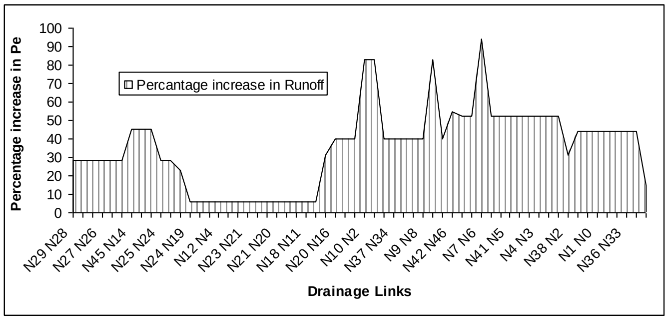

Fig.6: Percentage increase in runoff due to urbanization

Also required sizes for each link drains are compared with exiting link drains. Variation of estimated flows with the observed flows are compared and shown in fig.7.

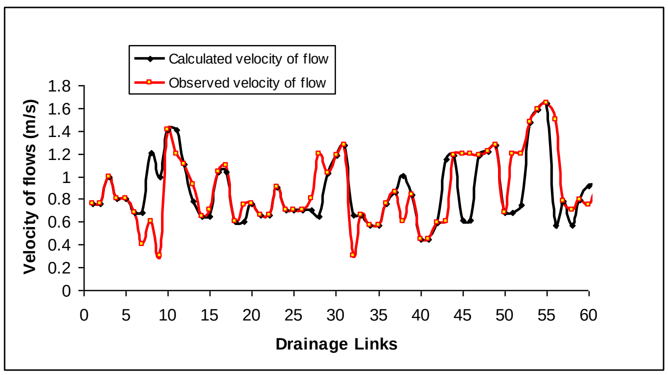

Fig.7: Variation of estimated velocity of flows with observed flows

Field observation has been made during heavy showers in the places where sizes of drains are not adequate and demarcated as shown in fig.7 for validation of developed mathematical model. Similarly, flow volumes through all the lateral feeder drains were computed. During computations, depth of deposition of silts and other wastes in the existing storm water link drains has been considered. In most of the places it is seen that if consecutive five or six feeder drains are inadequate to hold the accumulated rain water, the area gets water logged during heavy rain and also it is observed that massive silt and other wastage deposition in most of the link drains are the main causes of loosing their longitudinal bed slope to pass the excess storm water. It is seen that the demarcation of computed low lying areas in the developed mathematical model for the Akhawrah Drainage zone are matching with the actual field observation during flood in most of the places and shown in fig.8.

Table: 5 Results

Storm Sewer Link	Length (m)	Estimated sewer diameter (m)	Estimated Flow velocity (m/s)	Self-cleaning velocity (m/s)	Observed Velocity (m/s)
$N_{29}N_{28}$	180	0.60	0.765	0.85	0.765
$N_{29}N_{15}$	761	0.60	0.765	0.85	0.765
$N_{29}N_{27}$	631	0.89	0.99	1.15	0.99
$N_{27}N_{26}$	1331	0.66	0.8	0.85	0.8
$N_{27}N_{45}$	12	0.66	0.8	0.85	0.8
$N_{45}N_{25}$	12	0.52	0.68	0.82	0.68
$N_{45}N_{14}$	181	0.52	0.68	0.82	0.4
$N_{14}N_{13}$	12	1.08	1.21	1.3	0.6
$N_{15}N_{14}$	430	0.82	0.99	1.0	0.3
$N_{25}N_{24}$	745	0.54	1.405	0.82	1.405
$N_{25}N_{13}$	181	0.54	1.405	0.82	1.405
$N_{13}N_{12}$	719	1.07	1.11	1.32	1.11
$N_{24}N_{19}$	123	0.64	0.785	0.83	0.785
$N_{19}N_{18}$	12	0.47	0.65	0.82	0.65
$N_{19}N1_{12}$	212	0.47	0.65	0.82	0.65
$N_{12}N_{4}$	12	0.98	1.04	1.01	1.04
$N_{12}N_{11}$	12	0.98	1.04	1.01	1.04
$N_{23}N_{22}$	550	0.43	0.6	0.75	0.6
$N_{23}N_{21}$	125	0.43	0.6	0.75	0.6
$N_{22}N_{20}$	220	0.60	0.755	0.80	0.755
$N_{21}N_{19}$	12	0.49	0.66	0.83	0.66
$N_{21}N_{20}$	591	0.49	0.66	0.83	0.66
$N_{20}N_{17}$	12	0.79	0.91	1.0	0.91
$N_{18}N_{17}$	591	0.54	0.705	0.84	0.705
$N_{18}N_{11}$	212	0.54	0.705	0.84	0.705
$N_{17}N1_{6}$	12	0.44	0.705	0.84	0.705
$N_{17}N_{10}$	200	0.44	0.705	0.84	0.705
$N_{20}N_{16}$	244	0.48	0.65	0.86	0.65
$N_{16}N_{1}$	212	0.95	1.025	1.15	1.025
$N_{11}N_{10}$	600	1.18	1.18	1.2	1.18
$N_{10}N_{2}$	12	1.31	1.275	1.3	1.275
$N_{44}N_{8}$	601	0.49	0.665	0.86	0.3
$N_{44}N_{43}$	258	0.49	0.665	0.86	0.665
$N_{37}N_{34}$	304	0.39	0.57	0.73	0.57
$N_{34}N_{9}$	270	0.39	0.57	0.73	0.57
$N_{30}N_{9}$	772	0.60	0.765	0.80	0.765
$N_{9}N_{8}$	12	0.72	0.86	0.85	0.86
$N_{8}N_{7}$	602	0.94	1.01	0.90	0.6
$N_{43}N_{7}$	226	0.69	0.835	0.85	0.835
$N_{42}N_{46}$	138	0.30	0.445	0.65	0.445
$N_{42}N_{6}$	242	0.30	0.445	0.65	0.445
$N_{46}N_{47}$	232	0.42	0.595	0.75	0.595
$N_{7}N_{6}$	12	1.12	1.15	1.2	0.6
$N_{6}N_{47}$	168	1.17	1.18	1.2	1.18
$N_{41}N_{40}$	404	0.44	0.61124	0.75	0.61124
$N_{41}N_{5}$	232	0.44	0.61	0.75	0.61
$N_{47}N_{5}$	12	1.19	1.19	1.2	1.19
$N_{5}N_{4}$	389	1.23	1.22	1.2	1.22
$N_{4}N_{3}$	12	1.33	1.28	1.5	1.28
$N_{39}N_{38}$	555	0.51	0.685	0.86	0.685
$N_{39}N_{3}$	245	0.51	0.685	0.86	0.685
$N_{38}N_{2}$	228	0.59	0.745	0.80	0.745
$N_{3}N_{2}$	600	1.43	1.475	1.3	1.475
$N_{2}N_{1}$	12	1.80	1.585	1.75	1.585
$N_{1}N_{0}$	1000	1.94	1.645	1.9	1.645
$N_{36}N_{35}$	243	0.39	0.57	0.7	0.57
$N_{35}N_{32}$	323	0.64	0.785	0.82	0.785
$N_{36}N_{33}$	304	0.39	0.57	0.7	0.57
$N_{33}N_{32}$	202	0.63	0.79	2.1	0.79
$N_{32}N_{31}$	1890	0.80	1.84	1.75	0.92
$N_{31}N_{1}$	240	0.80	1.84	1.75	0.92

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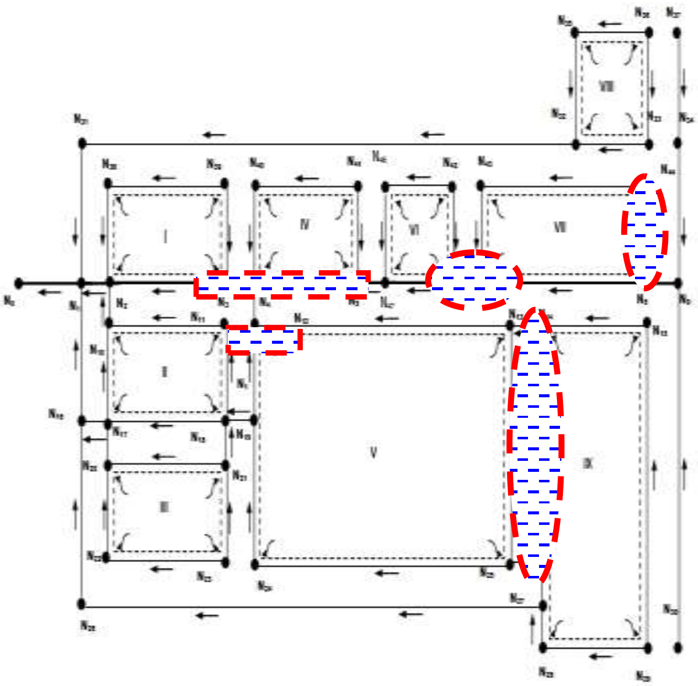

Fig.8: Projected water-logged area

V. SUMMARY & CONCLUSIONS

In the study area there is no separate sewage collecting system and deposition of wastes along with foully sanitation is a major constraint to achieve the optimal performances of existing drainage systems. Following conclusions may be drawn from the present study:

1. From the computed curve numbers of different sub-drainage zones, it can be stated that the percentage of impervious surfaces in Akawrah drainage zone is very high which accelerated the total rainfall runoff response of the area. More over the entire drainage zone is mainly a flat, low lying area which can be treated as main causes of stagnation of water.
2. Due to deposition of various wastes and foully sanitation in the existing drains throughout the year they losses their water carrying capacity during flood. These drains should be completely separated from sewerage collecting drain for safe passing of storm water during flood.
3. Pumping of water from low lying areas during flood may be an immediate measure to prevent the water stagnation.
4. Based on infiltration characteristics of soil it is observed that three types of soils are very much predominant in the study area namely -clay loam, sandy, sandy loam
5. Predicted results by SCS-CN techniques are more realistic. The objective of discretization of entire drainage zone into many sub-zones is to get more precise value. For better acceptability of the mathematical model as well as value of calibrated parameters, more trials are required.

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