Runoff Depth Estimation using SCS-CN Method in Jhargram Community Development Block - A Remote Sensing and Geographic Information System Approach

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Abstract Jhargram Community Development blocks which is situated on a watershed divider of Kansabati river basin and Dulung river basin. At a glance the area is suffering for water resource in some of the major parts. Surface runoff is one of the most important indicators of surface water availability, ground water recharge, soil practice etc. In this regard, estimation of runoff is highly needed for water resource planning, management and environment impact analysis. And Geographical Information System (GIS) and Remote Sensing (RS) techniques are used to calculate the runoff depth, it is one of the most time consuming way in recent days. The US Department of Agriculture (USDA), Soil Conservation Service Curve Number (SCS-CN) method which is the most widely used method is very effective in this study. In fact, the model is a quantitative description of land use-land cover and soil complex characteristics of a watershed and their impact on surface water flow. ERDAS Imagine 2014 and ArcGIS 10.1 are the platform which generate the input maps like sub watershed & micro watershed delineation, drainage map, soil map & hydrological soil map, classification of land use/land cover, elevation & slope map, Rainfall map, area calculation for each class. The rainfall map is prepared from the rainfall data of different stations. After sequentially used the equations of SCS-Curve Number method the different years from 2010 to 2014, the final prioritization map has been generated which shows the value of runoff depth from high to low. Similarly, there has been shown the runoff-rainfall relationship over the last five years. Wherever the runoff depth is high, the infiltration rate is low due to soil and slope. With seeing the results of this case study, this can be used for further management of water resources as well as water scarcity of this area.

Keywords GIS; Remote sensing; Runoff; SCS-CN

1. Introduction

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS - the number is still popularly known as a “SCS runoff curve number” in the literature. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. It is widely used and is an efficient method for
determining the approximate amount of direct runoff from a rainfall event in a particular area (Wikipedia).

In this study, I have customized existing SCS-CN hydrological model which considers parameters like slope, catchment size, vegetation, drainage density and drainage length. In order to study land use/land cover type I have generated unsupervised classification and the soil map which is collected from National Bureau of Soil Survey-Land Urbanization Practices input to Soil Conservation System (SCS) model rainfall-runoff estimation.

![Concept of water cycle system](image)

**Figure 1: Concept of water cycle system**

1.1. Objectives of Study

- To determine the quantity and rate from surface water flow.
- To deal with many watersheds related problems and it also focuses the needful decision for management.
- To validate the groundwater prospect zones with getting the run off maps.
- How effective and reasonable to generate run off estimation maps from SCS-CN method over the years using Remote Sensing and GIS technique.

1.2. Location of the Study Area

Jhargram police station serves this block. Headquarters of this block is at Jhargram. Total geographical area of this block is approximately 554 Sq. km. The maximum and minimum temperature varies from 45º C to 10º C and the average normal rainfall 1570 mm. The Jhargram block area covers the parts of two watersheds. The major watershed indicates Kasai river which is the main river flowing in the northern side of the block. And the minor watershed indicates Dulung River which flows south eastern side of the block.
2. Materials and Methods

A number of selective datasets are used for this study such as toposheets, soil map, DEM, satellite images from different sources. Topo maps are collected from Survey of India at the scale of 1:50000 were used for locations, to delineate watersheds and as a reference for all the thematic layers. Soil map is collected from National Bureau of Soil Survey (NBSS-LUP). LISS-IV satellite data of November 2012 was collected from NRSC, Hyderabad to prepare land use/land cover layer and to prepare drainage map as a reference of ASTER data and the ASTER Digital Elevation Model data downloaded from www.usgsearthexplorer.com website to generate major water basins, slope steepness, drainage channels. The monthly rainfall data was provided by Department of Irrigation, West Bengal and it is used after assigning the average annual rainfall.

Figure 2: Location of the study area
2.1. Generation of Various Types of Thematic Layers

After rectifying the base map is initially prepared from Toposheet (1:50000) provided by SOI. Moreover, the authentication of toposheet is very helpful for checking the location, land use/land cover map preparation, contour and drainage lines preparation and rectifying the other ancillary data. All the work completed through ArcGIS and ERDAS Imagine environment.

2.1.1. Preparation of Soil Map and Hydrological Soil Map

NBSS-LUP soil map was rectified with toposheets, block boundary and satellite data in ERDAS Imagine. The soil divisions are digitized in ArcGIS environment. There are five categories of soil identified by NBSS. These are Fine loamy ulti paleustalfs (W069), Fine loamy typic ustifluvents (W065), Fine loamy aeric ochraqualfs (W069), Fine aeric ochraqualfs (W070), and coarse loamy typic haplustalfs (W067).

Group A: Low runoff and high water transmission

Group B: Moderate infiltration and well runoff

Group C: Moderate runoff and poor infiltration capability

Group D: Very poor water transmission and high runoff
After analyzing the characters of different soil groups, the NBSS soil map has been categorized and merged with respect to the character of different Hydrological Soil Group (HSG) in GIS environment. Fine loamy ulti paleustalfs and Coarse loamy typic haplustalfs are converted into HSG – C which has low infiltration rate and high downward moment of water according to USDA. Fine loamy typic ustifluvents and Fine loamy aeric ochraqualfs are categorized into HSG – A which has the character of low runoff potentiality and high infiltration capability due to the contains of sand. Fine aeric ochraqualfs soil comes under HSG – D which has very low infiltration and high runoff potentiality. As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls 1983).

Figure 4: Soil map
2.1.2. Preparation of LULC and Overlay on Hydrologic Soil Group (HSG)

The land use/land cover classes have been identified using LISS-IV satellite data and toposheets used as a reference. With the visual interpretation technique, the classes have been found; Agricultural land, Forest, Scrub land, Mixed settlement (settlement mixed with vegetation), Water bodies, River, Social forestry and Urban area. It is very needful to show that the different land use classes have the different impacts on runoff systems. Like urban areas have the high runoff capabilities due to infrastructures as well as concrete areas and less soil. Other side, agriculture land has the less runoff those urban areas.

The final layout has been generated in Arc GIS interface. Final land use/land cover map was prepared to attach with the Curve Number for each land use classes area falling under different HSG. It was for that the USDA defines the different curve number in different soil group for different land use features. As per the perfection of land use classification the result will be more accurate for selecting the curve numbers and in that case the result of the runoff is more accurate for the watershed.

In case of urban landscape (there is one urban area which is Jhargram township) there is impervious area which leads to connected drainage systems directly from rainfall and some other areas in the township they do outlet on to lawns where minimum infiltration occurs due to impervious land. Actually the slope and height of the township are highest in Jhargram block so that the minimal infiltration occurs against very high surface flow. Several factors, such as the percentage of impervious area and the means of conveying runoff from impervious areas to the drainage system, should be considered in computing CN for urban areas (Rawls et al., 1981).
Figure 6: Land use/land use map

Figure 7: Overlay of HSG and LULC
2.1.3. Elevation and Slope Map

After processed the ASTER DEM in Arc GIS, the slope map was prepared and took the reference from toposheets. There are five zones (less than 45 meter, 45 – 60, 60 – 75, 75 – 100 and more than 100 meters) have been classified from the Digital Elevation Model. The highest peak of this block is 141 meter which lies at the southern part of Jhargram town. DEM proves the powerful tool and same like the conventional surveys and relief shading with one additional benefit of it providing a powerful analytical perspective. It provides the idea of terrain of the study area. The DEM emerges the degree of slope. Higher the degree of slope, higher the surface flow and soil erosion. The slope steepness map was categorized by five classes that is less than 2 degrees to 37 degrees. The steepest slope zone is within 11 to 37 degree which lies in the north and central zone of the block.

Figure 8: Elevation map
2.1.4. Preparation of Drainage and Watershed Demarcation

The drainage channels were extracted in ArcGIS from the ASTER 30-meter DEM. The SOI toposheets were used to reference for the drainage layer. In this context LISS-IV satellite image was used to validate the stream channels mainly 1st order streams by interpreting the moisture content specially in the valley fill areas because LISS-IV has the high resolution to identify those features. This block is situated with covering some parts of the two watershed areas. One is Kansabati watershed and another one is the Dulung watershed. Stream order is followed by the Strahler (1952) stream ordering technique in a hierarchical sequence and it helps to create the micro watersheds of that area. The ASTER DEM and the Dendritic drainage pattern help to extract the sub watersheds through ArcGIS environment. The 1st order streams helps to figure out the micro water basins from sub water sheds. There are 53 micro watersheds were showed out of 14 sub watersheds as per the drainage pattern and texture. Out of 53 micro watersheds there are 24 micro watersheds are under Kansabati river basin and the remaining micro watersheds are under Dulung basin area. The drainage basin properties and pattern depend on the number of classes i.e. nature, distribution, features. The number of quantitative features of a basin and its stream channels can be divided into linear aspect, aerial aspect and shape parameters. The details of micro watersheds are given below.
**Figure 10:** Sub-watershed

**Figure 11:** Micro-watershed
2.1.5. Rainfall Map

From the Irrigation department of West Bengal the rainfall data is collected. There are four rainfall zones according to its variation of average rainfall in a year and the rainfall measurement stations. Considering the nearby rainfall stations the rainfall boundaries has been simplified with the micro watersheds (MWS). The Pathra zone has the highest rainfall (1538.50 mm) and the Jhargram zone has the lowest rainfall (1427.32 mm) in comparing with other zones. The distribution of rainfall of this block is shown below.

A rainfall boundary has been drawn according to the rainfall stations and the variation of the rainfall with keeping in mind the 53 micro watersheds. It produces four rainfall zones which are Jhargram zone, Akhrasol zone, Manikpara zone and Pathra zone. According to the rainfall the Manikpara and Jhargram zone get the highest amount of rainfall and naturally it occurs the high amount of runoff with the impact of the permeability of soil.

2.2. Estimation of Runoff of using SCS-CN Method

United States Department of Agriculture (USDA) addressed the most affecting and widely used method first issued by Soil Conservation Service (SCS) in 1975 to estimation of run-off in small watersheds. After that it has been incorporated with current research works and other changes in Technical Release 55 (TR-55). It acts also rural to urban areas equally to estimate the discharge and volume of storm runoff in a watershed. The SCS Runoff Curve Number method has described its method in detail in 1985 and the equation is
\[ Q = \frac{(P - I_a)}{P - I_a} + S \]

Where,
- \( Q \) = runoff
- \( P \) = rainfall
- \( S \) = potential maximum retention after runoff begins
- \( I_a \) = initial abstraction

Initial abstraction \((I_a)\) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. \( I_a \) is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, \( I_a \) was found to be approximated by the following empirical equation:

\[ I_a = 0.3S \]

By removing \( I_a \) as an independent parameter, this approximation allows use of a combination of \( S \) and \( P \) to produce a unique runoff amount. Substituting equation 2-2 into equation 2-1 gives:

\[ Q = \frac{(P - 0.3S)}{(P + 0.7S)} \]

### 2.2.1. Generating CN Value

Curve Number ranges from 0 to 100, whose values were developed from annual flood rainfall–runoff data from the literature for a variety of watersheds generally less than one square km in area (USDA SCS, 1972) for different combinations of land use and soil. After the division of micro watersheds, the HSG map and LULC map have been selected for intersection and created merged polygon into each watersheds using spatial analyst tools. As per the description from USDA each soil group has its own CN value for the different types of land use type with different hydrologic conditions. Considering the instruction, the appropriate CN values have been assigned for each land use/land cover classes. To compute the CN values of the different micro watersheds as follows:

\[ CN = \frac{\sum (CN_i \times A_i)}{A} \quad (2) \]

Where,
- \( CN \) = Weighted curve number for the watershed
- \( CN_i \) = Curve number for specific land use feature
- \( A_i \) = Area of the specific land use feature failing in the specific HSG
- \( A \) = The total area of the micro watershed
Table 1: Hydrologic Curve Numbers (AMC-II) in Indian condition for different land use/land cover classes (based on USDA SCS, 1972)

| Land use/land cover classes | CN values |
|-----------------------------|-----------|
|                             | HSG-A     | HSG-C | HSG-D |
| Agricultural Land           | 55        | 69    | 83    |
| Forest                      | 36        | 60    | 79    |
| Mixed settlement            | 59        | 74    | 86    |
| Ponds/Lakes                 | 94        | 94    | 94    |
| River                       | 94        | 94    | 94    |
| Scrub land                  | 35        | 56    | 77    |
| Social forestry             | 43        | 65    | 82    |
| Urban area                  | 68        | 79    | 89    |

2.2.2. Estimation of S

S is the potential maximum retention after runoff begins. Basically it defines the watershed storage of runoff. It depends on the characteristics of the Soil-Land-Vegetation (SVL) complex. According to SCS the value of S is calculated by this formula:

\[ S = \frac{25400}{CN} - 254 \]  

This should be noted that the value of CN always varies within 0 to 100, whose values were developed from annual flood rainfall-runoff data from the literature for a variety of watersheds generally less than one square km in area (USDA SCS, 1972) for different combinations of land use and soil. The dataset has been arranged from the specific classes which is suitable in Indian conditions.

2.2.3. Runoff Depth Measurement

USDA Soil Conservation Service (SCS) adopted the CN method for estimating the storm runoff event but here it was used for annual average runoff depth in each watershed. The basic assumption of the SCS curve number is that, for a single storm event, potential maximum soil retention is equal to the ratio of direct runoff to available rainfall. This relationship, after algebraic manipulation and inclusion of simplifying assumptions, results in the following equations (USDA-SCS, 1972).

\[ Q = \frac{(P - 0.3 S)}{(P + 0.7 S)} \]  

After assigning the curve number for each land use feature, the weighted curve number for each watershed has been calculated that is defined as S, means potential maximum retention. The S value stands on the unique combination of soil hydrologic group, land use/land cover and antecedent moisture condition to define each Hydrologic Response Unit (HRU). But here the Antecedent Moisture Condition (AMC) was not used because in this study it has been focused on annual average runoff condition of the block not any particular event, day or month. Initially, the study watershed was decomposed into sub watersheds and subsequently, sub watershed was delineated into Hydrologic Response Unit (HRU) (Maidment, 1991), which involves the aggregation of areas located with a unique combination of soil and land use regardless of their spatial position in the watershed in the GIS environment. Each and every HRU has been simply added to obtain the surface flow in every micro watershed.
After that the $S$ has been used for runoff depth determination. The value of $P$ means Precipitation should be always higher than the calculated value of $0.3S$ then the result will be meaningful otherwise the value of $Q$ (Runoff) will be 0. In this content, the value of $Q$ was estimated in every micro watershed and observed the ranges according to the variation of runoff depth in that specific year.

### 3. Results and Discussion

The above outputs of the last five years from 2010 to 2014 depict the overall schematic view of runoff in Jhargram block. In this study the main focus is on the highest & low runoff zones because this decides the water scarcity zones as well as the water resource monitoring system. Starting from the year 2010, the minimum runoff depth is 703.16 (MWS-22) and the high runoff depth is 970.45 (MWS-14). As per the rainfall there are 13 high runoff zones, 8 low runoff zones and 32 medium zones. In 2011, there are 19 high runoff zones, 13 low runoff zones and 21 moderate runoff zones. The highest $Q$ is 1599.26 (MWS-14) and the lowest rate of $Q$ is 1300.19 (MWS-23). In 2012, there are 18 micro watersheds with high runoff, 10 micro watersheds with low runoff and 25 micro watersheds with moderate runoff. In this year, the highest $Q$ is 1298.85 which happen in MWS-2 and the lowest one is 979.77 happening in MWS-50. In this way, the runoff of 2013 says there is a highest runoff 1898.55 which is in the area of MWS-36 and the lowest one is 1615.32 which are in the area of MWS-24. In the year 2014, the highest $Q$ is 1079.10 which are in the area of MWS-1 and the lowest one is 809.48 which are in the area of MWS-23. All runoff maps of the different years are superimposed and generate a prioritization map that tells the overall figure of surface flow.

In the overall scenario of Runoff of five years, it clearly shows that the highest runoff zones are in the gentle slope areas where the soil is coarse loamy and fine loamy type. In the sense of Hydrological soil group, the C group is dominating in those zones which contain the low infiltration and moderate to well-draining system. The average values MWS 1, 2, 3, 4, 11, 14, 15, 16, 31, 29, 36, 37, these twelve micro watersheds are the high runoff priority zones and MWS 7, 10, 20, 21, 22, 23, 42, 43, 44, 45, 49, 50, these twelve micro watersheds are the high priority zone. The remaining 29 micro watersheds are the medium range runoff priority. But the noticeable thing is that the medium priority zone has the facility for both the surface flow and the percolation process.

A raster choropleth map (Figure-18) shows the density of the runoff depth in the entire area on the basis of its priority in different micro watersheds where the priority zones is clearly visible from low to high. The medium and low runoff happens in most of the valley fills and the two main river basin areas (Kangsabati River and Dulung River). Where the drainage density and degree of slope increases, the runoff also increases. The urban area (Jhargram) including the large village (Manikpara) is affected from this. According to USDA, here Hydrologic Soil Group C and D covered areas which are the form of have the high surface flow due to the nature of soil. The HSG-C is the form of coarse loamy typic haplustalfs & Fine loamy ulti paleustalfs and HSG-D is the form of Fine aeric ochraqualfs soil. These soils have the poor water infiltration capacity rate rather than runoff. And these areas have the high drainage density and very gentle slope. So in the rainy season generally the runoff increases.
| MWS | VQ_2010 | VQ_2011 | VQ_2012 | VQ_2013 | VQ_2014 |
|-----|---------|---------|---------|---------|---------|
| 1   | 925.28  | 1567.96 | 1200.16 | 1842.46 | 1079.10 |
| 2   | 924.00  | 1566.63 | 1298.85 | 1841.11 | 1077.81 |
| 3   | 914.22  | 1556.33 | 1288.79 | 1830.69 | 1067.86 |
| 4   | 902.71  | 1544.15 | 1276.92 | 1818.35 | 1056.12 |
| 5   | 878.45  | 1518.27 | 1251.78 | 1792.08 | 1031.33 |
| 6   | 882.35  | 1522.44 | 1255.83 | 1796.33 | 935.32  |
| 7   | 800.98  | 1341.25 | 1174.09 | 1715.41 | 953.34  |
| 8   | 803.83  | 1345.33 | 1178.07 | 1719.55 | 957.26  |
| 9   | 849.10  | 1486.55 | 1121.17 | 1759.80 | 901.21  |
| 10  | 732.94  | 1376.00 | 1008.02 | 1650.58 | 886.89  |
| 11  | 962.52  | 1590.27 | 1229.43 | 1861.12 | 1011.49 |
| 12  | 860.55  | 1498.97 | 1133.14 | 1772.46 | 912.97  |
| 13  | 884.06  | 1424.28 | 1157.61 | 1798.19 | 937.07  |
| 14  | 970.45  | 1599.26 | 1237.92 | 1870.38 | 1019.76 |
| 15  | 940.52  | 1565.12 | 1205.77 | 1835.18 | 1008.49 |
| 16  | 900.20  | 1532.68 | 1269.62 | 1804.71 | 1010.69 |
| 17  | 810.26  | 1543.86 | 1180.27 | 1816.18 | 961.11  |
| 18  | 820.89  | 1555.63 | 1191.51 | 1828.22 | 972.11  |
| 19  | 874.22  | 1417.32 | 1147.38 | 1787.46 | 927.00  |
| 20  | 715.96  | 1358.16 | 1090.58 | 1632.55 | 869.63  |
| 21  | 739.29  | 1382.63 | 1014.52 | 1657.28 | 893.34  |
| 22  | 703.16  | 1344.63 | 1077.39 | 1618.84 | 856.59  |
| 23  | 755.23  | 1300.19 | 1030.80 | 1673.98 | 809.48  |
| 24  | 900.89  | 1541.16 | 1274.00 | 1615.32 | 1053.25 |
| 25  | 874.68  | 1414.22 | 1147.87 | 1787.97 | 927.47  |
| 26  | 851.35  | 1489.00 | 1123.52 | 1862.29 | 903.52  |
| 27  | 847.32  | 1414.61 | 1119.29 | 1757.81 | 900.37  |
| 28  | 855.91  | 1421.95 | 1128.29 | 1767.34 | 908.21  |
| 29  | 932.60  | 1508.51 | 1203.84 | 1841.39 | 1042.20 |
| 30  | 849.14  | 1586.59 | 1121.21 | 1859.84 | 1001.25 |
| 31  | 953.17  | 1579.61 | 1219.40 | 1850.14 | 1017.73 |
| 32  | 830.26  | 1465.94 | 1101.38 | 1738.76 | 981.79  |
| 33  | 884.42  | 1424.66 | 1157.98 | 1798.58 | 1037.44 |
| 34  | 802.66  | 1435.43 | 1172.23 | 1707.53 | 953.25  |
| 35  | 841.56  | 1478.33 | 1113.26 | 1851.41 | 993.44  |
| 36  | 906.39  | 1524.63 | 1257.95 | 1898.55 | 1037.41 |
| 37  | 913.69  | 1534.04 | 1276.71 | 1803.03 | 1000.31 |
| 38  | 850.50  | 1488.07 | 1122.63 | 1761.35 | 902.65  |
| 39  | 853.07  | 1490.87 | 1125.32 | 1764.20 | 905.29  |
| 40  | 834.76  | 1500.89 | 1206.12 | 1843.82 | 986.44  |
| 41  | 870.95  | 1410.21 | 1143.98 | 1783.89 | 923.65  |
| 42  | 882.07  | 1322.15 | 1155.54 | 1696.03 | 835.04  |
| 43  | 707.91  | 1349.66 | 1082.28 | 1623.93 | 861.42  |
| 44  | 871.60  | 1310.91 | 1044.66 | 1684.60 | 824.32  |
| 45  | 879.48  | 1319.37 | 1052.85 | 1693.21 | 832.39  |
| 46  | 865.08  | 1403.87 | 1137.86 | 1777.44 | 917.62  |
| 47  | 845.94  | 1483.10 | 1117.85 | 1756.28 | 997.95  |
| 48  | 852.70  | 1490.46 | 1124.93 | 1763.79 | 904.91  |
Figure 13: 2010

Figure 14: 2011

Figure 15: 2012

Figure 16: 2013

Figure 17: 2014
Figure 18: Prioritization map of Runoff depth in mm

Figure 19: Rainfall zone wise distribution of average-runoff
4. Conclusion

It is very important to analyze Runoff in this study area which is useful for the protection of water resource and maintaining the water quality. In this study the value of runoff is not calculated seasonally because it is assumed that the maximum runoff occurs in the rainy season (June to August) and average rainfall data from different stations is used to estimate the depth of runoff. The above figures show that higher the rainfall occurs, higher the runoff depth. In this regard, due to the permeability of soil and degree of slope impact on the surface water flow despite of having huge rainfall in the different zones. As mentioned earlier the Jhargram block is situated covering with watershed divider and also with the part of two watersheds (Kangsabati River and Dulung River). In the monsoon season the basin faces the strong surface flow excepts some micro watersheds which is caused by different soil formulation and slope, but in the pre-monsoon period there is the crisis of water in the entire area. On the other hand, the study also shows the groundwater prospect zones. Where the high runoff occurs, the groundwater prospect will be poor. This needs to be planned scientifically by creating different water harvesting structures (check dam, rain water harvesting) and comprehensive treatment for controlling massive surface runoff to feed the water crisis area for better development.

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