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ESTIMATION OF SURFACE RUNOFF USING CURVE NUMBER METHOD- A GEOSPATIAL APPROACH

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Abstract – *The Natural Resources Consevation Service Curve Number (NRCS CN) is the widely used method for the estimation of surface runoff. The remote sensing and GIS techniques facilitate the estimate of surface runoff. This study mainly focused to estimate the runoff of KCAET Campus using the curve number method. The study was carried out in GIS environment using remote sensing data. The analysis was done for the year 2004 to 2007, 2018 and 2019 upto June. The land use map was digitized from Google earth of year 2006 and 2018. ArcGIS 10.2 was used for the analysis. About 28.5% of the total area belongs to high runoff potential class, 33.7% have medium runoff potential and 37.7% of the area has high runoff potential. The runoff percentage from the annual rainfall varied from 16% to 23% for the study period. The curve number values for normal conditions were 57.77 and 58.95 for the year 2006 and 2018 respectively. The integration of remote sensing and GIS along with NRCS curve number method was found to be a powerful tool in estimating runoff.*

***Key Words*: Remote sensing, GIS, NRCS CN, Rainfall, Runoff, Curve number**

1. INTRODUCTION

Water is a vital factor for augmenting the growth of agriculture, industry and economic development, especially in the perspective of rapidly increasing population and urbanization. Various aspects of water which related to earth were represented in terms of hydrologic cycle [1]. Precipitation and runoff are the two important hydrologic variables and the main transportation components of the hydrologic cycle. In the coming decades, climate change, surface water pollution and population growth together may produce a severe decline in fresh water supply and there will be water stress all over the country. The quantification and conservation of available water resources is essential to ensure sustainability. Estimation of surface runoff is essential to assess the potential water yield of a watershed, to plan water conservation measures including recharging of the ground water zones and reduction of sedimentation. This also helps in reducing the flood hazards at the downstream and it is an essential prerequisite of integrated watershed management [2].

Natural Resources Conservation Services Curve Number (NRCS-CN) method is widely used, simple empirical model with few data requirements and clearly stated assumptions. The method was originally developed by Soil Conservation Service, United States Department of Agriculture (USDA). The NRCS-CN method has been widely used for storm water modeling, water resource management and runoff estimation from rainfall events in urban or agricultural watersheds [3].

Generation of too many spatial input data is one of the major problems in the runoff estimation models. Conventional methods are too costly and tedious for the generation of input data. With the advent of Remote Sensing and Geographic Information System (GIS) technology, the derivation of such spatial information has become cost effective and easier. Remote sensing technology can enhance the conventional methods to a great extent in rainfall-runoff studies. Many researchers have been using the Geographic Information System along with remote sensing data to estimate runoff curve number value all over the world. There exists a good correlation between the estimated runoff depth and measured runoff depth using NRCS CN method along with GIS. The incorporation of remote sensing data and application of the NRCS CN model in a GIS platform provides a powerful tool in the assessment of runoff [4].

2. STUDY AREA AND DATA SOURCES

2.1 Study Area

The study was conducted in the KCAET Campus which is located in Tavanur village of Malappuram district. Area lies between 10° 51' 6.51" to 10° 51' 31.417" N latitude and 75° 59' 2.37" to 75° 59' 25" E longitude with elevation of about 13 m above MSL. The study area covers about 40 ha nourished by the river Bharathapuzha in the Northern side. The climate of the area falls under humid tropic and generally dry except during south west monsoon season. Average rainfall of the region is 2952 mm, in which south west monsoon contributes more. The area has around 200 rainy days in a year. The average annual temperature of the study area is 30 °C and during summer it goes upto 33 °C to 37 °C. The soil is mainly loamy in texture and the soil temperature regime is isohyperthermic. The study area has undulating topography and varying landuse patterns. Coconut, mango, paddy etc. are extensively cultivated in the area.

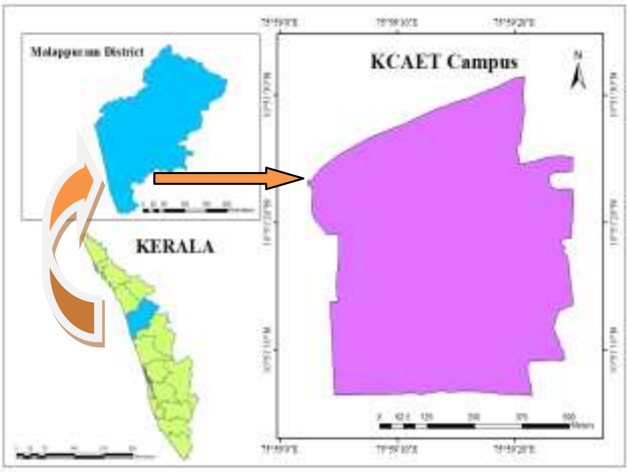

Fig -1: Location map of the study area

2.2 Data

The boundary of the KCAET Campus was demarcated using handheld GPS survey. The surveyed points were transferred into ArcGIS.
Sieve analysis was done using soil samples collected from 20 different locations in the study area to generate soil texture map. Land use map of the study area was digitized from Google earth imageries of 2006 and 2018. Daily rainfall measurements were collected from non recording type (Simon's type) raingauge from the study area.

Table -1: Data types and sources

Sl No.	Type	Source	Description
1	Boundary Points	GPS	Handheld GPS survey
2	Soil Data	Sieve analysis	Soil types
3	Land use	Google earth	Google earth imageries of 2006 & 2018
4	Rainfall	Simon's rain gauge	Non recording type rain gauge

3. METHODOLOGY

The NRCS CN method developed by NRCS (Natural Resource Conservation Service) of United States Department of Agriculture (USDA) is a stable and well established conceptual method for the estimation of runoff [5].

The runoff curve number equation is:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad P > I_a \qquad (3.1)$$

$$Q = 0 \qquad P \leq I_a \qquad (3.2)$$

where, Q is the depth of runoff, in mm; P is the depth of rainfall, in mm; I_a is the initial abstraction, in mm; S is the maximum potential retention, in mm.

The NRCS CN method based on water balance equation has two primary assumptions. First, the ratio of the actual amount of runoff (Q) to maximum potential runoff is equal to the ratio of the actual infiltration (F) to the potential maximum retention or infiltration (S).

Second assumption is the amount of initial abstraction (I_a) is considered as some fraction of potential maximum retention (S).

$$Ia = \lambda S \qquad (3.3)$$

where λ is the fraction of potential maximum retention and it was taken as 0.2 in this study.

The index of runoff potential before a storm event is the antecedent moisture condition (AMC). It is an indicator of availability of soil moisture before a storm and watershed wetness. The NRCS recommends to assign curve number values on the basis of AMC on the rainfall in 5 day period preceding a storm. AMC I is the dry condition of soils in the watershed and AMC II is the average moisture condition. AMC III is the condition which has heavy rainfall or light rainfall at low temperatures in the preceding five days of the storm.

The potential maximum retention (S) is the recharge capacity of the watershed. The potential soil water retention map was generated using raster calculator tool in arc gis based on the equation 3.4.

$$S = \frac{25400}{CN} - 254 \qquad (3.4)$$

3.1 Soil type

The Natural Resource Conservation Service (NRCS) classified the soils into four classes A, B, C and D based on the soil characteristics.

Table -2: HSG for USDA textural classes

HSG	Soil Texture
A	Sand, loamy sand or sandy loam
B	Silt or loam
C	Sandy clay loam
D	Clay loam, silt clay loam, sandy clay or clay

Different hydrologic soil groups and their characteristics given by USDA were described below.

- Group A- These soils have low runoff potential. Water transmission capacity is high. The percentage of clay is less than 10% and sand or gravel is greater than 90%.
- Group B- These soils have moderately low runoff potential. Water transmission capacity is unimpeded. The percentage of clay is around 10% to 20% and sand is 50% to 90%.
- Group C- These soils have moderately high runoff potential and water transmission is somewhat restricted through the soil. Percentage of clay vary from 20% to 40% and sand less than 50%.

- Group D- These soils have high runoff potential and water transmission is restricted or very restricted through the soil. The clay content is greater than 40% and sand is less than 50%.

Three textural groups like sandy loam, silt and silt loam were identified in the study area using texture calculator and USDA nomograph. The identified soil types are interpolated using Inverse Distance Weighting method in ArcGIS. A considerable of the area (around 44.4%) have sandy loam soil, whereas silt and silt loam soil together constitutes 55.6% of the study area. Sandy loam soil which have high infiltration rate as compared to silt and silt loam dominated in the study area.

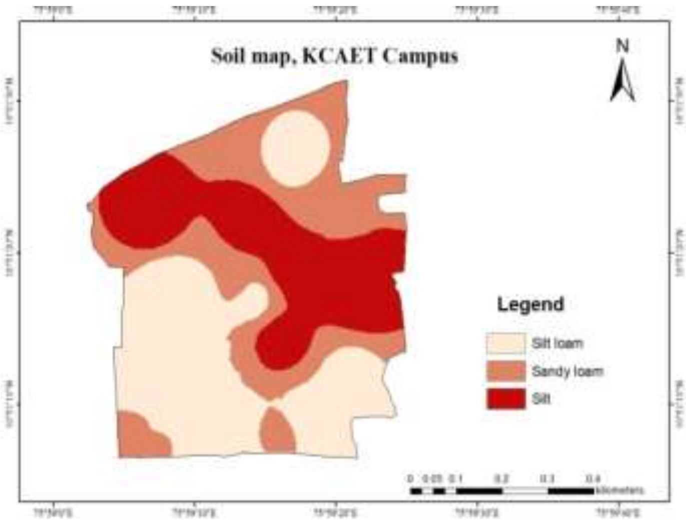

Fig -2: Soil map of the study area

3.2 Hydrologic soil group

Conditions for the classification of hydrological soil groups are applied in the ArcGIS interface and HSG map was prepared. Two hydrologic soil groups, A and B were identified in KCAET Campus from the soil texture map. The silt and silt loam belongs to hydrologic soil group B and sandy loam soil belongs to hydrologic soil group A. As stated by USDA, the HSG A and HSG B have good water transmission rate and low runoff potential.

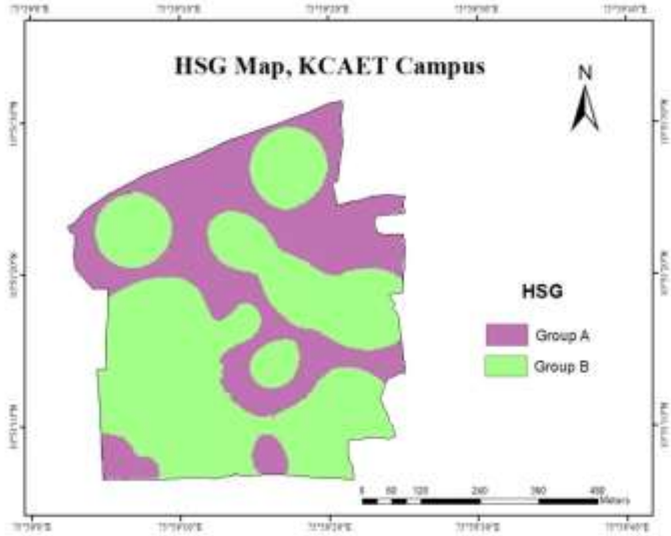

Fig -3: HSG map of the study area

3.3 Land use

The land use is the utilization of land resources by human being. The land cover change reflects in the impact on environment which is due to excessive human interventions. The Google Earth tool was developed recently and is widely used in many sectors. The Google Earth which releases high spatial resolution images is a free and open data source. The Google Earth images will provide detailed land use/land cover mapping facilities with relatively satisfactory results [6].

The land use map of the study area was digitized from the Google Earth imageries of the year 2006 and 2018. Based on the visual interpretation and field verification, landuse categories were analyzed and digitized. Mainly 7 landuse classes were identified in the area for the year 2006 and 10 land use classes were identified in the study area for the year 2018. Majority of the area was covered by thick vegetation with grass and litter covered in the soil. It comprises around 35.14% of the total area in 2006 which was increased to 46.4% in 2018. The digitized files in Google Earth are transferred to ArcGIS for the map preparation. The land use map and hydrologic soil group map prepared were intersected in arc GIS platform using intersect tool in the arc toolbox.

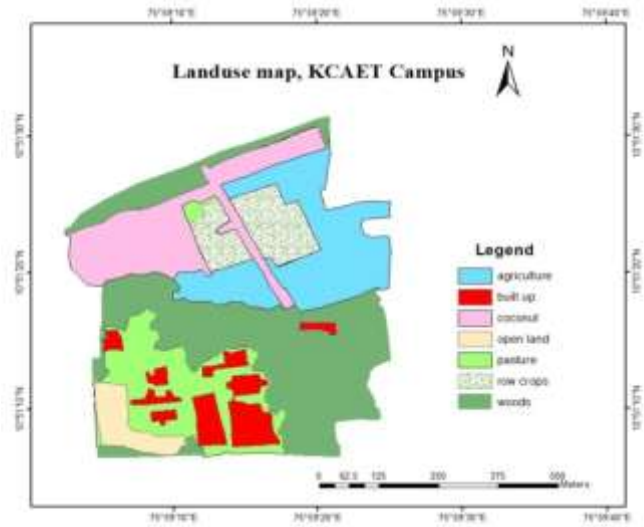

Fig -4: Land use map (2006)

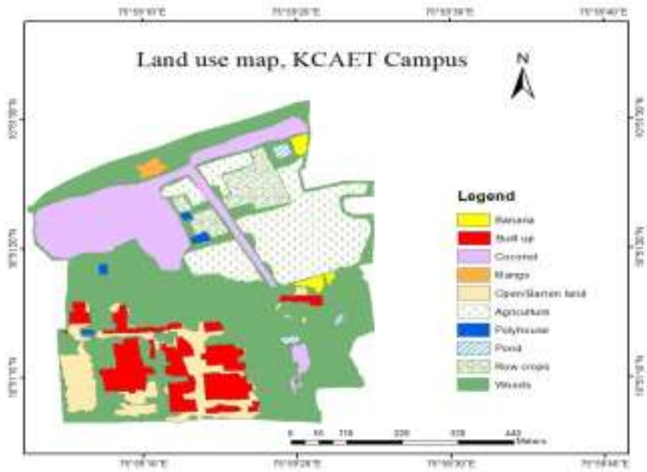

Fig -5: Land use map (2018)

3.4 Curve number

The runoff curve number is an empirical parameter which is used to predict the direct runoff which ranges from 0 to 100. A Lower value indicates the low runoff potential while the higher value indicates the high runoff potential. A CN of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount [7]. The curve numbers are assigned for different polygons in the intersected map on the basis of hydrologic soil group and landuse type.

Table -3: Curve numbers for different landuse classes

Landuse	**Cover description**	**Curve number for HSG**	
		A	**B**
Row crops	Continuous bush grass combination	65	67
Built up	Residential area by average lot size	77	85
Woods	Woods with grass-Good condition. Litter and shrubs covered the soil	30	73
Polyhouse	Farmsteads-buildings	72	82
Open land	Open space- Ground	79	72
Mango	Orchard with understorey cover	39	53
Coconut	Orchard without understorey cover	41	65
Banana	Scrub	33	47
Agriculture	With bush weed grass	35	56
Pond	Water body	0	0
Pasture	Good grass cover	39	61

4. RESULTS AND DISCUSSIONS

The Natural Resource Conservation Services Curve Number (NRCS CN) method was combined with ArcGIS 10.2 to estimate the runoff occurring from the study area. The NRCS CN equation is widely used due to its simplicity and flexibility in estimation of runoff. The thematic layers of potential maximum retention (S) and initial abstraction (I_a) were created, stored and analyzed with ArcGIS 10.2 software.

Table -4: Rainfall runoff correlation of the study area

Year	**AMC**	**CN**	**S**	**Q (taking λ=0.2)**
2006	**I**	37.47	423.87	$\frac{(P-84.77)^2}{P+339}$
	II	57.77	185.67	$\frac{(P-37.13)^2}{P+148.5}$
	III	75.92	80.56	$\frac{(P-16.1)^2}{P+64.4}$
2018	**I**	38.61	403.86	$\frac{(P-80.77)^2}{P+323}$
	II	58.95	176.87	$\frac{(P-35.3)^2}{P+141.49}$
	III	77.08	75.52	$\frac{(P-15.1)^2}{P+60.42}$

For the assessment of runoff from daily rainfall observations, the rainfall data from the study area was divided for four seasonal classes viz. pre monsoon season (April - May), south west monsoon season (June – September), north east monsoon (October- December) and post monsoon season (January – March). Not much rainfall was observed in the post monsoon season in the study area, hence no runoff was observed for the months of January, February and March.

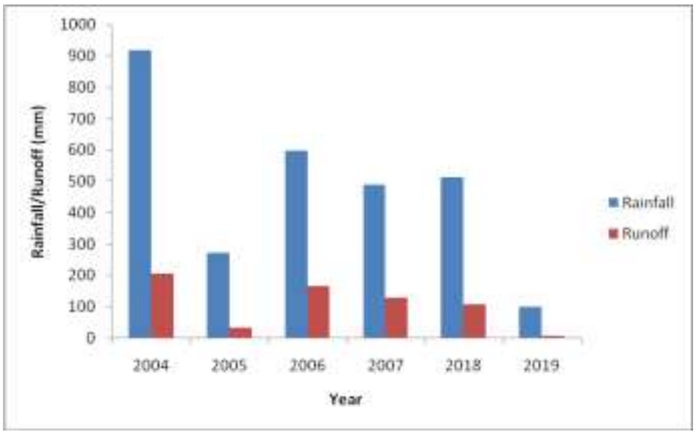

Chart -1: Rainfall - Runoff variation in Pre monsoon

About 60% of the total rainfall depth in Kerala is received from south west monsoon. The maximum amount of rainfall and thereby runoff depth was observed during June and July and the runoff percentage was in the range of 18 to 23.

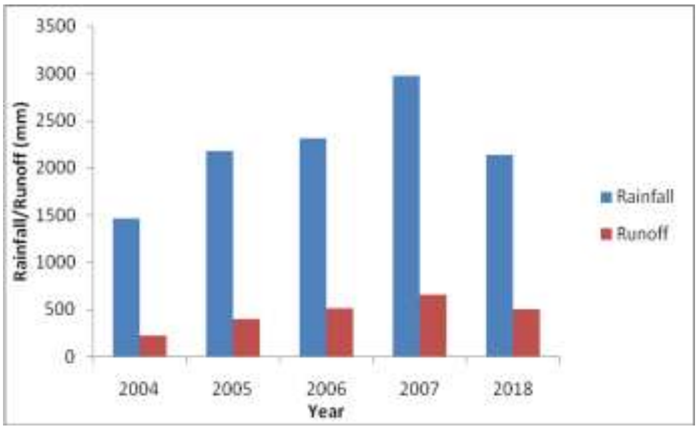

Chart -2: Rainfall - Runoff variation in south west monsoon

The north east monsoon contributes about 30% of the total rainfall. The maximum rainfall was observed during October in the season. The runoff percentage in this season ranges from 9% to 20%.

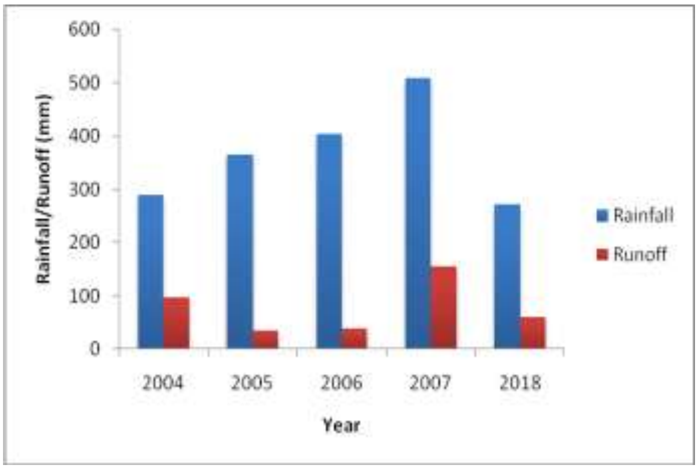

Chart -3: Rainfall - Runoff variation in north east monsoon

Yearly rainfall and runoff values obtained from the study area using NRCS CN method is given in table 5, and runoff percentage values from the study area varied from 19% to 23%. Also it is showing an increasing trend from 2004 to 2018.

Table -5: Yearly rainfall - runoff

Year	Rainfall (mm)	Runoff (mm)	Runoff (%)	Volume (m3)
2004	2675.18	533.02	19.92	208030.956
2005	2819.1	472.48	16.76	184406.031
2006	3320.05	720.48	21.70	281194.947
2007	3971.8	950.13	23.92	370824.426
2018	2919.8	672.68	23.04	262538.876

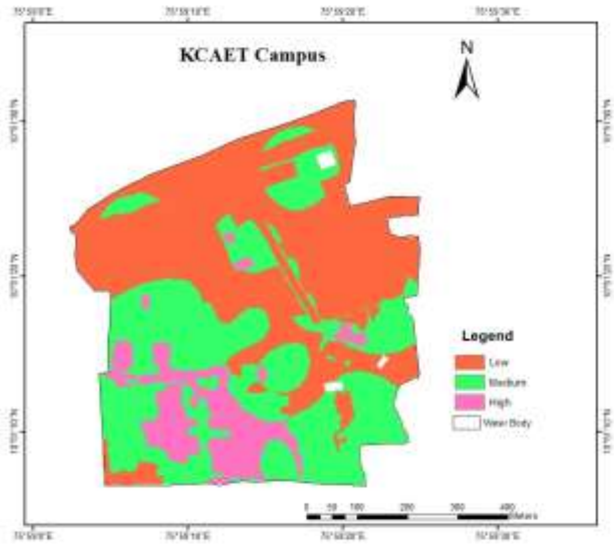

Fig -6: Severity range of runoff (2018)

The runoff severity is categorized into three classes viz. low, medium and high. Areas which has vegetative cover with ground cover with litter or grass and which belongs to HSG A will have low and medium runoff potential compared to land use with impervious structures and which belongs to HSG B. About 28.5% of the area have high runoff potential, 33.7% have medium runoff potential and 37.7% of the total area have low runoff severity range. Major part of the area which belongs to high severity range of runoff have built up and open spaces. Since the water bodies in the study area are water storage structures it does not produced any surface runoff.

5. CONCLUSIONS

Surface water that drains of the land into an outlet is called runoff and runoff water has the capacity to detach and transport the soil particles which leads to the severe erosion process. Runoff and subsequent erosion will reduce the productivity and quality of the land. The HSG map and land use maps were intersected in ArcGIS platform. CN values were assigned on the basis of HSG and land use. The composite curve number for the normal condition is 57.77, whereas for wet and dry conditions are 75.92 and 37.47 in 2006. In 2018, the composite curve number for normal condition is 58.95, whereas it is 77.08 and 3.61 for wet and dry conditions respectively. Analysis of the results showed that as the runoff percentage is increasing, the ground water recharge rate is reducing. This leads to the decline of water table resulting in water stress in terms of available fresh water. As the water demand is increasing due to population explosion and resource limitations, it is essential to recharge the ground water using the runoff generated.

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