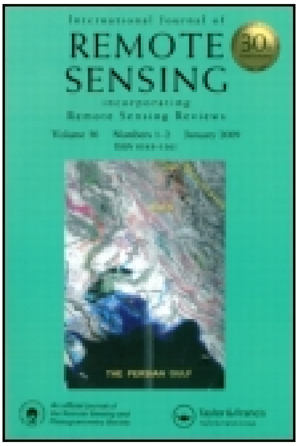

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Estimation of global SCS curve numbers using satellite remote sensing and geospatial data

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The Soil Conservation Service Curve Number (SCS CN) method is an efficient and widely used method for determining the direct runoff (effective rainfall) from a storm event for flood disaster assessment (rainfall-runoff modelling). The CN can be estimated based on the area's hydrologic soil group (HSG), land use/cover, and hydrologic condition. The two former factors are of greater importance in determining the CN value. This study reports an attempt to derive a global CN map. First, HSG was classified from digital soil maps. Second, CN was estimated as a function of HSG, land-cover classification, and hydrologic conditions according to USDA (1986) and NEH-4 (1997) standard lookup tables. Potential applications of this CN map may include real-time global flood assessment by incorporating an operational multisatellite precipitation estimation system (e.g. http://trmm.gsfc.nasa.gov).

1. Introduction

The United States SCS (Soil Conservation Service, now called the Natural Resources Conservation Service) Runoff Curve Number (CN) method is probably the most popular method for computing surface runoff (USDA 1986, Burges *et al.* 1998). Given its perceived advantages (simplicity, predictability and stability), this method has been widely used in many countries and successfully applied to situations ranging from simple runoff calculation, land use change assessment, to comprehensive hydrologic/water quality simulation (Chow *et al.* 1988, Srinivasan and Arnold 1994, Engel 1997, Burges *et al.* 1998).

Remotely sensed imageries are of immense use for identifying land surface features such as topography, stream networks, land cover and vegetation. Consequently, remote sensing techniques have become a viable alternative to conventional methods (e.g. SCS CN), particularly for inaccessible regions or complex terrains. Many researchers have used remote sensing data to estimate CN (Slack and Jackson 1980, Tiwari *et al.* 1991). Given the increasing availability of geospatial datasets derived from remotely sensed information, this study attempts to develop a global CN map. Possible applications of this CN map may include formation of an early warning system for global flood potential in real time by incorporating the multisatellite precipitation estimation system (http://trmm.gsfc.

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nasa.gov), which provides real-time rainfall information at high spatial and temporal resolution (Huffman *et al.* 2007).

2. Data

Information on soil properties was obtained from the Digital Soil Map of the World (DSMW) published in 2003 by the Food and Agriculture Organization of the United Nations (www.fao.org/AG/agl/agll/dsmw.htm). The soil parameters available include soil type classification, clay mineralogy, soil depth, soil moisture capacity, soil bulk density and soil compaction. Another source of global soil data is the International Satellite Land Surface Climatology Project (ISLSCP) Initiative II Data Collection (www.gewex.org/islscp.html), which provides girded data (100 km) for 18 selected soil parameters.

The global land cover data from the Moderate Resolution Imaging Spectroradiometer (MODIS) are used as a surrogate for land use/cover types. MODIS is a key instrument onboard the Terra and Aqua satellites, viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands (http://modis.gsfc.nasa.gov/). These data improve our understanding of global dynamics and processes occurring on the land and oceans. In this study the MODIS land cover type (yearly L3 Global 1 km) was used, which identifies 17 classes of land cover in the International Geosphere-Biosphere Programme (IGBP) vegetation classification scheme. This scheme includes 11 natural vegetation classes, three developed land classes, permanent snow or ice, barren or sparsely vegetated soil, and water bodies (Friedl *et al.* 2002).

Other useful datasets include the HYDRO1k (http://lpdaac.usgs.gov/gtopo30/hydro/) and Shuttle Radar Topography Mission (SRTM; www2.jpl.nasa.gov/srtm/). HYDRO1k (1 km) is a geospatial database providing comprehensive and consistent global coverage of topographically derived datasets such as elevation, slope, aspect and compound topographic index. The SRTM is a major breakthrough in digital mapping of the world (with 30 m horizontal spatial resolution), and provides a major advance in the availability of high quality elevation data for large portions of the developing world. These georeferenced datasets are of value for users who need to simulate hydrologic models on a local or continental scale. Note that the soil property and land cover classes are downscaled to the highest available digital elevation model (DEM) spatial scale using the bilinear interpolation method.

3. Procedure and results

The CN value can be derived based on the area's hydrologic soil group (HSG), land use/cover and hydrologic conditions, the two former factors being of greatest importance in determining its value (USDA 1986). First, HSG is classified from digital soil maps. Second, CN is estimated as a function of HSG, land cover classification, and hydrologic conditions according to USDA (1986) and the National Engineering Handbook Section 4 (NEH-4 1997) standard lookup tables.

The USDA soil classification map is an important indicator for infiltration rate. The classified 13 textural classes reflect the relative proportions of clay (granule size <0.002 mm), silt (0.002–0.05 mm) and sand (0.05–2 mm) in the soil. Three textural categories are recognized among the original texture classes: coarse (sands, loamy sands and sandy loams with $<18\%$ clay and $>65\%$ sand); medium (sandy loams, loams, sandy clay loams, silt loams, silt, silty clay loams and clay loams with $<35\%$

Table 1. Hydrological soil group (HSG) derived from soil properties.

HSG	USDA soil texture class	Soil content	%	Property
A	1, 2, 3	Sand, loamy sand or sandy loam types of soils	4.69	Low runoff potential and high infiltration rates even when thoroughly wetted; consist chiefly of deep, well to excessively drained sands or gravels
B	4, 5, 6	Silt loam, loam, or silt	8.41	Moderate infiltration rate and consist of soils chiefly with moderately fine to moderately coarse textures
C	7	Sandy clay loam	3.98	Low infiltration rates when thoroughly wetted and consist chiefly of soils with moderately fine to fine structure.
D	8, 9, 10, 11, 12	Clay loam, silty clay loam, sandy clay, silty clay or clay	5.78	Highest runoff potential, very low infiltration rates when thoroughly wetted and consist chiefly of clay soils
0	0	Water bodies	11.59	N/A
−1	13	Permanent ice/snow	65.55	N/A

Modified from USDA (1986) and NEH-4 (1997) lookup tables.

clay and <65% sand); and fine (clay, silty clays, sandy clays, clay loams, with >35% clay). Following the USDA (1986) handbook, four HSGs are derived from these soil properties (see table 1). Figure 1(*a*,*b*) show the spatial distribution of the 13 soil texture classes and HSGs, and figure 1(*c*) displays their histograms.

Table 2. CN derived from MODIS land cover classification and hydrological soil groups (HSGs) under fair hydrological conditions.

MODIS land cover classification		CN for different HSG (ABCD)				Hydrological condition (poor/fair/ good)
ID	Content	A	B	C	D	
0	Water bodies	N/A	N/A	N/A	N/A	N/A
1	Evergreen needles	34	60	73	79	Fair
2	Evergreen broadleaf	30	58	71	77	Fair
3	Deciduous needle leaf	40	64	77	83	Fair
4	Deciduous broadleaf	42	66	79	85	Fair
5	Mixed forests	38	62	75	81	Fair
6	Closed shrublands	45	65	75	80	Fair
7	Open shrublands	49	69	79	84	Fair
8	Woody savannas	61	71	81	89	Fair
9	Savannas	72	80	87	93	Fair
10	Grasslands	49	69	79	84	Fair
11	Permanent wetlands	30	58	71	78	Fair
12	Croplands	67	78	85	89	Fair
13	Urban and built-up	80	85	90	95	Fair
14	Cropland/natural vegetation mosaic	52	69	79	84	Fair
15	Permanent snow and ice	N/A	N/A	N/A	N/A	N/A
16	Barren or sparsely vegetated	72	82	83	87	Fair
17	Missing data	N/A	N/A	N/A	N/A	N/A

Modified from USDA (1986) and NEH-4 (1997) lookup tables.

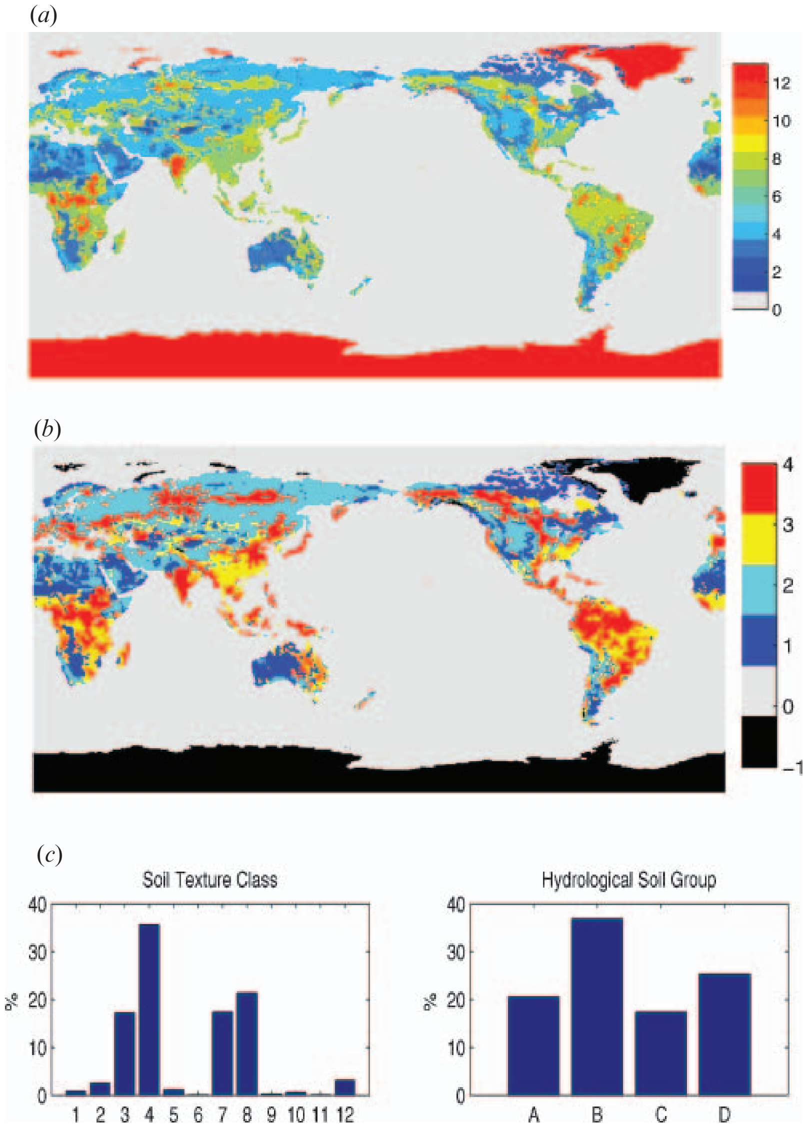

Figure 1. (*a*) USDA soil texture classification; (*b*) hydrological soil groups; and (*c*) the histogram of soil texture classes (left) and HSG (right).

The methodology for determining the CN values was adopted from USDA (1986) and USDA NEH-4 (1997). The MODIS land cover classification data were used in conjunction with HSG to estimate the CN, given the hydrological conditions (or antecedent moisture condition, AMC). In the NEH-4, AMCs are classified as poor, fair or good. Good AMCs have higher runoff potential than poor conditions, given the same amount of precipitation. Following the standard lookup tables in USDA (1986) and NEH-4 (1997), CN values were derived and are listed in table 2. Figure 2(*a*) shows a histogram of the global CN and figure 2(*b*) shows its spatial distribution, with higher CN associated with higher runoff potential. Note that the CNs displayed in figure 2(*b*) are for the 'fair' hydrologic condition from the standard

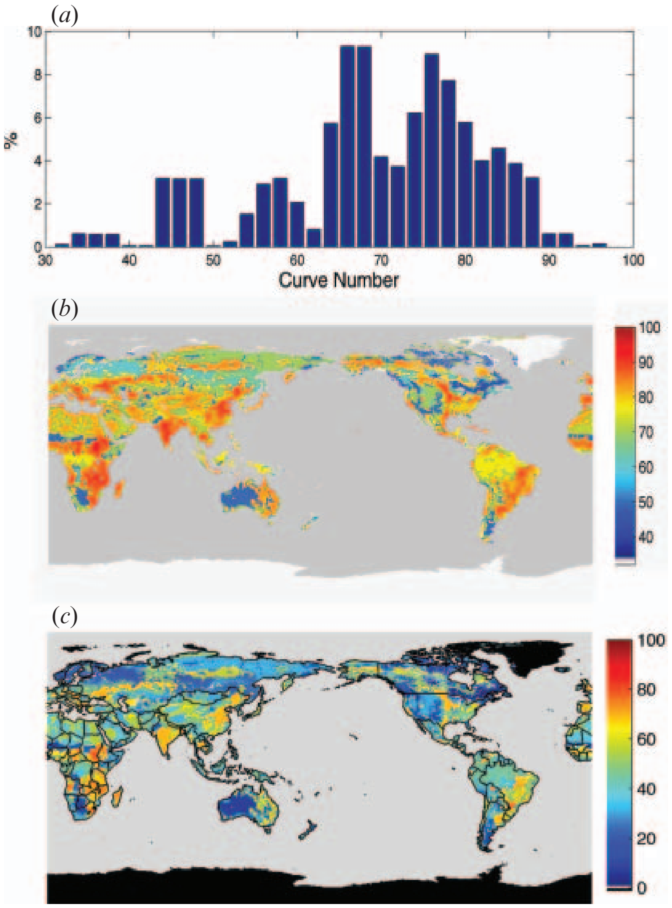

Figure 2. (*a*) Histogram of the global CN distribution; (*b*) a global CN map; and (*c*) global direct runoff generated by uniformly distributed precipitation of 100 mm.

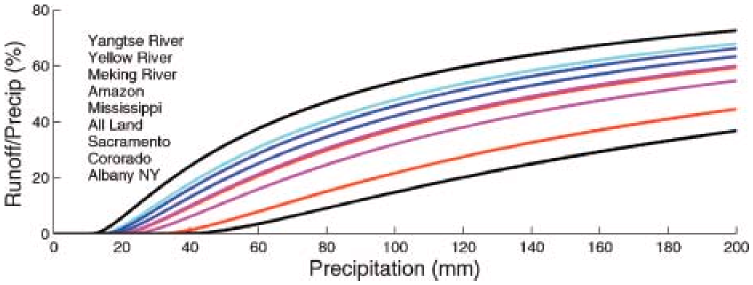

Figure 3. The ratio of runoff to precipitation (Q/P) as a function of precipitation and CN for several watersheds. Available in colour online.

lookup tables, which are used primarily for design applications. In practice, a lower and upper enveloping curve according to the poor or good AMC can be used to determine the variation range of CN (NEH-4 1997). Real-time global AMC can be readily derived from the NASA passive microwave sensor, the Advanced

Microwave Scanning Radiometer-EOS (AMSR-E) with a 1–2-day return visit globally (Njoku 1999, Njoku and Lakshmi 2003).

4. Summary and discussion

Among many hydrological models, the SCS CN method estimates runoff as a function of precipitation, soil property, land use/cover and hydrological condition. The latter three factors can be empirically approximated by one parameter, the CN (USDA 1986). The soil property and land cover are of much greater importance in controlling the values of CN than hydrological conditions (USDA 1986). In this report, a global CN map was estimated primarily based on soil property and land use/cover information under the 'fair' hydrological condition. The runoff can then be calculated using the rainfall–runoff relationship from NEH-4 (1997). Figure 2(*c*) shows the global direct runoff generated by uniformly distributed precipitation of 100 mm. Figure 3 shows that the direct runoff Q is a function of precipitation P and CN for several watersheds. With the global CN map, it may be helpful to estimate flood potential for places without *in situ* data if incorporating the rainfall input such as the NOAA-CPC rainfall product of 10 km spatial resolution or a satellite-based real-time precipitation estimation; early results are shown on the website: http://trmm.gsfc.nasa.gov/publications_dir/potential_flood.html.

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