MAPPING URBAN LAND COVER USING QUICKBIRD NDVI IMAGE AND GIS SPATIAL MODELING FOR RUNOFF COEFFICIENT DETERMINATION

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ABSTRACT

This research presents an integration of remote sensing and GIS for determining the runoff coefficient (C) recommended by American Society of Civil Engineers and Water Pollution Control Federation in 1969. The C is a runoff index used as an input parameter in the most commonly used procedure—the rational method for runoff calculation in small urban watersheds for storm drainage design and analysis. The objective of this study was to evaluate 8 and 16 bit QuickBird (QB) NDVI satellite imagery using an unsupervised classification and the ISODATA algorithm to map impervious area and open space used for the determination of C in GIS spatial modeling. The research hypothesis was that mapping impervious area and open space using high spatial resolution NDVI satellite imagery, generated using the ISODATA algorithm, was an efficient and effective information extraction approach for accurately determining the C value. The 2004 data were provided by the City of Sioux Falls, South Dakota. The overall classification accuracies of the six QB NDVI thematic maps produced were similar, about 92%. In order to assess the utility of high spatial resolution satellite imagery and to validate the composite runoff index geographic model developed by Thanapura in 2005 and 2006, the C values were calculated in GIS spatial modeling and compared to the industry standard C. Finally, the hypothesis was accepted that finer resolution image and mapping approach used in this study allowed for better discrimination of land cover and thus a more accurate C estimation.

INTRODUCTION

Engineering hydrology is concerned with analyzing and designing hydraulic structures for safe and effective passage of flood flows. Two basic levels of analysis exist. In the first level, a peak flow calculation is used to determine the maximum runoff rate at a given point resulting from a storm event. The designs at this level of analysis are often for storm sewers and culverts whose only function is to convey runoff away from areas where it is unwanted. The second level is more complex. This analysis consists of the generation of a runoff hydrograph throughout a storm to provide information on flow rate versus time and runoff volume. This type of information is essential when drainage basins are too large or too complex to be treated by peak flow estimation methods, or when the analysis of natural or artificial detention or retention facilities is required (Methods and Rocky, 2003). Estimation of peak discharge rates and synthesizing complete discharge hydrographs are, therefore, two of the more challenging aspects of engineering hydrology (Viessman and Lewis, 2003).

In small and mid size urban watersheds, accurate estimation of storm water runoff volumes and peak discharge is critical for the design of minor drainage structures. Examples of minor hydraulic structure types can range from small crossroad culverts, levees, drainage ditches, urban storm drain systems, and airport drainage structures to the spillway appurtenances of small dams (Viessman and Lewis, 2003). Calculating peak discharge composed of surface runoff through a development will allow planners to place appropriately sized culverts, sewer pipes, and storm drains to assure effective storm water flow out of an area. Determining the limits and being too conservative not to spend more money than necessary in design structures can lead to considerable damage such as flooding cellars (Kuichling, 1889).

In the United States, many of the farmlands, wetlands, forests, and deserts have been changed into human settlements during the past 100 years (USGS, 1999). Population growth and urban development can create potentially severe problems in urban water management (Chow et al., 1988). Transformation of rural lands into urban increases a watershed's response to precipitation. Large amounts of pervious land use have been replaced by impervious land use, and a network of man-made drainage has altered the natural drainage characteristics. Construction of houses, commercial buildings, parking lots, paved roads, and streets increases the impervious cover in a watershed and thus reduces infiltration and generates runoff. Consequently, the impact of land use changes in urbanization has caused an increase in erosion and the discharge volume of storm runoff and a decrease in time of concentration in a watershed (Draper S.E., 1981; USDA-NRCS, 1986). Furthermore, the spatial pattern of flow in the watershed is altered, and there is an increase in the hydraulic efficiency of flow through artificial channels, curbing, gutters, storm drainage and collection systems. These factors accelerate the volume and velocity of runoff and result in larger peak flood discharges from urbanized watersheds than occurred in the preurbanized condition (Chow et al., 1988).

Due to rapid growth and the concentration of people in the populated areas, many urban drainage systems constructed under one level of urbanization are now operating under a higher level of urbanization and have inadequate capacity. Thus, the determination and re-evaluation of runoff volume and peak discharge are important issues in urban stormwater management. A number of computerized watershed estimation models have been proposed and used for planning and management. Methods for calculating these variables range from the well-known runoff formulas, such as the rational method (Kuichling, 1889), the Soil Conservation Service Curve Number (SCS-CN) method (USDA-NRCS, 1986), and regression-based methods developed by the U.S. Geological Survey, to advanced computer simulation models such as the Storm Water Management Model (SWMM) and the NRCS Technical Release 20 (TR-20) [USDA-NRCS, 1992] {Chow et al., 1988; Methods and Durrans, 2003; McCuen, 2005}.

To estimate runoff from storm rainfall, methods such as the rational and the SCS-CN formulas use a runoff index. This runoff index parameter is critical to the determination of the runoff volume and peak discharge. Its accurate estimation is essential for effective investigation of drainage analysis and minor designs. Changes in land use include surface characteristics such as impervious cover and vegetation, which affect the resulting runoff index and speed of runoff travel in the drainage area (Ferguson, 1998). Urban sprawl has added to the difficulties in effective runoff index calculation since a basic problem exists in quantifying detailed spatial extent and distribution of various land cover classes and accurately updating that information in a timely manner.

Conventional ground-based methods for both runoff index values are time-consuming and labor-intensive procedures since detailed land use/land cover, soils, and/or slopes data are required. Utilization of satellite remote sensing can provide spatially and temporally detailed land cover information as input for the runoff index determination for both of the runoff methods.

The main focus of this research is to determine runoff index—the runoff coefficient, C. The C is a runoff index used as an input parameter in the most commonly used procedure—the rational method for runoff calculation in small urban watersheds for storm drainage design and analysis (Pitt et al., 1999). The C is recommended by the American Society of Civil Engineers (ASCE) and the Water Pollution Control Federation (WPCF) in 1969 and McCuen in 2005

(McCuen, 2005).

The objective of this study was to evaluate 8 and 16 bit Normalized Difference Vegetation Index (NDVI) QuickBird (QB) satellite imagery using an unsupervised classification and the ISODATA algorithm in order to map impervious area and open space used as input for the industry standard C determination in GIS spatial modeling. This application of geospatial technologies to study urban hydrology for determining runoff coefficient could benefit engineers in designing hydraulic structures and improving maintenance. It would also afford better and timelier estimates of runoff within a drainage basin, potentially reducing loss of life and damage to property caused by unusual weather events.

METHODS

This research paper presents an integration of remote sensing and Geographic Information Systems (GIS) for mapping urban land cover for the determination of runoff index—the runoff coefficient, C in urban watersheds. The theoretical foundation of this research is that mapping impervious area and open space using high spatial resolution NDVI satellite imagery generated with the ISODATA algorithm is an efficient and effective information extraction approach for accurately determining the C value. Various procedures and comparisons of the generated runoff coefficients were presented and reviewed by practicing professionals, including the City Drainage Engineer and the City Geographic Information Systems manager, for the City of Sioux Falls, South Dakota, on August 9, 2005 and again on February 3, 2006.

Study Area

The City of Sioux Falls, located in southeastern South Dakota, covers 40,208 acres (16271.6 hectares) and has a population of approximately 138,000. Climatologically, Sioux Falls has a continental climate with an average rainfall of 23.86 inches (60.6 cm) and approximately 40 inches (101.6 cm) of snow annually. The majority of the precipitation comes in spring and summer with May and June being the months of maximum precipitation for the region. The study area for this project, the southwestern part of the city, is centered at 43^{O} 31’ 18” north latitude and 96^{O} 44’ 42’’ west longitude. This area encompasses 2,908.58 acres (1177.06 hectares) [Figure 1] and 86.13% consists of hydrologic soil group B—shallow loess and sandy loam (McCuen, 1982; 2005). The study site includes various land use/land cover types and all or part of 26 hydrological urban sub-basins (Figure 1).

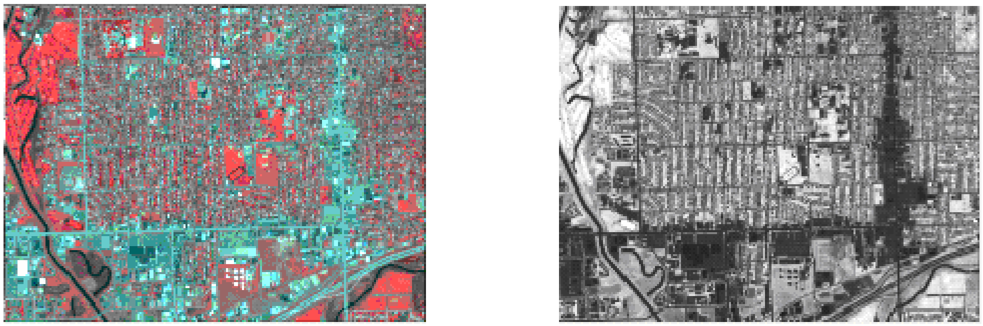

(a) **(b)**

Figure 1. The 2004 QuickBird (QB) images of the study area are at the same scale (unsigned 8 bit): (a) The QB multi image (4-3-2) on the left and (b) The QB NDVI image on the right.

Digital Data & Pre-Processing

The 2004 remotely sensed data and most of the vector GIS data layers were provided by the City of Sioux Falls. Data used in this project include orthophoto mosaics with 2 ft. (0.6 m) and 0.5 ft. (0.15 m) resolution, QuickBird satellite image with 7.96 ft. (2.39 m) resolution and include data layers such as parcels, city limit boundary, and hydrography. The data sets were processed and merged to combine the remotely sensed data with the GIS layers for the study area. The April 23, 2004, orthophoto was used as a reference to integrate all data sets into the same map projection and unit, with the Universal Transverse Mercator (UTM) map projection, World Geodetic System (WGS) 1984, and horizontal units in feet. Software used in this project consisted of ERDAS Imagine 8.7, ArcMap 9, ArcView 3.3, and, Microsoft Excel 2002.

The two digital orthophotographs were acquired on April 23, 2004 and May 20, 2002 by the Sanborn Mapping

Company Inc. and Horizons, Inc., respectively. Both orthophotos were collected and scanned to meet the combined requirements of National Map Accuracy Standards; 90% of all contours will be within ½ contour interval, and 90% of horizontal positions shall be within 1/30 of one inch at the specified map scale. Both orthophotos were provided in UTM projection, WGS84 datum, and planar distance survey units in feet. Additionally, both orthophotos were subset to the study area and the 2002 orthophoto was degraded 3x3 using ERDAS Imagine 8.7. Overlaying the subset orthophotos demonstrated good alignment between images. Therefore, an image-to-image registration was not required.

The 11 bit QuickBird leaf-on image was collected on April 26, 2004. The image was radiometrically corrected and orthorectified prior to this study. The image was provided by the City of Sioux Falls in unsigned 16 bit data type with UTM projection, WGS84 datum, and units in meters. The image has four bands (including the blue, green, red, and near-infrared) and was imaged at a 2.39-meter spatial resolution. The image was observed with no signs of atmospheric degradation such as haze or clouds. The histograms of all multispectral bands showed a normal distribution. The subset QB image was created in unsigned 16 bit data type and also rescaled into 8 bit dynamic range in unsigned 8 bit data type using ERDAS Imagine 8.7. Geometric corrections were performed. Both of the subset scenes were registered to the 2004 orthophoto with 60 ground control points in a Root Mean Square (RMS) of 0.4846 pixel. The red channel (band 3: 630-690 nm) and the near infrared channel (band 4: 760-900 nm) of each registered subset image was processed to create the QB NDVI imagery (NDVI = Band 4 - Band3/ Band 4 + Band3) in float point single precision 32 bit for the study area.

The 2004 NRCS SSURGO 1:24,000 data set of the soil survey area (SSA) named “Minnehaha County, South Dakota” and its standard metadata files were downloaded from the Soil Data Mart at http://soildatamart.nrcs.usda.gov on June 7, 2004. The soil data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The soil layer was in a single zip file in ArcView shapefile format, with a geographic coordinate system and using North American Datum (NAD) 1983. This layer was processed using ArcView 3.3 geoprocessing and Microsoft Excel 2002 to create a soil layer associated with hydrologic soil groups in the project coordinate system for this study area. In overlaying the soil layer with the subset QB imagery, hydrological features demonstrated a good fit. Therefore, a vector to image registration was not necessary.

Geographic Model

The goal of this project was to assess the utility of high spatial resolution satellite imagery and to validate the composite runoff index geographic model developed by Thanapura in 2005 and 2006 (Thanapura et al., 2005; 2006). Spatial modeling in GIS was developed using the composite runoff index geographic model as shown in Model 1 to for calculating the runoff coefficient, C. The resultant C values were then compared to the industry standard C.

Model 1. The composite runoff index geographic model (© 2005-2006 Pravara Thanapura. Use with permission) [Thanapura et al., 2005; 2006]:

$$RI_c = \quad [f_{(j/i)} \mathrm{\ x\ } RI_{(j)}]$$

Where:

RI_c or Runoff Index$_{composite}$ is the sum of the component runoff index within an area (i) delineated by the description of the area;

f or the fraction of area covered $_{(j/i)}$ is the component (j) of the area (i) divided by the total area (i). Note that the component of the area is delineated by surface characteristics of land cover, hydrologic soil group, and/or slope;

RI(j) or Runoff Index (j) is a runoff index of the component (j) of the area (i) determined by the surface characteristics and/or its hydrologic soil groups.

To achieve this goal, a sequence for digital processing and analysis was proposed for mapping land cover—impervious areas and open spaces— using 8 and 16 bit QuickBird NDVI imagery and developing GIS spatial modeling for the determination of C (Figure 2). These steps were implemented to create and integrate spatial information such as land cover, soil and/or slope as required by the composite runoff index geographic model in Model 1.

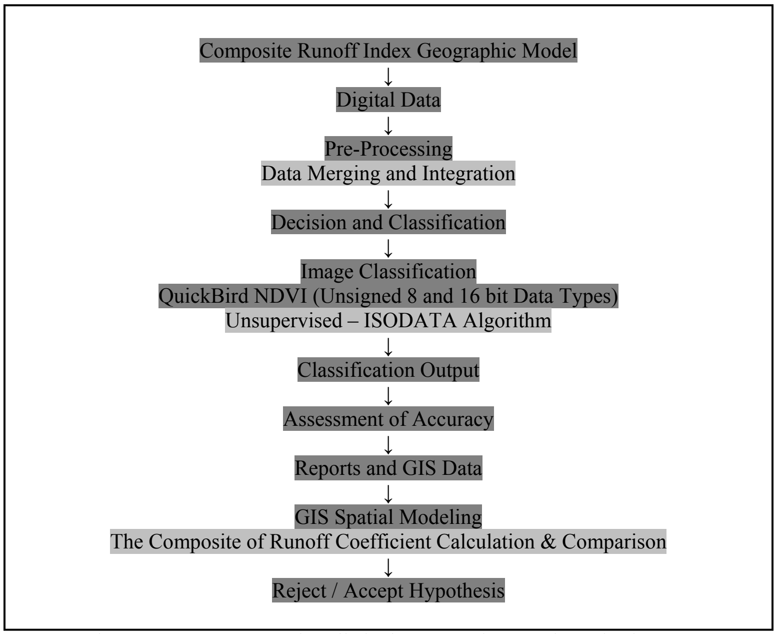


Figure 2. Sequence for digital processing and analysis.

Classification Approach

A Normalized Difference Vegetation Index (NDVI) was selected for this research project because of the land surface reflectance characteristics of the QuickBird (QB) red (630-690nm) and NIR (760-900nm) bands. The relatively simple NDVI was utilized for the following reasons:

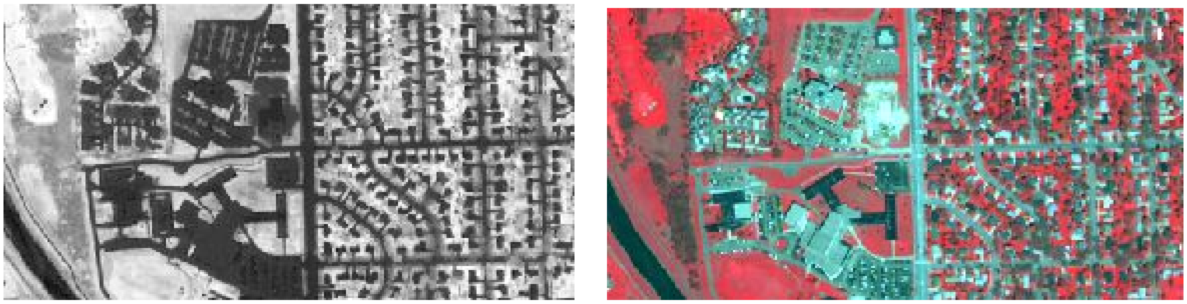
1. Reduction of heterogeneous spectral-radiometric characteristics within land cover surfaces portrayed in a high-resolution image.
2. Normalized potential atmospheric effects within the image.

NDVI has been shown to have high correlation with green leaf biomass and the green leaf area index. Chlorophylls, the primary photosynthetic pigments in green plants that absorb light primarily from the red and blue portions of the spectrum, while a higher proportion of infrared is reflected or scattered. As a result, vigorously growing healthy vegetation has low red-light reflectance and high NIR reflectance, and hence high NDVI values. Impervious surfaces (e.g., asphalt, concrete, buildings, etc.) and bare land (e.g., bare soil, rock, dirt, etc.) have similar reflectance in the red and the near infrared, so these surfaces will have values near zero. NDVI is calculated using the formula (Near infrared – red)/(Near infrared + red). This relatively simply algorithm produces output values in the range of -1.0 to 1.0.

According to a previous study (Thanapura et al., 2005 and 2006), the best method for assigning categories of open space and impervious areas was to apply a 50/50 spectral cluster threshold within NDVI, using the unsupervised classification method (ISODATA algorithm), to maximize control over the menu of informational classes and to maximize correlation between spectral homogenous classes and the informational categories (i.e., impervious area and open space). This methodology when utilized consistently on a defined seasonal basis can provide a constant for reproducing mapping of both impervious and open space classification.

Also this previous study used solely 8 bit data for mapping. The current study included both 8 and 16 bit data types to test whether or not 16 bit would, in terms of dynamic range (level of brightness), produce a finer-scaled and more precise NDVI map since 16 bit allows over 60,000 values.

Figure 3 below shows a visual comparison between 8 bit QuickBird NDVI in unsigned 8 bit data type (0-255) for impervious areas and open spaces in the urban environment: a) the QB multispectral image displayed using bands 4, 3, and 2 for red, green, and blue, respectively, b) the QB NDVI image, and c) the natural color orthophoto used for reference and validation. In the NDVI image, the impervious surfaces are the dark areas with low NDVI DNs and the brighter areas are vegetated areas with high NDVI DNs.



(a) The 2004 QuickBird NDVI **(b)** The QuickBird multi spectral image (4-3-2)

(c) The 2004 Orthophoto (1-2-3)

Figure 3. The registered 2004 images visual comparison of impervious areas and vegetative open spaces at same scale and location in residential areas (unsigned 8 bit).

Classification Scheme & Method

Table 1 shows decision rules used in this study for image classification and accuracy assessment. The decision rules were defined from the urban land cover of the rational coefficient (C)—impervious area and open space described in the runoff coefficient (C)—and from the character of surface recommended by the American Society of Civil Engineers (ASCE) and the Water Pollution Control Federation (WPCF) in 1969 and McCuen in 2005 (McCuen, 2005). The classification scheme was used to generate six QB NDVI thematic maps using the ISODATA algorithm (three each for 8 bit and 11 bit) with ERDAS Imagine 8.7 and assigning unsupervised spectral classes of 2, 100, 200 spectral clusters. The same labeling criteria—DNs 50/50 spectral cluster threshold—was then used to assign spectral clusters in to two classes, impervious area and open space.

Table 1. Decision rules of urban land cover mapping for runoff index determination (© 2005-2006 Pravara Thanapura. Use with permission)

Labels Land Cover Character of Surface:	Rules
Impervious Areas	If land area has < 25% covered with areas characterized by vegetative open spaces then **Impervious Area (1)** If land area > or = 75% characterized by impervious surfaces (e.g., Asphalt, concrete, and buildings.) then **Impervious Area (1)** If land area > or = 75% covered by bare land (e.g., Bare rock, gravel, silt, clay, dirt, and sand or any other earthen materials.) then **Impervious Area (1)**
Open Spaces	Else if land area < 25% covered with areas characterized by impervious surfaces then **Open Space (2)** If land area > 75% covered with vegetation naturally existing or planted [e.g., grass, plants, tree (leaf-on /leaf-off), forest, shrub, and scrub.] then **Open Space (2)**
	Else **Impervious Area (1)**

Sampling Design & Accuracy Assessment

To assess the accuracy of NDVI QuickBird thematic maps, a simple random sampling method was chosen to ensure unbiased sample selection. To provide a statistically sound assessment of accuracy, a conservative sample size equation was used to calculate the sample sizes to insufficient samples for filling in an error matrix for this project (Congalton and Green, 1999). Over 500 sample points were generated for each thematic map using the ISODATA algorithm to insure good distribution across the study area. To accomplish this, ERDAS 8.7's random number generator function was used to select random points (groups of pixels) for comparison to the 2004 2 ft. (0.6 m) and the 2002 0.5 ft. (0.15 m) spatial resolution orthophotos. The assignment options of 3 x 3 window size and clear majority rule were selected to create random points and define its class. The clear majority means that more than 50% of pixels in the window size are a certain class. Thus, the program will automatically discard random points not sufficiently representing relatively homogenous areas. This function will minimize image-to-image registration errors and spatial resolution differences between the QB image and the orthophoto and thus help to accurately interpret a representation of each reference point on the orthophoto. To assure visual interpretation consistency, these reference points will individually evaluated by Eric Warmath, GIS Coordinator, Department of Transportation, State of Nevada. Mr. Warmath is qualified with many years of photo interpretation experience, including work at the USGS and the Department of Defense.

In some cases, there were conflicts due to 'lean' in the orthophoto or mixed pixels around the edges. These points were re-evaluated using the 2004 orthophoto. Quality controls were performed on the data set by the principal author. Finally, the error matrixes of six thematic maps were generated using the same set of sample points, and the overall classification accuracy results were calculated (Table 2). Figure 4 shows the classification accuracy and assessment sites over NDVI QuickBird thematic map (Map ID#1) generated using 8 bit QB NDVI and unsupervised spectral classes of 2 spectral clusters. Finally, the detailed map was then converted as a GIS input into the proposed GIS spatial modeling as described later for calculating the composite runoff index for the rational method.

Table 2. Accuracy assessment results for six NDVI QuickBird thematic maps

Accuracy Assessment Results[1]					
Unsupervised Classification -- ISODATA Algorithm					
Using Labeling Criteria -- DNs 50/50 Spectral Cluster Threshold					
Map ID	**Class Names**	**QB NDVI - Unsigned 8 bit**			
		Spectral Clusters	**Producer Accuracy**	**User Accuracy**	**Area[2] (Acres)**
Map 1	Impervious Area	2	91.89%	91.15%	1516.35
	Open Space		90.57%	91.32%	1392.23
Overall Classification Accuracy = 91.24% and Overall Kappa Statistics = 0.8245					
Map 2	Impervious Area	100	91.86%	91.86%	1511.4
	Open Space		91.39%	91.39%	1397.18
Overall Classification Accuracy = 91.63% and Overall Kappa Statistics = 0.8325					
Map 3	Impervious Area	200	91.86%	91.86%	1511.48
	Open Space		91.39%	91.39%	1397.1
Overall Classification Accuracy = 91.63% and Overall Kappa Statistics = 0.8325					
Map ID	**Class Names**	**QB NDVI - Unsigned 16 bit**			
Map 4	Impervious Area	2	91.86%	91.86%	1507.45
	Open Space		91.39%	91.39%	1401.13
Overall Classification Accuracy = 91.63% and Overall Kappa Statistics = 0.8325					
Map 5	Impervious Area	100	90.70%	92.86%	1494.39
	Open Space		92.62%	90.40%	1414.19
Overall Classification Accuracy = 91.63% and Overall Kappa Statistics = 0.8327					
Map 6	Impervious Area	200	90.70%	92.86%	1494.04
	Open Space		92.62%	90.40%	1414.53
Overall Classification Accuracy = 91.63% and Overall Kappa Statistics = 0.8327					

[1] Reference totals = 502 points; impervious area = 258 points and open space = 244 points.

[2] Total areas = 2908.58 acres (1177.06 hectares).

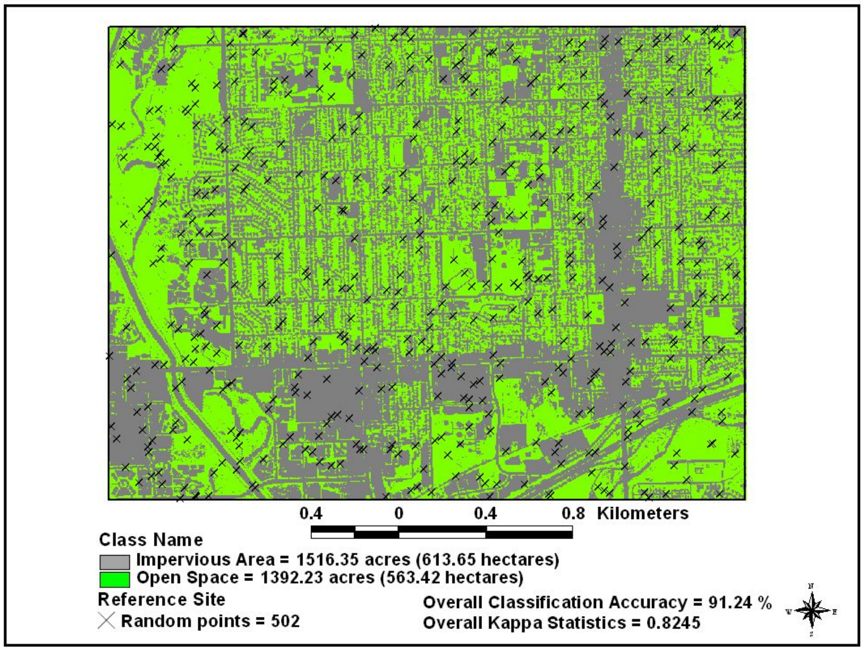


Figure 4. Classification result of QuickBird NDVI thematic Map ID #1.

GIS Spatial Modeling for the Rational Coefficient (C) Determination

In this study, the composite runoff index geographic model (Model 1) was applied to develop GIS spatial modeling for the composite of the rational coefficient, C calculation as proposed in Model 2. The GIS spatial model requires (1) the combined surface characteristics of impervious area and open space, and (2) hydrologic effect of soil groups and/or slopes. The surface characteristics were derived from the least accurate QB NDVI thematic map, Map ID #1 (Table 2), and the 2004 NRCS SSURGO 1:24,000 data set provided the hydrologic soil groups and slopes. The geometric and coincidence modeling functions in ArcView3.3 Geoprocessing were then used to design a sequence of steps to build the composite runoff index GIS spatial modeling. The process output was a new data set of geographic features in ArcView shapefile format. The data contained new polygons that described new spatial relationships of the data sets among impervious areas and open spaces, hydrologic soil groups, slopes. The sample 2004 parcels covered about 30% of the study area were used to clip the data in order to create a GIS sample layer as described in Table 3 as GIS ID. Next, the fraction (f) of the composite area covered of each parcel within each GIS sample boundary was calculated, and the proposed C values in Table 4 were assigned to the composite area covered. Then, the RI_c of each parcel within GIS sample layers were calculated. Finally, the average C was determined; the total sum of the RI_c values was divided by total number of parcels within each GIS sample layer. In order to assess the utility of high spatial resolution satellite imagery and to validate the runoff composite geographic model, the resultant C values were compared to the industry standard C as shown in Table 6.

Model 2. The Composite Runoff Index Geographic Model for the Runoff Coefficients Calculation. [© 2006 Pravara Thanapura. Use with permission]:

$$RI_c = [f_{(j/i)} \text{ x } RI_{(j)}]$$

Where:

RI_c or Runoff $\text{Index}_{composite}$ is the sum of the component runoff coefficients within a parcel boundary (i) delineated by the land activity code of the City of Sioux Falls (Table 3);

f or the fraction of area covered $_{(j/i)}$ is a component (j) of the area (i) divided by the total area (i). Note that the component of the area is a subset of polygon features delineated by surface characteristics of land cover—impervious area and open space (GIS layer = ArcView shapefile) derived from the QB NDVI thematic Map ID #1 using the ISODATA algorithm and hydrologic soil group and slope;

RI(j) or Runoff Index (j) is a runoff coefficient (Table 4) of the component (polygon)[j] of the area (i) determined by the surface characteristics associated with hydrologic soil groups and its slopes.

Table 3. GIS Sample Parcel Layer by GIS ID

GIS ID	GIS Sample Vector Layer Descriptions						
	Activity Code[1] and Sample Parcel Description	Runoff Coefficient (C)[2] Description of Area	Number of Sample Parcels	Total Areas[3]	Impervious (%)	Open Space (%)	Soil Group B[4] (%)[5]
1	11 Single Family - Residential 1/8 acre (0.125 acres or 505.85 sq.m^2)	Residential: Single Family	312	35.55 acres or 143864.63 sq.m^2 1.23%	49.73	50.27	99.94
2	11 Single Family - Residential 1/4 acre (0.25 acres 1011.71 sq.m2)	Residential: Single Family	3284	576.6 acres or 2333399.3 sq.m^2 19.87%	40.06	59.94	99.76
3	11 Single Family - Residential 1/3 acre (0.3330 acres 1347.59 sq.m2)	Residential: Single Family	357	100.06 acres or 404925.30 sq.m^2 3.45%	34.56	65.44	100
4	11 Single Family - Residential 1/2 acre (0.5 acres 2023.41 sq.m2)	Residential: Single Family	140	54.51 acres or 220592.43 sq.m^2 1.88%	33.30	66.70	100
5	11 Single Family - Residential 1 acre (4046.83 sq.m2)	Residential: Single Family	43	26.1 acres or 105622.13 sq.m^2 0.9%	27.16	72.84	95.57
6	11 Single Family - Residential 2 acres (8093.65 sq.m2)	Residential: Single Family	4	4.56 acres or 18453.52 sq.m^2 0.16%	29.34	70.66	100
7	31 Banks and Financial Institutions	Business: Downtown & Neighborhood	17	14.96 acres or 60540.50 sq.m^2 0.52%	81.75	18.25	100
8	33 Other offices	Business: Downtown & Neighborhood	56	63.96 acres or 258834.93 sq.m^2 2.2%	72.77	27.23	100
9	64 Warehousing, Distribution, and Wholesale	Industrial: Light	11	20.04 acres or 81098.37 sq.m^2 0.7%	89.80	10.20	94
		Total	4224	896.34 acres or 3627331.12 sq.m^2 30.89%	43.17	56.83	98.81

[1 and 2] The sample parcel site descriptions are defined by (1) The City of Sioux Falls 2004 parcel activity codes and (2) The runoff coefficient, C, used in the rational method recommended by the American Society of Civil Engineers (ASCE) and the Water Pollution Control Federation (WPCF) in 1969 (McCuen, 2005), respectively.

[3] The study area is 2908.58 acres (1177.06 hectares).

[4] B: The soil characteristics are shallow loess and sandy loam (McCuen, 1982).

[5] The total area of hydrologic soil group B of each sample layer by parcel - activity code.

Table 4. Proposed runoff coefficients for the composite runoff calculation defined from the runoff coefficient, C recommended by the American Society of Civil Engineers (ASCE), the Water Pollution Control Federation (WPCF) in 1969, and McCuen in 2005, respectively (McCuen, 2005)

Land Cover	Runoff Coefficients (C)[2] for Hydrologic Soil Group			
Character of Surface[1]:	A[3]	B[4]	C[5]	D[6]
	Sandy Soil		Heavy Soil	
Impervious Areas (e.g. Pavement, roofs, etc.)	0.85	0.85	0.85	0.85
Open Spaces (e.g. Lawns, etc.)				
Flat, 2 percent	0.08	0.08	0.15	0.15
Average, 2-7 percent	0.13	0.13	0.20	0.20
Steep, 7 percent	0.18	0.18	0.30	0.30

[1] See a description of character of surfaces in Table 1—Decision Rules.

[2] The coefficients are applicable for storm of 5-10 years. See the hydrologic design standards and criteria for minor structures table in Table 5.

[3] A: Soils having a low runoff potential due to high infiltration rates. These soils consist primarily of deep, well drained sands and gravels (ConnDOT, 2000).

[4] B: Soils having a moderately low runoff potential due to moderate infiltration rates. These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (ConnDOT, 2000).

[5] C: Soils having a low runoff potential due to slow infiltration rates. These soils consist primarily on soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture (ConnDOT, 2000).

[6] D: Soils having a high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious parent material (ConnDOT, 2000).

Table 5. Minor Structure Design Frequencies (Viessman and Lewis, 2003)

Type of minor structure		Return period, *Tr*	Frequency = 1/*Tr*
Highway crossroad drainage*			
0-400	ADT*	10 yr	0.10
400-1700	ADT	10-25 yr	0.10-0.04
1700-5000	ADT	25 yr	0.04
5000+	ADT	50 yr	0.02
Airfields		5 yr	0.20
Railroads		25-50 yr	0.04-0.02
Storm drainage		2-10 yr	0.50-0.10
Levees		2-50 yr	0.50-0.02
Drainage ditches		5-50 yr	0.20-0.02

Table 6. The Runoff Coefficient (C) results and comparisons

GIS ID*	GIS Vector Layer Descriptions Activity Code and and Sample Parcel Description	C (avg.) Results	C Standards (McCuen, 2005) Description of Area	Recommeded C by ASCE &WPCF in 1969	Recommeded C by McCuen in 2005
1	11 Single Family - Residential 1/8 acre (0.125 acres or 505.85 sq.m^2)	0.48	Residential: Single Family	0.30-0.50	0.40
2	11 Single Family - Residential 1/4 acre (0.25 acres 1011.71 sq.m^2)	0.43	Residential: Single Family	0.30-0.50	0.40
3	11 Single Family - Residential 1/3 acre (0.3330 acres 1347.59 sq.m^2)	0.40	Residential: Single Family	0.30-0.50	0.40
4	11 Single Family - Residential 1/2 acre (0.5 acres 2023.41 sq.m^2)	0.39	Residential: Single Family	0.30-0.50	0.40
5	11 Single Family - Residential 1 acre (4046.83 sq.m^2)	0.32	Residential: Single Family	0.30-0.50	0.40
6	11 Single Family - Residential 2 acres (8093.65 sq.m^2)	0.34	Residential: Single Family	0.30-0.50	0.40
7	31 Banks and Financial Institutions	0.71	Business:		
			Downtown	0.70-0.95	0.85
			Neighborhood	0.50-0.70	0.60
8	33 Other offices	0.68	Business:		
			Downtown	0.70-0.95	0.85
			Neighborhood	0.50-0.70	0.60
9	64 Warehousing, Distribution, and Wholesale	0.74	Industrial: Light	0.50-0.80	0.65
	Total (avg.)	0.50		0.43-0.65	0.54

* See Table 3 for information about sample parcels.

RESULTS & DISCUSSIONS

The measure of classification accuracies for the six QB NDVI thematic maps produced is presented in Table 2 using decision rules from Table 1. Figure 4 shows the QB NDVI thematic map with the lowest overall classification accuracy used as a GIS input into the Sioux Falls GIS spatial modeling for the composite of runoff coefficient, C calculations. Table 2 shows the producer's and user's accuracies of each category, the overall accuracies, and the overall kappa statistics of mapping impervious area and open space. These were obtained from the 8 and 16 bit QB NDVI imagery using unsupervised classification. The ISODATA algorithm of 2, 100, and 200 spectral clusters, with the same labeling criteria for the DNs and a 50/50 spectral cluster threshold for assign spectral clusters into two classes, was applied. Comparing the overall classification accuracies, there was no significant difference in accuracy assessment results and area differences (acres) between 2, 100, and 200 clusters, using the same data type and spectral clusters. One hundred cluster classes yielded the same result as 200 or the 16 bit data as far as accuracy percentage. The difference in acreage is 0.5 (Map# 2, 3, 5, 6) or 0.25% (Map# 1 & 4) for the total acreage percentage for the area

(100% = 2009 acres).

The overall classification accuracies of the six QB NDVI thematic maps showed similar results, about 92% with high Kappa value of 0.83 on average and similar percentages of producer and user accuracy. Average producer's accuracy ranged from 91.66% (open space) to 91.48% (impervious area), and average user's accuracy varied from 92.07% (impervious area) to 91.04% (open space). In general, the producer of the open space can reasonably state that 91.66% and 91.48% of the time an area that was "open space" or "impervious area" was identified as such, respectively. A user of this classification would find that 91.04% and 92.07% of the time that an area is visited on the ground the classification says "open space" and "impervious area", respectively. In other words, 91.48% of the impervious areas that have been correctly identified as "impervious area" and 92.07% of the areas identified as "impervious area" within the classification are of that category. Furthermore, 91.66% of the open spaces have been correctly identified as "open space" and 91.04% of the areas identified as "open space" within the classification are of that category.

Finally, the average composite runoff coefficient C values of the nine GIS sample vector layers as showed in Table 3 were calculated and compared to the industry standard C. The results of this comparison are shown in Table 6 in order to validate the utility of QB NDVI imagery for the determination of C. The overall average C estimate of total 4224 observations, covering approximately 30% of the study area, was 0.5 similar to those industry standard C values recommended by the ASCE & WPCF in 1969 and McCuen in 2005. Comparing estimated C values within GIS ID demonstrated that the new design methodologies produced C results similar to those found in the industry standards. This is reflected in the fact that the finer resolution image and mapping approach used in this study allowed for better discrimination in land cover and more accurate runoff coefficient estimation and thus validated the study hypothesis.

CONCLUSIONS

This applied research demonstrated that no significant difference occurred with 8 and 16 bit QuickBird (QB) NDVI satellite imagery using an unsupervised classification and the ISODATA algorithm for mapping impervious area and open space in the determination of runoff coefficient C in GIS spatial modeling. Mapping impervious area and open space, using fine spatial resolution NDVI satellite imagery generated with traditional unsupervised classification—the ISODATA algorithm, is a more accurate and simpler. This efficient data extraction approach increases speed and potentially reduces costs of both the analysis and mapping processes. The composite runoff index geographic model, developed by Thanapura in 2005 and 2006, and GIS spatial modeling were successful in accurately determining the rational coefficient C in urban watersheds. Therefore, the hypothesis of this study was accepted that the finer resolution image and mapping approach used in this study allowed for better discrimination of land cover and thus a more accurate C estimation. The application of this approach could be beneficial to engineers who are responsible for drainage analyses, the design of minor types of hydraulic structures, and maintenance and improvement projects in urban areas.

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