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GIS-BASED WATERSHED ANALYSIS AND SURFACE RUN-OFF ESTIMATION USING CURVE NUMBER (CN) VALUE

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A study was conducted in the Calabarzon Region, Philippines, to determine the natural boundary and extent of watershed areas as well as the amount of run-off they can generate. Geospatial processes determined the natural boundary by following the highest ridge dividing each watershed and showed that the basin in this part of the region has a total area of around 93,000 ha and consists of three catchments/watersheds. The Kaliwa watershed occupies the largest area, 50.7% of the total, followed by Kanan watershed with 42.2%. The Agos river, the confluence of these two watersheds, flows down to the Polillo Strait and serves as the political boundary between the two municipalities. It has a catchment area of 7.1%. A curve number (CN) model showed the watersheds combined surface run-off is around 243 million cubic meters based on soil type, landcover and 30-year precipitation data. The Kaliwa watershed occupies the largest area and is capable of generating the highest surface run-off, followed by the Kanan watershed and Agos river catchment with 119 M, 108 M and 16 M cubic meters, respectively. The quality of soil and high precipitation results in a high amount of run-off. These findings are significant to the community living in and around the area and can be used by managers for decision and policy making.

INTRODUCTION

The Agos River traversing the Sierra Madre Mountain located in Northern Quezon Province is the confluence of the Kaliwa and Kanan Rivers and the watershed down to the Polillo Strait. This is also a known boundary separating General Nakar from its neighboring town, Infanta. Upstream are two watersheds, the Kaliwa Watershed Forest Reservation proclaimed on June 22, 1968 under Proclamation No. 573 and the unproclaimed Kanan Watershed. These areas are both covered by Presidential Proclamation No. 1636 declaring them as National Park and Wildlife Sanctuary/ Game Refuges dated April 18, 1977, (DENR-Philippines). These are the only part of the Sierra Madre Mountain with lush forests.

A project has been proposed to use them as source of potable water and for electric generation to support requirements in greater Manila area (GMA) due to its abundant and clear water supply. Scarce information about this area is available however, especially for the public due to limited study. Thus, a GIS-based study of these watersheds was conducted to determine the natural boundary, areal coverage, and how much run-off can be generated. The most common method of estimating run-off is the widely used and empirical USDA-SCS-CN model (Walker et al., 2001; and Pandey et al., 2003) which was applied due to its simplicity and efficiency in watershed run-off estimation. It requires precipitation, landcover and hydrologic soil group information. In a developing nation like the Philippines, data are limited especially in some areas that never been subjected to research. This study was conducted using available and computer processed information focusing on precise area delineation based on natural watershed boundaries, and estimating surface run-off inside watersheds given their area, soil type, land cover and precipitation information. The Spatial Analyst extension of the ArcGIS application was used to carry out the delineation process while the ArcCN Run-off developed by Zhan and Huang, (2004) which was designed following the SCS-CN model simplified by Ponce and Hawkins, (1996) was utilized. It effectively demonstrated the potential maximum soil retention.

MATERIALS AND METHOD

In this study, a digital elevation model (DEM) was generated from 1:50,000 scale topographic maps for watershed delineation; satellite images to update landcover; soil maps and physical information; and 30-year (1976-2005) rainfall information obtained from the Philippine government agencies. The watershed delineation and capacity estimation were carried out using GIS techniques. The CN, which is a function of hydrologic soil group and landuse/land cover, were used together with the rainfall data to estimate the surface run-off capacity of the watershed.

Location of the study area

The study area is within Luzon Island and part of the Calabarzon Region, provinces of Quezon and Rizal, Philippines. The west side falls within Rizal while the east side falls within Quezon province. The prevailing climatic type according to coronas classification (PAGASA-DOST, Philippines) is type IV in the eastern side and type III in the western side of the study area. It is located between latitude 14^{o} 31' 35'' to 15^{o} 1' 48'' North and longitude 121^{o} 16' 18'' to 121^{o} 38' 28'' East (Figure 1).

Watershed delineation

From the smallest organisms to biggest trees, a life support system relies on the kind of environment within the watershed area. Watersheds are affected by climate change. It is significant

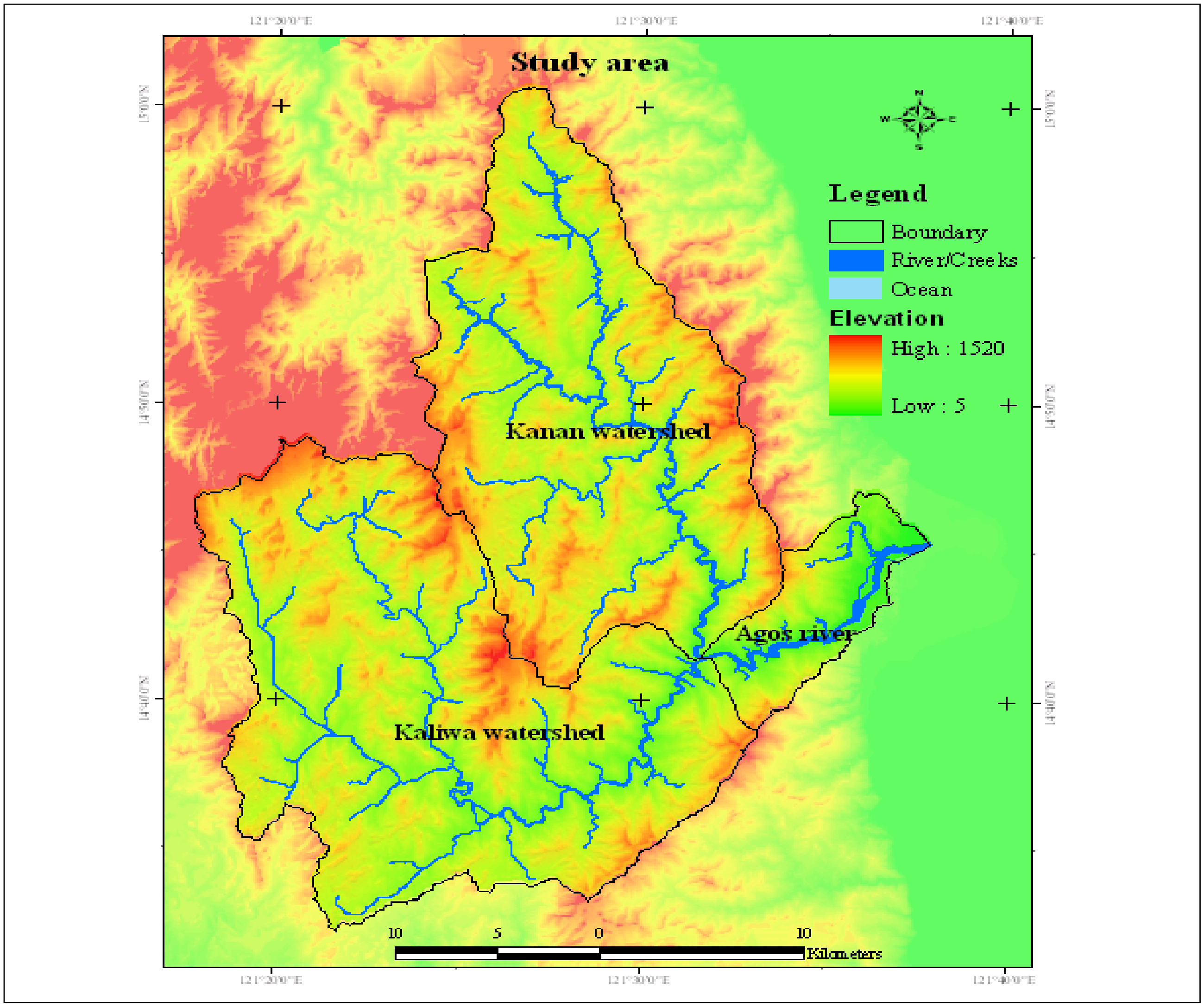

Figure 1. The study area.

to the economic development and environmental protection; and plays vital role in a sustainable economy. More than 70% of the country's land area falls within the watershed (Pulhin et al., 2006) and these areas are the backbone of the Philippine economy due to its significant role in providing water supply and electricity. The most important dataset in this part of the research is the elevation information. Thus, prior to any other work, a Triangular Irregular Network (TIN) from digitized topographic map was obtained from the DENR-NAMRIA. It then converted into a DEM (Figure 2-a) and became an input to the catchment tool (Figure 3). Determining watershed boundary was not an easy task as it entails carefully delineating the natural boundary of the mountain that forms the watershed area. However, using the spatial analyst extension of the ArcGIS, the procedures were hastened and made easy by combining the tools to build a catchment tool out of hydrology tools from ArcToolbox.

Though all necessary tools to be used are present, lack of knowledge on the sequences of use may result in improper and undesirable output. Thus, the catchment tool was built to automatically delineate and hasten the process. The following processes were implemented by the catchment tool. Each is explained based on the definition in the ESRI manual.

a. Filling- conditioning of the raster DEM or filling of sinks in a raster to remove small imperfections.

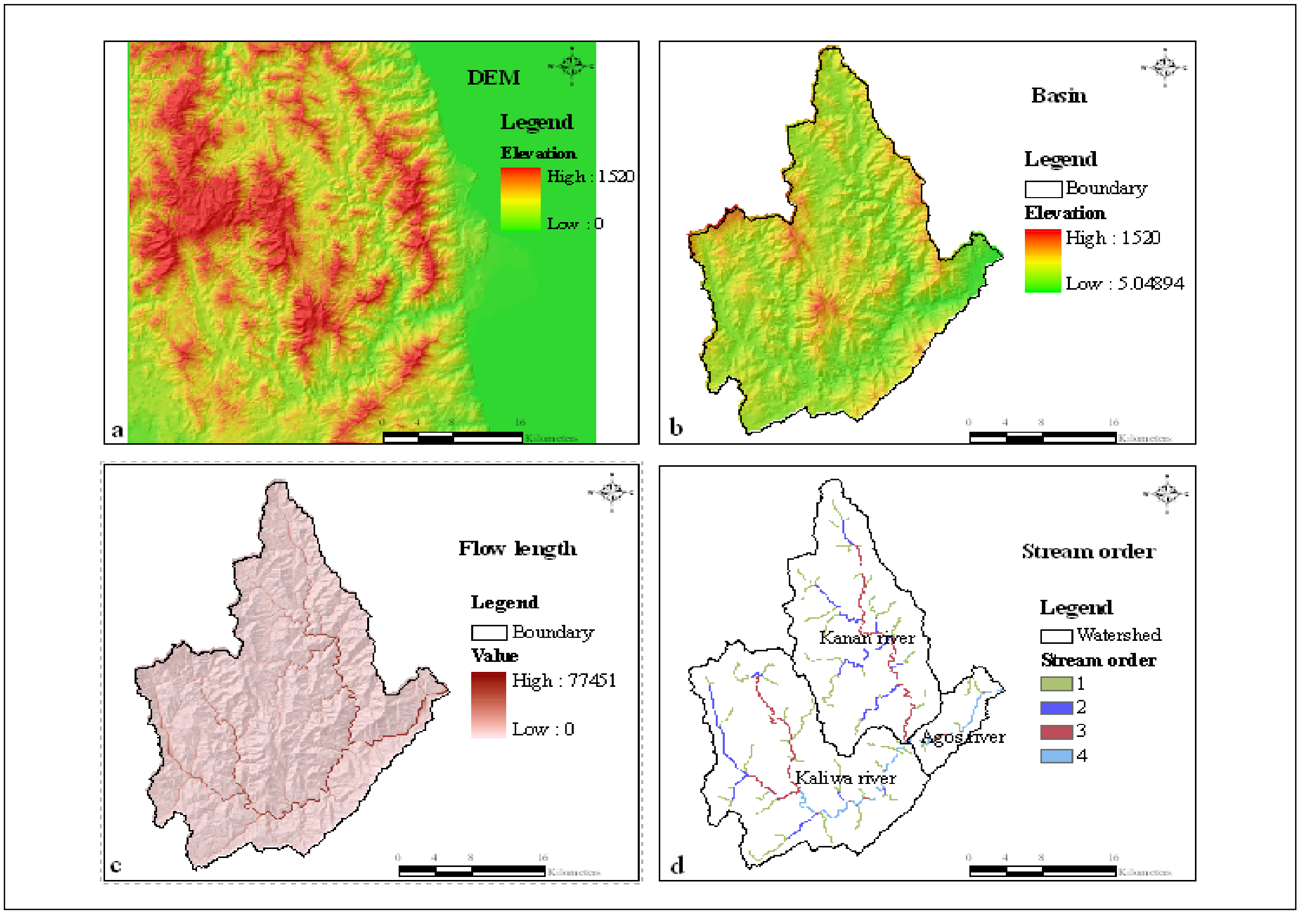

Figure 2-a: DEM, 2-b: Masked Basin, 2-c: Flow length and 2-d: Stream order.

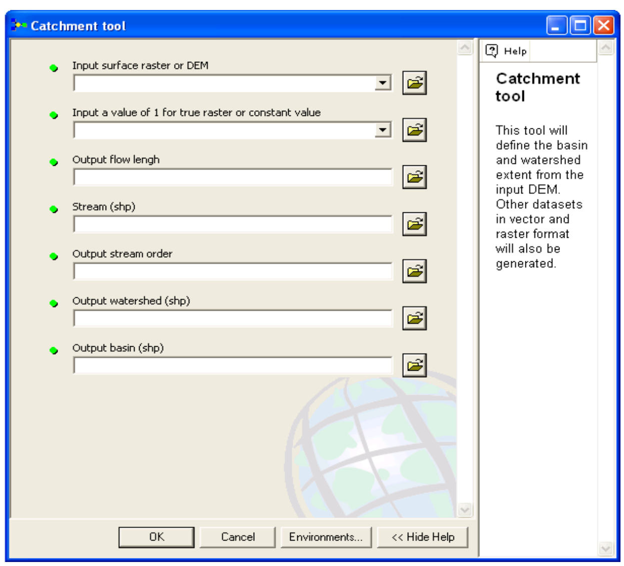

Figure 3. Catchment tool built to automate the process.

b. Sink- these are the sink pixel or areas of internal drainage in the data generated during the creation of DEM.

c. Flow direction- a process to create a raster flow direction from each cell to its steepest downslope neighbor.

d. Flow accumulation- a process to create a raster of accumulated flow to each cell.

The procedure was implemented twice using the same built tool but with a different extent of DEM input. To save computer space and processing time, a basin was first obtained using the original DEM (Figure 2-a) as input. When the entire area covered by the whole basin was determined, the exact coverage of the basin was masked (Figure 2-b) and became a final input in the second process which eventually generated the final outputs. From the flow accumulation raster dataset (Figure 2-c), a streams (rivers/creeks) and stream order were generated.

A conditional statement was embedded inside the tool as a threshold to create the stream network. A threshold value of 10000 was used. This means a stream will be created in every 10000 value of the pixels flowing in the same direction. Stream link and flow direction raster datasets were used to draw the watershed which eventually was converted into a vector format as the final result. Stream order was also determined (Figure 2-d). Similarly, from the flow direction dataset, flow length and basin were generated by the catchment tool.

Surface run-off estimation

Surface run-off is one of the major components of the water cycle. It is the water flow over the land surface which normally occurs when rainfall exceeds the maximum saturation level of the soil and when surface depressional storage is filled to capacity. It is also known as overland flow (Pidwirny, 2006). Run-off is affected by topography, soil type, vegetation and amount of precipitation. There were many models implemented by other researchers such as AGNPS (Young et al., 1987), EPIC (Williams, 1995) and SWAT (Arnold et al., 1996) to estimate run-off. In this study however, the surface run-off was calculated based on Natural Resources Conservation Service (NCRS) [formerly Soil Conservation Service (SCS)] curve number run-off method. The CN method presumes that in a rainfall event, the ratio of actual retention of soil after run-off starts to the potential maximum retention of soil is equal to the ratio of direct run-off to rainfall. This assumption was simplified by Ponce and Hawkins (1996) resulting in the below described run-off equation wherein the curve number (0 = CN =100) shows a convenient representation of the potential maximum soil retention (S). The simplified equation is as follows, (Ponce and Hawkins, 1996):

$$\text{Run-off} = (\text{rainfall} - 0.2S)^2 / (\text{rainfall} + 0.8S) \quad \text{if rainfall is} > 0.2S \tag{1}$$

$$\text{Run-off} = 0 \quad \text{if rainfall} <= 0.2S \tag{2}$$

where: S= (1000/CN) – 10 in inches and S= (25400/CN) – 254 in mm, SI units.

Curve number (CN) is a function of landuse/land cover and hydrologic soil group. In the course of the study, there was no information available about the hydrologic soil group. Thus, we adopted the widely known USDA-NRCS hydrologic soil group information because it is the most common and simple method of measuring direct storm run-off volume using curve number value. The soil data obtained was digitized and the corresponding hydrologic groups were determined and encoded. There are four hydrologic groups such as A, B, C and D as described in USDA-NRCS (2002) which are essential factors in order to determine CN value. The National Soil Survey Handbook, title 430-VI describes the hydrologic group as follows:

"Hydrologic group is a group of soils having similar run-off potential under similar storm and cover conditions. Soil properties that influence run-off potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonally high water table, intake rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. The influence of ground cover is treated independently".

In that same reference, hydrologic classes were grouped based on their infiltration characteristics such as:

A. (Low runoff potential): The soils have a high infiltration rate even when thoroughly wetted. They chiefly consist of deep, well drained to excessively drained sands or gravels. They have a high rate of water transmission.

B. The soils have a moderate infiltration rate when thoroughly wetted. They chiefly are moderately deep to deep, moderately well drained to well drained soils that have moderately fine to moderately coarse textures. They have a moderate rate of water transmission.

C. The soils have a slow infiltration rate when thoroughly wetted. They chiefly have a layer that impedes downward movement of water or have moderately fine to fine texture. They have a slow rate of water transmission.

D. (High runoff potential): The soils have a very slow infiltration rate when thoroughly wetted. They chiefly consist of clay soils that have a high swelling potential, soils that have a permanent high water table, soils that have a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. They have a very slow rate of water transmission.

To prepare the landcover data needed, an analogue map was updated through classified Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images taken in January 14 and 30, May 5, 2005 and SPOT 5 also taken of that same year. Vegetation discrimination was implemented by taking Normalized Difference Vegetation Index (Tucker, 1979 and Jackson et al., 1983). Discriminating vegetation to non-vegetation can be done using NDVI because it has been correlated with green leaf biomass and green leaf area index due to chlorophylls presence in the foliage. The chlorophyll which is the primary photosynthetic pigment in green plants absorbs light from the red and blue portions of the spectrum while a higher proportion of infrared is reflected or scattered back to the atmosphere. The Visible Near Infra-Red (VNIR) bands 3 and 2 from ASTER (15 meter resolution) and same bands from SPOT 5 (10 meter resolution) images representing the near infrared and red bands of electromagnetic spectra were used. A threshold value of 0.30 was considered to separate non-vegetation from vegetated area to enhance vegetation discrimination. The NDVI value ranges from -1 to 1. A high NDVI value indicates denser vegetation. The equation used is as follows:

$$\text{Near infrared} - \text{red} / \text{Near infrared} + \text{red} \tag{3}$$

The images were then classified using maximum likelihood algorithm in supervised classification method, a method that is based on training samples. A total of 20 trained samples were obtained and were reduced to 7 classes after analysis and recoding processes. Some parts of the area were cloudy and became a nuisance during classification because cloudy portions mimicked the spectral characteristics of moist or watery areas. Thus, they were given their own class name. It was then vectorized to finally remove the cloud and replace with correct class which was decided based on the combined actual knowledge of the area and existing old landcover map taking into consideration the surrounding vegetation.

RESULTS AND DISCUSSION

Watershed delineation

The catchment tool built from the existing geoprocessing tools of ArcGIS precisely delineated the watershed's natural boundary. Once a DEM is loaded, a number of useful outputs will be generated such as flow length, stream network/order, flow length, watershed and the whole basin. Figure 2-b, c and d showed the basin, flow length and stream order datasets, respectively. The basin shows the combined area covered by Kaliwa and Kanan watersheds including the catchment within the stretch of Agos River. The elevation in the study area ranges from 5 to 1520 meters above sea level (Figure 2-b). Flow length which was used to calculate the length of the longest flow path in a given basin has a value ranging from 0 to 77451 (Figure 2-c). The streams or creeks were generated using a threshold value of 10000 and used as input together with the flow direction to identify the stream order (Figure 2-d). The Strahler method of stream order wherein an order increases when the streams of the same order intersect was used. This is useful in identifying the main stream and its sources. The study area has a highest order of four represented by the Agos River. The entire basin has a total land area of 93,347 hectares with the Kaliwa watershed as biggest with 47,312 hectares (50.69%) followed by the Kanan watershed with 39,362 hectares (42.17%). The catchment within the stretch of Agos river covers an area of 6,672 (7.15%) as shown in Table 1. The Kaliwa watershed is within the administrative jurisdiction of Rizal province while the Kanan and Agos River is within Quezon.

Surface run-off

Based on the existing soil information and generated landcover map, the hydrologic soil groups in the study area were C and D, with the group D occupying the biggest part of the mountain. The soil type in this part is dominated by clayey soils while the soil group along the Agos river is characterized by group C.

The CN value was calculated based on hydrologic soil group and landcover ranging from 0 to 98. Zero values were those of waterways. A high CN value indicated high surface run-off (Figure

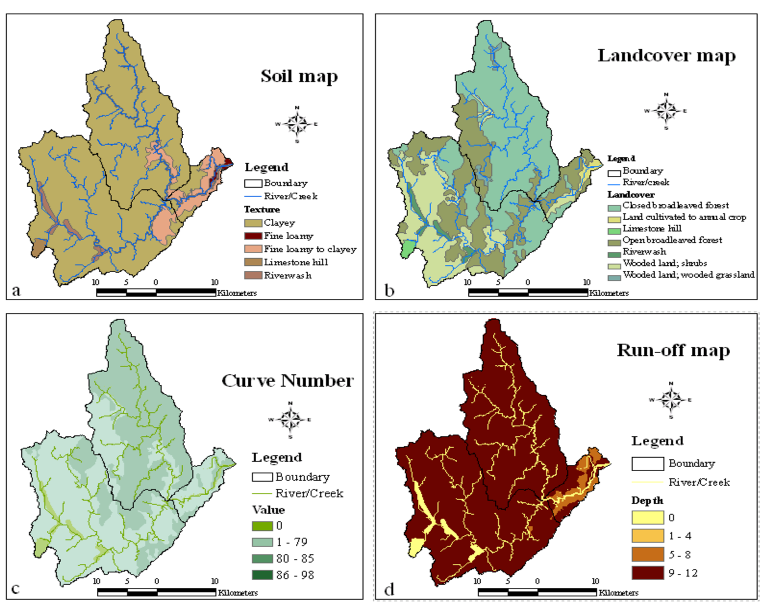

Figure 4-a: Soil, 4-b: Landcover, 4-c: Curve number and 4-d: Run-off maps.

Table 1 Watershed area based on spatial calculation.

Name	Area (ha)	Percentages (%)
Agos river	6672.84	7.15
Kaliwa watershed	47312.33	50.68
Kanan watershed	39362.63	42.17
Total	93347.80	100

4-c). With the high annual average rainfall of 4009 mm from 30-year precipitation data (1976-2005), a depth of surface run-off ranging from 0-12 inches (Figure 4-d). Multiplying the area by the run-off depth, a total volume was estimated ranging from 0 to 90 million cubic meters (Figure 5). This range brought the total run-off capacity of the whole watershed to around 243 million (M) cubic meters (Kanan: 108 M, Kaliwa: 119 M and Agos river: 16 M cubic meters) given the average precipitation of 334 mm/month equivalent to 13 inches or annual average of 4009 mm.

In this study, the assumption was a single precipitation event per month. It could vary of course depends of the storm event frequency. The high precipitation and quality of soil in the area had influenced the high CN and run-off rate.

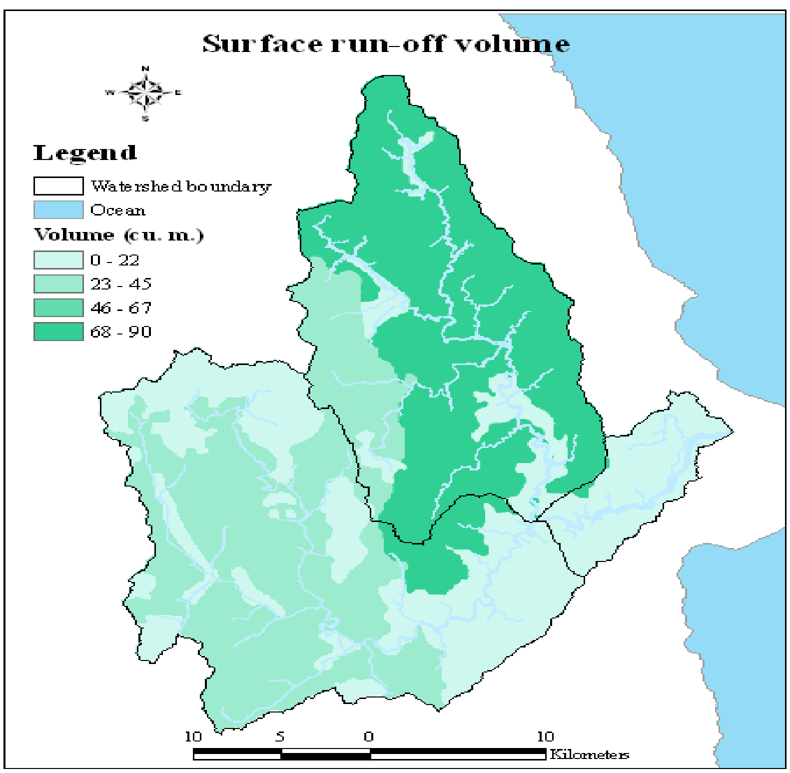

Figure 5. Map showing the volume of surface run-off in a given area.

CONCLUSIONS

The natural boundary of the watershed was accurately delineated and the run-off capacity was determined through GIS-based analysis. With this technique, frequent study can be undertaken anytime as long as new information is obtained and applied at various scales. CN value remained in the forefront when it comes to run-off calculation. This information is significant to the general public, particularly those living within and adjacent to this area. It could also provide input for policy and decision making for the benefit of the general public. Lastly, further detailed soil study as a basis for hydrologic soil group determination and evenly collected precipitation information is encouraged to obtain more detailed and reliable output.

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