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Research Article

Spatial Modelling of Soil Conservation Service Curve Number Grid and Potential Maximum Soil Water Retention to Delineate Flood Prone Areas: A Case Study

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Abstract: The Soil Conservation Service Curve Number (SCSCN) is a hydrological parameter used to describe storm water runoff potential for drainage areas and it is a function of Landuse, Hydrological Soil Groups (HSGs) and Digital Elevation Model (DEM). This study described how to estimate the SCS CN and Potential Maximum Soil Water Retention (PMSWR) to delineate flood prone areas. The study was carried out in the Accra Metropolitan Area which lies in the dry savannah coastal zone of the southern part of Ghana and is approximately 5º 33´ 00´´ N of the Equator and 0º 12´ 00´´ W of the Greenwich Meridian. The HSGs, Land use and DEM were used to generate the SCS CN and the PMSWR of the study area. The results of the SCS CN, PMSWR and slope maps indicated areas with high runoff potential and areas prone to flooding during storms. This study proved that the PMSWR and SCS CN values are important hydrological parameters to determine areas of high runoff potential and thus delineating flood prone areas.

Keywords: Accra, DEM, flood, runoff, potential maximum soil water retention, SCS CN

INTRODUCTION

In Accra and most urban settlements in Ghana, provision of infrastructural facilities has substantially lagged behind the rapid rate of housing development. Inadequate storm water drainage is one of the most serious problems facing Accra today. Flooding in low-lying areas, erosion of steep slope areas and pollution of streams by waste discharges have been identified as the major environmental problems facing the city. These problems are interrelated in that, flooding is caused by inadequate drainage systems and accumulation of solid waste deposited in streams. Frequent flooding affects many people at Mateheko, Nima, Tesano, Kaneshie, Dzorwulu among other places (Sam, 2009).

The main streets of Accra are paved and most of the land in the catchment has been developed with hard surfaces such as roof tops and paved areas therefore very small part of the catchment has capacity to retain water. These contribute to rapid surface runoff during storms. Flooding has been rampant during rainy seasons in Accra (Nordlander, 2011). The severe perennial flooding is generally attributed to blockage of major drains by accumulated solid waste caused by years of neglect and lack of maintenance. Also, the amount of storm water runoff has increased several times in the last two decades as a result of increased residential, commercial and infrastructure developments. Due to these factors and more, very small part of the catchment has capacity to retain water and thus contribute to rapid surface runoff (Sam, 2009). The aim of this study therefore was to delineate flood prone areas of the Accra Metropolis using a spatial hydrological modeling approach based on Potential Maximum Soil Water Retention (PMSWR) and Soil Conservation Service Curve Number (SCS CN).

MATERIALS AND METHODS

Study area: Accra is the capital city of Ghana. It covers an area of about 240 km² and has an estimated population of about 2 340 000. The population growth rate is estimated at 3.4% per anum in the city itself but up to 10% in itsperi-urban districts. Accra lies in the dry savannah coastal zone of the southern part of Ghana. It is approximately 5º 33´ 00´´ N of the Equator and 0º 12´ 00´´ W of the Greenwich Meridian (Anon., 2010) (Fig. 1). There are two rainy seasons. The average annual rainfall is about 730 mm, which falls primarily during the two rainy seasons. The first begins in May and ends in mid-July. The second season begins in mid-August and ends in October.

There is very little variation in temperature throughout the year. The mean monthly temperature ranges from 24.7°C in August (the coolest) to 28°C in March (the hottest) with annual average of 26.8°C. Relative humidity is generally high varying from 65% in the mid-afternoon to 95% at night. The predominant

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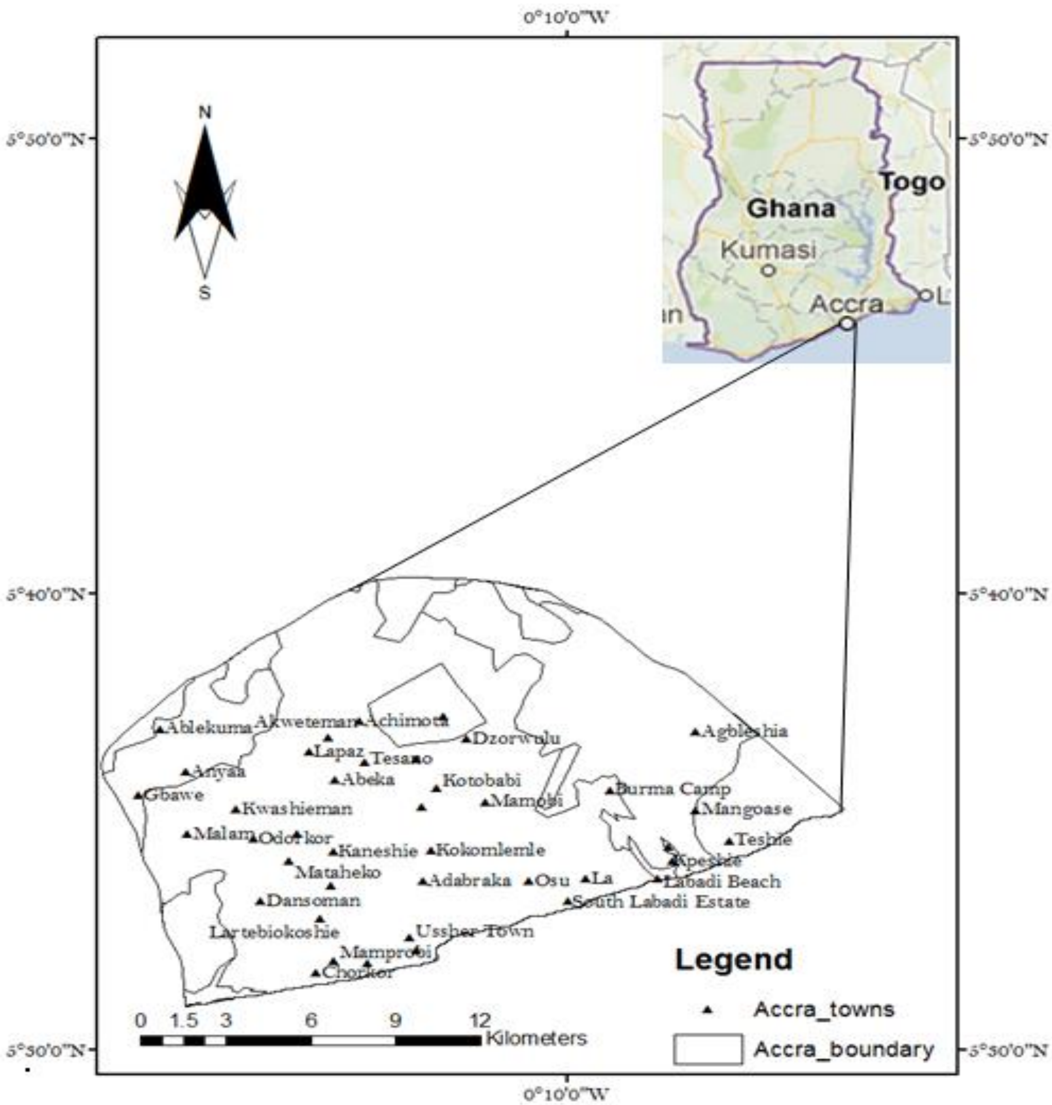

Fig. 1: Study area

wind direction in Accra is from the WSW (West-South-West) to NNE (North-North-East) sectors. Strong winds associated with thunderstorm activity often cause damage to property by removing roofing materials. Several areas of Accra experience micro climatic effects. Low profile drainage basins with a north-south orientation are not as well ventilated as that orientated east-west. Air is often trapped in pockets and an insulation effect gives rise to local increase in air temperature of several degrees (Anon., 2006). Drainage in Accra usually consists of natural drains and a few major storm water drains. There is also a network of small drains known as gutters to serve as storm water drain and convey domestic waste.

Data acquisition: Data for the study included DEM, land use and soil data. The DEM was obtained from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Models. The land use data was obtained from the department of Geomatic Engineering at the University of Mines and Technology. The soil data was also obtained from the CSIR-Soil Research Institute in Accra. The Digital Elevation Model (DEM) was extracted and clipped to the study area.

Methods used: Flood prone areas were delineated from the study area using SCS CN and PMSWR. The procedure adopted to achieve this objective is summarized in the flow chart in Fig. 2.

Performing drainage analysis: The DEM used to create the SCS CN grid was prepared by performing "fill sink" since some sinks are due to errors while others are natural parts of the DEM. In order to model

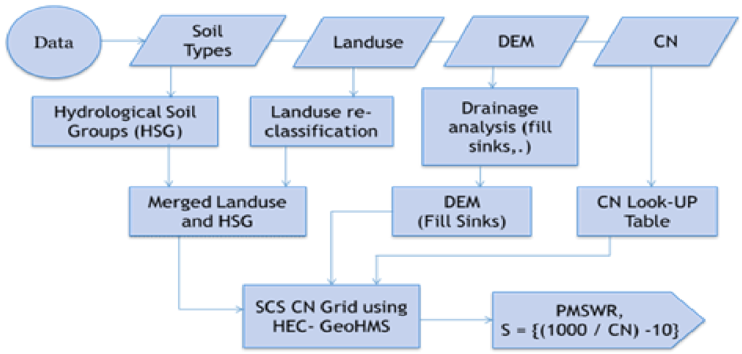

Fig. 2: Flow chart for generating SCS CN and PMSWR

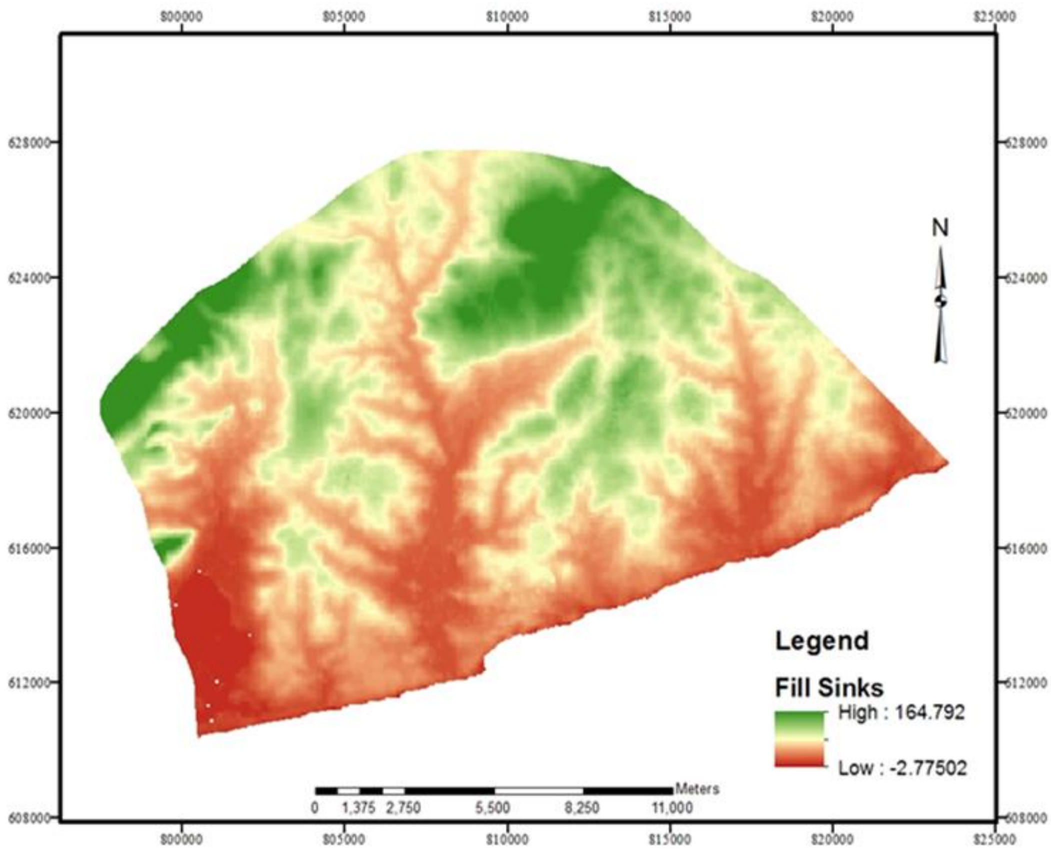

Fig. 3: Fill sinks of study area

flow, all sinks in the DEM are due to errors must be filled. The "fill sink" procedure modifies the elevation value to eliminate these problems. Figure 3 shows the fill sink of the study area.

Slope generation: Slope map was generated from the DEM data. For raster images, it is the maximum rate of change in elevation over each cell and its neighbors. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. The output slope raster can be calculated as percent slope or degree of slope. The slope of the study area is presented in Fig. 4. A Boolean analysis was done to consider areas with slope up to 5°.

SCS CN analyses: The information needed to generate a SCS CN Grid of the study area includes the HSGs, land use and DEM. In order to generate the SCS CN Grid, the DEM, the land use and the HSGs have to be "prepared". The original land use data of Accra was reclassified into four major categories namely; Water, Residential, Forest and Agricultural. This was done to minimize the different categories in the data for easy analyses. The reclassified land use data was then

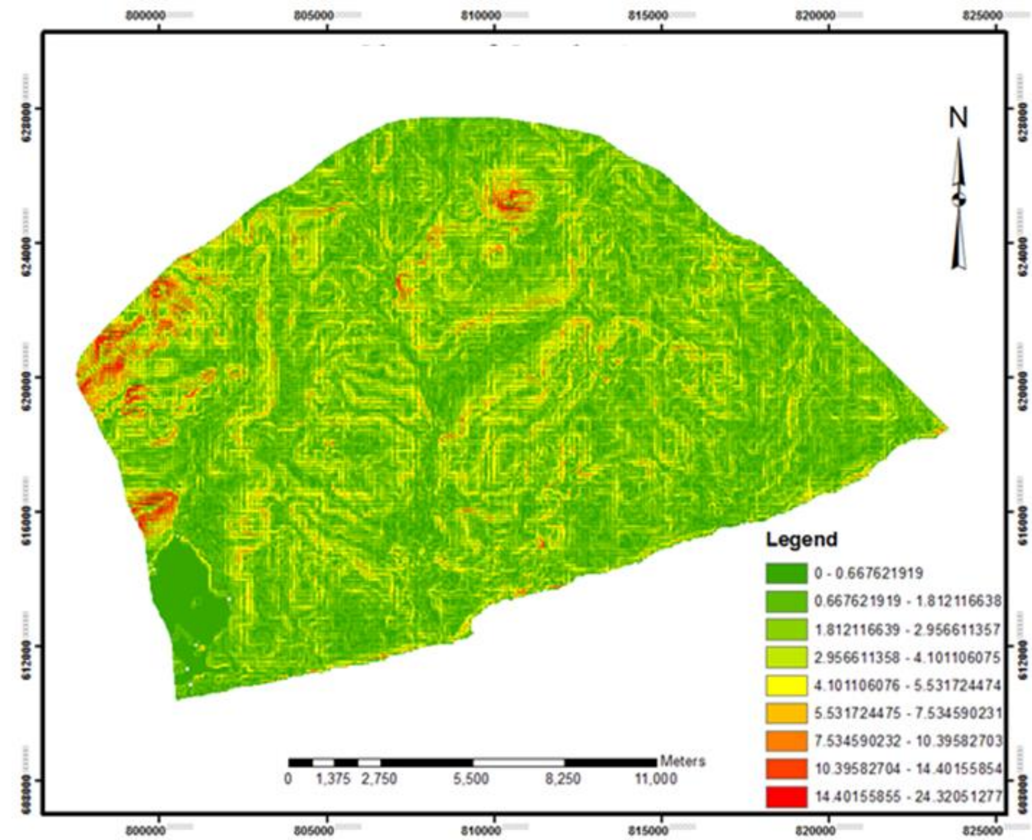

Fig. 4: Slope map of the study area

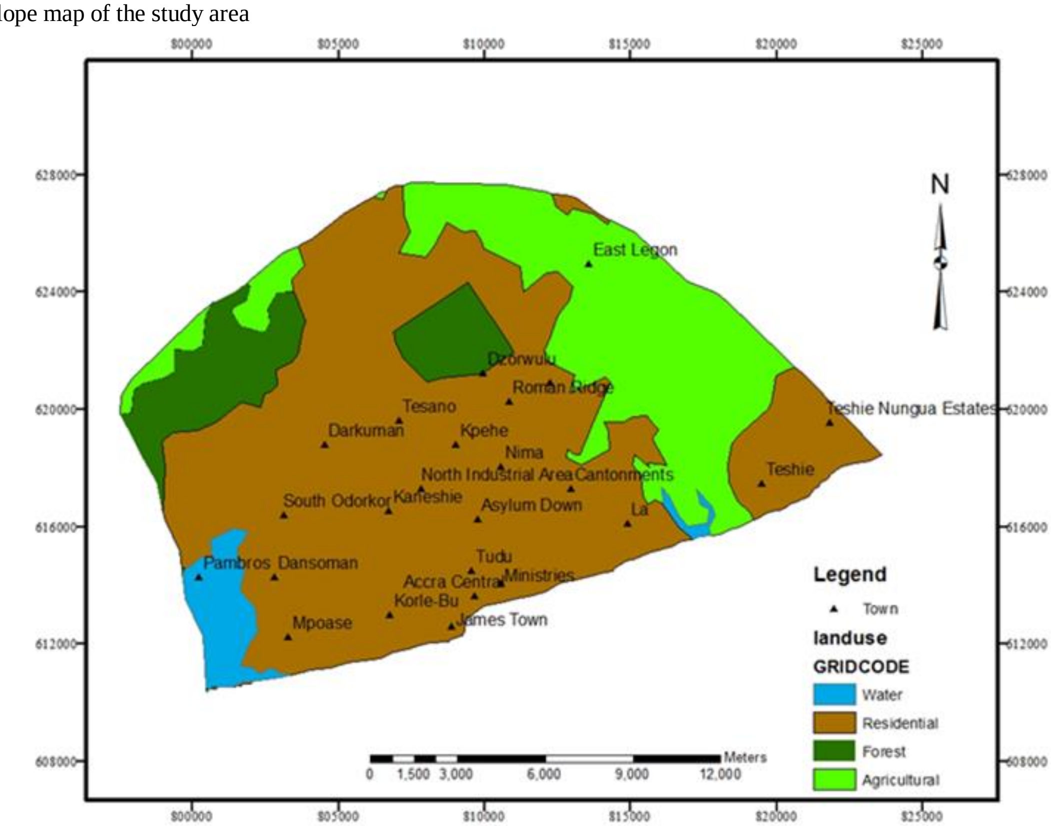

Fig. 5: Land use map of Accra

converted to polygons. The map of the reclassified land use of Accra is shown in Fig. 5.

The soil data of the study area contains various soil types and the characteristics of these various soil types were used to generate the HSGs for all polygons in the study area.

The four hydrologic soil groups which indicate the amount of infiltration are as follows (USDA, 1986):

- **A:** Soil with high infiltration rates (lowest CN with more sands and gravels)
- **B:** Soil with moderate infiltration rates
- **C:** Soil with slow infiltration rates
- **D:** Soil with very slow infiltration rates (highest CN with more silts and clays)

The percentage of each soil group in a particular polygon was also calculated. After preparing the HSGs, the soil and land use were then merged to create polygons. A look-up table to contain SCS CN for all land use and soil groups was also created.

After merging the HSGs and the land use data, a map with new polygons representing the merged soil

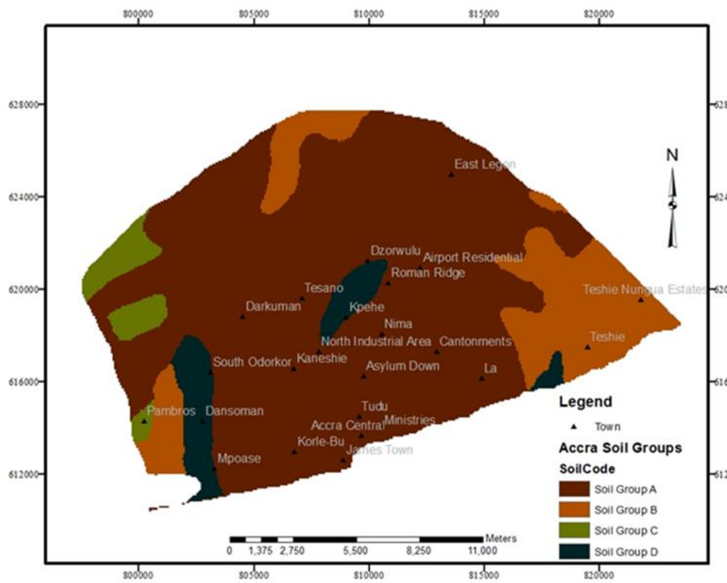

Fig. 6: Map of HSGs of Accra

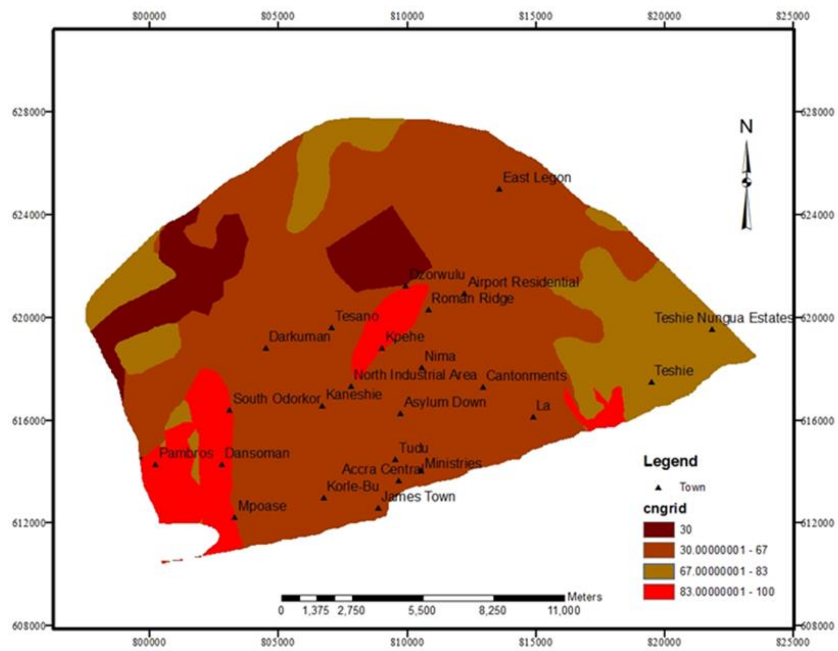

Fig. 7: Map showing SCS CN for Accra catchment

hydrological groups and land use was generated. The appropriate SCS CN values for each reclassified land use were assigned (Anon., 2013a).

The reclassified land use, HSGs, DEM (fill sinks) and the look-up table (CN Look-up) were merged to create the SCS CN grid. The SCS CN values for each polygon are shown in Fig. 7.

Potential Maximum Soil Water Retention (PMSWR): After generating the SCS CN grid, the PMSWR (S) was determined for each polygon using Eq. (1):

$$S = \{(1000/CN) - 10\} \tag{1}$$

The estimate of PMSWR is related to the soils and land cover conditions of the study area through SCS CN which depends on land use and HS Gs of the study area.

RESULTS AND DISCUSSION

Hydrological Soil Groups (HSGs): Soils are classified into Hydrologic Soil Groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. A HSGs map is shown in Fig. 6. HSGs A, B, C and D were found in the Accra catchment. According to SCS Scientists, Group A soils have low runoff potential due to high infiltration rates (7.62-11.43 cm/h), Group B soils have a moderately low runoff potential due to moderate infiltration rates (3.81-7.62 cm/h), Group C soils have a moderately high runoff potential due to slow infiltration rates (1.27-3.83 cm/h) and group D soils have high runoff potential due to very slow infiltration rates (>1.27 cm/h). From the map in Fig. 6, a large percentage of the soil in Accra belongs to Soil Group A, followed by Groups B, D and C respectively. The SCS CN values for each HSGs and corresponding land use classes adopted from the description of HSGs for Ghana (Anon., 2013b), are presented in Table 1.

Table 1: CN look-up table for land use and HSGS of study area

	Curve number (CN)			
Land use description	A	B	C	D
Water	100	100	100	100
Residential	57	72	81	86
Forest	30	58	71	78
Agricultural	67	77	83	87

HSG "A" leads to low CN values while the HSG "D" leads to high CN values in the Accra catchment. A map showing the SCS CN of areas in the Accra catchment is presented in Fig. 7. The areas with SCS CN values ranging from 67-100 have the highest runoff potential and in terms of land use and HSG combination, they are mostly residential and wetlands

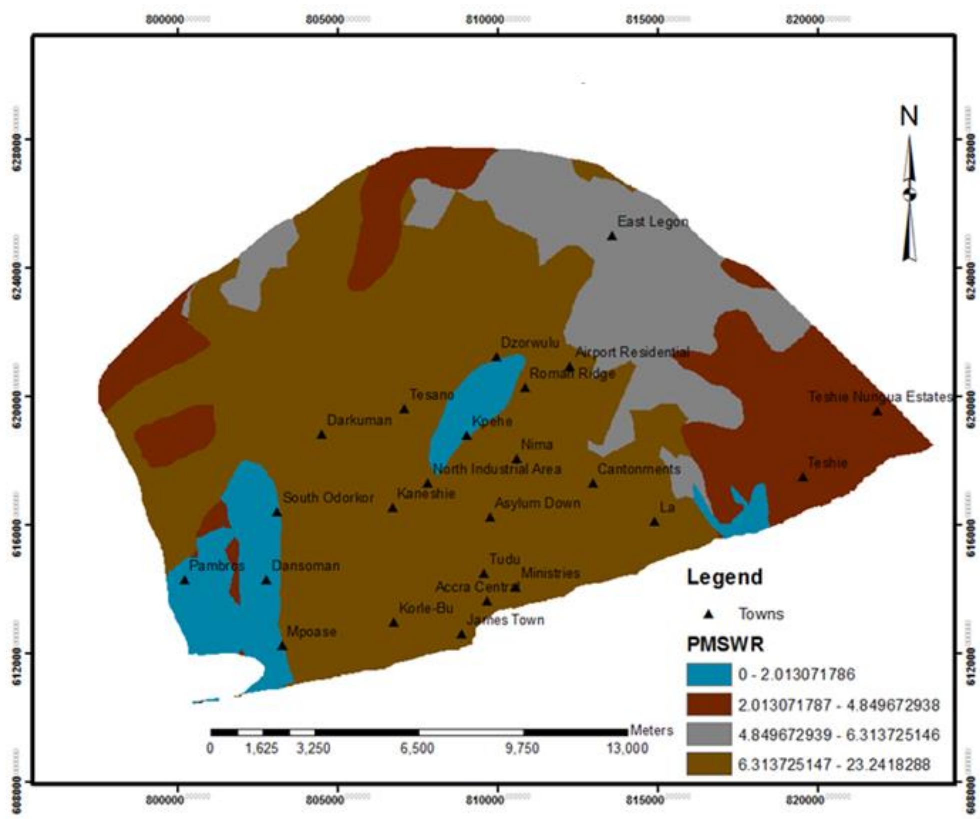

Fig. 8: Map of PMSWR of Accra

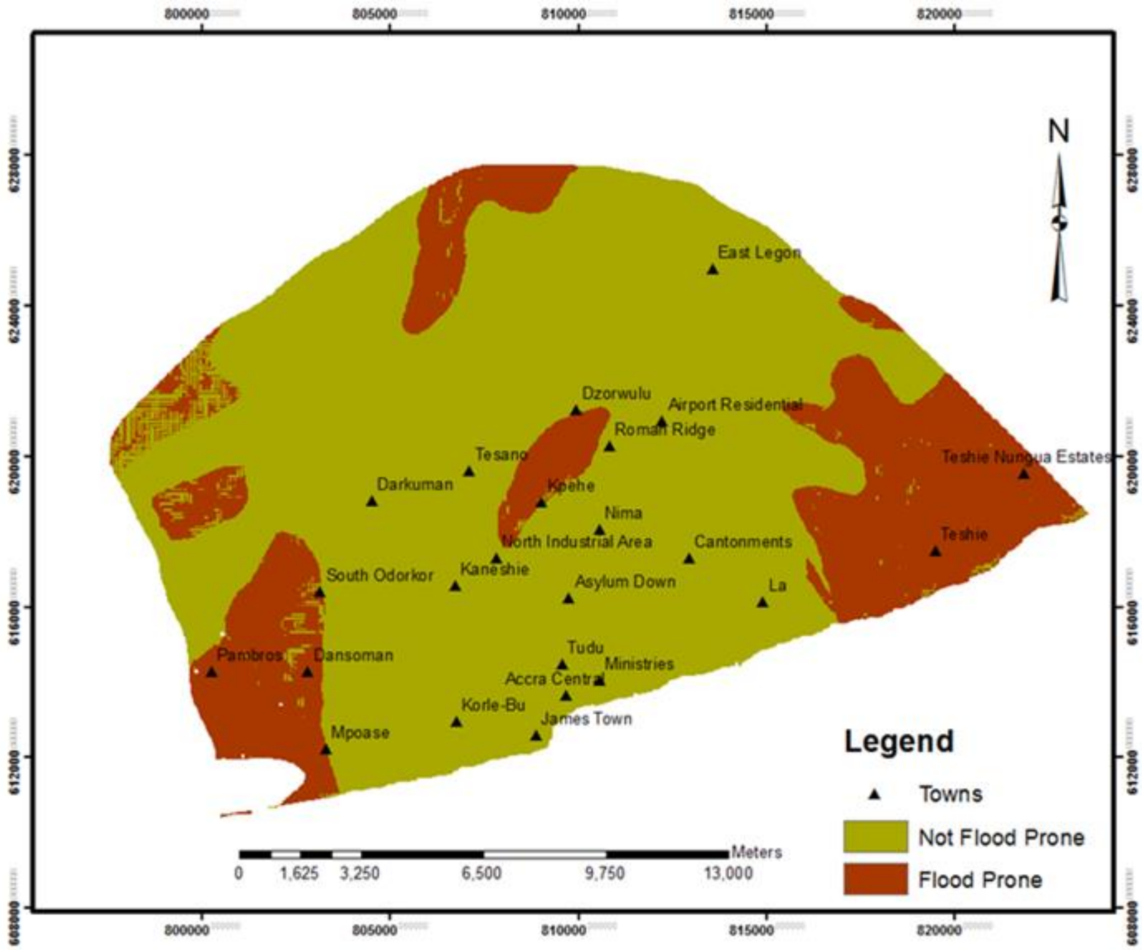

Fig. 9: Map of flood prone areas in the Accra catch men

with Soil Groups D and C and this explains their high SCS CN values. Also areas with CN values ranging from 30-67 have low runoff potential and the land use in these areas are mostly forest, agricultural and residential with HSGs of mainly A and B.

In order to delineate areas with high runoff potential, a Boolean analysis was used to consider areas with SCS CN ranging from 67-100.

Potential Maximum Soil Water Retention (PMSWR): Based on the SCS CN Method, the PMSWR of the Accra catchment was estimated. The map of the PMSWR values for the study area is shown in Fig. 8. It is obvious that the estimated PMSWR is related to the soils and land use of the study area through CN which is a function of the land use and HSG.

From Fig. 8, the areas with low PMSWR values are the areas with high runoff potential hence prone to flooding when there is storm. The spatial patterns of the PMSWR are mainly determined by the spatial heterogeneousness of land use/cover (or vegetation) and soils of inundated areas (Chen *et al*., 2012). The representation of such a combination is the SCS CN value. Therefore, it can be seen from Fig. 7 and 8 that the spatial distributions of the CN and PMSWR are similar.

Areas in the Accra catchment with PMSWR values less than (5) were considered in a Boolean analysis in order to delineate areas with high runoff potential. Areas with low PMSWR values (area of interest) are represented as flood prone because they have high runoff potential and can therefore be easily flooded when there is storm.

Flood prone areas: In order to determine the areas in the Accra catchment that have high runoff potential and thus can easily be flooded during storms, a final Boolean analysis was generated based on Boolean maps of CN grid, PMSWR and the slope. Figure 9 indicates the flood prone areas.

CONCLUSION

This study has indicated that the PMSWR and SCS CN values calculated are important hydrological parameters used to determine areas of high runoff potential and thus delineate flood prone areas in the catchment of Accra. It is obvious that the estimation of PMSWR is related to the soils and land cover conditions of the study area through SCS CN which depends on land cover and HSGs in the study area. The ability to perform spatial analysis for the development of spatially distributed hydrologic parameters, such as PMSWR, not only saves time and effort, but also improves accuracy over traditional methods. The curve number was used as a single parameter to estimate the PMSWR of the study area, however, land use and soil group data from different years can be used to estimate SCS CN from different years to determine the impact of land use on the PMSWR of the study area within a specified period. With appropriate rainfall data, the SCS CN can be used to determine the direct runoff for individual events.

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