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**ORIGINAL RESEARCH ARTICLE**

# RAINFALL-RUNOFF MODELING FOR CHALLAWA AND JAKARA CATCHMENT AREAS OF KANO CITY, NIGERIA

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**ABSTRACT**

*For the past decade, the magnitude and frequency of rainfall that resulted into flooding of Kano city have been relatively high and there is need to manage the flood in order to safe life and properties. This research aimed at generating Challawa and Jakara catchment areas runoff for hydrological applications. The two catchments were first delineated and their basic physical properties were extracted from processed 30 m x 30 m Digital Elevation Models (DEMs) of the respective watershed. Basin models of the watersheds were imported from ArcGIS 10.7 to Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS) environment, the meteorological models were developed in HEC-HMS with rainfall data and control specifications assigned which defined the period and time step of the simulation run. SCS-Curve Number, Unit Hydrograph and Muskingum methods were used for estimation of loss, runoff and flow routing respectively. The rainfall-runoff simulations were carried out for 31 years of maximum daily rainfall record (1988 – 2018). The simulated flow rate obtained can be used for further hydrological analysis such as flood frequency analysis and in design of safe and economical drainage and flood control facilities or in maintenance of culverts, sewers, bridges and roads for Jakara and Challawa catchment areas. It is recommended that; the catchment areas be gauged while further research should be conducted on the quality of the simulated flow obtained.*



## 1.0 Introduction

Recently, the use of hydrological models to estimate runoff of a catchment that are ungauged have gained considerable attentions from hydrologists and students of hydrology all over the world. Many researches conducted in urban flooding have resulted in the development of many mathematical modeling tools both free and commercial (Rangari et al., 2018). For example, with the advent of Storm Water Management Model (SWMM), HEC-HMS, HEC-RAS, MIKE LOOD modelling of the urban flood became easy and outputs of great understanding have been generated by these models. ArcGIS has made the work simpler due to its ability to extract data for directs inputs to the model (Hasyman et al., 2015).

Generally, hydrological models are primarily classified as statistical and deterministic models. The statistical models produce outputs that have partial randomness while deterministic models do not give randomness. Furthermore, deterministic hydrologic models are further classified into three major categories; lumped model, semi-distributed model and distributed model. Lumped model assesses the catchment response simply at the outlet without obviously counting for an individual sub-basins response. The semi-distributed model is partly permitted to change in space with a division of the catchment into a number of sub-basins. Whereas, the distributed model, permits its parameters to change in place at a resolution normally chosen by the client (Tassew et al., 2019).

Good storm water design practices help to maintain drainage systems, minimize disturbance to existing drainage patterns, control flooding of property, structures, and roadways, and minimize environmental impacts of storm water runoff. Urbanization tends to increase downstream peak flows, runoff volumes, and runoff velocities. These changes can cause the capacity of adequately designed drainage systems to be exceeded and disrupt natural waterways (Antigha et al., 2014). In Kano Metropolis, urban growth has, over the years, resulted in land use changes and modifications, which significantly increased area of imperviousness. As urbanization continues, there will be increase in population density and more areas will be devoted to infrastructural development which will in turn increase impervious surfaces. With urbanization and increase in impervious surfaces threat of flooding is bound to increase during any major storm event.

Rainfall-runoff models are often used as a tool for a wide range of applications such as the modeling of flood events, the monitoring of water levels during different water conditions or the prediction of floods (Tassew et al., 2019). Flow rate data are required for flood modelling and in flood risk assessment. Hence, this research is aimed at obtaining flow data through rainfall-runoff modeling for ungauged Challawa and Jakara catchment areas in Kano city.

A number of case studies carried out through researches have shown high efficiency in the use of HEC-HMS to simulate runoff from rainfall data for a given watersheds Tassew et al., 2019; Rangari et al., 2018; Chang et al., 2015). Therefore, this study employed HEC-HMS instead of using traditional methods to simulate runoff data using rainfall data and other watershed characteristics for the catchments of concerned. This research would consider two basins (Jakara and Challawa basins). Challawa comprised Gwale, Kano Municipal Council, Tarauni and Kumbotso Local Government Areas consisted of 32 wards (districts) while, Jakara basin comprised Dala, Fagge, Ungogo and some part of Nasarawa Local Government Areas consisted 62 wards (districts).

## 2. MATERIALS AND METHODS

### 2.1 Description of Study Area

Kano State is located in the Northwestern Nigeria on latitude 12°N and longitude 8.30°E within the semi-arid Sudan savannah zone of West Africa. Kano has a mean height of about 481 m above sea level (Mustapha et al., 2014). The state was created on May 27, 1967 from part of the Northern region, Kano State borders Katsina State to the north-west, Jigawa State to the north-east, Bauchi State to the south-east and Kaduna State to the south-west. Kano Metropolitan Area consists of eight Local Government Areas which include Fagge, Dala, Gwale, Kano Municipal, Tarauni, Nassarawa, Kumbotso and Ungogo LGAs with total area of 499 km$^2$ and a total population of 2,828,861 people (NPC, 2006). The latest official estimate (for 2016) is 3,931,300 inhabitants and it does suffice to say that the city is densely populated. Kano City is the second largest industrial center after Lagos State in Nigeria and the largest in the Northern Nigeria with textile, tanning, footwear, cosmetics, plastics, pharmaceuticals, ceramics, furniture, food and beverages and other industries (Mustapha et al., 2014). The city's infrastructure both Government owned and Private owned cannot be overemphasized. These infrastructures include schools (elementary and higher institutions), health centers, communication centers, religion centers and other social amenities.

The temperature of Kano usually ranges between a maximum of 33°C and a minimum of 15.8°C although sometimes during the harmattan it falls down to as low as 10°C. Kano has two seasonal periods, which consist of four to five months of wet season and a long dry season lasting from October to April. The movement of the South West maritime air masses originating from Atlantic Ocean, influences the wet season which starts from May to September.

The mean annual rainfall is about 800 mm around metropolitan Kano. Great temporal variation occurs in the amount of rainfall received and no two consecutive years record the same amount. The movement of the tropical maritime air masses from the southwest to the North determines the weather of Kano State during the wet season (Mustapha et al., 2014).

The hydrogeology of Kano is distinguished by three large watersheds; the outfall to River Challawa, the outfall to River Jakara and the other is to River Wateri. These basins are considered as the main receptacles of runoff from the city. Figure 1 shows the map of Kano metropolis.

The first source of the River Jakara is traced into the Kano city (i.e. the Jakara/Rafin Mallam) and the second source is the Bompai Industrial Estate (the Getsi). The River and its tributaries have most of their length within the Metropolis. Along the stretch of the banks are rapid encroachment of settlements which increases their risk and vulnerability to flooding. For this, the quality of the water is very low and not suitable for many uses. While Challawa River takes its source from Kaduna and Katsina States in the Katsina Highlands around Malumfashi, which also serves as one of the headwaters of the Challawa River System which creates dendritic networks moving eastward. Some of its major tributaries include Koganya, Kwakwa, Jare and Marashi all of which join the Challawa River. The last three tributaries meet at Damagari in Tudun-Kaya, Karaye Local Government. Koganya flows into Challawa at the upstream of the Gorge Dam in Rogo Local Government area. Other Rivers from this axis that joined the Challawa are Kumanda, Kariya, Bagwari and Bargi

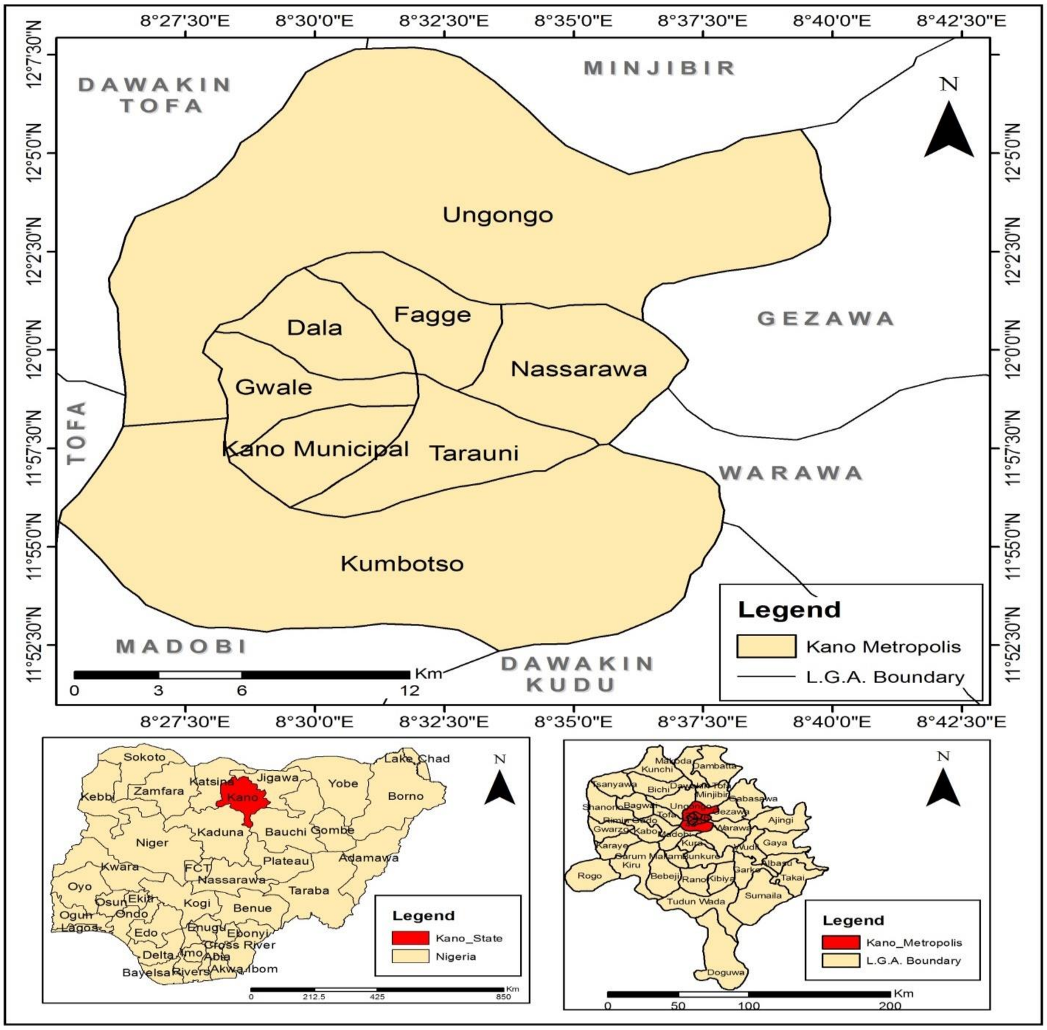


Figure 1: Map of the study area

## 2.2 Input Data

The data required for running rainfall-runoff modelling included rainfall, digital elevation model, land use/land cover 30 m x 30 m digital elevation model of the Challawa and Jakara basins were obtained from United States Geological Survey (USGS) website and used to extract basic physiographic characteristics of the catchment areas. ArcGIS 10.7, ArcHydro tool and HEC-GeoHMS were used for terrain pre-processing, basin processing and model development to generate the characteristics of basin and input files for HEC-HMS.

Other required data included Basin storage (S), Initial abstractions (Ia), Time of concentrations ($T_c$), Curve numbers (CN), Lag time and Muskingum parameters k and x. These parameters were obtained using the following Equations;

| | | |
|---|---|---|
| Basin storage (S) | $S = \frac{(25400-254CN)}{CN}$ | *(1)* |
| Time of concentration | $T_c = 0.0078\frac{(L)^{0.77}}{(S^{0.385})}$ | *(2)* |
| Initial abstractions (Ia) | $I_a = 0.2S$ | *(3)* |
| Lag time | $L = 0.6T_c$ | *(4)* |
| Muskingum constant (k) | $K = N\Delta t$ | *(5)* |

### 2.3 Land-use/land-cover (LULC) Classification of Challawa and Jakara Basins

The methods of LULC classification followed by Ahmad (2020), Haruna *et al.,* (2019), Alfa et al., and (2018) were adopted for this research. LULC is required for the estimation of catchment area Curve Numbers (CN) and the CN is in turn required for rainfall- Runoff modelling using HEC-HMS. The LULC classifications were carried out for the periods of 1988 - 2018. Figure 2 shows the flowchart methodology for LULC classification.

### 2.4 Watershed analysis of Challawa and Jakara basins in Kano city

For this study, Challawa and Jakara basins in Kano city were considered. This study was conducted using ArcHydro tools, HEC-GeoHMS 10.7 and ArcGIS 10.7. To accomplish the task of watershed analysis, three major processes were carried out which included terrain pre-processing, watershed delineation and terrain processing and basin model development. Figure 3 shows the flowchart of watershed analyses methodology.

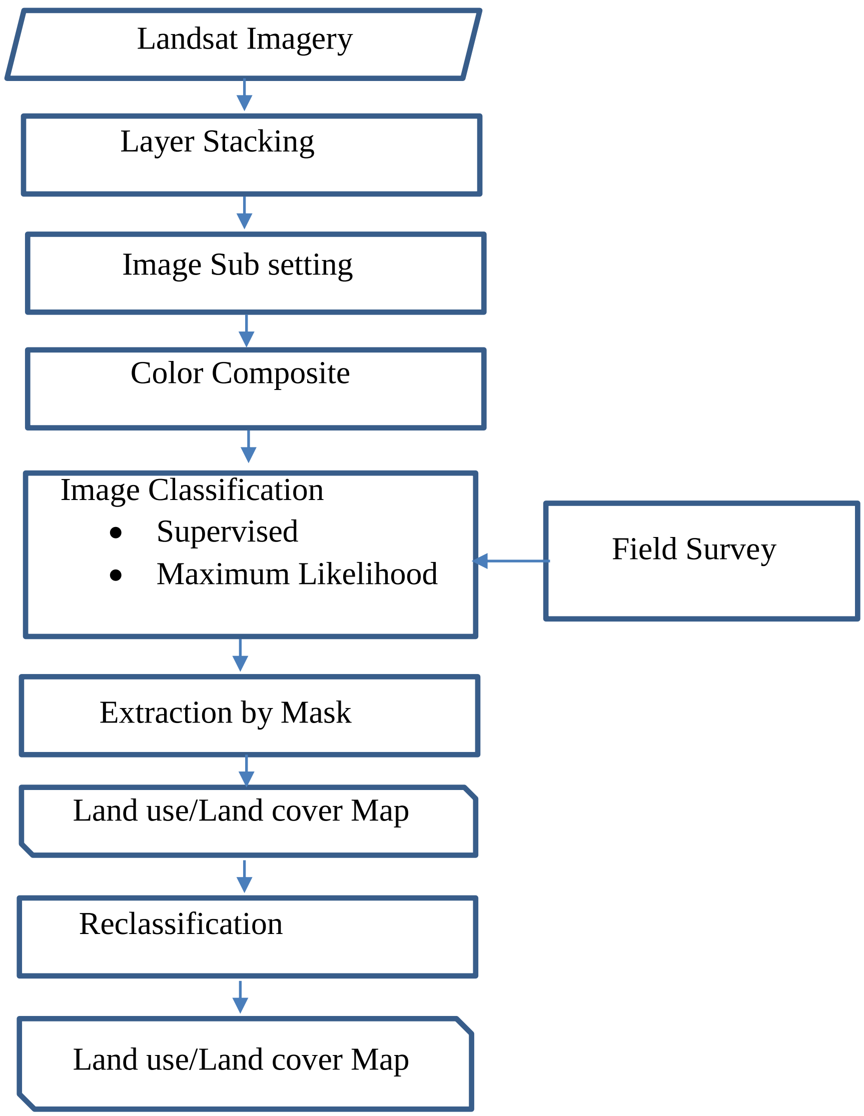


Figure 2: Land-use/Land-cover classification methodology flow chart

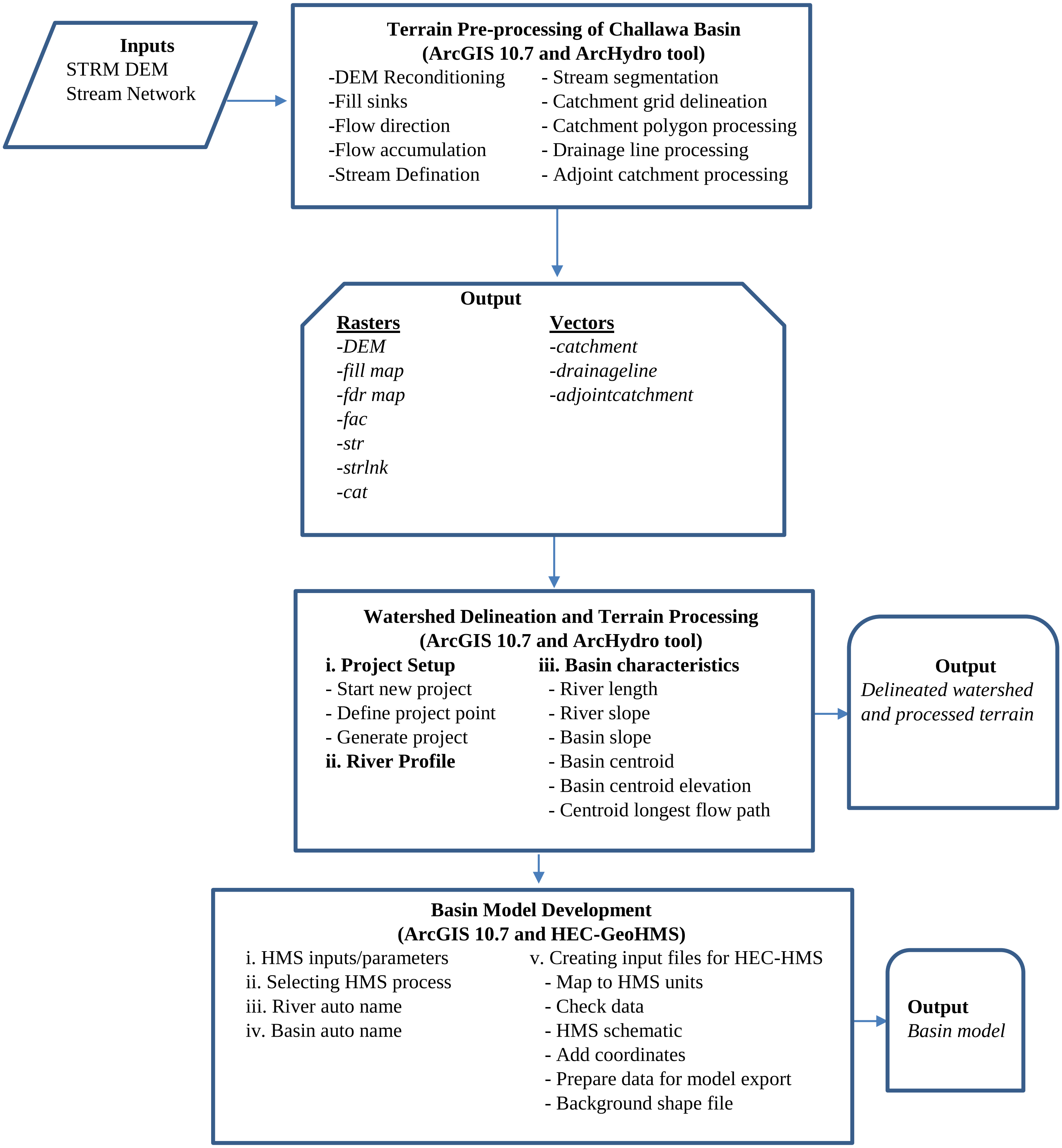


Figure 3 Flowchart of watershed analyses methodology

## 2.5 Rainfall-runoff Modeling in HEC-HMS

Rainfall-Runoff Modelling in HEC-HMS required four major components; Basin Models, Meteorological Models, Control Specifications and Time-Series Data. The methods followed by Rangari et al., (2018), Rathod et al., (2015), Choudhari et al., (2014), Martin et al., (2012), Merwade, (2012) and HEC-HMS Technical Reference Manual guidelines were adopted in this study. Two catchment areas were considered for this research (Challawa and Jakara).

Rainfall-runoff simulations were ran for thirty one years of maximum daily rainfall events (1988-2018) for Challawa and Jakara basins in Kano metropolis.

## 3. RESULTS AND DISCUSSIONS

### *3.1 LULC for Challawa and Jakara Catchment Areas of Kano City*

The results of LULC characterization for Challawa and Jakara catchment areas for year 2018 are presented in Figure 4 and Figure 5 respectively. The vegetation and Water body in both catchment areas are low as it can be seen, vegetation covered 18.05% land use, water body covered 1.06% for Challawa catchment area and 16.61% vegetation, 0.45% water body for Jakara catchment area in year 2018. In comparison of the two catchments, it could be observed that Jakara catchment area with built area of 64.26% is more urbanized than Challawa catchment area with built up area of 60.87%. The land use land cover classifications were used alongside with soil data for estimation of curve numbers for both catchment areas.

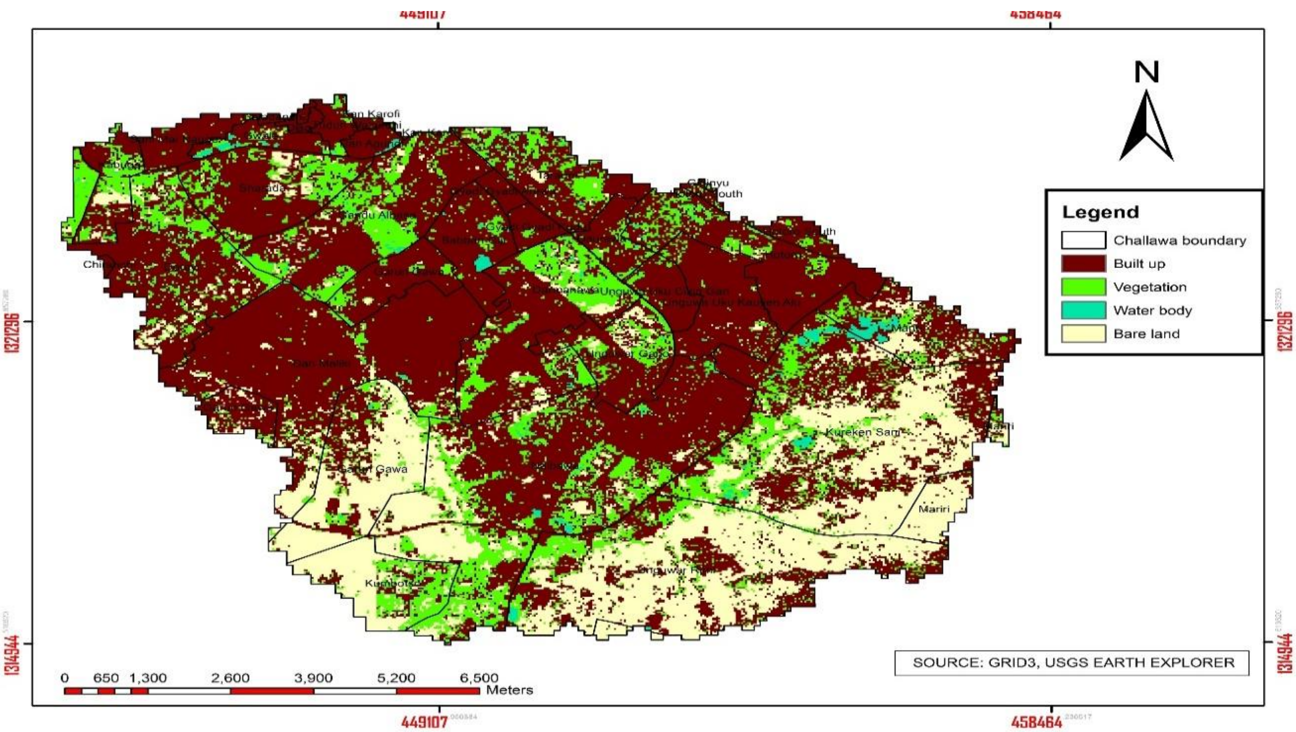


Figure 4: Challawa land use land cover classification map for year 2018

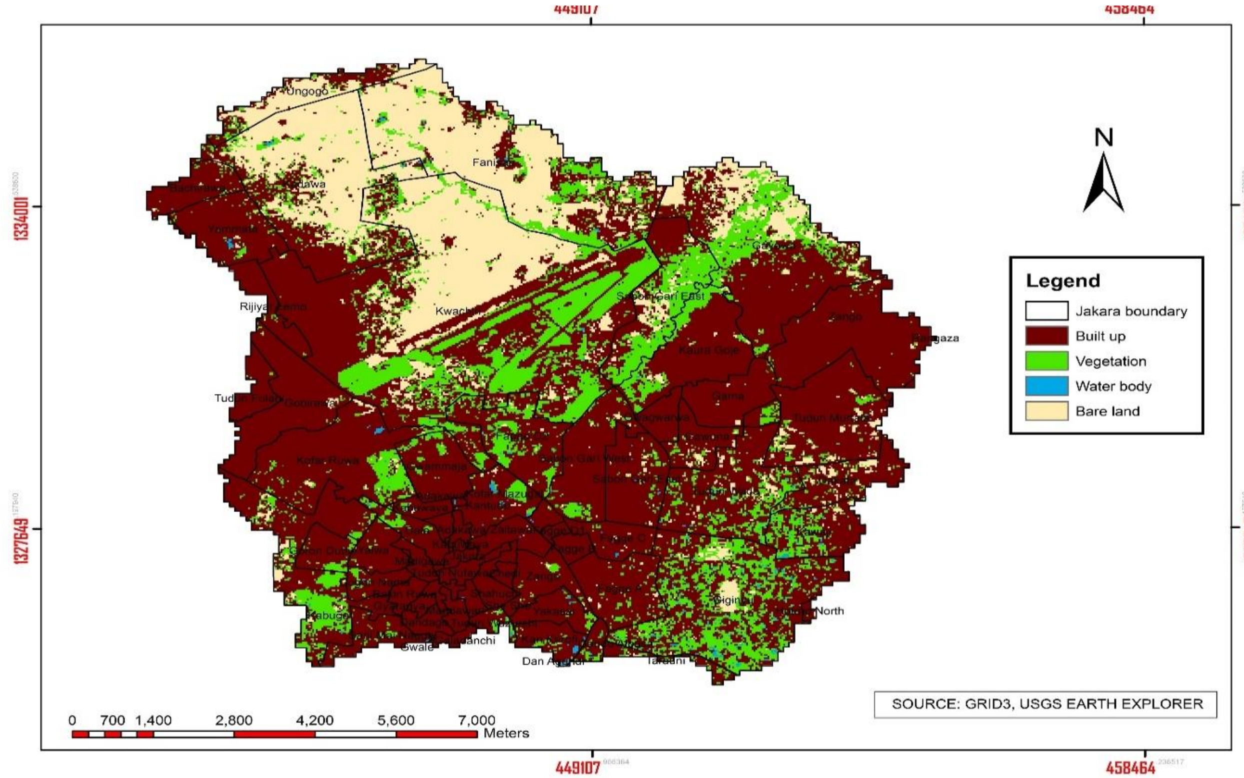


Figure 5: Jakara land use land cover classification map for year 2018

## 3.2 Rainfall-Runoff Simulations Using HEC-HMS 4. 2

### *3.2.1 Challawa basin model*

Figure 6 shows the Challawa basin model. From Figure 6, it can be seen that Challawa basin has 15 subbasins, 7 junctions, 7 reaches and one outlet.

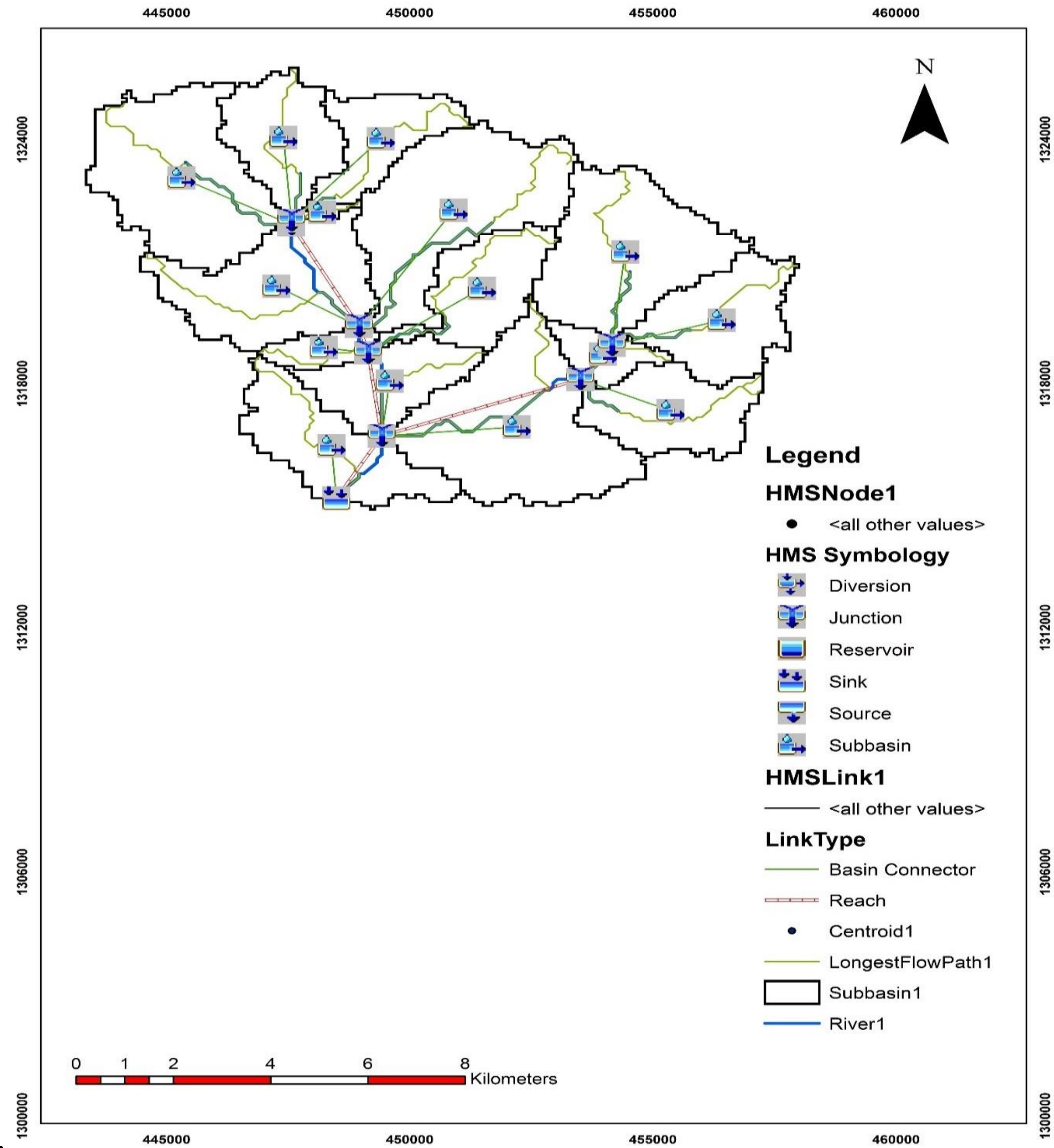


Figure 6: Challawa Basin Model

### *3.2.2 Computed HEC-HMS input parameters for Challawa basin*

Table 1 shows input parameters for Challawa basin. From Table 1, it can be seen that, subbasin "W160" has the biggest basin area of 11.92 km$^2$ with longest flow path, basin slope, curve number, storage, initial abstraction, time of concentration and lag time of 4651 m, 0.0049, 82, 2.1951, 0.4390, 101 minutes and 60.60 minutes respectively. While subbasin "W190" has minimum basin area of 0.40 km$^2$ with longest flow path, basin slope, curve number, storage, initial abstraction, time of concentration and lag time of 1707 m, 0.0216, 78, 2.82, 0.56, 26 minutes and 15.78 minutes respectively. Muskingum parameters k and x values were estimated to be 1 for k and 0.2 for x and used for all the sub-basins.

**Table 1: HEC-HMS input parameters for year 2018 Challawa basin simulation**

| Sub-basin | Drain-ID | Basin Area ($km^2$) | Longest flow path (m) | Basin slope (m/m) | CN | S | $I_a$ | $T_c$ (Mins) | Lag time (Mins) |
|---|---|---|---|---|---|---|---|---|---|
| W160 | 17.0000 | 11.9232 | 4651.0010 | 0.0049 | 82.0000 | 2.1951 | 0.4390 | 101.0030 | 60.6018 |
| W170 | 18.0000 | 5.9316 | 6167.9422 | 0.0099 | 85.0000 | 1.7647 | 0.3529 | 95.4172 | 57.2503 |
| W180 | 16.0000 | 4.6315 | 6087.7806 | 0.0049 | 81.0000 | 2.3457 | 0.4691 | 124.1885 | 74.5131 |
| W190 | 19.0000 | 0.4046 | 1707.1707 | 0.0216 | 78.0000 | 2.8205 | 0.5641 | 26.2925 | 15.7755 |
| W200 | 20.0000 | 9.8054 | 5857.7530 | 0.0022 | 88.0000 | 1.3636 | 0.2727 | 162.6705 | 97.6023 |
| W210 | 21.0000 | 12.6894 | 8187.2330 | 0.0032 | 91.0000 | 0.9890 | 0.1978 | 182.2641 | 109.3584 |
| W220 | 22.0000 | 11.0967 | 5607.9437 | 0.0024 | 88.0000 | 1.3636 | 0.2727 | 153.9108 | 92.3465 |
| W230 | 25.0000 | 1.7218 | 5179.1608 | 0.0041 | 85.0000 | 1.7647 | 0.3529 | 116.6048 | 69.9629 |
| W240 | 23.0000 | 5.7248 | 2753.6001 | 0.0069 | 84.0000 | 1.9048 | 0.3810 | 58.9601 | 35.3760 |
| W250 | 24.0000 | 6.8009 | 6936.0208 | 0.0041 | 85.0000 | 1.7647 | 0.3529 | 146.1082 | 87.6649 |
| W260 | 26.0000 | 2.0230 | 2212.8179 | 0.0091 | 85.0000 | 1.7647 | 0.3529 | 44.8304 | 26.8982 |
| W270 | 29.0000 | 5.0964 | 4974.3777 | 0.0068 | 88.0000 | 1.3636 | 0.2727 | 93.6560 | 56.1936 |
| W280 | 27.0000 | 13.5416 | 4010.8410 | 0.0028 | 87.0000 | 1.4943 | 0.2989 | 111.6392 | 66.9835 |
| W290 | 28.0000 | 6.2328 | 6936.0210 | 0.0022 | 91.0000 | 0.9890 | 0.1978 | 185.4966 | 111.2980 |
| W300 | 30.0000 | 7.2916 | 5398.4978 | 0.0005 | 88.0000 | 1.3636 | 0.2727 | 270.0820 | 162.0492 |

CN = Curve number, S = Storage, $I_a$ = Initial abstraction and $T_c$ = Time of concentration

### *3.2.3 HEC-HMS output results for Challawa basin*

The main purpose of running HEC-HMS was to get flow data for Challawa catchment of Kano city. Following the standard procedures and guidelines of running HEC-HMS model as described in the HEC-HMS technical manual Table 2 shows the results for year 2018 simulation. From Table 2, it can be seen that, Challawa basin has a total drainage area of 104.9154 $km^2$ with a peak discharge of 188.00 $m^3/s$ and discharge volume of 36.99 mm. Subbasin "W200" has highest peak discharge of 83.2 $m^3/s$ with a discharge volume of 36.11 mm, followed by Subbasin "W220" which have 72.6 $m^3/s$ peak discharge with a discharge volume of 34.92 mm while Subbasin "W190 recorded lowest peak discharge of 2.7 $m^3/s$ with a discharge volume of 39.98 mm.

**Table 2: Result for year 2018 simulation**

| Subbasin | Drainage Area ($km^2$) | Peak Discharge ($m^3/s$) | Volume (MM) |
|---|---|---|---|
| W160 | 11.9232 | 32.9 | 39.98 |
| W170 | 5.9316 | 25.4 | 44.40 |
| W180 | 4.6315 | 24.6 | 38.63 |
| W190 | 0.4046 | 2.7 | 39.98 |
| W200 | 9.8054 | 83.2 | 36.11 |
| W210 | 12.6894 | 54.0 | 36.11 |
| W220 | 11.0967 | 72.6 | 34.92 |
| W230 | 1.7218 | 8.4 | 36.11 |
| W240 | 5.7248 | 25.7 | 39.98 |
| W250 | 6.8009 | 29.5 | 44.40 |
| W260 | 2.0230 | 12.2 | 56.56 |
| W270 | 5.0964 | 45.8 | 28.72 |
| W280 | 13.5416 | 56.6 | 31.64 |
| W290 | 6.2328 | 36.7 | 36.11 |
| W300 | 7.2916 | 36.8 | 32.69 |
| Outlet | 104.9154 | 188.0 | 36.99 |

### 3.2.5 Jakara basin model

Figure 7 shows the Jakara basin model . From Figure 7, it is observed that, Jakara basin has 17 subbasins, 8 junctions, 8 reaches and one outlet. .

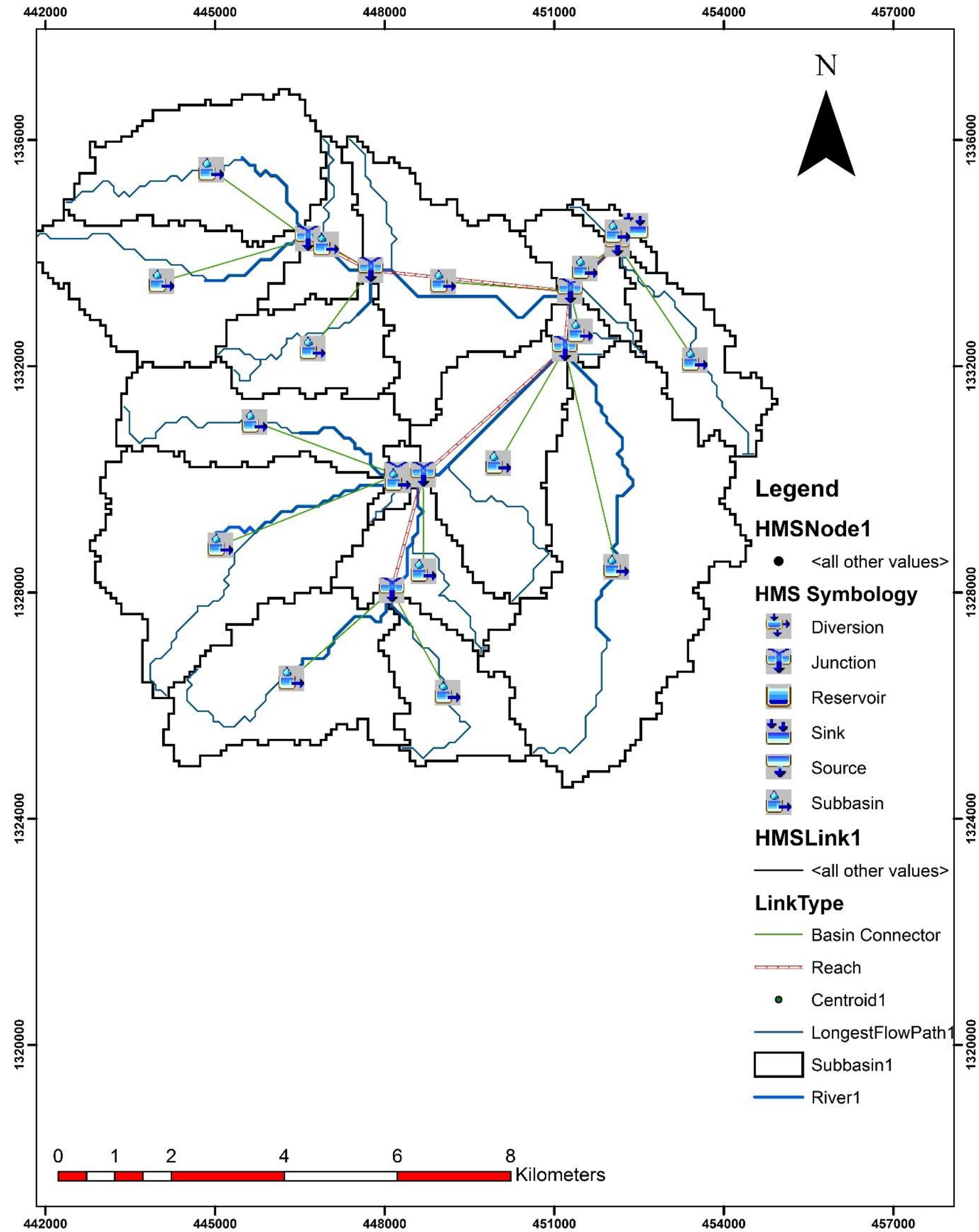


Figure 7: Jakara Basin Model

### *3.2.5 Computed HEC-HMS input parameters for Jakara basin*

Table 3 shows computed HEC-HMS input parameters for year 2018 Jakara basin simulation. It can be observed from Table 3 that, subbasin "W280" has the biggest basin area of 20.27 km$^2$ with longest flow path, basin slope, curve number, storage, initial abstraction, time of concentration and lag time of 9223.77 m, 0.0065, 85, 1.76, 0.35, 153.20 minutes and 91.92 minutes respectively. While subbasin "W300" has minimum basin area of 0.69 km$^2$ with longest flow path, basin slope, curve number, storage, initial abstraction, time of concentration and lag time of 1444.74 m, 0.0040, 87, 1.49, 0.30, 136.79 minutes and 82.07 minutes respectively. Muskingum parameters k and x values were estimated to be 1 for k and 0.2 for x and used for all the sub-basins.

**Table 3: HEC-HMS input parameters for year 2018 Jakara basin simulation**

| Sub-basin | Drain-ID | Basin Area (km$^2$) | Longest flow path (m) | Basin slope (m/m) | CN | S | $I_a$ | $T_c$ (Mins) | Lag time (Mins) |
|---|---|---|---|---|---|---|---|---|---|
| W180 | 18.0000 | 8.6002 | 6113.5908 | 0.0050 | 85.0000 | 1.7647 | 0.3529 | 123.5141 | 74.1084 |
| W190 | 19.0000 | 0.7059 | 1497.7251 | 0.0523 | 87.0000 | 1.4943 | 0.2989 | 16.9040 | 10.1424 |
| W200 | 20.0000 | 2.6601 | 3143.9508 | 0.0104 | 87.0000 | 1.4943 | 0.2989 | 55.7902 | 33.4741 |
| W210 | 21.0000 | 8.2386 | 5902.2136 | 0.0037 | 82.0000 | 2.1951 | 0.4390 | 134.1988 | 80.5193 |
| W220 | 22.0000 | 2.4019 | 2721.7620 | 0.0061 | 82.0000 | 2.1951 | 0.4390 | 61.0568 | 36.6341 |
| W230 | 23.0000 | 4.3647 | 5144.0259 | 0.0017 | 83.0000 | 2.0482 | 0.4096 | 163.6706 | 98.2024 |
| W240 | 24.0000 | 4.6143 | 4001.5161 | 0.0057 | 82.0000 | 2.1951 | 0.4390 | 84.8289 | 50.8973 |
| W250 | 25.0000 | 9.5558 | 6330.9961 | 0.0039 | 82.0000 | 2.1951 | 0.4390 | 138.8014 | 83.2808 |
| W260 | 26.0000 | 0.9556 | 1569.3613 | 0.0028 | 82.0000 | 2.1951 | 0.4390 | 53.8258 | 32.2955 |
| W270 | 27.0000 | 8.8068 | 6798.7766 | 0.0040 | 85.0000 | 1.7647 | 0.3529 | 146.0918 | 87.6551 |
| W280 | 28.0000 | 20.2737 | 9223.7715 | 0.0065 | 85.0000 | 1.7647 | 0.3529 | 153.1997 | 91.9198 |
| W290 | 29.0000 | 6.8182 | 6327.6992 | 0.0041 | 87.0000 | 1.4943 | 0.2989 | 136.7884 | 82.0731 |
| W300 | 30.0000 | 0.6887 | 1444.7393 | 0.0040 | 87.0000 | 1.4943 | 0.2989 | 44.3466 | 26.6080 |
| W310 | 31.0000 | 13.3522 | 6971.1559 | 0.0038 | 88.0000 | 1.3636 | 0.2727 | 151.0514 | 90.6309 |
| W320 | 32.0000 | 4.2011 | 4241.4344 | 0.0054 | 88.0000 | 1.3636 | 0.2727 | 90.1367 | 54.0820 |
| W330 | 33.0000 | 8.9015 | 6152.0230 | 0.0043 | 88.0000 | 1.3636 | 0.2727 | 130.7820 | 78.4692 |
| W340 | 34.0000 | 4.6401 | 4564.8113 | 0.0043 | 88.0000 | 1.3636 | 0.2727 | 103.9898 | 62.3939 |

CN = Curve number, S = Storage, $I_a$ = Initial abstraction and $T_c$ = Time of concentration

### *3.2.5 HEC-HMS output results for Jakara basin*

Table 4 shows Jakara basin global summary result for year 2018 simulation, . From Table 4, it is observed that, Jakara basin has a total drainage area of 109.7759 km$^2$ with a peak discharge of 207.70 m$^3$/s and discharge volume of 36.56 mm. The highest peak discharge of 82.7 m$^3$/s with a discharge volume of 36.11 mm was recorded at subbasin "W280". While subbasin "W300 recorded lowest peak discharge of 6.3 m$^3$/s with a discharge volume of 38.63 mm.

**Table 4: Result for year 2018 Jakara simulation**

| Subbasin | Drainage Area ($km^2$) | Peak Discharge ($m^3/s$) | Volume (MM) |
|---|---|---|---|
| W180 | 8.60 | 41.0 | 36.11 |
| W190 | 0.71 | 8.30 | 38.63 |
| W200 | 2.66 | 20.40 | 38.63 |
| W210 | 8.24 | 33.90 | 32.70 |
| W220 | 2.41 | 14.90 | 32.69 |
| W230 | 4.36 | 15.50 | 33.78 |
| W240 | 4.61 | 26.80 | 32.69 |
| W250 | 9.56 | 38.40 | 32.69 |
| W260 | 0.96 | 6.40 | 32.69 |
| W270 | 8.81 | 37.50 | 36.11 |
| W280 | 20.27 | 82.70 | 36.11 |
| W290 | 6.82 | 32.60 | 38.63 |
| W300 | 0.68 | 6.30 | 38.63 |
| W310 | 13.35 | 61.10 | 39.98 |
| W320 | 4.20 | 28.60 | 39.98 |
| W330 | 8.90 | 45.40 | 39.98 |
| W340 | 4.64 | 27.70 | 39.98 |
| Outlet | 109.78 | 208.7 | 36.56 |

### *3.2.6 Simulated flow data for Challawa and Jakara basins*

Consequently, the simulated flow data obtained for Challawa and Jakara basins are presented in Table 5 and can be used for further hydrological analysis. From Table 5, it could be seen that, the flow rate of Jakara basin is higher than that of Challawa basin across the period of consideration (1988-2018). This is because, Jakara basin is more urbanized than Challawa basin as proven by the LULC characterization result. Additionally, Mukherjee, (2016) revealed that urbanization greatly influenced the runoff generation. Furthermore, the drainage area of Jakara basin is higher than that of Challawa basin which is one of the parameters that influence runoff generation in catchment area (Kavian and Mohammadi, 2012).

Table 5: Simulated flow data for Challawa and Jakara catchment areas

| Year | Challawa Flow rate ($m^3/s$) | Jakara Flow rate ($m^3/s$) |
|---|---|---|
| 1988 | 207.70 | 342.1 |
| 1989 | 168.20 | 285.9 |
| 1990 | 145.30 | 252.4 |
| 1991 | 140.70 | 245.6 |
| 1992 | 181.00 | 304.3 |
| 1993 | 185.50 | 310.8 |
| 1994 | 178.90 | 301.3 |
| 1995 | 148.30 | 256.8 |
| 1996 | 255.00 | 407.2 |
| 1997 | 151.60 | 527.5 |
| 1998 | 262.20 | 417 |
| 1999 | 168.50 | 286.4 |
| 2000 | 251.50 | 402.5 |
| 2001 | 204.80 | 534.6 |
| 2002 | 172.30 | 291.8 |
| 2003 | 224.90 | 366 |
| 2004 | 170.00 | 260.2 |
| 2005 | 261.90 | 380.9 |
| 2006 | 295.10 | 423.3 |
| 2007 | 196.90 | 296.3 |
| 2008 | 166.40 | 255.5 |
| 2009 | 202.70 | 294.3 |
| 2010 | 177.50 | 260.7 |
| 2011 | 243.80 | 346.1 |
| 2012 | 210.20 | 522.3 |
| 2013 | 280.50 | 391.7 |
| 2014 | 226.30 | 598.3 |
| 2015 | 305.20 | 410.8 |
| 2016 | 316.80 | 401.5 |
| 2017 | 194.00 | 251.9 |
| 2018 | 188.00 | 208.7 |

## 4. Conclusion and Recommendations

The flow rate data for ungauged Jakara and Challawa catchment areas of Kano city have been successfully simulated through rainfall-runoff modelling using HEC-HMS 4.2. The results can safely be used for further hydrological analysis. It is strongly recommended that, the catchment areas should be gauged, and further research be conducted on the quality of the simulated flow obtained.

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