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Assessment of the Impact of Land Use and Land Cover Change on the Surface Runoff of Hadejia River System, Kano, Nigeria

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Abstract: Land use and land cover changes, mostly driven by anthropogenic activities, affect the processes of the water cycle. The impacts of land use (LU) and land cover (LC) changes between 1995 and 2015 on the surface runoff of the Hadejia River System (HRS) were investigated. The LULC changes obtained through re-classifications of selected Landsat satellite images and their effects on runoff peak discharges and volumes were assessed using selected hydrologic models for runoff generation and routing available within the HEC-HMS. Physically-based parameters of the models were estimated from the LULC change maps together with a digital elevation model and soil datasets of the basin. The simulated flows from the 90 sub-catchments were routed to the basin outlet afterwards to obtain the accrued effects in the entire river basin. Model results obtained generally revealed significant and varying increases in the runoff peak discharges and volumes within some sub-basins in the whole catchment, though the change was not significant at the basin outlet. In the sub-catchments within Kano and Jigawa states, increase between 15-20% and 10-15% were observed in the peak discharge respectively. These are the areas with the highest increase in agricultural activities and urbanization within the whole catchment. In the entire basin, however, the flood peak discharges and volumes increased by at least 3.57% and 8.18% respectively. From these results, the study concludes that changes were more pronounced in Kano and Jigawa states due to the increase of urbanization and farming activities in those areas, leading to reduction of infiltration and hence, increase in surface runoff. The study successfully outlined the hydrological consequences of land cover changes, emphasizing the importance of sustainable land use and catchment management strategies. Hence, integration of remote sensing, GIS, and the hydrological model (HEC-HMS) can be used to solve hydrological problems in a river basin.

Keywords: HEC-HMS model: land use change: river network: runoff.

I. Introduction

Land use and climate are determinant factors that influence the global energy and water cycle [15]. Their influences on the water cycle are usually reflected in the long-term spatial and temporal variation of water balance components such as surface runoff, soil moisture, evapotranspiration, groundwater and stream flow [17] (Memarian *et al*., 2014). Land-use and land-cover change (LULCC) is a general term for the human modification of the earth's terrestrial surface. Humans have used land and its resources to obtain food and to fulfill other essential basic needs, and in the process, have modified and are modifying land in various ways and intensities. Population growth, rapid economic development, and poverty have been identified as the underlying causes of land-use change resulting in deforestation and land degradation, among other effects [1].

LULCC is one of the major factors that alter the flow regime, seriously affecting water resources because it has a direct effect on the condition of water resources, agricultural economic growth, and climate as a result of which surface runoff is also altered greatly [11]. Understanding the influence of LULCC on river flow regimes is important for sustainable catchment management [19]. Generally, knowing the impacts of land use and land cover change on water resources depends on an understanding of the past land use practices, current land use and land cover patterns, and prediction of future land use and land cover. The LULC changes have impacts on hydrological processes by altering interception rates, soil water, evapotranspiration, infiltration, and groundwater, which eventually lead to changes in surface runoff, stream flow and flood frequency [24].

Land use changes, such as urbanization and agricultural activities cause greater surface runoff. Urban areas have enormous paved areas in the landscape that increase impervious surfaces. Therefore, little rainfall infiltrates into the soil profile, which produces larger surface runoff [9]. LULC plays an important role in influencing the water cycle through changes in ET, soil water holding capacity, and the vegetation's ability to intercept precipitation [24].

Reference [16] studied hydrologic response to land use changes in the Great Lakes states (Minnesota, Wisconsin, and Michigan) and showed that greater risk of flooding was caused by deforestation. Reference [2] assessed the land use and land cover changes and its implications to flooding along Omambala floodplain in Anambra State. The result showed a considerable change in the

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pattern of land use and land cover classes with a significant increase in population which leads to progressive change of natural vegetation to other anthropogenic activities The study concluded that various anthropogenic land use activities especially poor farming system leading to increasing sparse vegetation, bare surface and built-up area are major factors that affect natural vegetation thereby worsening the incidence of flooding in the study area.

Remote Sensing and GIS provides a large amount of data about the earth surface for detailed analysis and change detection with the help of sensors. Some of the important data used in hydrological modeling that are obtained from remote sensing includes digital elevation model (DEM) and land use/cover maps. Reference [13] applied RS and GIS in mapping the LULC of the hydrology of Luvuvhu River Catchment in Limpopo Province. The study found that new developments were impacting the hydrological processes.

To assess environmental impacts on hydrological processes, three methods are generally used. These are paired catchments approach, time series analysis or statistical methods, and hydrological modeling [14]. Hydrological modeling is important for watershed management as hydrology is the driving force behind many activities occurring on the watershed.

The purpose of a model is to represent a complex system in a simplified way. There is a wide variety of models to represent the complex hydrologic dynamics of the earth system. On the basis of process description, hydrological models can be classified in to three main categories [14]: (i) *Lumped models* - Lumped hydrologic models parameters do not vary spatially within the basin and thus, basin response is estimated only at the outlet, without clearly accounting for the response of individual sub basins; (ii) *Distributed models* - Parameters of distributed models are fully allowed to vary in space at resolution chosen by the user; and (iii) *Semi distributed models* - Parameters of semi distributed models are to some extent allowed to vary in space by dividing the basin in to a number of smaller sub basins. The main advantage of these models is that they need a smaller amount of data than fully distributed models. The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is considered a semi distributed model.

HEC-HMS is open source computer software developed by U.S. Army Corps of Engineering´s Hydrologic Engineering Center that helps in simulating the hydrologic cycle (precipitation, evapotranspiration, infiltration, surface runoff and base flow) of a catchment by describing its physical and meteorological properties. HEC-HMS has been applied in hydrology and has been successfully calibrated and validated. Reference [10] developed HEC-HMS and Hydrologic Engineering Centre's River Analysis System (HEC-RAS) models for Kankai River basin of Nepal and Kävlinge River basin of Sweden to analyze the effects of rainfall on surface runoff and peak discharges of these rivers and ultimately produce flood inundation levels to assess the flood risks in both areas. The result showed that the flooding impact of Kävlinge River is significantly less as the catchment is small with defined flow route while the Kankai River being a large catchment with braided river form inundates vast downstream flood plain region during high flood level.

Reference [8] applied HEC-HMS in Wadi Cheliff-Ghrib watershed in Algeria, in modelling the rain-flow. The model was used to predict hydrologic response of the basin to climate change scenarios and land use. The result predicted the impact of downpours, changes in land use due to urbanization, deforestation and reforestation on the peak flow and on runoff. Another study by [7] employed the HEC-HMS in conjunction with the HEC-Geo HMS and GIS to calculate the discharge of the Al-Adhaim River catchment and embankment dam in Iraq using simulated rainfall-runoff data. For loss, transformation, and routing calculations, the Soil Conservation Service-Curve number (SCS-CN), SCS Unit Hydrograph, and Muskingum methods were used respectively. Findings revealed that observed and simulated hydrographs were highly correlated. For calibration and verification, the model's performance was assessed using a coefficient of determination of 90% which shows that the model is suitable for hydrological simulations in the Al-Adhaim river catchment.

Reference [5] used the HEC-HMS model to estimate the peak hydrograph for baseline land use condition, which was then used to estimate the impact of LULC mapping accuracy levels on the forecast of The Big Darby Creek Watershed, located near Columbus, Ohio, which is experiencing increased urbanization. The results revealed that minor changes in land cover classification had no significant impact on hydrologic modeling results in rural basins. However, hydrologic changes in urbanizing watersheds are noticeable.

It is clear that humans have applied drastic changes on the terrestrial biosphere, principally through urbanization, agriculture, and several developmental activities. Nevertheless, the impacts of such changes on the hydrologic cycle are poorly understood. Understanding the effects of land use change on the hydrologic cycle is very important for development of sustainable water resource. The Hadejia- Jamaare River System (HRS) has flow variation due to the impact of LULC change on surface runoff. The basin is undergoing land use change from severe cultivation and urbanization as a result of population growth which has an impact on the hydrologic response of the basin, including surface runoff. This informed the need for this study which assessed the impact of land use and land cover changes on runoff of the HRS.

II. Materials and Methods

A. Study Area

The Hadejia River System (HRS) is located within two Nigerian states of Kano and Jigawa and lies between latitudes $10^0 30^1$N – $13^0\ 05^1$ N and longitudes $7^0 50^1$E – $15^0 05^1$E (figure 1), with a delineated watershed area of 49,889.63 km^2 [6]. The basin is one of the most important agricultural regions in Nigeria that produces food and cash crops including sorghum, rice, millet, groundnuts,

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wheat, cowpeas and vegetables under both rainy and irrigated farming. Two major dams were constructed on the up-stream locations in Kano State to support the large Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and Kano City Water Supply (KCWS).

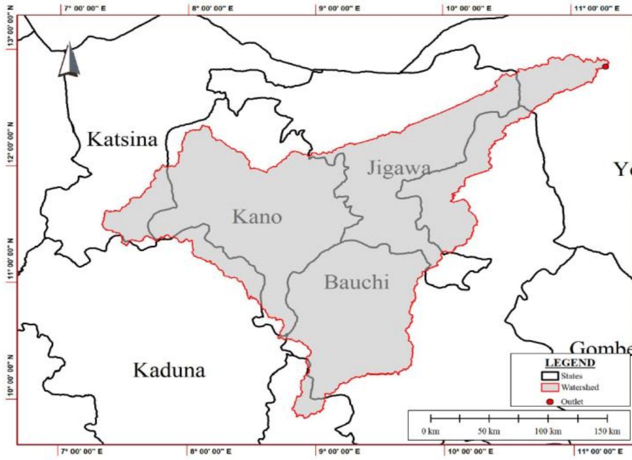

Fig. 1: Hadejia- Jama' are Watershed

B. Data Requirements

Landsat imagery for 1995, 2005 and 2015 were downloaded from the USGS and classified to determine the LULC changes and 30m resolution DEM from the Shuttle Radar Topography Mission were employed to obtain the topographical data of the study area. Nigeria soil map was downloaded from FAO and used to determine soil classes and their properties. Rainfall data was downloaded from TAMSAT to determine measured precipitation and river stream flow data were obtained from Nigeria Hydrological Service Agency, Abuja, to determine measured stream flow.

III. Data Analysis

For the model to load data, the land use types were reclassified to the corresponding HEC-HMS land uses. Although there are several classification schemes available, the supervised classification method was used. This algorithm was chosen because it is regarded as a very powerful classifier since it is not affected by solar illumination and also includes the influence of shading effects to highlight the target reflectance characteristics [21]. The images were classified into five categories: built-up areas, farmlands, tree cover, grassland, water bodies, and wetland.

After classification of the images (1995, 2005, and 2015), LULC change detection was performed, employing the post classification approach. The post classification comparison technique is the most widely used method for change detection because there is no need for image co-registration, it has low sensitivity to spectral variation, and it provides "from-to" change information [20]. Based on that classification scheme, the changes in land use and land cover, as well as the average rate of change over a 20-year period were analyzed using the percentage bias method.

For HEC-HMS modeling, different methodologies were applied. The methodology comprised two phases:

- Terrain preprocessing using the Digital Elevation Model (DEM), and HEC-Geo HMS for the preparation of hydrographic features and watershed delineation and;
- HEC-HMS model development.

For terrain preprocessing, the DEM sinks were filled, flow direction and accumulation were estimated, and catchments were delineated using extensions in ArcGIS environment. The catchment boundaries were drawn and stored as different shapefiles and the longest flow path and basin centroid were determined.

Following these processes, the developed model was exported to the HEC-HMS software. HEC-Geo HMS was used for additional processing, which included the estimation of hydrologic parameters such as curve numbers. The second step in developing the model was sub-basin delineation. Sub-basin delineation was completed through Arc Hydro tool, which split the watershed into smaller areas for analysis. Arc Hydro's delineation function automatically creates a separate sub-basin for each stream segment, but this initial delineation may be modified in HEC-Geo HMS to increase or decrease the number of catchments.

In order to simulate the rainfall-runoff model (HEC-HMS), the study employed the loss, transform, and routing methods. Due to a lack of data in the study area, the SCS Curve Number was chosen as one of the methods for calculating loss from a rainfall event. The Curve Number (CN), the percentage of imperviousness, and the initial abstraction are all required parameters for loss computation [3].

The study then determined the hydrologic soil group from the soil data and the basin lag time values were computed using the

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transform method during data processing using the HEC Geo HMS application in ArcGIS environment and stored in the attributes table of the sub-basin data layer. Flood routing method was employed to determine the flow hydrograph at the downstream point of the catchments. It is an approach to estimate how the magnitude and celerity of a flood wave varies than that at the inflow point as it moves along the catchment and is a function of basin characteristics such as slope and length of channel, channel roughness, channel shape, downstream control and initial flow condition [20]. The Muskingum method for channel routing was chosen where the X and K parameters were evaluated. The K parameter is time of passing of a wave in reach length and X parameter is constant coefficient that varies between 0 - 0.5. These parameters were estimated with the help of observed inflow and outflow hydrographs. The parameters required for running the HEC-HMS model are listed in table 1.

Table 1: HYDROLOGICAL MODEL (HEC-HMS) CATCHMENT PARAMETERS FOR HRS

No	Model	Method	Parameter required (Unit)
1	Loss Rate Parameter	SCS Curve Number	Initial abstraction (mm), Curve Number and Impervious area (%)
2	Runoff Transform	SCS Unit Hydrograph	Lag time (min)
3	Routing Method Constants	Muskingum	Travel time (K) and dimensionless weight (X)

IV. Results and Discussion

A. Results

Landsat imagery of 1995, 2005 and 2015 were classified into six general categories of land use/cover which included farmland, grassland, tree cover, wetland, built up area and water bodies, covering a total area of 49,889.63 sq. km. Fig 2 shows the result of the LULC of the study area for the year 1995. The farmland accounted for about 41,307.24sq.km (82.80%) of the total area, followed by grassland and tree cover occupying 6,716.91sq. km (13.46%) and 1,430.08sq.km (2.87%) of the total area respectively. Wetland, built-up area and water bodies are 3.75sq.km (0.01%), 87.77 sq.km (0.18%) and 343.86 sq.km (0.69%) respectively. For 2005 (figure 3), farmland covered 42,247.49 sq.km (84.68%), grassland 5,708.70 sq.km (11.44%), tree cover 1,447.92sq.km (2.90%), wetland 4.32sq.km (0.01%), built-up 156.30sq.km (0.31%) and water bodies 324.90sq.km (0.65%). For 2015 (figure 4) farmland covered 42,394.97 sq.km (84.98%), grassland 5,432.90sq.km (10.89%), tree cover 1,453.84 sq.km (2.91%), wetlands 4.32sq.km (0.01%), built-up 275. 62q. km (0.55%) and water bodies 328.00sq.km (0.66%). Figure 5 presents a summary chart for LULCC, table 2 presents the areal distribution of the classes, and table 3 shows the change detection calculated from the classification.

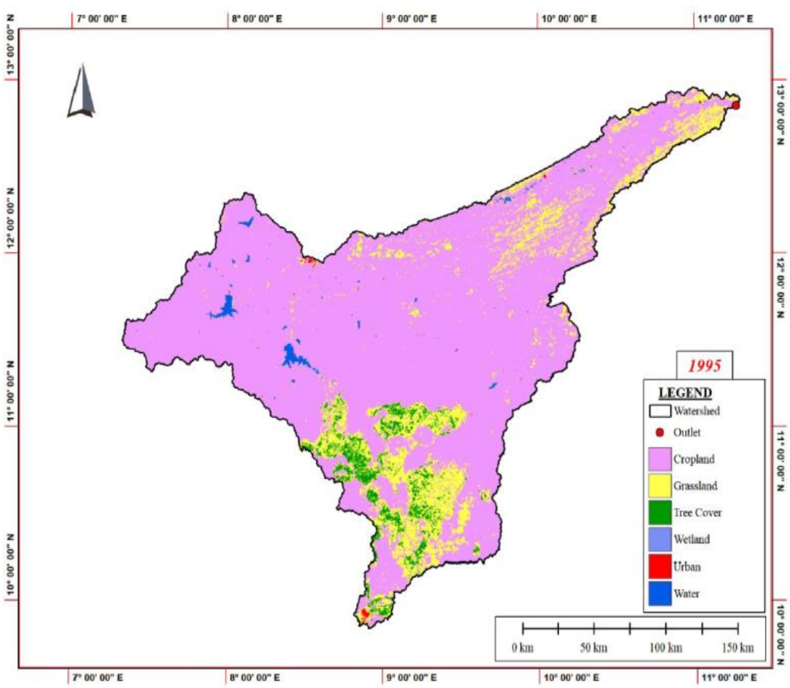

Fig. 2: Classified land use/cover for 1995

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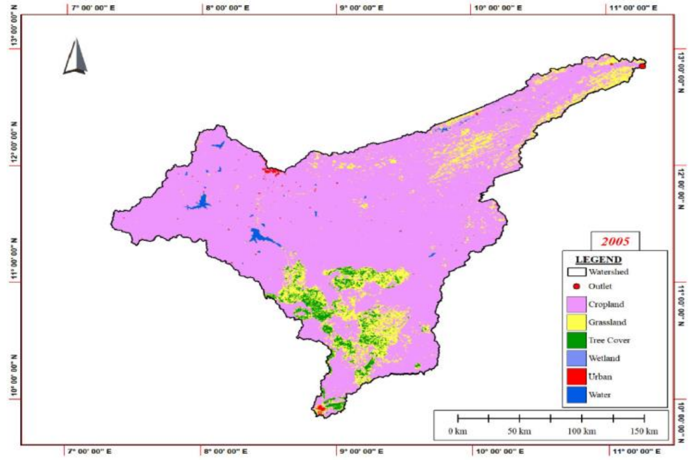

Fig. 3: Classified land use/cover for 2005

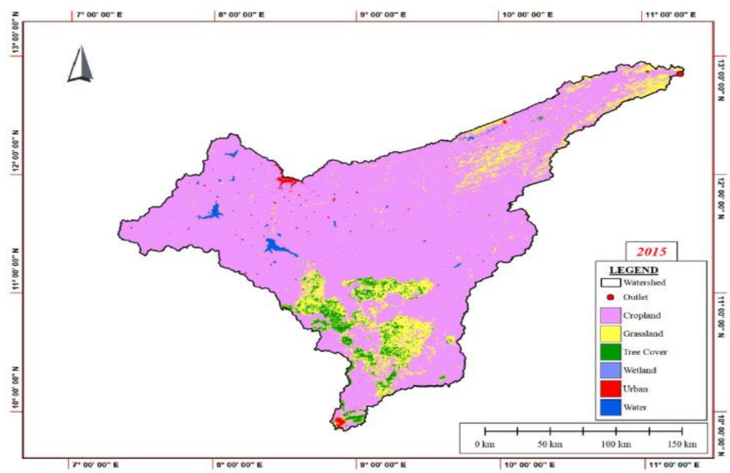

Fig. 4: Classified land use/cover for 2015

TABLE 2: AREAL DISTRIBUTION OF LAND USE/LAND COVER CATEGORIES IN THE HRS

Land Use	Land Use (1995)		Land Use (2005)		Land Use (2015)	
	Area (sq.km)	% cover	Area (sq.km)	% cover	Area (sq.km)	% cover
Farmland	41,307.24	82.80	42,247.49	84.68	42,394.97	84.98
Grassland	6,716.91	13.46	5,708.70	11.44	5,432.90	10.89
Tree cover	1,430.08	2.87	1,447.92	2.90	1,453.84	2.91
Wetland	3.75	0.01	4.32	0.01	4.32	0.01
Built-up	87.77	0.18	156.30	0.31	275.62	0.55
Water bodies	343.86	0.69	324.90	0.65	328.00	0.66
Total Area Covered	49,889.63		49,889.63		49,889.63	

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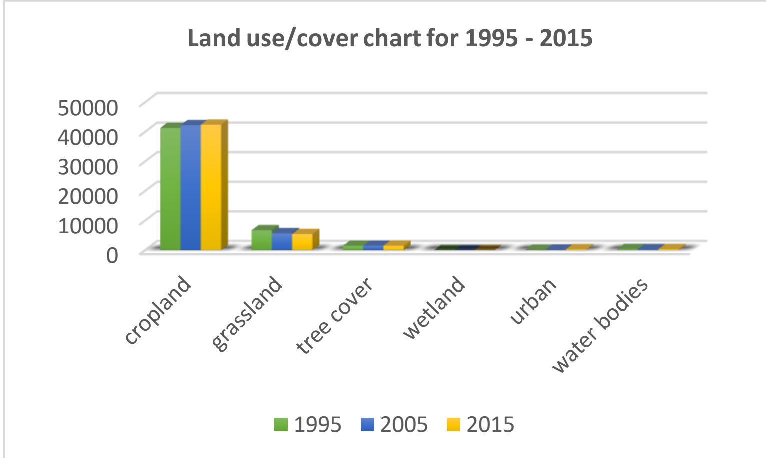

Fig. 5: Land use/land cover summary for 1995, 2005, and 2015

Table 3: Change Detection (1995 – 2015)

Change Detection	Area sq.km			% Cover		
Class	1995	2015	ΔLULC	1995	2015	Δ%
Farmland	41,307.24	42,394.97	1,087.72	82.80	84.98	2.63
Grassland	6,716.91	5,432.90	-1,284.02	13.46	10.89	-19.12
Tree Cover	1,430.08	1,453.84	23.75	2.87	2.91	1.66
Wetland	3.75	4.32	0.56	0.01	0.01	15.00
Built-up Area	87.77	275.62	187.84	0.18	0.55	214.01
Water bodies	343.86	328.00	-15.86	0.69	0.66	-4.61
Total Area Covered (sq.km)	49,889.63	49,889.63				

For hydrological modeling, the temporal variation of the flow at the outlet of the catchment was assessed by considering the model's response to land use and land cover changes over a period of twenty years. The basin was divided into 90 Sub-basins based on the river network, using a threshold for stream generation of 400km^2. Runoff from the sub-basins was estimated by using the SCS-CN and SCS Unit Hydrograph methods for loss and transformation calculations respectively. Terrain pre-processing and model development using HEC-Geo HMS is shown from Fig. 6 to Fig. 9.

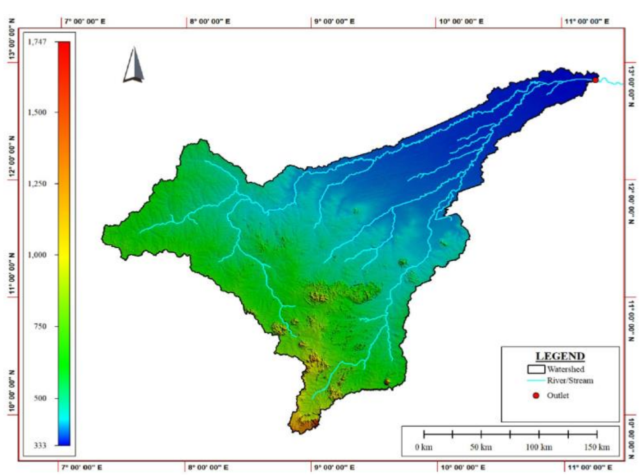

Fig. 6: Digital Elevation Model for HRS

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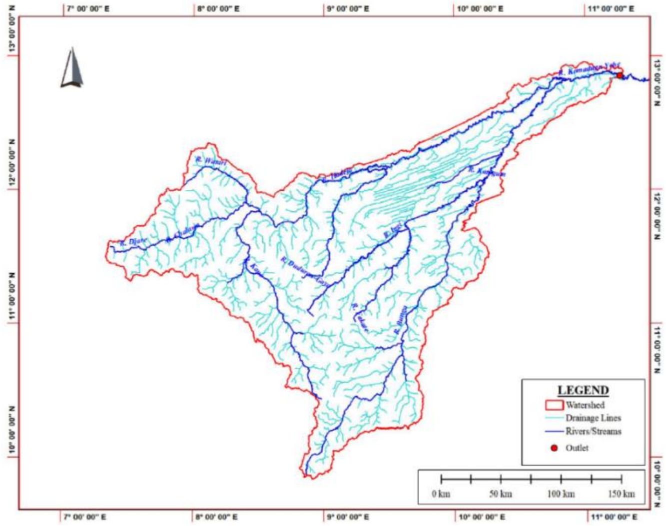

Fig. 7: Map showing River and Stream Network of HRS

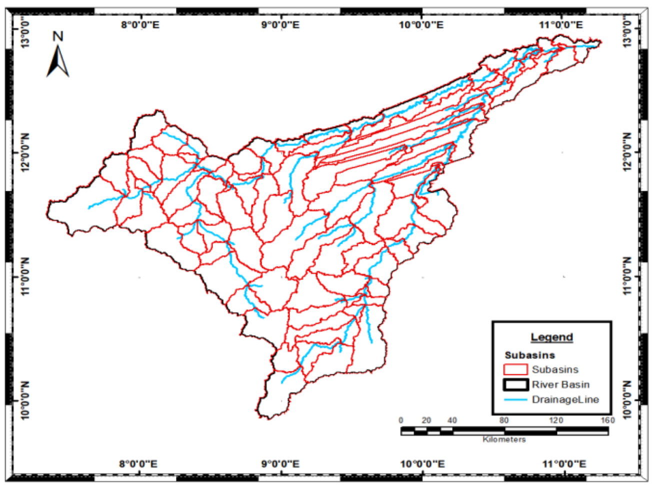

Fig. 8: Map showing Sub-basin division of the HRS

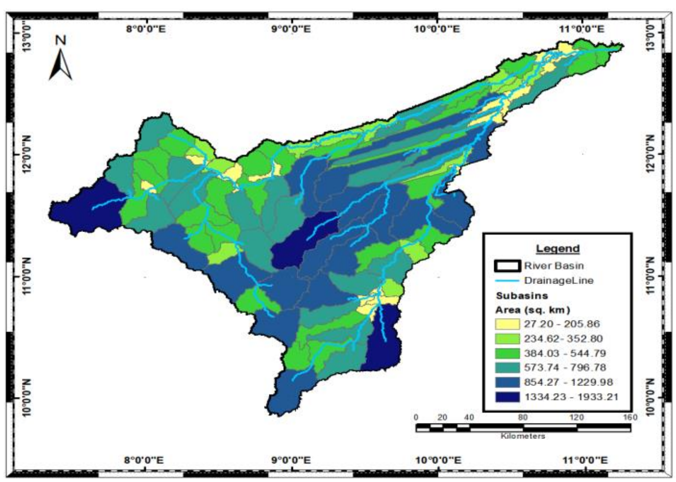

Fig. 9: Map showing the Sub-basin Areas (sq.km)

The soil data analysis showed that for HRS there were twelve main soil types which were merged with the land use/land cover type file to calculate the curve number. The Soil Conservation Service Curve Number loss (SCS curve number) method was used to generate the direct runoff. The Curve Number (CN) grid file, which is required to build the HEC-HMS model, was created using soil map and land use datasets. CN values were used to determine the characteristics of the stream/sub-basin and to estimate the hydrological parameters used in the model (Figures 11 and 12). CN values range from 30 corresponding to permeable soils with high infiltration rates to approximately 100 corresponding to water bodies.

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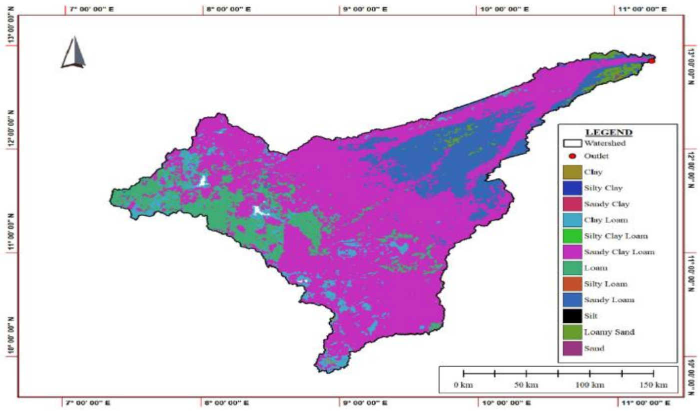

Fig. 10: Soil Texture Map of HRS

The transform prediction models in HEC-HMS simulate the process of excess rainfall to direct runoff in the catchment and transform the rainfall excess in point runoff [23]. During the analysis of the study data, the SCS Unit Hydrograph model was used to convert the excess rainfall into runoff. Hence, the transform model converts the excess rainfall from millimeters (mm) to cubic meters per second (m^3/s), this is called the Unit hydrograph. The resultant hydrograph at 25 year return period is shown in figure 11 for Kano sub-basin and figure 12 for entire basin at the outlet. Peak discharge calculated with HEC-HMS for the whole watershed is 9,298m^3/s while at sub-basin level, in Kano sub-basin is 758.2m^3/s.

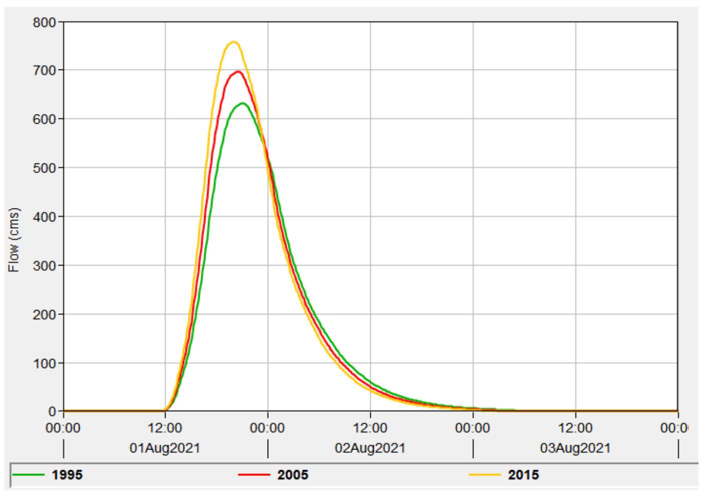

Fig. 11: Hydrograph for Kano Sub-basin

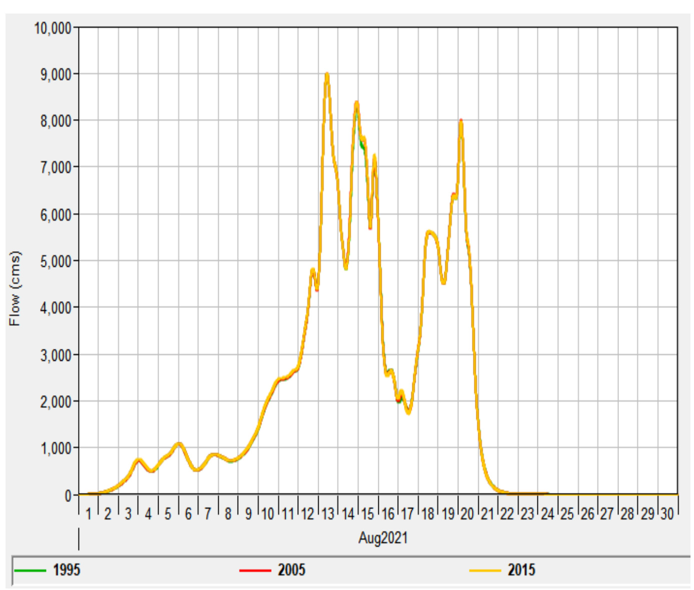

Figure 12: Hydrograph for HRS Catchment Outlet

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TABLE 3: TOTAL WATERSHED FLOW COMPUTATIONS

Drainage Area	Peak Flow (m3/s)		Flow Volume (Mm3)		Peak Difference (%)	
(sq. km)	1995	2015	1995	2015	1995	2015
49,886.40	8,977.6	9,298.00	4,793.27	5,185.72	1.23	3.57

For lumped flow routing technique using the Muskingum method, calibration of two parameters, X and K, was required in this model. X is a dimensionless weight that is a constant coefficient ranging from 0 to 0.5, where X is a factor representing the relative influence of flow on storage levels. It can be assumed that the value equals 0.1 as an initial value of the calibration parameters, which was corrected during the calibration process. K is the parameter having a unit of time and value ranging from 1 to 5 h. It is related to the delay between discharge peaks. The rainfall runoff processes of the dendritic catchment systems were simulated using the HEC-HMS software's hydrological modeling system. After considering the pre-processing in the HEC-Geo HMS, the model was imported as a basin file into the HEC-HMS software and is presented in Figure 13. The percentage flow volume was then determined for 1995 and 2015 (figure 14), and the percentage peak flow for 1995 and 2015 (figure 15).

The results indicate a remarkable decrease in grassland and increase in farmland. At the same time, Table 3 shows the peak flow and peak volume within the watershed and this indicated increase in the volume of runoff. The study is in line with the study of [18], which states that land use changes may likely influence the availability of water resources and hydrological cycle by changes of infiltration rate.

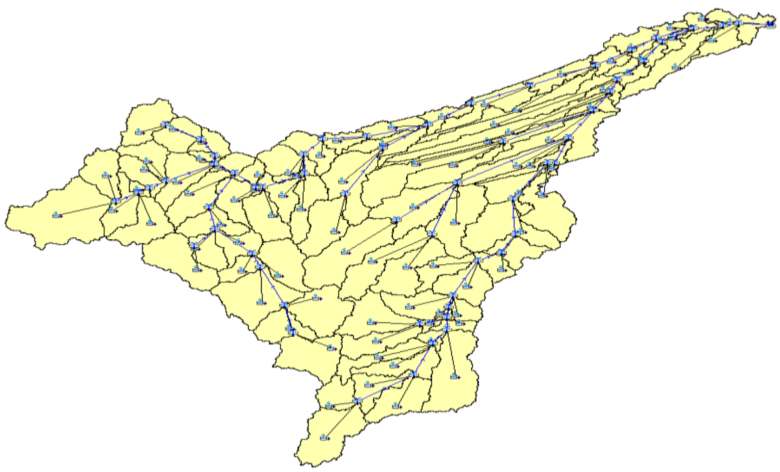

Fig. 13: Hydrologic modeling of the HRS using HEC-HMS

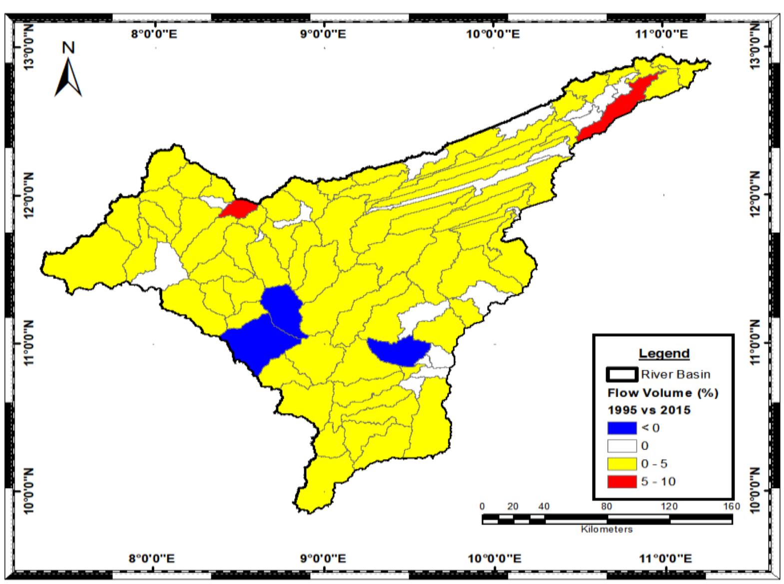

Fig. 14: Map of HRS showing flow volume (%) between 1995 and 2015

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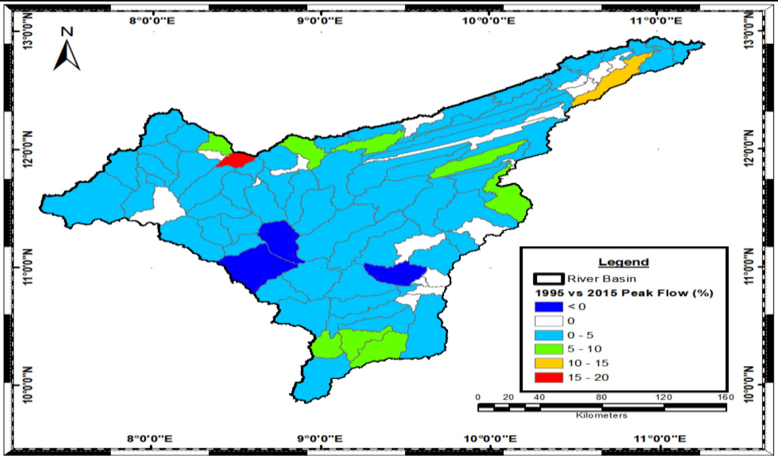

Fig. 15: Map of HRS showing peak flow (%) between 1995 and 2015

Figure 16 shows the annual rainfall over the study area from 1995-2015 with a significant positive trend in the rainfall values over the years and this imply an increase or positive change in rainfall amounts.

The dataset spans the years 1995 to 2015, with yearly rainfall observations recorded in millimeters. Rainfall varies significantly from year to year, ranging from 475.14mm in 1995 to 649.27mm in 2015. Annual rainfall varies with time, although there is no discernible linear trend in the data; rather, there are changes from year to year. Some years have more rainfall (e.g., 2015, 649.27mm), while others have less (e.g., 1995, 475.14mm). In comparison to previous years of the same duration, 2015 looks to have had quite heavy rainfall. The dataset shows no evidence of severe low rainfall episodes. Annual rainfall variability has consequence for the region's agriculture, water resource management, and infrastructure design. Years with lower rainfall may be associated with drought conditions, while years with higher rainfall may increase the risk of flooding.

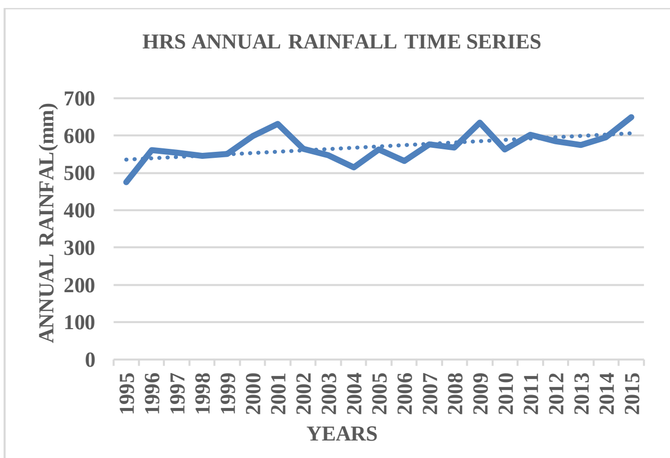

Fig 16: Time Series Graph of Rainfall

B. Discussion

Findings show that the watershed has undergone tremendous LULC changes in the 20-year period. Farmland increased by 2.16% while grassland decreased by 2.57%. This indicates an increase in farming activities around the basin. Also, built-up area increased with 187.84 sq.km, mainly due to the population growth around the basin. This is in line with a similar research carried out by [4], which revealed decrease in grassland and water bodies with an increase in built-up and agricultural land use in northwestern Nigeria basins. There has been an increase in demand for new cultivation land and settlement which in turn resulted in shrinking of other types of land use and land cover of the area. This change in grassland to farmland affects the volume and percentage of surface runoff generated. Similarly, grassland alteration to urbanization can increase the volume and the percentage of runoff, often significantly. When natural surfaces are replaced by more impermeable man-made surfaces such as buildings, paved roads and concrete which have very low infiltration capacities, the hydrological consequence is enormous and often resulting to increase in peak discharges and total volume of runoff. The area of the basin occupied by built-up has witnessed tremendous increase, and the areas largely impacted by these changes are within Kano and Jigawa states. These are relatively peaceful and predominantly agricultural regions; hence people from neighboring states, particularly Yobe and Borno states that are experiencing conflicts, flee to nearby Kano and Jigawa states for safety and livelihoods.

The model successfully attempted to estimate the effects of land cover changes on the surface runoff and volumes of the HRS.

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The result revealed that the detected land cover changes have increased peak discharges and runoff volumes within the sub-catchments. This effect is more severe within the areas where higher rates of urbanization and agricultural expansions were rampant. The results showed that the peak flow and peak volume for 2015 was more than that in 1995; moreover, they indicated an increase of 3.57% and 8.18% respectively. The results of simulations revealed that urbanization and agricultural activities are the strongest contributors to changes in surface runoff. Figure 16 shows that the highest flow volume percentage (5 -10%) is in Kano and Jigawa states while figure 17 shows the highest peak (15-20%) is in Kano followed by 10-15% in Jigawa state. The percentage domination of a specific land use in a certain region is partly determined by the percentage of runoff generation and flows. Thus, the change of grassland use to agricultural and urbanization land use does affect the volume and percentage of runoff generation. Previous studies [22], [12] have reported flood incidences to this effect, and more flood challenges, particularly the recurrent and flash floods, should be anticipated with their related consequences, provided the land use change pattern carries on in the same manner into the future.

At the basin outlet change in runoff is not significant because not many indices have changed as a whole, but at sub-basin level, Jigawa and Kano are the major sub-basins that have significant changes due to urbanization and farming. Also, the effect of increase in urbanization cannot be seen in the basin as a whole because the proportion in area of built up (275.62sqkm) is small compared to that of farmland (42,394.97sq.km). The results show that the change in land use (increase in farmland and urbanization) will affect surface runoff peak and volume. This effect is much significant on the sub-basin level than in the basin as a whole. Grassland have high porosity and delay the release of water to the catchment outlet. Grassland removal implies less infiltration due to a decrease in soil permeability, less interception of rainfall by the tree canopies and thus more runoff and high flow peaks. Urbanization can also be considered as a potential main environmental stressor that affects the surface runoff within the basin. The increase in urban area would result in decreased infiltration caused by surface sealing. Increases in impervious surfaces result in increased storm-runoff volumes and flood peaks and decreased groundwater recharge.

V. Conclusion

In this study, satellite data and GIS were integrated with a hydrological model to evaluate the impacts of land use and land cover changes on the surface runoff of the HRS. These techniques were applied to assess the land cover dynamics and their effects on the hydrology of the watershed using HEC-HMS. Land use and land cover change during a 20 period (1995 – 2015) were analyzed, then HEC-HMS model were tested for its performance at the HRS in order to examine the hydrological response of the watershed to changes in land use and land cover.

The study concludes that the rapid decrease of grassland and the expansion of urbanization and agricultural land use is a signal for high environmental flow in one end and increased water demand in the other end, thus, the increased surface runoff anticipated will almost certainly cause flooding.

Also, from the HMS simulation, it can be concluded that LULC changes were more pronounced in Kano and Jigawa states due to the increase of urbanization and farming activities in those areas, which lead to reduction of infiltration and hence, increase in surface runoff. Land use changes due to urbanization and agricultural expansion remain one of the notable threats to the hydrology of most regions in Nigeria. The findings from this study can be used to support policy and strategies geared towards watershed management. Future studies should aim to investigate land cover/use scenarios best suited for minimizing the volume of flows in the basin for catchment management purposes.

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