Comparative Assessment of SRTM and UAV-Derived Dem in Flood Modelling

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Flooding is one of the most devastating natural disasters occurring annually in many parts of the world. This study investigates the performance of DEM with different spatial resolution in flood modelling along the floodplain of Shiroro dam, Nigeria. Three different DEMs of 30 m, 15 m and 3 m spatial resolution covering the study area were investigated. The performance of the DEMs for flood modelling was evaluated with the aid of flood inundation modelling (3D analyst) tools in the ArcScene environment of ArcGIS 10.4 using results obtained from the shallow water St. Venant's equation. The shallow water St. Venant's equation was implemented in MATLAB software using the given river bathymetric information obtained from the dam authorities. The study determined the discharge quantity and flow velocity at some identified nodes along the river and its tributaries, thus, providing a basis for determining possible flood levels within the study area. Three flood levels were identified for each of the three used DEMs. For the original and re-sampled SRTM DEMs, the identified flood levels were 200 m, 250 m and 280 m, while for the UAV-derived DEM, 150 m, 205 m and 250 m were identified as the flood levels. Flood events covering the three identified flood levels were then simulated in ArcScene in order to estimate inundating settlements within the study area. The original 30 m and 15 m resampled resolution SRTM DEM had maximum and minimum height values of 612 m, 125 m and 585 m, 136 m respectively. In contrast, the UAV-derived DEM shows different characteristics, with maximum and minimum values of 497.22 m and 113.53 m, respectively. Further analysis showed that while the UAV derived DEM reliably predicted the flood risk situation due to its high resolution, the other two DEMs over predicted the flood risk situation of the area.

Keywords: DEM resolution, Floodplain modelling, Shiroro dam, UAV and Vulnerability

INTRODUCTION

Societal needs for reliable information on flood characteristics are increasing as the occurrence of flood events has become a common experience in many parts of the world due to global warming and increase in rainfall, coupled with anthropogenic activities which include construction of houses along the floodplains (Usman and Ifabiyi, 2012; Pena and Nardi, 2018). Depending on the magnitude of the flood, the occurrence often results in loss of lives and property with huge economic implications. More than two billion peoples who lived in floodplains worldwide between 1998 and 2017 were affected by flood disaster (WHO, 2020). It was also estimated that Nigeria suffered combined losses of more than $16.9 billion in damaged properties, oil production, agricultural and other losses due to flood events in 2012 alone (Komolafe, 2015; Egbenta et al., 2015).

Environment Agency (EA) opined that there are 2.7 million properties at risk of fluvial and coastal flooding, three million properties at risk of pluvial flooding and 660,000 at risk from both (Environment Agency, 2018). Furthermore, with an amorphous population growth, construction and development of dwellings on floodplains (Pottier et al., 2005) and more extreme and intense rainfall events due to phenomenon such as

global warming (Ward et al., 2014; Corringham and Cayan, 2019), the frequency, magnitude and impacts of flood events are only going to increase, which makes accurate modelling, prediction and forecasting of future flooding occurrences highly important as it will ensure better management of flood risks.

The rapid advancement in remote sensing data collection and monitoring over the last decade has facilitated more widespread flood modelling activities (Keshtkar et al., 2017). The wide availability of Digital Elevation Models (DEM) together with supercomputers to handle the required simulation power has made 2D flood modelling the preferred option for predicting flood properties including extent, depth and velocity, especially in urban areas where surface dynamics are very high. The equations governing the hydrodynamic behaviour of an incompressible fluid are based on the classical concepts of conservation of mass and momentum. For many practical surface-water flow applications, knowledge of the full three-dimensional flow structure is not required, and it is sufficient to use mean- flow quantities in two perpendicular horizontal directions (Laxmi and Narendra, 2016). 2D flood models have the capability to model the flow in both directions i.e. along the river and perpendicular to the river (Tarekegn et al., 2010). The 2D flood model main

inputs are river and floodplain geometric data, hydraulic parameters and boundary conditions. With the extensive use of 2D flood models, the resolution and quality of DEMs have come under greater focus especially in urban hydrology (Ozdemir *et al.,* 2013; Saksena and Merwade, 2015; Pena and Nardi, 2018; Ogania *et al.,* 2019).

Nevertheless, researchers have continued to study the effect of DEM resolution on the estimation of flood properties (Balica *et al.,* 2012; Aerts *et al.,* 2014; Barraga´n *et al.,* 2015; Zazo *et al.,* 2015; Jafarzadegan and Merwade, 2017; Hawker *et al.,* 2018; Bhuyian and Kalyanapu, 2018; Nkwunonwo *et al.,* 2019; Lim and Brandt, 2019; Karamuz *et al.,* 2020; Kepeng *et al.,* 2021; Talchabhadel *et al.,* 2021). While some of these efforts opined that higher resolution DEMs produce more accurate flood modelling, Azizian and Brocca, (2020) affirmed that it is not necessarily the highest resolution DEM, but the optimal resolution DEM, that produces most reliable flood modelling result.

Saksena and Merwade (2015) analysed a range of DEM resolutions from 6 m to 30 m in flood modelling and sought to relate the differences arising from the use of the various DEM resolutions with the resultant flood inundation maps and then use this information to create improved flood inundation maps from low-resolution DEMs. It was observed that increasing the grid size of the DEM increased the flood areas and flood depths. However, regardless of flood type, low-resolution DEMs will always result in an overprediction of flood extent and depth. In contrast, other studies have shown the opposite trend for surface water flooding (Mukherjee *et al.,* 2013; Hawker *et al.,* 2018; Ogania *et al.,* 2019; Mohamed and Ali*,* 2019; Talchabhadel *et al.,* 2021; Kepeng *et al.,* 2021).

To this end, the aim of this study is to investigate how DEM resolution affects flood modelling results along the floodplains of Shiroro dam, Nigeria. Three DEMs of different resolution, covering the study area were investigated. These DEMs are: (i) 1 arcsec Shuttle Radar Topographic Mission (SRTM) DEM (i.e. 30 m spatial resolution), (ii) resampled SRTM DEM re-sampled of 15 m spatial resolution and (iii) 3 m resolution DEM generated from a UAV mission. The performance of the 3 DEMs for flood modelling was evaluated with the aid of flood inundation modelling tools in the Arc Scene environment of ArcGIS 10.4 using shallow water St. Venant's equation.

MATERIAL AND METHODS
Study Site
The study area is Shiroro dam floodplain, located in Shiroro Local Government Area of Niger State, Nigeria. It is situated between Longitude 6º 27' 00''E to 7º 05' 30''E and Latitude 09º 44' 00''N to 10º 11' 30''N. It is 550.364 meters downstream of the confluence of River Kaduna and River Dinya at Shiroro village. There are tributaries of the River Kaduna within the Shiroro watershed, chief among them being rivers Dinya, Sarkin Pawa, Guni, Erena and Muyi. The tributaries flow majorly in the north-south direction while the remaining tributaries flow in the northwest to southeast direction. The area is generally low lying with some conspicuous hills and it is well drained by River Shiroro and its tributaries (Adie *et al*., 2012). The land use activities within the area include residential and agricultural. The dam is used basically for hydroelectric power generation. Due to high elevation difference, the risk of damage caused by flood is very high in this area. The general climate of the study area is the Tropical Monsoon type characterized by alternate wet and dry season, with rainfall occurring in the rainy seasons of May to October. Temperatures are relatively high throughout the year hovering between 27^0C and 35^0C (Suleiman, 2014). Rain starts in April and the length of raining season is between 161-200 days (Anzaku *et al.,* 2019).

Flood occurrence within the study area has become an annual occurrence which peaks at raining season. Specifically, in recent years, different flood scenarios of varying magnitude of consequential effect have been experienced in 1990,1992, 1994, 1996, 1998, 1999 to 2000, 2003, 2006, 2010, 2012, 2015, 2018, 2019 and 2020 (NEMA, 2020). The major causative factor of this flood is the opening of the dam's spillways (Usman and Ifabiyi, 2012; Abayomi *et al.,* 2015) to the downstream of the study area in a bid to reduce the water volume when it exceeds the dam's capacity to avoid dam collapse or failure. Figure 1 shows the map of the study area while Figure 2 depicts Shiroro dam and the downstream flow of water.
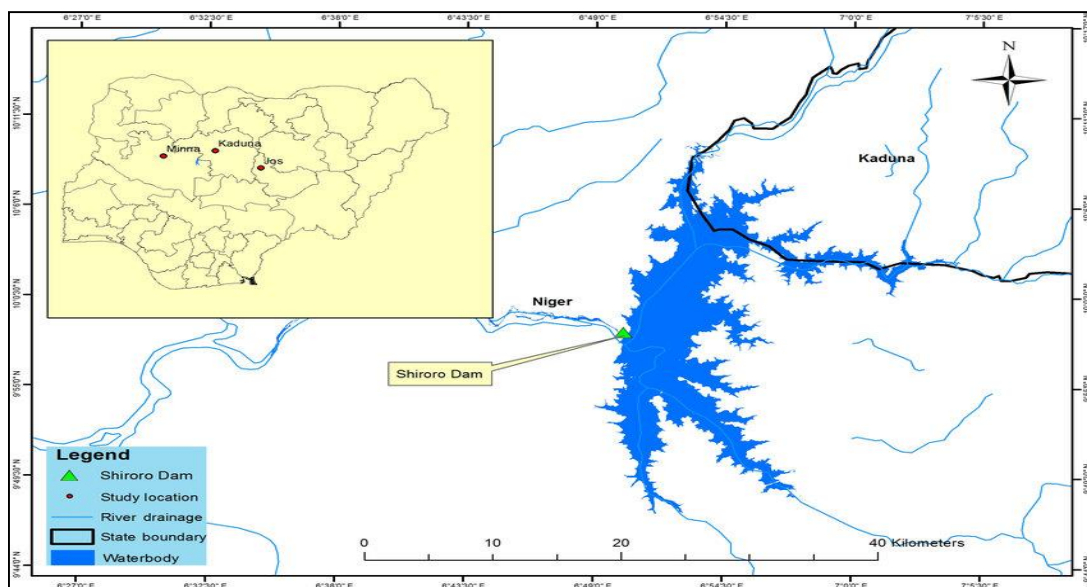
Figure 1: Map of the study area
Source: Ministry of land and survey, Minna, Niger State

Figure 2: Shiroro dam and the downstream flow of water (Source: Google Earth Map)

Data Acquisition
The data type, source and characteristics of data used for this study are presented in Table 1.

Table 1: Details of the data used for the study

S/N	Data	Source	Spatial resolution	Date of data acquisition	Accuracy
i	SRTM 30 m DEM	(USGS, http://earthexplorer.usgs.gov)	30 m	2000	3-4 m
ii	SRTM 15m DEM	Resampled from SRTM of 30 m DEM	15 m	2000	5 m
iii	UAV - derived DEM	Field mission	3 m	2019	1.5 m
iv	River channel Bathymetry	Dam authority	-	2020	-
v	Water discharge	Dam authority	-	2020	-
vi	Water level	Dam authority	-	2020	-

A Trimble UX5 aerial imaging solution was deployed for the acquisition of the UAV images of the study area. The acquired images were processed using Trimble Business Center Photogrammetry Module (Version 3.30). The data was post-processed in UTM 32N projected coordinate system referenced to the WGS84 global ellipsoid. 52 GCPs were established across the study area and only 20GCPs were used for the adjustment of tie points (aero-triangulation) succeeded by the production of Digital Elevation Model. Details of the flight parameters for the UAV mission are as provided in Table 2. The processing software (Trimble Business Center Photogrammetry Module (Version 3.30)) was also used to extract the height of the buildings from the digital surface model in order to achieve the digital elevation model for the study area which is the major concern of this research.

Table 2: Flight planning parameters for the UAV mission

S/N	Parameter	Value
i	Flying height	200 m
ii	Flight speed	8-15 m/s
iii	Forward lap	65%
iv	Side lap	70%
v	focal length	24mm
vi	Flight time is approximately	15minutes
vii	Battery capacity	25-30minutes
viii	Flight time	15minutes
ix	Number of GCPs	52points
x	Number of GCPs used for georeferenced	32points
xi	Number of GCPs used for the adjustment of Tie points	20points

The DEMs

The statistics of the three different DEMs of different spatial resolutions used in this study are presented in Table 3 while Figures 3(a - c) show the 30 m SRTM DEM, the 15 m re-sampled SRTM DEM and the 3 m UAV-derived DEM.

Table 3: Statistics of the 3 DEM's

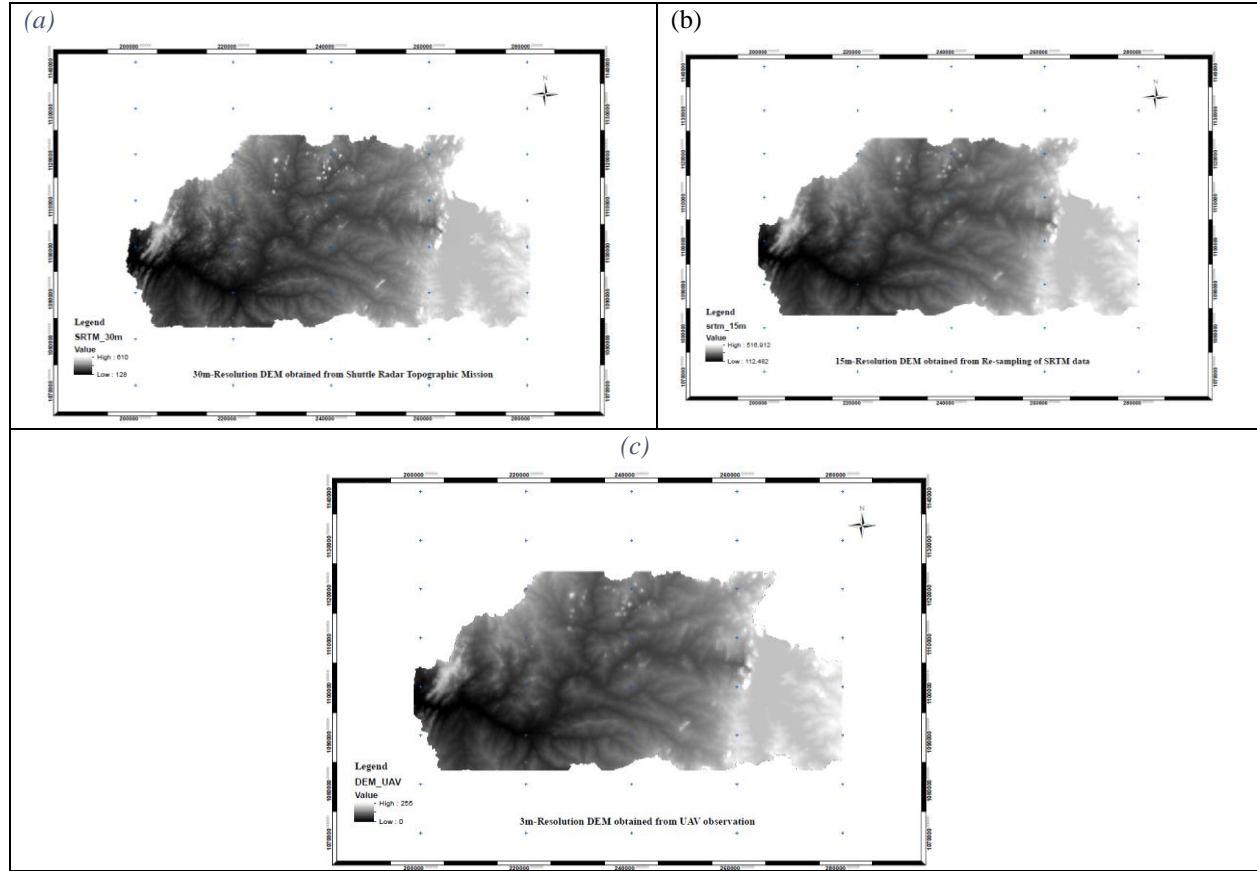| Parameter	SRTM 30m resolution	15m re-sampled SRTM DEM	3m UAV-derived DEM
Min height	125	136	113.53
Max height	612	585	497.22
Range	487	449	389.69
Standard Deviation	68.38	67.58	63.16

Figure 3: (a) 30 m DEM (b) 15 m-Resampled DEM (c) 3 m UAV-derived DEM

Flood Simulation Approach
The 2D flood inundation modelling was carried out using ArcGIS 10.4. ArcScene in ArcGIS 10.4 is capable of simulating surface flooding caused by rainfall as well as river flooding. Prior to flood simulation in ArcScene, the river discharge and flow velocity were computed in MATLAB software using the conventional shallow water St. Venant's equation as given by (Brunner *et. al.,* 2020) (see Equations 1):

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = -gAS_f + gAS_o - gA\frac{\partial h_o}{\partial x}$$

$$(1)$$

where,

Q = discharge

A = cross-sectional area

$\frac{\partial Q}{\partial t}$ = rate of discharge with respect to time

$\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right)$ = rate of discharge with respect to cross-sectional area

g = acceleration due to gravity

S_f = frictional slope

S_o = reference slope

$\frac{\partial h_o}{\partial x}$ = channel bed-topography; where Q can be computed as:

$$Q = \frac{A}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}}$$

$$(2)$$

where,

R = hydraulic radius

n = Manning coefficient of roughness

A = cross-sectional area

S = channel slope in the direction of flow

$\frac{\partial h_o}{\partial x}$ is obtained from the Digital Elevation Model (DEM),

A is measured on ground and

S_f and S_o deduced from $\frac{\partial h_o}{\partial x}$

Q is computed using equation (2)

Thus, by simultaneous substituting the computed value of Q and A from equation (2) into equation (1) allow us to calculate the actual flow rate $\frac{\partial Q}{\partial t}$ in Equation (1).

RESULTS AND DISCUSSION
Figures 3a to 3c presents the DEMs used for this research. The closeness in value of standard deviation between SRTM of 30m resolution and 15m re-sampled SRTM DEM further show that both the datasets are of the same source and have similar level of accuracy and spatial attributes.

Derived Flood-levels
The three DEMs were tested to determine flood levels capable of inundating the studied floodplains. Figure 4 shows the delineated catchment area and drainage basin from all the three (30 m, 15 m, and 3 m) resolution DEMs. The size of the drainage basin is about 2000sq.km and the catchment area is about 466.995sq.km, a total of about 12 water channels were identified to be contributing significantly to the flow of water within catchment area (Figure 4), signifying that the stream flows frequently downstream with a gentle slope or gradient.
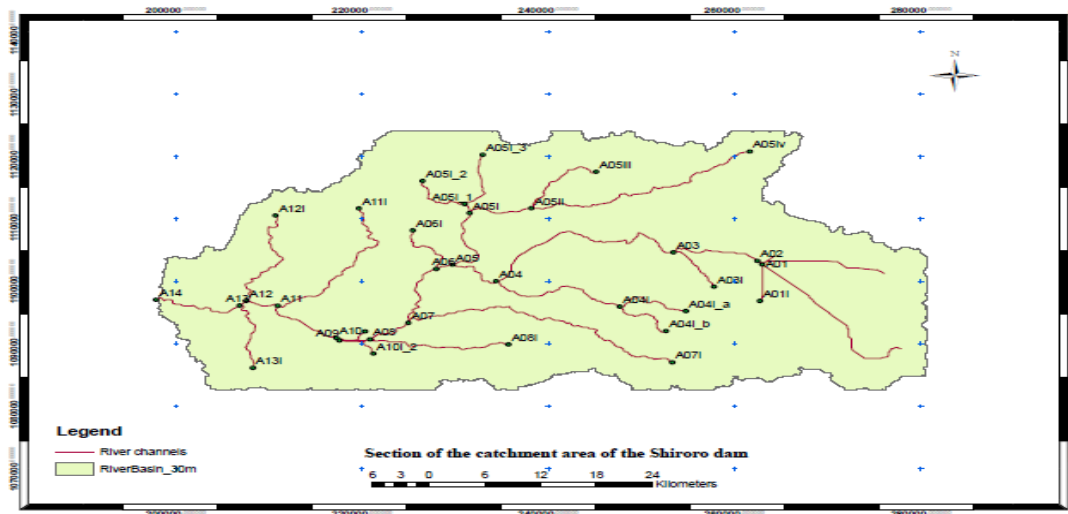

Figure 4: Delineated catchment area from the 30 m, 15 m and 3 m resolution DEMs

To compute the flood levels, equations 1 to 2 were implemented in the MATLAB software using the given river bathymetry and the three different DEMs. Using the starting and ending nodes as major identification points along the 12 identified water channels (catchment areas) for the stream, the river discharge of each of the identified nodes provided a basis for the determination of levels that can be obtained from the stream given an initial discharge of $114.38 m/s^3$. The used initial discharge value corresponds to the dam discharge when the spillway is opened (Dam Authorities, 2020). Table 4 shows the computed discharge and flow velocity at each of the nodes.

Table 4: Discharge rate at selected nodes within the Shiroro dam basin using 30 m, 15 m and 3 m DEMs

		30 m DEM			15 m DEM			3 m DEM		
Sta_ID	Settlements Name	Elevation (m)	Discharge (m/s^3)	Velocity (m/s^2)	Elevation (m)	Discharge (m/s^3)	Velocity (m/s^2)	Elevation (m)	Discharge (m/s^3)	Velocity (m/s^2)
A01	Gidan Patuko	373.07	114.38	1.27	373.08	114.38	1.27	345.61	114.38	1.27
A02	Gidan Patuko	280.09	1154.42	9.07	280.21	1153.72	9.06	304.23	770.10	6.05
A03	Awolu Saga	256.09	219.00	1.53	256.95	215.59	1.51	228.89	387.96	2.72
A04	Sumaila	223.20	152.48	1.12	223.20	154.47	1.13	194.86	155.12	1.13
A05	Bere	211.10	293.92	1.35	211.07	294.28	1.35	183.78	281.24	1.29
A06	Tungan Gamba	209.33	146.16	0.94	209.32	144.95	0.93	184.77	108.94	0.70
A07	Layi	197.05	227.45	1.06	196.13	235.77	1.09	168.08	265.17	1.23
A08	Nil	174.97	314.13	1.99	174.98	307.48	1.95	147.31	304.65	1.93
A09	Nil	174.39	69.90	0.43	174.40	69.91	0.43	144.60	151.13	0.94
A10	Nil	174.30	74.73	0.43	174.31	75.07	0.44	146.24	321.15	1.87
A11	Nil	167.08	161.14	0.91	168.07	149.78	0.84	140.20	147.29	0.83
A12	Nil	159.30	264.57	1.46	159.31	280.81	1.55	132.73	259.44	1.43
A13	Lawo Ravo	159.12	73.96	0.43	159.12	74.41	0.44	137.57	380.77	2.24
A14	Nil	128.00	343.64	1.72	127.85	344.49	1.72	106.45	343.65	1.72

The three major discharge values obtained at certain nodes in Table 4 for the 3 used DEMs shows the heights where the inundation will occur in the study area and its environs. The results presented in Figures 5a - 5c shows that when the 30 m and 15 m DEMs were used for the flood modelling, estimated flood heights of 200 m, 250 m and 280 m were capable of flooding the entire floodplain of Shiroro and its environs. In the case of the 3 m UAV derived DEM, significant flood heights of 150 m, 205 m and 250 m, respectively, were estimated and found to be capable of flooding the entire floodplain of Shiroro Dam and its environs.

Similarly, Tables 5 and 6a-b show the number and names of the settlements that would be affected by the various flood levels considering the various DEMs used for the study. The various flood levels were thereafter simulated in the ArcScene environment to create a flood vulnerability graphical model for the study area based on the various identified flood levels (Figures 6a - c).
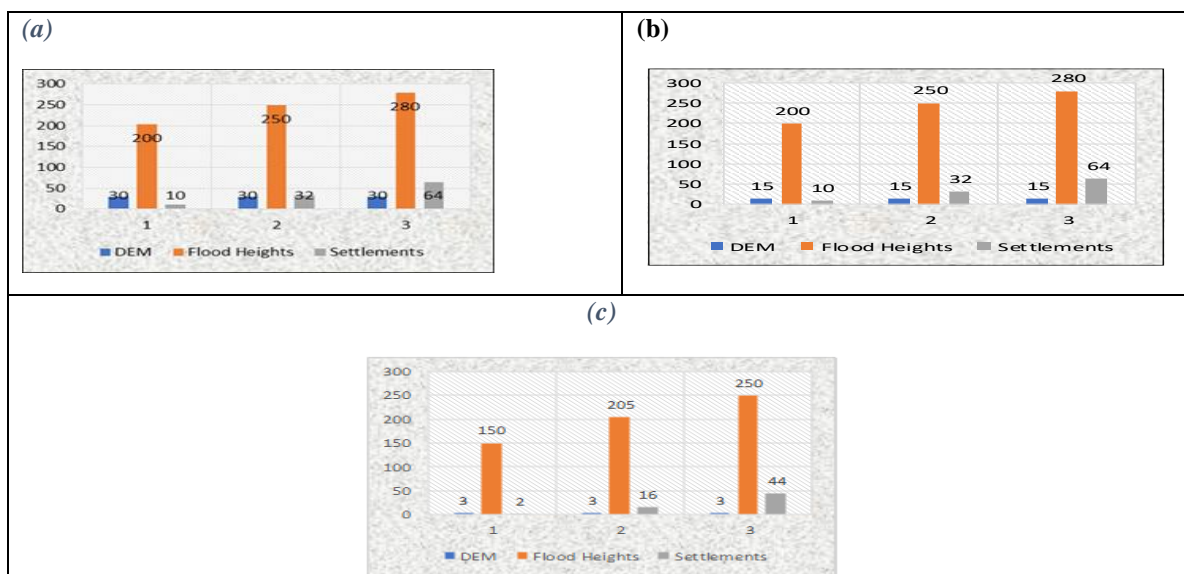
Figure 5: (a) Flood-heights of 30 m SRTM DEM based on 200m, 250m and 280m (b) Flood-heights of 15 m Resampled SRTM DEM based on 200m, 250m and 280m (c) Flood height of UAV 3 m DEM based 150 m, 205 m and 250 m
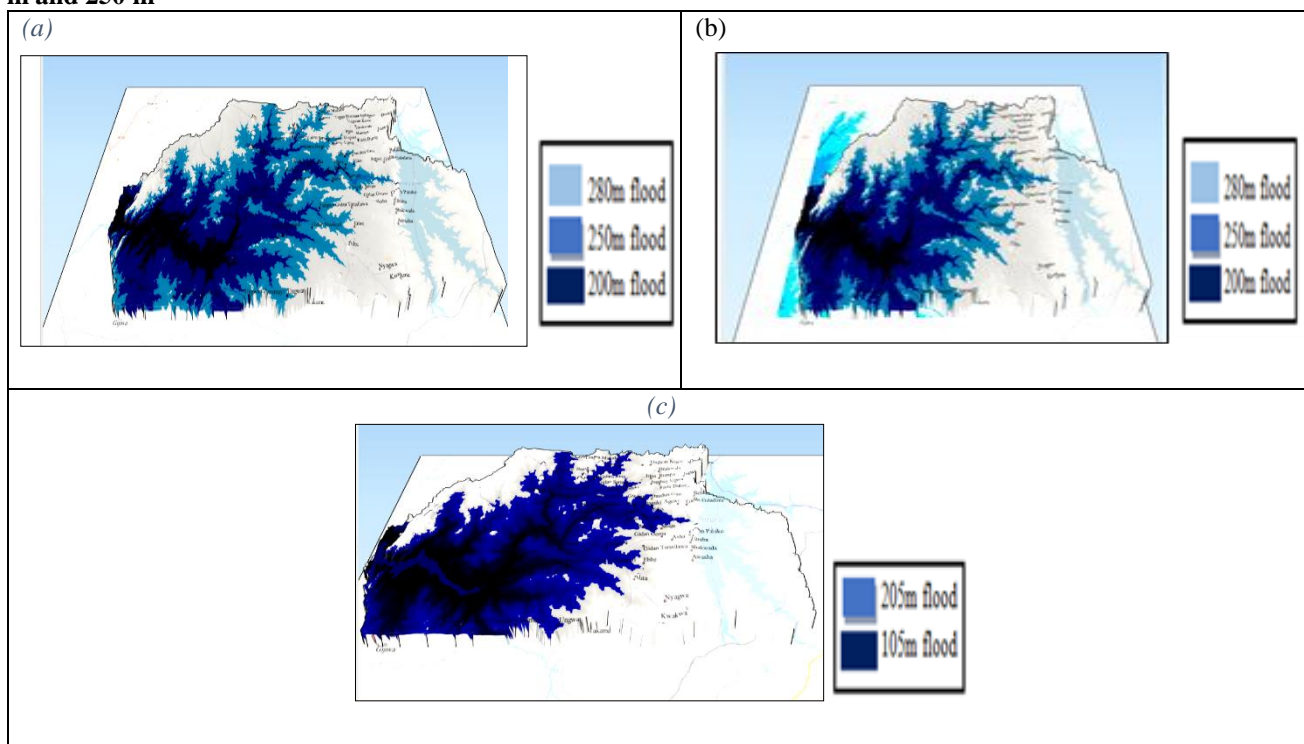

Figure 6: (a) Vulnerability graphical model for the study area based on 30 m DEM; 200 m, 250 m and 280 m flood extents (b) Vulnerability graphical model for the study area based on 15 m DEM; 200 m, 250 m and 280 m flood extents (c) Vulnerability graphical model for the study area based on 3 m DEM; 150 m, 205 m and 250 m flood extents

Table 5: Number of settlements that are vulnerable based on flood levels for the three DEMs

30 m DEM flood levels			15 m DEM flood levels			3 m DEM flood levels		
Flood Extents			Flood Extents			Flood Extents		
204 m	250 m	280 m	204 m	250 m	280 m	150 m	205 m	250 m
Vulnerable Settlements			Vulnerable Settlements			Vulnerable Settlements		
10	32	64	8	28	60	2	16	44

Table 6a: Name of settlements vulnerable to inundation at 200 m, 250 m and 280 m flood heights deduced from 30 m and 15 m DEMs

Flood Height (200 m) Settlements Name	Flood Height (250 m) Settlements Name					Flood Height (280 m) Settlements Name			
Lawo	Lawo	Gidan Gwari	Gidan	Luwa	Dami Gidan	Gidan Gwari	Samboro	Kafa Gidan	Gwadaro
Manta	Luwa	Maguga	Sumila	Sabon Gida	Sarumai Gidan	GidanUsisi	Manta	Madatsi Gidan	Kawo Tungan
Maikakaki	Sabon	Maowo	Bere Tungan	Gijiwa	Madaki Gidan	Masuku Gidan	Kami	Basakuri	Makuha
Jiko	Gijiwa	Zungoro	Gamba	Rawo	Peleta Gidan	Maikomo	Seikna	Padgaya	Guadaguri
Kami	Kunu	Rawo	Gini Kurmin	Kunu	Saraki Kaura	Madaka	Asape Hill	Sumaila	Gwaria
Seikna	Kwochi	Manta	Gurmana Gidan	Kwochi	Pawa	Kakuri	Guwa	Awolu	Masuku
Asape	Kami	Jiko	Madatsi	Kami	Kwatayi Gidan	Tungan Dada	Berikago Tungan	Baha	GidanWani
Berikago	Layi	Maikakaki Tunga	Mangwa Kauran	Seikna	Bako	Gbaro Allah	Gamba	Gini	Zungoro
Zungeru Rafi	Seikna	Dada	Pawa	Layi Jiko	Shamiki Gwope	KurminGurmana Yako	Bere Gijiwa	Gusuru Yelwa	
	Guwa	Samboro		Manta	Magwa	Maowo	GidanMagwi	Maguga	
	Berikago Guwa	Berikaga							

**Table 6b: Name of settlements vulnerable to inundation at 150 m, 205 m and 250 m flood heights deduced from
3 m DEM**

Flood Height (150 m)	Flood Height (205) m		Flood Height (250 m)	
Settlements Name	Settlements Name		Settlements Name	
Jiko	Bere	Kawo	Kauran Pawa	Seikna
Maikakaki	Gidan Madaki	Tunga Makubo	Gijiwa	Kami
	Sumaila	Gwadara Irina	Maowo	Guwa
	Maowo	Gidan Sarumai	Zungoro	Berikago
	Tungan Gamba	GidanMadaki	Masuku	Ungwan Zarumayi
	Guwa	Dami	Maguga	Kwochi
	Berikago	Gwope	Bero	Kunu
	Layi	Shamiki	Tunga Gamba	Sabon
	Seikna	Yako	Guwa	Luwa
	Kami	Gusuru	Berikago	Gijiwi
	Gidan Madatsi	Awolu	Kafa	Sabon
	Kunu	Baha	Padgaya	Lawo
	Luwa	Gini	Gidan Basakri	
	Sabon	Yelwa	Gidan Madatsi	
	Rawo	Kuemin Gurmana	Sumaila	
	Gijiwa	Kwatayi	Layi	

The identified three flood-risk levels conformed to earlier studies conducted to determine flood risk communities affected by violent water within Niger State, Nigeria (NSEMA, 2021). Although, earlier works by NSEMA (2021) has also identified three flood-risk zones (low, medium and high), it did not identify the flood heights where the risks are high as this study has done. Also, comparing the results obtained in this study with the earlier study of NSEMA (2021), it can be observed that only the 3 m DEM conformed with the existing ground condition (NSEMA, 2021) while the two other DEMs (i.e. the 30m and 15 m SRTM DEMs) over-predicted the flood risk situation.

CONCLUSION
The performance of 3 DEMs for flood modelling was evaluated in this study with the aid of flood inundation modelling tools in the Arc Scene environment of ArcGIS using the Navier Stokes St. Venant equation. The findings from the study confirmed that accurate terrain data has a great impact on modelling flood hazard. Specifically, the results of flood simulations varied in response to different DEM resolutions, which could be associated with the degree of topography representation of these DEMs. It was also discovered that high-resolution DEM can provide relevant and reliable flood modelling results while in contrast, low resolution DEMs deteriorates the performance of flood models. The UAV-derived flood hazard maps provide more defined flood extent and clearly show the distribution of hazard levels. Hence, a high-resolution DEM is necessary if the decision-maker is interested in local-scale inundation predictions. Further, the use of accurate DEM for flood simulation can provide an initial assessment of the possible population and areas that could be affected by low, medium and high flood hazard. In this study, it was discovered that the realistic flood levels within the Shiroro floodplains were 150 m, 205 m and 250 m as against the 200 m, 250 m and 280 m flood levels obtained from the SRTM data. Such evaluation is useful for determination of possible evacuation centres and establishment of major infrastructure for the populace around the floodplain.

Based on the outcome of the study, it can be concluded that the choice of resampling a low accuracy DEM might not necessarily suffice in improving the modelling capacity of a DEM as it will not significantly improve the quality of the flood modelling. It is concluded that accurate simulation of topography has significant effect on flood simulation results. The study has scientifically justified the reason for the 2012 flood extent got to the affected communities along the Shiroro dam floodplain.

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