Morphometric Analysis of Dadin Kowa Dam Catchment, Gombe State, Nigeria

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Abstract

Dadin Kowa dam was constructed for multipurpose use. These three main uses are water supply for Gombe Metropolis, Irrigation agriculture and generation of hydroelectricity. Despite its importance, the Dadin Kowa dam's catchment has not been comprehensively studied as its morphometric characteristics is either lacking or inadequate and therefore, hindering effective planning and conservation efforts as well as effective development of water resource management strategies, potentially compromising the socio-economic and ecological integrity of the catchment. SRTM Digital Elevation Model data of the basin was obtained, while extraction of the basin was delineated using Geographic Information System technique. The morphometric analysis of the basin was categorized into 3 sections: linear, relief, and areal, while the generation of each of the parameters in each category were achieved through the use of ArcGIS software. The study revealed that the basin is an elongated basin with a perimeter of 2,305.92 km and total stream length of 758,647.9 km. Dadin Kowa basin was also found to be an 11th order stream based on the 30m resolution of the SRTM data. The bifurcation ratio of the basin being 6.2 means the basin has a very low risk of getting flooded unless created by other conditions. The Rho value was 0.082 which indicates that very little water is retained in the river channels. The drainage density of the basin was 23.6 km which means the catchment has high drainage density which means it has high runoff and low percolation. The high stream frequency of 190.4 is also indicative of low permeability. The basin with a form factor (Ff) of 0.36 indicates a moderately compact shape. The Dadin Kowa basin has an elongation ratio of 0.6 which was interpreted as having an average relief region. Among other recommendations were that morphometric analysis of river basins are better assessed through the use of geospatial techniques. Moreover, since the basin at its present state has a very low risk of getting flooded, sustainable utilization of the basin and its resources should be put in place in order to extenuate environmental hazards in the area.

Keywords: Dadin Kowa Dam catchment, Geospatial techniques, Gongola basin, morphometric parameters, morphometric analysis and watershed

Introduction

Dam is a geomorphic control system, a structure, or a barrier that regulates the flow of surface water and groundwater flow systems. It is a hydraulic structure of fairly impervious material built across a stream to create a reservoir on its upstream side (Prasiddha, 2015). Dams are regarded as artificial lakes. The primary use of dams is for water retention. It also regulates the stream flow or discharge coming from the entire catchment. The quality and quantity of the discharge into the dam affect the overall performance and lifespan of the dam. The reservoir is a stable body of water, as a result, it dissipates the incoming flow energy of the river thereby initiating stagnation and subsequent deposition of the sediments, solutes, and colloids being transported by the stream onto the floor of the reservoir. Sedimentation and accumulation of these substances in the reservoir can alter the geomorphic and hydrological characteristics of the reservoir (Ezekiel, 2017).

Gross alteration of the reservoir's characteristics by sedimentation processes can affect the efficacy of the dam, sometimes even transforming dams from being economic lifelines to a sitting time bomb. Thus, many countries of the world have sectors dedicated to the supervision and evaluation of the condition of dams. In India for example, the government has constituted lake and dam development authorities at state levels to handle issues of management, utilization, and sustainability of dams. In China, dam management is multi-tiered with smaller dams managed by the communes, the medium size dams managed by the states, and large dams managed by the regional government. In the US, dams are managed by experts constituted by the authority (Gopal *et al,* 2010). While in Nigeria, dams are managed by the Federal Government through the River Basin Development Authorities (RBDA) established by Act No. 35 of 1987.

Dadin Kowa Dam's catchment, spanning an extensive area of 32,261.27 sq.km, is a vital geographical and hydrological entity with significant implications for water resource management, environmental sustainability, and regional development. Despite the importance of Dadin Kowa dam's catchment in water resource management, a comprehensive understanding of its morphometric characteristics is either lacking or inadequate and therefore, hindering effective planning and conservation efforts (Dawha, 2023). Consequently, there exists a notable gap in the understanding of the morphometric characteristics that define the catchment. The lack or inadequate data of a comprehensive morphometric analysis of the dam's catchment hinders the formulation of effective water resource management strategies, potentially compromising the socio-economic and ecological integrity of the region.

The catchment's hydrological network consisting of rivers, streams, and tributaries facilitates the natural flow of surface water. The intricate network of watercourses influences drainage patterns and contributes to the overall hydrological balance of the region. The catchment functions as a watershed, collecting and channeling precipitation into the Dadin Kowa Dam. This hydrological function plays vital roles in regulating water availability and mitigating the impact of floods and droughts in the surrounding areas (Dawha, 2023). The availability of water resources from the Dadin Kowa Dam catchment is a cornerstone for agricultural productivity in Gombe State. Irrigation schemes supported by the dam contribute to enhanced agricultural practices, fostering food security and supporting the livelihoods of local communities (UBRBDA, 1986).

The morphometric parameters which include drainage density, stream order, and basin shape, play pivotal roles in shaping the hydrological dynamics of a catchment (Dawha, 2023). Yet, the lack of detailed knowledge regarding these parameters within the specific context of Dadin Kowa Dam catchment limits the ability to address key challenges such as flood control, drought mitigation, and sustainable land use planning (Dawha, 2023). Furthermore, without a robust understanding of the catchment's morphometric features, the potential impacts of climate change on water availability and ecosystem health remain inadequately assessed. Therefore, this study seeks to assess the morphometric characteristics of Dadin Kowa dam's catchment and investigate the hydrological dynamics influenced by the identified morphometric characteristics.

Description of Study Area

The Dadin Kowa basin is the area of the Gongola basin from the embankment that created the reservoir to the source of the river on the Jos Plateau. It is located between Latitude 8^{o} 30′N to 11^{o} 30′N and Longitude 8^{o} 50′E to 12^{o} 20′E draining portions of Borno, Yobe, Gombe, Bauchi and Plateau States into the Benue River (Fig.1). The Dadin Kowa dam catchment encompassing a vast area of 32,261.27 sq.km. Palio-geomorphic evidences show that the Gongola River on which the Dadin Kowa reservoir was constructed used to flow into the Lake Chad, until the Benue Trough captured it (Dawha, 2023). It was constructed at a narrow valley on the western pediment of the Bima sandstone hill. Incidentally, the elbow of capture forms the mouth of the reservoir (Fig.1). The elbow represents the zone where the rivers flowing into Lake Chad Basin was captured by the Benue Drainage System. This abruptly changed the previous direction of the flow from the northeast direction to southeast (Fig.1)

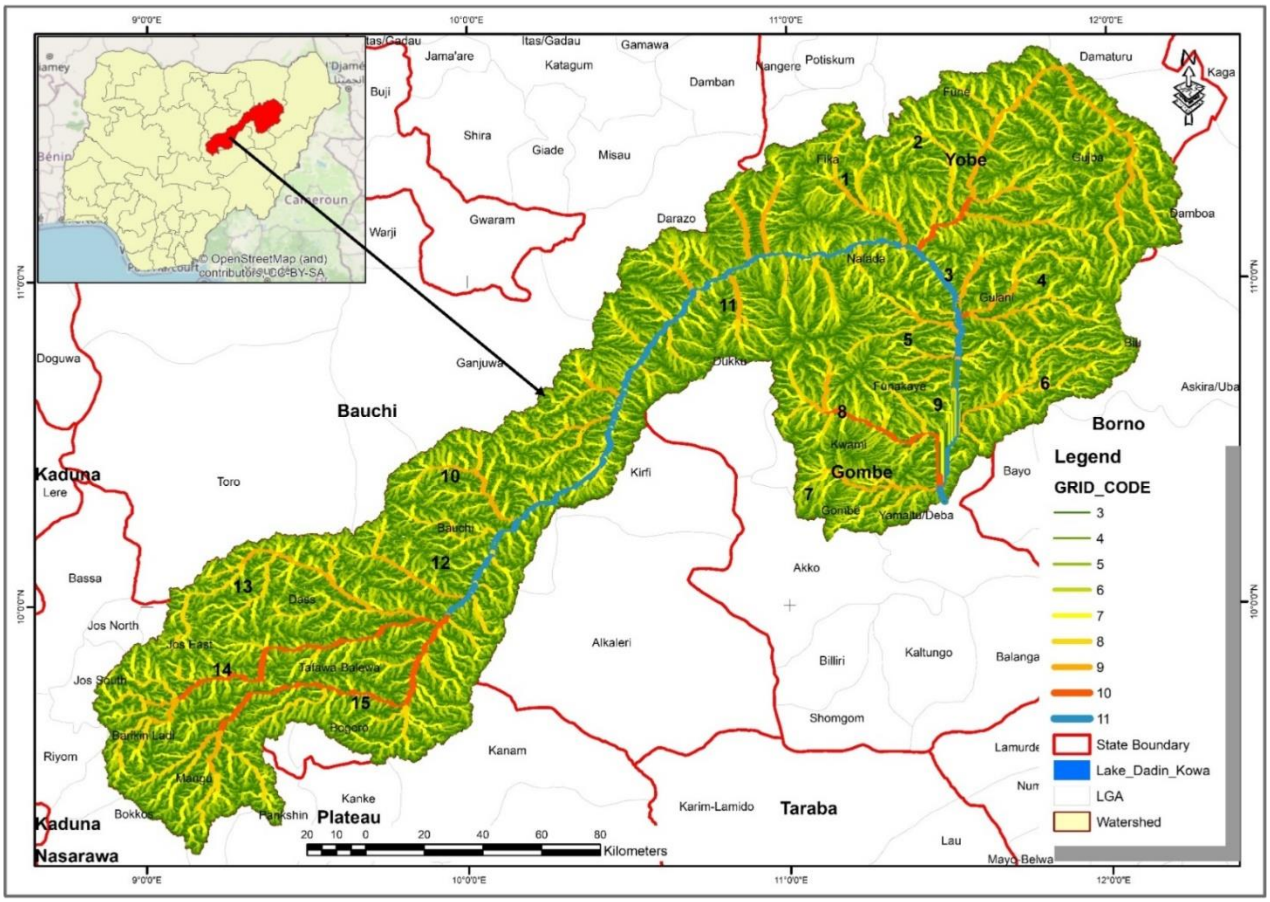

Fig. 1: Study Area (Dadin Kowa Dam Catchment)

River Gongola on which Dadin Kowa dam was constructed rises from the Jos Plateau and flows through Bauchi hills and plains, and part of Gombe State before reaching Dadin Kowa, a border town between Borno and Gombe States. The Dadin Kowa dam is the second-largest dam in Nigeria after the Kainji Dam. It holds a significant geographical and hydrological importance in the region. The catchment's expansive size encompasses diverse geographical features, including highlands, plains, and water bodies. The topographical diversity within the catchment contributes to its ecological richness and provides a habitat for a variety of flora and fauna. The catchment's landscape includes hills, valleys, and plains, creating a mosaic of ecosystems that influence local climate patterns and biodiversity (Dawha, 2023). The central geographical feature of the Dadin Kowa dam catchment is the Dadin Kowa dam itself, constructed for multipurpose use including water storage and management, it has a pivotal role in addressing the region's water needs. As a result, the catchment serves as a critical source of water supply for agricultural, industrial, and domestic purposes, significantly impacting the socio-economic development of the region (Dawha, 2023).

The Gongola Basin in which the Dadin Kowa dam reservoir is located stretches across complex geologic structure, comprising the crystalline Basement Complex rocks and sedimentary formations (Abashiya, 1999; Arabi *et al* (2009). The geologic formations of the study area have a strong influence on the topography. In the upper course of the basin, the Jos Plateau highland reflects high relief of hilly environment while the Bauchi upland plains is made up of basement complex residual hills and pediments (Carter *et al*, 1963). The basin possesses substantial ecological resources, including forests, grasslands, or other forms of natural vegetation (Dawha, 2023). The presence of such vegetation can contribute to various ecosystem services, such as carbon sequestration, biodiversity conservation, soil erosion prevention, and regulation of local climate.

Methodology

Data was collected using both primary and secondary methods of data collection. The primary sources generated the quantitative and qualitative data while the secondary data came from Topo maps (Bajoga SE, Gombe NE, Gulani SW and Wuyo SW) obtained from the Upper Benue River Basin Development Authority, (UBRBDA) Yola. Others include Digital Elevation Model (DEM) obtained online and processed using ArcGIS 10.7.1. The assessed and analyzed outcome was then displayed in both visual and numerical formats. Major elements of the basin analyzed in this study include:

B. Stream Number

This is computed using the equation

$\sum N_u$ ……………………………………………………………………………….equation 1

Where

N - Number of Streams

u - Stream Order

$\sum$ - Summation sign

C. Stream Segment

The segment is therefore equal to the stream number N_U.

Where

N - Number of streams

u - Stream Order

D. Basin Perimeter

The perimeter was measured through GIS technique using ArcGIS 10.7.1 software.

E. Stream Length

It is designated with the sign L_u. Thus $L_u = L_1 + L_2 + L_3 + \dots L_n$**…………….…….**equation 2

Where

L_u - is the total stream length,

L_1, L_2, L_3,..........are length of individual stream order/segments.

F. Drainage Density (Dd)

Drainage Density is obtained by feeding variables in the equation:

$Dd = L_u/A$ ……………………………………………………………………………equation 3

where:

Dd - is the drainage density

L_u - is the total stream length of all stream orders in the basin

A - is the area of the basin expressed in sq.km

G. Basin Area

The basin area was obtained through GIS method using ArcGIS 10.7.1

H. Stream Frequency

The stream frequency is estimated by the equation:

$\sum N_u/A$ ……………………………………………..………………………..…equation 4

Where

N_U - is the number of stream segments

A - is the total basin area and

$\sum$ - is a sign for summation

I. Bifurcation Ratio

Bifurcation was obtained using the equation:

$Br = N_u / N_{u+1}$ ……………………………………………………………..…equation 5

where

Br - Bifurcation ratio

N_u - Number of streams in a given order

N_{U+1} - Number of streams in the next higher order.

J. Stream Gradient

Stream Gradient was obtained using the equation:

G = Rise (VI) / Run (HE) …………………………………………………….....equation 6

where

G - Gradient

VI - Vertical interval

HE - The Horizontal Equivalence (distance)

Analysis of Morphometric Characteristics of the Dam's Catchment

The morphometric analysis of the basin was categorized into 3 sections (linear, relief, and areal features). The first section deals with the delineation of the catchment area, calculation of its perimeter and length as well as linear properties of the river and its tributaries. These include stream order, stream number, and stream lengths. The second section deals with relief-related morphometric parameters of the catchment such as relief ratio and ruggedness numbers. The third aspect (aerial) of the catchment examined the form factor, elongation ratio, drainage density, and length of overland flow as indicated in Table1.

Table 1 Values of Morphometric Parameter of Dadin Kowa Dam Basin

S/NO	Stream Order (U)	Stream Numbers (Nu)	Total Stream Length (km)Lu	Mean Stream Length (Lu/Nu)	Stream Length Ratio (Lu / Lu-1)	Bifurcation Ratio Rb	Length of Overland Flow (KM)	RHO Coefficient
1	1st order	4656455	481574.4	0.10				
2	2nd order	1025651	139617.9	0.14	0.29	4.5		
3	3rd order	286607	71187.8	0.25	0.51	3.6		
4	4th order	98139	35179.4	0.36	0.49	2.9		
5	5th order	35537	16308.3	0.46	0.46	2.8		
6	6th order	13460	7766.5	0.58	0.48	2.6		
7	7th order	7005	3667.5	0.52	0.47	1.9		
8	8th order	678	1755.2	2.59	0.48	10.3		
9	9th order	31	860.6	27.76	0.49	21.9		
10	10th order	7	366.5	52.36	0.43	4.4		
11	11th order	1	363.8	363.80	0.99	7.0		
Total		6123571	758647.9		5.09	62	1.58	0.082159874
Mean					0.51	6.2		

Source: Researchers Analysis

Linear Aspects

Stream Order and Stream Numbers

Stream order is a hierarchical organization of streams that shows the positional ranking of the stream segment in the basin. It is the first step in quantitative analysis of a watershed as advocated by Horton (1945). Strahler's (1964) stream ordering system was employed in determining the numbers and Orders of Streams. The Dadin Kowa catchment was thus determined to be an eleventh (11th) order stream. There are a total of 6,123,571 streams in the basin with 4,656,455 of them being first-order streams, 1,025,651 second order, and one (1) eleventh order stream as shown in Table 1.

Analysis of the stream orders and stream numbers disagrees with Waugh (1990) as presented by Wanah (2017) who says there should be a positive relationship between stream orders and stream numbers, as in this case analysis shows an inverse relationship between stream orders and stream numbers in that as the stream orders are increasing, the stream numbers decrease. Stream orders and stream numbers are the sole factors that determine the bifurcation ratio of a basin which is an indicator of floodability of the basin (Dawha, 2023). Dadin Kowa catchment with a 6 to 1 ratio of stream orders to their next higher order, therefore presents a very low risk of flooding.

Stream Lengths

The total stream length of Dadin Kowa basin stood at 758,647.9 km with the first order streams having a total length of 481,574.4 km and the 11th order stream with a length of 363.8 km. The average stream length on the other hand refers to the average distance sediments and solutes travel before the stream gets bifurcated or ends at its local base level. Thus, the mean stream length of the basin stands at 123.89 meters. The relatively short distance of average stream length is an indicator of the type of relief and geology of the basin which gave rise to much first-order stream that is by nature, very short streams. The basin axial length however stood at 301 km. This refers to the length of the basin from the mouth at the base level to the furthest tip of the basin at the source

Bifurcation Ratio

Bifurcation ratio refers to the ratio of stream numbers in a particular order to the number of streams in the next higher order. The bifurcation ratio of the catchment is presented in Table1 The bifurcation ratio between the first and second-order stream numbers gave 4.54 and between the tenth and eleventh-order being 7 means on average, not less than 4 first-order streams merged to give rise to each second-order stream and not less than 7 tenth-order streams merged to give rise to the eleventh order stream. The mean bifurcation ratio of the basin was 62/10 = 6.2. The significance of the mean bifurcation ratio is in flood prediction. As stated by Waugh (1990 in Ayele, 2017) any basin with less than 3.0 mean bifurcation ratio has increasing flood risk accordingly. This is so because smaller streams draining into a higher or larger stream means the basin is well dissected by relatively smaller streams that drain the overland flow into a larger stream. This consequently reduces the risk of flooding but when the smaller streams are few relative to the higher order it will mean few small streams drain the overland flow thus rendering a higher risk of flooded condition (Ayele, 2017). The bifurcation ratio of Dadin Kowa dam basin being 6.2 therefore means the basin has a very low risk of getting flooded unless created by other conditions otherwise, it is a well-drained basin.

Relief Parameters

Basin Relative Relief

Dadin Kowa Dam's Basin's relief range between 1742 to 217m AMSL. It refers to the difference in height between the lowest and the highest point in the basin. The absolute relief of Dadin Kowa Dam Basin is 1525 which might be due to the high relief of the source of the river which is Jos plateau.

Gradient or Stream Slope

Gradient refers to average increase of height per unit measurement. In other words, it refers to the degree of steepness of an object relative to the horizontal plane. The source region on the Jos Plateau has the highest elevation (1400 m AMSL) while the reservoir area around the Dam has the lowest elevation of 250 m AMSL giving a differential height of 1742 – 217 = 1525meters. The distance between the two points is 230 km. Thus, based on the gradient of the basin, there is a seven (7) meter rise in every 1kilometer distance. The seven (7) meter rise in slope for every 1kilometer distance shows that the stream has a relatively steep slope which means faster evacuation of overland flow of water and strength for eroding debris along its course.

Area Parameters

Rho Coefficient

Rho Coefficient refers to the ratio of Stream Length Ratio to Bifurcation Ratio (Horton, 1945 cited in Ayele *et al*, 2017). It is an important parameter as it helps in determining the relationship between the drainage density and the geomorphic evolution of the basin (Ikusemoran *et al*, 2018). The Rho value is an indication of the storage capacity of the drainage network itself. A small Rho coefficient value means lower capacity to store water while higher values indicate more capacity of the drainage network to store water in their channels (Ayele *et al.*, 2017). The Rho value for Dadin Kowa drainage network was 0.082 (Table1) which is very small and indicates that very little water is retained in the river channels. This means that the catchment does not have many ponds or marshy areas that retain water along the river course. Since all water eventually reaches the dam, the implication is that the dam is the only storage system there is in the catchment which puts more pressure on the management.

Drainage Density

Drainage Density refers to the numerical measure of landform dissection, it expresses the length of stream available to drain a unit area of the basin (Horton, 1945 cited in Bharadwaj *et al.*, 2014). The Dadin Kowa drainage basin has a drainage density of 23.6 km of river channel per sq. km area (based on the 30-meter resolution image). This is a true reflection of the area seeing the relative height of the source region to the local base level which is the reservoir. Chorley (1969 cited in Bharadwaj *et al,* 2014) observed that drainage density shows the runoff potentials of the basin as well as its infiltration capacity (in relation to the vegetation cover of the catchment). Drainage density is also an indicator of groundwater potentials of a basin and its relations with runoff and permeability (Bharadwaj *et al.*, 2014). Areas with low drainage density are generally areas with high permeability, dense vegetation cover, and low relief while high drainage density is an indicator of areas with low permeability, low vegetation cover, and high relief (Nag, 1998 cited in Bharadwaj *et al.,* 2014; Yahya *et al*, 2016). Having a drainage density of 23.6 km means the catchment has high drainage density which means it has high runoff and low percolation. This finding has negative implications on underground water availability as areas with high runoff and low percolation may be difficult areas for groundwater potentials

Stream Frequency

Stream frequency refers to the total number of stream segments of all the orders of a stream per unit area (Horton, 1945 cited in Ravindra & Vijay, 2017). Stream frequency is an indicator of the permeability of the soil, infiltration capacity, and relief of the basin (Ravindra & Vijay, 2017). The stream frequency of Dadin Kowa basin is 190.4. The high stream frequency is also indicative of low permeability of the soil type while those with relatively low stream frequencies are indicative of better percolation, denser vegetative cover, and relatively more gentle slope.

Circularity Ratio (Rc)

Circularity ratio is the ratio of the basin area (A) to the area of a circle having the same perimeter. The circularity ratio of the Dadin Kowa basin is 0.4. Values of circularity index range between zero for a line and one for a circle. A circularity index closer to one indicate a more circular basin than those tending toward zero. Since the circulatory ratio of the basin is 0.4 which tends towards 0, it means the shape of the basin is more elongated than circular. The circularity ratio of a basin is however, influenced by climate, geological formation, vegetation cover, length and frequencies of streams as well as relief and slope of the basin (Sandeep, 2016).

Form Factor (Ff)

Form Factor of a basin is used to evaluate flood conditions of a basin and it is expressed as the ratio of the area of the basin (A) to the square of the basin length (L^2) (Horton 1945 cited in Lalduhawma *et al.,* 2018). The Dadin Kowa basin has a form factor of 0.36, the value of form factor should be less than 0.79 (Lalduhawma *et al.,* 2018). A basin with a form factor (Ff) of 0.36 indicates a moderately compact shape. It suggests that the basin's area is distributed in a way that does not heavily favor elongation or irregularity. This value implies that the basin is neither elongated nor circular, but rather somewhere in between as seen on Table 2.

Table 2. Interpretation of form factor ratio

Form Factor	Shape	Nature of Flow
0	Highly Elongated	Low peak flow and longer duration
0.6	Slightly Elongated	Flatter peak flow and longer duration
0.6 – 0.78	Circular	Moderate to high peak flow with short duration
0.78 – 1.0	Perfectly Circular	High peak flow for short duration

Source: Madhavan, 2014

Overall, the basin is slightly elongated (0.36). Basins with a high form factor indicate high peak flows of shorter duration while basins with a low form factor, which is indicative of the circular nature of the basin, should have lower peak flows that last longer (Chopra, 2005 cited in Lalduhawma, *et al.,* 2018). The form factor of the basin, therefore, is translated as a moderate stream with average peak flows of moderate duration.

Elongation Ratio

Elongation ratio is an important shape index in basin analysis. It shows the roundedness or relative elongation of a basin which explains the infiltration and runoff tendency of the basin in general (Lalduhawma *et al.,* 2018). The value of elongation ratio ranges between zero and one with zero depicting a highly elongated basin and one for an almost circular basin. The Dadin Kowa basin has an elongation Ratio of 0.6. Values tending towards one are indicative of landforms of regions with low relief while 0.6 upwards are regions with high relief and steep slopes (Strahler, 1964 cited in Lalduhawma *et al.,* 2018). The Dadin Kowa basin can therefore be interpreted as having an average relief region.

Texture Ratio

Texture ratio is a function of drainage density and stream frequency (T=N1/P) and is grouped into 5 categories (Sadhasivam *et al.,* 2020): Less than 2 = very coarse, 2 - 4 = coarse, 4 - 6 = moderate, 6 – 8 = fine, greater than 8 = very fine. Factors that influence texture ratio include climate, vegetation cover, soil texture, infiltration capacity, and stage of the soil's development (Sadhasivam *et al.,* 2020). The texture ratio of Dadin Kowa is very high and this may be due to the steepness and geology of the environment that led to the development of many stream segments amounting to a total of 11 stream orders (Sadhasivam *et al.,* 2020).

Compactness Coefficient

Compactness coefficient shows how the basin shape compares to the basin shape of circular nature having the same size of area (Ravindra & Vijay, 2017). A compactness coefficient of one (1) indicates that the basin will function as a circular basin with a faster peak flood time while those with lower values indicate a slower time to reach peak flow (Ravindra & Vijay, 2017). The Dadin Kowa basin returns values that are higher than 1 and therefore, shows that generally, the basin will take a relatively short time to concentrate the flow of water in its channels for peak flow to occurs.0

Length of overland flow

Length of overland flow indicates the average time it takes for overland flow to concentrate into a channel flow (Zekang *et al.*, 2012). It is an important property as it influences hydrologic and hydrographic development of a basin. The value of the length of overland flow is 1.58 which is considered low. A basin with a relatively lower overland flow value means a steeper and faster overland flow while values relatively high indicates more gentle slope and so slower overland flow. These also affect the overall energy of the basin to accomplish fluvial processes

Conclusion

Morphometric analysis of Dadin Kowa Dam's catchment has been carried out in this study using geospatial technique. It has been established in this study that Dadinkowa basin is an elongated basin from Jos Plateau to the mouth of dam in Gombe State. Based on the SRTM DEM data that was used for the study, the basin is an 11^{th} order catchment. The bifurcation ratio of Dadin Kowa dam basin was 6.2 and therefore means the basin has a very low risk of getting flooded. Hence, the basin needs to be properly utilized in order not to expose the area to possible environmental hazards. Moreover, the Rho value for Dadin Kowa basin was 0.082 which is an indication that very little water is retained in the river channels because catchment the basin does not have many ponds or marshy areas that retain water along the river course. Therefore, since all water eventually reaches the dam, the implication is that the dam is the only storage system in the catchment which puts more pressure on the catchment and the need to effectively manage the basin. The drainage density of 23.6 km means the catchment has high drainage density which means it has high runoff and low percolation which has negative implications on underground water availability as areas with high runoff and low percolation may be difficult areas for groundwater potentials. Prioritization of the sub basin for assessment of susceptible of the sub basin

Recommendation

The following recommendations are made from the findings of the study.

i. Application of geospatial techniques should be encouraged in carrying out morphometric analysis of drainage basin because of its numerous advantages such as large area coverage and locational accuracy over manual method
ii. Since at present, it was revealed that the basin has a very low risk of getting flooded based on the value of the bifurcation ratio. The Basin should therefore, be sustainably managed so as to maintain the present flood hazard status.
iii. Moreover, since very little water is retained in the river channels because the catchment does not have many ponds or marshy areas that retain water along the river course. Therefore, since all water eventually reaches the dam, there is the need to effectively manage the basin.
iv. The catchment has high drainage density, that is, high runoff and low percolation which has negative implications on underground water availability as areas with high runoff and low percolation may be difficult areas for groundwater potentials.

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