



Determination of normal operating heights and surface areas of reservoirs in Kangimi catchment for flood mitigation.

^{1,*}M. K. A. Abdulrahman
²I. A. Abdulkareem
³M. O. Mohammed
⁴A T. Mudi

^{1,4}Department of Mathematics & Statistics
Kaduna Polytechnics
P.MB. 2021, Tudun Wada, Kaduna, Kaduna, Nigeria

Department of Agric. and Biro-Environmental,
Engineering, Kaduna Polytechnics
P.MB. 2021, Tudun Wada, Kaduna, Kaduna, Nigeria

³Department of Mathematics
Kwara State College of Education
Ilorin, Kwara, Nigeria.

*kamilabdulraman@kadunapolytechnic.edu.ng

Abstract: The reservoir network model for flood control has undergone several theoretical and conceptual approaches to formulation and computation. An attempt in this work is to implement the model and find out its performance. Several hydrological measurements were taken in the catchments and the average infiltration is found to be 0.1757mh^{-1} . The length of open channel flow into the dam from all sub-catchments was measured and the Soil Conservation Service *curve number* description of land use pattern was adopted in this work. These data were put together to obtain parameters like the curve number, time of concentration as well as constants K which is catchment dependent. Similarly, with $\rho \in [2,3]$, $\rho = 2$ is utilized in this work. These parameters were used to obtain the normal operating heights of the expected reservoir in the network using the minimum, average and maximum rain rate recorded in the catchment. The approach was repeated for sediment consideration in the model and the difference between these heights was used to determine the capacities of the reservoirs in the network. The results obtained show the flat nature of the catchment and a single layer difference between the sub-catchments and the Kangimi dam is reflected in the normal operating heights obtained. Moreover, the relationship between the area of sub-catchment, the respective surface area of the reservoir in the catchment, and provides a benchmark for the sizing of reservoirs expected in the sub-catchments. Since the dam is expected to take all excess water from the sub-catchment, the capacities for dead, temporary and permanent mark of the dam were obtained to be 186455029.5m^3 , 1215798789m^3 and 13476269498.33m^3 respectively.

Keywords: mathematical modelling reservoir; normal operating height, time of concentration; infiltration

1 INTRODUCTION

Modelling reservoir network connection for flood control is born out of studies on flood events at the expense of the main causes of flood. The reservoirs that handle runoff within a catchment range from small to medium depending on the rainfall pattern, relief, vegetation and land use regulations. Small scale reservoirs are used generally to control flood [1] and the sediment transport and accumulation on the other hand receives attention but concentrates on large reservoirs with continuous water inflow [2] and dynamic estimation of sediment was considered in [3]. The design has also gone through some mathematical principles as described in [4]. These forms of reservoirs are easy to construct, manage and

Acknowledgement: The first author wishes to acknowledge the support from the Tertiary Education Trust Fund, TETFund through the grant no: TETF/DR&D/CE/UNI/KADUNA/RG/2020/VOL1

Citation: Abdulrahman MKA et. al., Determination of Normal Operating Heights and Surface Areas of Reservoirs in Kangimi Catchment for flood mitigation. IJMCS, 2023. 1(2): p. 6-16.



are ranged from small to big in capacity for effective flood control, irrigation, navigation, recreation and other water use. The issue of multi-reservoir as a network for different purposes were considered in [5-8]. Efforts to get a simple and concise tool for pond design and management of flood prevention is worth encouraged. It is proven that network of reservoirs is the most effective for catchment water management [7, 9, 10]. To this end, water management, flood control, sedimentation, reservoir design and other issues in respect of water resources still require mathematical approach in terms of modelling, analysis and computation. This will increase multi dimension knowledge base for this class of problem. For multi-purpose dam like Kangimi, several works have been done on different aspect of the dam and the catchment. In Ologunorisa [11] studied the hydroclimatology of the Kaduna River Basin and establishes criteria for water resources management in the entire basin. Sediment yield was the focus of the work reported in [12] for the entire watershed of river Kaduna. The dam safety report [13] shows that Kangimi dam is one of the three dams in Kaduna state while the economic importance and water quality to support the activities of farmer and federal government initiative on RUGA was studied in [14]. The sediment discharge and prediction of Kangimi dam was carried out and reported in [15] which similar work discussed in [12, 16] focused on land use for Kangimi and Kaduna in general.

2 BACKGROUND

Modelling and indeed mathematical modelling are ways to study real life situations [17, 18]. It is cheaper and provide opportunity to try different scenarios which may not be possible in real life. Unfortunately, not all attempts to model real life problem produce the required result. In the case of non-linear reservoir network model for flood control, attempts have been made to consider aspect of reservoir design, location size, sedimentation as well as useful life of these reservoirs that ensure free flow of water within the network and the downstream [3, 19-28]. Having developed these procedures, it is a standard practice to verify the performance of the model in a catchment. Firstly, to reconcile real life and model scenario and secondly to verify the accuracy of the model on the available data in the catchment. A catchment is an area that captures and channels all the rainfall and run-off to a particular river system or basin. There are ten sub-catchments identified as contributory to Kangimi dam. These ten flows into Kangimi dam are shown in Figure1 and the outflow through Kangimi dam flows into river Kaduna which is about 3km apart.

Kangimi dam is located in Igabi, local government of Kaduna state in northern Nigeria between the Latitude $10^{\circ}46'N$ and Longitude $7^{\circ}25'E$ which covered an area of 1500 km^2 . It is a savannah vegetation, fairly flat with peaks ranging between 583.67m to 673.19m [15]. The Kangimi dam was constructed in 1975 with initial design capacity of about $59.8M \text{ m}^3$ which cover an area 12km^2 with approximate length of 9.63km and depth ranges between 12.92m and 17m [15, 16]. It is about 3,22km upstream of river Kaduna and about ten major inflows into the dam which in this consideration is expected to flow in from different sub-catchments. There are some interdependent flows between these sub-catchments but we restrict this work to direct inflow to the dam. These features coupled with the findings in [16] show that increase in agricultural growth and bare surface led to an increase in annual stream flow and sediment yield. This scenario may likely increase in near future as we expect more settlements build up, industrialization, urbanization and related concepts which will reduce the perviousness of the catchment and increase in runoff generation.



Figure 1: Kangimi Dam showing the point of inflow from the sub-catchment and River Kaduna

3 MODEL IMPLEMENTATION AND DATA NEEDS

To justify the intent of this work, the ten inflows into the dam arises from the sub-catchments which for the intent of flood control is assumed to have a reservoir that flows into Kangimi dam. It is reported in [12, 16] that inflows are seasonal between May and October. This shows that for other period of the year there will be no flow. The network topology for the reservoirs in the network is shown in Figure 2 which indicates that water from the ten reservoirs flows into Kangimi dam and the dam releases water to river Kaduna.

Each reservoir in Figure 2 represents the expected capacity of reservoir in each sub-catchment where the area of the sub-catchment and the surface area of the reservoir have been determined in [22] as

$$A_j = \left(\frac{A_{sc_j} I_{sc_j} t_c}{k} \right)^{1/\tau} \quad (1)$$

Where A_{sc_j} is area of sub-catchment, I_{sc_j} is the rain rate with the minimum, average and maximum value used. If the entire catchment has been homogeneous in nature, these values of rain rates are used for the entire catchment. t_c is the time of concentration of each sub-catchment. The k and τ are constants with values of 1/120 and 3/2 respectively [29]. The surface area is then computed for the the three rain rates computed from a 20years rainfall data [15]. This result is presented in Table 1 with the time of concentration is given by

$$t_c = \frac{l^{0.8} \left(\frac{1000}{CN} - 9 \right)^{0.7}}{1140 \sqrt{Y}} \quad (2)$$



Where l is drainage channel, CN is the curve number taking as average CN from different land use of the catchment and Y is the slope. Due to different land use in the catchment, the time of concentration which depends on the curve number has the result presented in Table2.

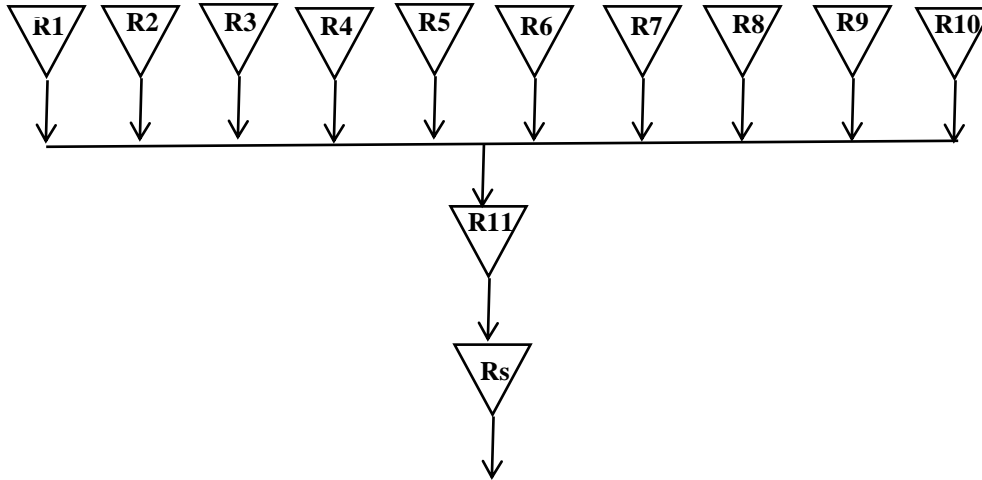


Figure 2: Network diagram of Kangimi Catchment

4 DETERMINATION OF NORMAL OPERATING HEIGHTS

The model equation developed in[19] modified and adapted to the configuration in Figure 2 gives

$$\left. \begin{aligned}
 A_j \dot{H}_j &= \begin{cases} 0 & ; H_j > H_j^0 \\ A_{scj} I_{scj} c_j - B_j \sqrt{H_j - H_m} & ; H_j \leq H_j^0 \end{cases} \quad j=1,2,\dots,m-1 \\
 A_m \dot{H}_m &= \begin{cases} A_{scm} I_{scm} c_m + \sum_{j=1}^{10} (B_j \sqrt{H_j - H_m}) - B_m (H_m - H_s)^{3/2} & ; H_m < H_m^{temp} \\ A_s \dot{H}_s = B_m (H_m - H_s)^{3/2} - L_s & \end{cases}
 \end{aligned} \right\} \quad (3)$$

and the normal operating height is obtained by setting (3) to zero. It is to be observed that (3) describe movement of water between three connected reservoirs but in the case of this network, the first 10 reservoirs depend solely on rain harvest. In other words, there are no connected reservoir upstream as one of the basic assumption of this work. This gives

$$A_{scj} I + \sum_{i=\sigma_1}^{\sigma_2} (B_i \sqrt{H_i - H_j}) - B_j \sqrt{H_j - H_m} = 0 \quad (4)$$

and each of these reservoirs flows into the dam indexed m , i.e.

$$H_j^0 = \left(\frac{A_{scj} I_j c_j}{B_j} \right)^2 + H_m \quad ; \quad \text{for } j=1,2,\dots,10 \quad (5)$$

where $B_j = \left(\frac{2}{3} \right)^{3/2} \sqrt{g} L_j$



Also from the second equation in (3)

$$A_{sc_m} I_m c_m + \sum_{j=1}^{11} (B_j \sqrt{H_j - H_m}) - B_m (H_m - H_s)^{3/2} = 0$$

which gives

$$H_m = \left(\frac{\sum_{j=1}^{11} A_{sc_j} I_{sc_j} c_j}{\sqrt{\frac{8g}{27} L_m}} \right)^{2/3} + H_s \quad (6)$$

where the index m is the eleventh reservoir in the network. The homogeneity of rainfall pattern in the entire catchment necessitates equation (5) and (6) to become

$$\left. \begin{aligned} H_j^0 &= \left(\frac{A_{sc_j} I c}{B_j} \right)^2 + H_m \quad ; \quad \text{for } j = 1, 2, \dots, 10 \\ H_m^0 &= \left(\frac{\sum_{j=1}^{11} A_{sc_m} I c}{\sqrt{\frac{8g}{27} L_m}} \right)^{2/3} - H_s^0 \end{aligned} \right\} \quad (7)$$

Equation (7) shows that there are inter relationships between the reservoirs in the network and the connecting stream being river Kaduna. The three heights recorded in [12] above sea level will serve as the normal operating heights for the three rain rates. These heights are 377m, 683m and 1544m [12] which are taking as height due to minimum, average and maximum rain rates respectively.

5 CONSIDERATION OF SEDIMENT INFLOW

As long as water flows into a reservoir in the nature of catchment under consideration, sediment inflow is inevitable. The flow affect the reservoir in many ways depending on intended use of the reservoir. The modification of (3) reported in [25] gives

$$A_j \dot{H}_j = \begin{cases} 0 & ; \quad H_j > H_j^0 \\ A_{sc_j} I_{sc_j} c_j - B_j \sqrt{H_j - H_m} & ; \quad H_j \leq h_j^0 \end{cases} \quad j = 1, 2, \dots, 10 \quad (8a)$$

$$A_s \dot{H}_s = B_m (H_m - H_s)^{3/2} - L_s \quad (8b)$$

$$A_m \dot{H}_m = \begin{cases} 0 & ; \quad H_m > H_m^{temp} \\ A_{sc_m} I_{sc_m} c_m + \sum_{j=1}^{10} (B_j \sqrt{H_j - H_m}) + K \left[\sum_{j=1}^{10} (B_j \sqrt{H_j - H_m}) \right]^p & \\ -K(1-T_e) [B_m (H_m - H_s)^{3/2}]^p - B_m (H_m - H_s)^{3/2} - A_m f & ; \quad H_m \leq h_m^{temp} \end{cases} \quad (8c)$$

By setting (8a) to zero we obtained (5) and (8b) due to sediment inflow gives



$$x^\rho + \frac{1}{K(1-T_e)} x - \frac{AI + K \left(\sum_{i=1}^{m-1} (A_{sc_i} I) \right)^\rho - A_m f}{K(1-T_e)} = 0 \quad (9)$$

where $x = B_m (H_m - H_s)^{3/2}$ and

$$H_m = \left(\frac{x}{B_m} \right)^{2/3} + H_s \quad (10)$$

Relying on the value of $\rho \in [2,3]$ in [30], we take $\rho = 2$ and (9) can be solved as a quadratic equation i.e.

$$x^2 + bx - c = 0 \quad (11)$$

where

$$b = \frac{1}{K(1-T_e)} \quad \text{and} \quad c = \frac{\sum_{j=1}^m (A_{sc_j} I_{sc_j} c_{sc_j}) + K \left(\sum_{i=1}^{m-1} (A_{sc_i} I_{sc_i} c_{sc_i}) \right)^2 - A_m f}{K(1-T_e)}$$

With $K = \frac{1}{\ln Q}$ where $Q = \sum_{j=1}^{10} B_j \sqrt{H_j - H_m}$ [28] which is computed to be $K=0.070758181$.

The infiltration in Kangimi has been found to be 0.1757mh^{-1} based on the infiltration data of the catchment. The trap efficiency of the dam is taking as 80% while the average CN is estimated to be 69.4. The normal operating heights for Kangimi dam are computed through the three heights of river Kaduna, this is can be seen in equation (10) where H_m depends on the values of H_s . The other normal operating heights of the other reservoirs in the network can be determined by (5). The three heights refer to in this work corresponds to the three rain rates used. In the dam itself, the heights are taking as the permanent height, temporary height and flood height of the dam. This is now used to determine the capacities of each of the reservoirs based on the three rain rates.

5.1 Discussion of Results

The modelling and its implementation on a real-life situation possess a big challenge in adaptation and reconciliation. Most often situation adaptation bring to fore some unrealisable issues either from the formulation or the data need. Within these divides, attempts have been made to close this gap in order for the model to be as close as possible to real situation. The parameters obtained from the field are refined to allow a smooth implementation. For the current scope of the work, the materials in [12, 16, 31] coupled with the field data were used for the computation which are strictly for this catchment.

Figure 1 is the aerial view of Kangimi dam with the ten major inflows from the sub-catchment and is captured as network topology shown in Figure 2. The ten points indicated by the names of the sub-catchment where the water flows into Kangimi dam. As a multi-purpose dam, there is need for continuous assessment of our reservoirs in order to maximally enjoy its benefits. In Table1, the surface area of the reservoirs were estimated to take care of the water in the sub-catchment thereby reducing the burden on the dam and the connecting stream. The percentage of these surface areas to the entire areas of these sub-catchment are between 0.12%, 1.18%, and 2.03% of Bahago and 0.35%, 3.42% and 5.92% of Loko-Danyaro for minimum, average and maximum rain rates respectively. To a large extent



the maximum rain rate is used to get the maximum capacity of the reservoir that will take care of water in the sub-catchment. In Table 2, the normal operating height were fairly equal for minimum rain rate at 377m and average rain rate at 683m. This is normal for this type of catchment that is flat in nature. But the normal operating height in respect of maximum rain rate differs ranging between 1884.6m and 1544m. While the three heights in Kangimi dam are computed to be 377m, 683m and 1544m, it can be inferred that all sub-catchments are re relatively close to the height in the dam and are just a single layer above the dam.

The normal operating heights with sediment inflow consideration as least value for the three rain rates is 377.05m, 683.16-746m and 1544.21m. The highest values are 377.12m, 748.97m and 1844.86m which gives height of sediment a fairly uniform in minimum rain rate as 0.05m and the maximum rain rate at 0.21. The irregular values were obtained in the average rain rate between 0.16m for the dam itself and 65.97m in Kangimi main.

With the normal operating heights in Table 2, the expected capacity of each reservoir in the network is presented in Table 3. The current surface area of Kangimi dam can holds 452400m³, 819600m³ and 185280000m³ for the three rain rates. The sum of capacity of all reservoir in the sub-catchment is expected to determine the three levels of the receiving reservoir. Hence, the dead, active and emergency capacity of Kangimi dam is computed as 187069132.34m³, 1237150496m³ and 13643814394.44m³.

6 CONCLUSION

Attempts at implementation of this work on Kangimi catchment is to provide framework for the implementation of the model. From literature, approach to hydrological computation is highly subjective. The subjectivity in our view and laid a foundation for a strong debate on the validity or otherwise of the process involved. The determination of various normal operating heights, the surface areas as well as the capacities of reservoirs in the network is to provide avenue for insight into the current happening in the sub-catchment, provides insight into the next phase of water resources management in the catchment, examine and re-examine the current trend and ultimately determine benchmark for the stability of the network.

The parameters obtained in each sub-catchment were utilized to obtain the surface areas, the normal operating heights and the expected capacities of reservoir that will save the Kangimi dam and continuously serve the purpose of water augmentation and flood mitigation. the sum of all capacities of the reservoirs in the network is expected as the design capacity of the dam for permanent, temporary and flood height which in this case are expected to go with the computation with the three rain rates, The existing record of flood in Kaduna has never been traced to Kangimi catchment which is an indication that the dam still serves its purposes. The values obtained for capacities of Kangimi dam is above all other values recorded by researchers, this is not unlikely as the data need and non-consideration of infiltration in the entire catchment. Also, the constants in the sediment transport equation which were found to be between 2 and 3, since 2 is used in this work, it might be a way to check the response of all values in (2,3]. it is also to be observed that the flat nature of the catchment may allow runoff to gather through this model and a single layer between all reservoir and the Kangimi dam. It is hoped that these areas identified as well as the stability study of the network will bring more insight into the results obtained for the catchment.



Table 1: Distribution of land use, time of concentration and surface area of reservoir

SUBCATCHMENT	LENGTH (m)	TOTAL AREA (m ²)	DISTRIBUTION OF THE LAND USE AREA AND CURVE NUMBER						SLOPE	TIME OF CONCENTRATION (hr)	SURFACE AREA OF RESERVOIR (m ²)		
			VEGETATION 70	FARM LAND 63	WATER BODY 80	BARELAND 58	UNCLASSIFIED 67	SETTLEMENT 75			MIN	AVE	MAX
Loko-Koro	2700	10991760.26	6547791.642	1630407.831	1162598.464	632136.10	594214.5395	424611.6822	1.88	0.17	27378.19	264458.72	457468.22
Loko-Hali	2190	6426288.29	3828139.969	953211.3613	679708.5022	369575.82	347405.1334	248247.51	2.05	0.15	17199.85	56819.56	287396.11
Loko- Balbela	2400	7435132.38	4429108.395	1102853.207	786413.9393	427594.44	401943.2428	287219.15	4.29	0.11	15335.18	50659.64	256238.95
Bahago	3500	29081458.45	17323824.95	4313652.817	3075945.813	167247460	1572143.591	1123416.70	4.16	0.14	44279.41	146276.63	739874.38
Kangimi Main	7900	114667312.7	68307318.76	17008602.83	12128361.47	6594516.81	6198914.715	4429598.12	4.01	0.22	151610.46	500843.78	2533292.39
Rafin Kurmin Zaria	5500	51660871.71	30774381.54	7662857.251	5464170.316	2971016.58	2792786.63	1995659.396	1.12	0.34	119071.36	393351.14	1989589.39
Rafin Gora	5900	21162747.41	12606648.74	3139070.384	2238383.758	1217069.54	1144058.086	817516.9003	3.41	0.20	46517.68	153670.74	777274.16
Rafin Jagiwa	4300	10674248.51	6358649.889	1583311.312	1129015.247	613876.00	577049.8547	412346.2036	3.89	0.16	25067.25	82809.42	418854.13
Loko- Hadamshi	8300	9142469.50	5446169.125	1356102.527	966998.9834	525783.39	494241.8842	353173.5828	3.37	0.24	30315.05	100145.49	506540.81
Loko-Danyaro	2300	1497508.79	892065.9963	222125.4838	158391.5027	86121.726	80955.32268	57848.76246	3.12	0.12	5766.91	19050.94	96360.57

Table 1: Normal operating heights of reservoirs in the catchment

SUBCATCHMENT	LENGTH OF WIER (m)	SURFACE AREA OF RESERVOIR (m ²)			NORMAL OPERATING HEIGHTS (m) (Water)			NORMAL OPERATING HEIGHTS (m) (Water+Sediment)		
		MIN	AVE	MAX	MIN	AVE	MAX	MIN	AVE	MAX
Loko-Koro	67.08	27378.19	264458.72	457468.22	378.25	695.00	1616.46	377.06	693.15	1595.92
Loko-Hali	86.05	17199.85	56819.56	287396.11	378.24	695.00	1575.49	377.05	685.23	1554.95
Loko- Balbela	107.28	15335.18	50659.64	256238.95	378.24	695.00	1574.00	377.05	684.94	1553.46
Bahago	216.6	44279.41	146276.63	739874.38	378.25	695.00	1599.47	377.06	689.86	1578.92
Kangimi Main	272.64	151610.46	500843.78	2533292.39	378.32	695.00	1905.40	377.12	748.97	1884.86
Rafin Kurmin Zaria	365.00	119071.36	393351.14	1989589.39	378.25	695.00	1603.33	377.06	690.61	1582.79
Rafin Gora	278.55	46517.68	153670.74	777274.16	378.24	695.00	1575.87	377.05	685.31	1555.32
Rafin Jagiwa	136.78	25067.25	82809.42	418854.13	378.24	695.00	1576.48	377.05	685.42	1555.94
Loko- Hadamshi	392.42	30315.05	100145.49	506540.81	378.24	695.00	1565.79	377.05	683.36	1545.25
Loko-Danyaro	115.58	5766.91	19050.94	96360.57	378.24	695.00	1565.07	377.05	683.22	1544.53
Kangimi Dam	121.57	12000.00	1200.00	1200.00	378.2418	694.9948	1564.7489	377.05	683.16	1544.21

Citation: Abdulrahman MKA et. al., Determination of Normal Operating Heights and Surface Areas of Reservoirs in Kangimi Catchment for flood mitigation. *IJMCS*, 2023. 1(2): p. 6-16.



Table 2: Capacities of reservoirs in the network

SUBCATCHMENT	LENGT OF WIER (m)	AREA (m ²)	SURFACE AREA OF RESERVOIR (m ²)			CAPACITY OF THE RESERVOIR (m ³)		
			MIN	AVE	MAX	MIN	AVE	MAX
Loko-Koro	67.08	10991760.26	27378.19	264458.72	457468.22	10321882.15	180625307.89	729985847.01
Loko-Hali	86.05	6426288.294	17199.85	56819.56	287396.11	6484384.30	38807758.55	446826422.94
Loko- Balbela	107.28	7435132.378	15335.18	50659.64	256238.95	5781394.81	34600534.66	398003201.85
Bahago	216.6	29081458.45	44279.41	146276.63	739874.38	16693667.58	99906939.44	1168051396.37
Kangimi Main	272.64	114667312.7	151610.46	500843.78	2533292.39	57168214.69	342076301.65	4774377267.50
Rafin Kurmin Zaria	365	51660871.71	119071.36	393351.14	1989589.39	44890886.67	268658832.30	3148682195.62
Rafin Gora	278.55	21162747.41	46517.68	153670.74	777274.16	17537277.57	104957117.82	1208751508.48
Rafin Jagiwa	136.78	10674248.51	25067.25	82809.42	418854.13	9450415.41	56558836.80	651623296.83
Loko- Hadamshi	392.42	9142469.495	30315.05	100145.49	506540.81	11428780.71	68399370.75	782628491.82
Loko-Danyaro	115.58	1497508.794	5766.91	19050.94	96360.57	2174125.63	13011789.26	148811869.91
Kangimi dam	121.57	12000.00	12000.00	12000.00	12000.00	4524000.00	8196000.00	18528000.00
Computed capacities of the dead, the active and flood heights						187069132.34	1237150496	13643814394.44

References

1. Gotoh, H., et al., *Flood control and small-scale reservoirs* WIT Transactions on Ecology and the Environment, 2011. **146**.
2. Bashar, K.E. and A. Eltayeb, *Sediment accumulation in roseires reservoir. Nile basin water Science & Engineering Journal*, 2010. **3**(3): p. 46-55.
3. Abdulrahman, M.K.A., M.S. Abdulkarim, and M. Saidu, *Dynamic sediment estimation and useful life of retention pond in a network for flood control*, in *18th National Engineering Conference 2016*, College of Engineering, Kaduna Polytechnic.
4. Hirad, M. and A.S. Ramamurthy, *Multi-reservoir design using ponyryagin principle*. *Advances in Water Resources*, 2002. **25**: p. 677–687.
5. Chih-Chiang, W. and H. Nien-Sheng, *Multireservoir flood-control optimization with neural-based linear channel level routing under tidal effects*. *Water Resources Management*, 2008. **22**: p. 1625–1647.
6. Chih-Chiang, W. and H. Nien-Sheng, *Multireservoir real-time operations for flood control using balanced water level index method*. *Journal of Environmental Management*, 2008. **88**: p. 1624–1639.
7. John, W.L., *Optimal operation of multireservoir systems: state-of-the-art review*. *Journal of Water Resources Planning and Management*, 2004. **130**(2).
8. Regulwar, D.G. and P.R. Anand, *Multi objective multireservoir optimization in fuzzy environment for river sub basin development and management*. *Journal of. Water Resource and Protection*, 2009. **4**: p. 271-280.
9. Quentin, B.T. and W.M. Larry, *Optimizing retention basin networks*. *Journal of Water Resources Planning and Management*, 2008. **134**(5): p. 432–439.

Citation: Abdulrahman MKA et. al., *Determination of Normal Operating Heights and Surface Areas of Reservoirs in Kangimi Catchment for flood mitigation*. *IJMCS*, 2023. **1**(2): p. 6-16.



10. Kaini, P., K. Artita, and J.W. Nicklow, *Evaluating optimal detention pond locations at a watershed scale*
11. Ologunorisa, T.E., O.S. Durowoju, and A. Akinbobola, *Hydroclimatology of the Kaduna river basin*. American Journal of Climate Change, 2021. **10**(03): p. 353-369.
12. Daramola, J., et al., *Estimating sediment yield at Kaduna watershed, Nigeria using soil and water assessment tool (SWAT) model*. Heliyon, 2019. **5**(7): p. e02106.
13. (NUWSRP), N.U.W.S.R.P., *Dam Safety Measures Report*. 2004: Federal Republic Of Nigeria Federal Ministry Of Water Resources
14. Abdulkareem, I.A., et al., *Water quality potential of kangimi dam reservoir towards rural grazing area (RUGA) development in Igabi local government, Kaduna state*. Nigerian Journal of Water Resources, 2022. **8**(1): p. 10.
15. Abdulkareem, I.A. and C.J. Agunwamba, *Prediction and estimation of sediments discharge from Kangimi dam reservoir catchment, Kaduna, Nigeria*. Universal Journal of Environmental Research and Technology, 2018. **7**(1): p. 19.
16. Umar, S.B. and A. Shuaibu, *Analysis of land use/land cover and climate impacts on Kangimi streamflow and sediment yield: Kangimi catchment, Kaduna Nigeria*. Platform Journal of Engineering 2020. **4**(2).
17. Catherine, M.B., *What is modelling and simulation? Principles of modeling and simulation: A multidisciplinary approach*, ed. A.S. John, M.B. Catherine, and Hoboken. 2009, New Jersey: John Wiley & Sons Inc.
18. Uwe, S., *Towards an alternative approach to modelling in school mathematics*. The Mathematics Enthusiast, 2018. **15**(1 & 2).
19. Abdulrahman, M.K.A., A.A. Moh'd Ismail, and S.L. Kek, *Determination of normal operating heights of reservoirs in a network using non-linear reservoir method*. British Journal Of Applied Science & Technology, 2013. **3**(1): p. 34-47.
20. Abdulrahman, M.K.A., A.A. Moh'd Ismail, and L.K. Sie, *Effects of network configurations on the stability of reservoir network*, in *International Science Postgraduate Conference 2012*, PGSSFS, Editor. 2012, UTM: IBNU SINA INSTITUTE OF FUNDAMENTAL Science.
21. Abdulrahman, M.K.A., A.A. Moh'd Ismail, and L.K. Sie, *Stability analysis of reservoir network model for flood control*, in *2nd Regional Conference on Applied and Engineering Mathematics*, W.Z.A. Wan Muhamad and W.D. Wan Suhana, Editors. 2012, Penerbit Institut Matematik Kejuruteraan, Universiti Malaysia Oerlis: Penang Malaysia.
22. Abdulrahman, M.K.A., A.A. Mohd Ismail, and S.L. Kek, *modelling of reservoir network for flood control using nonlinear reservoir routing model*. International Journal of Engineering Science and Technology (IJEST), 2012. **4**(7): p. 3295-3303.
23. Abdulrahman, M.K.A., A.A. Mohd Ismail, and K.S. L., *Optimal control of water flow in a reservoir network for flood control*. Transaction of Nigerian Association of Mathematical Physics, 2017. **42**: p. 113.
24. Abdulrahman, M.K.A., A.A. Mohd Ismail, and L.K. Sie, *Effects of sediment inflow on reservoir network for flood control*. International Journal of Mathematics and Applied Statistics, 2013. **45**(15): p. 103-110.

Citation: Abdulrahman MKA et. al., *Determination of Normal Operating Heights and Surface Areas of Reservoirs in Kangimi Catchment for flood mitigation*. IJMCS, 2023. **1**(2): p. 6-16.



25. Abdulrahman, M.K.A., A.A. Mohd Ismail, and L.K. Sie, *Reservoir network modelling with alternative reservoir and sediment considerations*. British Journal of Mathematics and computer science, 2015. **9**(4): p. 13.
26. Abdulrahman, M.K.A., A.T. Mudi, and A.N. Arowona, *Minimum time for maximum allowable sediment accumulation in a reservoir for flood control*. Transaction of Nigerian Association of Mathematical Physics, 2020. **57**: p. 12.
27. Abdulrahman, M.K.A., A.A. Muhd Ismail, and L.K. Sie, *Stability analysis of reservoir network model for flood control*, in *2nd Regional Conference on Applied and Engineering Mathematics (RCAEM-II)*. 2012.
28. Abdulrahman, M.K.A., S.O. Soladoye, and A.U. Sanda. *Estimation of constants in sediment transport equation for reservoir network for flood control*. in *53 Annual National Conference*. 2016. Ahmadu Bello University Zaria: MAN.
29. Liebe, J., N. van de Giesen, and M. Andreini, *Estimation of small reservoir storage capacities in a semi-arid environment: A case study in the Upper East Region of Ghana*. Physics and Chemistry of the Earth 2005. **30**: p. 448–454.
30. Vaibhav, G. and V. Jothiprakash, *Estimation of useful life of a reservoir using sediment trap efficiency*. Journal of Spatial Hydrology, 2008. **8**(2): p. 1-14.
31. Ayinla, A.I., M.G. Gwari, and A. Amina, *Hydro-Habitat sustainability and economic valuation of kanimi dam reservoir, kauna nigeria* Nigerian Journal of Water Resources, 2018. **4**(1): p. 12.