Determination of Suitable Sites of Water Harvesting Dams in the Northeastern of Nineveh Province

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Keywords

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Abstract

The increasing of water demand resulting of population growth, climate change, and the water policies of neighboring countries of Iraq led to the needing to specify other sources of water in the arid and semi-arid areas of Iraq. The aim of this study is to harvest the rainwater that produced by the catchment area of seasonal Al-Khoser river. The Easter side of Mosul city is divided by the stream flow of this river then combined to Tigris river inside of Mosul city. Three sites of rainwater harvesting dams (RWHDs) were chosen in the catchment of this river. The storage volumes of RWH reservoirs were estimated using HEC-HMS model. The elevation-Area-Storage curves of those RWH reservoirs were identified with live storage, dead storage, flood storage, and outlet capacities (sluice gate, bottom out let and spillway). The results of the study showed that sufficient quantities of surface runoff water are available in the Al-Khoser Basin, which can be stored (dead and live storage) in those three reservoirs 0.96, 1.60, and 2.5 MCM.

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1. INTRODUCTION

Rainwater harvesting (RWH) is an old-new technique that can ensure the availability of water for arid and semi-arid region (Al- Ansari, et al., 2013). By this technique, reservoirs of small earth dams can be established to store the surface runoff of a selected catchment area. This surface runoff is produced by rainwater and may represent as the rainfall that is neither infiltrated into the soil nor retained on the land surface (Chow et al., 1988). Rainfall water productivity can be significantly improved by applying a RWH technique based on availability of a surface reservoir (Zakaria, et al., 2013, P.1665). The success of RWH systems depends on several factors, including rainfall, catchment characteristics and socio-economic factors (Ndeketeya & Dundu, 2021).

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A number of researchers including Derdour et al., 2018; Darji et al., 2019, have used HEC-HMS to simulate the rainfall-runoff process and to estimate the direct runoff of their study area. They conclude that HEC-HMS model has the advantage over other models and recommended it for runoff simulation. Other researchers have studied the selection of suitable sites for reservoirs, their size, and type for rainwater-harvesting techniques to be used to suit diverse goals such as water supply, limited power generation, and supplementary irrigation (Al-Ansari et al., 2013). Skhakhfa & Ouerdachi, 2016, they studied the efficiency of HEC-HMS model in wadi Ressoul, Algeria. The results of measuring runoff approved the results of the model. Al-Aqeeli et al., 2021 proposed two reservoirs on the Greater Zab River along the border between Iraq and Turkey. The aim of their study was to show the importance of exploiting the appropriate sites for construction of dams on the borders of riparian countries, a multi-reservoir system was designed across the border of two riparian countries. In addition, simulation models that express the possible operating mechanisms for this system were created.
The current study aims to explore three sites of Al Khoser watershed for proposed rainwater harvesting dams and to determin their aspects.

2. METHODOLOGY

2.1 Study Area

The basin of Al Khoser seasonal river (652 km^2) is located at 45 km northeast of Mosul city in Nineveh Governorate, Iraq (Figure 1-a), the Basin has a length of 39 km, average slope of 0.06 m/m, and a maximum land elevation of 1260 (m.a.s.l.) (Figure 1-b). The slope and topography are varied in the study area where steep slope is in the northern part of the basin while it is almost flat at south part Most of the study area is usually cultivated mainly with Barley crop, Wheat comes in second place during the winter, in addition to olive trees.

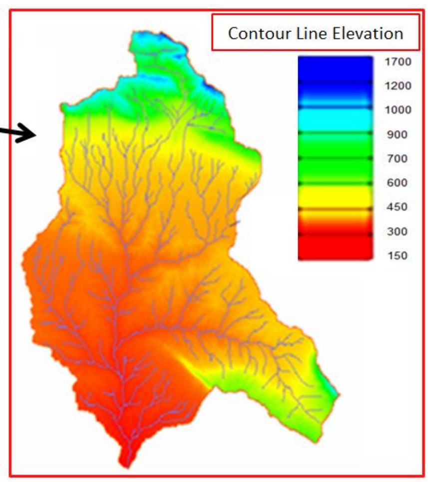

Figure 1-a. Locatation of al khoser basin at Nineveh, Iraq, source: google map

Figure 1-b. Elevation of al-khoser main basin

The study area includes some scattered pastures, and a limited part of urban (residential) areas. The soil of the main part of the study area is of the type: Silty Clay Loam, Silty Clay, Silty Loam and about 18% of the area is limestone (Al-Naqib, 1980; Ezzedine, M. 2005).

2.2 Rainfall of the Study Area

The daily rainfall data of Mosul station was relied on which was the nearest stations to the studied area. The total annual rainfall varied during the study period (1985-2020). The minimum total annual rainfall was about 97 mm during the season (2007-2008), while the average total annual rainfall was about 342 mm during the season (2007-2008), the maximum total annual rainfall reached 618 mm during the season (2018-2019).

2.3 Framework

Al-Khoser river basin was selected and divided into three sub-basins, which necessitated the design of three dams at the outlets of these basins. the HEC-HMS was used in order to estimate the discharge and the volume of surface runoff. The design of these RWH included the determination of elevation-area-storage curve, dead, live, flood storage, and the capacities of their outlets. Results of Basin (2B) was adopted as a sample of calculations.

2.4 Location Sites of Harvesting Dams

Al-Khoser basin was divided into three sub-basins, (Table 1). The connections of selected RWHDs were presented in figure 2.

Table 1. The main and sub-basins of al-khoser seasonal river locations

Dam No	1	2	3	4
Basin No	1B	2B	3B	4B
Area (km2)	652	167.81	121.67	173.83
Length (km)	39.00	21.27	17.97	21.29
X-coordinate	338171.1	338325.8	341050.6	338723.2
Y-coordinate	4037318.4	4055154.7	4053914.4	4046955.9

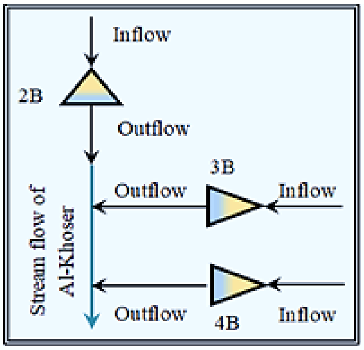

Figure 2 . The conviction style of the three RWHDs

2.5 Simulation Model

Digital elevation model (DEM) is used to select the suitable location of rainwater harvesting dams. The Global Mapper (GM) model and watershed modelling system (WMS) were used to investigate the cross sections of the valleys, where the dams will be constructed. Delineate catchment areas can be satisfy by WMS model based on DEM data of the study area (Al- Ansari, et al., 2013).

2.6 Runoff Model

For each selected dam site, the total depth of daily rainfall was provided to the HEC-HMS in order to estimate the runoff hydrograph for individual rain storm and the volume of surface runoff .

2.7 HEC-HMS Model

HEC-HMS is a physically based, semi-distributed hydrologic model developed to simulate the hydrologic response of a watershed (Scharffenber et al., 2010). HEC-HMS was developed to estimate direct runoff of Al-Khoser watersheb based on the selected following methods:

2.7.1 The exponential loss method

This method is modeling the infiltration rate reduction as an exponentially decreasing function of accumulated infiltration (HEC-HMS Technical Reference Manual, 2000).

The potential loss rate (It) may express as follows:

$$It = (LR + II) * PRt^{ER} \quad (1)$$

$$II = 0.2 * IIR * (1 - CML/IIR)^2 \quad (2)$$

$$LR = ST/RTL^{0.1*CML} \quad (3)$$

where PRt = precipitation rate (mm/hr) at time *t*, ER = precipitation exponent, LR = loss rate coefficient at the beginning of the time interval, II = incremental increase in the loss rate coefficient during the first IIR (mm) of accumulated loss, It. If (It *)* is greater than IIR, II = zero, CML is the accumulated loss (mm) (HEC-1 Flood Hydrograph Package Users Manual, 1998), (HEC-HMS Technical Reference Manual. 2000).

2.7.2 Transform Method

Clark's model start with the continuity equation:(Technical Reference Manual. 2000)

$$\frac{dS}{dt} = It - Ot \quad (4)$$

In which $\frac{dS}{dt}$ = change of water storage; I = the average inflow; Ot= the out flow at t of time.

The storage at time t (for linear reservoir model) is related to outflow as:

$$S(t) = R * O(t) \quad (5)$$

where R =constant linear reservoir parameter.

The basin storage coefficient, R, is an index of the temporary storage of precipitation excess in the watershed as it drains to the outlet point.

$$\frac{R}{Tc+R} = 0.65 \quad (6)$$

Time Concentration (Tc) of clark model was over estimated, so Kirpich formula was used

$$Tc = 0.00013 * L^{0.77} * S^{-0.385} \quad (7)$$

Where: Tc= Time of concentration, (hr). L= Length of channel from the farthest point to the outlet of the watershed, (km). S= Slope of the longest hydraulic length.

2.8 Model Calibration and Applications

The HEC-HMS model was calibrated (manual and optimized) using observed data (Table 2). The match between observed (II) and simulated hydrograph of the direct runoff was very acceptable in terms of shape, volume and discharge of the runoff (Figure 3) so it was considered. The final parameters values for optimized calibration of the HEC-HMS model were recorded (Table 3). The statistical criteria that evaluate the performance of the HEC-HMS model were recorded (Table 4), showing that the results of HEC-HMS model is very close to the observed data. In the first step of application process, the locations of the proposed RWH dams were selected based on the DEM of the study area in addition to the hydrological and dams were selected based on the DEM of the study area in addition to the hydrological and geological conditions, then HEC-HMS was applied for each selected dam in order to estimate direct runoff volume that inters the reservoir of the selected dam. The procedure was applied for each individual rainfall storm of the average rainfall seasons which occurred in 2000-2001 of the study period 1985–2018.

Table 2. Observed hydrographs data of season 2003-2004 at the al-khoser watershed (Ezz-Aldeen, M., 2005)

Rainstorm No.	date	Rainfall Depth (mm)	Intensity mm/hr	Peak Runoff (m^3/sec)	Peak Sediment (Kg/m^3)
I	19/2/2003	19	0.9-8.0	32	2.6
II	22/2/2003	18	2.0-3.5	51	3.2

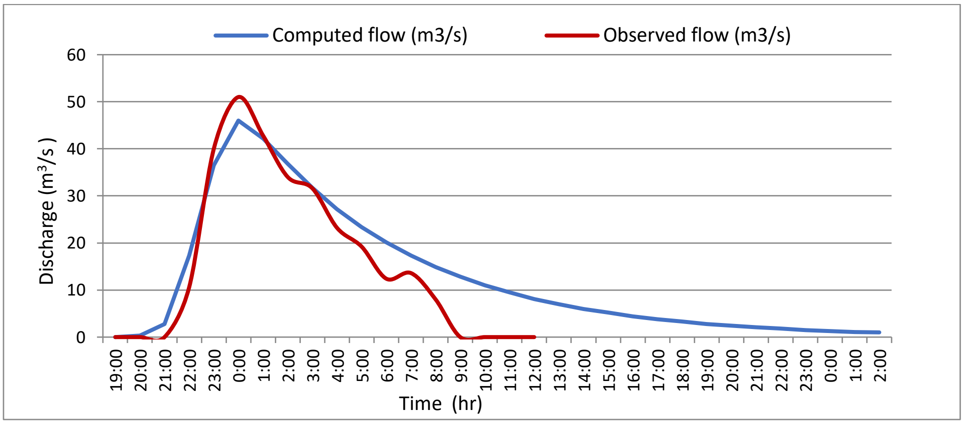

Figure 3. Comparison between computed and observed direct runoff hydrograph

Table 3. Optimized calibration results for HEC-HMS model using Clark - exponential methods

Method	Parameter	Units	Intial values	Optimized values	Objective Function Sensitivity
Clark U. H.	Storage Coefficient	HR	5.500	6.6145	1.32
Clark U. H.	Time of Concentration	HR	4.500	3.2942	1.12
Exponential	Coefficient Ratio		0.650	0.95	4.48
Exponential	Exponent		0. 85	0.79890	-2.06
Exponential	Initial Coefficient	(MM/HR)^(1-x)	0.700	0.89975	-5.57
Exponential	Initial Range	MM	0.0	0.0	0.00

Table 4. Statistical criteria results using Clark - exponential method

Statistical criteria	Value	Unit
Nash–Sutclife Efficiency (NSE)	96.4	%
Root Mean Square Error (RMSE)	1.5	m3/S
Mean Absolut Error (MAE)	2.3	m3/S
Observed peak Discharge	51	m3/S
Simulated peak Discharge	46	m3/S

3. DAMS HYDROLOGICAL ASPECTS

Hydrological aspects of the three RWHDs included elevation-area-storage curves, dead storages, live storages, flood storages, and the capacities of the outlets.

3.1 Elevation-Area-Storage Curves

WMS was used to identify the elevation-storage curves for the three RWHDs. This relation was adopted to specify the relationship between the elevation and area of storage. Figure 4 show the elevation-storage curves of RWHD that located in 2B.

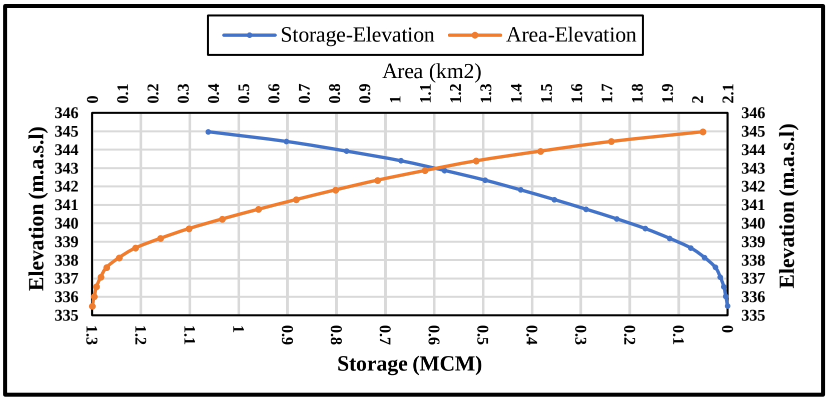

Figure 4. Elevation-Area-Storage curve of RWHD that located in 2B

3.2 Dead Storage

The dead storages of RWHDs were specified based on amounts of sedimentation that observed at the out let of main basin, in addition to the economic reservoir life is 25 years. The dead storage for each RWHD was calculated. Table 5 shows the calculation of dead storage for the reservoir of 2B basin.

Table 5. Calculation of dead storage for 2B reservoir based on clark and exponential methods

Date	Dayly Runoff Discharge (MCM)	Sediment Equation S=0.0661*Q^0.942 (Mkg\day)	Suspended Load (SL) (Mkg\month)	Not.
1-31/10/2000	0	0	0	Oct.
24/11/2000	3.2	0.197720973		
30/11/2000	3.8	0.232465018	0.430185991	Nov.
01/12/2000	20.4	1.132069467		
15/12/2000	23.4	1.288257849		
16/12/2000	5.7	0.340592887		
22/12/2000	1.9	0.121000552		
23/12/2000	3	0.186058571	3.067979326	Sept,
27/01/2001	16.8	0.942850429	0.942850429	Jan.
16/02/2001	18.1	1.011427312	1.011427312	Feb.
13/03/2001	38.5	2.059232893		
21/03/2001	5.2	0.312375245		
29/03/2001	1.3	0.084632291		
30/03/2001	3.8	0.232465018	2.688705446	Mar.
08/04/2001	1.5	0.096845495		
13/04/2001	17.8	0.995628	1.092473495	Apr.
15/05/2001	1.8	0.114992141	0.114992141	May
			9.348614139	SL Mkg/year

7029.033187	SL m3/year
8434.839825	Total L m3/year
210870.9956	Total L m3/25year
0.210870996	Total L MCM/25year

The sedimentation amounts were distributed arbitrary to the three sub-basins of RWHDs according to area percentage of each sub-basin relative to the main basin. According to this procedure, the following mathematical equations (8, 9, and 10) were identified for 2B, 3B, and 4B respectively. The mathematical equations carfuly describe the relation between susbended load and discharge of runoff.

$$S = 0.0661 * Q\text{^}0.942 \quad (8)$$

$$S = 0.0649 * Q\text{^}0.942 \quad (9)$$

$$S = 0.0649 * Q\text{^}0.942 \quad (10)$$

3.3 Live Storage

To determine the live storage of RWHDs, the average year of the rain series was used in HEC-HMS to specify the daily runoff for this time series, daily runoff was converted to monthly runoff. The monthly water demand at downstream of basin 2 was estimated to be 0.4829 MCM. The Tabulation Method (Table 6) was used to calculate the live storage for reservoir of 2B basin.

Table 6. Calculation of live storage for reservoir of 2B basin

Month	Inflow (MCM)	Demand (MCM)	Deficit (MCM)	Surplus (MCM)	Acc. Deficit (MCM)	Acc. Surplus (MCM)	Water wasted (MCM)
10	0	0.4828	-0.4829		-0.4829		3.1045
11	0.2193	0.4828	-0.2636		-0.7465		
12	1.8834	0.4828		1.4005		1.4005	
1	0.579	0.4828		0.0961		1.4966	
2	0.6247	0.4828		0.1418		1.6384	
3	1.7675	0.4828		1.2846		2.923	
4	0.6642	0.4828		0.1813		3.1043	
5	0.0565	0.4828	-0.4264		-0.4264		
6	0	0.4828	-0.4829		-0.9093		
7	0	0.4828	-0.4829		-1.3922		
8	0	0.4828	-0.4829		-1.8751		
9	0	0.4828	-0.4829		-2.358		

3.4 Flood Storage

To determine the flood storage, the highest wave rain observed was used within the time series adopted of rain. 50.000 cubic meters for the three RWHDs were store in reservoir while the remaining water is released to downstream by spillway.

3.5 Capacities of Outlets

The capacities of sluice gates were determined based on the inflow rates for the sub-basins which represent the water requirements at the bottom of the three RWHDs. The capacity of bottom out let and spillway were specified based on the highest flood storm in the highest rainy year. The highest rainall depth was 43.5 mm during season 2000-2001. The volumes of water product at the outlets of 2B, 3B, and 4B were 1.4322, 1.0384, and 1.4386 MCM. According to this methodology, the capacity of the bottom out let was inserted 0.1 MCM. The spillway capacity was calculated based on the highest wave in the highest rainy year. As mentioned previously, 50,000 cubic meters of this wave were reserved, the rest of this wave represents the capacity of the bottom out with spillway.

3.6 The Elevations

The elevations of dead storage (sluice gate), live storage (spillway), and flood storage of RWHDs were identified using elevation-area-storage curves. In addition, dam crest, dam base were identified. The elevations of dam crest for RWHDs were determined by add the free board (F.B) of each dam to the head of water (H) in the reservoirs using equation 16.

$$F.B = 4\%(H+F.B) \tag{11}$$

4.0 HYDROLOGIC ASPICTS OF RWHDs

the hydrologic aspicts of the three harvisting dams were inserted in Table 7.

Table 7. Hydrologic aspicts of the three harvisting dams

Details of RWHDs	2B	3B	4B
Dead storage (MCM)	0.210870996	0.152429177	0.213443999
Live storage (MCM)	0.75	1.447570823	2.28656
Flood storage (MCM)	0.05	0.05	0.05
Elevation of sluice gate (m.a.s.l)	340.0	339.8	301.3
Elevation of spillway (m.a.s.l)	344.650	344.8	306.8
Elevation of Flood storage (m.a.s.l)	344.814	345.2	307.1
Elevation of dam crest (m.a.s.l)	345.2015	345.583	307.479
Elevation of dam base (m.a.s.l)	335.5	336	298
Head of water (m)	9.314	9.2	9.1
Free board (m)	0.3875	0.383	0.379
Head of dam (m)	9.714	9.583	9.479
Capacity of sluice gate (MCM)	0.4829	0.350	0.495
Capacity of bottom outlet (MCM)	0.1	0.1	0.1
Capacity of spillway (MCM)	1.2822	0.8884	1.2886

5.0 RESULTS and DISCUSION

5.1 Runoff Results

The estimated runoff volumes that enters the selected reservoirs were produced by rainfall of season 2000-2001. The results of Table 8 showed that there are appropriate quantities of water worth considering that can be stored in the selected dams reservoirs, then, to be employed for various purposes to achieve the water demand in a semi-arid environment where there is no surface water available.

Table 8. Harvested runoff of selected Basins, over the 2000-2001 (average rainfall season)

ID of RWHDs	2B	3B	4B
The annual Volume of surface runoff (MCM)	5.7946	4.1948	5.9479

The average annual quantities of surface runoff were 5.7946, 4.1948 and 5.9479 MCM in basins 2, 3 and 4 respectively with a total of 15.9373 MCM. The hydrological conditions are similar for the three selected basins, however, the area of basin 4 was the main reason that lead the surface runoff of basin 4 greater than each of basins 2 and 3. The total rainfall depth for the average rainfall season is about 263.4 mm, the mimimum and maximum rainfall dept were 5.7 and 43.5 mm respictivily that produced runoff with volume of 0.047 and 1.4322 MCM with 1.3 and 38.5 m^3/sec of peack runoff discharge respictivily for the basin 2B. while same rainfall depths gave the followin results: for basins 3B, Runoff volumes were 0.0295 and 1.0384 with peack runoff discharge of 0.9 and 27.9 m3/sec respictivily. While for basins 4B, the runoff volumes were 0.0422 and 1.4386 MCM with peack runoff discharge of 1.3 and 39.9 m3/sec respictivily.

5.2 Hydrologic Aspicts of RWHDs Results

The results shows that the dead storage volumes of the three reservoirs of basins 2B, 3B and 4B will reach up to 0.210870, 0.152429, and 0.213443 MCM. The topography of the seasonal Al-Khoser River catchment, in addition to the conditions of construction rainwater harvesting dams are combined to be the dominant factors that determine the Hydrologic aspects of RWHDs. The results shows that there is an abundance of water harvested from basins of Al-Khoser River during the average rainy season (2000-2001). The live storage of selected reservoirs of basins 2B, 3B, and 4B reach up to 3.1045, 2.250, and 3.184 MCM respectively. However, as a result of the dominant factors, it is not possible to store the entire live storage due to limited capacity storage of the reservoirs in addition it is not possible to increase the height of the dam due to a limited depth of the valley at the dam site. Therefore the maximum volume of live storage of reservoir 2B, 3B, and 4B that can be stored reach up to 0.7500, 1.447570, and 2.286560 MCM respectively. The capacity of bottom out let and spillway were specified based on highest rainall depth for the study period (1985-2020) which was found to be 43.5 mm during season 2000-2001. The volumes of water product from this highest rainy at the outlets of 2B, 3B, and 4B were 1.4322, 1.0384, and 1.4386 MCM, based on clark and exponential methods of HEC-HMS model. Accordingly, the capacity of the bottom out let was inserted 0.1 MCM. The spillway capacity was 50,000 cubic meters based on the highest wave in the highest rainy year. The Capacity of sluice gate of selected RWHDs reach up to 0.4829, 0.350, and 0.495 MCM for the reservoirs 2B, 3B, and 4B respectively. The spillway elevations of the three selected RWHDs reach up to 344.650, 344.8, and 306.8 m.a.s.l, while the flood elevation reach up to 344.814, 345.2, and 307.1 m.a.s.l. The spillway capacity of reservoirs 2B, 3B, and 4B reach up to 1.2822, 0.8884,and 1.2886 MCM respectively.

6. CONCLUSION

The volumes of water harvested are larger than the capacity of the dams reservoirs that can be constructed at the outlets of the selected basins during the average rainy season 2000-2001. In the present study, the main basin was divided into three sub-basins. The spacing between these three reservoirs helps to achieve maximum benefit to the people living on the study area. The most important of RWHDs, which is increasing job opportunities, as the availability of water contributes effectively to the agricultural production of crops of national income.

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Conflict of Interest

The authors declare that they have no competing interests. Confict of Interest- None, and the research was not funded.

Contribution of Authors

Saleh Mohammed Saleh Zakaria: Conceived and designed the analysis, performed the computer simulations, developed needed model, and wrote the paper.**Yousif H. Al-Aqeeli:** Contributed mathmatical calculation, analysis tools, , and wrote the paper**.** **Ali A. Abdulmawjood :** Performed the text mining analysis and Collected the data**.**, **Omar M. A Mahmood Agha:** statistical analysis

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