Coupled 1D Hydrodynamic-Water Quality Model of Kobadak-Sibsa River System for Salinity

A. Haque, K. M. A. Hossain, and N. Shadia

Abstract—**Salinity intrusion creates severe problems in agriculture and drinking water sources in the floodplain of tidal rivers due to low upstream flow and climate changes. This study focuses on 1-D advection-dispersion modeling of the Kobadak-Sibsa river by HEC-RAS. This work has been carried out in simulation of temporal distribution of salinity concentration in different locations which help to identify which location exceeds the chloride limit of drinking water of 1000 ppm and chloride limit in agricultural water limit of 1500 ppm. The hydrodynamic model was coupled with 1D salinity modeling. The calibration was done for the month June 2016. Then the validation was done using the data of July 2015. It has been found a good agreement between simulated and observed water level for Manning's roughness coefficient as 0.021. Once the hydrodynamic model was calibrated and validated, the 1D advection-dispersion model was performed and calibrated and validated for the year 2016 and 2015 for different dispersion coefficients (D) for different reaches as a tuning parameter. It has found that the higher the dispersion co-efficient the higher the salinity concentrations that the dispersion co-efficient varied from 25 m^2/s to 9000 m^2/s which showed good agreement between simulated and observed salinity data. From December salinity gradually increases and reaches its peak in April or May. Maximum salinity concentration has been determined in different locations by simulating this model. This hydrodynamic and water quality coupled modeling can be helpful for lesson learning to prevent salinity intrusion in the Kobadak river.**

Index Terms—**Hydro-dynamic modeling, salinity, Kobadak-Sibsa, HEC-RAS.**

I. Introduction

The amount of salt in rivers is referred to as salinity and it can be found in different forms in the river. Generally, the concentration of salinity is expressed either by total dissolved solids measurement (TDS) or the electrical conductivity measurement (EC) [1].

Bangladesh is a riverine country and was formed by deltaic deposits of the Ganges-Brahmaputra-Meghna. Due to the commission of Farakka Barrage on the Ganges River in 1975 and carrying a large amount of silt and human intervention causes the natural flow of the Kobadak-Sibsa river has been drastically reduced and altered [2]. In at last twenty years, flow volume in the dry season (December – April) has been declining. So, surface salinity downstream of Kobadak and

Sibsa river begin to increase rapidly from December and reaches the peak in late March or early April. Salinity intrusion has a serious environmental impact. Especially along with the coastal areas around the sanctuary forests where the salty water has increasingly been intruding [3]. In recent years, groundwater-based water supply in the coastal area is suffering from several major problems mainly arsenic contamination, lowering of the water table, salinity, and non-availability of suitable aquifers [4]. The Kobadak River originates from the Mathabangha at Chuadangha which is one of the most important distributaries of the Ganges River. It falls into the Sibsa at Paikgacha, Khulna. Over a while, the river has lost its drainage capacity due to morphological characteristics of the river that is governed by human interventions and the sedimentation process. So during each peak monsoon, waterlogging is a common phenomenon due to the overflow of water in the bank [5]. The recent 262-crore Kobadak River dredging project will allow us to lead a comfortable life along the banks of the river. This dredging project might be solved water-logging in their areas and more freshwater will flow through the Kobadak-Sibsa river.

SWR is composed of 15 sections, occupying 17% of the suburban areas of Bangladesh. The land's 62% is farmland, its 15% is covered with mangrove forests (Sundarbans), and its 13% is water areas [6]. Sundri top dying disease will occur if salinity exceeds 15000 ppm, water becomes less useful as salinity increases to 1000 ppm [7], irrigation water becomes doubtful if salinity exceeds 1500 ppm [8].

In the past, different researchers have worked on salinity intrusion where they used a numerical and analytical model to research salinity intrusion. 2D and 3D numerical models are extensively used to study salinity intrusion, as well as these models, give detailed results. In the Sebou river estuary, the salt intrusion was computed using HEC-RAS 1D and it was found that there was a steep decrease in the salinity profiles of Sebou estuary [9]. The effect of sea-level rise on salinity intrusion in the Sebou estuary was studied by HEC-RAS 1D. It has been found that with increasing sea level rise there observed an increase in the time period for the violations of salinity standards. They also run the model for different range of discharges and they found an inverse relationship between discharge and salinity intrusion [10]. For this, the 1D Mathematical model has been found effective in the preliminary phase of a project or for lesson learning.

In this study area, the Kobadak river is the source of fresh water, a non-tidal river, and the Sibsa river is a tidal river. The width of the Kobadak river is small with the width varied from 100-250 meters is facing salinity intrusion from Sibsa during flood tide. The variations of salinity concentration in the lateral direction are small compared to the longitudinal

direction as well as for this kind of large study area, the one-dimensional advection-dispersion model is suitable. So, In this research, an attempt has been made to analyze salinity concentration at different locations using HEC-RAS 1D. The specific objective of this study is-

1) To set up the hydrodynamic model of the Kobadak-Sibsa river system using HEC-RAS and its calibration, validation, and simulation.
2) To set up of water quality model and performing a water quality calibration, validation and simulation of the Kobadak-Sibsa river system using HEC-RAS.
3) Simulation of salinity concentration at different locations of the study area using HEC-RAS.

II. STUDY AREA

For the present study, the Kobadak-Sibsa river is chosen as the downstream of the Kobadak and the Sibsa river is a mixed estuary. Upstream of Kobadak river is not mixed and in fact, it is the most important source of fresh water supply in the downstream in South West region and the recent completion of Kobadak dredging project will allow the researchers to contribute to restore the environmental flow and prevent salinity intrusion. Fig. 1 [11] shows the study area which was conducted on the 130 km of Kobadak-Sibsa River stretching between the Jhikargacha river station in the upstream and the Sibsa River in the downstream named Nalianala_Hadda river station. The average width of the Kobadak river is 400 m including its floodplain. The Kobadak River flows in the southern periphery and meets Sibsa near Paikgacha an important source of the Sibsa river. The average width of the Sibsa river is 1250 km and is about 100 km long. The river forms much of the boundary between Paikgachha and Dacope upazilla. Inside the Sundarbans Reserve Forest, it meets the Passur River, then separates again near Mongla, before reaching the Bay of Bengal [12].
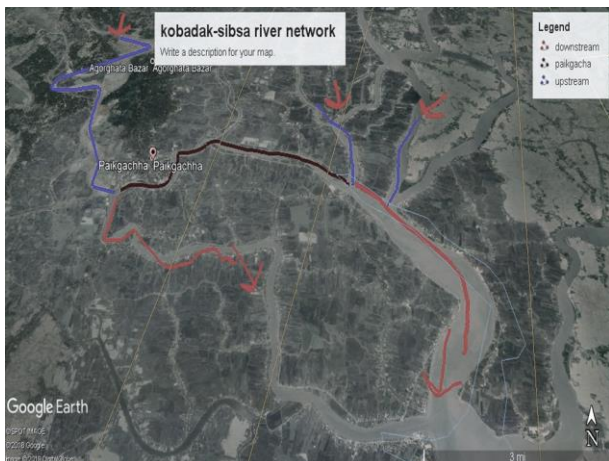

Fig. 1. The Kobadak-Sibsa full network (Source: https://www.google.com/earth/).

III. METHODOLOGY

A. Data Collection

For the development of the hydrodynamic and salinity model of Kobadak-Sibsa River, data of bathymetry, discharge, stage hydrograph, and salinity concentration at

different stations have been collected from relevant sources which are shown in Table I. 30 cross-section data (19 of Kobadak, 6 of Passur river, and other 5 are interpolated) of Kobadak-Sibsa river were collected.

TABLE I: DATA COLLECTION

Data type	Source	Data location	Period
Bathymetry	BWDB	Kobadak-Sibsa	2000-2017
Discharge	BWDB	Jhikargacha	2015,2016
Water level	BWDB	SW-162-164,258-259	2000-2017
Salinity	BWDB	SW-162,258,259	2000-2017

B. Model Setup

For model simulations, the hydrodynamic and one-dimensional advection-dispersion model is coupled. For this coupling, two steps are involved which are as follows:
● Hydrodynamic modeling
● Water quality analysis

In the hydro-dynamic model setup, Schematic diagram was drawn in the geometric editor of HEC-RAS. Then bathymetry data for the year 2016 were inserted for Kobadak and Sibsa river.Then, the flow hydrograph of Jhikargacha SW-162 and stage hydrograph SW-258, 242 for another upstream branch have been inserted as the upstream boundary condition. For the downstream branch, two stage hydrographs SW-259, 164 have been inserted as the downstream boundary condition. Data for January 2016 to December 2016 are used. SW-29 stage hydrograph is used for calibration and validation for June 2016 and July 2015 respectively. The time step used for the one-dimensional hydrodynamic model is 6 hours.

First, a new water quality file was created. Then arbitrary constituent was selected as Water Quality constituents. Tracer was mentioned as conservative. The minimum cell length was given 200. Salinity concentration data for three upstream branches and two downstream branch rivers have been inserted as the boundary condition. No branch is neglected as upstream flow is very important for salinity analysis. Initial salinity concentration and different dispersion co-efficient for different reaches have also been inserted for model simulation [13]. The maximum allowable time step used for the one-dimensional advective-dispersion model is 30 minutes. In water quality computations options, the user can select the maximum allowable time assigned by the model and the model codes constantly adjust the model time step to ensure a Peclet number less than 0.4 and Courant number less than 0.9 to enhance model stability [14]. Paikgacha station is used for calibration of salinity graph for January 2016 to December 2016. For validation, the model was run for the year of 2015 for the hydrodynamic analysis. Then, three upstream boundaries and two downstream salinity concentrations for the year 2015 were inserted. Then the salinity model is simulated and validated for the Paikgacha stations for the year 2015.

IV. DATA ANALYSIS AND RESULTS

A. Calibration and Validation of Hydrodynamic and Salinity Model

For calibration and validation of the Hydrodynamic and

salinity model, 2015 and 2016 data were used because all the data were available for all the stations for these two years. The hydrodynamic model is calibrated using the data of June 2016 (Fig. 2). Then this model is validated using the data of July 2015 (Fig. 3). Model simulated tidal range showed a satisfactory agreement with the observed values for Manning's roughness coefficient as 0.021. Once the hydrodynamic model is calibrated and validated, the salinity model is performed and calibrated for the year 2016 for different dispersion, the coefficient (D) for different reaches as a tuning parameter. It has been found that for Kobadak upstream dispersion co-efficient D=25 m^2/s, Kobadak river downstream D=780 m^2/s, Paikgacha D=2000 m^2/s, Sibsa upstream D=300 m^2/s, and downstream D=9000 m^2/s which are shown in TABLE II . Being a small river, the dispersion coefficient of Kobadak is low, on the other hand, the river Sibsa is a big river with a width varying from 1000m to 5000m for which the dispersion coefficient is found in an increasing trend. Then the salinity model is again validated for the year 2015 and found very good agreement between observed and simulated salinity concentration. For the 1D salinity model, the R^2 was found around 0.86 for both calibration and validation.
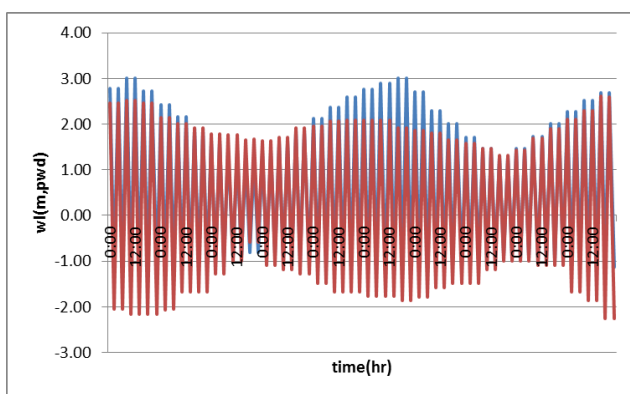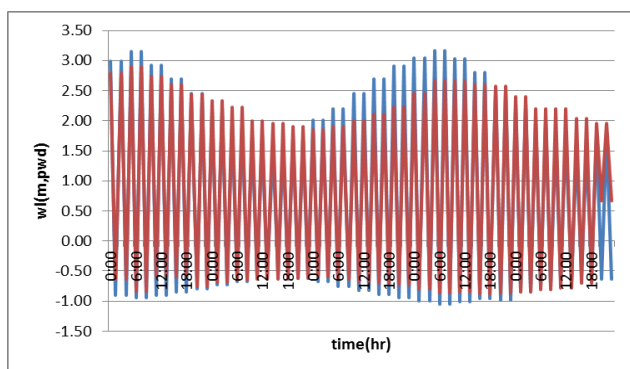

Fig. 2. Calibration graph for *n*=0.021.

Fig. 3. Validation graph for *n*=0.021.

The salinity concentration value of the River is determined by Water Quality Analysis through HEC-RAS. The salinity concentration differs with the different advection-dispersion coefficients used in the model. From the table, it has found a relationship between salinity and dispersion coefficient. At the upstream where there is a source of freshwater, the dispersion co-efficient is smaller but at downstream of reaches where the salinity concentration is high, the dispersion co-efficient is larger. For the reach, Paikgacha (station no:39), the salinity concentration value determined

from the model is compared to the original salinity concentration value of the Paikgacha SW-258.

Salinity concentration is given and computed in mg/L. The unit of the dispersion coefficient is in m2/s. Calibration is done for January 2016 to December 2016 which is shown in Fig. 4. The maximum possible value of the dispersion coefficient is determined through analysis which is shown in TABLE II . Here, we used the fixed dispersion co-efficient value. We simulate the model with lower and upper limit value dispersion co-efficient. But there was seen no significant difference comparing with the water quality model simulated by fixed dispersion co-efficient value. It has also been found that it requires comparatively less time simulating with only fixed dispersion co-efficient. The high fluctuations in the concentration are also observed simulating with lower and upper limit value dispersion co-efficient.
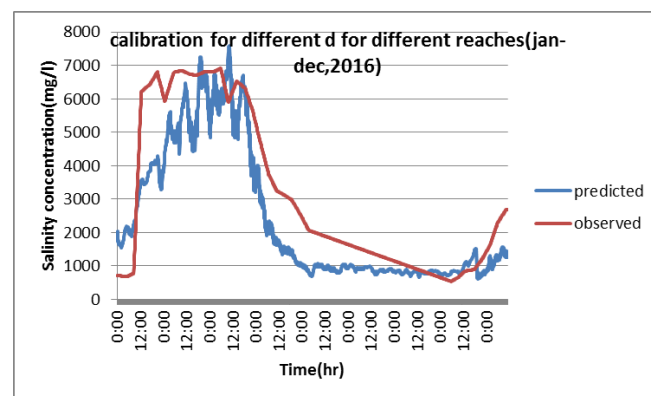

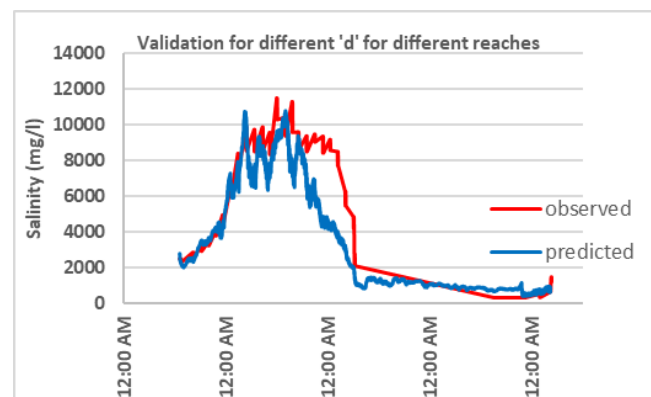Fig. 4. Salinity concentration graph for different d at SW-258(paikgacha).

Fig. 5. Salinity concentration graph for different d at SW-258(paikgacha).

TABLE II: FIXED DISPERSION AT DIFFERENT REACHES

River	Reach	RS	Fixed dispersion(m^2/s)
Kobadak-Sibsa	Paikgacha	40	2000
Kobadak	Upstream	60	25
Kobadak	Downstream	30	780
Sibsa	Upstream	52.5	300
Sibsa	Intermediate	39	548
Sibsa	Upstream	70	105
Sibsa	Downstream	5	9000

Table II provides the dispersion co-efficient used for different reaches. So when considering the main channel with branches it will be better to use different co-efficient values for different reach. Dispersion coefficients were estimated based on the Fischer equation [14]. This equation is based on velocity, top width, frictional slope, shear velocity, depth of the channel. The magnitude of the dispersion co-efficient

also depends on the magnitude of the salinity boundary conditions.

B. Simulation of Salinity Concentration at Different Locations

It has been found that from December salinity gradually increases and reaches its peak in April or May. Maximum salinity concentration is found in different locations such as in Jhikargacha 135 mg/L, Tala Magura 335 mg/L, Godaipur 4670 mg/L, Paikgacha 7700 mg/L, Bishnipur 8650 mg/L, Sutarkhali 12250 mg/L, Nalian 13000 mg/L . The maximum salinity was observed in the month of May for the Kobadak river but for the Sibsa, river maximum salinity was found in the month of April or March.

Fig. 6 is for Agorghata which locates at a distance of 20 km upstream of paikgacha. It indicates that the maximum salinity is 1600 mg/L which occurs in the month of mid-April and at this time the water is not usable either as water drinking or agricultural purposes. In the monsoon period, the salinity does not create problems in the livelihood of the people living in this area as the salinity concentration remain below the threshold limit for agricultural and drinking uses value Which can be observed from the temporal distribution of salinity concentrations. The pre monsoon time period of salinity limit exceedance can be considered as a great problem for this location. In near Jhikargacha station, the maximum salinity simulated by the model is 330 mg/L in the month of May. This station is suitable both for drinking and irrigation purposes throughout the year.
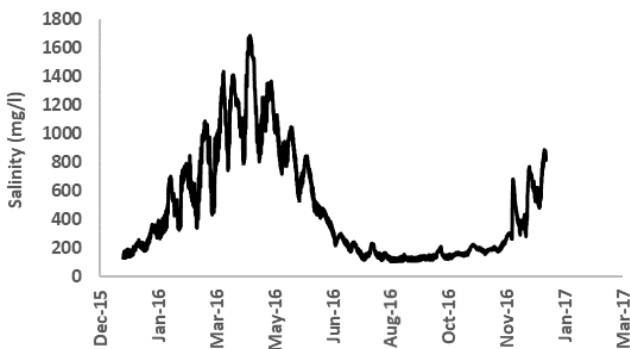

Fig. 6. Salinity graph at Agorghata.

At Godaipur, In Fig. 7, it is indicated that the maximum salinity is 4670 mg/L which occurs in the month of mid -April. This station is located at about 9 km downstream of Agorghata. The salinity for this station increases by almost 2.5 times then that of salinity located at the Agorghata station.The salinity concentration is not in good range for agricultural and drinking water purposes. The fluctuation of concentration is also very high at pre-monsoon period as it is situated in the station where fresh water meets with saline water. But for this station, the fluctuations in the salinity during monsoon period is less compared to the salinity of the pre-monsoon period. This difference in the fluctuations is caused by the total amount of upstream water that passes through this river.

Fig. 8 is for Paikgacha. It is shown that that the maximum salinity is 7700 mg/L which occurs in the month of mid -April.Here the amount of salinity is higher than Agorghata and Godaipur station. As this location is located near the tidal

river name Sibsa the salinity concentration is very high. During the year of 2016 the salinity remain above the 1000 mg/L which indicates that the water is not suitable for drinking purposes but can be used this location for irrigation purposes. Thorough the Paikgacha the Kobadak river meets with the Sibsa river and fall into Bay of Bengal for which salinity increases gradually in the downstream upto 34000 mg/L and it has found that at Nalian station the maximum salinity is about 13000 mg/L in the month of March. At Nalian station the boundary of Mangrove forest is started and extented upto Bay of Bengal. If the salinity exceeds 15000 mg/L, it will be threat for sundri trees and sundri top dying disease will be seen which will create severe ecological imbalance for this region. The salinity is increasing in the Sibsa river and Kobadak river because there are also other two upstream branches in the Sibsa river. These two branches bring salinity from Rupsha -Passur river.
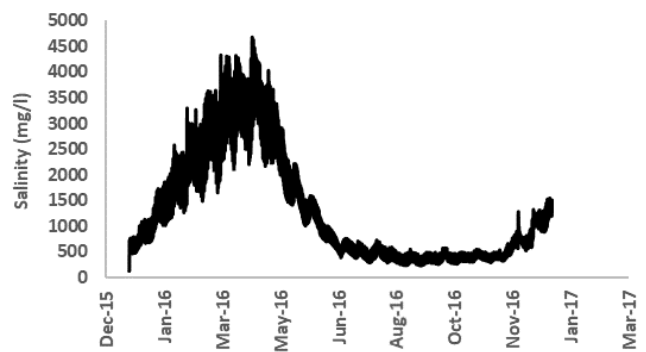

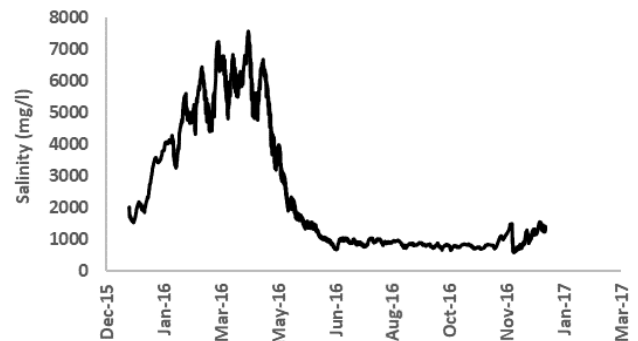Fig. 7. Salinity graph at Godaipur.
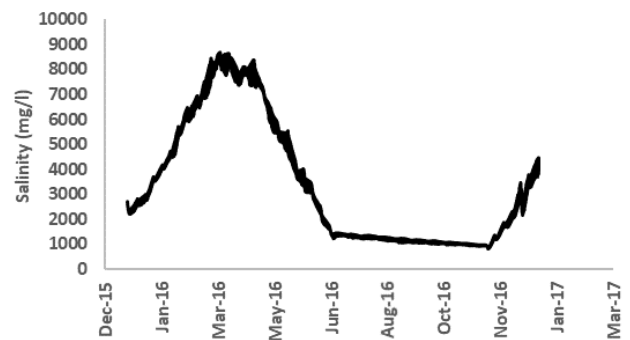

Fig. 8. Salinity graph at Paikgacha.

Fig. 9. Salinity graph at Bishnipur.

Fig. 9 is for Bishnipur and this station is located at downstream of Kobadak river where Upstream Kobadak river bifurcates near the Paikgacha station. That shows that the maximum salinity is 8650 mg/L which occurs in March. As this location locates in the tidal river the salinity

concentration is usually very high. From this Fig. 9 we have seen that the maximum salinity is observed in March but for the upstream station the maximum salinity is observed in the month of April or May. The time difference to observe the peak is due to insufficient upstream flow through the Kobadak and other upstream river branches.

V. CONCLUSIONS

In this study, an attempt has been made to analyze salinity concentration at some specific location. The calibrated and validated model can be effectively used to determine salinity distribution along the river length. The temporal distribution of salinity concentration at different locations helps us to identify that the maximum salinity occurs in April and May, at the end of the dry season, During December to May. Water is neither used as a source of drinking water nor for irrigation, nearly paikgacha and its downstream as salinity concentration exceeds water drinking limit 1000 ppm and agricultural water limit 1500 ppm (WHO, 2011). The salinity intrusion zone has increased and is more than in any previous years. Salinity in Jhikargacha, Hazirbaagh, Ujjalpur, Bankra, Deara, Digdana, Mathshia, Chakla, Nowali remain within safe limits throughout the year. But it has been found that the maximum salinity in Agorghata is 1600 ppm, in Godaipur is 4670ppm, in Paikgacha is 6500ppm, and downstream of Paikgacha such as in Bishnipur is 8650ppm, in Sutarkhali is 12250ppm, in Nalian is 13000ppm for the year of 2016. Thus this model here describes the temporal pattern of the salinity concentration. This salinity model has given a 6 hourly salinity concentration change which is much more similar to the observed salinity concentration. It is found that the HEC-RAS 1-D advection-dispersion model can serve as a tool to describe the salinity distribution as a solution for hydrodynamic and water quality analysis which can be very supportive for water policymakers and engineering to make initial estimates on the salt distribution along the estuary. Finally, the downstream boundary should extend to the sea so that one can investigate the impact of climate change and sea-level rise on salinity distribution.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The first author was responsible for setup the 1D hydrodynamic-salinity model and writing the article. The second author was the supervisor of the first author who provided valuable suggestions to conduct this research study. The third author contributed to improve the work according to reviewers. All authors approved the final version of the work.

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