**Journal of Academic and Applied Studies**
**(Special Issue on Applied Sciences)**
**Vol. 3(10) October 2013, pp. 32-45**
**Available online @** www.academians.org

**ISSN**1925-931X

# Flood Management of Sistan River using Levee

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**Abstract**

Flood is one of the natural disasters that leave great deal of financial and human losses every year. Application of levee is among the common flood control measures. Sistan Alluvial Plain is permanently prone to floods because of being situated on the edge of Hirmand Basin and also having negligible ground slope. Increasing of maximal flow rate by levee, using HEC-RAS mathematical model were studied in the present research. For this purpose, the geometrical plan of the river was prepared with the aid of HEC-GeoRAS software and through using regional topography data. After importing the data to HEC-RAS model, flood phenomenon was simulated in different return periods. Results of the current research indicate that Sistan River is not able to transport water at a flow rate exceeding 810 ($m^3/s$); this current is equivalent of flood with recurrence interval of 9 years. To enhance the flood conveyance capacity of Sistan River, levee structure was applied. The results show that using levee increased river's conveyance capacity up to the flow rate of 1700 ($m^3/s$) which is equivalent of a recurrence interval of 107 years. Therefore, application of levee on Sistan River can favorably mitigate the risks resulting from flooding in Sistan Plain.

**Keywords: Floodzoning, Flood control, Levee, HEC-GeoRAS, HEC-RAS, Sistan river.**

## I. Introduction

Flood is one of the most important natural evils leaving detrimental impacts on human society. In addition, this natural disaster annually causes great deal of human and financial losses (Cook and Merwade, 2009). These losses include destruction of agricultural soils, devastation of different installations such as channels, bridges, routes, and other constructions, transport of solids into dam lakes, death of organisms including humans, destruction of urban societies, and ultimately, wastage of a large volume of high-quality and suitable waters (Shu et al., 1993).

Tate et al (2002) implemented a model for preparing the flood zones using HEC-RAS and GIS programs in Waller River, Austin, Texas. The digital model of the ground was analyzed through merging HEC-RAS data and the flood zones were determined. HosseinZadeh et al. (2003) applied GIS for hydraulic analysis using HEC-RAS and stated that: HEC-GEORAS makes a remarkable contribution to development of geometrical data for entry into HEC-RAS

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environment and also representation of water surface profile. Earles et al. (2004) demonstrated capability of HEC-Geo-RAS model for simulation of floods in plains and determination of the needed hydraulic parameters for HEC-RAS software as well as application of output results of HEC-RAS model in Los Alamos, New Mexico, USA. Lagason (2008) delineated the domain of KOTA MARUDU Floodplain using HEC-RAS and ARCVIEW GIS models. Cook and Merwade (2009) studied effect of topography data and geometrical state on flood maps by means of HEC-RAS and FESWMS software packages. They concluded that inundation forecast and diversity of the maps related to flooding with different factors modeled by FESWMS was less successful than HEC-RAS in the regions under study. Solaimani (2009) merged the hydraulic model of HEC-RAS with ArcGIS software in the upstream section of TAJAN River and estimated the flood zonation. Yang et al. (2010) analyzed the mutual impacts of levees and flood control dam through a research conducted by means of HEC-RAS model. Their results revealed the fact that design and construction of levees with heights of 1.2, 1.4, and 1.8 meters could lead to reduction of the dam elevation. Tayari et al. (2011) applied Hec-GeoRas and examined different methods to protect the Khabr river located in Kerman province, Iran. The results showed that one of the best ways to protect the lands around the river is using levee on either sides of river. Preparation of flood maps provides valuable information for managers and experts to reduce flood damages (Hassanpour et al., 2012).

Sistan Plain has a population of around 400,000 persons. The region's economy is deeply reliant on agriculture. More precisely, agriculture and fish farming account for 38% of the economy, 54% belongs to the service sector, and the industry sector only accounts for the rest 6%. Since unemployment rate is very high in the region, Iran's government recently has carried out irrigation systems in 120,000 hectares of the agricultural fields (Beek et al., 2008).

The average gradient of Sistan River is very gentle and nearly 0.0002. Additionally, current fluctuations of Sistan River are high due to vast extent of the upstream watershed basin. In this respect, flood control procedures seem vital to be deployed taking into account the damages inflicted by the flood occurrences in the history of the region under study.
In the past 50 years major floods have occurred in Sistan plain. The most important floods occurred in 1957, 1982, 1989, 1991 and 1998 and not only cause damage to thousands of acres of farmlands but also Zahak and Zabol cities were affected by flooding (Lumbroso et al., 2005).
The aim of this research is to determine the flooded area with different return periods and evaluate the impact of levee on flood control. Hec-Ras and Hec-GeoRas are used for determining the flood areas. Then the levee height calculates in Hec-Ras model to protect the lands which are located near the river.

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## II. Materials and Methods

### *A. The study area*

Sistan Plain is located in northern Sistan and Baluchistan Province of Iran. Surface area of Sistan Region is 15.1971 km$^2$. This region lies between northern longitudes of 29 to 32 degrees and latitudes of 60 to 64 degrees. Sistan climate is hot and warm due to adjacency to LOUT Desert. The maximal annual temperature is 40-45 ˚C and the average temperature is 21.7 ˚C. Relative humidity varies in the range of 2 to 52 percent (Sarani et al., 2012). Sistan River branches of Hirmand River and has an average annual water yield of 2.6 billion meter cubed and very high fluctuation of discharge. Sistan River is approximately 70 kilometers long. The altitudes in the river source and mouth (at the lowest point) are respectively 492 and 473 meters from free sea level (Fatemi, 2011).

### *B. Flood simulation using HEC-RAS*

HEC-RAS is a software program which enables the users to perform hydraulic computations of the river for steady and unsteady (transient) current states in natural and artificial channels. Output data of HEC-RAS model might be water surface profile variations for different flow rates with varied recurrence intervals in desired lengths of the river, current velocity values, normal depth, critical depth, and hydraulic properties and parameters in the river. Model inputs include cross sections of the water channel, roughness coefficients, nominal discharges in different recurrence intervals, and the distance between the sections. Water surface profile is computed in the hydraulic model from one section to the next one under steady state flow conditions through solving energy equations using standard stepwise technique.

127 lateral sections mapped along the 70-km length of the river were used in the current study and then transferred to AutoCAD software. Subsequently, all of data including: cross-sections, three diversionary dams namely Kohak, Zahak, and Sistan, 4 lateral channels around Zahak and Sistan Dams, Zahak-Niatak Spillway were imported from AutoCAD to HEC-GEORAS. These data were finally transferred to HEC-RAS model. Sistan River and the respective structures are illustrated in Figure 1.

Kohak Dam has been constructed with a length of 68 meters at a distance of 2 kilometers from Iran-Afghanistan border.

Zahak diversionary dam is located 15 kilometers far from Kohak Dam having a length of 53.4 meters and with 8 gates in 2.5*3.1 meter dimensions.

TaheriChannel branches off the left bank of Sistan River in the position of ZahakDiversionary Dam and advances 7 kilometers from the beginning of the dam relatively parallel to Sistan River's trajectory. This channel intersects Zabol_Zahedan Road after passing through a sandy

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Journal of Academic and Applied Studies

**ISSN**1925-931X

desert then is divided in branches and discharges into Hirmand Plain Swamp in southwestern part of Zabol at the end of its 40 kilometer course.
Sistan's diversionary dam is situated 17 kilometer away from Zahak Dam and has a length of 154 meters and 6 gates in 3.2*24 meter dimensions.
The major Channel of ShibAb branches from the Sistan Dam headwater in the left bank of Sistan River. This channel is approximately 19 kilometers long and has been designed for irrigating some part of lands in ShibAb Region of Sistan. The excess water of agriculture discharges into Hirmand Plain through natural or artificially constructed drainage systems.
For preparing the TIN map of the region, the present research benefitted from the mapped data of river course with accuracy of centimeter, DGN maps with accuracy of 14 meters, and DEM topography maps with accuracy of 10 meters. To build the TIN map, all of data were converted into point topography file format. The point data used in construction of TIN are shown in Figure 2. TIN map of the region under study is observed in Figure 3.

Hec-GeoRAS is one of the options of GIS which provides HEC-RAS with needed geometrical data (Hassanpour et al, 2012). Then, hydraulic analysis of current in HEC-RAS model analyzes the output data and prepares the flood zone map (Ackerman, 2009). Hence, the cross-sections and the data of each structure including those of Kohak, Zahak and Sistan Dams, as well as diversionary channels:Taheri, Shahr, ShibAb, PoshtAb, were transferred to HEC-RAS model (Figure 4).

All hydraulic computations were performed using HEC-RAS software which is applied for analysis of one-dimensional steady and unsteady flows in open channels.

### *C. Model Calibration*

Calibration is an important part of modeling. The simulation results should be compared with observed data. Root Mean Squared Error (RMSE) criterion was applied to evaluate the calibration error. RMSE is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. These individual differences are also called residuals, and the RMSE serves to aggregate them into a single measure of predictive power.
The RMSE of a model prediction with respect to the estimated variable $X_{model}$ is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \quad (1)$$

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Where $X_{obs}$ is observed values and $X_{model}$ is modeled values at time/place $i$.

Hence the water levels measured in hydrometric station in Kohak Ford during 1989-2011 were used in order to calibrate the water level computed by HEC-RAS model. Accordingly, to achieve the best Manning's roughness coefficient and validate the model, roughness coefficient was changed as far as the difference between the observed and simulated water levels was minimized.

## Results and Analysis

### *A. Calibration Results*

Calibration results of the model are included in Table 1. It was observed that the data related to water surface extracted from the software in all flow rates of the river are very near to the real data.
RMSE value equals 13.24 cm, implying high precision of calibration.

### *B. Estimation of Flood Discharge*

Event frequency analysis technique was employed to determine the flood discharge for different recurrence intervals of SISTAN River. On this basis, the design flood discharge was estimated using the discharge values from 1958 to 2011 (53 years) via VIBOUL's formula. The result shows in equation (2).

$$Q = 360.6 Ln(T) + 16.56 \quad (2)$$

The logarithmic relationship between discharge and recurrence interval was prepared based on the diagram in Figure 4. Results of maximal flood discharge in different recurrence intervals are included in Table 2.
After running the HEC-RAS model, maximal conveyance capacity of SISTAN River was obtained equal to 810 ($m^3$/s) which is equivalent of a recurrence interval of 9 years. In this discharge, the value of diversion discharge for lateral ponds and weirs of the river was calculated according to Table 4.
As observed in longitudinal profile of the river in Figure 5, the river is capable of transporting water at a maximal discharge of 810($m^3$/s). In this state, the sections 2745.568, 1691.096, 2348.66, 20656.64, 19730.76, 15338.29, and 14499.54 are in critical state. And increase of discharge rate results in water overflow and inundation of the adjoining lands.
Flood was simulated for different recurrence intervals. Through importing HEC-RAS outputs to GIS, flood zoning map was prepared in different recurrence intervals. 10-year flood zone is shown in Figure 6. For estimating the extent of flood infiltration into the lands around the river,

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total area of river and its banks equaling 384.73 hectares is subtracted from the whole flooded area, and, the inundated areas in the surrounding lands were determined (Table 4).
In order to enhance the flood conveyance capacity of SISTAN River, a levee with a height of two meter was used. Through flow simulation in HEC-RAS model, the levees with average height of 2 meters were observed to be capable of controlling and transmitting the water current at a maximal flow rate of 1700 ($m^3$/s), equivalent of a recurrence interval of 107 years. Current distribution results in the lateral or diversionary channels are presented in Table 5.

*C. Using Levee*

In order to enhance the flood conveyance capacity of SISTAN River, a levee with a height of two meter was used. Through flow simulation in HEC-RAS model, the levees with average height of 2 meters were observed to be capable of controlling and transmitting the water current at a maximal flow rate of 1700 ($m^3$/s), equivalent of a recurrence interval of 107 years (Figure 7). Current distribution results in the lateral or diversionary channels are presented in Table 4.

## III. Conclusions and Discussion

Hydraulic analysis of Sistan river using Hec-Ras model is performed in this study. The floods with different return periods were simulated. Then, the results transport to the Hec-GeoRas in GIS environment and flood areas were prepared. To control the flood damages levees with average height of 2 meters were examined in Hec-Ras model. Results showed that using levee is very efficient in this area.
In this case, Hossein Zadeh et al. (2003), Lagason (2008) and Solaimani (2009) introduced Hec-Ras model and Hec-GeoRas tool for determination the flood areas.
Regarding using levee, Tayari et al. (2011) and Yang et al. (2010) have expressed the levee structure is an appropriate method to flood control.

In this study, the following results were obtained:

- ✓ HEC-RAS mathematical model is a suitable and efficient model for simulation of SISTAN River.
- ✓ Following the model calibration, it was observed that HEC-RAS model yields nearly realistic results and has reliable outputs.
- ✓ HEC-RAS mathematical model can be used for determining the height of levees.
- ✓ Levees with average height of 2 meters are able to control the floods with recurrence interval of over 100 years.
- ✓ Through simulation of regional floods and determination of the risk-prone regions and proposing appropriate solution of flood control by means of levees, the damages to

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**ISSN**1925-931X

agricultural fields and cities and villages in river's basin can be prevented and the managers will be provided with suitable program.

TABLE I. MODEL VERIFICATION

| year | Q($m^3$/s) | Depth(cm) | Simulated Depth of HEC-RAS(cm) | (R) |
|---|---|---|---|---|
| 1990-91 | 596 | 321 | 335 | 1.043 |
| 1992-93 | 404 | 263 | 285 | 1.083 |
| 1993-94 | 314 | 258 | 260 | 1.007 |
| 2005-2006 | 273 | 208 | 220 | 1.057 |
| 2007-2008 | 325 | 222 | 235 | 1.058 |
| 2008-2009 | 488 | 267 | 280 | 1.048 |
| 2009-2010 | 366 | 273 | 284 | 1.040 |
| 2010-2011 | 429 | 259 | 265 | 1.023 |
| 2012 | 149 | 174 | 190 | 1.091 |

TABLE II. Maximum Dischargeswith Different Return Periods

| Return Period (Year) | $Q_{max}$($m^3$/s) |
|---|---|
| 10 | 846.87 |
| 25 | 1117.29 |
| 50 | 1427.24 |
| 100 | 1677.18 |

TABLE III. Flow Channels

| Structure | $Q_{max}$($m^3$/s) |
|---|---|
| Taheri channel | 33.84 |
| Shahr channel | 33.84 |
| PoshtAb channel | 9.64 |
| ShibAb channel | 10.4 |
| Zahak- Niatak Spillway | 373.6 |

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TABLE IV. Relationship Between Flood Area And Return Period

| Return Period (Year) | Flood Area (ha) |
|---|---|
| 10 | 2118.9 |
| 25 | 3406 |
| 50 | 4128.3 |
| 100 | 6384.7 |

TABLE V. Flow Channels

| Structure | $Q_{max}(m^3/s)$ |
|---|---|
| Taheri channel | 81.73 |
| Shahr channel | 81.73 |
| PoshtAb channel | 56.19 |
| ShibAb channel | 53.9 |
| Zahak- Niatak Spillway | 806.6 |

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**Figures:**


**Figure.1.**Sistan River and the respective structures.

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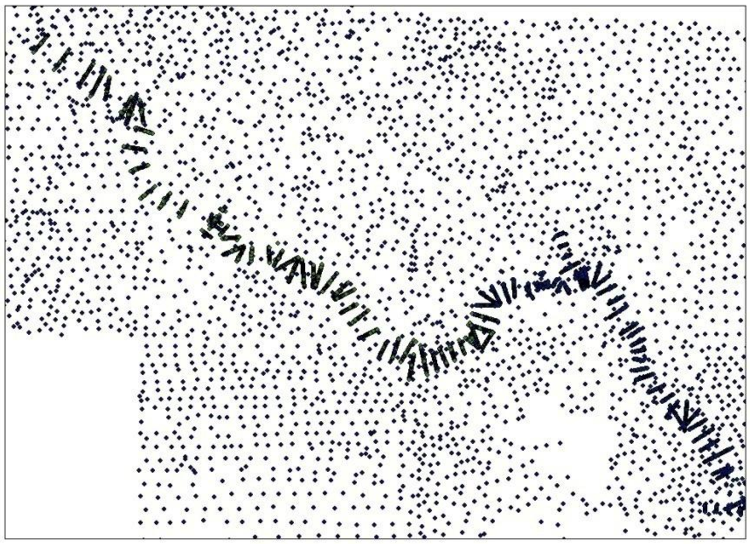

**Figure.2.**Topography points ofthe study area

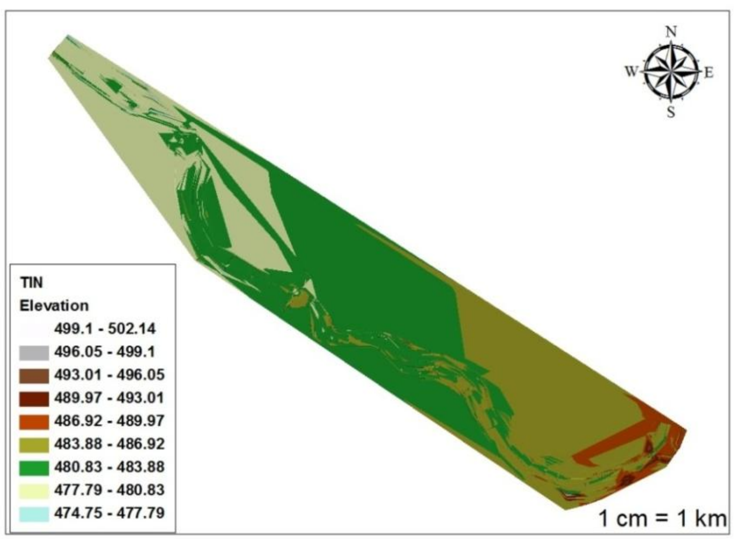


**Figure.3.** TIN

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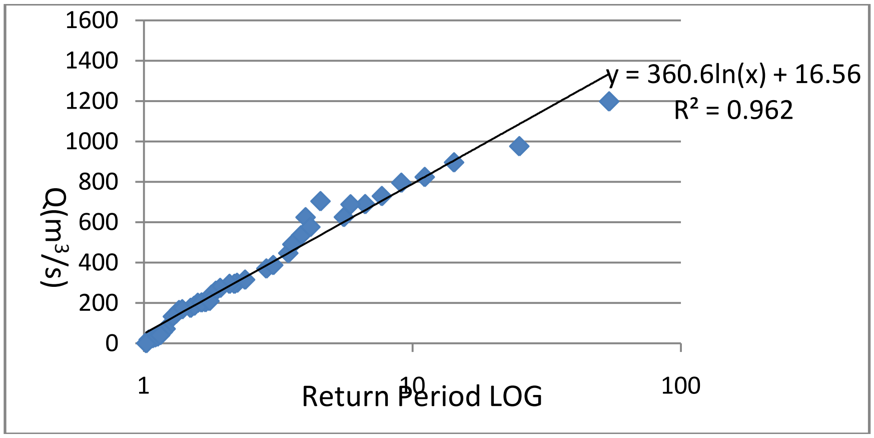


**Figure.4.**Return Period and Flow Regression

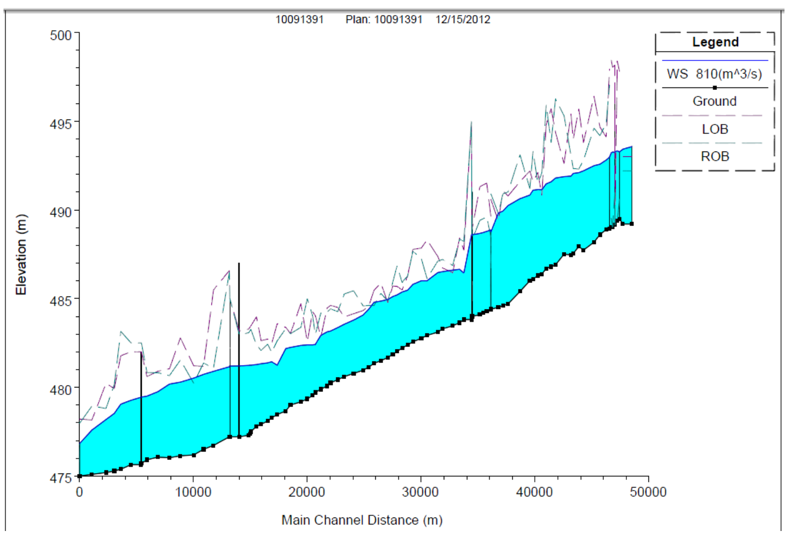


**Figure.5.**River profile of 810 ($m^3/s$)

**Journal of Academic and Applied Studies**
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**Vol. 3(10) October 2013, pp. 32-45**
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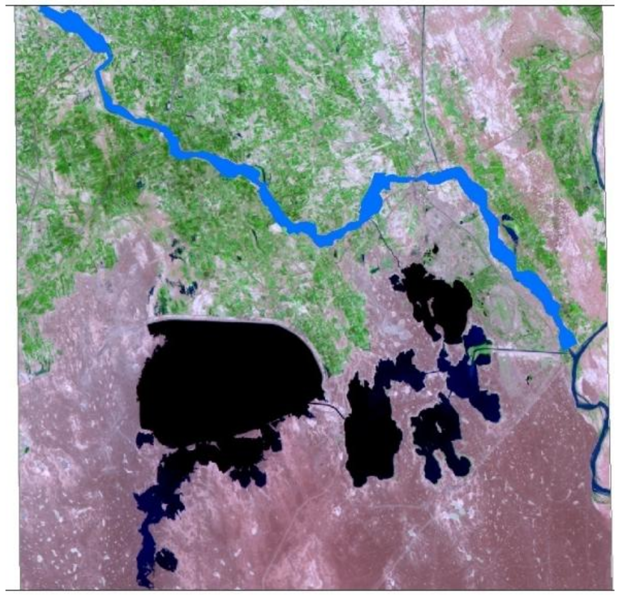

**Figure.6.**Flooded area with10-year return period

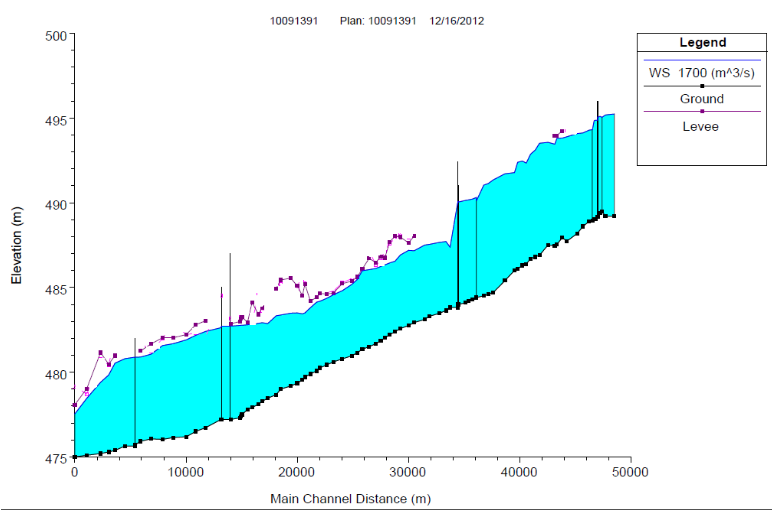


**Figure.7.**River profile of 1700 ($m^3$/s)

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**Journal of Academic and Applied Studies**
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