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Climate Change Impacts on Vulnerable Guddu and Sukkur Barrages in Indus River, Sindh

A. A. MAHESSAR, A. L. QURESHI*, G. H. DARS*, M. A. SOLANGI**

Sindh Barrages Rehabilitation Project, Irrigation Department, Government of Sindh, Karachi, Pakistan

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Abstract: The increased magnitude and frequency peak flood discharge in rivers and streams happened due to climate change which increased woes and concerns for passing safe discharges from the barrages. Climate change is major reason to increase the occurrence of extreme climatic events (i.e. as abnormal and severe low floods). The major risks from climate change at the barrages are from changes in discharges' patterns in rivers. In this paper, the statistics of historical flood peaks at Guddu and Sukkur barrages have been analysed that the maximum discharge was calculated is 33951m^3/s, 33963m^3/s and minimum4850 and 2870 m^3/s respectively.

The analysed results revealed that ten and thirteen super flood peaks at Guddu and Sukkur were calculated and concluded flood passing from these barrages caused occurrence of breaches in the protected bunds at upstream and downstream of barrages. However, the hydrologic analysis of the flood approach, particularly at Guddu and Sukkur barrages in Indus River was made by using the hydrologic statistics for analysing impacts of extreme flood events. Hence, the statistical methods were used for process of flood frequency for derivation design of barrages and flood passes for safeguarding flood damages and nature and behaviour condition of Indus River.

Generalised Logistic (GL) and Gambel methods have been used for flood frequency at Guddu barrage and its result exhibited that for one in hundred years' event discharge rate 43,765 m^3/s and 44,526 m^3/s at Guddu barrage as well as the California method for Sukkur its result revealed a flow rate of 47,000 m^3/sfor one in hundred years' event. As result, it is estimated that the extreme future floods may occur at barrages due to climate change.

Keywords: Statistical Methods, Flood Frequency, Extreme Events, Hydrograph, Indus River, Barrages

1. INTRODUCTION

The extreme climate change may likely to affect flows in the Indus River. The climate change develops impact son flood discharges in two ways; firstly, the source of Indus River is glaciers Tibetan Plateau where the temperature is soaring which leads melting the glaciers 'snow consequently. There is certainty of the long term impacts of climate change and indicates that these glaciers may be lost, resulting in an overall decrease in river flows. Secondly, the frequency of erratic monsoon storms(as observed in 2010) may become more frequent and result in an increase in peak discharge in the Indus at Barrages(ESA, SBIP, 2015). The major impacts of climate change in Sindh are swelled temperatures and increased frequency of the extreme precipitation events, both extremely high and low precipitation resulting in floods and droughts (ESIA, SBIP, 2014).

Climate change is expected to raise the occurrence of severe climatic events. The major risk of climate change at barrage is from changes in discharges in river; however, there a real so potential impacts from flow extremes which may be mitigated to some extent by increasing regulation of the upstream river. Flow extremes maybe mitigated to some extent by increased regulation of the upstream river, which will result from future planned dam schemes on the Indus and its tributaries (PAD, 2015).

The heavy rainfall spell in country occurred during monsoon period 2010 and it turn into historical peak rainfall. The unpredicted rainfall took placed in the northern areas, causing raised the water level in tributaries and hill torrents that consequently caused to raise the water stages in Indus river (Usman and Khalil, 2015).

The unpredictable occurrence of floods cause abrupt rise water stage in river and exceeds the capacity of river body. The raising water flood stage in river which cause of occurrence of breaches of bunds and became cause of billion US dollars in recent past during 2010 floods. This developed phenomenon primary effects on human and animal population and devastates structural and non-structural infrastructures(Mahessar, et al. 2013a).

In general, flooding was studied from hydrological approach (Junk *et. al*., 1989), resulting in a lack of analysis of the mechanisms of flood transmissions fromhydro-geomorphic(Fryirsand Brierley 2013).

++Corresponding author: E-mail: amahessar@yahoo.com

*US-Pakistan Center for Advanced Studies in Water, Mehran University Engineering and Technology, Jamshoro, Pakistan,

**Basic Science and Related Studies, Mehran University Engineering and Technology, Jamshoro, Pakistan,

Flood is a high water level in a river, usually the water at which the river outflows its banks and submerge the adjacent areas (Raghunath, 1991).Floods are catastrophic among all the natural calamities in the global (Seyedeh, *et. al*, 2008) that cause of loss of properties, lives, health and wealth etc. Even though with several years of technical techniques and knowhow, floods still keep on its devastation almost in every part of earth. Climate change is major cause to increase the risk of extreme hydrological events (Milly, *et al*. 2002).Hence, extreme climate change and occurrence of flash floods is aggravated by increasing urbanization in the global (UN, 2010).These situation and growths have pose a heavy emphasis on the prediction of flood extent, damages and destructions levels for the reason of calamity (Milly, 2008).

Hydrological systems are infrequently packed together through extreme events, such as, droughts, floods and serious storms. For many engineering purposes, as a result, analysis of flood frequency must be made in order to check the occurrence of exceeds discharges, so that precautionary attempts be made accordingly (Chow, 1988).

2. STATISTICAL METHODS FOR FLOOD FORECASTING

Various statistical methods have been used for the predictions of future floods are made upon the available records of past floods. Statistical approaches can be adopted to forecast the maximum flood that is anticipated in a river with given frequency, subject sufficient past records are available. Secondly, the predictions will be precise only if there have been no appreciable changes in regime of the stream during or after the period of records. These methods are unable to give precise results when lesser past records are available. For the success of any of the probability methods, sufficient past record must therefore, be made available. These methods were of great importance and widely practiced before unit hydrograph theory came into picture. Forecasting the future floods by these methods is carried out on the same lines as was done for forecasting the future storms by simple probability methods. The various statistical distribution or equation have been devised and suggested by various investigators and can be used. The available methods include California method, Gambel method, Generalised Logistic (GL), Foster Method, Hazen's method and Chow's method(Kumar, 1976).California method, Gambel method and Generalised Logistic (GL) methods have been used in this research work.

3. INDUS RIVER: GUDDU TO SUKKUR REACH

River Indus is one of the largest river sin south Asia that covers watershed area about 332,000 square miles (860,000 km^2). The main source of the river is from Tibet Plateau China but also snow and monsoon waters. Indus River crosses around 3100 km (1900 miles) through India and Pakistan to the Arabian Sea. River Indus also receives water at Panjnsa dcreated through the junction of the Chenab and Sutlej rivers and moves to Arabian Sea through three barrages Guddu, Sukkur and Kotri (Mahessar, *et al*., 2013b, Qureshi *et.al* ,2014).

Indus River is passing from Sindh and its total length is 537 miles having 108 miles reach from Guddu to Sukkur barrages. Guddu barrage is located at altitude 28.3164 North and longitude 69.2101East and Sukkur barrage at altitude 27.4447 North and longitude 68.5658East(**Fig-1a and b**). The flood peak discharge data for historic periods of Guddu and Sukkur barrages were collected from Irrigation Department, Government of Sindh (**Fig-2**).

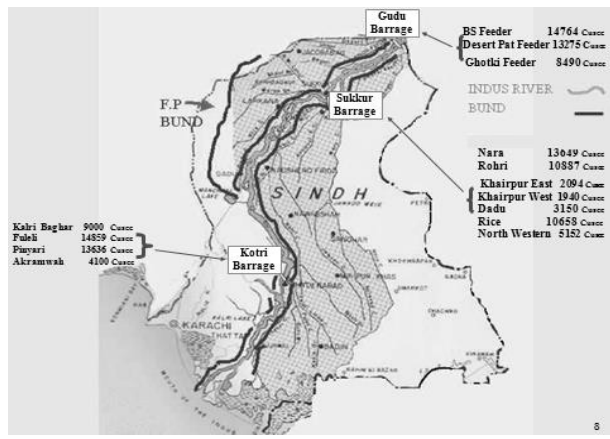


Fig.1(a): Locationmap of Guddu-Sukkur

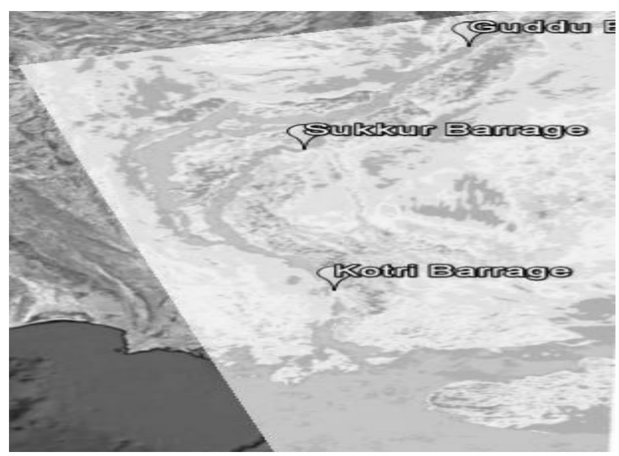


Fig. 1(b): Imagery of flood (2010)

4. RESULTS AND DISCUSSIONS

4.1 Statistics of historic discharges at Guddu and Sukkur

The flood frequency (return period) analysis was carried out to predict the occurrence of discharge of

Guddu and Sukkur barrages through analysis of hydrologic statistics.

Whereas, the occurrence of heavy flood events due to climate change such as severe storms and glaciers melting in catchment area of Indus River are widespread. However, the design discharge of Guddu barrage is 31150m^3/s(GBIP (2014).The ten (10) times supper floods at Guddu barrage were observed from 1964 to 2016i.e. 1973 (30670), 1975 (28371), 1976 (33951), 1978 (32710), 1988 (32903), 1992(30751), 1995 (27972), 1989 (26740) and 2010 (32509) m^3/s but the maximum flood in 1976 (33950)and minimum in 2004(4834 m^3/s)after construction of the barrage.

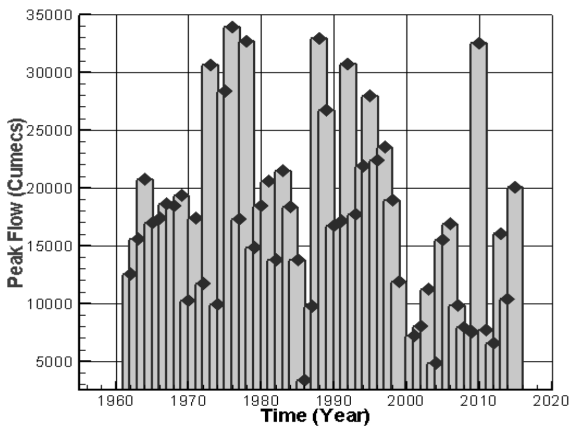
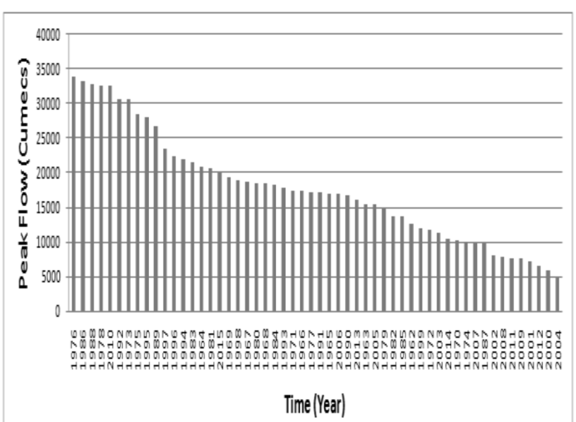


Fig-2: Flood Peaks Flow at Guddu barrage.



Fig–3:Peak Flows from (Supper to Normal Floods) at Guddu barrage.

Fig.3 exhibits that there is lot of variation in the historic discharge at Guddu barrage, the maximum flow is 33951 m^3/s in 1976 and minimum flow is 4834 m^3/s in 2004. It's different is about seven times in fifty-four historic peak flows. The different of maximum and minimum flows represent actual nature of behaviour and conditions of Indus River. The supper flood occurred ten times such as in 1976, 1986, 1988,1978,2010,1992,1973,1975,1995 and 1989 which varies from 33,951 to 26,740m^3/s. While very high flood occurred seven times i.e. 1997, 1996, 1994, 1983, 1994, 1981 and 2015 and discharges varied from 23,524 to 20,077m^3/s. However, from 1992 to 1972 in the span of ten years' nine supper flood was observed. The unpredictable floods were observed from 1973 to 1995 and also 2010 at Guddu barrage. The occurrence of ten (10) super flood from 1973 to 2010, and seven (7) very high floods from 1981 to 2015 were experienced and super flood occurred after average 5 year and every high flood after average seven years. On average the occurrence of super floods is one in every five years.

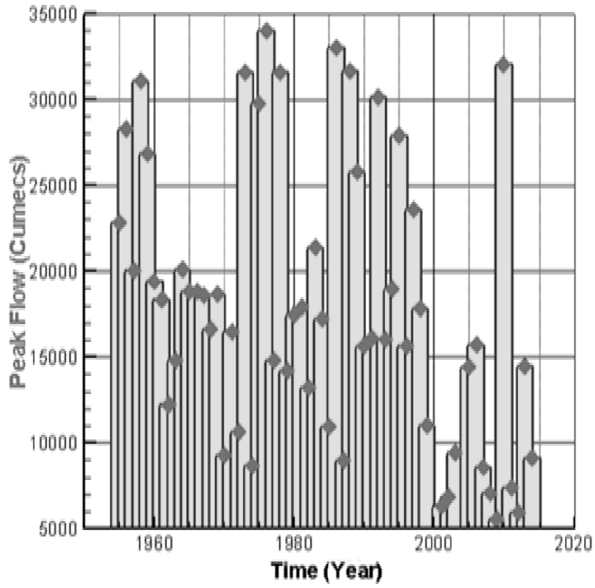
Table–1: Statistics of historical Flood Peak Flows at Guddu Barrage

Flood Stage	Threshold Flow(m^3/s)	No. of year occurrence	Frequency (%)
Super Flood	25470	10	17
Very High Flood	19810-25470	7	13
High Flood	14150-19810	12	22
Medium Flood	9905-14150	14	26
Low Flood	5660-9905	9	18
Normal Flood	5660	2	4

Fig. 3 and **Table.1** demonstratethatoccurrence of supper floods ten(10) times and its frequency 17%. The very high flood occurred seven (7) times and its frequency 13%, high floods 12 times and its frequency 22%, Medium flood 14 times and its frequency 26%, Low flood ten time and frequency 18% and Normal flood 2 times and its frequency 4% were analysedin the historic period of 54 years at Guddu barrage.

The erratic supper flood occurred at Guddu barrage with discharge 33970 m^3/s in 1976 while the design discharge of Guddu barrage is 31150m^3/s. It was observed that it is difficult to pass erratic supper floods which occurred due to climate change and became cause of occurrence of breaches and overtopping the embankments at upstream of barrage. Therefore, huge area of Sindh came under destruction of structural and non-structural developed which cause billions of US$ loss in country.

The heavy floods occurred frequently in Indus River due to climate change. The soaring temperature became major cause of melting of snow and abnormal rainfall in the watershed area of Indus River. The designed discharge of Sukkur barrage was 42,450m^3/s but it was reduced up to 25,450 m^3/s due to water supplying problems to irrigation system**(Fig. 4)**. However, there is experience of thirteen (13) times of super floods at Sukkur barrage such as in 1976, 1986, 2010, 1988, 1978, 1973, 1958, 1992, 1975, 1956, 1995, 1959 and 1989. The very high floods were observed five (5) times i.e. 1997, 1955, 1983, 1964 and1957 in the 60 years of historic period.



Fig–4 Shows Peak Flow at Sukkur barrage.

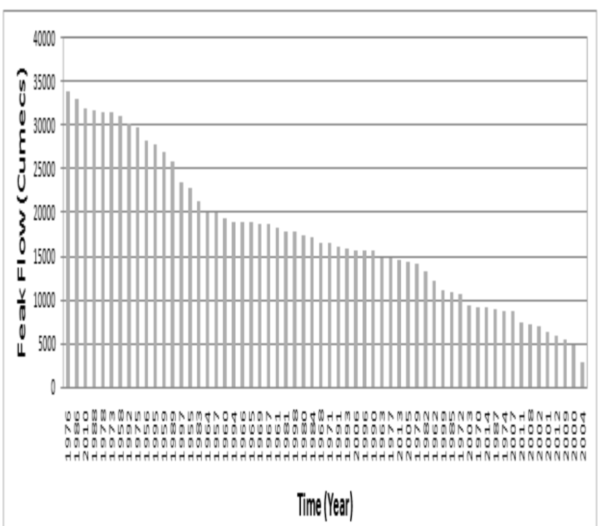


Fig.5: Peaks at Sukkur barrage from (Supper to Normal Flows).

Fig. 5illustrates that there is much variation in the historic discharges at Sukkur barrage, the maximum flow was 33951m^3/sec 1976 and minimum flow is 2870m^3/s in 2004 and its different is about seven times in sixty historic peak flows. The difference of maximum and minimum flow represents actual nature of behaviour and conditions of Indus River. The supper flood occurred thirteen (13) times such as in1976, 1986, 2010, 1988, 1978, 1973, 1958, 1992, 1975, 1956, 1995, 1959 and 1989and discharges of super floods varied from 33951 to 26740 m^3/s. Hence, very high flood occurred seven (7) times i.e. in 1997, 1955, 1983, 1964 and1957 and discharges varied from 23525 to 20015m^3/s.

Table2:Statistics of historical Flood Peak Flows at Sukkur barrage.

Flood Stage	Threshold Flow (m ^{3}/s)	Number. of Year occurrence	Frequency
Super Flood	**25470**	**13**	**21%**
Very High Flood	**19810-25470**	**5**	**8%**
High Flood	**14150-19810**	**23**	**39%**
Medium Flood	**9905-14150**	**5**	**9%**
Low Flood	**5660-9905**	**11**	**18%**
Normal Flood	**5660**	**3**	**5%**

The unpredictable supper floods were observed from 1956 to 1995 in recent2010 at Sukkur barrage. The occurrence of thirteen Super flood from 1956 to 2010, and very high flood from 1955 to 1997 were experienced andon average the occurrence of super floods is 1 in every 5 years.

Fig. 5 and **Table–2**show that supper floods occurred thirteen (13)times and its frequency 21%. The very high flood occurred five (5)times and its frequency 8%, high floods twenty-three(23)times and its frequency 39 %, medium flood five (5) times and its frequency 18%, Low flood 11 time and frequency 18% and normal flood three (3) times and its frequency 5% in the historic period of 60 years at Sukkur barrage.

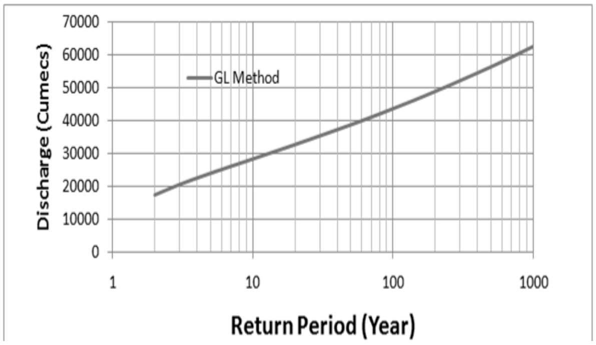
Table–3:Occurrence of breaches on upstream of Sukkur and Guddu barrages.

S. No.	Barrages	Upstream Bund	Locations of Breaches	Flood Year
1	Guddu Barrage	Left Marginal Bund (LB)	at miles 10, 11,12 and 14	2010
2	Sukkur barrage	Right side (Torri bund)	at mile 13	

The erratic supper flood was at Sukkur barrage with discharge 33970 m^3/s in 1976 while the design discharge of Guddu barrage is 25450m^3/s. However, recent supper flood 2010 caused occurrence of some breaches as described in Table-3. It was observed that it is difficult to pass supper floods which occurred due to climate change and became cause of occurrence of breaches and overtopping the embankments at upstream of barrages. Therefore, large area of the country came under destruction of structural and non-structural developments which cause billions of US$ loss of nation.

4.2 Flood Frequency

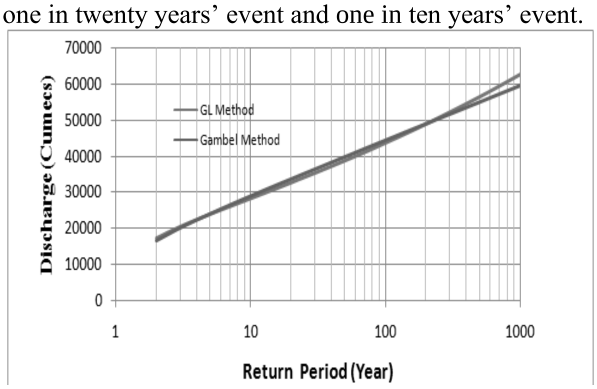
The severe floods occurred due to climate change in the Indus River has posed emphasis for analysing the flood return period/frequency. Hence, California, Gambel and Generalised Logistic (GL) methods have been used for predicting future floods at Guddu and Sukkur barrages. The analysed results from these statistical methods were discussed as under:



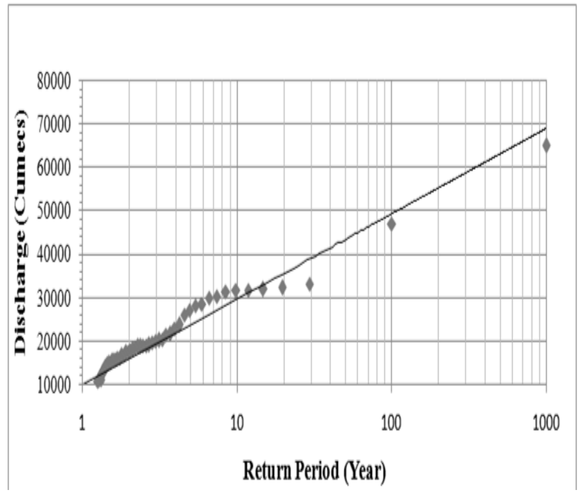
Fig–6:Return Period (in years) at Guddu Barrage computed by Generalised Logistic (GL)method.

Fig–6shows that return period of flood satGuddu barrage, one in hundred years' event might occur 43765m^3/s has been estimated for one in fifty years' event the discharge rate could be 38837m^3/s. For one in twenty years' event the flood discharges could be 32768m^3/s and one in ten years' event the discharge could be 28350 m^3/s by using Generalised Logistic (GL) method and the design discharge of Guddu barrage is 31150 m^3/s.

The comparison of Return period/frequency (Year) has been shown in **(Fig-7)** which shows less variation between them. The Generalised Logistic (GL) methods revealed that return period of flood at Guddu barrage one in hundred years' event could occur 43765 m^3/s and Gambel method shows that the return period at Guddu barrage one in hundred years' 44526 m^3/s and average by both methods is 44146 m^3/s. For one in fifty years' event, one in twenty years' event and one in ten years' event have been forecasted through GL method and their predicted values 38840, 32768 and 28400m^3/s respectively. The flood forecast at Guddu barrage has been made for one in fifty years' event, one in twenty years' event and one in ten years' event and their predicted values are 39800 m^3/s, 33822 m^3/s and 29100 m^3/s respectively by Gambel method. The both methods have average flood 44146, 39390, 33295 and 28748 for one in hundred years' event, one in fifty years' event, one in twenty years' event and one in ten years' event.



Fig–7: Computed Return Period (in years) at Guddu Barrage by both Generalised Logistic (GL) and Gambel Methods.



Fig–8: Return Period (in years) at Sukkur Barrage computed by California method.

The return period (year) floods at Sukkur barrage for one in hundred years' event can be 47000m^3/s and for event one in fifty years' flood forecast could be 41000m^3/s. While, for one in twenty years' event and one in ten years' event, the discharge rate at Sukkur barrage could be 33500 and 29500m^3/s respectively **(Fig–8)**.

5. CONCLUSIONS

The statistical analysis of historic peak discharges shows that there are ten (10) erratic supper flood sat Guddu and thirteen (13) supper flood at Sukkur barrage. As result from statistical analysis that could be difficult to pass the unpredictable supper flood from these barrages. However, further statistical methods have been used for predicting future floods and return period at Guddu and Sukkur barrages. The Generlized logistic (GL) and Gambel methods were used for flood frequency at Guddu barrage and its result shows that for 1 in 100 year events discharge rate 43,765 and 44,526 m^3/s at Guddu barrage. California method is used for forecasting future flood and its result revealed that for one in hundred years' event flow rate 47,000m^3/s.

It is concluded that the capacities of Guddu and Sukkur barrages may be revisited. The resilience of embankments at upstream of Guddu and Guddu to Sukkur reach should be made to safeguard the flood damages. Hence, flood passes on left marginal bund at upstream of Guddu barrage and also flood passes on left and right side at upstream of Sukkur barrage should be constructed for safe pass of excess flood water towards desert areas.

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