Proceedings of the Pakistan Academy of Sciences:
B. Life and Environmental Sciences 53 (3): 149–161 (2016)

ISSN: 2518-4261 (print), ISSN 2518-427X (online)

Pakistan Academy of Sciences

Research Article

Sustainable and Optimized Utilization of Water Resources: Inflatable Dams Potential in Pakistan

Muhammad Usman Rashid[1, *], Abid Latif[2], and Usman Ghani[3]

[1] Department of Civil Engineering, School of Engineering, Pakistan University of Management and Technology, Lahore, Pakistan
[2] Civil Engineering Department, University College of Engineering & Technology, Bahauddin Zakariya University, Multan, Pakistan
[3] Civil Engineering Department, University of Engineering and Technology, Taxila, Pakistan

Abstract: Development of new reservoirs are utmost important for their utilization of providing water for irrigation, hydropower and flood damages reduction etc. In-addition to constructing new reservoirs, the efficient and sustainable use of existing reservoirs is also important for rapid economic growth of world. Pakistan is blessed with rich surface water resources of 180 Billion m^3 annualy. However, total storage capacity of the three large dams is 17 Billion m^3 which is only 10% of the available water resources. The current study identifies the latest trends for optimizing the utilization of water from reservoir to agriculture farm and their possible application to Pakistan. The paper also investigates the potential of inflatable dams in Pakistan for recharging of groundwater, as diversion weir for small hydropower plants, water supply and creating artificial lakes for recreation purposes. On the basis of criteria developed in the study, 31 sites were selected for checking their feasibility. SRTM 90m digital elevation database and Google Mapper were used to develop digital elevation models and contours for studying different technical parameters. Total 27 sites were found feasible and indicated the potential for Inflatable Dams in Pakistan on the basis of preliminary results. For sustainable and optimized utilization of water resources, it is utmost important to implement the following measures identified for supplying water from reservoir to crop root zone are: remodeling/ modernization of barrages and canals including lining of distributaries and minors. Adoption of resource conservation technologies, and optimized cropping systems by including high value and high yield crops are recommended in the study for achieving the desired objectives.

Key Words: Water resources, Pakistan, inflatable dams, reservoirs operation, sedimentation, Tarbela, Diamer Basha

1. INTRODUCTION

Reservoirs play a vital role for rapid economic growth all over the world by providing water for irrigation, hydropower and reducing floods. During 20th century, the focus was only towards developing new reservoirs. However, now approach is shifted to preserve existing reservoirs as well as developing new reservoirs. Total 33,100 dams have been constructed worldwide whose total storage capacity is more than 6900 km^3 upto 2010. The worldwide development of new reservoirs is depicted in Fig 1. [1, 2].

Globally, the rate of reservoir sedimentation is about 0.1-2.3% annually with yearly average storage loss of about 1.0 % [3]. Due to sedimentation, estimated value of loss is approximately 9 billion US dollar per year. China is suffering from highest average annual storage loss, while the lowest average annual loss of storage has been observed in North Africa [3].

The current study emphasis the sustainable utilizes of water resources by developing new reservoirs and identifies the latest trends/measures for optimizing the utilization of water from reservoir to agriculture farm and their possible application to

Received, January 2016; Accepted, July 2016
*Corresponding author: Muhammad Usman Rashid; Email: usman.rashid@umt.edu.pk

Pakistan. Moreover, it investigates the feasibility and potential of inflatable Rubber Dams in Pakistan.

1.1 Importance of Reservoirs

Sediment deposition is the major cause of loss of reservoirs' capacities constructed during 20th century, which had already been built on the most captivating sites worldwide. On the other hand, many reservoirs are not providing optimized payback. The reason of lesser payback is that these reservoirs are not operating on the concept of optimization. The possible benefits are hydropower, irrigation, storage conservation and control of damages due to flood.

The demand of construction of reservoirs is increasing with growing population of the globe. The reservoirs and dams are helpful in serving mankind by production of food, fiber, hydro power and economic growth. About 30-40% of 268 million hectare land of the world is cultivated by 45,000 large dams. About 12 – 16 % of the world's food production is associated with reservoirs with significant global energy supply [1].

Many countries around the world have developed significant reservoirs for storage of available surface water resources in the river basin. Table 1 shows the %age storage developed in different river basin in the world. Pakistan has minimum %age storage from available water resources amongst the river basins compared in Table 1. It is, therefore, utmost important to develop new reservoirs. The existing storage capacity of the reservoirs of Pakistan has been provided in Table 2 [4].

1.2 Optimized Operation of Multiple Reservoirs

World Commission on Dams [2] reported that there is still great potential available to get more benefits from the existing reservoirs as they are not being operated on the principle of optimized benefits. Preferably, the design and operation of reservoirs should be such that to maximize net benefits which can be achieved by using various optimization methods. The optimization methods includes genetic algorithm, linear and dynamic programming which are also in practice in reservoir research studies. Genetic algorithm is a popular optimization method based on principles of mechanics of natural

Table 1. River Basins and developed storage reservoirs [8].

River basin	Average annual flow (MAF)	No. of dams	Live storage capacity (MAF)	%age storage
Colorado	12	3	59.62	497
Nile	47	1	132	281
Sutlej Beas (India)	32	5	11.32	35
Yellow River	345	7	68.95	20
Pakistan Indus System	145	3	14.06	10*
World Average	**20,000**	**-**	**8,000**	**40**

Table 2. Reducing Storage Capacity due to Reservoir Sedimentation [8].

Reservoir	Live Storage Capacity (MAF)		Storage Loss (MAF)
	Original	Year 2014	Year 2014
Tarbela	9.69 (1974)	6.4	3.29 (34%)
Mangla	5.86(1967) +2.88*(2012)= 7.48	7.4	0.85 (10%)
Chashma	0.72 (1971)	0.26	0.46 (64%)
Total	**16.27**	**14.06**	**1.60(26%)**

* 2.88 MAF storage was added in 2012 due to Mangla raising

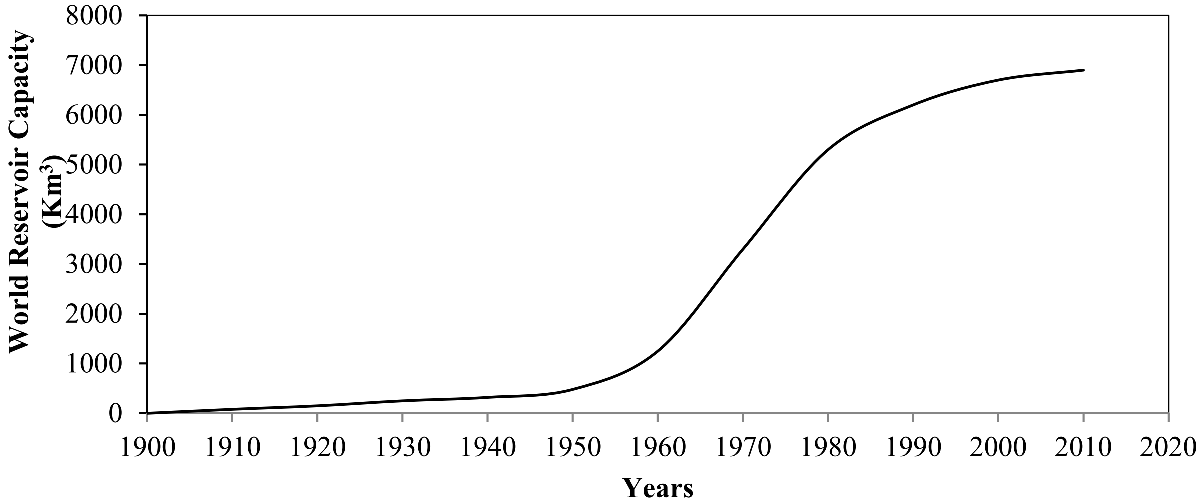

Fig. 1. Development of World Wide Reservoirs [1].

science and selection. This method is suitable for multi task characterization and many advantages to other methods [5-8].

To characterize the rule curve of reservoirs for multiple reservoirs operations Chen and Chang formulated hyper cubic distributed genetic algorithm (HDGA) [9]. However they neglected the sediment evacuation effect for optimization. Suiadee and Tingsanchali worked on Nam Oon reservoir, Thailand and produced combined simulation genetic algorithm (GA) model to evaluate optimum operational rule curves. The powerful and robust proposed model was combination of simplicity and simulation techniques [10]. To optimize the rule curve of Tapu Reservoir in Taiwan, a flushing model was prepared. The flushing model was a combination of simulation and sediment evacuation based on genetic algorithm optimization concept [11]. The model ROSSE i.e. Reservoir optimization-simulation with sediment evacuation was developed for Tarbela dam located in Pakistan. The GA based model helped to optimize the rule curves [12].

To forfeit the energy crises of Pakistan and to improve the irrigation system, optimized operation of multiple reservoirs on Indus Basin is mandatory. Currently the researchers are more focussed on design and operation of individual reservoirs than multiple reservoirs. Whereas, there is urgent need to derive the method of optimization for multiple reservoirs in order to improve the storage conservation, irrigation system, power generation and to reduce the flood damages.

The optimized hydropower, irrigation, storage and flood damages reduction benefits of reservoirs in Indus Basin, Pakistan are summarized in Table 3. Rashid et al. [13] revealed that objective-function for irrigation, hydropower and storage conservation benefits will be improved by 13%, 11% and 84% whereas flood damages will decrease by 75%. The results also indicated enhancement of benefits upto US$ 960, 579, 533 and 649 M annually for all the four components. It is evident from the Table 3 that by optimized operation of multiple reservoirs operation by considering sediment evacuation of multiple reservoirs, the benefits will be enhanced by about 49%.

1.3 Inflatable Rubber Dams

Inflatable dam consisting of a sealed inflatable rubber coated fabric tube anchored to a concrete foundation constructed across a river (Fig. 2). Inflation is introduced by use of air or water or both. When fully inflated the inflation acts like impound to water and behaves like other fixed dam. The particular feature of inflated dams is the quick deflation for preventing floods. Deflation occurs automatically as the backwater reaches a certain level. In developed nations like United States, use of inflatable dams is increasing rapidly and over 200 inflatable dams have been installed since 1980. Table 4 summaries the worldwide use of inflatable dams [14-16].

The concept of inflatable dam is relatively new in South Asia. However, it had been used to large extent in Australia, China and Scandinavia

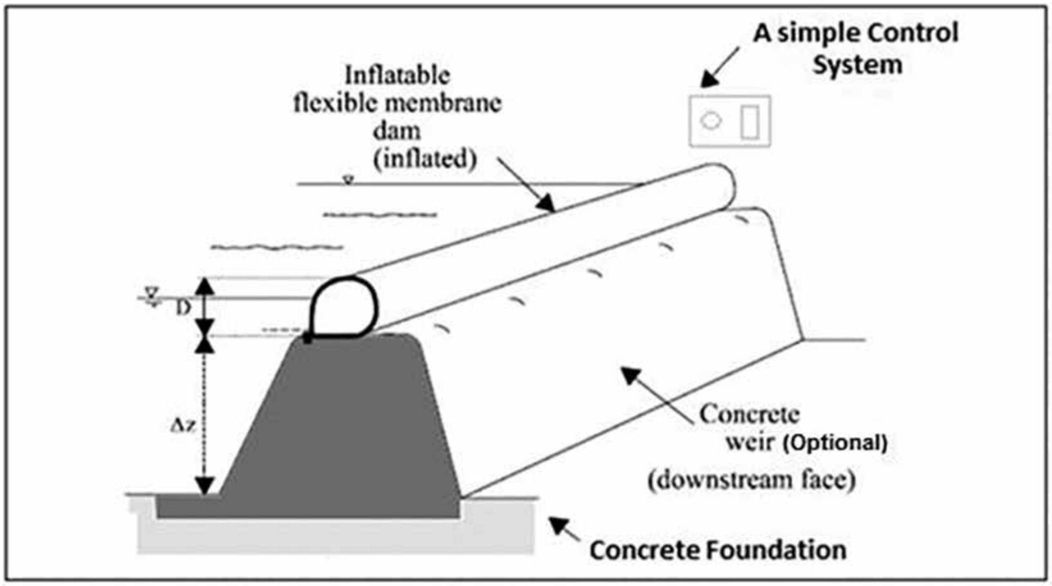

Fig. 2. Schematic view of inflatable Rubber Dam.

countries. Rubber dams have added advantage of simple and short period of construction. Moreover, these dams have shown good performance in seismic areas [17]. Rubber Dams have been used since last 60 years for river and coastal engineering applications. The use of water stored in rubber dams for irrigation purposes is most recent practice adopted in Australia. Chansen [18] developed new method for predicting the overflow characteristics and guidelines suggesting optimum location of deflector in the rubber dams. Discharge calculations and analysis are of great importance and necessary for good operation and sediment controlling of cascade rubber dams. The

Table 3. Enhanced benefits due to optimized operation of multiple reservoirs.

Sr. No.	Reference	Case Study Reservoirs	Total Optimized Benefits (Million $/year)	Increase in Benefits w.r.t. existing rule curves (Million $/year)	% Enhanced optimized value
1	Khan et.al (2009)	1. Tarblea	1147	82	42%
2	Rashid et al. (2015)	1. Tarbela 2. Diamer Basha	2988	977	49%

Table 4. Summary of Inflatable Dams World Wide [15-16].

Country	Year Introduced	Type of inflation	Number of Dams Installed
France	1972	Water	25
Austria	1977	Water	60
Japan	1978	Air or Water	> 700
Germany	1984	Air or Water	40
USA	1988	Air & Water	111
Australia	1997	Air or Water	3
Czech Republic	1980	Water	20

principles of water balance and weir flow are the basis of fall discharge and maximum discharge of cascade rubber dams [19]. The long term (35 years) investigation of construction, operation, management and maintenance of a rubber dam of 20 dams in Hong Kong concluded that rubber dam had been successfully used for many different purposes such as irrigation, flood control, environmental improvement and water supply [20].

Hassan and Kabir [21] studied the appropriateness and consequence of rubber dam on agriculture in Bangladesh. The outcomes were evaluated in three categories i.e. hydraulics, agriculture and socioeconomic. The results indicated the agriculture performance adequate. Socio economic conditions depicted its financial viability in terms of profitability. The rubber dam was found hydraulically safe with high probability of water availability. Finally, the results revealed great affect on national economics of the country along with its suitability for recharging ground water.

Rubber dams have been considered successful to lower the flood damages and irrigation purposes in Hong kong. Moreover, due to versatility of different benefits, Rubber dams were recommended multipurpose dams [22]. Inflatable Flexible Membrane Dams (IFMD) had been used for many years in developing and developed countries as a flexible weir for inflatable dams. Latest computations were derived specifying wall pressure distribution for overflow conditions and hazards [23].

Yadav [24] elaborated the benefits of rubber dams as simple hydraulic structure, easy to operate, high seismic resistivity, low construction cost, minimum affects on ecology and environment, very useful for water management of urban areas, high construction feasibility and its effectiveness to cater high variation of low and high flows and tides. Sarker et al . [25] discussed the performance of rubber dam on irrigation improvement in South Asian Region by evaluating the parameters i.e., Command Area Efficiency (CAE), Management Performance Ratio (MPR), Yield Efficiency (YF) and Benefit Cost Ratio (BCR). On the basis of results obtained, 63.9% CAE, 0.028 MPR, 41.8 kg/m^3 YF and 1.34 BCR, it was concluded that the overall irrigation performance and agriculture outputs had been enhanced. Some constraints were also identified in the study as lack of stake holders and farmers participation.

The inflatable and deflating characteristics are great advantage of rubber dam as when water need to be store so the dam is inflated and when the chances of flood risk increases the dam is deflated. Silt deposits, debris and garbage can be evacuated by deflating the dam. Ceramic chips coating and stainless steel mesh have been used for inflatable dams for improving the flexible membrane [26].

2. DESIGN CRITERIA FOR SELECTING THE SUITABLE SITES IN PAKISTAN

The design criteria defined for the selection of potential dam sites are as follows:

- It is evident from literature review that most of existing inflatable dams in the world and in China are located downstream of the bridges. Similarly, for exploring the inflatable dam sites in Pakistan, the location of bridges on Ravi, Sutlej and Jhelum have been given preference for preliminary studies. Other sites on rivers in plain areas have also been explored in the study.
- Those areas where groundwater is depleting are given preference.
- The areas lying in sweat groundwater zone has given preference.
- Massive Resettlement should not be involved due to reservoir.
- Geotechnical and geological ground conditions should favour the construction of dam.
- Negative impact on installations i.e. railway bridge etc. should not be affected due to reservoir.
- The areas near cities have given importance.

3. SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM) DIGITAL ELEVATION DATA

SRTM was internationally established in 1960 for obtaining digital elevation models and high resolution digital topographic database and images of world. The 30 m (one arc second) resolution of the raw data was only available for United States initially. However, in November 2011, similar resolution limited featured data was released for Australia and for remaining world only 90 m Digital Elevation Data (DED) has been provided [27] . STRTM 90 m (3 arc second) DED has been used in the study because of its added advantages i.e., It is freely available worldwide and has best quality. Its results are considered reliable all over the world. It has been successfully utilizes for developing Digital Elevation Models (DEM) of sites all around the world. SRTM has limitation that its DED is only available at 90 m resolution. However, 90 m DED is workable for present study because all the proposed sites considered for Inflatable rubber dams lies on plain area of Punjab Province having mild slopes and objective of the study is to find out the potential of inflatable rubber dams in Pakistan. The comparison of SRTM data base was done with high resolution Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) and concluded that the results were compatible with each other [28].

4. TECHNICALANALYSIS FOR PROPOSED DAM SITES

The tentative locations were identified as per developed design criteria using Google Earth software. 31 selected sites for checking their suitability are shown in Table 5. The location of selected sites has also shown in Fig. 3. The sites have been donated by respective ID. Nos. as mentioned in Table 5.

Table 5. Proposed sites of Inflatable Dams in Pakistan taken in the study for checking their suitability.

ID. No.	Description of Dam	River
1	Victoria Bridge	Jhelum
2	Lahore Islamabad Motorway Bridge	Jhelum
3	Khushab bridge	Jhelum
4	Jhelum bridge on GT road	Jhelum
5	Head Muhammad-wala bridge near Multan Byepass on Khushab road	Chenab
6	Muzaffargarh Chenab bridge near Muzaffargarh road Multan	Chenab
7	Okara Faisalabad road bridge	Ravi
8	KhanewalKabirwala road bridge	Ravi
9	Toba Chichawatni road bridge	Ravi
10	Road bridge on river Sutlej near Pakpattan	Sutlej
11	Road bridge on river Sutlej near Mailsi Syphon	Sutlej
12	Site near road bridge (N5) on river Sutlej near Bahawalpur	Sutlej
13	Musa Shaheed bridge on river Sutlej at Jalalpur Road	Sutlej
14	Bridge on Arifwala Sahiwal road near Bahawalnagar	Sutlej
15	Ravi River near Baghdad Sharif	Ravi
16	Ravi River at Kamalia Harappa Road	Ravi
17	Satluj River near Kanganpur	Sutlej
18	Satluj River near Mandi Ahmad Abad	Sutlej
19	Chenab River near KotKhaira	Chenab
20	Chanb River near JalalpurBhattian	Chenab
21	Satluj River near Fatehpur	Sutlej
22	Chenab River near Bhawana	Ravi
23	Ravi River near Sayedwala	Chenab
24	Chenab River near Khangarh	Jhelum
25	Jhelum River near Kurpalka	Chenab
26	Chenab River near Chowk Permit	Jhelum
27	Jhelum River near Jhawarian	Jhelum
28	Chenab River near Garh Maharaja	Chenab
29	Jhelum River near Mohibpur	Jhelum
30	Chenab River near Qadirabad	Chenab
31	Jhelum River near Tetri	Jhelum

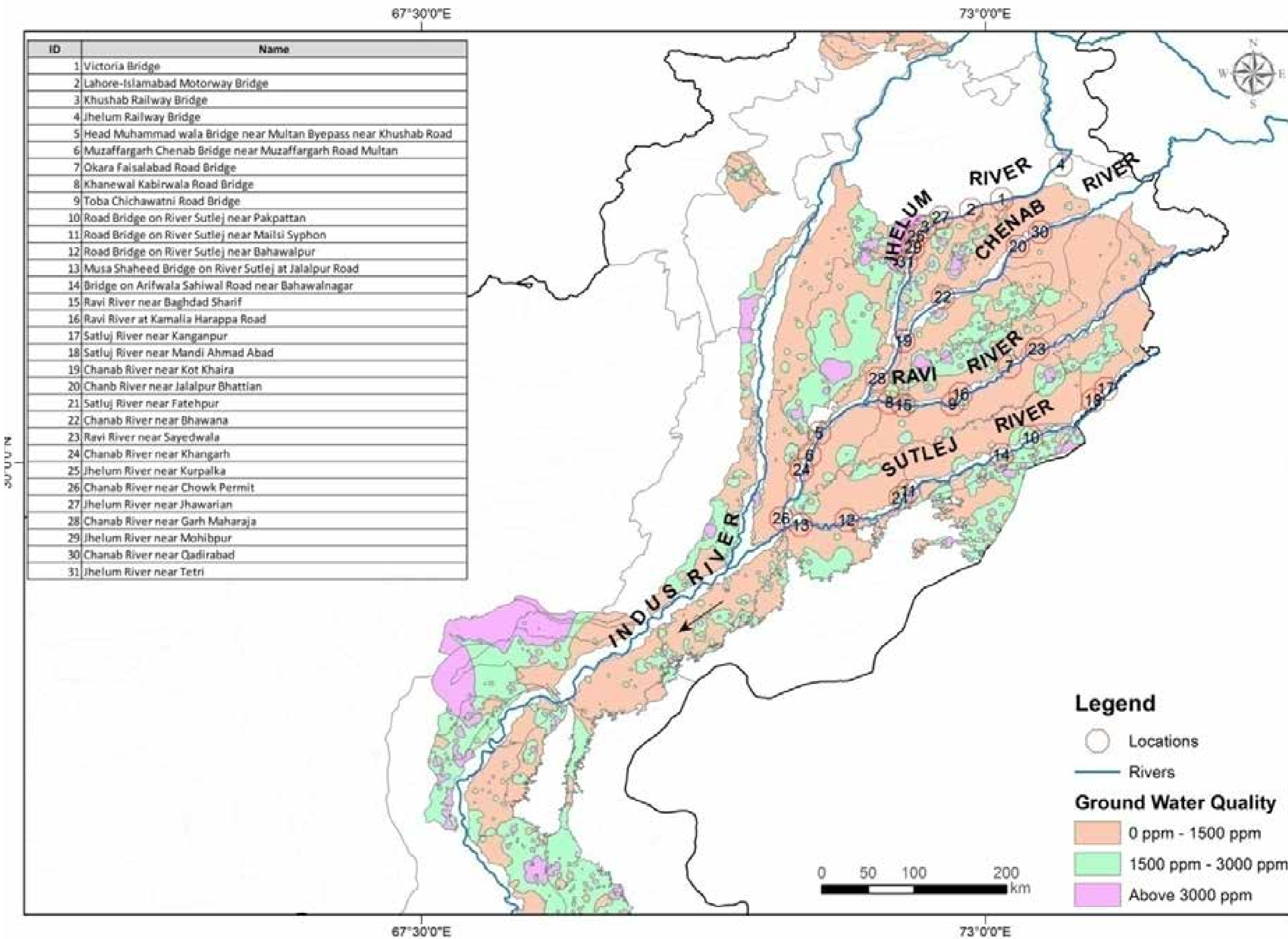

Fig. 3. Location of Inflatable Dams in Pakistan along with the Groundwater quality.

Water quality maps developed using 2012 groundwater data have been used to analyze the groundwater quality at the proposed locations. As per design criteria, the proposed sites must be located in sweat water zone and the groundwater shows the trend of depletion. The groundwater quality map at the proposed dam locations is shown as Fig. 3. The groundwater quality has been graded in three ranges on the basis of total dissolved solids (TDS) as presented in Table 6. The groundwater quality at the proposed location is generally good, as the inflatable dams are located on rivers. However, two sites on Sutlej River at Fatehpur and Mailsi siphon bridge were observed in Bad groundwater zone having TDS quantity greater than 3000 ppm and were discarded from the list of selected sites. SRTM 90 m Digital Elevation database has been used to develop Digital elevation models (DEM) of all the selected sites. Google Mapper is then used to resample the data and to generate 3 m contours at the proposed dam sites for different heights. The pond area has been accessed at different dam heights. The selection of final dam height and pond area is subject to different parameters i.e. public buildings and installments, resettlement of people, sufficient availability of pond etc. Moreover, after analyzing different sites it has been observed that 3 m dam height is considered suitable for finding the reservoir area and capacity. It has been analyzed that the sufficient pond area and capacity of two dams at Muzaffargarh Chanab Bridge near Muzaffargarh Multan on Chanab river (ID. No. 6) and Musa Shaheed bridge on river Sutlej at Jalalpur Road (ID. No. 13) were not available. These two locations are not considered feasible for constructing inflatable dams. The pond area of sites from ID. No. 15 to 31 have been computed by taking the general slope of rivers in plain areas of Punjab i.e. 1in 4000.

Table 6. Range to grade groundwater quality**.**

Sr. No.	Range of Total Dissolved Solids in PPM	Quality
1	0-1500	Good
2	1500-3000	Marginal
3	>3000	Bad

The exact capacity of reservoirs can only be determined by conducting Bathymetric survey. The bathymetric survey of all the sites is not available. Hence, the approximate capacity of those sites whose bathymetric survey is not available has determined using the criteria as follows:

Capacity of reservoir = average height of dam x pond area.

5. RESULTS REGARDING PRELIMINARY ASSESSMENT OF SUITABLE PROPOSED SITES INFLATABLE DAMS IN PUNJAB, PAKISTAN

On the basis of technical analysis, the results have been formulated in terms of groundwater quality, dam height, dam length, reservoir area and reservoir capacity to predict the feasibility of

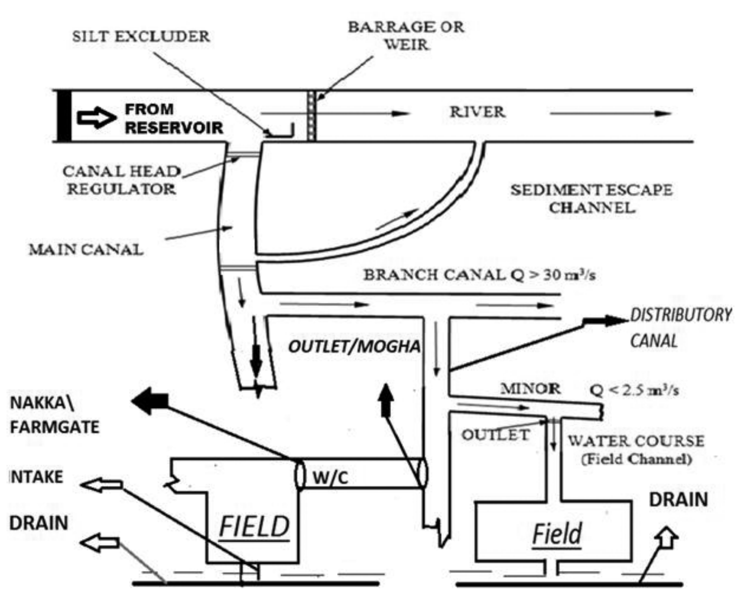

Fig. 4. Schematic Diagram of Typical Irrigation system of Pakistan

Table 7. Summary of results regarding preliminary assessment of suitable proposed sites Inflatable Dams in Pakistan.

Sr. No.	ID. No.	Description / Location of Dam	River	GroundWater Quality	Dam Height m	Dam Length m	Reservoir Area Million m^2	Reservoir Capacity Million m^3
1	1	Victoria Bridge	Jhelum	Good	3	856	5.1	7.65
2	2	Lahore Islamabad Motorway Bridge	Jhelum	Good	3	868	5	7.5
3	3	Khushab bridge	Jhelum	Good	3	716	10	15
4	4	Jhelum bridge on GT road	Jhelum	Good	3	1064	4.3	6.45
5	5	Head Muhammad-wala bridge near Multan Byepass on Khushab road	Chenab	Good	3	600	6.5	9.75
6	7	Okara Faisalabad road bridge	Ravi	Good	3	791	9.4	14.1
7	8	Khanewal Kabirwala road bridge	Ravi	Good	3	121	1.5	2.25
8	9	Toba Chichawatni road bridge	Ravi	Good	3	417	6.4	9.6
9	11	Road bridge on river Sutlej near Mailsi Syphon	Sutlej	Moderate	3	585	7.02	10.53
10	12	Site near road bridge (N5) on river Sutlej near Bahawalpur	Sutlej	Good	3	652	1.68	2.52
11	14	Bridge on ArifwalaSahiwal road near Bahawalnagar	Sutlej	Good	3	634	7.602	11.403
12	15	Ravi River near Baghdad Sharif	Ravi	Good	3	246	2.952	4.428
13	16	Ravi River at Kamalia Harappa Road	Ravi	Good	3	709	8.508	12.762
14	17	Satluj River near Kanganpur	Sutlej	Good	3	240	2.88	4.32
15	18	Satluj River near Mandi Ahmad Abad	Sutlej	Good	3	458	5.496	8.244
16	19	Chenab River near KotKhaira	Chenab	Good	3	718	8.616	12.924
17	20	Chanb River near JalalpurBhattian	Chenab	Good	3	1531	18.372	27.558
18	22	Chenab River near Bhawana	Ravi	Good	3	980	11.76	17.64
19	23	Ravi River near Sayedwala	Chenab	Good	3	1173	14.076	21.114
20	24	Chenab River near Khangarh	Jhelum	Good	3	875	10.5	15.75
21	25	Jhelum River near Kurpalka	Chenab	Good	3	1158	13.896	20.844
22	26	Chenab River near Chowk Permit	Jhelum	Good	3	790	9.48	14.22
23	27	Jhelum River near Jhawarian	Jhelum	Good	3	1003	12.036	18.054
24	28	Chenab River near Garh Maharaja	Chenab	Good	3	1114	13.368	20.052
25	29	Jhelum River near Mohibpur	Jhelum	Good	3	559	6.708	10.062
26	30	Chenab River near Qadirabad	Chenab	Good	3	1344	16.128	24.192
27	31	Jhelum River near Tetri	Jhelum	Moderate	3	381	4.572	6.858

proposed selected sites. The results are shown in Table 7. It was revealed that 27 sites out of 31 sites were considered suitable for constructing inflatable rubber on the basis for preliminary study which indicates the potential of Inflatable Rubber Dams in Punjab and Pakistan.

The typical diagram of irrigation system from the reservoirs to the agriculture filed is shown in Fig. 4. The latest trends identified for optimized utilization of water from reservoirs to agriculture farm have been elaborated in the following section.

6. IRRIGATION SYSTEM MANAGEMENT

Food and Agriculture Organization (FAO) [29] discussed that detailed diagnosis including the performance, present condition, original design and other deficiencies are very important for remodeling and modernization of any irrigation system. The important parameter for remodeling of irrigation channels is change in concept, structure and design. It considers modification in technology, techniques and future consideration of future needs of operation and maintenance [30].

FAO [31] presented detailed methodology for modernization of irrigation canal systems for improving performance. The strategy was developed for analyzing channel optimization on the basis of Mapping System and Services for Canal Operation Techniques (MASSCOTE). During the process of remodeling and modernization, the expectations and achievements had to be kept at realistic and practical level. The most economical and easy-to-implement options were selected to start the process of modernization. Fig. 5 depicts road map for enhancing irrigation water management at canal command level.

The structural measures identified in the present study for improving canal management and conveyance efficiency of canal system

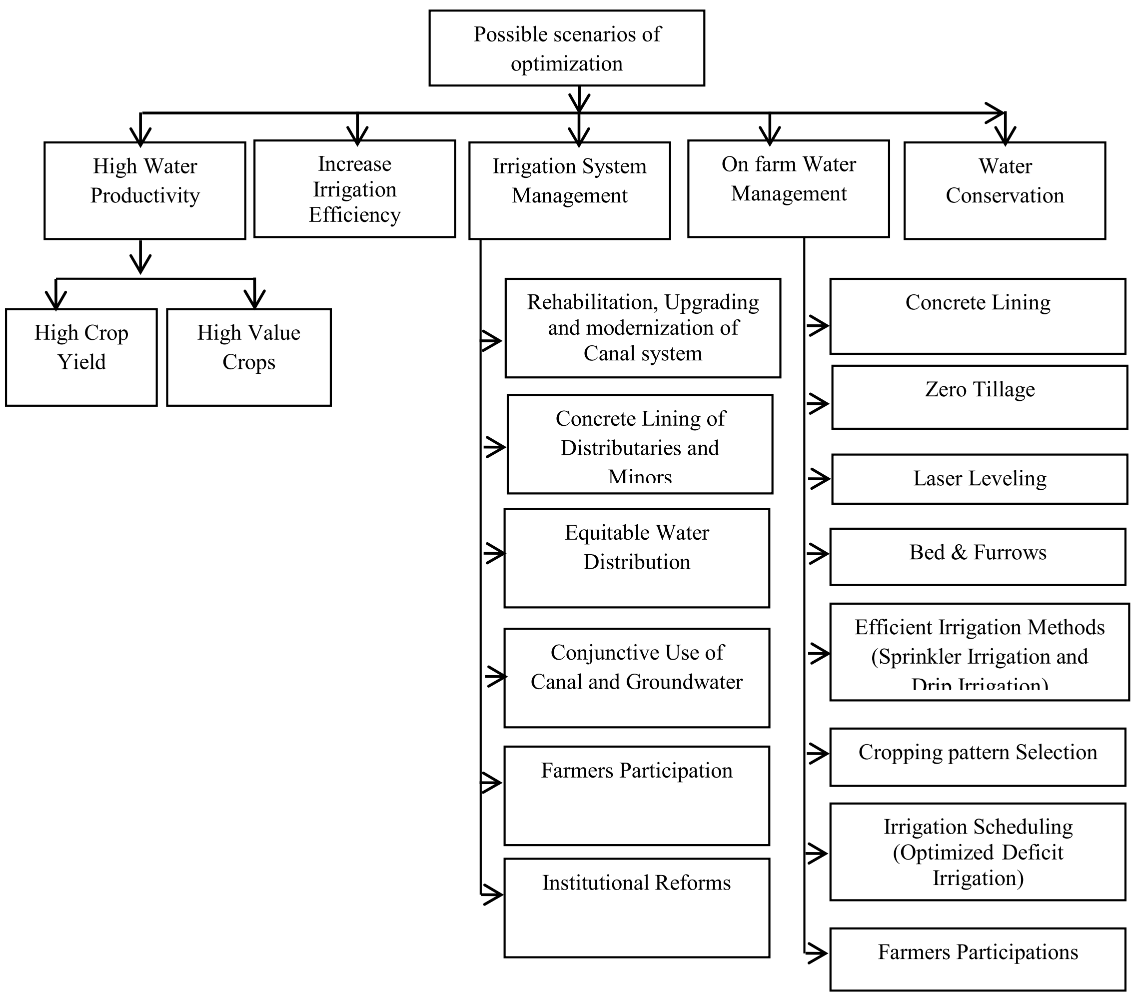

Fig. 5. Schematic Diagram of Optimization of irrigation water management at canal command level.

includes; rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. The rehabilitation and remodeling of canal involves improving the channel prism to cater for enhanced discharge, raising and strengthening of canal banks, providing cattle ghats, upgrading hydraulic structures had been suggested. Suggested water management measures are regular water flow measurements to ensure adequate, reliable and equitable water distribution at different levels of irrigation system and participation of farmers in the operation and maintenance of canal system using the ongoing reforms framework, whereby the farmers are being empowered for management of the distribution network.

7. ON-FARM WATER MANAGEMENT

An array of measures and practices for improved water management at the farm level includes: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling, zero tillage, and bed-furrow irrigation method. Adopting proper cropping systems considering land suitability and capacity building of farming community in improved soil, crop and water management technologies would enhance the water productivity in an effective and sustainable manner.

Resource conservation interventions (laser land leveling, bed & furrows and zero tillage) can save 50% water and increase the crop yield upto 25% [32]. Sarwar [33] concluded that laser land leveling (LLL) can enhance crop yield from 20 to 35% and save 25% irrigation water. Kahlown [34] evaluated the impact of resource conservation techniques on water and land productivity. These techniques were tested on 200 acres of land (Mona Reclamation Area) in LJC command. Halcrow [35] recommended increase in irrigation system efficiencies to 45% merely by educating farmers on use of water in fields and by water distribution management on farm lands in form of lining water lines. The use of RCIs has proved several benefits to wheat farmers. Water can also be saved up to 34% by using ridge furrow of 660 cm wide [36-37].

The demand side management by optimized cropping pattern can improve crop productions and reduce the pressure of water shortage to some extent. The growth of high delta crops should be avoided. The cropping pattern needs to be rationalized so that the pattern of crops provides high water productivity and crop yield. The traditional pattern of wheat-rice has resulted better economic return. The sugarcane crop has resulted poor water productivity and allocation of resources. The water productivity of Orchards is very high and also these are high value crops. Shakir [38-39] suggested that several organizations are involved in management and distribution of water, on farm water management and revenue collection at canal command levels in Pakistan. Generally there seems to be lack of coordination and overlap of activities among the agencies causing poor overall performance. It may be advisable to provide a single administrative unit bringing together all stakeholders. The last but not the least, the participation of farmers in management needs to be enhanced in real terms to create within them a sense of owner ship of the system. The prospective measures for reducing shortfall included enhancement in canal supplies, change in cropping pattern, canal lining and on farm water management.

The constraints for implementing the optimization strategies identified in the study include: physical constraints due to poor operation and maintenance of the system and inadequate water control structures. Institutional constraints due to public sector monopoly, lack of coordination among different institutions and agencies, limited specialization and skilled staff, limited involvement of farmers in irrigation management. Financial and economical constraints due to inadequate cost recovery and provisions for operation and maintenance of irrigation system.

8. CONCLUSION AND RECOMMENDATIONS

The case study reveals that there is much provision on the rivers in Punjab for small storages using inflatable rubber dams. Several benefits including ground water recharge, diversion weirs for small hydropower plants, creating artificial lakes for recreation purposes and for water supply by the use of rubber inflatable dams can be successfully achieved having flexibility in operation during lean and flood period. Total 27 sites, as summarized in

Table 5, were considered feasible for constructing inflatable dams which indicated their potential in Pakistan. Further detailed studies are recommended emphasizing both the technical and economical aspects of inflatable rubber dams before their construction in Pakistan.

For sustainable water resources management, it is recommended that optimized structural reforms from river to root zone of crops i.e., lining of channels, remodeling/up-gradation of hydraulic structures and the adoption of Resources Conservation Interventions (RCI) and high value/ yield crops at farm level are utmost imperative in addition to developing new reservoirs.

9. REFERENCES

1. White, W.R. *A Review of Current Knowledge World Water: Resources, Usage and the Role of Man-Made Reservoirs*. FR/R0012, Foundation for Water Research Allen House, Marlow, Buckinghamshire, UK (2010).
2. World Commission on Dams and Development. *A New Framework for Decision-making*. Earthscan Publications Ltd., London (2000).
3. Khan, N.M., M.S. Babel, R.S. Clemente, T. Tingsanchali, & H.T. Loung. Reservoir optimization-simulation with a sediment evacuation model to minimize irrigation deficits. *Journal of Water Resources Management* 26: 3173-3193 (2012).
4. Khan, N.M. *Reservoir Optimization-Simulation with Sediment Evacuation Model: A Case Study of Tarbela Dam, Pakistan*. Ph.D. thesis, School of Engineering and Technology, Asian Institute of Technology, Pathumthani, Thailand (2008)
5. Michalewicz, Z. *Genetic Algorithms, Data Structures and Evolutionary Programs*, 3rd ed. Springer, Berlin (1996).
6. Chang, F.J., L. Chen & L.C. Chang. Optimizing the reservoir operating rule curve by genetic algorithm. *Journal of Hydrological Processes* 19: 2227-2289 (2005).
7. Wardlaw, R., M. Sharif. Evaluation of genetic algorithm for optimal Reservoir system operation. *Journal of Water Resources Planning and Management* 125: 25–33 (1999).
8. Haq, I.U., & A.R. Khan. *Water and Sustainable Development*. Proceedings of Conference on World Water Day, 22 March 2015, Lahore. Pakistan Engineering Congress, Lahore, Pakistan (2015).
9. Chen, L. & F.J. Chang. Applying a real-coded multi population genetic algorithm to multi Reservoir operation *Journal of Hydrological Processes* 21: 688-698 (2007).
10. Suiadee, W. & T. Tingsanchali. A combined simulation–genetic algorithm optimization model for optimal rule curves of a Reservoir: a case study of the Nam Oon Irrigation Project, Thailand. *Journal of Hydrological Processes* 21: 3211-3225 (2007).
11. Chang, F.J., J.S.Lai & L.S. Kao. Optimization of operation rule curves and flushing schedule in a Reservoir. *Journal of Hydrological Processes* 17: 1623-1640 (2003).
12. Khan, N.M. & T. Tingsanchali. Optimization and simulation of Reservoir operation with sediment evacuation: a case study of the Tarbela Dam, Pakistan. *Journal of Hydrological Processes* 23: 730-747 (2009).
13. Rashid, M.U., A.S. Shakir, N.M. Khan, A. Latif & M.M. Qureshi. Optimization of Multiple Reservoirs Operation with Consideration to Sediment Evacuation *Journal of water resources Management* 29(7): 2429–2450 (2015).
14. Mason, D. *The Inflatable Rubber Dam in Water Resource Management.* Sumitomo Electric Europe Ltd., London, UK (1999).
15. International Commission on Large Dams Small Dams. *Design, Surveillance and Rehabilitation of Dams;* Volume 2. ICOLD Committee on Rubber Dams (2011)
16. Schweiger, P.G. & W.B. Bingham. *Reliability and Performance of Inflatable Dams*. Proceedings ASDSO Annual Conference, Minneapolis, USA (2003).
17. Jena, J. Rubber Dam and its prospect. In: *Proceedings of International Conference on Structural and Civil Engineering.* SOA University, Bhubaneswar, India, p. 60-63 (2012).
18. Chanson, H. Hydraulics of rubber dam flow: A simple design approach. In: Proceedings *13th Australian Fluid Mechanics Conference.* Monash University, Melbourne, Australia, p. 255-258 (1998).
19. Zhang, Q. & Y. Diao. Cascade Rubber Dam fall discharge calculation and analysis. *Canadian Journal of Civil Engineering* 38(8): 957-971 (2011).
20. Zhang, X.Q., P. Tam. & W. Zhang. Construction, operation and maintenance of Rubber Dam. *Canadian Journal of Civil Engineering* 29: 409-420 (2002).
21. Hassan, S. & I. Kabir. Feasibility of Natore Rubber Dam on Mahanonda river in Bangladesh and its performance on irrigation. *American Journal of Engineering Research* 3(1): 27-34 (2014).
22. Tam, P. Use of Rubber Dam for flood mitigation in Hong Kong. *Journal of Irrigation and Drainage Engineering* 123(2): 73-78 (1997).
23. Chanson, H. A review of the overflow of inflatable flexible Membrane dam. *Australian Civil/Structural*

Engineering Transactions 39(2): 107-116 (1997).
24. Yadav, V., Mehta, D., & Waikhom, S. Suitability of Rubber Dam as a river water management tool. In: *Proceedings National Conference on Recent Research in Engineering and Technology. Dr. Jivraj Mehta Institute of Technology,* Mogar-Anand, Gujrat India, p. 16-22 (2015).
25. Sarker, K.K., X.Y.Wang., N. Islam., C.L. Xu., & X.D. Qiao. Performance Evaluation of the Rubber Dam project for irrigation development. *Scientific research and Essay* 6(22): 4700-4707 (2011).
26. Tam, P.M. & X.Q. Zhang. Management of Rubber Dam in Hong Kong. *Canadian Journal of Civil Engineering* 26(1): 123-134 (1999).
27. Nikolakopoulos, K. G., E. Kamaratakis & N. Chrysoulakis. SRTM vs ASTER elevation products: Comparison for two regions in Crete, Greece. *International Journal of Remote Sensing* 27(21): 4819-4838 (2006).
28. Hirt, C., M.S. Filmer & W.E. Featherstone. Comparison and validation of recent freely-available ASTER-GDEM ver1, SRTM ver4.1 and GEODATA DEM-9S ver3 digital elevation models over Australia. *Australian Journal of Earth Sciences* 57(3): 337–347 (2010).
29. FAO. *How Design, Management and Policy Affect the Performance of Irrigation Projects: Emerging Modernization Procedures and Design Standards*. Food and Agriculture Organization, Bangkok (2002).
30. FAO. *Modernization of Irrigation System Operations. Proceedings of the Fifth International Information Techniques for Irrigation Systems Conference,* Aurangabad, 28-30 October 2000. Food and Agriculture Organization, p. 21-36 (2000).
31. FAO. *Modernizing Irrigation Management – The MASSCOTE Approach*; *FAO Irrigation and Drainage Paper 63.* Food and Agriculture Organization, Rome (2007).
32. Chaudhry, A. *Resources Conservation Technology and Bed and Furrow System for Crop Production*. Training Manual for Training at TII AME in Uzbekistan and OWFM in Pakistan, p. 1-43 (2000).
33. Sarwar, A., & W.G. Bastiaanssen. Long term effects of irrigating water conservation on crop production and environment in semi arid areas. *Journal of Irrigation and Drainage Engineering* 6(127): 31-38 (2001).
34. Kahlown, M.A., M.A. Gill, & M. Ashraf. *Evaluation of Resource Conservation Technologies in Rice-Wheat System of Pakistan*. Pakistan Council of Research of Water Resources, Islamabad, Pakistan (2002).
35. Halcrow. *Pakistan Water Sector Strategy*: *Executive Summary, Volume 1*. Ministry of Water and Power. Federal Flood Commission, Islamabad, Pakistan (2002).
36. Kahlown, M.A., M. Ashraf, & M. Yasin. *Water Management for Efficient Use of Irrigation Water and Optimum Crop Production*. Research Report No. 3-2003. PCRWR, Islamabad (2003).
37. Kahlown, M.A., M.S. Shafique, & M. Iqbal. *Improved Irrigation Methods for Efficient use of Irrigation Water under Different Water table Depths.* Publication 231, Mona Experimental Project, WAPDA, Bhalwal, Pakistan (1998)
38. Shakir, A.S., & M.M. Qureshi. Irrigation water management on canal command level: A case study of Lower Bari Doab canal system. In: *Proceedings of International Conference on Water & Flood Management*, 12-14 March 2007, Dhaka, Bangladesh, p. 215-222 (2007)
39. Shakir, A.S., N.M. Khan, & M.M. Qureshi. Canal water management: Case study of Upper Chenab canal in Pakistan. *Journal of Irrigation and Drainage* 59: 76–91 (2010).