Evaluation of Sediment Flushing Feasibility of Small Reservoirs in Potohar Plateau of Pakistan

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Abstract- There are more than about 25000 dams world-wide having volume above 6400 billion cubic meter exceed about. Whereas the storage quantum for the dams is reducing drastically due to unhealthy distribution of silt charge in the flowing water and sediment-deposition. The study was performed to investigate the impact of the application of Atkinson's Methods of storage conservation of small dams. Real time application of such methods has been exercised on small dams in Punjab Pakistan to conserve their storage life. The process of flushing using the low level built in outlets were developed for clearing the storage from sedimentation at large scales. A total of 62 dams in Potohar Plateau of Punjab were initially considered, however the above said techniques have been applied on only 33 dams. The data was collected from Small Dams Organization and Irrigation Department of Punjab, Punjab, Pakistan. Statistical indices including Sedimentation Balancing Ratio (S.B.R), Drawing downed Ratio (D.D.R), Long Term Capacity Ratio (L.T.C.R or LTCR), Fully Drawing downed for Sedimentation Balancing Ratio (S.B.Rd), Flushed reservoir Width Ratio (F.W.R) and Top of reservoir Width Ratio (T.W.R) have been used to assess the flushing impacts. The results of study revealed that only seven reservoirs have successfully been flushed in a certain time period.

Keywords: Sediment flushing; small dams/ reservoirs, flushing evaluation / feasibilty

I. INTRODUCTION

Water storage is depleting annually with an alarming rate throughout the globe (Shao et al. 2021 [1], Granados et al. 2021 [2]. Pakistan with major dependence on agriculture has two number of major dams Terbela and Mengla with storage capacity existing of about 14.2 Bm^3 and 7.30 Bm^3 respectively. The dams were reducing their live storage day by day due to higher rate of silt deposition. These dams has lost about 30% of storage capacity overall. Further, Pakistan has made its development in small capacity reservoir for local jurisdiction to fulfill water demand and enhancing agricultural innovations in huge barren areas. But the issue bearing is that these dams are reducing their storage capacity sharply with average of 1.5 to 2.5 % annually. The objective of this research is analytical study of flushing indicators for determining the feasibility for flushing techniques through reservoirs. Among the available flushing indicators, identifying the most critical parameter after successful modelling and experimentation. The study also include the analysis of flushing strategy in the small dams of Punjab and indicating the rate of flushing in existing reservoirs.

In People's Republic of China, very high ratio of storage loss was observed (about 2.25 %) Shao et al. 2021 [1]. The annual water capacity / quantum loss of nearly 1.5% was observed in Middle Eastern region, 1 in central Asian part, 0.5 in southern Asia part, 0.3 in Southern East Asian region, 0.3 in pacific region, 0.2 in Saharan Region of Africa, 0.2 in Northern American States and Northern European part, 0.183 % in Southern European region while 0.1 in Southern American and Mexican region, Aldeen 2020 [3], Boretti and Rosa (2019) [4].

Through providing an opening just above the dead storage level of the conservative water body i.e. dams, the velocity of water is increased which helps in removing or transportation of the sediments which otherwise deposits in the bed of the channel or stream in a very huge quantum. (Aldeen 2020 [3], Itsukushima et al. 2019 [5]. White, 2001; Emamgholizadeh, 2008)[6-7].

Due to the procedure of sudden flushing in a reservoir, great quantum of the stored and conserved water is wasted in regards of removing deposited particles which ultimately costs higher for the conservation of water. (Fi-John et al., 2003)[8]. Today, after extensive researches, number of well-known techniques are formulated including to clear the reservoir from whole of the sediment deposition called as "Fully flushed" and some percentage of sediment deposition is allowed to remove at cost of little quantum of water wastage known as "Partial Flushing". (Moridi A., Yazdi 2017, Emamgholizadeh, 2006)[9-10].

At the very initial stages of researches to be made practically applicable, D.Rohan method (1911) was applied for complete wash away of sediment deposition from the reservoir conservation which was practically applied in Spain in 1925 using a low level outlets just above the dead storage level of reservoir or conservator. The same application was also found in the annals of history in the 16th century developments [11].

Water resources management, reservoir conservation, sediment transport studies and sediment modeling are world-wide hot issue (Souter et al., 2020 [12], Herman et al. 2020 [13], Aldeen 2020 [3], Moridi and Yazdi 2017 [9], Reservoir flushing is one of the most challenging and daunting research area which has been addressed in this research paper. It is observed that every site and region has its own problems and investing the impact of flushing the reservoirs becomes an original and novel study. Exploring the impact of application of Atkinson, a special and challenging flushing technique for small reservoirs using the real life data has made this research paper an original one and highly useful for engineers and managers working in the field of water resources conservation, development and management.

There are about 26 conservation reservoirs for which the complete data of flushing is available worldwide (Mohammad et al. 2020 [14], White et al, 2000)[6]. Similarly, Atkinson a very renowned researcher on the practical implementation of these techniques in 1996 applied his exhaustive study on nearly fourteen number of reservoirs and picked up six reservoirs which were successfully been cleared / flushed.

Through the studies, six number of parameter or indicators are originated to assess the reservoir about its flushing feasibility the indicating numerical inputs are then originated to assess the practical implementation of flushing techniques in the field. These are S.B.R. (Sedimentation Balancing Ratio), D.D.R. (Drawing downed Ratio), L.T.C.R or LTCR. (Long Term Capacity Ratio: the threshold criteria in assessing the flushing features) S.B.Rd (Fully Drawing downed for Sedimentation Balancing Ratio), F.W.R. (Flushed reservoir Width Ratio) and T.W.R (Top of reservoir Width Ratio). Detail is depicted in below:

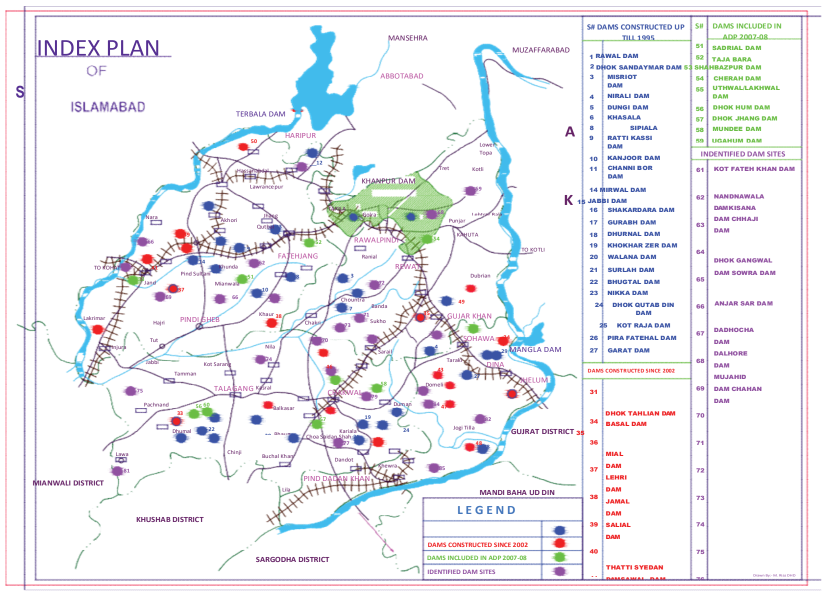

Figure 1: Index Plan of Completed, Nearing Completion, in Pipeline and Identified Dams in Potohar Plateau, (Source; Small Dams Organization, Punjab)

S.B.R	> 1
LTCR	= 1
D.D.R	> 0.7
F.W.R	> 1
T.W.R	> 1 and < 2

This research with collaboration of Irrigation Department of Punjab and Small Dams Organization Punjab, Pakistan is executed on nearly 33 small reservoirs in Potohar plateau of the country (Figure 1) to assess the flushing feasibility. The outcomes have been tabulated in detail.

II. Literature Review

Stream or Riverine flow is proportionally balanced as regard to its particle distribution in a proper quantum. Due to human interventions in form of construction of conservation bodies, weir, headworks, barrages, dams etc. the natural stream flow is disturbed suddenly and the velocity of the flow is reduced considerably and appreciates the deposition of particles of sediments upstream of the conservator / weir/ reservoir as the surface area of the water is increased so much which ultimately caused for the loss of appreciable storage from the reservoirs / dams Morris (2020) [15], Wang et al. 2020 [16] (Figure 2)

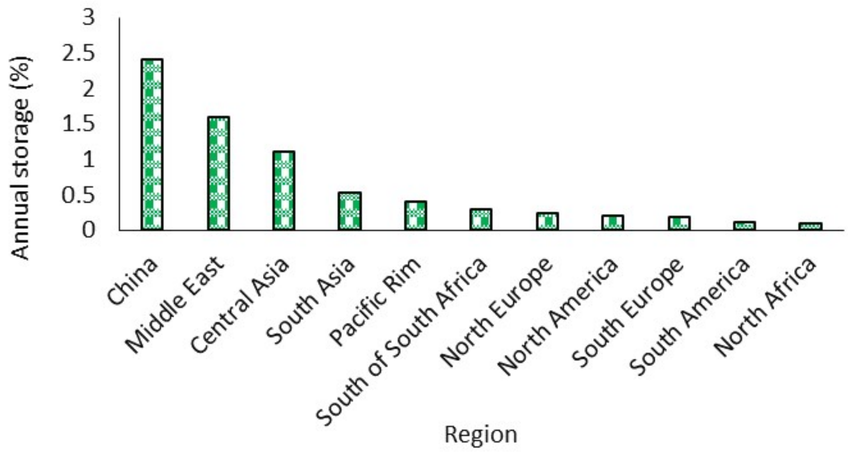

Figure 2: Regional Distribution of Reservoirs regarding sediment concentration

As per practical studies, it is generally observed that there is nearly 0.65 to 0.75 % of loss in a storage of reservoir capacity on annual basis.

As the stream or river flows falls into the reservoir or storage site, the volumetric capacity as well as corresponding cross sectional properties are increased which ultimately reduce the turbulent flow behavior and the corresponding velocity of water is reduced that encourages the deposition of huge amount of sediment which traps in to the bottom base of the dams or reservoir and it causes a huge quantum of water storage capacity reduction (Aldeen 2020 [3], Mohammad et al. 2020 [14], Espa et al.. 2019 [17].

The suspended state of sediment when hits the reservoir at upstream face, the large size particles like gravels and heavy sands is trapped there and due to very low velocity of water, the fine sediment is deposited in a wide shape all along the Stream or river bed as well as reservoir base in a very tight compacted shape (Aldeen 2020 [3], Mohammad et al. 2020 [14].

Due to excessive deposition of particles in the conservator or reservoirs, various impacts are observed as stated underneath:-

1. Reduction is storage conservation.
2. Trapped compacted delta deposited in bed
3. Disturbance in navigation process
4. Environmental Pollution
5. Tremors impacts
6. Scrapping or abrasion.
7. Reduction in Energy.
8. Sluice Inlets as well as Outlets are disturbed.
9. Accretion as well as Degradation observed in the reservoir

There are number of practical techniques devised to better conserve the storage as discussed underneath:

1. Complete Water-shed operated Management
2. Dredging of the reservoirs based on typical procedures.
3. Excavation far deep in dry situation.
4. Hydro-suction for silts.
5. Routing the bulk sediment and sluicing.
6. Bypassing for the particles of sediment.
7. Hydro venting of the sediments based on density induced currents.
8. Removing the sediment trapped from conservator. (Aldeen 2020 [3], Mohammad et al. 2020 [b)18],

As explained by White in 2000 [6] nearly fifty five world reservoirs were experimented in detail to opt flushing techniques and procedures but unfortunately only twenty five dams data is available to study for this practical research. The researcher Atkensin (1996a) [10] applied the theory of flushing practically on 14 reservoirs and formulated a technique SOPs for flushing operation based on its successful results for nearly 6 numbers of reservoirs which are totally flushed in an effective way while all others are partially or percentage wise selected. The results were obtained for these sites as Beira and Ichauri of India, Gabedem & Palegnidra of Switzerland, Gemuond of Austria, Hengshian, Gaunting, Hisonglin, Sanmenxia and Shuecaozi in People’s Republic of China, Santo-Diminego inVenizuela, Guerinsey in USA, Ouschi-Kurrgen of the Former USSR Russian Federation, then Sefeud-Riud in Iran. Successfully operated and fully achieved flushed dams and reservoirs in the world are: Baira in India, Gabidem or Palagnidra of Switzerland, Gemeund in Austria, Hangshan in People’s Republic of China, & Santo-Domienego of Venezuela.

More than 25,000 storage and retention reservoirs with a total capacity of almost 6,500 billion cubic meter (Bm^3) are available worldwide (Figure 3 and 4), (ICOLD, 1998; White etc., 2000; Green, 2001)[19-21]. Most reservoirs exists in North America but are about 7,200 in numbers for getting the impounding volume approximately 1800 Bm3, but the most limited number of reservoirs exist in Central Asia for roughly 77 in numbers, mostly with impounding volume around 149 Bm3. For certain areas of the earth, the volume of impounding rivers and lakes for impounding volumes (measured as Bm3) is: South Asia roughly 4132 (320), Southern Europe 3221(146), Pacific Rim 2279(276), Northern Europe 2271(948), People's Republic of China 1896(648), Southern America 1497(103), Sub-Saharan Africa 965(574), People's Republic of China 1896(648), Southern America 1497(103)

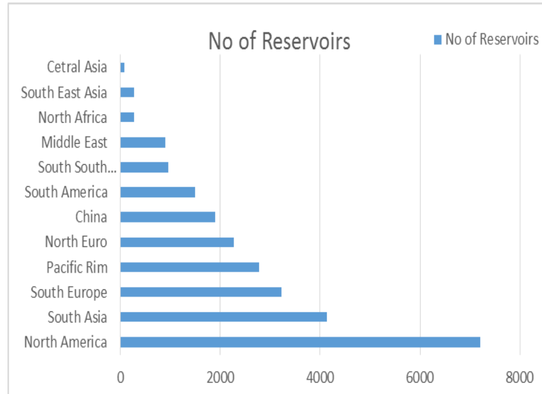

Figure 3: International Storage impounding reservoir distributions (White et al., 2000)

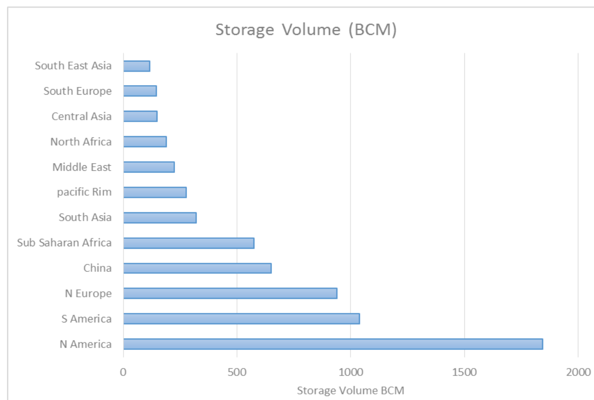

Figure 4: Worldwide distributions of water storages (White et al., 2000)

The flushing procedures have been implemented on about fifty dams but the data for only twenty-five reservoirs are available. (White et al., 2000) [20] (Figure 5). Across the Democratic Republic of China, 21 across total, the greater portion of the impounding rivers have to be washed out. The amount of flushed conservation reservoirs & the amount of dams in a reasonable number of countries is accordingly: Switzerland having five, Former USSR having four, India having three, USA having three, Puerto Rico having two, Austria having one, Costa Rica having one, Guatemala having one, Iran and Japan having one, New Zealand having one, Pakistan having one, Sudan having one, Taiwan having one, Tunisia having one, and Venezuela having one respectively.

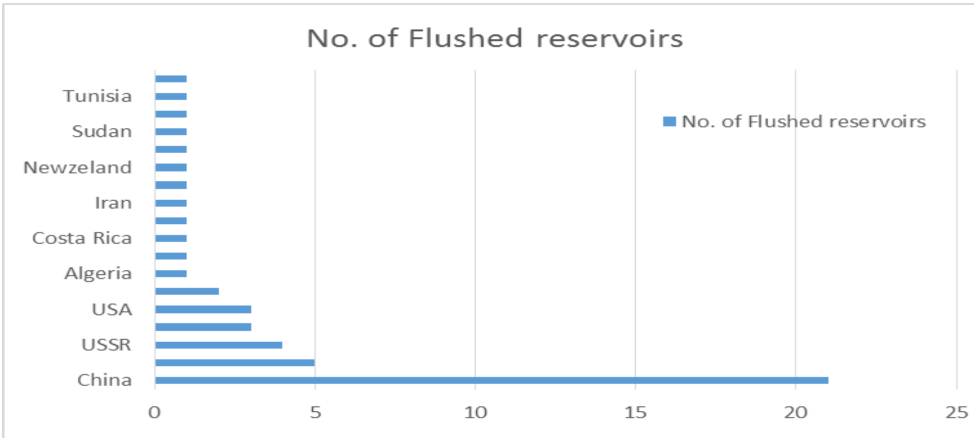

Figure 5: Distribution worldwide of flushed reservoirs

Flushing Efficiency or (Fe)
Flushing production may be calculated for the proportion of the eroded sediment bed accumulated volume to the volume of water used during flushing at any of the time intervals prescribed. (Morris and Fan, 1992b)[7].

Factors impacting performance of flushing
Number of aspects that impact flushing output are responsible for that. Chaudhry, Wang et al [16], Aldeen 2020[3], Muhammad Asif (2014)[8], Samad Emamgholizadeh (2006)[7] specifically shows about output flushed by the low-level outlets has far less sedimentation because the accessible region too lower. Orthoe (1934) further explained as follows varying factors:-

• Flushing have been particularly efficient where an impoundment valley depth is significantly decreased and the channel discharge efficiency is larger.

• The outlet for the flushing has acquired significant significance with respect to its scale during the flushing process as it is achieved with the full drawdown point in the river.

• Height of flushing outlet depicts corresponding performance of flushing. Wang et al [16], Aldeen 2020[3], J.-L.Bertrand (2002)[23].

• The flushing process is also influence by length and time span.

• flushing is significantly impacted by lake depth in valley. (Wang et al [16], Aldeen 2020[3], Atkinson, 1996b) [24].

• Gradient often describes significant value in the reservoir flushing procedure.

• The reservoir capacity may influences flushing activities.

• Shape provides and depicts the significant view for evaluating the viability of flushing.

• The placement in the sedimentation having large locations at river often impacts the flushing cycle.

• Siltation particle forms also play a part in flushing activity.
• Sediment particle shape represents the flushing activity at large.
• The flushing feasibility also specifies the age factor that is the time span for accumulated silt.

Variables for Flushing Reservoir Feasibility Assessment

Atkinson (1996b) proposed six variable figures to determine the sustainability of large-scale reservoir flushing operations described in detail below;

From the indicators listed below it should be informed that both the SBR & correspondingly the LTCR could be the main flushing variables for assessing the overall sustainability of the project. The limits specified for the effective flushing process for SBR should be greater than one and the correspondingly the value or threshold of LTCR should strictly be close to unity, the DDR should rather be higher than value of 0.7[24].

III. Research Objective and Approach

Pakistan, which is heavily dependent on its production and GDP based on agriculture, has two major large dams which are Terbela at Indus and Mengla at Jehlum, having a storage conservation capacity nearly 14.2 Bm^3 & 7.30 Bm^3 respectively. Warsak Dam is also well known large dam of Pakistan. The conservation dams reduced their long span of life-storage very fast due to enormous silt deposition. These large dams have lost nearly 30% of the overall storage valley capacity.

Pakistan also developed small capacity based reservoirs for the local use and jurisdiction to meet increasing water demand & to enhance agricultural productions in vast barren lands and areas. The problem, however, is that these dams sharply minimize their own storage capacity with an average of 1.5 to 2.5 per cent per annum.

It is therefore a dire need to increase / enhance the available storage capacity of water for existing dams using the current innovations. The procedure of flushing the sediment is economically and technically a very viable and feasible. In addition, the study may be rationalized for the new developments and technologies in reservoirs having a great deal for flushing parameters and statistics as per new model. The main objectives are as follows;

i. Analytical analysis of flushing criteria to assess the viability of flushing through reservoir technologies. Identify most important variable after successful modeling and trial and error among all the readily accessible flushing factors.

ii. Study of the flushing procedure in Punjab's small capacity dams and indication about the flushing rate in existing reservoirs.

IV. Methodology

Small Dams Organization, as a project of the Department of Punjab Irrigation is administratively, technically and operationally responsible and dutiful for all the construction, full operation and complete maintenance of these Small Reservoirs throughout the province of Punjab. This organization experiments and studies the viability of small capacity dams in mountainous Punjab areas for local region development. This organization has been further connected with the Irrigation Department field of research. With this organization the data for reservoirs is calculated. Geometric data was obtained at the offices for dams where same has been provided in detail by the project offices.

The feasibility of subsequent sediment infested flushing out from the reservoir is evaluated through six variable numbers as suggested through Atkinson's comprehensive research. The research was applied technically on the available partially been flushed nearly fourteen dams in

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numbers and then observed that only five out of just six indicators meet successfully all the conditions in exclusively both partially & completely flushed capacity reservoir but only the LTCR a threshold provided a constraint in a value to better assess about the efficient feasibility in dam. Thus, this LTCR is established at the value of 0.77 for effective dams which was formerly unity in publication.

Development of Equations for SBR and LTCR of Reservoirs

LTCR is a threshold for determining the reservoir or dam to really be optimal for flushing procedure, hence, parameters for flushing assessment are ascertained from the research as described in the preceding for more ready references.

Q_f depicts about the discharge at the time of operation for the flushing.

T_f depicts about the time duration at the process for flushing.

L specifies about the length for reservoir.

D_{50} specifies about the size for particles i.e. for sediment

S depicts about the slope in the longitudinally dimensions of the reservoir.

W specifies about the width for the bed,

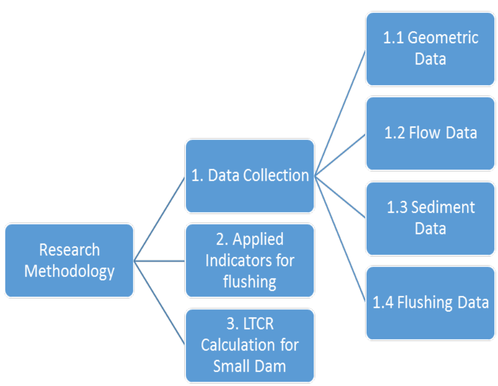

Figure 1: Flow diagram showing methodology adopted to achieve the targets

A is specified the whole of the available surface area that associated with in the impounding reservoir

C_o/V_{in} specifies about the limiting value for capacity inflow at or during operation of flushing

$$S.B.R = K.L^a.(C_o/V_{in}).Q_f{}^c.T_f{}^d.S^e.A^f \quad (1)$$

$$L.T.C.R = K.L^a.(C_o/V_{in})^b.Q_f{}^c.T_f{}^d.S^e.A^f \quad (2)$$

Here the *K* specifies about the coefficients of equations for SBR and the corresponding LTCR anyhow the components *a*, *b*, *c*, & *d*, and e and then f depicts about the exponents for the equations.

V. Results

Evaluation of Flushing Operation Efficiencies for the Small Reservoirs:

In Punjab 33 small dams were considered to compare the flushing feasibility of all these dams towards future use to conserve extra storage (Table 1 and Figure 6). The longer - term Capacity Ratio also called LTCR defined significant level for ultimate flushing systematic review. There are number of input variables for computing the value of flushing indicators mentioned in the literature.

In view of the flushing process the ponds are further categorized in sorted array after the LTCR estimation as below. Table underneath depicts only about seven number of the dams which are efficiently flushed beyond 0.7 being LTCR. The LTCR value of nearly nineteen reservoirs could not be effectively flushed, being very below 0.5. Though seven numbers of the dams are partially flushed through the proper operation of some operational aspects (Figure 6).

TABLE 1: FLUSHING PARAMETERS / INDICATORS

Sr.	Sites in Punjab	Primary indicator		Secondary Inicator			
		S.B.R	L.T.C.R	S.B.Rd	D.D.R	F.W.R	T.W.R
1.	Raawal	5.12	0.561	6.12	0.861	0.05	0.191
2.	Dunge	0.363	0.632	0.53	0.732	0.06	0.572
3.	Jebbi	0.433	0.783	0.65	0.732	0.31	1.256
4.	Piro Fatehal	1.214	0.471	1.61	0.84	0.09	0.631
5.	Jemargal	0.391	0.924	0.82	0.555	0.09	0.391
6.	Tein Pura I	0.032	0.352	0.05	0.82	0.12	0.733
7.	Miaul	0.021	0.664	0.031	0.72	0.08	0.575
8.	Lahri	1.942	0.332	2.421	0.84	0.12	0.745
9.	Kheai	0.181	0.284	0.215	0.864	0.07	0.756
10.	Gheazial	0.327	0.532	0.471	0.746	0.08	0.622
11.	Doemeli	0.152	0.38	0.183	0.844	0.24	0.982
12.	Saliel	1.272	0.416	1.781	0.761	0.05	0.677
13.	Sawaal	1.521	0.275	1.975	0.82	0.12	0.841
14.	Talekna	2.093	0.844	3.344	0.684	0.06	0.51
15.	Jebba	0.784	0.263	1.054	0.781	0.16	1.01
16.	Jelwal	0.414	0.675	0.645	0.686	0.12	0.591
17.	Dherabi	0.222	0.813	0.297	0.81	0.17	0.522
18.	Menwal	1.131	0.253	1.555	0.771	0.13	0.923
19.	Shah Habeeb	0.006	0.223	0.012	0.761	0.05	0.981
20.	Phalena	0.071	0.793	0.12	0.711	0.04	0.511
21.	New Dhok Taehlian Dam	1.892	0.322	2.624	0.762	0.09	0.771

TABLE 1: FLUSHING PARAMETERS / INDICATORS (Continued)

Sr.	Sites in Punjab	Primary indicator		Secondary Inicator			
		S.B.R	L.T.C.R	S.B.Rd	D.D.R	F.W.R	T.W.R
22.	Dhurnel Dam	1.551	0.461	2.344	0.713	0.07	0.674
23.	Uthwal/Lekhal Dam	1.765	0.491	2.131	0.851	0.17	0.634
24.	Ugeham Dam	2.15	0.661	2.923	0.771	0.14	0.575
25.	kokerzer dam	1.62	0.394	2.343	0.741	0.19	0.745
26.	kout raja dam	0.98	0.303	1.359	0.751	0.33	1.005
27.	Dhok Sendaymar Dam	1.28	0.906	2.759	0.522	0.15	0.585
28.	Shahpor dam	0.70	0.972	0.952	0.78	0.91	0.464
29.	Mesriot dam	1.26	0.527	2.405	0.59	0.24	0.751
30.	Domali dam	2.07	0.405	2.557	0.85	0.41	1.142
31.	Khaesala Dam	1.76	0.924	2.825	0.68	0.14	0.522
32.	Jaawa dam	0.81	0.383	1.102	0.75	0.18	0.744
33.	Wealana Dam	8.80	0.312	12.581	0.75	0.27	0.903

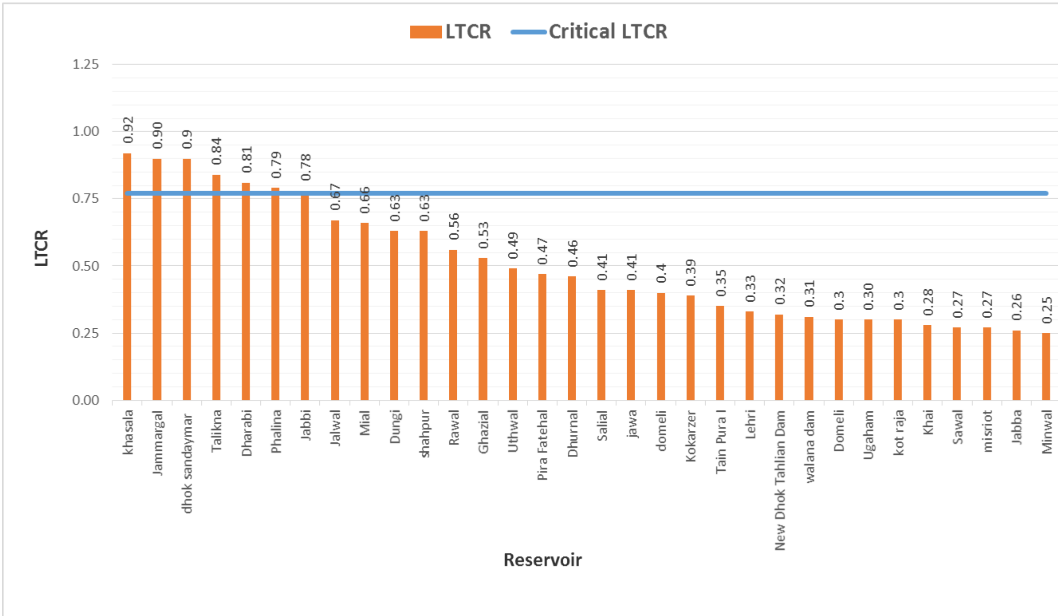

Figure 2: LTCR values assessed for the 33 small reservoirs in Punjab

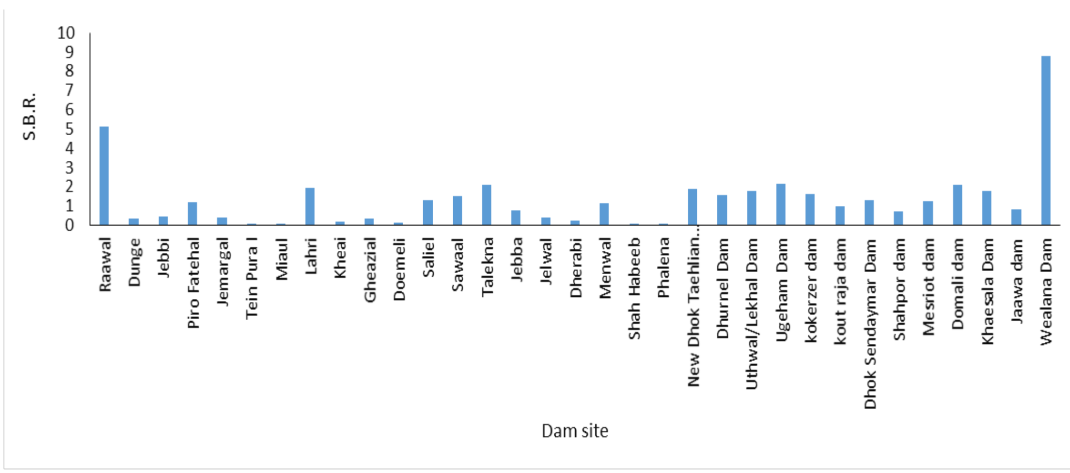

Figure 7: SBR values assessed for the 33 small reservoirs in Punjab

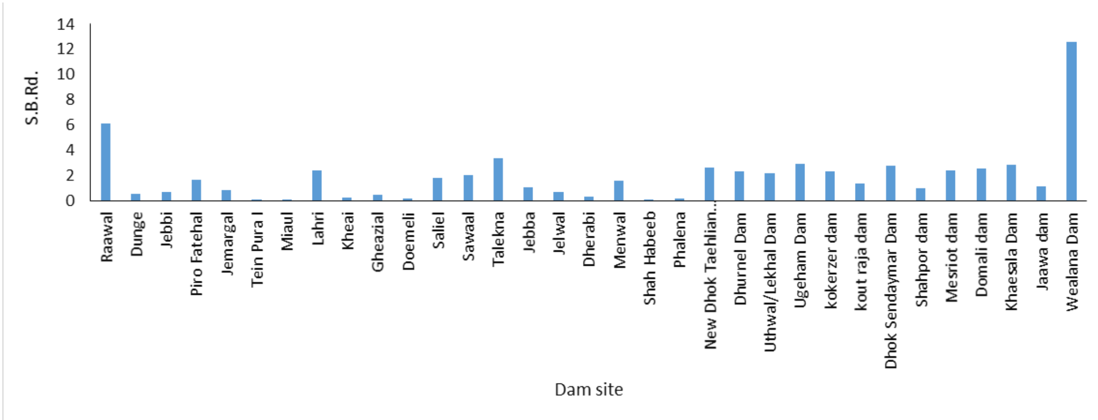

Figure 8: SBRd values assessed for the 33 small reservoirs in Punjab

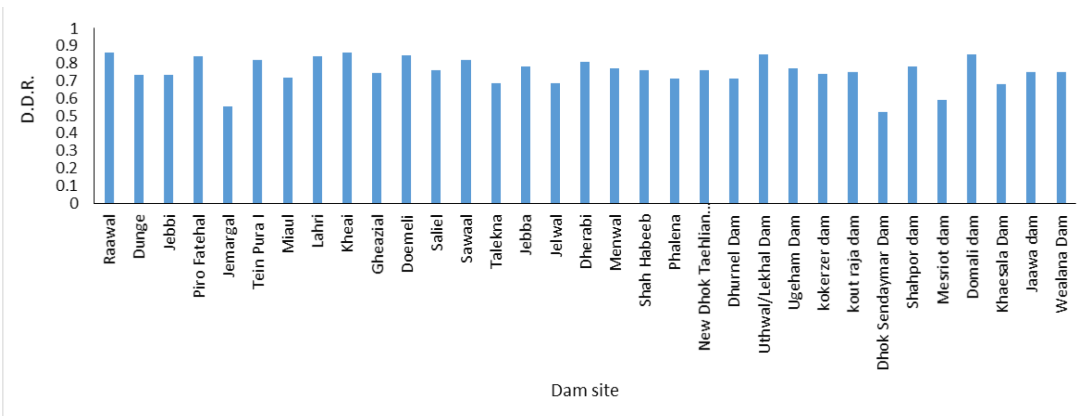

Figure 9: D.D.R values assessed for the 33 small reservoirs in Punjab

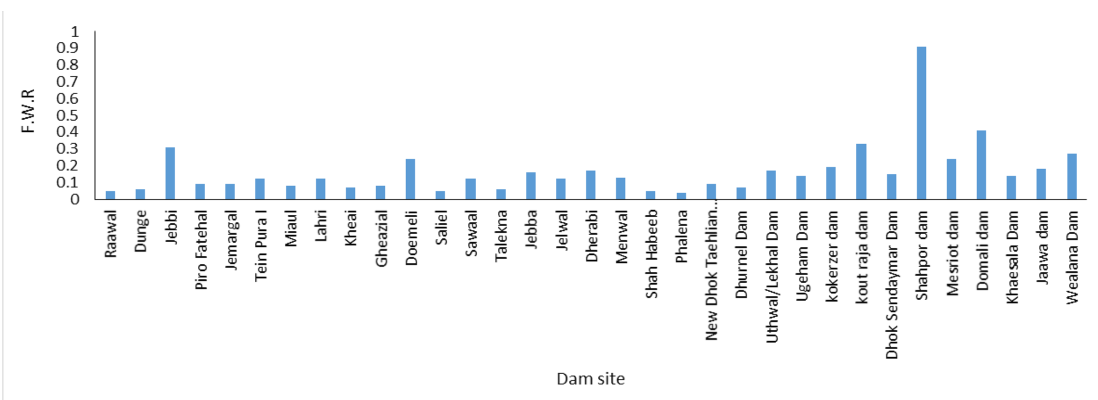

Figure 10: F.W.R values assessed for the 33 small reservoirs in Punjab

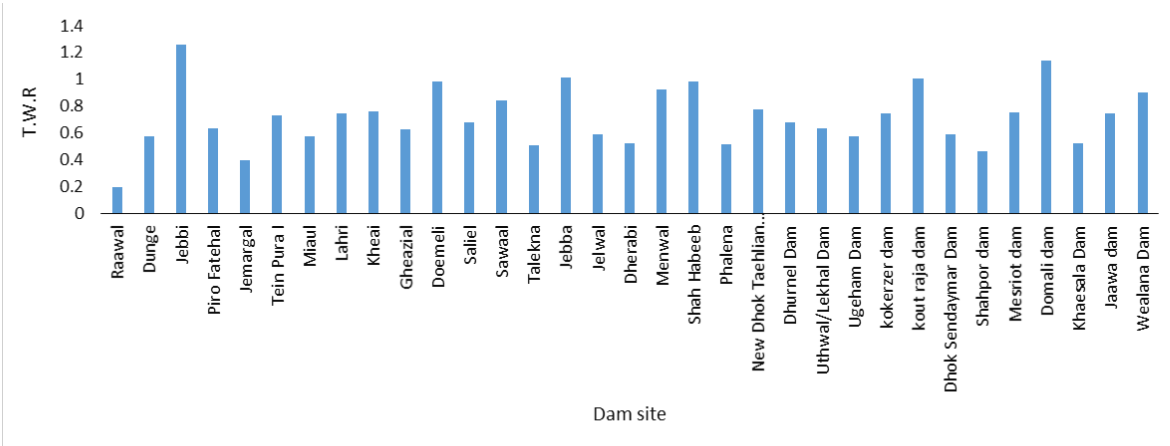

Figure 11: T.W.R values assessed for the 33 small reservoirs in Punjab

A 33 small capacity dams were identified and threhold of LTCR variables were evaluated using the calculus technique, and it was confirmed that nearly 7 numbers of small capacity dams were efficiently flushed as respective values were nearest to the unit. Only around seven small capacity dams have been partly flushed because the LTCR values threholds between 0.5 and 0.77. However the rest could not be flushed away.

Finally, it was suggested that the flushing procedure should be applied after 10 years, which is highly sustainable, as well as the flushing would be performed in the flood season during July to the August.

VI. Acknowledgement

The authors acknowledge and are thankful to the Punjab Irrigation Department and Small Dams Organization for providing data and cooperating In completion of this research.

VII. Summary and Conclusions

The procedure adopted for both the Atkinson approach and the non-linear multiple regression analytical equations give similar values of flushing indicators i.e. SBR (Sediment Balance Ratio) and the LTCR (Long Term Capacity Ratio) with a difference of about 9 to 12 percent is noted. The LTCR is the critical indicator in flushing assessment of the reservoir. The literature has mentioned the value of LTCR for the successful operation of flushing to be the unity is not reliable and is then adjusted and finalize the threshold at 0.77 to be the limiting value of LTCR for which the further assessment of flushing was adopted. It was based on the observations made by the Atkinson and other researchers on 15 number of international dams from which it was clearly be observed that all the practically fully flushed dams have value more than 0.77 which is fixed as a modified threshold for future studies. The assessment of thirty three numbers of small dams in Punjab was done. On the basis of calculation it was cleared that only seven numbers of the reservoirs are successfully been flushed which are Dhok Sandaymar, Khasala, Phalina, Dharabi, Jabbi, Talikna and Jamargal dam. It was concluded from the literature review that about single flushing in a 10 years must be done to conserve the water capacity of the reservoir. Each year flushing is not recommended to be unnecessary and costly and hence one flushing must be performed each ten years.

Flushing feasibility for Punjab dams for which the LTCR exceeds 0.77 i.e. seven successfully flushed reservoirs in LTCR calculations, flushing facilities and control measures must be developed for innovative objectives in order to store and expand reservoir life.

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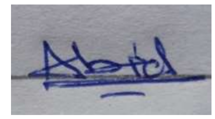

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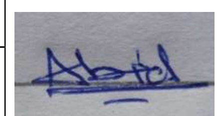
4	Tahir Sultan (4th author)	statistical analysis	
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