Mehran University Research Journal of Engineering and Technology
Vol. 40, No. 03, 671-679, July 2021
p-ISSN: 0254-7821, e-ISSN: 2413-7219
DOI: https://doi.org/10.22581/muet1982.2103.19

Performance Evaluation Methods for Check-Dams in Balochistan: A Review

Vengus Panhwar[1a], Arjumand Zaidi[1b], Asmat Ullah[1c]

RECEIVED ON 06.08.2019, ACCEPTED ON 29.11.2019

ABSTRACT

This study aims to illustrate and present various techniques for evaluating the performance of check-dams and proposes some suitable approaches for impact assessment of dams built in the Balochistan province of Pakistan. These dams were built during the last decade to overcome the challenges of water scarcity and depleting aquifers due to excessive Groundwater (GW) extraction. It was expected that these dams would recharge the GW resources and save the aquifer system from collapsing. Check-dams have traditionally been the permanent source of water within the province. A check-dam is used to delay the floodwater runoff to make it available for domestic and agriculture purposes or to recharge GW. The water along these dams permeates into the ground to keep the aquifer genuinely stable throughout the year. The data were collected based on studies of published research papers and reports of international organizations containing key characteristics of performance evaluation techniques. This review will help to evaluate procedures, policy, and governance interventions in Balochistan by comparing them with the adopted practices in other regions of the world and its impact on the well-being of the society. In this paper, the performance evaluation of check-dams for specific cases is presented. The knowledge acquired will be utilized to highlight state-of-the-art practices and to identify the need for further research in this field.

Keywords: Arid Region, Aquifer, Groundwater Recharge, Field Survey, Remote Sensing

1. INTRODUCTION

GW is a reliable resource in terms of its availability throughout the year. This is the reason that it is known as one of the important and dependable water supply sources for all climatic regions all around the world [1]. It is available in some quantity almost everywhere [2]. In most of the arid and semi-arid regions of the world, the interaction between surface water and GW plays a significant role in the ecohydrological system [3-5]. In many areas of the world including Pakistan, GW is considered as the primary source of drinking water supply, agriculture, and industrial uses [6]. Several regions of Pakistan are dependent on groundwater for drinking and agriculture purposes [7], and its usage contributes about US$ 1.3 billion to the national economy per year as an agricultural output [7, 8]. The utilization of GW for irrigation purposes in Pakistan has a long history especially in Balochistan province where GW is considered as the only dependable source of water to meet both agricultural and domestic needs. Not long ago, shallow GW table of about 7-10 meters in the province was a reality, and local people used to extract water easily through open wells with rope and container, Persian wheels, karezes, responding pumps, and hand pumps [9]. This convenience, on the other hand, caused overexploitation of this precious resource and a drastic decline of water in streams, lakes, and aquifers or GW storages has become

[1] U. S Pakistan Center for Advanced Studies in Water, Mehran University of Engineering and Technology, Jamshoro, Sindh, Pakistan. Email: [a]venguspanhwar23@gmail.com (Corresponding Author), [b]arjumand.uspcasw@faculty.muet.edu.pk, [c]asmatullah@faculty.muet.edu.pk

another reality. For people who have witnessed the GW abundance in the province will be shocked to know that a continued overdraft of GW is causing a decline of the water table at rates up to 3 meters/annum [9]. Some development programs that were initiated in the province to benefit farmers proved to be harmful to water resources. The electrification program in the rural areas was among them that became detrimental for GW resources and resulted in large-scale drilling of tube wells [9].

The number of tube wells was increased due to the establishment of the National Electricity Grid System (NEGS) in the 70s. Since current statistics are not available, an old study is referred here that reported that during 2001-2002 Balochistan had 25,734 tube wells in which 11,371 were operated at diesel while others were run by electricity [10]. The study done by Ahmed [10] in 2005, based on 17 years of data, also estimated the yearly growth rate of 6.7 and 7.4% for electric and diesel-worked tube-wells, respectively. Looking at these figures, it is likely that since 2005 these values would have escalated even further. Another reason for GW depletion as reported by Pakistan Council of Research in Water Resources (PCRWR) was failing of the government to construct new water reservoirs and dams in the province [11]. Not only the humans were responsible for this calamity, but nature had its role at as well in aggravating the already grave situation. The changes in the climate with either insufficient precipitation or extreme rainfall events caused either long dry spells or floods in the regions.

To address water issues of the province, the Government of Balochistan (GoB) has initiated several projects**,** including 100 - Dams project, to construct check-dams on the alluvial fans to reestablish a balance between the discharge and recharge of groundwater aquifers**.** These dams were built during the last decade to overcome the challenges of water scarcity and depleting aquifers due to excessive GW extraction in the arid zones of the province. Balochistan Irrigation Department is the execution agency of this project, whereas, the project is sponsored by the Ministry of Water and Power, Government of Pakistan, Islamabad [12]. It was expected that these dams would recharge the GW resources and save the aquifer system from collapsing. This paper provides a review of different methods reported in the literature for evaluating the performance of check-dams in improving GW recharge, livelihood, and socio-economic conditions. This study will become a prerequisite for advanced analysis to identify the observation and strengths of these methods and suggest sustainable solutions to measure the effectiveness of these methods.

1.1 Motivation for Review

The GW exploitation in Balochistan has become a serious issue, and it can be easily speculated that with the current rate of withdrawal, soon there will be no accessible GW [13]. As indicated by Balochistan Conservation Strategy, more than 90% of all easily accessible water resources, including the share of Indus water and the GW storage, will ultimately be utilized in the next 50 years if the present rate of utilization continues [14]. The 100 - dams project was initiated in June 2009 with a plan to construct 100 dams (20 Dams in Package-I) in the province over 6 years. The modified cost of Package-I is Rs. 2,154.080 million [12]. Till to date, 20 dams have already been constructed. Since an enormous amount of investment was involved in this project, the time has come to evaluate the performance of the built dams against their predefined objectives. For performance evaluation, it is imperative to review those practices, which are being employed in other regions of the world so that a meaningful comparison can be made.

1.2 Scope of Review

In this study, different methods for evaluating the performance of check-dams are described. Since check dam is not a new concept and much literature could be found in this area but we mainly focused on the article which closely matches with the agro-climatic condition of Balochistan and socio-economic condition of the society**.** The data were collected based on studies of the published research papers and reports of international organizations containing key characteristics of performance evaluation techniques being employed all over the world. The objective of this review was a careful screening of the published articles to compile searched methods, review their scope in selecting the relevant performance indicators,

and discuss the conclusions derived regarding their effectiveness. The ultimate goal of this study is to pave a path towards effective performance evaluation of check-dams built in Balochistan using most appropriate methods. Further, the research gaps are identified by contrasting and comparing the prior studies and proposing suggestions for future researchers.

2. INDIVIDUAL APPROACHES

2.1 Importance of the Study

The growing demand for irrigation water and domestic purposes during the last few decades is met by introducing new sources of water [15], but the cost of technology and environmental factors limit the achievement of the demand [16]. The GW dependency is expanding particularly in places where surface water is constrained, and precipitation is erratic. Several regions of the world are experiencing a decline in their GW table due to its over-exploitation [17, 18]. Many researchers have called for similar studies to check the performance of check-dams constructed in other countries that how these dams impacted the GW recharge and the lifestyle of individuals living in the surrounding areas [19]. Moreover, many scientists and climatologists have presented a clear indication and scientific evidence about the global warming of the earth that is causing variations in the climatic patterns [20]. Change in climatic conditions is said to have increasing detrimental impacts on the freshwater supplies worldwide [21]. It is predicted that land area with rising water stress will become greater than twice of the land area with diminishing water stress by the 2050 year [22]. Therefore, in dealing with extreme events, the developing countries are the most vulnerable to these changing climatic patterns due to their limited adaptive capacities [23].

Moreover, water temperatures and extremities in weather pattern may cause many hazards such as droughts and affect water quality and quality especially in arid and semi-arid areas [24]. This situation may, in turn, affect food availability, stability, access, and consumption [25] influencing society, economy, environments, and human health. GW recharges may also get delayed in water stresses area [26].

2.2 Impacts of Check-Dams in Predominating Arid Zones of Asia

Kalamkar *et al.* [27] conducted a study to evaluate the socio-economic impact of check-dam of Tarakpur area of Gujarat by selecting five villages. Pre (2008-2009) and Post (2012-2013) changes were considered due to the construction of a check-dam to support agriculture. Both primary and secondary data were collected in this study. For primary data, pre-designed and pre-tested surveys were collected from 300 households. Predefined performance indicators, including an increase in water supply, income generation, livestock, and crop yield, and change in cropping pattern, were selected and against them the performance of the dams was measured. The result showed significant impacts in terms of enhanced crop yields, livestock growth, and reduction in migration in the water-stressed periods after the construction of check-dams. Besides irrigation, the water was also used for drinking, bathing, and washing purposes. Overall, the study supported the development of such interventions in solving water scarcity through a case study of Tarakpur area of Gujarat, India. The author suggested that check-dams should be constructed to help farmers and laborers to improve their livelihoods.

Raja *et al.* [19] conducted a study on the impact of a check-dam on recharge of an aquifer which was constructed in Melmuthanur village in India using GIS (Geographical Information System) and hydrology tools. In his research, water table fluctuation method was used to find out GW recharge. The results showed an increase in the GW recharge even in the driest periods after the construction of the dam. However, the researcher considered the performance of the check-dam as moderately effective. It can be inferred from this study that it is not sufficient to know if a check-dam is causing an increase in the water table in the area? Instead, the level of effectiveness in restoring GW resources is more important to weigh the benefits derived against its investments.

Another researcher, Renganayaki and Elango [17], observed the performance of check-dams through Managed Aquifer Recharge (MAR) method near Chennai in India. He also emphasized the importance of the geology in finding out suitable recharge locations that can increase the impact and efficiency of

check-dams. He identified various geological locations that can help in recharging the water aquifers and improving the GW quality. The study also revealed an improvement in the living standards around the constructed check-dams. This method was one of the useful methods for GW development, and the results of the study proved that regular maintenance of these dams might ensure a sustainable renewal of GW. The check-dam by MAR method can, therefore, be considered as one of the finest options for efficient and sustainable management of GW.

Shit *et al.* [28] assessed the performance of check-dams to control rill-gully erosion in a small catchment area of Paschim Medinipur of West Bengal, India. A field study was conducted for reducing runoff and sediments to observe the efficiency of check-dams. The methodology is divided into different phases. In the first phase, field survey and rill-gullies were measured, whereas, in the second phase, check-dams were constructed and their role on erosion control was observed. Results showed a positive response due to the installation of check-dams in reinforcing upstream channel stability and reducing sediment yield by 41.5%. This finding implied that construction of check-dams does not only help to improve the GW table, but also provides an efficient mechanism for soil conservation and reducing high sediment yield. At this point, this can also be suggested that any future study where cost-benefit analysis of check-dams is conducted, the additional benefits of such kinds should also be considered.

Another success story was reported by Khlifi *et al.* [29] who evaluated the impacts of small check-dams on agricultural development in Northwestern Tunisia. A socioeconomic survey was conducted, and nearby farmers were interviewed. The water conserved by check-dams was used to irrigate vegetable crops, fodder, fruits, and tree plantation. The survey results verified the benefits achieved by doubling the average income of the community through increased crop production and livestock. The additional advantage was an increase in sheep productivity due to water availability to grow fodder.

Muralidharan *et al.* [30] evaluated the response of groundwater table after the construction of a check-dam in Hyderabad, India. In his study, the percentage of recharge by artificial (check-dam) and natural (rainfall) processes were compared by time window frames and tritium technique, respectively. An increase in the natural groundwater recharge by 22-32% was observed in that area owing to the construction of the check-dam.

2.3 Local Studies in Pakistan

Ashraf *et al.* [16] evaluated the Karez irrigation scheme in Balochistan-Pakistan to know if that is performing well or not? He also studied the possible impacts on the local community regarding the performance of the scheme in addressing the present issues and proposed necessary measures accordingly. Under this scheme, the provincial Irrigation and Power Department (IPD) was responsible for providing surface water by constructing perennial canals, small check-dams, and flood control irrigation schemes in different parts of the province. A survey of the farmers was conducted to know the performance and constraints of the scheme. Based on this study, a need for improvement to sustain Karez system by regular cleaning and protecting it from floods was identified and appropriate measures by adopting available technologies and agronomic practices to overcome the shortcomings were suggested. This fact implies that the interventions done in the province to restore Karez irrigation systems are not up-to-the-mark and there is a need for a holistic and integrated approach to identify the problematic areas and their possible solutions.

Another study was conducted by Ashraf *et al.* [31] to assess the impact of three dams in the Pothwar, region of Punjab-Pakistan. These dams were constructed by the Punjab Government for the development of agriculture, GW recharge, and to help future managers for efficient and sustainable use of dams in Pakistan. In this regard, pre-tested questionnaire survey from farmers was conducted, and secondary data such as precipitation, inflows, and outflows were collected from relevant organizations to ascertain annual water released from the three dams and annual precipitation to meet crop water requirements. The results showed that there is an increase in the cropping frequency and crop yield. Also, the GW was elevated in the area which led to a rise in the number of wells.

Mian and Khan [32] conducted a study to measure the effect on Karez flows due to the construction of check-dams in Balochistan. Pechi dam was selected to determine the recharging amount and extent of groundwater. The result shows that reflowing of water was observed in Karezes due to this intervention. However, due to the absence of monitoring of record, the reflowing of Karezes was not possible to quantify.

3. SUMMARY

Most of the research work indicating the positive response of check-dams on livelihood was conducted by Mudrakartha [33], Palanisami *et al.* [34], Gale *et al.* [35], and Neumann et. al. [36] during 2003-2006 Renganayaki and Elango [17]. Moreover, feasibility studies as well as the studies from other cited literature show that the performance of check-dams are appreciated by the local communities. This is mainly due to the rise in GW, which eventually increased employment of people living near the check dams, and improved flood control [37-39]. It was observed that most of the researchers develop survey questionnaire to examine the impact of check-dams, which helped them to identify the positive impacts of check-dams with increased crop production, yield, and the number of livestock. Table 1 summarizes the review of performance evaluation methods for check-dams found in the literature. Table 2 summarizes the performance indicators for evaluating check-dams. It was also observed that one objective is being addressed by more than one indicator, and similarly, one indicator is serving many objectives.

4. CONCLUSIONS AND RECOMMENDATIONS

The purpose of writing this paper was to review the available literature on the effectiveness of check-dams that may solve GW recharging issues in the water-stressed area in the long run. In this study, state-of-the-art practices, reviewed in national and international literature, are highlighted, and a need for further research on performance evaluation of Balochistan's check-dams using appropriate indicators and effective methods is realized. This review also presents various key performance indicators, used by different researchers for choosing appropriate techniques for performance evaluation of check-dams in Balochistan. Various individual and integrated approaches were proposed by the researchers from studies conducted in the predominant arid regions of Asia and most common of these were on-site interviews. Construction of check-dams on larger scale in Balochistan is relatively new and therefore performance evaluation of these check-dams in Balochistan has not been widely studied. The studies cited here have used single parameter approach for the performance evaluation of check-dams, i.e., either groundwater recharge, control of soil erosion, or socio-economic impacts instead of using an integrated approach. Moreover, the following observations were made during the literature review;

(i) There is a need for a holistic assessment based on all relevant performance indicators. Most studies, done so far, addressed only one indicator for this purpose.
(ii) None has addressed the impact of dams on the lower riparian areas that may include diminishing water supply in the downstream region. If people living in the lower reaches are not allowed to use dam water, then their rights will be violated. Presence of policy interventions in this regard should not be overlooked.
(iii) The lower performance of the dams may be due to many reasons including unsuitable site selection for dams' construction. Therefore, before any impact assessment studies, the criteria for dam site selection should be evaluated. In case of Balochistan, the site selection studies for 100 dams' project may be consulted to uncover design related faults (if there exist any).
(iv) Small dams may also affect river flows that need to be studied.
(v) Impact on ecology is another aspect that has been neglected widely.

Therefore, it can be concluded that although all these studies are valuable, these did not follow a holistic approach by including all critical aspects of performance evaluation. It is, therefore, necessary to first identify all possible performance indicators so that the questionnaire developed for future study will include all pertinent questions. Studies performed following these above mentioned guidelines, would

Table 1: Summary of Performance Evaluation Methods for Check-Dams

Research Topic	Objectives	Country/ Area	Data/Method	Analysis Tool	Result/ Findings	Reference
Socio-Economic Impact of Tarakpur Check-dam in Khambhat Area of Gujarat	To detect pre and post construction changes in the socio-economic status of people	India, Gujarat	Informal, Formal interviews and data collected from irrigation and other relevant organizations	Statistical Analysis	Increased in operational land by 3.4%. More than 94% of the land beneficiary is irrigated.	Kalamkar *et al.* [27]
Evaluation of Karez irrigation scheme in Balochistan-Pakistan	To know if the scheme is fulfilling its objectives or not, and to detect impacts on the local community	Pakistan, Balochistan	Climate, Soil Topography, Discharge, Survey Questionnaire, and relevant secondary Data	Statistical Package for Social Scientist	20% to 30% increase in water supply and irrigated areas respectively	Ashraf *et al.* [16]
Impact of a Check-dam on Groundwater Recharge	To determine the efficiency of check-dam in flood and groundwater characteristics.	India, Melmuthanur	Rainfall and water level of observed well	The GIS and hydraulic model	Increased in groundwater recharge although a loss in precipitation in some seasons.	Raja *et al.* [19]
A Review on Managed Aquifer Recharge (MAR) by check-dams	To identify the impact of check-dam in recovering groundwater level, quality, and livelihood.	India, Chennai	Experimental work	Managed Aquifer Recharge (MAR)	Increased in Groundwater quality, quantity by 1.5m and income of livelihood.	Renganayaki and Elango [17]
Assessing the Performance of Check-Dams to Control rill-gully Erosion	To measure the effectiveness of check-dams for reducing runoff and sediments.	India, Paschim Medinipur	Field surveys and Soil samples were collected	Experimental Lab testing and UV-VIS Spectrophotometer used for analysis	41.5% of sediment production is reduced through sediment trapping and reduction of erosion.	Shit *et al.* [28]
Impacts of Small Hill dams on agricultural development	To assess the impact of dams constructed in farming systems and farmer's incomes.	Tunisia, Jendouba	Annual Average Rainfall data, runoff and silting-up values calculated by Empirical Formulae spillway discharge and survey questionnaire	Hierarchical cluster analysis using one-way ANOVA	Increased in total farm area by 16% and rise in net income to 14,000 TND	Khlifi *et al.* [29]
Evaluation of check-dam recharge through the water-table response in the ponding area	To estimate the efficiency of check-dam in recharging groundwater and to compare groundwater recharge by artificial and natural rainfall means.	India, Hyderabad	Rain gauge, Field Tests and Surveys/ monitoring	Time window frame and Tritium Technique	22 % and 32% increase in groundwater recharge due to the construction of a check-dam	Muralidharan *et al.*[30]
Impact of small dams on agriculture and groundwater development	To assess the impact of dams on groundwater and agriculture development and suggest some strategies in improving land and water efficiency.	Pakistan, Punjab	Survey Questionnaire/ Field Visit, Precipitation, inflows and outflow data	Statistical Analysis	Increased in crop cultivation, yield and groundwater table.	Chang and Wang [18]
Effect of Delay Action Dam on Flow of Karez	To find out the extent and recharging extent of groundwater	Pakistan, Balochistan	Historical rainfall, evaporation and runoff data and collection of field samples.	Regression and curve number model	Reflowing of karezes due to delay action dams	Mian Khan [32]

Table 2: Performance Indicators for Evaluating Check-Dams		
Indicator ID	Key Indicators	Driving Mechanism
A	Groundwater recharge	The GIS and hydraulic model Field survey Soil sample experimental work
B	Livelihood	Survey
C	Socio-economic condition	Survey
F	Frequency and intensity of floods	The survey, Literature review

have more value in evaluating the performance of constructed check-dams. One of the reasons for limited scoped studies may be the cost involved in collecting data related to all relevant indicators. Field studies are time and resource intensive and limited in adverse weather and law and order situations. Some remote areas are also not easily accessible. To supplement field collected information, remote sensing data and techniques can be utilized at minimal costs. Remote sensing has become one of the efficient and cost-effective techniques after the availability of high-resolution data free of cost. Thus, for countries like Pakistan with budgetary constraints, the need is to use efficient but cost-effective methods. It is, therefore, suggested that state-of-the-art geospatial techniques should be employed for analyzing dams that are located in remote areas. More detailed field surveys at selected locations with easy access should be carried out to validate the findings.

ACKNOWLEDGMENT

The authors acknowledge the support provided by the US-Pakistan Center for Advanced Studies in Water, Mehran University of Engineering and Technology, Jamshoro, Pakistan, in conducting this study.

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