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RESEARCH ARTICLE

GULLY PLUGGING SPILLWAY IS AN EFFECTIVE GULLY REHABILITATION MEASURE: A CASE STUDY OF DISTRICT GUJRAT-PAKISTAN

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ABSTRACT

Soil erosion is the universal land degradation event which invites an enormous challenge for its rehabilitation. Among all forms, gully erosion is the most worst and visible form of water erosion which cannot be controlled without any permanent gully stabilization structure. Therefore, the study was conducted to evaluate the impact of gully plugging spillway to rehabilitate the eroded land. For this purpose, a highly eroded site was selected within the study area, surveyed to estimate the structural design and brick masonry work was executed accordingly. The consequences of study clearly illustrated that straight drop spillway is an effective hydraulic structure which considerably fulfilled its objectives by plugging the gully to stop further erosion as well as stabilizing the eroded land.

KEYWORDS

Soil Erosion, Gullied Land, Silt Load, Rehabilitation, Spillway, Masonry Work.

1. INTRODUCTION

Soil erosion is a geographically predominant land degradation phenomenon which confronts the global agriculture (Leh et al., 2013). It is a natural occurrence encompassing a series of processes which cause the loosening of soil; thus, moving away the soil particles under the action of different agencies such as water, wind, glaciers and other geological agents (Guerra et al., 2017). Although, soil erosion is a widespread problem since the establishment of settled agriculture; however, its current magnitude and impact on global ecosystem has been augmented to a greater extent than ever before. It is estimated that erosion accounts for 83% of global degraded land which results in degradation of approximately 1.6 billion ha of world's land (Bai et al., 2008). Soil erosion is a serious threat to agricultural activities as its happening has a dreadful impact on fertility as well as productivity of soil; hence, leading to a huge loss in crop production (Munodawafa, 2012). Moreover, it disturbs the soil structure due to crusting and creates off-site environmental pollution by eutrophication as well as silting up of water bodies (DeJong-Hughes et al., 2001; Bing et al., 2013; Issaka et al., 2017).

Rainfall is one of the major causes of erosion which makes the soil profile undermined due to its beating action and removes the whole sheet of fertile soil (Ziadat et al., 2013). The consequences of this erosion are further extended when sheet erosion is converted into rill erosion and ultimately gullies are formed (Khalko et al., 2013).

Gully erosion is the worst and most visible form of water erosion which is a universal land degradation process prevailing in rural, urban as well as forested localities (Abdulfatai et al., 2014; Tebebu et al., 2010; Castillo et al., 2016). Gullies are defined as small channels or valleys formed due to cutting action of concentrated as well as intermittent runoff during and immediately following heavy rains (Soil Science Society of America, 2008). It is a key process regarding the production of sediments [14] which shares 10% to 94% of deposits in water bodies (Addis et al., 2015; Bennet et al., 2000; Poesen et al., 2003). Gully formation is triggered by different man-made as well as physical factors such as improper land use, over grazing, topography, soil type, vegetative cover, etc. (Pathak et al., 2005). Gullies can be classified on the basis of different characteristics such as size, shape, drainage, continuation and discharge rate; moreover, its shape depends upon the gully initiation process (FAO, 1997; Soufi, 2004).

Gullies cannot be stabilized by ordinary tillage operations; thus, a concrete action is needed in this regard to plug them by different permanent gully stabilization structures such as spillways, concrete dams, gabion structures etc. (Soil Science Society of America, 2008; Poesen et al., 2003; Valentin et al., 2005). The basic purpose of these structures is to detain silt, nutrients and moisture as well as halt further land deterioration by checking the velocity of runoff water, reducing its erosive power and increasing the contact time of water with soil; thus enhancing the deposition of flood load (Zia et al., 2004). Among different gully rehabilitation measures, spillway is an effective hydraulic structure, which is a flow path constructed across the flowing water to dissipate its kinetic energy and retain silt load to avoid further advancement of gully (Khalko et al., 2013).

The gully control structures are laid in the gully section, throughout the length, according to the profile of gully bed. Amongst different types of spillways, the chute spillways are located at the gully head for safe disposal of runoff water from head to the gully bed. The drop spillways are placed along the gully bed in series to act as control points, so that the gully bed cannot be eroded below the crest level of the structure. Drop inlet spillways are constructed at the places of high depression in the gully bed for storing the water.

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1.1 General Status of Water Erosion in Pakistan

Pakistan faces a severe problem of soil erosion and water loss hazards in rainfed areas. It has been reported that 76% of the total area of Pakistan is subjected to erosion in one form or the other. Out of which, water erosion is active on 36% and wind erosion on 40% area (Chaudhry 2013). Pakistan has been divided into diverse agro-ecological zones on the basis of its climate, geology, agricultural land use, physiology and water availability (Ahmad et al., 2019). Among these zones, Barani land zone confronts severe land degradation due to soil erosion which includes Pothwar uplands, piedmont plains, riverain areas, salt range, Murree hills and Thal areas. This land degradation depends upon the inherent soil properties and other major factors such as land use practices, climate, slope and ground cover (Li et al., 2004).

The hilly areas surrounding Indus Basin have large and steep slopes causing soil erosion during the period of intense summer rainfall. Likewise the soils of Pothwar plateau are loose which are prone to soil erosion causing gully formation. It has been estimated that about 19 million hectare productive land has been deteriorated due to both wind as well as water erosion, out of which 13 mha is eroded due to water (Anjum et al., 2010). Moreover, about 40 billion tons of soil is annually brought into Indus-Basin; thus, the efficacy of canal irrigation system goes to decline and life span of major reservoirs is reduced. In upstream, the infrastructure is damaged due to washing away of soil; while, in downstream, the efficiency of hydropower system goes to decline due to sediment load (Zia et al., 2004; Zia et al., 1995).

1.2 Erosion problem in study area

Gujrat is located to the south of Pothwar region, extending from 32° 34′ 26″ N, 74° 4′ 44″ E, and consists of both Eastern piedmont as well Western alluvial plains. The western region is formed due to flood flow of Jhelum as well as Chenab Rivers; while, the eastern region is located at the foothills of Himalayas and is formed as a result of sheet flood deposition by hill torrents (Beg, 1993). This piedmont area is categorized into piedmont basin as well as young and old piedmont plains. Among these divisions, old piedmont plain is considered as highly vulnerable to gully erosion (Reconniasance Soil Survey, 1968). This region is characterized by sub humid climate which experiences great rainfall conditions. The average annual rainfall ranges from 670-750 mm out of which about 80% is received during monsoon season.

2. Methodology

2.1 Site Survey

The study was based on constructing spillway in eroded land and evaluating its impact regarding rehabilitation of gullies. For this purpose, survey was conducted during the month of January, 2018 at village Hanj of Tehsil and District Gujrat, Punjab, Pakistan, which is located between 32° 45' 41.52'' N and 74° 21' 26.20'' E at 911 ft elevation from sea level. The Gully was located at Hanj in the land of Muhammad Sharif S/O Mian Khan which was surveyed carefully (Table 1) to estimate the structural design of spillway.

Table 1: Survey of site location

Year of Study	Location of Spillway	Village Name	Name of Farmer	Catchment Area	Length of Nullah
2017-2018	32° 45' 56.18'' N 74° 21' 38.28'' E	Hanj	Muhammad Sharif S/O Mian Khan	0.775 km²	0.73 m

2.2 Designing of spillway and execution of work

Straight drop spillway was designed across the gully bed. For this purpose width and height of gully bed was measured for the calculation of different components of spillway (Fig. 1) and an estimate was prepared for the execution of brick masonry work according to the particular design of structure.

In order to design the structure, the runoff of the gullied area was calculated by using the following formula:

$$Q = CIA$$

Where Q is the runoff in $ft^3\ s^{-1}$, A is the catchment area in acres, I is the rainfall intensity in inches $hour^{-1}$ and C is the coefficient. The discharge capacity of spillway should be equivalent to this above calculated runoff for the safe discharge or passage of runoff water. Therefore, calculated runoff was considered as the discharge capacity of structure and following formula was used to calculate the other components

$$Q = 3.2LH^{1.5}$$

Where Q is the discharge capacity in $ft^3\ s^{-1}$, L is the length of spillway in ft which was equal to the width of gully bed and H is the notch in ft. Net drop or fall was calculated by measuring the height of gully bed (Table 2).

Table 2: Detail of Calculated Particulars

Discharge Capacity	Length	Net Drop or Fall From Crest to Bed Level	Notch
271.52 $ft^3\ s^{-1}$	30 ft	3 ft	2 ft

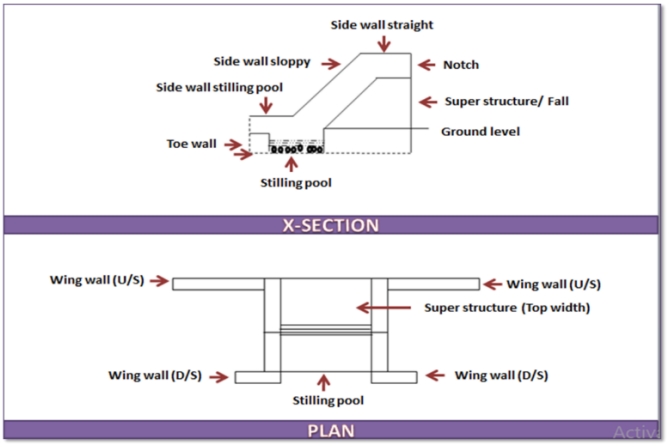

Figure 1: Components of Straight Drop Spillway

3. Results and Discussion

Health of soil is the primary concern to farmers and the global community whose livelihoods depend on well managed agriculture that starts with the dirt beneath our feet. While there are many challenges to maintaining healthy soil, there are also solutions.

In the current study the impact of straight drop spillway was observed in conserving soil from water erosion. Gully erosion caused considerable land degradation at study site which is reported to deteriorate physiochemical as well as biological properties of soil and to impart significant loss to soil fertility as well as productivity (Lal et al., 1998). According to previous research findings, due to this loss of soil fertility, a negative correlation exists between soil loss and soil productivity (Novara et al., 2018).

In current study, water erosion substantially influenced the soil texture of gullied area due to which upper surface of soil turned sandy and unfertile. This might be due to structural degradation due to high kinetic energy and beating action of rainfall which leads to decrease in the stability of soil structure and segregates the soil particles (Van Dijk et al., 2002). The correlation between soil loss and soil texture has been explained in previous study, according to which, relationship between soil loss and silt as well as clay was found to be negative (Oguz et al., 2006). Because smaller soil particles (silt and clay) are carried away to a longer distance with runoff water as compared to larger sand particles.

In this study, it was observed that the erosion reduced the crop productivity of soil. Similar outcomes are also demonstrated by (Oguz et al., 2006; Kumar and Pani, 2013). Reduction in crop productivity might be due to nutrient loss due to runoff, decreased rooting depth and reduction in nutrient as well as water holding capacity of soil (Ali et al., 2006). As the runoff water washes away chemically active soil particles i.e. clay and organic units, soil physiochemical properties are governed by sand particles. Therefore, soil's ability to hold nutrients and moisture declines which lead to yield loss and can worsen flooding (Tuo et al., 2018).

In present study, it was revealed that construction of spillway significantly fulfilled its objectives by plugging the gully to stop further erosion as well as stabilizing the gullied section by raising the flow line, which formed sufficient soil depth for vegetative growth. It has been stated that spillways dissipate the maximum kinetic energy of flowing water which results in safe disposal of runoff water by checking the erosion towards down-stream side of the structure (Aal et al., 2017). Dissipation of kinetic energy reduces the flow velocity which is not only beneficial to reduce the soil erosion, but also very helpful to deposit the silt particles present in the flow water over the gully bed, causing control of the gully development. Moreover, settling of silt load helps in land levelling, improving soil physiochemical properties and increasing the soil fertility as well as productivity (Mohawesh et al., 2015).

4. Conclusion

Prevention is the first priority of erosion control; however; gully formation is its most grievous form which can't be controlled without permanently plugging it. Current gully plugging spillway was positioned at the gully bed to develop a control point or to break the flow of water in order to improve land productivity, which is one of the most suitable and common permanent gully control structures, causing deposition of sediments; thus, to fill the gully section.

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