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Research Article

INFLUENCE OF DRY AND WETNESS ON SEDIMENT TRANSPORT IN IRRIGATION CHANNELS

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Abstract: In the present study, experiments were conducted to predict the influence of dry and wetness on aggradation and degradation in irrigation channels. The soil moisture characteristic curve (SMCC) of the experimental field was fitted with the retention curve (RETC) model to determine the soil hydraulic parameters. Soil dry and wetness significantly affected the sediments transport in irrigation channel. Erosion of sediments during the process of degradation was lesser under wet bed as compared to dry bed conditions, whereas, deposition of sediments during the process of aggradation was greater under wet bed as compared to dry bed conditions. Soil wetness reduced erosion and increased deposition of sediments in irrigation channels.

Keywords: *Aggradation Degradation, Infiltration, Irrigation channels, Sediments transport*

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Introduction

Irrigation channels are commonly used for surface irrigation, particularly in developing countries like India. Sediments transport in irrigation channels affects the discharge rate and delivery of nutrients to plants. Least cogitation is being given while designing, dealing operation and maintenance activities of an irrigation channel. Sediments laden water is often supplied directly from rivers or canals to the farm through irrigation channels, and hence deposition takes place along the length of the irrigation channels.

Water from wells is also used for irrigation, which is mostly sediments free. It is supplied at the inlet of irrigation channels. In such situations, flow has high tractive force and low sediments load at the inlet of irrigation channel. Consequently, erosion takes place at upstream reaches of the irrigation channel due to flowing water. Efficient nutrients delivery to crops requires accurate predictions of flow and sediments transport in irrigation channels. The sediments transport in an irrigation channel depends on the flow rate, infiltration rate, slope, field length, size of the sediments and sediments carrying capacity of the flow. As the water flows along the irrigation channel, the flow rate decreases with distance because of water infiltration [1]. Thus, it is imperative to have a thorough understanding of infiltration effect on sediments transport and its quantification from irrigation channels to provide advice in proper flow and sediments transport management.

Studies have been carried out in different counties for predicting the transportation of sediments in irrigation channels [2,3]. Soni (1981) [4] developed a mathematical model of sediments discharge in the form of diffusion equation. The model, which consists of coupling of sediments continuity and motion of flow equations, predicted sediments discharge and compared it with data available in literature. It is also being widely used for calculating the maximum depth as well as length of aggradation. Bhallamudi and Chaudhry (1991) developed a numerical model for studying aggradation and degradation in alluvial channels by solving the Saint Venant equations describing unsteady flow and continuity equation for the conservation of sediments. They compared the model predicted bed level changes due to overloading and development of longitudinal profile because of changes in base level with experimental data obtained in laboratory flumes and found the agreement to be satisfactory.

The aggradation problem in alluvial channel for finite length was solved by Gill (1983) [5] with appropriate boundary conditions by using diffusion type equation, which is applicable for the aggradation problem in steep alluvial channels. Two types of solution were estimated *viz*., harmonic and error function solution and found that small value of time error function is more suitable for estimating the aggradation. However, large value of time error function is preferred for estimating the aggradation by using diffusion type equation. Bjorneberg, *et al*., (2006) observed that the concentration of dissolved reactive phosphorus (DRP) increases with distance and decreases with time on account of water infiltration. Raghuwanshi, *et al.,* (2011) [6] measured the Kostiakov infiltration model parameters by using the water front advance data with the method of one- and two-point at 50, 75 and 100% of the border length. They compared the various irrigation parameters such as inflow volume, application efficiency, tail to water ratio, deep percolation ratio and low quarter distribution uniformity. The parameters obtained by two-point method had better results as compared to one-point method. They also found the coefficient of Kostiakov infiltration model (k) decreasing along the border length and no fixed pattern for its exponent. The infiltration parameters estimated by 75% of the field length gave better irrigation performance and a cut-off strategy was arrived based on the advancement of wetting front. This strategy not only reduced the deep percolation loss but also increased the application efficiency. Kothyari and Jain (2010) [7] conducted experiments for the estimation of degradation profiles of channel bed, which consists of cohesive sediments. The channel bed material was made of various types of material such as sand, clay and gravel. The percentage of clay in the sediments as well as unconfined compressive strength affected the degradation profiles. They also proposed an algorithm for the estimation of bed and water surface profiles. Zhang, *et al*., (2012) [8] developed a numerical model to simulate unsteady flow, sediments transport and infiltration in irrigation furrows by using the modified Saint Venant equations. They used Kostiakov equation to compute infiltration. Mailapalli, *et al*., (2013) [9] developed a furrow irrigation model with a steady state sediments transport and used various infiltration models such as Kostiakov-Lewis, 1D-Green Ampt and 2D-Fok for calculating the infiltration.

In literature, most of the studies have only been carried out for aggradation and degradation but none considered dry and wetness of the bed for studying sediments transport in irrigation channel, though, dry and wetness play a significant role in the transportation of sediments through irrigation channels, especially in wet bed, which may affect the sediments carrying capacity of the channel. The present study was formulated with the objectives: (i) to study the influence of dry and wetness of bed on aggradation and degradation in irrigation channel and (ii) to determine the hydraulic parameters of soil in irrigation channel.

Materials and Methods

Numerous studies have been carried out for studying sediments transport in irrigation channel and only a few studies are carried out either experimentally or employed simpler model for simulation of subsurface flow [10-12]. Moisture flow through subsurface is complex in nature and is difficult to analyze due to the non-linearity in soil hydraulic relations. Infiltration plays a significant role in the analysis of flow through irrigation channels, especially when the soil is dry, which also affects the sediments carrying capacity of the channel. Many of these studies did not consider dry and wetness of bed for studying sediments transport in irrigation channel in addition to aggradation and degradation data. Hence, a detailed laboratory experiments were conducted involving both aggradation and degradation along with wet and dry bed conditions at the Civil Engineering Department, Indian Institute of Technology, Roorkee, Uttarakhand, India [14-16].

A laboratory experiments were carried out to collect the necessary data, *i.e.*, collection of soil samples from the experimental flume and determination of soil bulk density, porosity, soil moisture, texture and hydraulic parameters for the purpose of study. The particle size distribution was carried out by sieve analysis. The particle size distribution curve for the soil used in the study has been shown in [Fig-1]. The percentage of various types of soil was determined as per the Bureau of Indian Standards (2720).

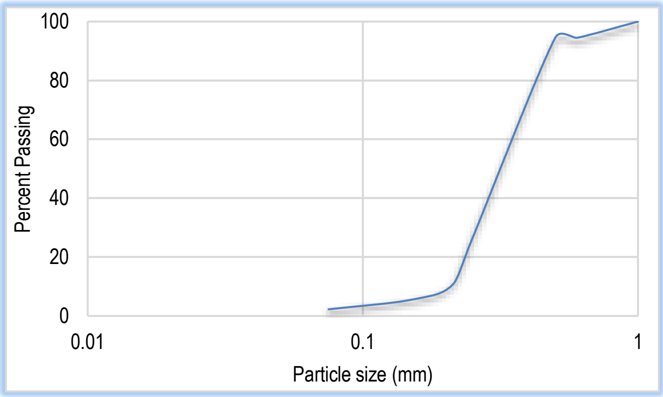

Fig-1 Particle size distribution of soil sample

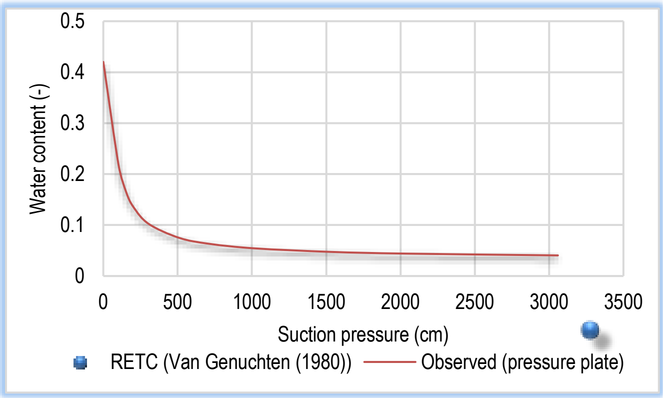

Fig-2 Soil moisture characteristics curve of soil sample

Table-1 *Soil Hydraulic parameters for the soil sample used in experimental flume*

K_s(m/day)	α_v(cm^{-1})	n_v	θ_s	θ_r	ρ
6.8	0.10	2.55	0.42	0.045	0.42

The soil of experimental site contained about 3.2% very fine sand, 22.0% fine sand, 68.2% medium sand and 6.6% coarse sand. From pressure plate apparatus, the plot of soil suction versus equilibrium moisture content was obtained, which defines the soil moisture characteristic curve (SMCC) of the experimental field at different soil profiles. The SMCC of the experimental field was fitted with the retention curve (RETC) model to determine the soil hydraulic parameters [17]. [Fig-2] represents the observed and RETC fit soil moisture characteristic curve for the soil sample used in experimental flume. [Table-1] provides the hydraulic parameters for the soil used in the experimental flume.

Irrigation channels experiments

Experiments on irrigation channel were conducted in a 15 m long, 0.5 m wide and 1.5 m deep rectangular recirculatory tilting flume in the hydraulics laboratory. The recirculatory system consisted of a rectangular tank sloped bottom to collect the sediments laden flow from downstream end of the flume. A 25 H.P. pump was connected with a tank and a supply pipe for maintaining the circulation. A 10 cm diameter supply pipe line was connected to upstream end of the flume. An orifice meter of 7.5 cm diameter was installed to calibrate the supply line for the measurement of discharge, which was controlled by a valve. A floating wooden wave suppressor provided at the inlet of flume for damping the disturbances at the free surface. Rails made from metallic tube are provided on top of the side walls. A movable carriage with a pointer gauge was mounted on a carriage, which could move on the rails. The pointer gauge was used for measuring water surface and bed profiles. An adjustable gate at downstream end of the flume was used to control the depth of flow in the flume. In these experiments, the flume was filled with the soil to a depth of 1 m, and the desired slope was given to it. The recirculatory system was then filled with water and pumps were started to circulate the water. The valve was slowly adjusted to give specified discharge and allowing the bed to adjust. Because of the effect of entrance and exit conditions on the flow, about 3 m length of flume at upstream as well as downstream end was not considered.

A predetermined amount of sand was carefully added manually for a fixed duration. The sediments were added to the water at a location where the water from the flume directly strikes for their proper mixing due to eddy current. Bed materials transported through the flow were collected at downstream end of the flume. A nylon net (trap) with opening large enough to pass the water and small enough to retain the bed materials was placed at downstream end of the flume.

Fig-3 Aggradation in progress due to sediment overloading

Fig-4 Degradation in progress due to passage of clear water

Table-2 *Experimental runs at IIT Roorkee*

Run(1)	q_o(m^2/s)(2)	h_o(m× 10^{-2})(3)	S_o(× 10^{-2})(4)	$\Delta q_s/q_{so}$(5)
1	0.0198	5.0	1.4	4.0

The values of the initial uniform water discharge (q_o), the uniform flow depth (h_o), the initial bed slope (S_o), the equilibrium sediments discharge (q_{so}) and the increment in sediments discharge at upstream end (Δq_s) considered in this experiment have been shown in [Table-2]. The experiments were conducted for two cases, *i.e.*, (i) aggradation and (ii) degradation, to analyze the effect of dry (dry bed) and wet (wet bed) conditions on the transportation of sediments. The wet bed conditions were obtained by supplying water in the flume for a long time interval, while the dry bed conditions were obtained by filling the bed with dry sand (sun-dry) in the flume. Experiments were conducted in which the sediments were injected at upstream end and the aggradation at downstream was studied. [Fig-3] demonstrates the process of aggradation at upstream section of the flume. The experiments were also conducted to study degradation due to the passage of clear water by considering wet and dry bed conditions in channel. [Fig-4] shows the degradation process at upstream section of the experimental flume. The flow depth and bed profiles were measured by point gauge. Experimental runs were carried out for estimating the bed profiles for different time intervals.

Results and discussion

Experiments were conducted to predict the aggradation and degradation under wet and dry bed conditions. The initial dry and wetness of soil significantly affect the sediments transport in irrigation channels. Therefore, the effect of dry and wetness on the sediments transport was studied in detail and is presented in the following sections.

Degradation due to passage of clear water

Water in irrigation channels under gravity flow condition moves from up- to downstream that picked up sediments from the channel bed as the initial flow rate at entry had high carrying capacity and low sediments load. Consequently, erosion took place at upstream reaches of the irrigation channel. This might be due to the fact that the initial flow rate was high at upstream reaches, which led to increase in tractive force at upstream reaches, causing high erosion at the inlet. As the water flows along the irrigation channel, velocity and flow rate decrease with distance because of water infiltration, which subsequently increased the sediments load. At some points, the sediments load in the irrigation channel becomes either equal or greater than the transport capacity due to reduction in flow rate and further transportation of same amount of sediments not to be possible. Thus, the sediments transport capacity of flow reduced and sediments deposition took place at downstream reaches of the irrigation channels.

[Fig-5] and [Fig-6], demonstrate that degradation is dominant at upstream reaches of the irrigation channel due to high carrying capacity of flow and low sediments load at that location. At upstream sides, impact of degradation was clearly visible from the bed elevation, which was eroded to 65.5 and 62.15 cm in wet and dry bed conditions after a run of 60 minutes, respectively, but on the other hand in down streamside, bed elevation was observed highest under wet bed conditions. Almost similar results were observed after a run of 75 minutes. Variation in flow depth due to degradation under dry bed condition was witnessed higher than wet bed condition. The observed flow depth at a given time decreased to a certain distance from the upstream end and remained stable and afterwards with the dominance of degradation from upstream reaches of the channel, the depth of flow increased. As moved away from the upstream reaches, the effect of degradation became negligible. This was due to fact that sediments load increased or became equal to transport capacity of the channel. Flow cannot transport the excess sediments load, thus, deposition took place at the middle as well as downstream section of the channel. Consequently, erosion reduced at middle as well as downstream reaches of the channel. Deposition took place at downstream side, which led to decrease in depth of flow and became almost constant at downstream reaches of the channel. It can also be observed from [Fig-5] and [Fig-6] that dry bed had higher flow depth as compared to wet bed, which reflected more erosion from dry bed conditions because of higher tractive force exerted by flow. From [Fig-5] and [Fig-6], it was observed that the wet bed had less erosion at upstream reaches of the channel as compared to dry bed. The increase in soil moisture (wet bed) might have increased cohesion and plasticity among the soil particles but reduced erodibility. As the moist soil (wet bed) is more cohesive than the dry soil, the particles are less likely to become suspended in moist than in dry soil. Suspended particles in dry bed may block the capillaries by sealing the soil pores while migrating downward along the water.

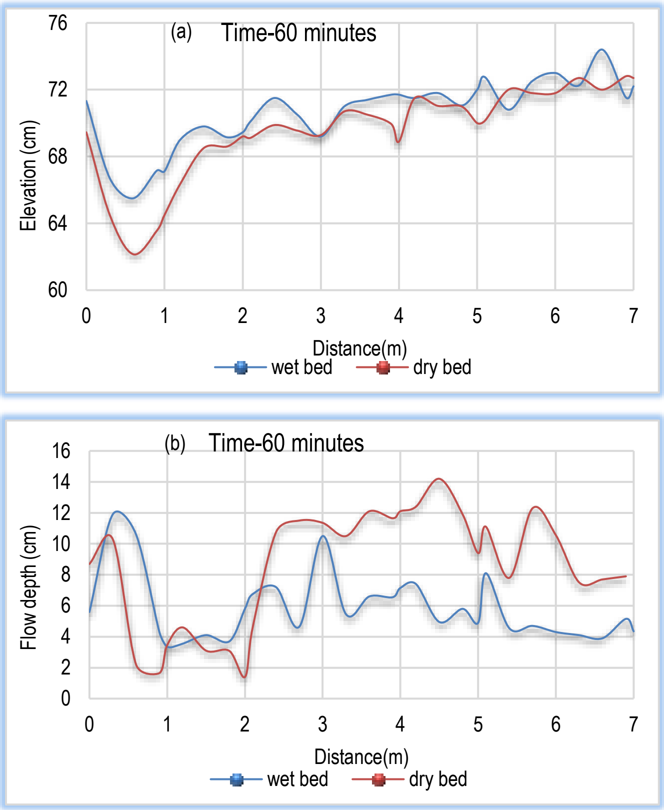

Fig-5 Bed and water surface profiles at time=60 minutes in wet and dry bed conditions due to degradation

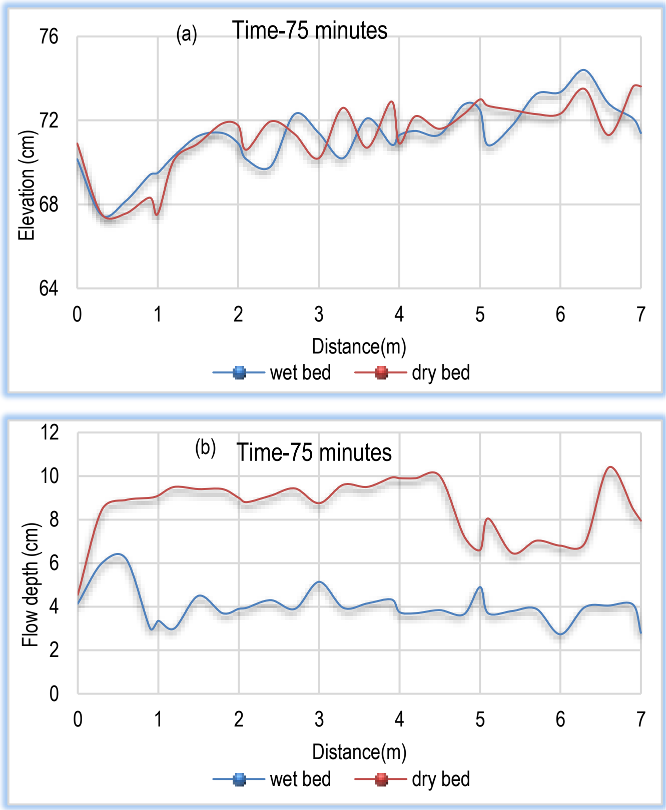

Fig-6 Bed and water surface profiles at time=75minutes in wet and dry bed conditions due to degradation

This process would increase the runoff and erosion in dry soil. The soil texture being sandy would also promote crust formation in dry soil due to easy downward transportation of the suspended soil particles. It is concluded that degradation would lower in wet bed conditions as compared to dry bed conditions which reduces the sediments transport in irrigation channel.

Aggradation due to sediments overloading

In these experiments, the flume was filled with sediments up to a depth of 1 m and levelled. Desired slope at upstream of the flume was given by using electrical arrangement. By applying sieve analysis, the size of the sediments (d50) used was found to be 0.32 mm, whereas, their mean and standard deviation of particles were 0.32 and 1.41 mm, respectively. To simulate the conditions of aggradation taking place in a channel when the rate of sediments supply increased over the initial sediments transport rate, the additional sediments were dropped manually at a desired constant rate into the recirculatory system at upstream end of the flume.

The section of sediments injection was located near upstream end of the flume but far enough from the entrance to be unaffected by entrance disturbances. The excess sediments load was progressively deposited in the flume and aggradation took place. The bed profiles at various sections and different timings were observed which can be seen from [Fig-7] and [Fig-8] that the aggradation was dominant at upstream reaches of the irrigation channels and decreased afterwards. This might be due to the fact that sediments laden flow was applied at upstream reaches of the channel where bed load increased and transport capacity reduced. Consequently, deposition took place at upstream reaches of the channel. Impact of aggradation was visible clearly from the bed elevation. At upstream side, it increased to 74.95 cm and 74.3 m under wet and dry conditions after a run of 40 minutes. Almost similar results were observed after a run of 60 minutes.

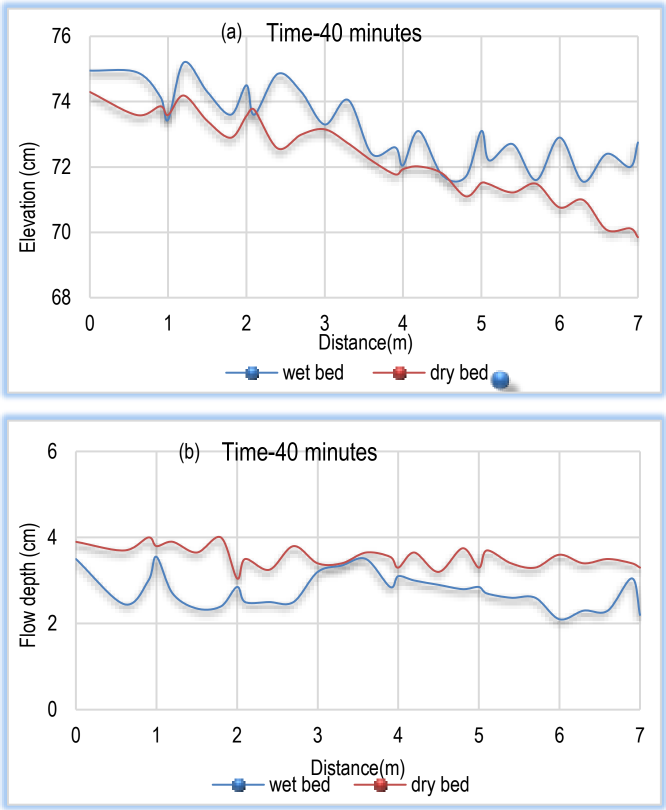

Fig-7 Bed and water surface profiles at time=40minutes in wet and dry bed conditions due to aggradation

[Fig-7] and [Fig-8] show that the depth of flow was wavy in nature because of the presence of ripples and dunes on the bed. Waviness of flow depth was initially higher at upstream reaches, which gradually decreased with distance. According to [Fig-6] after 40 minutes of experiment, the observed and computed depths of flow demonstrate good agreement up to a distance of 5 m in the channel. After 60 minutes of run, [Fig-8] reflects that the depth of flow remained lower under wet than dry bed conditions throughout the channel length. In dry bed, the depth of flow was fluctuating up to 3 m length and increased continuously up to 4.5 m length and stabilized afterward, which might be due to the fact that aggradation was dominant near the inlet, leading to the deposition of majority of the excess sediments. At later distances, the effect of aggradation became less dominant, leading to an increase in flow depth. It can also be seen from [Fig-7] and [Fig-8] that dry bed had higher flow depth as compared to wet bed, which caused more erosion from dry bed due to tractive forces. Infiltration plays a significant role in the analysis of flow through irrigation channels, especially when the soil is dry, which also affects sediments carrying capacity of the channel. It can be seen from [Fig-7] and [Fig-8] that wet bed had more deposition of sediments at inlet of channel as compared to dry bed.

The maximum depth of deposition occurred at upstream reaches of the channel. During the irrigation in dry bed, physical structure of the soil had been changed due to suspension and deposition of sand particles at downstream end of the channel, such as formation of crust (seal) on surface of the bed along the channel length as the soil particles settled down and clogging took place. Consequently, a crust appears on bed surface, which increased the runoff and erosion in bed significantly. During the aggradation process, a greater number of dunes and ripples appeared on the surface under wet bed conditions, which enhanced the roughness of channel bed and created more shear stress to flow at bed surface. It also affected the sediments carrying capacity of the channel and more deposition of sediments occurred along the length of irrigation channel. In contrast, dry bed had loose particles due to which shear stress of dry bed reduced and flow faced low resistance as compared to wet bed. Therefore, the deposition of sediments in wet bed was higher than in dry bed since former was more prone to the deposition than the latter one.

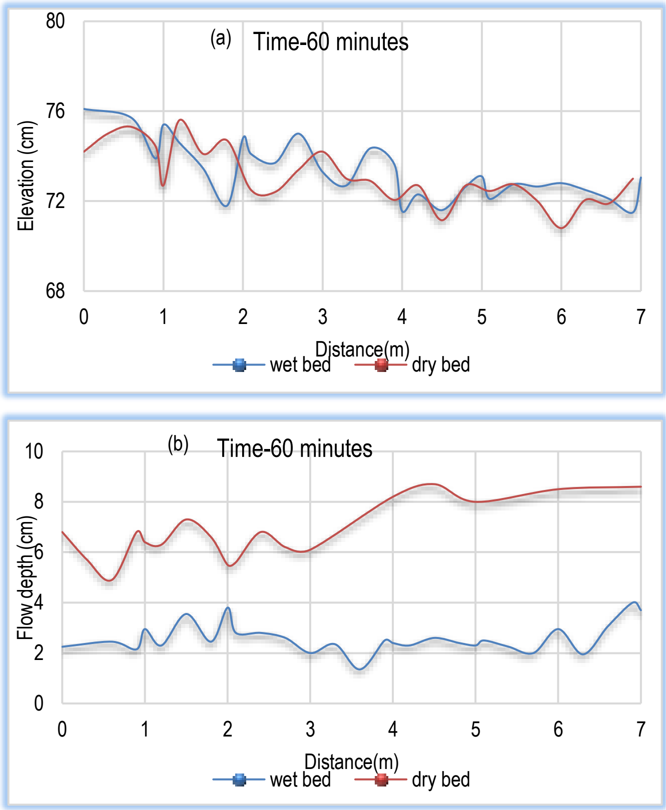

Fig-8 Bed and water surface profiles at time=60minutes in wet and dry bed conditions due to aggradation

Conclusion

The present study is concerned with the experimental study of aggradation and degradation considering the influence of dry and wetness of soil in irrigation channels. This study is an advancement of earlier findings, most of which did not account dry and wetness of soil for studying sediments transport in irrigation channel.

The dry and wetness significantly affect the sediments transport in irrigation channel. It was observed that erosion of sediments was lower during the process of degradation, while deposition of sediments was greater during the process of aggradation under wet bed as compared to dry bed conditions. It was noticed that during the process of aggradation and degradation, greater depth of flow occurred under dry bed than wet bed conditions. The study reveals that soil wetness reduces the erosion during the degradation process but increases the deposition of sediments during the aggradation process in irrigation channels.

Application of research: The study reveals that soil wetness reduces the erosion during the degradation process but increases the deposition of sediments during the aggradation process in irrigation channels.

Research Category: Irrigation channels

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Study area / Sample Collection: Indian Institute of Technology, Roorkee, 247667, Uttarakhand, India

Cultivar / Variety / Breed name: Nil

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Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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