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Proliferation of Gully Erosion in the Submontane Punjab, India

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ABSTRACT
The Submontane of Punjab in India is more prone to gully erosion. The present study was carried out to study the proliferation of gully erosion in the Submontane Punjab India district Hoshiarpur and falling in the agro-climatic zone locally known as kandi area. The main objectives were to study the characteristics and patterns of gullies in submontane Punjab India, three micro catchments designated as catchment I, II and III with different shape, size and topography were selected. They were surveyed for proliferation of gully erosion in respect to its extent and distribution. Spot studies in the region show severity of gully erosion in all the catchments with dominant U-shaped gullies. The distribution of different ordered gullies indicates that the first order gullies dominated in all the catchments as compared to other orders in each catchment. The number of gullies decreased with increased order. The mean length of the gullies in general increased with increasing order of the gullies. Directly draining gullies were the initiative gullies and showed a great variation of severity of erosion. Based on gully length large gullies having size greater than 10 m long dominated in all the catchments but maximum in catchment III followed by catchment I and catchment II. Based on depth of medium (1-5 m deep) gullies were dominating in all the catchments except in catchment III. Very high correlation exists between mean length and order of the gullies besides continuous increment in texture and density of the gullies indicate that there is severity of gully erosion. So concept of gully initiation and its development should be kept in mind to find the appropriate solutions to check proliferation of gully erosion.

Key words: Proliferation, gully erosion, submontane, pedology, basin elongation

INTRODUCTION
Land is the prime support for production of biomass. Soil erosion is universally recognized as a serious to man's well being. Water and wind are the two major agents of soil erosion. Four kinds of accelerated water erosion are commonly recognized: sheet, rill, gully and tunnel (piping) in which gully erosion is the most spectacular form of soil erosion by water as the damage caused by it relatively permanent and is more spectacular than rill and inter-rill erosion and is discontinuous within the landscape. Gregory and Walling (1973) described the gully erosion as ephemeral drainage channels which incise into thick sediment deposits or bedrock. Gullies are dynamic systems that constantly transfer or store sediments along their channels. Gully erosion can generally be described as the most catastrophic and usually impressive form of rainfall-induced erosion (El-Swaify, 1983). Hauge (1997) gave a more rigorous description i.e., gullies are distinguished from rills by a critical channel cross sectional area of one square foot.

Gullies as per agricultural lands have been defined as the channels deep enough to interfere with, and not to be obliterated by normal tillage operations typically ranging from 0.5 to 25-30 m depth (Soil Science Society of America, 2001). These vary both in space and time and there are no widely agreed upon dimensions for distinguishing gullies from rills. Gully erosion is defined as the erosion process whereby runoff water accumulates and often recurs in narrow channels and over short periods, removes the soil from this narrow area to considerable depths (Poesen *et al*., 2002). A most recent definition of gully has been given by Morgan (2005), according to which the gullies are relatively permanent steep-sided watercourses, which experience ephemeral flows during rainstorms.

Gullies are characterized by a head cut and various nick points along their water course and have relatively larger depth and smaller width than the stable channels carrying large sediment loads and display a very erratic behavior. It is the consequence of water that cuts down into the soil along the line of flow. Gullies form in exposed natural drainage-ways, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Deep gullies cannot be crossed with common types of farm equipment. Generally, ditches deep enough to cross with farm equipment are considered gullies. Gully erosion is usually common in arid and semi-arid regions characterized by denuded landscape and flash floods. Depending upon soil profile and rainfall characteristics, gullies are also common in humid tropics. Gullies may be established by deepening of rills, slumping of slide slopes, tunneling, piping and burrowing activity of animals. Gully erosion is a threshold phenomenon and occurs only when a threshold is attained in terms of flow hydraulics, rainfall, topography, pedology and land use has been exceeded (Moghaddam and Saghafi, 2008). Indeed gully erosion is a significant land degradation process and source of sediment production. Sediment production from gullies has been reported to be about 147% of that produced from rill and inter-rill erosion (Grissinger and Murphy, 1989). The contribution of gully erosion to overall soil loss rates and sediment production rates on the global scale ranges widely between 10 and 94% (Poesen *et al*., 2003).

Shiwalik Hills located below Himalayas and above Indo-Gangetic Plain in Punjab, Haryana, Himachal Pradesh, Jammu and Kashmir and Uttar Pradesh. Soil erosion in Punjab Siwaliks especially Hoshiarpur district is nearly a century old problem (Glover, 1946; Gorrie, 1946). This area covers over 19000 km^2 and about 5.03 lac hectares in land in the form of 10-20 km wide strip falling in the lower Shiwalik hills and agro-climatic zones locally known as kandi area (Kukal *et al*., 1991). The submontane Punjab, comprising of Hoshiarpur, Gurdaspur, Nawanshahar and Ropar districts occupies about 10% of the area of the state lies in the outer range of Shiwalik hills with height of 400-700 m above mean sea level. These foothills are also sparsely populated and severely eroded because of its undulating topography and intense rains, particularly during July to September, when more than 80% of the annual rainfall is received. Rest of the rainfall in winter plays good role in scour formation due to less vegetation cover.

In submontane Punjab large tracts of land are dissected by gullies. On the basis of present erosion hazard, around 25% of the area of Punjab Shiwaliks has high erosion hazard followed by 27 as increased to severe and 48% as moderate (Kukal *et al*., 1991). Spot studies in the region have shown that gully erosion with gully density varying from 2.8 to 80 km^{-2} and gully texture varying from 94 to 4966 km^{-2} is mainly due to localized weakening of vegetative cover, lower friction and increased runoff velocity (Kukal *et al*., 2006). Erosion from hilly land in Shiwaliks is estimated at 10,000-15,000/t/km/year from over 19,000 km^2. Soil loss and runoff is reported to vary from

22-225 t/ha/year and 35 to 40%, respectively (Sur and Ghuman, 1994). There is large spatial and temporal variability in the region with respect to rainfall amount and distribution. Prolonged drought periods and large number of high intensity rainstorms is a very common feature. The rainfall aggressiveness, the ratio of highest monthly rainfall to the total annual rainfall, is an index of concentration of rainfall in a single month and has been shown to be a good indicator of gully texture (Fournier, 1960). Rainfall aggressiveness varies largely (55.9-502.4) in the submontane Punjab (Matharu *et al*., 2003).

Although it is widely recognized that gully and sheet erosion threaten sustained agricultural production in much of India. About 3.669 million hectares of land was under ravine reported in 1976 by National commission on Agriculture and in Punjab it was reported about 0.015 million hectares. Very little information is available about the current status of erosion and whether the situation is worsening. Since the country is very active geomorphologically, it is not clear whether an inherently erodible environment or human impact is the major causal factor explaining the severity and spatial distribution of erosion. Currently various models have been developed for better and accurate erosion map developments (Torkashvand, 2008a, b; Dengiz, 2007; Torkashvand and Haghighat, 2009; Imanparast and Hassanpanah, 2010). So due to lack of complete information about the prohferation of gully erosion, its initiation and development in the study area, present study was carried out to study the proliferation of gully erosion in submontane Punjab, India. So that appropriate measures and new strategies should be taken to control gully erosion.

MATERIALS AND METHODS

Description of the study area: Siwalik Hills located below Himalayas and above Indo-Gangetic Plain in Punjab, Haryana, Himachal Pradesh and Uttar Pradesh covers over 19000 km^2. These foothills are sparsely populated and severely eroded. Severe erosion, frequent landslides, gullies and flash flooding are attributed to over-grazing and tree cutting. The study was carried out in Saleran catchments in block Hoshiarpur II, of district Hoshiarpur in Submontane Punjab and locally known as Kandi area (Fig. 1). Three nonagricultural adjoining micro- watersheds differing in their shape, size, slope and vegetation status were selected for the present study. The catchments were designated as I, II and III having size of 11.8, 20.6 and 8.6 hectares, respectively (Fig. 2). These catchments are situated 75.380 E longitude and 31.480 N latitude and the site is located 360.5 m above the mean sea level. The land in this area is highly undulating with deep ravines and is badly dissected by innumerable gullies (choes). The catchments are mainly under forest and pasture land use.

Soil: Soil temperature undergoes wide fluctuations during the year. The major soil groups recognized in the area are Ustipsamments and Ustorthents. Soil texture of the catchments ranged from loamy sand to sandy loam with pH ranging from 6.8 to 8.2. The soils are mainly low in organic carbon. Soil moisture changes with the changes in amount of rainfall. The soil remains dry in winter and becomes wet during monsoon period or on the onset of rains.

Climate: The climate in this region is semi arid and is having sub-humid type of climate as per the classification of Thornthwaite (1948) with an average annual rainfall recorded between 800-1100 mm. Owing to the type of terrain and difficulty involved in exploitation of underground water rainfall in the area constitutes major water resource. The mean monthly rainfall is maximum

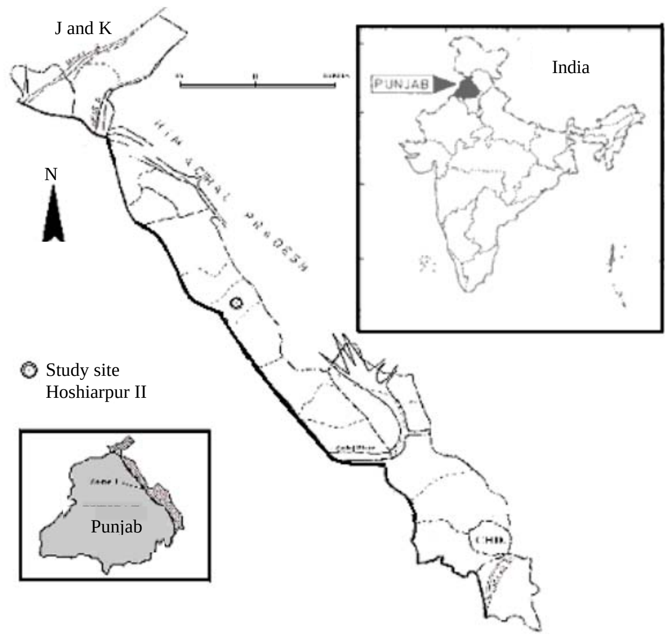

Fig. 1: Location map of the study site (Glover, 1946)

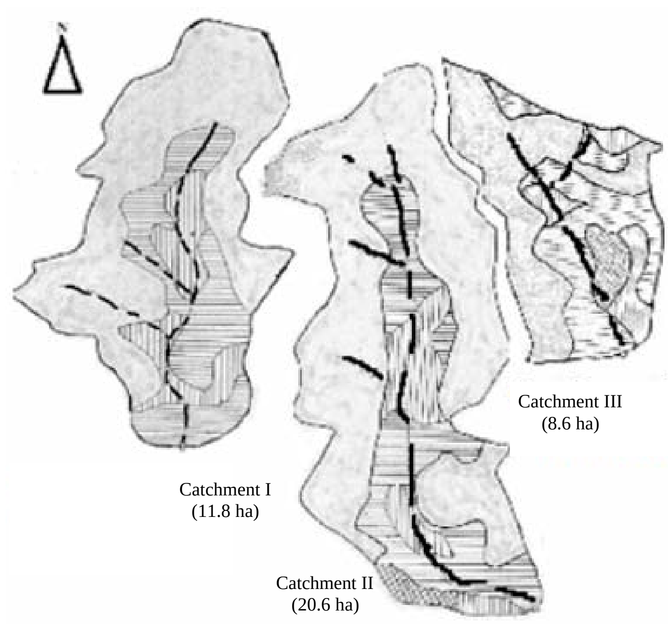

Fig. 2: Sketch of study catchments (Rasool, 2010)

in July and minimum in April. About 80% of the annual rainfall is received during the Kharif season and 20% during the Rabi season. Rainfall during summer monsoon period is of major concern, as it constitutes 80% of annual rainfall that causes soil erosion in the area. Summer monsoon rains are received in 20 to 30 storms of which 10 to 20 produce runoff. Two to three rainstorms occur with average rainfall intensity greater than 120 mm h^{-1}. These high intensity rainstorms though concentrated for a short period play a big role in causing gully erosion (Lal, 992). Air temperature at this site undergoes wide fluctuations during the year. The mean annual temperature of the area is 24.1°C with mean summer and mean winter temperatures of 32.80 and 14.50°C, respectively. During pre-monsoon months of May and June, high temperature and desiccating winds create scarcity of fodder. Because of high temperatures and low relative humidity during these months, the vegetation cover on the ground becomes sparse and situation becomes worse due to the grazing and browsing of available grass tufts and bushes by cattle. High intensity rainstorms thus cause huge runoff that supports the gullies to develop and also the formation of gully heads in the area. During winter season also when there is scarcity of vegetation gully heads initiate and develop.

Geological and geomorphological features: The lower Shiwaliks are characterized by grey to light grey micaceous fine to medium sand stone occasionally with pseudo conglomerates containing pebbles of calcareous clay and shale (Mahajan *et al.*, 2000). The geology of the area consists mainly of alluvial detritus derived from sub-serial wastes of mountains, swept down by seasonal ephemeral streams (choes) and rivers and rocks and deposits from the Upper Miocene to the Lower Pleistocene age (Wadia, 1976). The soils of the area are represented by the great groups of Ustorthents, Ustipsamments and Haplustalfs. The predominant minerals present in these soils are illite, semectite, kaolinite and chlorite (Singh, 1979). A variety of heavy minerals like garnet, tourmaline and biotite etc have also been reported in the area (Sur *et al.*, 1999).

Gully erosion survey: A detailed field survey for gully erosion was carried out in three selected catchments during the year 2005 and 2008. For this purpose, the selected catchments were divided in to grids of 100×50 m^2 each. Gully marking was done with the help of measuring tape and thread in each catchment. Gully network i.e., length and direction of all the gullies were sketched on the counter maps at a scale of 1:2000 by hand after measuring the distance with reference to wooden pegs laid out in the grids in the field. The gullies up to the first order were marked on the maps.

Gullies were classified according to the extent of bifurcation. The gully in which no other gully drains is designated as first-order gully. The first order gully is never bifurcated. The gully in which two first order gullies drain is designated as second order gully. When the two second-order gullies meet together, a third-order gully is formed which when meets with another third order gully results in a forth-order gully (Fig. 3).

The length of different ordered gullies was measured in each catchment from the gully erosion map using a thread and measuring scale. The length of the thread coincided with each gully length marked on map and multiplied by the scale of map gave the gully length. The total length of the gullies per unit area was expressed as Gully density in km km^{-2}. The number of first-order gullies per unit area was expressed, as Gully texture number km^{-2}.

Catchment characteristics: Among the shape indices for drainage basins, the most well known are probably the compactness index, C (Gravelius, 1914), the form factor, F (Horton, 1932), the basin circularity, c (Miller, 1953), the basin elongation, E (Schumm, 1956) and the lemniscate ratio, K (Chorley *et al.*, 1957). By definition, all these indices are dimensionless. Catchment shape was determined by calculating the following indices:

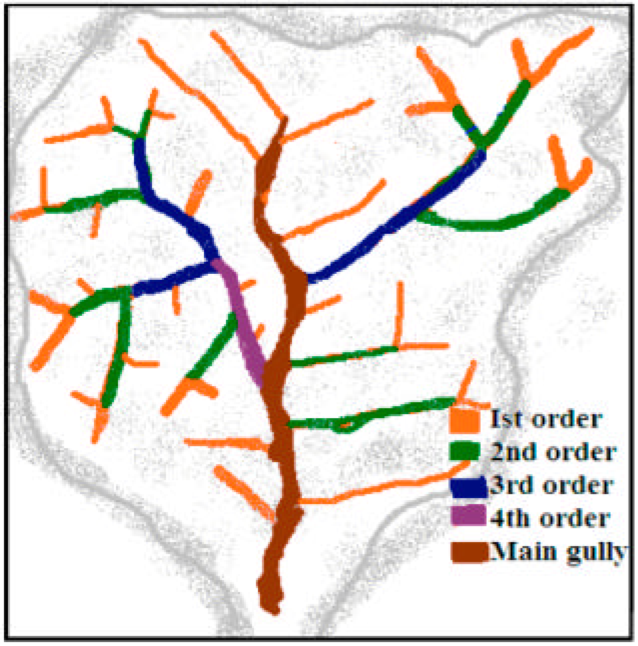

Fig. 3: Schematic diagram showing designation of different ordered-gullies

- Lemniscate ratio (K)
- Basin elongation (E)
- Form factor (F)
- Compactness coefficient (C)
- Basin circulatory (c)

Average fall in gully slope: It was determined as the ratio of elevation at highest and lowest points of the main gully to the distance between the two points:

$$\text{Average fall in gully slope} = H_H - H_L / D \quad (1)$$

where, H_H is the highest elevation point, H_L is the lowest elevation point.

Soil erosion density (SED): Soil erosion density was calculated as the empirical equation given by Morgan (2005):

$$SED = 1.55Dd - 5.16K - 1.09 \quad (2)$$

where, Dd is the gully density (km km^{-2}) and K is the lemniscate ratio

Statistical analysis: The data was statistically analyzed by correlation between different parameters as described by Gupta (1991).

RESULTS AND DISCUSSION

Catchment characteristics: The gully erosion and its distribution influenced by shape, size and topographical characteristics. The shape was discussed in its indices, which includes lemniscate ratio, compactness coefficent, form factor, basin circulatory and basin elongation. The lemniscate ratios were 0.98, 1.13 and 0.88 in catchment I, II and III representing in Table 1. Lemniscate ratio of catchment II was observed to be maximum followed by catchment I and catchment III. Hence based on lemniscate ratio, catchment III is more prone to erosion hazard followed by catchment I and II. Similar trend was indicated by compactness coefficient (C) which was lowest (1.27) in catchment III followed by catchment I (1.34) and the highest (1.49) in catchment II (Table 1). There was reverse trend for form factor and basin elongation which were highest for catchment III followed by catchment I and II. Low Lemniscate ratio, compactness coefficient and high form factor were responsible for more compactness of catchment III and hence more risk of soil erosion. This is to due to the shorter time of concentration from the remotest point in the catchment to reach the outlet for runoff in compact catchment compared to that in oblong ones (Morgan, 2005). Lower values of compactness coefficient indicates more compact catchment hence more erosion hazard. On the other hand the values of form factor (F) and basin circulatory (c) and basin elongation (E) was highest in catchment III followed by catchment I and least in catchment II. Higher values are associated with more erosion hazard.

Compactness coefficient (C) and basin circulatory (c) combine the perimeter and the area of the catchment or drainage basin. Form factor (F), basin elongation (E) and lemniscate ratio (K) combine the basin length and area. Several authors have questioned the value of the compactness and the basin circularity indices for hydrological analyses, because these only describe the basin shape and not its orientation towards the outlet (Horton, 1932; Chorley *et al*., 1957). Others have pointed out that precautions need to be taken when measuring the perimeter because of its scale dependency (Roche, 1963; Jarvis, 1976; Gardiner, 1981).

The average fall in gully slope was not in line with average slope of the catchments nor was it related to the size of the catchments. It was the highest in catchment I (13.4 cm m^{-1}) and followed by 12.6 cm m^{-1} in catchment III and 8.3 cm m^{-1} in catchment II (Table 2). Based on lemniscate ratio and average fall in the gully slope and slope steepness, catchment III could be projected to be the most prone to soil erosion hazard followed by catchment I and II. Slope steepness was shown to be highly related to the existence of gullies (Meyer and Martinez-Casasnovas, 1999). Interestingly, catchment III considered to be most prone to soil erosion hazard was smallest in size (8.6 ha) followed by catchment I (11.8 ha) and catchment II (20.6 ha).

Average slope of catchment III was highest (39.5%) followed by that of catchment I (38%) and catchment II (35.9%) (Table 2). Again the slope was highest in catchment III and lowest in

Table 1: Shape indices and size of the study catchments

Catchment	Lemniscate ratio (K)	Basin elongation (E)	Form factor (F)	Compactness cofficient (c)	Basin circulatory (c)
I	0.98	0.57	0.23	1.34	0.56
II	1.13	0.53	0.21	1.49	0.45
III	0.88	0.60	0.26	1.27	0.62

Table 2: Area and slope of catchments

Catchment	Size (ha)	Max length (m)	Average slope (percent)	Average fall in gully slope (cm m^{-1})
I	11.8	679.5	38.0	13.4
II	20.6	952.0	35.9	8.3
III	8.6	553.0	39.5	12.6

biggest catchment II. The catchment III and I was thus more prone to erosion hazard based on its shape than catchment II. The maximum length of catchment III was lowest (553 m) and that of catchment II (952 m) the highest as shown in Table 2.

Extent and distribution of gully erosion: Gully texture (number of first-order gullies per km^2 area) of the selected catchments was maximum 1163 km^{-2} in catchment III followed by catchment I (1052 km^{-2}) and catchment II (1019 km^{-2}) (Table 4). Same pattern was observed in gully texture and soil erosion density. Gully density in catchment III was observed 35.06 km km^{-2} followed by catchment I (34.3 km km^{-2}) and least for catchment III (22.34 km km^{-2}) (Table 3). Gully erosion density was the highest 48.7 (km km^{-2}) in catchment III than catchment I (47.0 km km^{-2}) and lowest 27.7 km km^{-2} in catchment II. Catchment III was expected to have highest value of gully erosion density due to its compact shape, low lemniscate ratio (0.97), high average fall in gully slope, highest average slope and low vegetation status. This is due to the shorter time of concentration for runoff in compact catchment compared to that in oblong ones (Morgan, 2005). This resulted in highest peak runoff rate and sediment density in the catchment, which was 187.9 I/s/ha and 12.9 t ha^{-1}, respectively (Matharu *et al*., 2003). Thus gully erosion density was the result of lower vegetation status and lower values of lemniscate ratio, higher value of average slope. High values of gully texture are a response to a more seasonal rainfall regime with rains of greater intensity (Morgan, 2005). The distribution of gullies on either side of main gully can be attributed to the main slope steepness. In catchment I and III, the slope steepness was more or less of same magnitude on both sides of the main gully. Gully formation is largely controlled by the generation of the sufficient volume of runoff and by a sufficient level of relief energy, which depends on the slope gradient (Vandeale *et al*., 1997; Venderkerckhove *et al*., 1998). Desmet *et al*. (1999) also indicated that the spots in landscape where gullies start are more controlled by slope gradient.

Regarding distribution of gullies on either side of the main gully as shown in Table 4, the gully texture was observed to be slightly higher on the side facing south-west in almost all the three catchments except in catchment II. Same trend was observed in relation to gully density. This may

Table 3: Gully erosion indices in the study catchments

Catchment	Gully texture (No km^{-2})	Gully density (km km^{-2})	Soil erosion density (km km^{-2})
I	1052	34.30	47.0
II	1019	22.34	27.7
III	1163	35.06	48.7
Average	1052	31.00	41.0

SED (kmkm^{-2}) is calculated as SED =1.55GD-5.16K-1.09 Where, GD = gully density (kmkm^{-2}) and K = lemniscate ratio

Table 4: Distribution of gully texture and its density in the study catchments

	Gully texture (No km^{-2})			Gully density (km km^{-2})		
Catchment	NE SIDE	NE SIDE	Ratio	SW SIDE	SW SIDE	Ratio
I	1771	1714	1:0.97	62.5	27.6	1:0.4
II	1126	1084	0.96:1	21.8	25.3	0.9:1
III	1594	1531	1:0.96	47.9	44.9	1:0.9
Average	1497.2	1443.2	1:0.96	44.1	32.6	1:0.7

NE = Northeast side indicates the slopes facing southwest direction of main gully and SW = Southwest side are slopes facing northeast direction be due to high steep slope dominated in southwest side of main gully. Sargeant (1984) recognized four categories of gully erosion based on gully density which were low, medium, high and very high and gully density varied from <1 km km^{-2} for low to >0.5 km km^{-2} for very high degree of gully erosion. In foothills of Shiwaliks (Punjab) Kukal *et al.* (1991) specified drainage density <4 km km^{-2}, 4-15 km km^{-2} and >15 km km^{-2} for low, moderate and severe degree of gully erosion, respectively. As the gully density in the catchments under study ranged from indicated highly severe degree of gully erosion in all the catchments.

Gully patterns

Gully number: The percentages of first-order gullies were highest in catchment III (72) followed by catchment II (69) and I (67%) as shown in Fig. 4. The second order gullies were highest in catchment almost equal in all the catchments. The third order gullies were highest in Catchment I having max percentage (8%) as compared to catchment II (6) and catchment III (4). The fourth-order gullies although very rare and existed only in catchment I and II. The distributions of different ordered gullies shown in Table 5 indicate that the first order gullies dominated in all the catchments. The relationship between percent gully number and gully order indicates that the percent number of gullies decreased with increased order. The data shows that it is not necessary that the gullies of different orders drain into the next higher order, rather these may drain directly into any higher gully orders. Many first-order gullies drained directly into fourth order gully, thus signifying the fact that the gully network in the catchment is expanding fastly (Nakano *et al.*, 1985).

Gully length: The mean length is depicted in Fig. 5 of first order 17.6 13.8 and 17.8 m in catchment I, catchment II and catchment III. This mean length increased positively with increase in gully order and attained mean length 55, 28.8 and 49 m in their final orders of catchment I, catchment II and catchment III, respectively. The mean length of the gullies in general increased with increasing order of the gullies and showed a very high correlation of $R^2 = 0.98$ as shown in

Table 5: Classification of gullies based on their depth in the study catchments

		Percent gullies		
Depth		Catchment I	Catchment II	Catchment III
<1 m	Short	17	16	25
1-5 m	Medium	44	43	41
>5m	Large	39	41	34

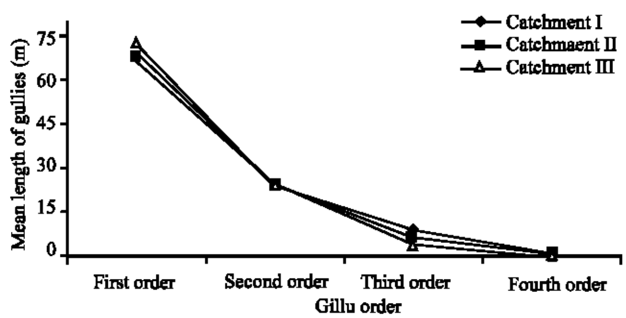

Fig. 4: Relation between number of gullies (percent) and gully order

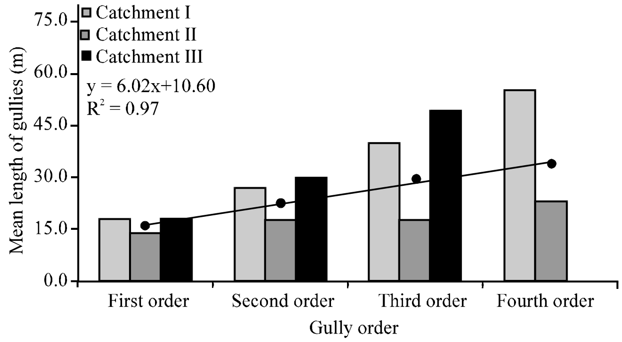

Fig. 5: Relationship between gully order and mean length of gullies

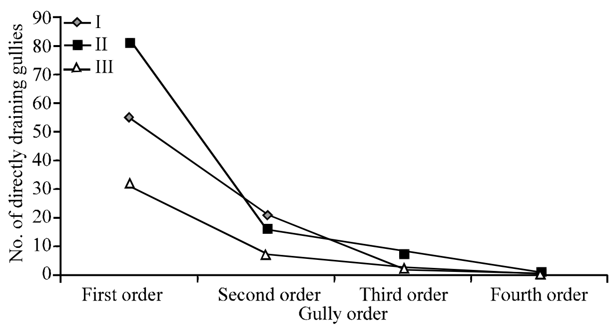

Fig. 6: Relationship between number of directly draining gullies and gully order

Fig. 5. It was a great view that as the gully order increased, there was increase in mean gully length (Nakano *et al.*, 1985). Lower order gullies were receiving the runoff at a low velocity and were into the higher order gully at a very high velocity which increased the length of higher order gullies at a faster rate (Nakano *et al.*, 1985). Also the longer gullies grow at a faster rate than the shorter gullies (Burkard and Kostaschuk, 1997). This shows that the higher order gullies grew at a faster rate than lower gullies as mean length of highest order gullies was more.

Directly draining gullies: Directly draining gullies were the initiative gullies and showed a great variation of severity of erosion. The number of first and second-order gullies draining directly into main gully was highest in catchment II (81) as compare to catchment I (55) and catchment III (32) while that of third-order gullies was highest in catchment I (21) followed by catchment II (16) and fourth order observed one gully each in catchment I and II (Fig. 6). The overall total number of all gully orders draining directly in to the main gully in study area catchments were observed maximum in catchment II (105) than catchment I (79) and least in catchment III (42). All the third and fourth-order gullies drained directly into the main gully in all the three catchments. Second and third order directly draining gullies were responsible for high runoff collection and high slit load. It is because of the fact that second and third order gullies which directly drained into main gully with high runoff velocity, which played a key role to increase soil loss from the catchments.

Gully classification: Gullies were classified on the basis of length, depth, shape and morphology in the study catchments.

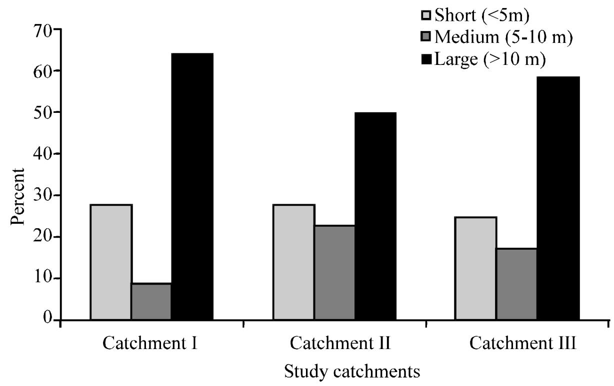

Fig. 7: Classification of gullies based on their length in the study catchments

Based on gully length: Gully length was distributed in to three categories small (<5 m), medium (5-10 m) and large gullies (>10 m). The data is depicted in Fig. 7 showing that large gullies (>10 m) are dominated by 64, 50 and 58 in the catchment I, catchment II and catchment III followed by 28, 28 and 25% of short gullies (<5 m) in catchment I, catchment II and catchment III. The maximum 64% large gullies were observed in catchment I and 58 percent in catchment III as compared to 50% to catchment II. Gullies having larger area grow at a faster rate and hence cause increased runoff from the catchments (Burkard and Kostaschuk, 1997). Hence for priority consideration of gully treatments, catchment III and I need to be attended first.

Based on gully depth: Based on gully depth (Bennett) gullies were classified as short (<1 m), medium (1-5 m) and large (>5 m). Of the total sampled in three different catchments, the percentage of gullies based on depth ranged from 17, 16 and 25% of short gullies in catchment I, catchment II and catchment III, respectively. 44, 43 and 41% as medium gullies and 39, 41 and 34% of large gullies were identified in the catchment I, II and III, respectively (Table 5). The medium gullies were dominated over large and short gullies in all the three catchments.

Based on shape: In all the catchments, mostly U-shape gullies were identified on the basis of shape aped gullies. U shaped gullies are formed in the area where subsurface soils are either equal or more erodible than the surface soils while as the condition of erodibility is reverse in V shaped gulhes (Bennett, 1939). In all the catchments, the soil erobility of subsurface soils was higher that of surface soils in the gully beds (Matharu *et al.*, 2003).

Based on morphology: Gully morphology revealed that the gullies in the three catchments were dendritic and trellis. The gully having many tributaries is called as dendritic gully and the gully in which the tributaries enter perpendicularly in to the main stream are trellis types of gullies (Bertrand and Woodburn, 1964). The gullies in the catchments were spread as a network of branches of different orders. All the three catchments having one common main gully each that divided the catchment in to two faces known as northeast side and southwest side. This main gully spreaded with many branches throughout entire sides. Gully branching in catchment I and II was up to fourth order while as in catchment III it was up to third order. Gullies in the catchments drained in to the higher order gullies transversely while many of the gullies were draining in to higher order gullies at or near the right angle. Hence the gullies in the area could be

Table 6: Temporal variations of gullies in the study catchments (2003-2008)

Catchment	Gully texture (km km^{-2}) 2003	Gully texture (km km^{-2}) 2008	Percent increase	Gully density (No km^{-2}) 2003	Gully density (No km^{-2}) 2008	Percent increase
I	758	1052	39	31.7	34.30	8
II	440	1019	132	15.5	22.34	44
III	722	1163	61	15.8	35.06	128
Average	640	1052	64.0	21.0	31.00	48

designated as trellis type gullies. As the gullies in the area were both dendritic and trellis type, these could also be designated as compound type gullies (Bertrand and Woodburn, 1964).

Temporal variation of extent of gullies: Mapping of gully erosion change from 2003 to present study in a three catchments in the region have revealed that both gully texture-number of first-order gullies per unit area and gully density increased over the years. The catchment II experienced highest increase in gully texture (132%) followed by catchment III (61%) and catchment I (39%) where as the catchment III experienced highest increase in gully density (128%) as compared to catchment II (44%) and catchment I (8%) as shown in Table 6. Interestingly, the percent increase in gully texture was significantly higher than gully density almost in all the catchments except in catchment III. This indicates that more number of first-order gullies were added every year than the addition in the gully length. This may be due to rainfall aggressiveness (Morgan, 2005). It is thus clear that gully networks have been expanding with time in the region. Therefore it is prerequisite to adopt new strategies to control gully erosion.

Sargeant (1984) recognized four categories of gully erosion based on gully density which were low, medium, high and very high and gully density varied from <1 km km^{-2} for low to >5 km km^{-2} for very high degree of gully erosion. In foothills of Shiwaliks (Punjab) Kukal *et al.* (1991) specified drainage density <4 km km^{-2}, 4-15 km km^{-2} and >15 km km^{-2} for low, moderate and severe degree of gully erosion, respectively. As the gully density in the catchments under study ranged from 22.34 to 35.06 km km^{-2} (Table 6), it indicated highly severe degree of gully erosion in all the catchments.

CONCLUSION

Gully density in the catchments under study ranged from 22.34 to 35.06 (km km^{-2}), gully texture ranged between 1019 to 1163 km^{-2} and gully erosion density ranged from 27.7 to 48.7 also indicating that there is high severe degree of gully erosion in all the catchments. The catchment II experienced highest increase in gully texture (132%) followed by catchment III (61%) and catchment I (39%) where as the catchment III experienced highest increase in gully density (128%) as compared to catchment II (44%) and catchment I (8%) from the year 2003 to 2008. In foothills of Shiwaliks (Punjab) drainage density was classified as <4 km km^{-2}, 4-15 km km^{-2} and >15 km km^{-2} for low, moderate and severe degree of gully erosion, respectively. As the gully density in the catchments under study ranged from 22.34 to 35.06 (km km^{-2}) indicated highly severe degree of gully erosion in all the catchments. Controlling on large scale by concrete or other structures is cumbersome and expensive. Eighty percent of failure of gully control structures reported in the area. Therefore, other measures should be taken to control gully erosion. It is better saying Prevention is better than cure. So concept of gully initiation and its development should be kept in mind to find the appropriate solutions of controlling gullies for further proliferation.

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